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SNS CO-OP – SNS Collaborative Operations and Output Optimisation

SNS JOURNAL/2025

6G SNS CO-OP

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Call 3 Projects

Foreword from the European Commission

Europe has long stood at the forefront of mobile communications, housing industry-leading telecom equipment manufacturers and some of the world's most talented wireless researchers. Our continent's track record in shaping each generation of mobile technology is a testimony to its innovative spirit and collaboration strengths.

Even before the full deployment of 5G networks, the European Commission demonstrated foresight by mobilising substantial investments in 6G research and technology. To realise this vision in a structured and effective manner, the Commission established the Smart Networks and Services Joint Undertaking (SNS JU), in partnership with the 6G Industry Association. This initiative is driving coordinated research and development from 2021 through 2028, backed by €900 million in public funding, matched by an equivalent commitment from industry.

Digital infrastructure is the backbone of our modern economy, and maintaining Europe's sovereignty and competitive edge in 6G is crucial in that context. Advanced 5G and later 6G are indispensable enablers for the EU to deliver on its vision of an "AI continent", as they will ensure the connectivity needed for high-quality, secure and sustainable AI-enabled services at scale. By partnering with European industry and collaborating with other leading nations, we support the development and deployment of 6G technology promoting not only technology excellence but also policy goals including sustainability, affordability, security, and resilience.

I am proud to showcase the remarkable innovations emerging from the 79 projects featured in this 2025 SNS Journal. I encourage you not only to explore these pioneering efforts but also to review the SNS progress assessment in the last part of this book, which offers a comprehensive overview of SNS achievements, vision, international cooperation, trials, challenges, and the broader strategic implementation of 6G research and innovation.

We are now at the midpoint of the SNS JU initiative, which has received a positive evaluation in the Horizon Europe mid-term review. The global race toward 6G is accelerating, with standardisation efforts already underway and the prospect of commercial systems on the 2030 horizon. The coming phase is pivotal; the most promising 6G technologies—developed in SNS projects featured in this book and those yet to come—must be selected, tested, adapted to market needs, and monetised to deliver valuable services to society. These technologies must be not only performant but also remain human-centric and contribute to EU policy objectives.

I am thankful to the European researchers working on these projects for establishing Europe as a global leader in 6G, while also laying the groundwork for the next generations to follow on the innovation path.

Thibaut Kleiner,

Director for Future Networks in DG Connect, European Commission

Foreword from the Smart Networks and Services Joint Undertaking (SNS JU)

Erzsébet Fitori,

Executive Director of the Smart Networks and Services Joint Undertaking

As we enter 2025, digital connectivity in Europe stands at a defining moment. The continued evolution of smart networks and services is not just an engineering challenge but a strategic imperative, one that underpins Europe's economic competitiveness, technological sovereignty, and societal progress.

The Smart Networks and Services Joint Undertaking (SNS JU), created under the Horizon Europe framework, remains at the forefront of this transformation, driving research, innovation, experimental platforms and large-scale trials that will shape the future of connectivity in alignment with European values.

This SNS JU Journal 2025 presents an overview of the 79 research, innovation, and trial projects that form the backbone of the SNS JU's portfolio. These projects, funded by approximately €500 million of EU funds serve as a cornerstone for Europe's ambition to lead in 6G technology development while improving the deployment of 5G. They reflect the strong commitment of European policymakers, industry leaders, and researchers to build a resilient, competitive, and sustainable digital infrastructure.

The SNS JU's mission is twofold: first, to foster Europe's technological sovereignty in 6G by supporting the research and innovation ecosystem necessary to drive standardisation and early market adoption by the end of the decade; and second, to accelerate the deployment of 5G across Europe to enable digital lead markets and facilitate the twin digital and green transitions. These objectives are not only aligned with the broader European Union policies on cybersecurity, industrial competitiveness, and sustainability but also serve as a fundamental enabler of the EU's Digital Decade Policy Programme.

In 2024, the SNS JU launched its third call for projects, marking another year of remarkable growth. With the addition of 16 new projects, this initiative strengthens Europe's position in global technological competition by addressing critical areas such as network infrastructure, edge computing, AI-driven network intelligence, and the development of next-generation components and devices. The selected projects will contribute to the creation of a first-class European supply chain for advanced 5G systems and lay the groundwork for 6G architectures.

As global competition intensifies, Europe faces a decisive moment. The scale required to remain competitive necessitates close collaboration across the entire value chain, involving industry leaders, SMEs, academic institutions, and national governments. The SNS JU serves as the key platform to align these efforts, in view of Europe maintaining its influence in shaping the future of global 6G standards.

Beyond the technological race, the SNS JU is deeply committed to embedding European values into future networks and services. Security, privacy, resilience, and sustainability remain at the heart of our research and innovation initiatives. The projects within this Journal reflect these principles, integrating cutting-edge advancements in areas such as cybersecurity, AI, quantum technologies, and energy-efficient network solutions.

Looking ahead, Europe's success in 6G will hinge on its ability to build on the foundation of 5G, drive research excellence, and create industrial leadership via building use and business cases for emerging technologies. The SNS JU, through its collaborative public-private partnership model, remains a vital instrument in achieving these goals. We invite you to explore the pages of this Journal, showcasing the remarkable contributions of European researchers, innovators and industry leaders, who are collectively shaping the digital future of Europe and beyond.

Introduction from the 6G Smart Networks and Services Industry Association (6G-IA)

Colin Willcock,

Chairman of the Board of the 6G-IA, Vice-Chairman of the SNS JU, Vice-Chairman of the ETSI Board.

The SNS JU is moving ahead at full speed; 16 new Research and Innovation (R&I) projects have started in January 2025 as part of Call 3 of the SNS JU, complementing the 35 Call 1 projects (operational since 2023) and 28 Call 2 projects (operational since 2024). This brings the total number of SNS JU projects to 79. The combined work and outcomes of these projects, address a broad range of novel enabling technologies, Key Performance Indicators (KPIs) and envisioned use cases. These use cases cover a diverse set of vertical fields and are expected to drive global 6G developments and deliver impactful European solutions for next-generation networks and services.

As well as the total number of projects, an important aspect is the impressive participation of top European experts from varied backgrounds (industry, academia, Radio and Telecom Operators, Small and Medium Enterprises or SMEs, etc.). This is proof of the significance of this endeavour for the European stakeholders and indicative of the impact it will potentially deliver. With over 505 unique beneficiaries funded so far, and an SME participation of 25%, the SNS JU projects engage a broad and varied ecosystem of EU experts who have joined forces to deliver novel solutions that will realise the next-generation of networks and services.

The structured design of the SNS JU in Phases, and the constant monitoring and adaptation of the work programme, has allowed for an impressive range of technologies, enablers and use cases to be already addressed by the 79 projects of the first three calls. Spearheaded by Hexa-X-II, which is the Flagship SNS JU project, and supported by the SNS CO-OP project, the 79 projects cover all the key technological areas including the envisioned 6G Architecture, AI native solutions for Radio Access Network, core and telco-cloud, Non-Terrestrial Networks (NTN), Optical communications, Security and Service provision, and novel devices and components, while addressing the needs of more than 11 different vertical sectors. This portfolio has been further enriched to tackle critical aspects via the 3rd Call of the SNS JU (Started 2025) aiming at higher-TRL solutions promising to impact standardisation activities. This call notably includes two key lighthouse projects on Sustainability and Micro-electronics.

As we have passed the midpoint of the SNS JU, it is important to look back at the accomplishments and achievements of the projects, which are summarised in this journal. From the technological requirements analysis, use case definitions, architectural designs, to the early insights for smart networks and services, the SNS JU has already achieved a lot. The successful enlargement of the international and EU ecosystem of the SNS JU was also a key achievement for the SNS JU. The monitoring and analysis of global 6G trends and innovative collaboration tools, delivered by the Coordination and Support Action projects, are a proof that the SNS JU is definitely on the right track for impactful results.

6G, the sixth generation of wireless technology, heralds a transformative leap beyond the capabilities of 5G, transcending more enhancements in speed, latency, and capacity. Still in its design and research stages, 6G nevertheless began being pre-standardised in 2025, and aspires to redefine connectivity through unprecedented innovations, facilitating immersive holographic communication, seamless extended reality experiences, and the pervasive integration of artificial intelligence. Its development encompasses pioneering advancements in Terahertz spectrum utilisation, quantum computing, intelligent reconfigurable surfaces, and decentralised network paradigms. As global dependence on digital connectivity deepens, 6G is poised to become the cornerstone of a hyper-connected, intelligent world, shaping the technological landscape for decades to come.

Ten key milestones

We identified ten key milestones and topics:

1. **Three calls for projects successfully launched**, resulting in 79 projects that are up and running (35 projects in 2023, 28 projects in 2024 and 16 projects in 2025), with a global budget of more than €500 million. A fourth Call expected in 2025 worth €130 million.
2. **6G standardisation study stage** began in 2025.
3. **EuCNC 2024**: the event attracted more than 1,000 delegates from over 40 countries and more than 50 exhibitors to Antwerp, Belgium in early June 2024. Next event scheduled for early June 2025 in Poznan, Poland.
4. **MWC 2024**: the "6G Horizon" session titled "Bridging Perspectives for a Sustainable Future" was hosted by the SNS JU.
5. **Cooperation between projects**: various workshops took place that drew on cooperation between SNS projects such the 6G series.
6. **Global cooperation**: the 6G-IA drafted 28 Memoranda of Understanding (MoUs) with similar programmes and peer organisations to strengthen collaboration between initiatives inside and outside Europe.
7. **20 successful Open Calls** with 180+ trials and pilots and 280+ third parties involved.
8. **SME involvement**: SMEs' participation exceeded 20%.
9. Increased activity for the **replicability initiative**.
10. **Sustainability, inclusion and cybersecurity** addressed at the programme level and by the individual projects, illustrated by several White Papers, the 6G-IA WiTaR (Women in Telecommunication and Research) Working Group (WG) and the introduction of Key Values (KVs) and Key Value Indicators (KVIs). Cybersecurity is also a core focus of many SNS projects.

SNS, an innovative initiative to foster R&D

The SNS (Smart Networks and Services) programme provides a unique opportunity for the European Information and Communication Technologies (ICT) industry to compete in the global market for 6G infrastructure deployment, operation, and services. The SNS JU unites industry leaders, academic institutions, and policymakers to drive the development and implementation of cutting-edge technologies. By fostering collaboration and knowledge sharing between stakeholders, the SNS JU aims to address critical challenges in the telecommunications sector, including enhancing network performance, strengthening security and privacy, and enabling new applications and services. Through strategic investments and initiatives, the SNS JU plays a pivotal role in shaping the future of connectivity in Europe and beyond, driving economic growth, fostering innovation, and advancing societal progress.

SNS PROGRAMME INNOVATIONS AND ACHIEVEMENTS

Launched late in 2021, the SNS programme is structured into three main phases. Since its inception, the programme and its associated projects have made significant progress and had a substantial impact. Seventy-nine projects are currently contributing actively to its success.

The programme is progressing rapidly, with the Steering Board (SB), Technology Board (TB), Communications Task Force, SNS and 6G-IA Working Groups, and the SB Open Calls Task Force all operating at full capacity. It has gained significant momentum, driving dynamic collaboration across projects. This is reflected in cross-project workshops and active participation in major international conferences such as the ETSI Research Conference, EuCNC & 6GS 2024, the Global 5G Event, Globecom, MWC 2024, and 5G Techritory in 2024. Looking ahead to 2025, projects are already scheduled to make key contributions to multiple events, including MWC 2025—which included an SNS session, and more than 20 projects showcase their work at organisation booths and stands – they will also do at EuCNC and 6G Summit 2025.

6G USE CASES

6G collaboration and competition are intensifying globally, with regional initiatives in North America, Europe, and Asia-Pacific. All the initiatives have started to define use cases (UCs) and applications. To date, between five and thirteen key UCs have been identified. Six UCs, including holographic communication, digital twins, and telesurgery, require advanced network capabilities. A second group focuses on imaging, sensing, and space-terrestrial integration, while a third group, including critical infrastructure and emergency services, is relevant but not being prioritised.

Large-scale 6G trials are underway worldwide, testing AI-driven automation, Open RAN, and Terahertz communication. Europe's SNS projects are validating URLLC and joint communication-sensing solutions. China and South Korea are exploring Terahertz and AI-native networks, while the emphasis in Japan is on sustainability. North America and Brazil are focused on spectrum utilisation, smart agriculture, and remote healthcare. These trials are shaping 6G development, refining its technologies for real-world deployment.

INDUSTRY CHALLENGES

In recent years, several pressing challenges have emerged, spanning societal, economic, sustainability, and inclusion-related concerns, all of which demand thoughtful analysis and innovative solutions. The industry is actively addressing critical societal and inclusion issues through a focus on Key Value (KV) and Key Value Indicators (KVI), while also tackling major environmental and security challenges. Additionally, the sector faces ongoing cybersecurity threats, requiring continuous adaptation to an ever-evolving digital threat landscape.

For 6G systems, technology assessments must incorporate environmental, social, and economic Key Values (KVs), aligning with global goals such as the United Nations Sustainable Development Goals (UN SDGs). These values are measured through Key Value Indicators (KVIs), which guide the SNS initiative by ensuring that technological advancements address impacts on sustainability, digital inclusion, and economy.

Through the SNS JU, Europe is leading efforts to integrate KVs and KVIs into 6G discussions alongside traditional KPIs. Various SNS projects, including those within the 6G-IA Societal Needs and Value Creation (SNVC) Sub-Group and the 6G4Society Support Action, are working to define, evaluate, and implement KVIs.

While some projects have begun measuring KVIs, challenges remain, including prioritisation issues, measurement gaps, and ensuring practical applicability. Engagement with KVIs is nevertheless fostering responsible innovation, helping align 6G development with societal needs, improving public acceptance, and broadening the scope beyond purely technical design considerations.

Key Value Indicators (KVIs)/ Key Values (KVs)

6G technology assessments must integrate environmental, social, and economic Key Values (KVs), measured through Key Value Indicators (KVIs). The SNS 6G initiative, led by Europe's SNS JU, ensures that advancements align with sustainability, digital inclusion, and economic impacts. SNS projects have begun defining KVs, measuring KVIs. Challenges remain, however.

Sustainability

Sustainability is a core tenet of the SNS programme, addressing environmental, social, and economic impacts beyond just energy efficiency. It focuses on reducing energy consumption and carbon emissions through AI-driven network management, optimised designs, and energy-aware services. Standardised metrics for ICT energy usage ensure transparency, while real-time monitoring and resource allocation enhance efficiency. The 6G-IA White Paper (December 2024) identifies key sustainability challenges, enabling technologies, and research gaps. Raising user awareness and promoting Green technology adoption are crucial for a sustainable 6G ecosystem.

Inclusion

Inclusion is a core principle in all SNS projects, ensuring equitable and accessible next-generation networks while promoting diversity and digital accessibility. The WiTaR (Women in Telecoms and Research) Working Group actively championed gender diversity in 2024 through mentorship programmes, leadership training, and networking events. By collaborating with the industry and academia, WiTaR has enhanced visibility for female experts at major conferences and advocated for policies supporting gender balance in tech and research careers.

Cybersecurity

By adopting Zero Trust principles, data-centric security, and advanced technologies such as AI and Confidential Computing, the global technology and security communities can build a secure, resilient and innovative 6G infrastructure. A strong cybersecurity foundation will not only safeguard digital ecosystems but also unlock the full potential of 6G to drive the next wave of technological advancements.

Replicability

The replicable initiative initiated several years ago with the AIOTI Large Scale Pilots and the 5G PPP projects now includes replicable use cases and solutions developed by SNS JU Call 1 and Call 2 projects.

The SNS OPS survey was conducted again in 2024, and additional replicable use cases have been collected. In addition, Call 1 projects, which have developed and trialled these use cases, have used the replicability assessment tool to measure a replicability level. In addition to the initial cooperation with the Horizon Result Platform and the Horizon Booster project, a new cooperation has been set up with the techfinder.io project, whose objective is similar but covers the full spectrum of digital tech. The cooperation's goal is to align the replicability level to provide Digital Innovation Hubs (DIHs) and integrators with a consistent indicator for the ease of replication for a given use case/solution. The updated replicability catalogue currently contains more than 130 use cases, which will be supplemented by the new Call 3 projects following the 2025 survey.

SME INVOLVEMENT AND SUCCESS STORIES

Since the launch of the first SNS calls, more than 100 SMEs from 27 countries have participated in projects and cascade funding. The SME WG accounts for more than 60% of those SMEs. Although slightly lower in the 2024 SNS call, the involvement of SMEs has consistently surpassed the 20% SME participation targeted by SNS JU. In addition, the SNS Stream C / D projects with Open Calls have been instrumental in attracting many SMEs as external participants receiving Financial Support to Third Parties (FSTP).

Projects' presentation

The SNS JU was established in November 2021 as a legal and funding entity, one of the European Partnerships to step up the Green and digital transition. It aims to facilitate and develop industrial leadership in Europe in 5G and 6G networks and services. This Partnership is led jointly by the European Commission and the 6G-IA.

The 6G-IA is the voice of European Industry and Research for next-generation networks and services. The 6G-IA brings together a global industry community of telecoms and digital actors, such as operators, manufacturers, research institutes, universities, verticals, SMEs and ICT associations.

The SNS JU fosters alignment with EU Member States on 6G Research and Innovation and deployment of advanced 5G networks. The SNS JU sets out an ambitious mission with an EU budget of €900 million for the period 2021-2027. The private sector will contribute with at least equal resources (i.e., €900 million) to the SNS JU activities. The SNS JU funds projects that shape a solid research and innovation (R&I) roadmap and deployment agenda by engaging a critical mass of European stakeholders and facilitating international cooperation on various 6G initiatives.

As of 2025, 79 projects have been launched. The first thirty-five (35) SNS JU projects corresponding to the first call for proposals were launched in January 2023 in four main complementary work streams. They include two CSAs (Coordination and Support Actions). They are critical in establishing a solid R&I foundation for Europe, defining the next-generation networks.

Twenty-eight (28) additional SNS JU projects corresponding to the second call for proposals were launched in January and March 2024 in three workstreams, including one CSA.

Sixteen (16) SNS JU projects were selected corresponding to the third call for proposals in three workstreams and one CSA.

Call 1 Projects

The 35 SNS Call 1 projects started in January 2023 with four streams and two Coordination and Support Actions (CSAs).

This section provides details on Call 1 SNS projects stream by stream and ends with the CSAs.

Stream A

SMART COMMUNICATION COMPONENTS, SYSTEMS, AND NETWORKS FOR 5G EVOLUTION SYSTEMS

The seven projects under this stream follow an evolutionary path towards the development of 6G networks. The selected projects demonstrate complementarity and have been selected in such a way as to create a complete system view. Research topics covered include energy efficient radio networks, adaptive Open RAN, integrated 5G-Non-Terrestrial Networks (NTN), AI-based edge platforms, and intelligent resource management ensuring security, privacy & trustworthiness.

5G-STARDUST

5G-STARDUST's ambition is to deliver a fully integrated 5G-NTN autonomous system with novel self-adapting end-to-end connectivity models for enabling ubiquitous radio access.

OVERVIEW

5G-STARDUST is aimed at proving the unification of Terrestrial Networks (TNs) and Non-Terrestrial Networks (NTNs) into a holistic architecture, building on the foundations of 5G and paving the way towards 6G communication systems. The proposed unification framework is conceived to flexibly serve a number of possible Use Cases (UCs), relevant for mobile and satellite operators, vendors, and service providers. In this respect, the overall concept "orbits" around the exploitation of regenerative satellite payloads, hence allowing NTN nodes to act as smart 5G space nodes, implementing gNB functions in space as well as User Plane Functions.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The architecture concept is centred on the implementation of gNB functionalities in space, either entirely within each space node or distributed (i.e. through 5G functional splits in space). In particular, the main focus is on the case of integrating 5G-enabled Low Earth Orbit satellite constellations with TNs. Hence, 5G-STARDUST's ambition is to prove the coexistence of TN and NTN segments within a unified network architecture concept, building on key pillars: 1) unified 5G NR-native radio interface, 2) self-organised network architecture, 3) user-centric satellite system design, 4) multi-link exploitation, and 5) AI-based optimisation of radio and network functions. The selected key functionalities are then being integrated in a dedicated lab testbed for final demonstration.

INNOVATION

The main innovation pillars constituting the baseline of 5G-STARDUST are i) self-organised network architecture building on a flexible space configuration with gNB operated in space, ii) unified radio interface counting on user-centric beamforming and AI-based Radio Resources Management (RRM) optimisation, as part of a reference O-RAN based architecture fusing together TN and NTN components, iii) AI-based multi-link optimisation aimed at scheduling communication link and dispatching traffic flows according to Quality of Service (QoS) requirements and link capacity availability, iv) QoS-oriented network architecture relying on an overarching Software-Defined Networking (SDN)-based layer and on Artificial Intelligence (AI)-based network slicing optimisation. As to this latter point, an important role is certainly also played by the deployment of routing algorithms in space and the switch from TN to NTN infrastructures, which is triggered and managed at Core Network (CN) level. Last but not the least, an important innovation element is the allocation of dedicated network functions in space and the potentials of even deploying application service onboard satellites, such as multi-access edge computing, further reduce the overall latency of reference services.

USE CASES/ SCENARIOS

5G-STARDUST project identified key UCs to demonstrate the functionalities of an integrated 5G-based TN-NTN network, comprising mobile transportation systems, PPDR, private and governmental networks, residential broadband, and hyperconnected automotive sector. Out of these scenarios, 5G-STARDUST further narrowed down the selection to 5G-enabled residential broadband and aeronautical communications to demonstrate the corresponding functionalities in the so-developed lab testbed. As to the first scenario, the objective is to show the seamless transition from TN to NTN achieve more cost-effective operations (i.e. network switch at night). On the other hand, the second scenario deals with the coexistence and later switch from TN to NTNs in the various phase of aircraft flights, i.e. from take-off to landing through cruising phases. As such, the objective is to provide the switch from on e network to another, once either of the two available networks (i.e. TN or NTNs) are not any longer available or offer less satisfactory QoS/QoE guarantees than the other, hence necessitating a network handover. The considered scenarios are being implemented in a common testbed lab (expected to reach TRL4/5 at the end of the project), where the main elements necessary to demonstrate end-to-end connectivity are being integrated. The overall layout of the functional testbed architecture and the description of the related SoftWare/HardWare (SW/HW) components is then summarised in the next section, where the status of the integration process is also shortly discussed. Finally, it is also worth noticing that the procured testbed will be considered the main outcome of the project in light of its capabilities of showcasing the full functionalities of an integral 5G-enabled NTN system. Nevertheless, the project has been also developing standalone simulation and emulation tools to prove the other findings of the project, though not reaching the necessary maturity for being implemented in the general Proof-of-Concept (PoC) of the project.

RESULTS

The main outcome of 5G-STARDUST is a PoC for demonstrating integrated 5G/6G-NTN communication system. The PoC includes TN and NTN segments, transporting data from servers to User Equipment through shared RAN and 5G CN infrastructures. In particular, UE prototypes operating at FR1 and FR2 frequency ranges are used, able to either use TN or NTN connectivity, achieved through dedicated gNBs, either on ground or space. The space segment is characterised by realistic channel emulators. The Centralised/Distributed Unit parts of the gNB are implemented as SW components in a dedicated HW, while the Radio Unit is directly embedded in Xilinx boards. It is noteworthy that the overall setup will be used for verifying the overall system architecture and for validating the benefits of an end-to-end 5G enabled NTN architecture, through real-world applications such as video streaming, file transfer, and web browsing. Finally, the preliminary results collected for the assessment of the unified radio interface and the self-organised network paradigm prove the performance improvements coming from the deployment of a unified 5G/6G unified network architecture in terms of servicing many use cases and offering satisfactory Key Performance Indicators.

Satellite And Terrestrial Access For Distributed, Ubiquitous And Smart Telecommunications

5G stardust

Coordinated by
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January 2023-December 2025

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Verticals: Automotive, transportation, residential broadband, PPDR, and governmental

Partners: Accelleran, Gigasys Solutions, Innovations for High Performance Microelectronics, Telefonica ID, Ericsson, Parallel Wireless, i2CAT, NEC Laboratories Europe, Polytechnical University of Catalunya, ARM Microprocessor, RunEL

6GREEN

The 6Green project aims to create an innovative, service-based, and comprehensive ecosystem that promotes energy efficiency across the entire 5/6G value chain.

OVERVIEW

6Green envisions the 5/6G ecosystem as a sustainable, interconnected, greener, flexible end-to-end intercompute system, able to properly interface stakeholders by means of latest generation intent-based and cloud-native paradigms, and facilitating their interactions according to green economy business models and agreements. This will enable 5/6G vertical applications and network slices to be dynamically, scalably, and autonomically placed in the edge-cloud continuum, instantiated, modified, migrated, and released in a coordinated fashion, when and where really needed by end-users to minimise the induced impact at the infrastructure layer.

The ultimate objective is to enable and to foster 5/6G networks and vertical applications, reducing their carbon footprint by a factor of 10 or more with respect to business-as-usual scenarios.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The centrality of the Service-Based Architecture (SBA) in the 5/6G ecosystem lies in its ability to engage with both the infrastructure and vertical application domains. This positioning makes it well-suited to collect metrics, making informed decisions, and facilitating backpressure propagation to other stakeholders. For this reason, 6Green is extending the currently specified 5G SBA Network Functions (NFs) to host the new features required for collecting information, making decisions and actuating new configurations to the ecosystem in a way that involves all the stakeholders in the decision process.

The primary enabling technologies that will facilitate the realisation of the project's vision will be Artificial Intelligence, Cloud-native approaches, and the Edge-cloud continuum.

These technologies will be integrated into an SBA composed of different frameworks that can interact synergistically to achieve the project's decarbonisation target.

INNOVATION

The project targets highly innovative goals, such as the introduction of cross-domain mechanisms to map the energy ascribable to each stakeholder, with a sort of energy-driven "backpressure" from the infrastructure level to the vertical industries. This backpressure is meant to carry information on Operating Expenditures (OpEx) and energy-aware metrics extracted from the infrastructure (i.e., the estimate of the induced resource usage footprint, suggestions on how to scale/ reconfigure microservices/sidecars to meet the requested performance, while enabling the infrastructure to act in a green and OpEx-sustainable fashion) and relevant events or data (e.g., handover events of specific User Equipment, UEs, etc.) to drive smart scaling operations in a reactive or proactive fashion.

Thanks to this backpressure, players at any level will be enabled to close a part of the optimisation control loop and take significant business advantages

in the 5/6G competitive market. It can be noted that the interaction of the control loops in the various administrative domains will depend on the green 5/6G business models that will be applied.

The integration of new AI mechanisms in the 5/6G SBA is also a target of 6Green, to reduce the energy consumption/carbon footprint of both the network and the vertical applications dynamically and holistically, as well as exploiting renewable energy sources supplying the distributed infrastructure.

USE CASES/ SCENARIOS

6Green develops three main use cases:

- **UC1:** Critical Operation Maintenance during Energy-Constraint Disaster Scenarios, focuses on maintaining operations in case several parts of the computing capabilities are unavailable (e.g., out of power, destroyed, sabotaged, etc.) or may become unavailable due to non-infinite power supply redundancy (e.g., electrical grid is offline, while local battery and solar powered backup is still available). In such a situation, certain functions need to be deprioritised, moved to other execution resources, or even stopped, with the final goal of minimising consequences for the users.
- **UC 2:** Energy-Efficient Augmented Reality Remote Assistance System, aims to develop a Remote Visual Assistance application allowing to replace travel of expert technicians for advanced and augmented remote collaboration and inspection tools, thus reducing travel costs and related CO_2 emissions and time spent, as business trips account for a large share of the carbon footprint in many companies acting in any vertical market sector.
- **UC 3:** Zero-Carbon Clientless Virtual Enterprise Desktop as-a-Service (DaaS), deals with remote Desktop as a Service (DaaS) solutions in a real cloud environment. Moreover, passing from the public cloud to 5/6G edge-cloud continuum, DaaS can benefit from 5/6G native security, slice integration with the private enterprise network infrastructure, etc. Therefore, it could become more than attractive for companies and a flexible means to efficiently support employees' smart working (and, therefore, to further reduce Green House Gas (GHG) emissions).

RESULTS

The 6Green Project has already achieved several results and, entering its last year, the Consortium will now focus on the integration of the outcomes achieved at the different layers of the 5/6G ecosystem.

As such, the outcomes can be summarised as i) Infrastructure layer: implementation of an observability framework that combines data collection and policies for extracting KPIs from infrastructures metrics or for simulating resources usage, introduction of traffic offloading mechanisms, and development of cloud-native enablers for end-to-end management and automation including scale-to-zero. ii) Network Platform layer: definition of all the NFs in the 6Green SBA and software release of the open-source ones, development of lifecycle management mechanisms for network slices, and design of Machine Learning (ML)-powered network slicing policies that can satisfy multi-criteria trade-offs. iii) Vertical Application layer: preliminary design of green business models, conception of Decarbonisation Level Agreements (DLAs) that include energy and carbon footprint considerations in the business models established among the involved stakeholders, and identification of the policies to be specified in the Service Level Agreements (SLAs)/ DLAs and preliminary examples provided for scaling operations.

Green Technologies for 5/6G Service-Based Architectures

Coordinated by
Roberto Brusch, CNIT

January 2023-December 2025

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Partners: CNIT, Atos, Ericsson Italy, Telenor, Telefonica ID, Orange, Ubitech, Internet Institute, Oculavis, ICCS, Eurecom, CNR, Smile, HPE

ACROSS

ACROSS offers a secure E2E network and service management platform for managing modern and future 6G services, addressing dynamicity, complexity, and scalability over an expanding cloud continuum.

OVERVIEW

The ACROSS project designs and implements an end-to-end service deployment and management platform for next- generation networks and services, aiming at unprecedented levels of automation, performance, scalability, and energy efficiency. The platform is built on a highly distributed grid of domain-level orchestrators, integrated through a cloud-managed, multi-domain orchestrator using standardised interfaces. ACROSS incorporates deep telemetry, AI-driven intelligence, zero-touch provisioning, and robust security mechanisms to optimise operations across heterogeneous cloud-edge deployments. It is validated through real-world use cases and aligned with global standards to drive impactful contributions to 6G advancements.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

ACROSS orchestrates end-to-end services and resources across access, core, edge, and cloud domains. At its core, ACROSS includes i) a zero-trust integration fabric for secure interactions among private distributed domains, ii) the ACROSS Multi-Domain Orchestrator (AMSO), and iii) several ACROSS Domain Orchestrators (ACDO). These components interact through standardised interfaces, enabling interoperability with existing and future ecosystems.

ACROSS promotes a set of platform services that assist end-users' Service Level Agreements (SLAs), offering additional features, such as:

- Service validation via Network Digital Twin services
- SLA monitoring via Telemetry services
- SLA inference via Artificial Intelligence and Analytics services
- Zero-Touch SLA preservation via Automation services
- SLA Security & Trust

INNOVATION

ACROSS introduces several key innovations to redefine network management and orchestration:

1. **AI-Driven Predictive Lifecycle Actions**: Leveraging advanced Artificial Intelligence (AI) and Machine Learning (ML) algorithms, the platform predicts and preemptively resolves network issues, optimises resource utilisation, and enhances service reliability and quality.
2. **Zero-Touch End-to-End Orchestration**: Establishing seamless orchestration workflows across access, core, edge, and cloud domains.
3. **Deep Telemetry and Intelligent Insights**: A novel telemetry engine enables real-time monitoring and analysis.
4. **Vertical-Specific Applications**: ACROSS tailors orchestration and management solutions to meet the unique requirements of industries facilitating the deployment of customised, scalable, and secure services.

5. **Zero-Trust Security Integration**: The platform incorporates robust security measures, ensuring data integrity and resilience against cyber threats.

USE CASES/ SCENARIOS

- **UC 1: Stakeholder-Driven Zero-Touch Orchestration**

  This use case showcases the ACROSS platform's ability to process and act on policy-driven events initiated by stakeholders through its Northbound Interfaces (NBIs). It demonstrates the seamless integration of zero-touch provisioning mechanisms to automate recurring operations, improving policy execution and stakeholder interaction efficiency.

- **UC 2: Device-Driven Zero-Touch Orchestration**

  This scenario highlights the platform's advanced sensing capabilities, enabling it to autonomously process events from both infrastructure and end-user devices. These events trigger automated zero-touch actions that dynamically adjust the platform's services and resources to align with changing conditions, ensuring operational continuity and optimal performance.

- **UC 3: Intelligence-Driven Zero-Touch Orchestration**

  This use case focuses on integrating AI-driven intelligence to process telemetry data and autonomously generate actionable orchestration decisions. It exemplifies the platform's ability to predict and adapt to network changes, enabling proactive resource management and enhancing reliability.

- **UC 4: Holistic Zero-Touch Orchestration**

  This test case integrates stakeholder-driven, device-driven, and intelligence-driven capabilities into a unified framework. It demonstrates the platform's capacity to manage complex, composite orchestration tasks across multiple domains, showcasing its scalability, adaptability, and automation efficiency.

These use cases validate ACROSS's potential to deliver advanced, automated network management solutions, achieving its performance and business objectives through seamless, intelligent orchestration.

RESULTS

ACROSS makes impact via tangible results across different directions:

- A distributed service and resource orchestration platform built upon popular open-source platforms, such as Maestro[1] (Multi-domain orchestrator), ETSI OpenSlice[2] (Domain orchestrator), and OpenZiti (ACROSS Integration Fabric) to be demonstrated at ETSI ZSM[3].
- Deep service and resource telemetry via contributions to ETSI OpenSlice resource telemetry, ETSI TeraFlowSDN[4] transport network telemetry, and P4.org[5].
- Operator-grade network digital twins (Telefonica ID testbed in Madrid) addressing key telco operator use cases, such as DDoS detection and prevention.
- AI and Analytics models for predictive SLA preservation both in controlled environments (TID digital twins) as well as real testbeds (Patras 5G testbed[6]).
- Automation services for Zero-Touch SLA preservation and east-west platform expansion to new domains in dramatically lower times than possible today.

1. https://maestro-mkdocs.readthedocs.io/en/latest/
2. https://osl.etsi.org/
3. https://www.etsi.org/technologies/zero-touch-network-service-management
4. https://tfs.etsi.org/
5. https://p4.org/
6. https://wiki.patras5g.eu/

Automated zero-touch cross-layer provisioning framework for 5G and beyond vertical services

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January 2023-December 2025

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BeGREEN

BeGREEN Brings Forward the Design of Energy-Efficient Solutions into Radio Access, Edge, Network Functions and Management.

OVERVIEW

BeGREEN brings forward the design of energy efficient solutions into the radio access, edge, network functions and network management by pursuing, i) Radio Unit (RU), Distributed Unit (DU), and Central Unit (CU) solutions to reduce energy consumption, ii) using sensing and Integrated Sensing and Communication (ISAC), Reconfigurable Intelligent Surface (RIS), and relay to improve resource allocation and energy efficiency in the networks, and design and development of an O-RAN based 'Intelligence Plane', for Artificial Intelligence (AI)-assisted network function energy optimisation.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

BeGREEN proposed 'O-RAN based Intelligence Plane' architecture is a cross-domain framework designed to support efficient, AI-assisted, energy efficiency enhancement and monitoring. The Intelligence Plane include the Service Management and Orchestration (SMO) plus the non-Real-Time (RT) RAN Intelligent Controller (RIC), the Near RT-RIC and the developed rApps and xApps, which are empowered by the AI Engine and the datalake. The architecture considers extensions to allow the integration of Edge and Core domains, and of RAN technologies which are currently beyond the scope of traditional O-RAN implementations like Relays, RIS, and ISAC.

INNOVATION

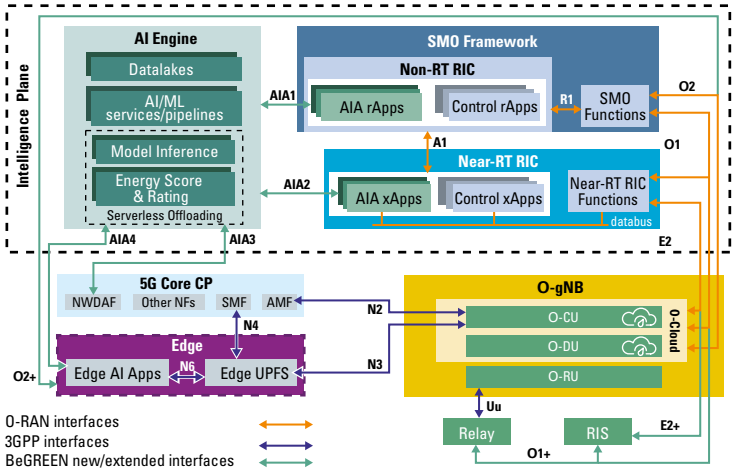
BeGREEN introduces the innovative Intelligence Plane solution, that is an O-RAN based architecture with its extensions to support efficient, and AI assisted, energy efficiency enhancement and monitoring, as described above. As part of this architecture, the proposed AI Engine provides a serverless execution environment hosting the AI/Machine Learning (ML) models, offering inference and training services to the rApps/xApps. Also, it manages the lifecycle of the AI/ML models.

A key innovation of BeGREEN is on providing energy efficiency ratings and energy scores through the Energy Efficiency Calculation rApps. These rApps characterise the energy efficiency of the overall network, and using eXplainable AI approaches, identify and quantify the contributions of the different RAN components to energy consumption and the contributions of the different enhancements proposed in BeGREEN to energy saving.

Together with the datalake, which includes metrics from different domains (such as RAN, core, ISAC and Edge applications (App)), the AI Engine allows to design and implement innovative AI-driven rApps/xApps. By decoupling the AI/ML services from the O-RAN control loops, the BeGREEN Intelligence Plane offers a modular and reusable framework that allows for independent model development and deployment.

BeGREEN also puts forward methods to the evaluate AI/ML-based solutions that enhance energy efficiency, including the Intelligence Plane itself. The dimensionality reduction techniques to minimise data inputs for ML models without impacting the model accuracy are proposed to reduce data processing overhead and improve the

BeGREEN Architecture



energy efficiency of ML models. The compute resource allocation in virtualised RAN (vRAN) scenarios are analysed, and Reinforcement Learning (RL) algorithms to dynamically decide on resource allocation according to network load and power consumption patterns are proposed.

Other innovations are on introducing DU and CU alternative architectures for reducing power consumptions, as well as integrated ISAC and RIS technologies for resource allocations enhancements. Further, system level analysis of ISAC and Relay assisted networks to propose the most energy efficient scenario are provided.

USE CASES/ SCENARIOS

BeGREEN solutions are not use case specific and can be used for all use cases. Some specific scenarios considered in the project are (non-exhaustive list):

- O-RAN based architectures
- Massive Multiple Input Multiple Output (mMIMO) and CF (Cell-Free) MIMO scenarios
- Relay assisted network scenarios
- Virtual RAN (vRAN) and Edge

RESULTS

BeGREEN has successfully proposed, implemented and tested the Intelligence Plane and related xApps, rApps and the AI Engine. BeGREEN also has analysed and proposed energy efficiency ratings and energy scores that are obtained by the dedicated rApps. In addition, methods for the dimensionality reduction for minimising the data used by the AI algorithms are introduced.

Other project achievements are the improvements of the resource allocation using ISAC and RIS technologies, the design and implementation of sensing systems (sub-6 GHz and mmWave) and RIS, and their integration for being used in specific scenarios are achieved and demonstrated.

On the DU and CU accelerations, it is shown that advanced architectures can be employed to reduce power consumption of modules with high computational complexity.

The Power Amplifier (PA) blanking technique introduced in BeGREEN to powers-off the RU PA when there is no data in the downlink stream is implemented on a commercial RU and a PA energy consumption reduction higher of more than 40% is achieved.

Furthermore, comparison of mMIMO cellular environments with CF-mMIMO deployments, to the collocated solutions regarding energy efficiency in difference scenarios, e.g., dense urban, rural, etc., as well as relay and RIS assisted scenarios are performed and presented.

Beyond 5G Artificial Intelligence Assisted Energy Efficient Open Radio Access Network

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NANCY

Focusing on energy-efficient wireless networks, adaptive Open Radio Access Networks, AI-based edge platforms, and intelligent resource management ensuring security, privacy, and trustworthiness.

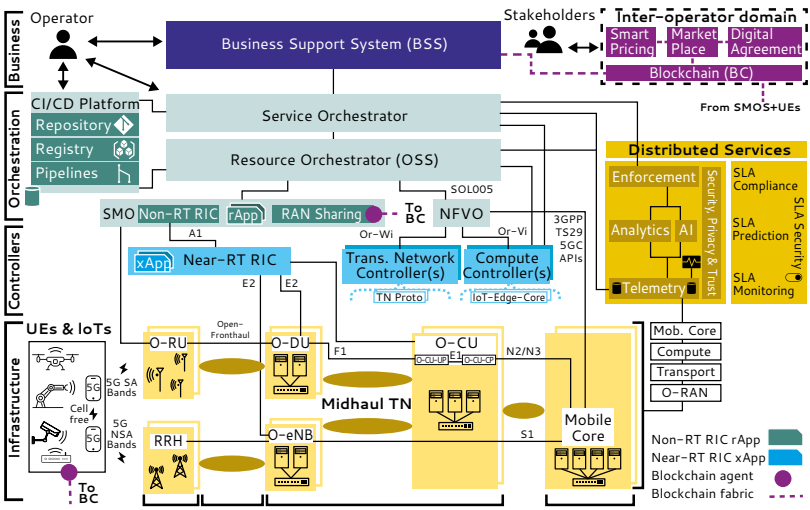
OVERVIEW

The future wireless networks will integrate several new technologies, such as Virtualisation and orchestration, and principles that aim to enhance scalability, flexibility, and resource management resulting in complex and diverse networks. However, without coordination and cooperation among mobile network operators, there can be duplication, redundancy, and inefficiency in data provisioning. To this end, NANCY aims to introduce a secure and intelligent architecture for next-generation wireless networks. By leveraging blockchain and artificial intelligence, NANCY will design flexible networking schemes, and intelligent resource management mechanisms focused on energy efficiency, security, privacy, and trustworthiness.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The figure illustrates the functional and deployment view of the NANCY architecture. The **Infrastructure** layer is comprised of distributed and heterogeneous physical devices that span across multiple interconnected domains. The **Controllers** layer consists of a set of infrastructure controllers that manage the underlying domain resources. Furthermore, the **Orchestration** layer provides end-to-end service and resource management within an operator's realm, as well as continuous integration and delivery of the operator's own or customer services. Finally, the **Business** layer hosts the operators' components to manage services and interact with other operators to exchange services and resources through a secure inter-operator domain.

NANCY high-level architecture



an artificial iNtelligent Aided unified Network for seCure BeYond 5G long term evolution

NANCY

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January 2023-December 2025

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Verticals: Automotive, Transport, Logistics, Media and entertainment

Partners: University of Western Macedonia, Ubitech, Tecnalia, Nec, I2cat, Italtel, Netcompany-Intrasoft, 8Bells, Thales, Draxis, Dreven, OTE, Virtual Open Systems, Institut Jozef Stefan, Consorzio Per La Ricerca Nell'automatica E Nelle Telecomunicazioni, Ericsson Italy, Business And Iot, Integrated Solutions, Innocube, Centre For Research &Technology Hellas, Sidroco Holdings, University Of Murcia, Scuola Superiore Sant'anna, Metamind Innovations, University of The Basque Country

INNOVATION

The NANCY innovations revolve around three main pillars:

- Pillar I: **A distributed and self-evolving B-RAN for dynamic scalability, high security and privacy in a heterogeneous environment**: The innovations include a theoretical model for Blockchain, a post-quantum cryptography scheme, a quantum key distribution emulator, a cell-free access mechanism with optimal cell selection, and a smart pricing approach that is based on reinforcement learning and reverse auction theory.
- Pillar II: **Towards the Pareto-optimal AI-based wireless RAN orchestration that maximises energy efficiency and trustworthiness**: The innovations include an open-source and modular orchestrator for AI/ML workflows, an AI-based Virtualiser for exploiting underutilised resources, a semantic communications scheme for efficient image transmission, and an explainable AI framework.
- Pillar III: **Distributed Multi-Access Edge Computing (MEC) for "almost-zero latency" and high-computational capabilities at the edge, where the data are generated**: The main innovations consist of a caching mechanism and a resource allocation scheme for offloading scenarios, and network anomaly detection and self-healing methods for timely identifying and mitigating potential cyber-attacks towards increasing the network security.

USE CASES/ SCENARIOS

NANCY envisions freeing the role of the network nodes and allowing them to interchangeably be connectivity/service consumers and providers. In this respect, three usage scenarios have been designed.

1. **Fronthaul network of fixed topology:** in this scenario, each device performs computation-intensive and delay-sensitive tasks, such as navigation or video streaming, leveraging access points equipped with edge computing capabilities. These access points offer high computational resources and support the execution of AI functions.
2. **Advanced coverage expansion:** the concept of advanced coverage expansion aims to address the growing demand for reliable, high-speed connectivity across various environments. This approach employs innovative techniques such as relaying, dynamic topologies, and optimised connectivity to improve network performance.
3. **Advanced connectivity of mobile nodes:** this scenario facilitates communication between vehicles and access points, as well as direct communication between vehicles. In this setup, content is exchanged among vehicles, with one vehicle serving as a relay to forward data to an access point. Given the potential lack of trust between vehicles, blockchain pseudonyms are utilised during data sharing to enhance security and protect privacy.

RESULTS

NANCY aims to deliver a secure and intelligent architecture for next-generation wireless networks. The project outcomes are focused on reducing infrastructure costs, minimising energy consumption and increasing environmental sustainability by optimising the utilisation of the network resources using AI-based approaches. Furthermore, by leveraging open standards the architecture features enhanced flexibility and scalability and can seamlessly adapt to varying workloads and requirements. Furthermore, the overall performance and efficiency of the network are improved through the resource management techniques. Another core advancement is the enhanced network, device, and user security and trustworthiness, enabled using blockchain and post-quantum cryptography methods. In addition, the explainable AI tool offers insights into the decision-making process of the AI models, further ensuring trust and transparency among AI, users, and network operators.

SEASON

An innovative Multi-Band over Space Division Multiplexing (SDM) optical network infrastructure, spanning the access, aggregation, and metro/long-haul segments.

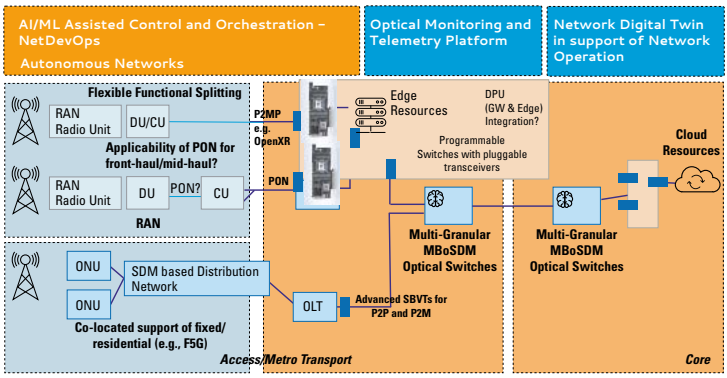
OVERVIEW

The SEASON project is developing a novel Multi-Band over Space Division Multiplexing (SDM) optical network infrastructure, spanning access, aggregation, and metro/long-haul segments. It will design, develop and validate novel transmission, switching, monitoring and Artificial Intelligence (AI) driven solutions, supporting requirements for X-haul in terms of capacity and energy efficiency. Upon successful completion, it will have a clear impact on society and emerging 5G services, being capable of scaling up network capacity and coping with challenging user needs through improved power efficiency, reliability, and self-management capabilities. New emerging services such as Augmented Reality (AR) pose stringent requirements in terms of reliability, connectivity and capacity.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The SEASON architecture targets innovative transmission and switching solutions operating on Multi Band (MB) over Space Division Multiplexing (MBoSDM). Data plane innovations include multi-granular MB/SDM switching nodes, advanced Digital Signal Processing (DSP), and Sliceable Bandwidth Variable Transceivers (S-BVTs) enabling both point-to-point (P2P) and Point-to-MultiPoint (P2MP) connectivity. The figure below displays overall network solution and main innovations.

SEASON also addresses the convergence of optical, packet and computing resources by incorporating coherent pluggable transceivers, within the latest generation of Data Processing Units (DPU). Architecture's crucial objective is to ensure energy efficiency and reduce the number of Optical to Electrical to Optical (O/E/O) conversions.



Self-Managed Sustainable high-capacity Optical Networks (SEASON) Network Solution

INNOVATION

The SEASON prime innovation concerns the design and the validation of a scalable, ultra-high capacity, and power efficient MBoSDM network infrastructure from access to cloud. For this to materialise, challenging solutions in the control and data plane should be addressed. To transform raw capacity to useful

information, it entails the development of multi-granular MBoSDM switching node with an extended operating spectral window, enabling dual fibre/core or band switching optimised for energy and cost efficiency. In terms of transmission, two different paths will be followed: i) upgrade a scalable and modular S-BVT capable to establish high-capacity (P2P and P2MP connections in a MBoSDM environment; ii) the optimisation of the DSP algorithms to enable up to 4x data-rate increase, while keeping power consumption low.

In addition, innovative solutions for the control plane are also envisaged. For example, a generalized telemetry, infrastructure and control service orchestration system will be designed for the MBoSDM infrastructure, able to deploy and manage the lifecycle of all network elements and integrated packet/optical systems.

USE CASES/ SCENARIOS

SEASON addresses two main use cases (UCs). The first UC focuses on the network perspective, showing how the SEASON solution enables a network operator to provide an innovative end-to-end infrastructure with capacity scaling, monitoring and AI/Machine Learning (ML) network operation in support of beyond 5G.

The second UC provides the user perspective considering challenging Augmented Reality applications for user-driven immersive experiences.

Use cases and trials are tightly combined with the Key Performance Indicators (KPIs) that SEASON wishes to demonstrate. Thus, SEASON envisages to show case i) x120 capacity increase compared to current C-band solutions ii) a 50% Capital Expenditures reduction, iii) <1ms mobile user latency via coordinated resource allocation at optical access and mobile network and iv) a >50% energy saving via dynamic spatial channels aggregation and deactivation of unused transceivers.

For the above mentioned KPIs to materialise many technical innovations are needed. For example, the design of a flexible and modular MBoSDM node able to switch/add/drop channels in at least 3 different bands (e.g., S, C, L) in an SDM/Multi Core Fibres (MCF) fibre infrastructure featuring up to 10 fibres/cores, able to cope with switching capacities scalable up to between 2.4-3.6 Pb/s, or suitable MBoSDM transceivers able to increase the capacity of the state-of-art transceivers up to 2×-4× by exploiting enhanced wavelength/space dimensions while enabling appropriate slice/band/core/fibre selection according to the network path.

RESULTS

In 2nd year, the design and the implementation of the control plane infrastructure was carried out as well as the design of innovative optical solutions for the data plane. First results on monitoring/telemetry, single/multi-domain control solutions, and AI/ML-based self-management are demonstrated. The main objective was to identify and characterise the key functional components of the SEASON control plane, their roles and responsibilities; and then define the interfaces that enable interworking across the different systems.

With respect to data plane, optical versus electrical aggregation and network optimisation with Digital SDubCarrier Multiplexing (DSCM) were analysed, for enabling both point-to-point and point-to-multipoint transceivers. Such solutions allow for a flexible and scalable network design, reducing overall costs and energy consumption. In addition, Reconfiguralbe Optical Add/Drop Multiplexers (ROADM)-free IP over wavelength division multiplexing (IPoWDM) networks were also explored. This approach eliminates the need for traditional ROADMs and is driven by recent advances in coherent transceivers and packet-switching Application-Specifif Integrated Circuit (ASICs).

Self-Managed Sustainable high-capacity Optical Networks

SEASON

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January 2023-December 2025

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Verticals: Augmented reality (AR) service for user-driven immersive experiences

Partners: CNIT, Ericsson, CTTC, ADVA, Telefonica ID, UC3M, Fraunhofer HHI, TIM, Polytechnical University of Catalunya, Infinera, WestAquila, Accelleran, WINGS-ICT, ERI, FiberCop

VERGE

The EU-funded research project VERGE aims to deliver an AI-empowered, flexible and modular edge platform, unifying communication and computation resources into an edge-cloud compute continuum that is seamlessly integrated within B5G.

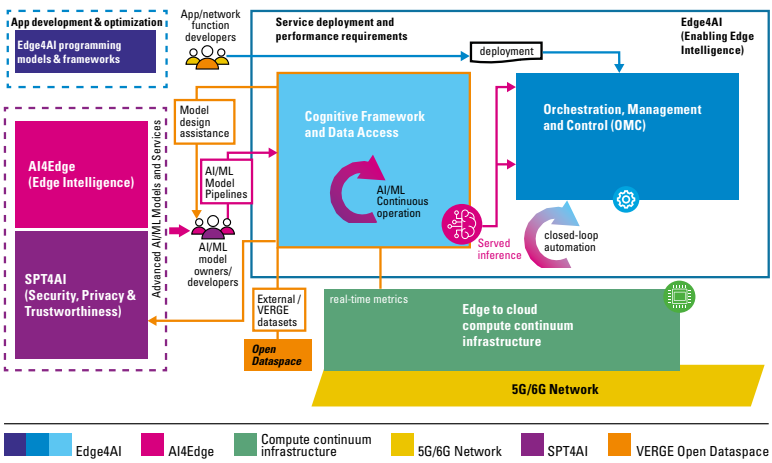
OVERVIEW

VERGE proposes an open, modular, and distributed edge architecture, designed to integrate seamlessly with the edge-to-cloud compute continuum. The overall VERGE concept has been built around three conceptual pillars: i) **"Edge for AI"** (Edge4AI), responsible for enabling the unified compute continuum environment, encompassing the heterogeneous pool of computing resources from the edge to the cloud; ii) **"AI for edge"** (AI4Edge), a portfolio of AI methods to optimise and automate different aspects of the computing and network performance in diverse and dynamic B5G/6G environments; and iii) **"Security, Privacy and Trustworthiness for AI"**(SPT4AI), addressing relevant challenges on robustness, privacy, safety, and explainability of the developed AI models, targeting to enhance their overall trustworthiness.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

VERGE's architecture is shown in the figure, depicting the main interactions between the three VERGE pillars: i) **the Edge4AI**, with its three key components, i.e., the Orchestration, Management, and Control (OMC) layer, the cognitive framework, and the programming models; ii) **the AI4Edge**; and iii) **the SPT4AI**. The edge-to-cloud compute continuum infrastructure is depicted at the bottom of the figure, abstracting all the available compute resources where the different applications, services, and intelligent algorithms are executed and orchestrated. 5G/6G network components, including RAN, core, and transport network, are represented below the compute continuum infrastructure. VERGE Open Dataspace represents the access to an open repository where datasets for the training of AI/ML models are stored.

VERGE architecture



AI-powered eVolution towards opEn and secuRe edGe architEctures

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January 2023–June 2025

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Verticals: Industry: Factory & process automation, Smart Cities: People mobility

Partners: Polytechnical University of Catalunya BarcelonaTech, CTTC, King's College of London, University of Oulu, University of Siena, Barcelona Supercomputing Centre, Samsung, Intel, Ericsson, Turkcell, Nearby Computing, hiro MicrodataCentres, Thalès, Arcelik, Holo-Light

Multiple stakeholders are involved in this complex ecosystem, including telecom operators, edge and cloud infrastructure providers, equipment manufacturers, and end users (e.g., vertical industries). A notable group among these stakeholders are the software developers (i.e., application and network function developers, AI/ML model owners and developers), who are expected to play a key role by designing applications, networks, and AI-enabled services that run on this heterogeneous infrastructure.

INNOVATION

VERGE consortium has identified a set of innovations:

- Advanced orchestration of AI-enabled smart city services in distributed edge environments
- Dynamic computation splitting for real-time services
- Dynamic computation offloading and split learning between edge and Extended Reality (XR) devices
- AI-driven network slicing for XR and for IoT-enabled autonomous tram services
- Relays with edge computing capabilities for supporting XR services
- Smart micro-orchestration of disaggregated RAN elements over Field-Programmable Gate Array (FPGA) platforms
- Security of AI Driven Tasks in Distributed Multiple Input Multiple Output (MIMO)
- Trustworthiness for AI4Edge framework using security/privacy by design
- AI model generalisation ensuring both accuracy and safety
- Causal discovery and hazard prediction using structural causal models
- Secure edge intelligence empowered by advanced learning solutions

USE CASES/ SCENARIOS

VERGE use cases target two vertical domains: **1) XR-enabled industrial use case (UC)**. This will focus on delivering immersive XR services with minimal latency and overall high Quality of Experience to enable and improve industrial processes, such as the collaborative product design and prototyping by remote engineering teams and the XR-aided remote robotic control. **2) Autonomous tram UC**. The focus is on the use of safety services running on-board an autonomous tram and at the edge infrastructure and fusing the input of multiple sensors (e.g., cameras, lidars) to augment the situational awareness of the driver.

RESULTS

VERGE has introduced an open, modular, distributed architecture for the edge computing evolution for **Beyond 5G** (B5G) and 6G, as detailed in D1.3 "*VERGE's final system architecture*". The proposed design facilitates the lifecycle management of cloud-native services, as well as AI pipelines developed for the optimisation of complex and heterogeneous edge-enabled environments, while supporting a suite of novel mechanisms to ensure the trustworthiness of AI solutions. A complete picture of the results obtained will be provided in deliverables: for the Edge4AI pillar in D2.2 "*Final Report on VERGE Edge4AI design*", for the AI4Edge pillar in D3.2 "*Final Report on VERGE edge intelligence and network management*" and for the SPT4AI pillar in D4.2 "*Final design and performance assessment of the VERGE solutions for security, privacy and trustworthiness for AI*". In turn, VERGE's open dataspace includes a variety of datasets that have been generated by the project and will be publicly available – refer to D1.4 "*Report on VERGE's open dataspace (v2)*" for a detailed description.

Moreover, VERGE has outlined eight demonstrations. Results obtained in VERGE demonstrations will be reported in D5.3 "*Showcasing VERGE Proof-of-Concept*".

Stream B

RESEARCH FOR RADICAL TECHNOLOGY ADVANCEMENT

in preparation for 6G and radical advancements of IoT, devices and software

The focus of Stream B is on novel technologies that are expected to be adopted in commercial networks within a mid- and/or long-term timeframe. Research topics considered in the 19 retained projects include, inter alia, novel 6G system architectures, advanced wireless and optical communication technologies, advances in Non-Terrestrial Networks, secure development of URLLC applications.

6G-NTN

The 6G-NTN project brings together high-level representatives from the mobile communication, satellite, and research communities to identify technical, regulatory, and standardisation enablers for the NTN component of 6G.

OVERVIEW

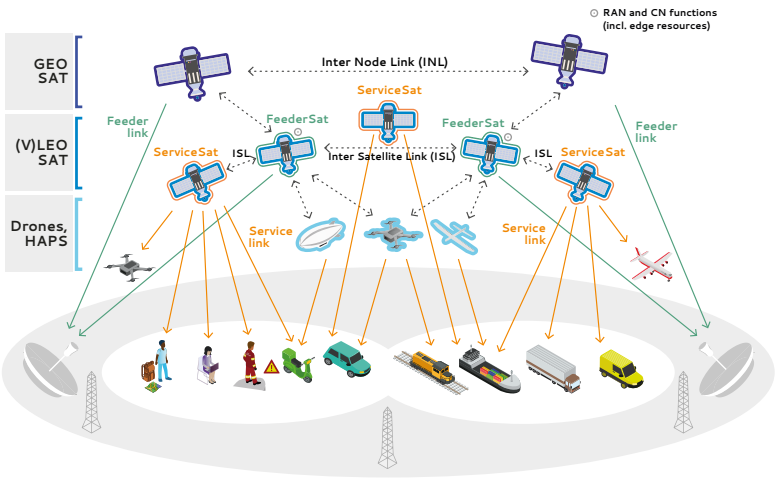
6G-NTN envisions full and native NTN integration into 6G to meet the growing vertical industries' and consumers' needs. The project develops an innovative 3D NTN/TN architecture to enable ubiquitous coverage with high data rate communication at quasi-ultra-low latency while providing high accuracy and reliable location service. It also defines a roadmap for technical, regulatory, and standardisation building blocks to enable integrated NTN service provisioning and a disruptive market offer by 2030-35, boosting Europe's tech leadership.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

6G-NTN's 3D multilayered, multiband, and multiterminal architecture integrates satellite and aerial platforms across orbital and atmospheric layers, combining satellites in Geostationary Earth Orbit (GEO), Medium Earth Orbit (MEO), and Low Earth Orbit (LEO) with High-Altitude Platform Stations (HAPS), interconnected through Optical InterSatellite Links (OISLs) and Radio Frequency (RF) feeder links.

OISLs provide high-bandwidth, low latency communication between satellites, enabling rapid data transfer. RF feeder links connect satellite constellations to ground stations, ensuring robust network integration. The architecture supports multiple frequency bands (C and Q/V) to optimise signal transmission across diverse terminal types, including handheld devices, drone-mounted equipment, vehicle-integrated systems, and fixed ground stations.

6G NTN architecture



6G Non-Terrestrial Networks

6GNTN

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January 2023-December 2025

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Verticals: Maritime, Automotive, Transportation, PPDR, Direct Communication over Satellites

Partners: University of Bologna, Thalès Alenia Space France and UK, Martel, Telit Cinterion, Greener Wave, Thalès SIX, CTTC, Ericsson Sweden and France, CTTC, DLR's Institute of Communications and Navigation, Orange, SES Techcom, Qualcomm Communications France, Digital for Planet.

INNOVATION

6G-NTN envisions a transformative leap beyond 5G, driven by a suite of cutting-edge technologies and innovations, namely: Disruptive performance compared to 5G NT; Spectrum coexistence between TN and NTN; 3D TN/NTN network architecture; Seamless and transparent service continuity; Reliable GNSS-independent positioning; Flexible, software-defined payloads; Virtual Network Function (VNF) orchestration and AI-enhanced RAN Intelligent Controller (RIC); Rapid adaptation to traffic variations; Integrated TN/NTN edge computing; Compact, lightweight terminals for in-vehicle use; Support for Public Protection and Disaster Relief (PPDR) services and light-indoor connectivity; and Enhanced throughput for superior connectivity.

USE CASES/ SCENARIOS

6G-NTN demonstrates transformative solutions via seven real-world use cases:

1. **Maritime Coverage for Search and Rescue**: Enhances coordination during maritime emergencies by integrating TN and NTN communication capabilities.
2. **Autonomous Power Line Inspection Using Drones**: Addresses challenges in long-range power line inspections, also in oil and gas (pipeline monitoring) and transportation (infrastructure inspection).
3. **Urban Air Mobility**: Facilitates drone management via multi-layer, fully integrated 6G NTN architecture surpassing 4G/5G capabilities.
4. **Adaptation to PPDR Events**: Ensures efficiency when TN are partially or completely unavailable.
5. **Consumer Handheld Connectivity and Positioning in Remote Areas**: Enhances user experience by enabling higher data rates, smooth TN/NTN transitions, and improved connectivity in indoor and remote areas.
6. **Continuous Bi-Directional Data Streams in High Mobility**: Prevents service interruptions where mobile data streams are essential.
7. **Direct Communication over Satellites**: Enables user equipment (UE) communication via satellite(s), bypassing the need for a feeder link connection between the satellite(s) and ground station(s)—relevant for HAPS, drones, and other NTN infrastructure components.

These use cases exemplify the enhanced capabilities and new services of the integrated TN/NTN infrastructure, showcasing its potential to address diverse communication challenges and create new opportunities.

RESULTS

6G-NTN developed a 3D multi-layered network architecture with GEO satellite overlay, dual LEO, and MEO constellations supporting C and Q/V bands and HAPS. Two LEO architectures were proposed: an identical satellite constellation and a distributed one with specialised service and feeder satellites.

It also identified requirements for handheld, drone, and mounted UE. Key innovations include payload design compliant with frequency regulations, Q/V-band antenna designs, and NTN spectrum use insights.

Candidate waveforms for air interface integration were identified for analysis: Cyclic Prefix OFDM (CP-OFDM), Weighted Overlap and Add OFDM (WOLA)-OFDM, Discrete Fourier Transform-spread OFDM (DFT-s-OFDM), Filtered OFDM (F-OFDM), Block-Filtered OFDM (BF-OFDM), Universal Filtered Multi-Carrier (UFMC), and Orthogonal Time Frequency Space (OTFS).

6G-NTN is now developing an AI-powered VNF orchestrator to ensure interoperability between multi-orbit satellites and TN, with an AI-driven network forecasting platform to predict virtualised network resource utilisation. It also initiated a deployment plan for NTN-based satellite networks, potentially refurbishing the 5G NTN space segment.

6G-SHINE

The 6G-SHINE project will pioneer the main technology components for wireless in-X subnetworks, short range low-power radio cells to be installed in industrial, vehicular and consumer entities.

OVERVIEW

6G-SHINE aims at designing the main technology components for in-X subnetworks, short-range low power radio cells located at the very end of the 6G 'network of networks', to provide pervasive wireless connectivity. Such in-X subnetworks can be installed in robots, as well as in vehicles, and consumer entities for immersive experiences. The project is expected to deliver significant advances in radio channel characterisation, physical layer, medium access control, radio resource management and network architectures for short-range communication, and integration with the broader 6G landscape.

6G-SHINE is a low Technology Readiness Level (TRL) project (2-4), where the most promising technology components will be demonstrated via Proofs-of-Concept in labs.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

In-X subnetworks are expected to support services whose requirements in terms of data rate, or latency and reliability, may be significantly more demanding than what is offered by existing technologies, including 5G. This calls for significant innovation in physical layer, medium access control and radio resource management. Subnetworks should be able to operate standalone but can benefit from connection with a parent 6G network. 6G-SHINE is developing methods for cost-effective and constructive integration of subnetworks into the larger 6G network, that can aid management of traffic, radio and computational resources.

INNOVATION

Physical layer research in 6G-SHINE is meant at leveraging the advantageous short-range characteristics of in-X subnetworks for supporting demanding communication requirements at low energy consumption. Relevant technology components include beamforming/beamfocusing, Reconfigurable Intelligent Surfaces (RIS), and self-conjugating metasurfaces. Since the presence of blockage can jeopardise communication reliability; solutions based on cooperative communication and network coding are explored. Medium access control research focuses on predictive schedulers, where context information and knowledge of underline application can be used for proactively allocating radio resources.

Since in-X subnetworks can spontaneously become very dense, 6G-SHINE is exploring solutions where radio resource management capabilities are distributed between the in-X subnetworks and the 6G parent network, also leveraging AI methods in the solution space.

Short-range radio channel modelling at different spectra of interest (below 20 GHz, millimetre wave, sub-Terahertz) for the scenarios of interest is also studied in the project.

The main technologies/innovations are depicted in the figure on the following page.

USE CASES/ SCENARIOS

Thirteen use cases for in-X subnetworks have been defined in the project, covering consumer, industrial and in-vehicle domains.

Examples of consumer use cases are:

- **Immersive Education** aims to enhance the interactive experience for a group of students and teacher(s), leveraging media content and XR technologies.
- **XR interactive gaming** in an indoor environment where one or more players play in a place equipped with XR interactive gaming tools.

Examples of industrial use cases are:

- **Robot control**, such as the control of multi-axis robots for leveraging the degrees of freedom offered by potential movement directions the robot can accomplish.
- **Visual inspection cell** to perform quality assurance in the manufacturing process through video feeds.
- **Subnet coexistence**: Tasks distributions among a swarm of small, specialised robots, configured to perform a specific function.

The in-vehicle use cases include:

- **Wireless zone Electronic Control Unit (ECU)**, utilised by sensors and actuators located in a vehicle zone to connect wirelessly to the zone ECU that manages them.
- **Collaborative wireless zone ECU**, covering automotive systems requiring collaboration or offloading between functions, sensors and actuators located at different zones of the vehicle.

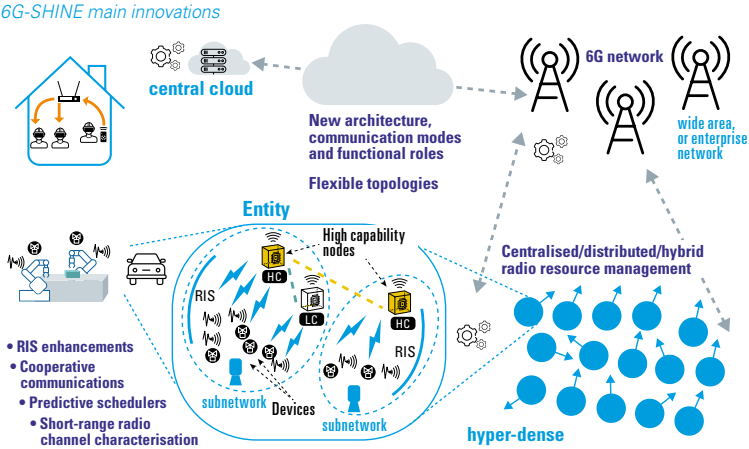
RESULTS

Achieving demanding communication requirements entails the usage of antenna arrays and beamforming techniques, able to reduce the impact of inter-subnetwork interference in dense deployments. Further, self-conjugating metasurfaces allow for beam alignment within 20 μs while drastically reducing energy consumption thanks to the signal processing moved at the electromagnetic level. The presence of blockage requires the usage of relays or RIS; relays are outperforming RIS in terms of achievable outage probability, while RIS allows for greater power savings.

AI-enabled radio resource management can improve spectral efficiency of above 20% with respect to heuristic schemes, while drastically reducing computational complexity in the execution phase.

Aspects of routing data and control signalling have been investigated with the aim of enabling the formation of subnetworks as well as rendering their interaction with the overlay 6G network seamless. Moreover, flexible subnetworks have been enabled by distributing the functionality of the user plane and control plane throughout the subnetwork nodes.

6G-SHINE main innovations



6G SHort range extreme communication IN Entities

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March 2023 – August 2025

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Verticals: Industrial, autonomous vehicle, consumer

Partners: Aalborg University, CNIT, University Miguel Hernandez of Elche, Apple Germany, Sony, Bosch, Interdigital, Fraunhofer IIS, imec, Keysight, Nokia Denmark, Cogninn.

6GTANDEM

By co-designing novel dual-frequency operation and an innovative highly integrated and distributed radio stripe system, 6GTandem will create superior value in energy consumption, service availability and system cost.

OVERVIEW

The 6GTandem project pioneers a dual-frequency multiple antenna system, integrating sub-Terahertz (Sub-THz) and sub-10GHz signals to meet future 6G application needs. Sub-THz frequencies enable ultra-high data rates but face significant propagation losses, while sub-10GHz signals are less affected by obstacles like walls providing robust coverage and support Internet of Things (IoT) devices with lower data rate requirements. By combining these frequencies and densifying sub-THz deployments, 6GTandem ensures high throughput and reliable coverage. The project advances scalable 6G Radio Access Network (RAN) evolution in Europe, delivering Radio Frequency (RF) hardware with unmatched performance, cost, spectrum, and energy efficiency.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

6GTandem will provide low-cost and lightweight radio stripes that enable flexible deployment, addressing challenges from the design of hardware components, such as chips ensuring the seamless operation of the entire system. Our primary focus revolves around the dense deployment of sub-THz radio units to deliver high data rates, complemented by sub-10GHz radio coverage to ensure a reliable connection. To deploy sub-THz frequencies, the project employs plastic microwave fibre (PMF), a cost-effective and flexible solution for indoor applications. Sub-THz radio units, interconnected via PMF and configured as "radio stripes," are installed on walls and ceilings. This arrangement brings the radio units closer to users, addressing challenges such as blocked line-of-sight and limited transmitted power.

INNOVATION

6GTandem combines innovative hardware and system design to address sub-THz transmission challenges. At the system level, the dual-frequency architecture is optimised to enhance reliability and adaptability through a modelling framework. On the hardware side, novel B12 HFC chips are co-designed with antennas and couplers to seamlessly integrate with low-loss plastic microwave fibre (PMF) tailored for the sub-THz D-band. The breakthrough "radio stripe" concept revolutionises sub-THz infrastructure, offering a low-cost, compact, and easily deployable solution that supports network densification.

USE CASES/ SCENARIOS

To identify future societal and industrial needs in health, entertainment, and industrial processes, the 6GTandem project has analysed potential use cases that would benefit from its dual-frequency, highly reliable, and high-capacity network architecture. The project focuses on key deployment scenarios, including **large venues, industrial sites, public transportation hubs, healthcare facilities, and educational institution**, all requiring high throughput, low latency, and reliability.

By considering these driver environments and the specific common characteristics or similar technical challenges of the individual use cases, 6GTandem's use cases were classified into the following four groups:

- **Augmented Reality (AR) / Virtual Reality (VR) / Extended Reality (XR)**

  Immersive technologies transform industries and daily life. 6GTandem supports medical applications such as VR-enabled remote surgery and Mixed Reality (MR)-assisted operations, industrial training with VR simulations, and interactive AR/XR solutions for events, classrooms, and public spaces.

- **Ultra-Reliable Low latency Communications (URLLC)**

  In smart manufacturing, URLLC ensures real-time data exchange for IoT, Artificial Intelligence (AI), and digital twins. 6GTandem enhances predictive maintenance, quality control, and remote monitoring, boosting efficiency and agility. AR/VR applications further support design, troubleshooting, and training.

- **Positioning/tracking**

  Advanced wireless technologies enable real-time tracking in logistics, supply chains, and crowded environments. Dual-frequency solutions provide precise positioning for goods, robots, and crowd management while ensuring privacy with passive tags.

- **High Throughput (not latency critical – federated learning)**

  Large venues like stadiums and airports benefit from privacy-conscious video surveillance enabled by federated learning. By decentralising sensitive data, 6GTandem combines security with privacy, leveraging dual-frequency systems to meet bandwidth and connectivity needs.

Through these use cases, 6GTandem enables energy-efficient, high-capacity, and reliable wireless communication addressing societal and industrial needs, supporting smarter healthcare, education, manufacturing, and public environments while shaping the future of wireless connectivity.

RESULTS

As the first step, the 6GTandem project has thoroughly analysed potential use cases that would benefit from its dual-frequency, densified multi-antenna network architecture. Several B11/B12 HFCs have undergone tape-outs, and Monolithic Microwave Integrated Circuits (MMICs) are now being measured. The first embedded Water Level Ball eWLB tape-out has been completed, with components soon to be mounted on Printed Circuit Boards (PCBs) and integrated with the manufactured low-loss Polarisation Maintaining Fibres (PMFs). An intense measurement campaign is scheduled for Q1 2025, providing critical data for further refinement.

Planning is already underway for a second eWLB tape-out to enhance system performance. Toward the project's conclusion, application-relevant communication over the sub-THz radio stripe, featuring integrated Antenna in Packages (AiPs), will be demonstrated in a laboratory setting. Combining simulations with measured data, a hybrid validation method will establish a robust foundation for 6GTandem's operation and system-level verification. The major impact of the project would be to demonstrate the "radio stripe" concept which can be an elemental part of densified multi-antenna systems for 6G.

A Dual-frequency Distributed MIMO Approach for Future 6G Applications

6GTandem

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January 2023-June 2026

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ADROIT6G

A Distributed AI-enabled Framework for the Management of Next-generation 6G Architectures.

OVERVIEW

ADROIT6G's overall project goal is to provide revolutionary research foundations for low Technology Readiness Level (TRL) technology advancements in preparation for the upcoming 6G network architectures. In particular, to evolve the existing service-based architectures of 5G mobile networks, and design, implement and validate a fundamentally new approach for a future-proof, cognitive, next-generation 6G architecture by adopting a fully distributed AI-driven dynamic paradigm, with functional elements automatically deployed on-demand as virtual functions in cloud-native environments, across the far-edge, edge and cloud domains, operated by different stakeholders. This will ultimately lead to improved performance, a higher level of control, increased transparency in interactions with digital services, support of future-looking applications and social acceptance.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The ADROIT6G architecture evolves the existing Service-Based Architecture (SBA) and the Service Based-Management Architecture (SBMA) of 5G networks by adopting a fully distributed and dynamic paradigm, with functional elements automatically deployed on-demand as virtual functions in cloud native environments across far-edge, edge, and cloud domains operated by different stakeholders. As illustrated on the next page, the ADROIT6G architecture consists of three cooperative inter-domain frameworks that operate over a programmable inter-computing and inter-network infrastructure. The distributed computing nodes at the far edge, edge, and cloud domains, each of them with their own characteristics and capabilities, are used to deploy virtual functions of software-defined disaggregated RAN and core network, virtual applications, as well as AI agents, which are orchestrated dynamically as part of the overall network control and management strategies.

INNOVATION

ADROIT6G proposes disruptive innovations in the architecture of emerging 6G mobile networks that will make fundamental changes to the way networks are designed, implemented, operated, and maintained. ADROIT6G aims to define, validate and affirm reference network-level 6G Key Performance Indicators (KPIs) and Key societal Value Indicators (KVIs) in extreme 6G use cases (UCs), thus setting the frontiers of 6G technology and bringing them one step closer for future exploitation. ADROIT6G will be executed over contiguous and sequentially aligned phases focusing on the requirements' analysis, the definition of UCs scenarios and methodologies, the design of the architecture, the development of the system's building blocks and their integration, technology validation in labs, and impact maximisation activities.

USE CASES/ SCENARIOS

Distributed Artificial Intelligence-driven open and programmable architecture for 6G networks

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January 2023-December 2026

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Verticals: Extended Reality, Industrial IoT, Collaborative Robots, NTN

Partners: ISI/ATH, CYENS, CNIT, EURECOM, University of Oulu, Mellanox Technologies, NOVA Telecommunications, Siemens, Orange Romania, CAFA Tech, eBOS Technologies, Iquadrat Informatica, Nextworks.

ADROIT6G innovations, functionalities, and performance are validated through three extreme 6G UCs, namely the holographic telepresence, Industrial IoT, and collaborative robots/drones in corresponding Proofs-of-Concept (PoCs) over several well-established 5G testbeds, which will be upgraded to support ADROIT6G innovations and architectural elements.

The purpose of the PoCs is to validate the capabilities of both the 6G technology and representative UCs of vertical industries that require 6G performance capabilities, in lab environments over appropriate testbeds, to allow their technological readiness for commercial exploitation within 4-5 years after the end of the project. During the project, each PoC will deploy a layered testing practice to drive development, involving significant representative tests, verifications, and validations such as:

- tests using specific UCs oriented for covering all service classes of specific vertical industries that are expected to be served by 6G technologies.
- test, measurements, validation, and demonstration of the PoCs in lab settings.

The expected outcomes target low TRL (2-4) technology advancement as required for future 6G systems. This means, at most, "technology validated in lab". Therefore, the UCs presented in the PoCs will generate experiments that will be proven in a combination of the testbeds and simulators and/or emulators, as depicted in the figure below.

Research will be performed with users rather than on users, and continuous improvements will be achieved through feedback from PoC roll-outs, providing the basis for information sharing, operation, learning and improvement.

ADROIT6G Proofs-of-Concept

PoC 1: Immersive eXtended Reality (XR) (Extreme eMBB)

PoC2: Industrial IoT
2a: Terrestrial 6G IIoT
2b: NTN (Extreme mMTC + NTN)

PoC 3: Collaborative robots (cobots) in construction (Extreme URLLC + extreme mMTC)

RESULTS

ADROIT6G has defined its reference architecture comprising four blocks: an AI-driven management and orchestration framework, an framework for crowdsourcing AI, an AI-driven control operations framework and a closed-loop functions.

CENTRIC

Using AI for wireless network design meet users' communication needs and environmental constraints.

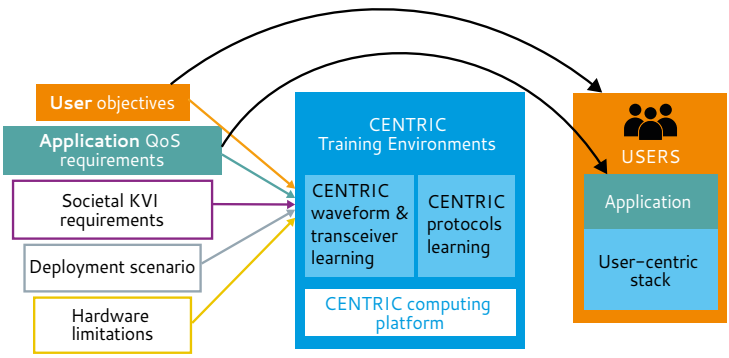
OVERVIEW

CENTRIC proposes to leverage artificial intelligence (AI) techniques through a top-down, modular approach to wireless connectivity that puts the users' communication needs and environmental constraints at the center of the network stack design.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

CENTRIC advocates for an approach to 6G communications whereby the application's requirements define the starting point for the design of the underlying protocol stack. An AI-native air interface (AI-AI), proposed by CENTRIC, will bring forth a degree of physical layer and protocol stack customisation unseen in the history of communication engineering. Leveraging the AI-AI, each user will benefit from the type and amount of connectivity it needs, whenever and wherever it needs it (see figure below). By delegating the design and implementation of communication systems to the AI-AI, application-layer vendors will be freed from having to maintain complex stacks and will be able to focus on their application products. The communication solutions that will emerge with the AI-AI will be application-specific and adaptable to the target scenarios.

The CENTRIC process for enabling an AI-native air interface



INNOVATION

The CENTRIC project is focusing on technical innovations, as listed below:

- E2E-learned waveforms and modulations
- AI-empowered MIMO communications
- Application- and scenario-specific learned protocols
- Sustainable and human friendly Radio Resource Management (RRM)
- Novel AI-computing hardware and real-time optimisation
- Training and monitoring environments for AI models
- AI-suitable testing frameworks and Proof-of-Concept

USE CASES/ SCENARIOS

The CENTRIC project will demonstrate novel AI-AI concepts through the development of laboratory Proof-of-Concept (PoC) implementations. These will validate the expected gains and shed light on the feasibility and cost of their implementation. Additionally, the PoCs will help to identify issues or unforeseen effects of the approach when operating the newly designed solutions.

RESULTS

Results from CENTRIC include:

- **CENTRIC Open-Source Repositories for ML Community**

  The CENTRIC project has published several open datasets and training environments for researchers and developers, as early adopters of CENTRIC results, working on emerging ML techniques for broad application in wireless communications.

- **The CENTRIC's AI-based MIMO Toolset**

  The CENTRIC'S MIMO toolset has been implemented through establishment of several open-source repositories, which include software implementations and documentations of the related simulation environments and developed AI-based MIMO algorithms. Each repository focuses on specific MIMO-AI algorithm, such as reinforcement learning for beam management in Integrated Sensing and Communication (ISAC) scenarios, AI techniques for wide to narrow beam prediction, multi-user MIMO neural network-based receiver, transfer learning techniques for neural receiver and learning based beam alignment.

- RL Based Beam Management in ISAC Scenarios – https://github.com/CENTRIC-WP3/RL-Based-Beam-Management-in-ISAC-Scenarios
- Multiuser MIMO Neural Receiver – https://github.com/CENTRIC-WP3/neural_rx
- Transfer Learning Techniques for Neural Receivers – https://github.com/CENTRIC-WP3/Transfer-Learning-Techniques-for-MIMO-Neural-Receivers
- Narrow Beam Prediction Using NN Decoder – at https://github.com/CENTRIC-WP3/Narrow-Beam-Prediction-using-Neural-Network-Decoder

- **Repositories for Protocol Learning and Emergence Challenges**

  These repositories address various challenges in protocol learning and emergence. Each repository focuses on a specific problem, such as multiple access with MuJoCo robots, random channel access with MARL, DCI learning for reducing the length of control messages, and 6G in-factory subnetworks for industrial applications. The repositories presented below offer a starting point for exploring alternative solutions, benchmarking, and customisation, and can be integrated with machine learning algorithms for further research and development.

- Multiple access with MuJoCo robots – https://github.com/CENTRIC-WP4/Multiple-access-with-MuJoCo-robots
- Random access with MARL – https://github.com/CENTRIC-WP4/Random-Access-with-MARL
- DCI learning – https://github.com/CENTRIC-WP4/DCI-Learning
- 6G in-factory subnetworks – https://github.com/CENTRIC-WP4/6G-infactory-subnetworks

Towards an AI-native, user-centric air interface for 6G networks

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CONFIDENTIAL6G

Ensure secure and private computation in the cloud-edge continuum of 6G by developing modern cryptographic techniques, tools, and libraries.

OVERVIEW

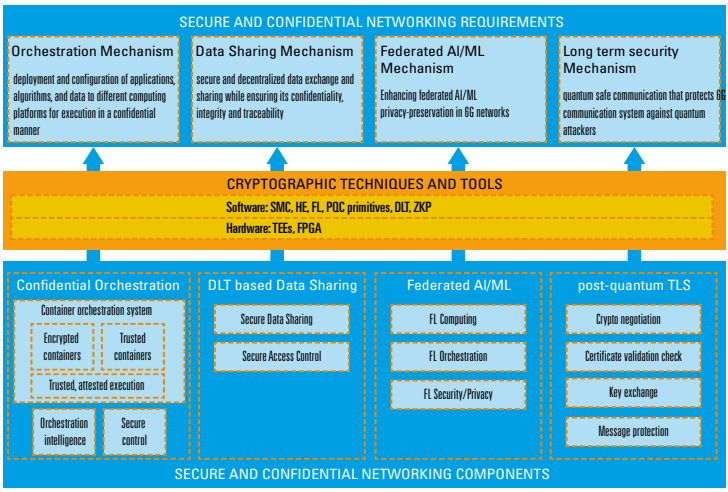
CONFIDENTIAL6G's main objective is to advance security and trustworthiness in 6G, by providing security enablers, developed as cryptographic primitives, libraries, and blueprints. CONFIDENTIAL6G emphasises on privacy preservation and security of sensitive data by focusing on protection of data in use by leveraging Confidential Computing; data in transit by enhancing communication protection with post-quantum cryptography, blockchain technologies and secure data access control; and security at the edge with post-quantum cryptographic conventions.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

Confidential networking guarantees secure data sharing over the cloud-edge communication, control and orchestration infrastructure in 6G networks. The challenge to achieving confidential networking depends on i) **confidential orchestration** that allows deployment and configuration of applications kept isolated from the platform provider, ii) **data sharing** that allows secure and decentralised data exchange, iii) **federated data processing**, and iv) **quantum safe communication** that protects 6G systems against quantum attackers.

The implementation of these mechanisms relies on all kinds of cryptographic techniques and tools, both software and hardware.

High Level Architecture for Secure and Confidential Networking



Confidential Computing and Privacy-preserving Technologies for 6G

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Verticals: Automotive, Airline, ICT infrastructure

Partners: WINGS ICT Solutions, Nokia Networks Finland, France and Greece, Telefonica, Technical University of Eindhoven, Ultraviolet, Zentric Lab, VTT, TNO, Foundation MDEA Software, Technical University of Graz, University College Dublin, ABSTRACT Machines, Technical University Wien

INNOVATION

CONFIDENTIAL6G utilises Fully Homomorphic Encryption (FHE), tailoring relaxed functionalities for specific AI applications and designing efficient encryption functions. It explores Secure Multi-party Computation (SMPC) protocols and architecture-agnostic Trusted Execution Environments (TEEs) with remote attestation. Post-Quantum Cryptographic (PQC) protocols will be developed for secure 6G applications, including Transport Layer Security (TLS). Blockchain privacy is enhanced with Zero-Knowledge Proof (ZKP) and FHE to protect Smart Contracts, while DLT is applied to sovereignty and authentication using Decentralised Identifiers (DIDs) and Anonymous Verifiable Credentials. Federated Learning (FL) challenges are addressed by scaling algorithms for hierarchical networks and edge computing, accommodating device heterogeneity and TEE capabilities. The project also develops Field Programmable Gate Arrays/Graphics Processing Units (FPGA/GPU)-accelerated FHE and PQC algorithms for far-edge nodes, with cryptographic acceleration for constrained devices.

USE CASES/ SCENARIOS

- **UC 1: Predictive maintenance for airline consortium using blockchain-based data sharing platform and federated AI/ML orchestration**. Federated AI/ML ensures computation is securely performed on data sets at edge data centres near airports, enabling predictive maintenance. Remote attestation verifies the integrity of algorithms and results. DLT-based Smart Contracts and transactions conceal asset metadata in aviation data marketplaces, supported by a blockchain-enhanced access control layer for immutable logs, consent traces, and blockchain-configured proxies. Secure metadata is encrypted and distributed via a Kubernetes-based orchestration layer across aviation companies.
- **UC 2: A privacy-preserving confidential computing platform for telecom cloud providers to mitigate internal threats**. Features include automated confidential Virtual Machine (VM) management via cloud APIs, TEE abstraction for cloud enablement, a framework for remote attestation, a secure VM management agent with TLS enclave support, and confidential container integration with Kubernetes.
- **UC 3: An intelligent connected vehicle platform for mission-critical services, Over-The-Air (OTA) updates, FL/ML, and vehicle-to-infrastructure communication**. Features include secure OTA updates for software delivery, adaptive Asynchronous Distributed Learning (ADL) for model handling, blockchain for tamper-proof ADL models and immutable software updates, vehicle digital identity for update verification, and privacy-preserving communication in FL servers to mitigate attacks like data poisoning and inference.

RESULTS

A significant outcome of the CONFIDENTIAL6G project is a detailed analysis of the current state of Post-Quantum Cryptography (PQC), providing a comprehensive toolkit of algorithms under consideration by NIST for standardisation. The project focuses on developing quantum-safe networking primitives to protect communication protocols from future quantum threats. CONFIDENTIAL6G introduces a unified software interface for TEEs to enhance security. Machine learning algorithms supporting FHE are being evaluated using industrial test data, alongside efforts to improve data privacy through federated AI/ML and advanced orchestration mechanisms. The project explores ZKPs to address verifiability challenges in FHE computations while leveraging blockchain technology for data verification and access control. A secure decentralised data-sharing framework has been designed, incorporating DLT, multi-party computation, FHE, and TEEs to ensure data integrity, immutability, and privacy preservation.

DESIRE6G

Meeting extreme KPIs through Deep Programmability in 6G AI-Native Systems.

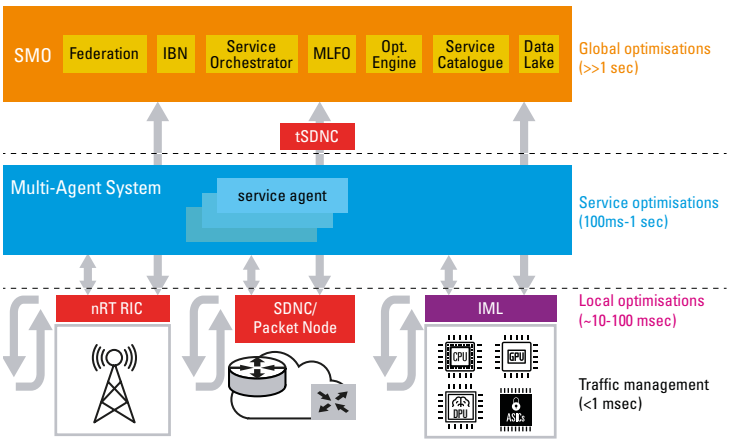
OVERVIEW

5G was set out to support various use case (UC) groups: enhanced Mobile Broadband (eMBB), massive Machine-Type Communications (mMTC), and Ultra-Reliable Low latency Communications (URLLC). While it laid the technical foundation for all three, eMBB emerged as the main commercial success. In DESIRE6G, we envision a 6G system that meets IMT-2030 requirements, without adding excessive complexity or overhead. By leveraging network programmability, we aim to support a wide range of UCs cost-effectively. Our research focuses on pushing the boundaries of a unified, flexible system for diverse UCs.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

Programmability starts with a standard API where verticals can express service requirements in a simple, efficient way. The system's layers must then collaborate to meet these requirements using available resources. While this can be complex, defining clear responsibilities for each layer makes this feasible. DESIRE6G employs several control loops at different timescales: i) real-time traffic management at packet level, ii) cloud-native user plane with local optimisation capabilities, iii) AI-driven, distributed service optimisation and iv) intelligent Service Management and Orchestration (SMO).

DESIRE6G multi-timescale control loops



INNOVATION

Aligned with the Open RAN principles, the SMO layer acts as a cross-domain management framework. It introduces intent-based service management, translating high-level business intents into actionable service templates. The SMO manages AI pipelines via the ML Function Orchestrator (MLFO) and handles non-real-time service lifecycle optimisation via the Optimisation Engine. Distributed ledger technology enables secure federation across administrative domains.

Operating across the RAN, core, and transport, SMO ensures cross-domain coordination via a microservices architecture enhancing modularity, scalability, and security. A Multi-Agent System (MAS) in the service

optimisation layer collects telemetry and drives decisions to maintain service assurance. MAS employs AI, with distributed agents analysing service requirements, topology, and network domain properties to detect issues and propose reconfiguration solutions. To address vulnerabilities inherent in distributed systems, MAS integrates secure communication protocols and remote attestation mechanisms.

The programmable user plane features its own optimisation loops while the Infrastructure Management Layer (IML) abstracts physical resource management, optimising function deployment, scaling and network function aggregation/disaggregation. Flexible traffic management further enhances multi-service handling with intelligent packet colouring and dropping. Real-time programmable network telemetry ensures accurate data collection for informed decision-making.

USE CASES/ SCENARIOS

The proposed innovations are validated through experiments in laboratory environments, and larger field evaluations using the ARNO[1] testbed in Italy and the 5TONIC[2] testbed in Spain. DESIRE6G focuses on two key 6G UCs: Augmented Reality (AR) and Digital Twins (DT) in industrial settings.

The AR UC features a camera-equipped drone and an operator wearing an AR headset for real-time inspection. Edge processing enables object detection and data augmentation, allowing operators to dynamically control the drone's movements and focus. It showcases the network's ability to deliver high-bandwidth, and low latency communication for real-time AR applications, ensuring a smooth user experience while mitigating issues like cyber sickness.

The DT UC involves a robotic dog transmitting sensor data to update its virtual model while receiving navigation commands, requiring ultra-low latency and high reliability. Most of the End-to-End (E2E) latency budget is used for processing sensor data, leaving milliseconds for communication. DESIRE6G's in-network acceleration, multi-level optimisation, and E2E data plane programmability ensure Key Performance Indicators (KPI) compliance. Both UCs benefit from optimised resource and energy management.

RESULTS

At this stage, key results include architectural and design documents along with early demos, presented at events and disseminated through conferences, journals, and talks[3].

The AR demo uses a YOLO-based object detection framework on NVIDIA Jetson ORIN, paired with a video camera for data capture and a VR headset for visualisation. It runs in a multi-tech setup, including the RAN and a programmable packet-optical edge network. Near real-time service (re)optimisation via the MAS, consistently maintains latency below 25 ms[4] using in-band telemetry from the programmable data plane.

For the DT UC, DESIRE6G ensures reliable, low latency communication between the robot and its digital twin at the edge. Initial results[4] highlight the platform's ability to orchestrate and deploy programmable network functions and application workloads while effectively managing traffic during congestion scenarios. Traffic management policies dynamically prioritise critical robot control flows, minimising latency spikes. The system outperforms state-of-the-art solutions by maintaining latency within acceptable limits even under heavy network loads, ensuring compliance with key operational KPIs.

1.http://arnotestbed.santannapisa.it

2. https://www.5tonic.org

3.https://zenodo.org/communities/desire6g/records

4.D5.2 Report on Evaluation Results and Initial Proof-of-Concept Demonstrations. Project Deliverable, 2025.

Deep Programmability and Secure Distributed Intelligence for Real-Time E2E 6G Networks

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January 2023-December 2025

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Verticals: Industry

Partners: University of Amsterdam, Ericsson Hungary and Turkey, Telefonica ID, Nvidia), ISR, Nubis PC, Accelleran, Tages Solidshield, Polytechnical University of Catalunya, University of Oulu, University Carlos III de Madrid, Eötvös Loránd University, CNIT, NEC Laboratories

DETERMINISTIC6G

Paving the way to groundbreaking E2E dependable time-critical communication architecture powered by 6G.

OVERVIEW

DETERMINISTIC6G developed architectures and algorithms for scalable and converged future network infrastructures to enable dependable end-to-end (E2E) time-critical communication across wired and 6G wireless domains. The main objectives were to design and develop:

- Deterministic services including Key Performance Indicators and Key Value Indicators for 6G use cases
- 6G features for deterministic wireless transmission and wireless-friendly enhancements for Time-Sensitive Communication (TSC)
- Artificial Intelligence based techniques for data-driven latency characterisation of 6G systems
- 6G time synchronisation to improve E2E time awareness and new concepts for deterministic edge cloud
- Security architecture for 6G deterministic communication
- Validation framework for new 6G concepts

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

DETERMINISTIC6G focused on defining system-level solutions for E2E dependable, time-critical communication across both fixed and wireless domains. To address unpredictable variations in communication, the project has developed Packet Delay Correction (PDC) techniques that enable bounded and predictable latency. It also explores data-driven latency prediction, enhancements to existing deterministic systems (such as TSN and DetNet), and the integration of time-awareness to improve reliability and dependability. Additionally, the project designs an architecture that supports the cloudification of application and control functions toward the edge cloud, integrated with TSC. All developed concepts are validated using a simulation framework.

INNOVATION

The DETERMINISTIC6G architectural enhancements towards E2E communication are depicted in the figure next page, where the numerals correspond to the following points

1. Future time-critical use cases and applications
2. Novel dependable service design concepts, including domain-specific service specification, and enhanced information exchange between the application and network domains
3. Mechanism for mitigating timing uncertainties in 6G (PDC) and latency prediction methods to characterise 6G network capabilities
4. Robust time synchronisation including hot standby support and data monitoring at the transport layer for security by design framework
5. Solution for tight integration of the edge domain with deterministic network to provide seamless E2E dependable communication
6. Traffic engineering methods for robust and optimised network configuration, taking the stochastic characteristics of 6G wireless system into consideration to ensure E2E dependable services across various communication domains

USE CASES/ SCENARIOS

DETERMINISTIC E2E COMMUNICATION WITH 6G

DETERMINISTIC6G

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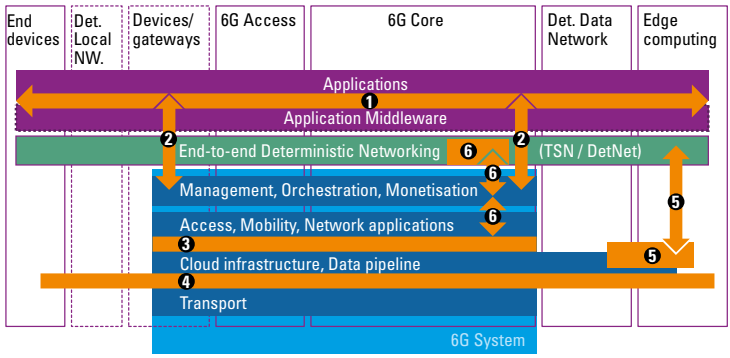
Verticals: Industrial automation

Partners: Ericsson, Cumucore, Orange, IUVO, Montimage, ABB, B&R Industrial automation, Silicon Austria Labs, Sant'Anna School of Advanced Studies, KTH Royal Institute of Technology, University of Stuttgart

DETERMINISTIC6G defined four use cases to guide the design of dependable 6G services, each integrating critical infrastructure components such as communication, computation, time synchronisation, and security. The goal was to meet the diverse and demanding requirements of various industrial applications. The use cases included fully immersive extended reality (XR), occupational exoskeletons (OE), adaptive manufacturing, and smart farming.

In industrial environments, workers must constantly adapt to new tools and technologies. XR supports this by enabling training, visualisation, maintenance, and control of complex systems. OEs help reduce physical strain during physically demanding tasks. When connected to a 6G network and enhanced with AI, OEs can collect data from multiple sensors and develop task-specific assistive strategies. Adaptive manufacturing enables flexible, rapid responses to market demands through dynamically reconfigurable processes. 6G plays a key role in enabling wireless control of modular machinery and collaborative automated guided vehicles. Smart farming uses automation and data-driven techniques to optimise agricultural practices—automating repetitive or hazardous tasks, predicting issues, and improving maintenance. Technologies such as IoT, AI, 6G, and edge computing help significantly increase productivity and efficiency in farming.

These use cases serve as reference points for developing new architectural components that improve predictability and ensure reliable, time-critical communication in next-generation networks.



DETERMINISTIC6G approach and concepts

RESULTS

Key architectural elements were developed, including 6G centric enablers, wireless-friendly design of E2E deterministic communication, enhanced resilient time-synchronisation, deterministic support in the compute domain, and digital twinning technologies. Achievements include i) Predictable Delay Control (PDC) mechanisms to manage jitter in radio transmissions and ensure consistent delay. ii) A deep neural network-based latency prediction approach iii) Algorithms designed to calculate and adapt robust E2E schedules. iv) An E2E delay analytics framework that identifies the significance of each network component and explores opportunities to optimise delays v) A security monitoring framework for real-time traffic monitoring, analysis, and automated remediation and vi) A simulation framework to validate wireless-optimised designs for E2E deterministic communication.

These advancements collectively aim to deliver comprehensive and reliable communication architecture.

ETHER

ETHER is going to provide a framework for the terrestrial/non-terrestrial network ecosystem that involves efficient and zero-touch resource management, provides solutions for key RAN challenges, and identifies the business opportunities for potential stakeholders.

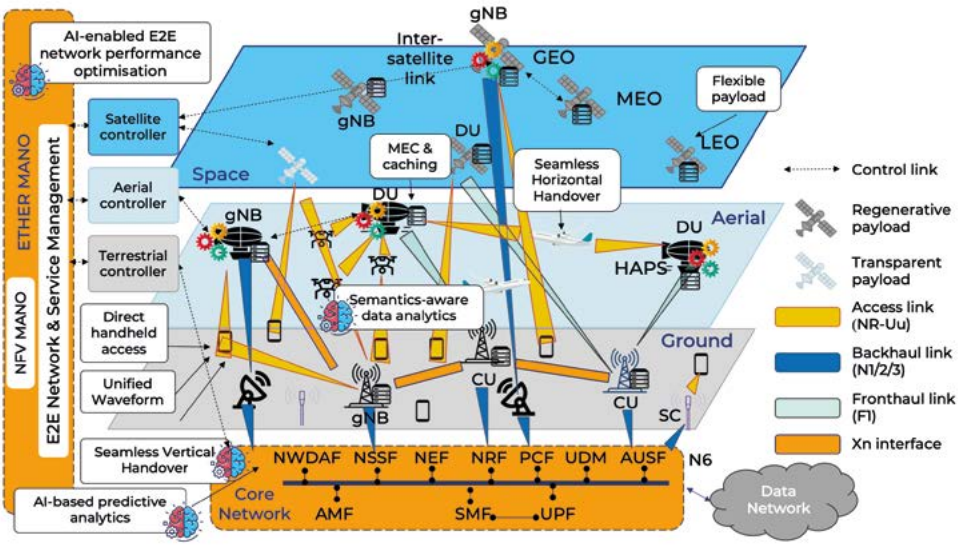
OVERVIEW

The ETHER project aims to remodel network ecosystems by integrating **terrestrial and non-terrestrial networks (NTNs) into a unified, sustainable 3D Radio Access Network (RAN)**. It focuses on AI-driven, zero-touch resource management, achieving 100% coverage, 99.99999% reliability, 3x energy efficiency, and a 95% reduction in Total Cost of Ownership compared to a solely terrestrial infrastructure. ETHER delivers a **fully programmable, multi-layered edge-computing architecture with self-evolving network slicing and orchestration**. By addressing RAN challenges, validating solutions through experimentation, and creating business strategies, ETHER drives innovation and investment in NTN integration, supporting seamless, future-ready connectivity.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The ETHER project introduces a **3D network architecture** integrating terrestrial and non-terrestrial connectivity with a focus on cost and energy efficiency. Key advancements include direct handheld Ka-band access, unified waveform design, flexible payloads, and seamless handovers for uninterrupted connectivity. Leveraging data analytics, edge computing, and caching ensures optimal performance, while AI-driven, Management and Orchestration (MANO) enable a self-evolving, efficient network. ETHER paves the way for scalable, next-generation communication systems.

ETHER 3D network.



INNOVATION

The ETHER project drives innovation across three core pillars: 1) **Unified RAN Advancements**: ETHER delivers global broadband, including direct Ka-band access for handheld devices, via advanced terminal antennas, distributed beamforming from Low Earth Orbit (LEO) satellite swarms, unified waveforms, and seamless handovers across diverse Radio Access Technologies (RATs). This ensures uninterrupted connectivity anywhere. 2) **Intelligent 3D Network Resource Management**: AI-powered, zero-touch optimisation analyses data from terrestrial, aerial, and space platforms. Flexible software-defined payloads enhance adaptability, enabling self-evolving networks that meet KPIs and respond dynamically to traffic demands. 3) **Distributed 3D Computing and Caching**: A multi-layered edge-computing and caching architecture reduces latency and cloud congestion by offloading tasks closer to data sources, supporting future 6G network needs efficiently.

USE CASES/ SCENARIOS

ETHER focuses on three key use cases: 1) **Service Provisioning for Delay-Tolerant IoT Applications**: Using LEO satellites, ETHER provides global coverage for delay-tolerant mMTC IoT applications. This approach ensures reliable connectivity despite service and feeder link interruptions. With flexible payloads, ETHER supports diverse devices and technologies, reducing dependency on specific vendors and enabling seamless integration of multiple systems. This flexibility drives innovation and expands market opportunities. 2) **Unified RAN for Direct Handheld Device Access in the Ka-band**: ETHER bridges terrestrial and non-terrestrial systems to provide seamless broadband connectivity to handheld devices in the Ka-band via LEO satellites. Advanced technologies, such as distributed beamforming with LEO swarms, ensure robust signal delivery. High-gain, energy-efficient antennas further enhance performance, enabling a unified Radio Access Network (RAN) for reliable, high-speed communication in any location. 3) **Air-Space Safety Critical Operations**: ETHER ensures persistent connectivity for safety-critical air and space operations by integrating TN, High Altitude Platforms (HAPs), and LEO satellite systems. This approach guarantees uninterrupted communication between air traffic control centres and operational hubs, enhancing safety and efficiency through real-time coordination and continuous data exchange.

RESULTS

The ETHER project has finalised its **3D architecture for seamless integration of TN-NTN networks** advancing 6G connectivity. Key features include **zero-touch operation and infrastructure mobility management** within the orchestration framework. Research has also progressed on low-level enablers like efficient RAN data transfers, handovers, flexible payloads, and direct handheld access. High-level innovations, such as zero-touch management, seamless registration, and end-to-end optimisation, ensure scalability and reliability. ETHER addresses growing global connectivity demands, especially in underserved and dynamic areas where terrestrial solutions fall short. A techno-economic analysis has shown that adopting the unified TN-NTN architecture cuts operational (OpEx) and capital (CapEx) costs significantly compared to terrestrial-only networks. Societal benefits include substantial energy efficiency gains by reducing terrestrial network densification through satellite and high-altitude platform integration.

sElf-evolving terrestrial/ non-Terrestrial Hybrid nEtwoRks

ETHER

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FLEX-SCALE

Future 6G networks will rely on large-scale deployments of smart MIMO antennas in both small-cells and cell-free RAN architectures.

OVERVIEW

FLEX-SCALE aims to enhance the capacity of backhaul networks while significantly reducing energy consumption by an order of magnitude -as required by 6G networks in support of forward-looking applications. The advancements developed will help shape the future of 6G hauling networks, delivering a substantial societal impact.

Specifically, the project enables flexible capacity scaling in a cost and energy efficient manner by enhancing network convergence, supporting single fibre Input/Output (I/O) interfaces and by implementing advanced networking intelligence by:

- **Enhancing network convergence** through Ultra-Wide Band and Space Division Multiplexing, achieved by implementing a novel ≥10 Pb/s Multi-Granular Optical Node (MG-ON). This approach leverages both spectral and spatial degrees of freedom, with a focus on using new wavelength bands across multiple spatial lanes, enabled by WaveBand selective Switch (WBSS) capabilities.
- **Supporting single-fibre I/O interfaces** in switches and network terminals to 10 Tb/s and beyond. This is accomplished by replacing power-hungry, bandwidth-limited electronic Digital-to-Analog Converters (eDACs) in ultra-high-speed transceivers with energy-efficient all-optical DACs (oDACs). These single-fibre, single-wavelength I/O interfaces can scale up to Pb/s capacity links through spectral and spatial multiplexing.
- I**mplementing advanced networking intelligence**, including autonomous Software Defined Networking (SDN) control, streaming telemetry, and Machine Learning (ML)-enabled data analytics. These innovations combined with energy-efficient routing algorithms will optimise packet traffic flows across spectral and spatial optical channels, further reducing energy consumption while maintaining a low blocking probability.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The end-to-end 6G network spans many segments from the Radio Access Network (RAN) to the Core network. The traffic from the RAN sites is directed via the fronthaul to Aggregation Routers that are connected to the Optical Transport network via Optical Nodes (ONs) located at the edge part of the 6G network have relatively lower capacity than the ONs that are deeper into the backbone network connecting to Metro and Core Routers. The purpose of all ONs across the network is to route and add/drop traffic to the corresponding routers, serving the needs of each network segment. As we move deeper into the core network, the capacity of the ONs increases and can exceed 10 Pb/s. The corresponding optoelectronic interfaces for each of the connections between the 6G cell-cites and the ONs, as well as among the ONs, need to support rates ranging from a few hundred Gb/s to ≥1 Tb/s in a single lane (being either spectral or spatial).

INNOVATION

FLEX-SCALE contributes to four innovation areas: i) FLEX-SCALE is able of efficiently utilising all available capacity scaling approaches in an orchestrated way and with novel complementary technologies that will also contribute to tremendous reductions in the power consumption of the entire network. ii) The FLEX-SCALE optical node approach is based on a key new switching device called WaveBand-selective Switch (WBSS). It is PIC-based, compact, and rapidly reconfigurable. iii) FLEX-SCALE implements ultra-high-speed, energy-efficient, flexible transceivers. The FLEX-SCALE program will deploy a sustainable SDN control system, an autonomous SDN network architecture and involved functions addressing a full-fledged closed-loop automation integration for disaggregated packet/optical networks. iv) FLEX-SCALE targets to develop optical performance monitoring (OPM) techniques agnostic to the modulation format.

USE CASES/ SCENARIOS

Based on three key requirements, 6G services are classified into seven categories: Enhanced Fibre Broad-Band (eFBB), Full Fibre Connection (FFC), Guaranteed Reliable Experience (GRE), Full Fibre BroadBand Connection (FFBC), Guaranteed Reliable Full Fibre Experience (GRFFE), Full Fibre Guaranteed Reliable BroadBand (FFGRB).

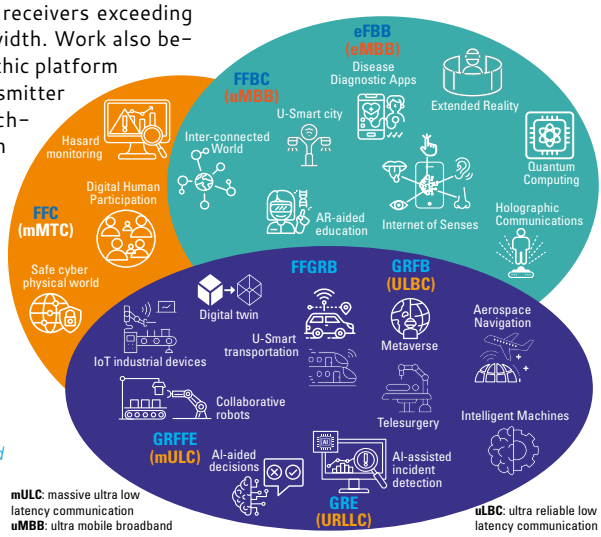
RESULTS

The initial phase of FLEX-SCALE made significant progress in network/system-level development and sub-system preparation for a demonstration platform. Work Package (WP) 2 defined eight key service requirements and KPIs for 6G, focusing on energy efficiency, ultra-low latency, and high-speed optical channels, guiding subsequent designs.

In optical transceivers, a plasmonic IQ modulator reached 774 Gb/s on a single carrier, while progress continued oDAC-based transmitters. Receiver innovations included plasmonic coherent receivers exceeding 100 GHz bandwidth. Work also began on a monolithic platform integrating transmitter and receiver technologies with high bandwidth packaging.

Architectural studies and modeling for the MG-ON led to finalised test structure designs, while assemblies. were developed for PICs.

Work Package 5 advanced the FLEX-SCALE control and orchestration architecture using the ETSI TeraFlow SDN controller. Three SDN controllers were developed, along with new interfaces OpenConfig model enhancements. Initial routing, spectrum assignment, and monitoring implementation were completed, along with a software release plan.



Classification of services based on three requirements (latency, bit rate, and fibre density)

Flexibly Scalable Energy Efficient Networking

FLEX-SCALE

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January 2023-December 2025

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HEXA-X-II

Hexa-X-II is the SNS 6G flagship project, providing a holistic view of the concepts and enablers to define a 6G end-to-end system that will deliver the future 6G digital services.

OVERVIEW

Hexa-X-II is the European flagship 6G research project gathering a wide range of partners from network and device vendors, operators, research institutes, academia, and SMEs. The project has bridged the gap between initial technology research and the upcoming 6G standardisation by creating a blueprint for the end-to-end 6G system with technical enablers developed within Hexa-X-II and in selected SNS JU projects.

The Hexa-X-II project also has a strong emphasis on environmental, economic, and social sustainability, defining a methodology for evaluation of the so-called key value indicators.

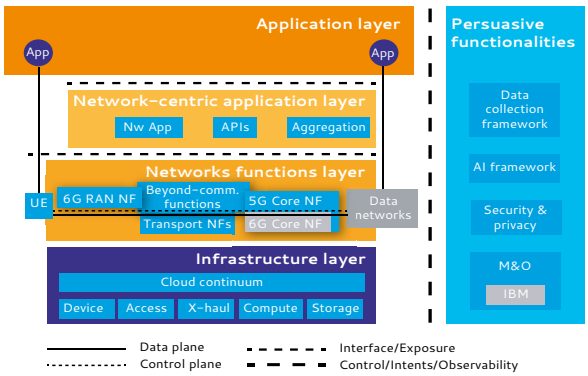
As a flagship project, the Hexa-X-II project has interacted with all the call 1 SNS JU projects, and a few call 2 projects, through a series of workshops to formulate the European view on 6G.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

Hexa-X-II has developed an end-to-end system blueprint (figure below) over several iterations. The 6G system will be developed with an evolved 5G core network (5GC), with a new 6G Radio Access Network (RAN). It will also employ pervasive service exposure and network application programming interfaces (APIs) allowing operators and third-party users to optimise the network to suit their needs. In addition, new beyond-communication services, such as localisation, sensing, AI- or compute-as-a-service will be supported and offered to other parts of the network and to end-users.

Intelligent network management and orchestration will also be supported, where e.g., intent-based management can enable efficient zero-touch operations, with different interworking closed loop controls.

End-to-end 6G system blueprint



INNOVATION

Hexa-X-II has developed a plethora of technical enablers and innovations. For instance, the definition of key 6G use cases and the developed initial framework for evaluation of KVIs, putting the sustainability at the forefront of the research.

In Hexa-X-II, there have been over 100 different enablers proposed and evaluated. For the end-to-end aspects, these include e.g. enhancements to the radio protocol, physical layer security, and intent-based service framework. Some of the architecture enablers are e.g., Machine Learning Operations (MLOps), Integrated sensing and communication (ISAC), compute offloading, multi-Radio Access Technology (RAT) spectrum sharing (MRSS), non-terrestrial networks (NTN), multi-connectivity, and application-layer optimisation.

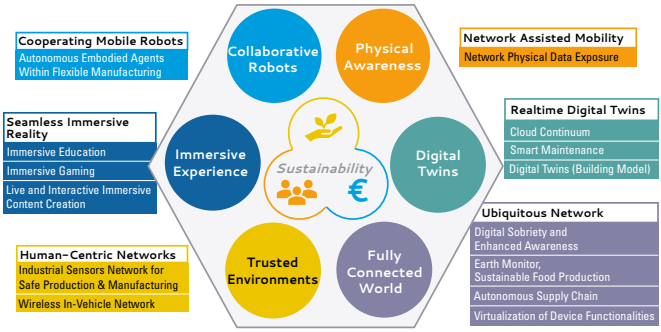
For the radio interface, some of the enablers are e.g., massive and distributed Multiple Input Multiple Output (MIMO), sub-THz channel modelling, intelligent air-interface for enhanced CSI acquisition, reconfigurable intelligent surfaces (RIS), waveform and modulation enhancements, or ISAC resource optimisation.

For the devices and flexible infrastructure, the enablers are e.g., enhanced sub-THz transceivers, system-on-a-chip technology, and zero energy devices.

For smart network management, the enablers are e.g., real-time zero-touch control loops, network programmability, or multi-domain federated learning.

USE CASES/ SCENARIOS

The Hexa-X-II project has developed a wide range of 6G use cases, which have been grouped into six different use case families, each with a representative use case as shown in the figure below.



Hexa-X-II Use Cases with Highlighted Representative Use Cases

- **Immersive Experience**: Seamless Immersive Reality goes beyond the 5G Extended Reality (XR) application and will enable seamless interactions with physical and digital objects on a massive scale.
- **Collaborative Robots**: Cooperating mobile robots will leverage the AI revolution and provide reliable connectivity for autonomous robots.
- **Physical awareness**: Network-assisted mobility, will deliver not only data but also generate information such as sensing spatial data, providing users with enhanced awareness of their surroundings.
- **Digital Twins**: Real-time digital twins will provide accurate digital representations of any combination of processes, products, persons and functionalities of a real-world items in e.g., industry or smart cities, and 6G will be able to provide low latency updates of the digital twin.
- **Fully connected world**: Ubiquitous networks will provide access to digital services to everyone on the globe, addressing the digital divide
- **Trusted environments**: Human-centric services require utmost reliability, security and privacy as the data pertains to the human body, e.g., monitoring health vitals, so that the service can persist, and that the data cannot be misused.

RESULTS

The Hexa-X-II project has released 19 technical deliverables, and has organised and been invited to numerous workshops and webinars, at e.g., EuCNC or MWC and taken leading roles in contributions to different 6G-IA and SNS JU whitepapers.

The use cases defined in Hexa-X-II were used as a baseline to consolidate the European view on 6G use cases, which was presented to 3GPP SA1 in May 2024 which has received significant tractions outside the project.

The project has also developed ten different Proofs-of-Concept (PoCs), e.g., AI-based air interface, over-the-air XR, etc. Many of these aspects are included in a system-level PoC showcasing an autonomous warehouse scenario using collaborative robots which will be finalised in June 2025.

6G offers the possibility to enable in a more sustainable way more efficient and effective networks offering improved performance and capacity while also enabling novel beyond-communication services such as sensing and compute offloading. Emerging technologies, such as generative AI and MLOps offers possibilities for more autonomous networks with zero-touch and intent-based management.

HEXA-X-II

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HORSE

HORSE proposes a novel human-centric, open-source, green, sustainable, coordinated provisioning and secure evolutionary platform.

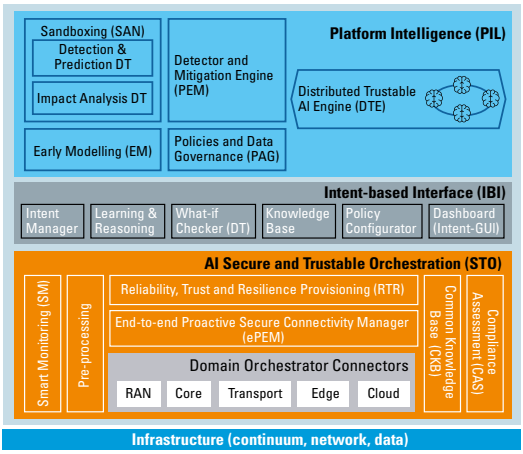
OVERVIEW

The HORSE aims to demonstrate how applications can leverage the ongoing evolution of 6G capabilities, but also to deal with solutions not yet foreseen, towards an omnipresent, smart and secure network service provisioning in the future network-of-networks landscape. HORSE proposes a novel human-centric, open-source, green, sustainable, coordinated provisioning and protection evolutionary platform. HORSE will also include predictive threats detection and impact analysis, proactive business-wise threats and breaches mitigation actions, programmable networking, semantic communications, Network Function Virtualisation, intent-based networking, AI-based techniques, in-network computing, and cross-layer management of physical layer features as they emerge in the 6G realm.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The HORSE reference architecture for future 6G networks offers a human-centric approach to security workflows by facilitating end-to-end security solutions. It enhances current systems by defining a smart, adaptive security layer that leverages Artificial Intelligence (AI) techniques to improve response and resilience. This layer provides early threat detection in a sandbox environment and identify and correct vulnerabilities by attacking the systems predicted to be exposed. The main components of the HORSE architecture include the Intent-Based Interface (IBI), which ensures easy user engagement; the Platform Intelligence (PIL), encompassing intelligent strategies that support the predictive goals of HORSE; and the AI Secure and Trustable Orchestration (STO), which provides the 6G infrastructure with the performance, reliability, and trust necessary to effectively orchestrate resources and deploy smart services.

HORSE Architecture



INNOVATION

The key HORSE innovation sits on proposing an end-to-end proactive solution for cybersecurity protection in 6G ecosystems leveraging several technological domains, including AI, predictive approaches, Digital Twin proactive analysis, intent-based, etc. This key innovation may be summarised as:

- A specific set of intelligent functionalities (Sandboxing, Early Modelling, etc.) used to replicate the entire 6G landscape (infra and potential attacks), to conduct both an analysis

of the attack impact and a preliminary analysis of the candidate actions to be deployed, to maximise effectiveness.

- Novel strategy responsible for detecting threats in a predictive form, proactively acting towards either removing or mitigating the impact of the foreseen threat.
- An intent-based human-centric approach, mapping high-level intents into security workflows able to react to security threats and vulnerabilities.
- An adaptive, dynamic and proactive security services orchestration strategy supporting recursive deployment of many functional components for multi-tenancy, high device heterogeneity (virtualisation), and end-to-end resource self-configuration, spanning across multiple domains and applications.

USE CASES/ SCENARIOS

The Secure Smart Light Rail Transit Systems (SS-LRT) use case is focused on the secure and efficient operation of systems in light transports. This scenario looks forward to integrating low latency communications and high bandwidth to assure a reliable connectivity between the trains, the stops and the Operations Centre. Besides that, it proposes distributed solutions to guarantee resilience and fast recovery in case of disaster, generating metrics in real-time to be analysed. In terms of Key Performance Indicators (KPIs), these implementations will improve the down time in 50 % and the availability in 20 %, both referred to resilience and disaster recovery.

The Remote Rendering to Power XR Industrial (R22XRI) use case is designed to boost the multiuser collaboration in extended reality (XR) environments, especially in the context of Industry 4.0. This scenario aims to develop a reliable and secure communications system facilitating the real-time interaction between distributed users, while protecting intellectual property from threats such as industrial espionage. This use case aims to evolve the industrial collaboration by enabling continuous interaction between users and machines in virtual shared environments, seamlessly integrating the digital and physical world. In terms of KPIs, the project will evaluate the decrease of errors in a 90 % and a reduction of costs of 50 %.

RESULTS

HORSE results will include i) a framework for securing infrastructure and data for the forthcoming 6G digital transformation, ii) a Compliance Assessment ensuring that all enforced security policies and solutions generated by the Trustable AI engine are in alignment with the considered regulatory framework, iii) Secure and resilient AI trustworthiness and explainability through Early Modelling module, iv) a new AI threat detector and mitigation engine, in charge of analysing, processing, and protecting network streams in complex and highly distributed network and infrastructures scenarios, and v) the integration of a Network Digital Twin for prediction and "what-if" scenarios.

The project already reached a partial implementation and deployment on the three testbeds, located at the premises of CNIT, Polytechnical University of Catalunya and University of Murcia. HORSE provided an early demonstration of the integration and correct operation of specific security functionalities, such as real-time attack detection, intent-based definition of mitigation strategies and their "what-if" verification, attack prediction using the Network Digital Twin, and secure orchestration.

Holistic, Omnipresent, Resilient, Services for future 5G Wireless and Computing Ecosystems

HORSE

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January 2023-December 2025

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PREDICT-6G

PREDICT-6G aims to create a deterministic 6G solution with seamless service delivery for vertical use cases, using novel technology and AI-driven control planes to ensure reliability and time sensitivity in network operations.

OVERVIEW

PREDICT-6G is developing a 6G architecture for seamless, reliable and time-sensitive service delivery. It integrates deterministic wired and wireless networks with a Multi-technology Multi-domain Data Plane (MDP) and an AI-driven Multi-stakeholder Interdomain Control-Plane (AICP) for real-time monitoring and prediction. An AI-powered Digital Twin (DT) provides early control for high performance.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

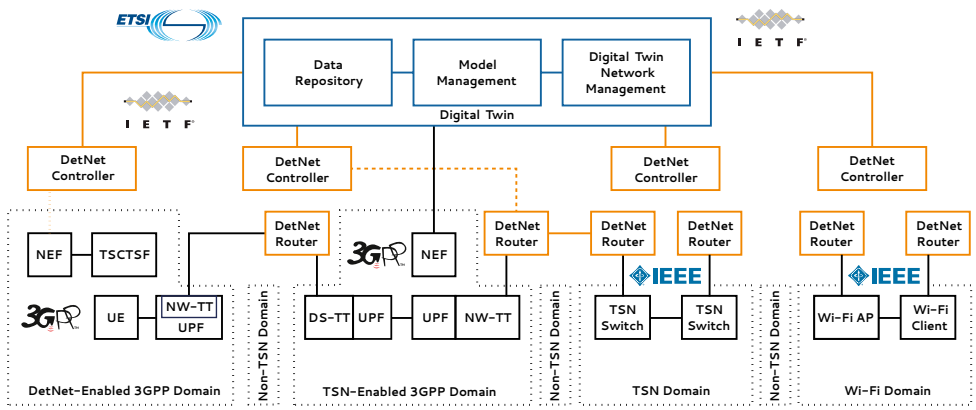
PREDICT-6G aims to provide End-to-End (E2E) multi-domain deterministic services with advanced automation across 3GPP, TSN and Wi-Fi, enabling automation for orchestration, provisioning and proactive measures to meet targets.

INNOVATION

PREDICT-6G aims to enable seamless, reliable communications across diverse networks with two key innovations: a MDP and a AICP.

- MDP: Supports deterministic services with cross-domain integration, time synchronisation and improved reliability.
- AICP: Uses a two-layer architecture to ensure Service Layer Agreement (SLA) compliance across domains

6G standardisation



USE CASE/ SCENARIOS

PREDICT-6G has three main use cases:

- **Smart manufacturing**: This use case intends to replace wired factory automation with wireless solutions for real-time data transmission and virtualised control, enabling scalable and agile operations at GESTAMP's smart factory.
- **Multi-Domain Deterministic Communication**: This use case intends to ensure seamless, reliable communications across technologies (e.g., 3GPP, TSN, Wi-Fi) and domains, supporting distributed sites and critical communications with bounded latency and reliability.
- **Deterministic Services for Critical Communications**: This use case addresses scenarios that require high availability, low latency and reliable group communication, such as cloud robotics, vehicle systems and factory automation, with synchronised workflows and real-time command cycles.

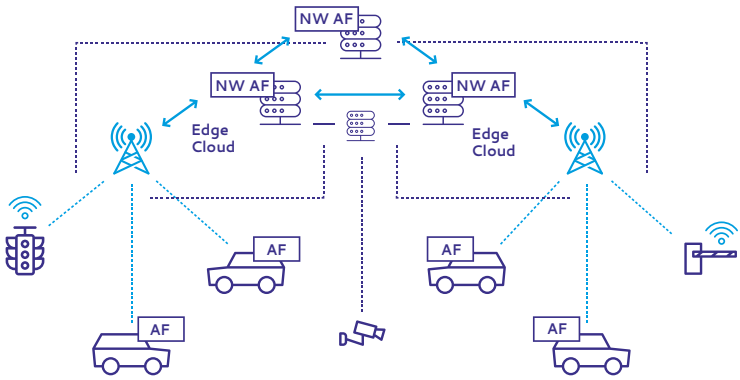
PREDICT-6G also explores:

- **Localisation and Sensing**: It integrates sensing into mobile networks for applications such as collision avoidance and remote object control, using multi-domain collaboration and ML analytics.
- **Extended Reality (XR) Applications**: It focuses on immersive gaming and interactive experiences that require ultra-low latency, high reliability and synchronised data delivery.

RESULTS

PREDICT-6G successfully advanced deterministic networking across domains. In the Multi-Technology Multi-Domain Deterministic Communication use case, it achieved low jitter, minimal latency, and high reliability over Wireless Local Area Network (WLAN), Time Sensitive Network (TSN), and 3GPP technologies, essential for Industry 4.0 and autonomous systems. The Smart Factory use case validated seamless 3GPP 5G integration, with and without TSN enhancements. The Localisation and Sensing use case showcased robust real-time data processing for applications such as collision avoidance, leveraging Artificial Intelligence/Machine Learning (AI/ML) and deterministic networks. The project demonstrated the ability of the PREDICT-6G architecture to establish, monitor and maintain deterministic services while meeting stringent Key Performance Indicators (KPIs).

Critical communication in a vehicular scenario



PRogrammable AI-Enabled DeterminIstiC neTworking for 6G

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Partners: University Carlos III of Madrid, Nokia Solutions and Networks Spain, Ericsson Spain, Intel Germany, Telefonica ID, Atos Italy, Gestamp Servicios, Nextworks, Cogninn, SIMAVI, Australo, Polytechnical University of Turin, Polytechnical University of Catalunya, CNR

PRIVATEER

PRIVATEER is to pave the way for 6G "privacy-first security" by studying, designing and developing innovative security enablers for 6G networks, following a privacy-by-design approach.

OVERVIEW

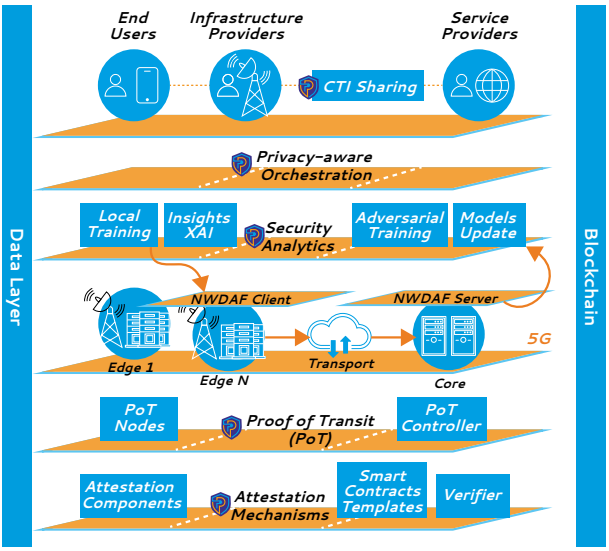
Privacy is a key focus of EU research and development for 6G, as it is seen as a top priority in the EU's 6G vision. The aim of PRIVATEER is to promote privacy as a primary requirement in the development of 6G security enablers, facilitating alignment with the privacy-oriented EU 6G vision and compliance with the GDPR and the upcoming ePrivacy regulation. In this context, the mission of PRIVATEER is to pave the way for 6G "privacy-first security" by studying, designing and developing innovative security enablers for 6G networks, following a privacy-by-design approach.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

PRIVATEER's Security and Privacy-Enabling Framework has multiple layers with unique components that work together to protect the network from attacks while preserving end-users' privacy, as shown in the figure below:

Specifically, PRIVATEER's architecture is based on four major pillars:

PRIVATEER's Security and Privacy Enabling Framework



- **Privacy-Aware Orchestration**: AI-driven mechanisms and blockchain technology are used for VNF placement and trust assessment. Proof-of-Transit (PoT) mechanisms ensure traffic integrity and order, enhancing network trustworthiness.
- **Decentralised Security Analytics**: The Edge Domain enhances performance through FPGA accelerators and utilises Network Data Analytics Functions (NWDAFs) in a federated learning deployment for intrusion and anomaly detection, ensuring data privacy.
- **Privacy-friendly Attestation**: Bootup and runtime attestation mechanisms verify virtualised environments and maintain system integrity. Distributed Identification introduces Verifiable Credentials (VCs) and Decentralised Identifiers (DIDs), registered on a Distributed Ledger, to authenticate users without third-party reliance.
- **Privacy-friendly CTI Sharing**: Establishment of a network for confidential and efficient threat data exchange among stakeholders, utilising a secure, distributed index and proxy system.

INNOVATION

PRIVATEER innovation potential lies in addressing critical privacy and security challenges in the transition from 5G to 6G networks. The project pioneers a privacy-by-design approach to develop advanced security enablers, leveraging cutting-edge technologies such as federated learning, explainable AI, and blockchain-based decentralised identifiers. PRIVATEER advances the state of the art by decentralising security analytics, enhancing privacy-aware network slicing, and implementing privacy-friendly mechanisms for cyber threat intelligence sharing. Its innovative methodologies, including adversarial AI robustness, multi-party computation, and privacy-preserving data pipelines, contribute to a cutting-edge integrated approach to privacy-first security. By integrating these advancements into a coherent, demonstrable 6G framework, PRIVATEER sets a new benchmark for privacy and security in next-generation networks.

USE CASES/ SCENARIOS

The PRIVATEER framework addresses critical security and privacy challenges across Intelligent Transport Systems (ITSs) and Smart Cities, focusing on safeguarding private networks, orchestrating secure logistics, and enhancing public transportation with privacy-centric solutions. For road operators, the framework enables robust defences against edge service compromises through advanced detection and AI-driven analytics. Logistics operations benefit from secure network resource orchestration, leveraging PRIVATEER's privacy-preserving mechanisms to ensure data integrity and secure communications. In the field of public transportation, a citywide network slice supports privacy-secure journey planning and AI-assisted functionalities, illustrating the framework's utility in managing sensitive data across multiple service providers.

Smart city initiatives include the deployment of a "neutral host" edge network by a municipality, emphasising the importance of infrastructure integrity and the need for distributed analytics to prevent security breaches. Additionally, a startup's smart city application across two cities showcases the necessity of multi-domain infrastructure verification and Proof-of-Trust to maintain the confidentiality and integrity of sensitive data.

RESULTS

PRIVATEER has already delivered the first version (Release A) of a set of software enablers for privacy-first security in 5G/B5G networks. These include: i) federated learning-based multimodal intrusion detection techniques, hardened against adversarial actions ii) explainable AI (XAI) tools and techniques to communicate threats, iii) streaming pipelines for data anonymisation, iv) trusted and secure hardware acceleration platforms for Federated Learning (FL), v) open annotated datasets for Machine Learning (ML) testing, vi) an intent-based manager tool for privacy preservation, vii) a privacy-aware orchestrator, viii) privacy-aware Proof-of-Trust mechanisms, ix) privacy-preserving Cyber Threat Intelligence (CTI) sharing mechanisms, x) Decentralised Identifiers for securing the 6G ecosystem. The project has also delivered reports related to 6G threat landscape overview. A comprehensive dataset has also been produced, including various types of Denial of Service (DoS) attacks in B5G networks. The dataset, as well as all documents detailing the above mentioned early implementations are openly accessible at the project's Zenodo community: https://zenodo.org/communities/horizon-ju-sns-privateer/

PRIVATEER

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Verticals: Intelligent Transportation, Smart Cities

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RIGOUROUS

The RIGOUROUS project aspires to identify and address the major cybersecurity, trust and privacy risks threatening the network, devices, computing infrastructure, and next generation of services.

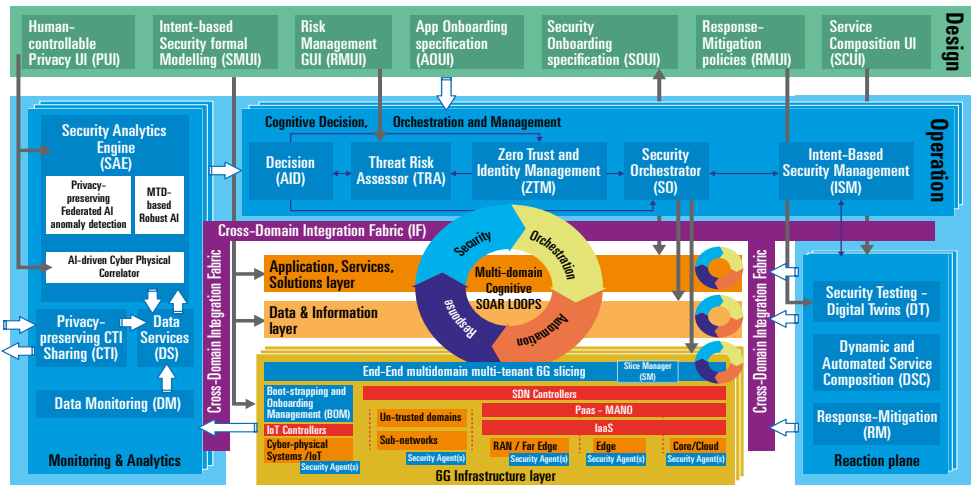
OVERVIEW

The RIGOUROUS project focuses on identifying and addressing the major cybersecurity, trust, and privacy risks threatening the network, devices, computing infrastructure, and next-generation services. RIGOUROUS is working towards addressing these challenges with a new holistic and smart service framework leveraging new Machine Learning (ML) and Artificial Intelligence (AI) mechanisms, which can react dynamically to the ever-changing threat surface on all orchestration layers and network functions. The new smart service framework can ensure a secure, trusted, and privacy-preserving environment for supporting the next generation of trustworthy continuum computing 6G services along the full device-edge-cloud-continuum on heterogeneous multi-domain networks.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The framework will ensure a secure, trusted, and privacy-preserving environment for the next generation of trustworthy continuum computing 6G services across different networks, as shown in the figure below. The DevOps lifecycle will prevent and detect anomalies or intrusions and enforce policies. A transition to Development, Security, and Operations (DevSecOps) will allow for a shift-left in security and thus ensure a secure continuous delivery and integration framework in large-scale digital production environments. Automation and dynamic orchestration will be used for ease of operability and management, while the human factor will be incorporated in the design and orchestration. Advanced security enablers are also being developed to bring automation and intelligence to the secure orchestration concept.

RIGOUROUS Architecture



INNOVATION

RIGOUROUS aims to create innovations targeting the challenges of 6G. It considers a holistic and integrated view of future networks, where AI, security, and privacy are at its core, with several innovations, such as: Intent-based Security & Privacy; formal modelling and onboarding specification; AI-based Security Orchestration across network segments; Privacy-preserving Federated AI for anomaly detection; E2E multi-domain 6G slicing over Zero-Touch security network management; 6G Zero-Trust Security Adaptations; AI-driven Decision-Making mitigation framework; Continuum cognitive Security Orchestration, Automation, and Response (SOAR) loops Reaction and mitigation; Dynamic and Automated Service Composition; Cyber-Physical Correlation; IoT Device Boot-strapping and Trusted Application Onboarding; Intelligent Detection and Mitigation of Economic Denial of Service (DoS) Attacks against 6G Network Slicing; Moving Target Defense based Robust Mechanisms for Enabling Trustable Autonomic Security; E2E Threat Risk Assessment; Holistic Security and Privacy framework; and Encryption as a Service.

USE CASES/ SCENARIOS

Four use cases focus on integrating components, showcasing security-oriented mechanisms for 6G, under a vision of integrated security management with AI-driven SOAR loops, and human-centric security and privacy:

- **UC 1: RIGOUROUS Platform Validation**. Revolves around the Orange Romania lab, validating the platforms' capability to enhance the flexibility of future telco infrastructures. It employs a DevSecOps approach to integrate security into the development lifecycle. It assesses performance through three threat scenarios, confirming the platforms' effectiveness in identifying, responding to, and mitigating complex cyber threats to vital 6G infrastructures.
- **UC 2: IoT-Based Smart City Platform**. A cloud-native IoT platform for smart city applications with extensive twinning capabilities, managing diverse IoT data, supporting various communication technologies and devices. Threat scenarios, such as unauthorised communications and economic DoS, are to be examined, emphasising correlations with critical assets.
- **UC 3: Utilities Management and Security**. This in-depth examination focuses on the data security of utilities management. Threat scenarios also encompass Distributed DoS (DDoS) attacks, code and data injection, and challenges posed by outdated systems.
- **UC 4: Public Protection and Disaster Relief (PPDR)**. Scenarios involving PPDR scene and team provisioning, potential intrusions, disclosure of device vulnerabilities, and dynamic security and privacy mechanisms. This case highlights the correlations between assets and critical elements that are at risk.

secuRe desIGn and deplOyment of trUsthwoRthy cOntinUum computing 6G Services

RIGOUROUS

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RESULTS

The project has delivered significant advancements to security and privacy in 6G networks. Key outcomes include the development of enablers addressing critical challenges and the dissemination of solutions and use cases through more than 30 publications. It has actively engaged with the research community by organising events at international conferences, delivering keynotes, and showcasing its progress through live demos.

A notable impact has been achieved in standardisation efforts, with over 45 individual contributions to 3GPP/ETSI. The team has also demonstrated relevant participation in 6G WGs, further strengthening its influence on the evolution of 6G standards.

With this effort, the consortium is advancing toward the realisation of a human-centric secure 6G architecture, with solutions that constitute true innovations to telecommunication networks and will lead to strong 6G solutions, integrated and demonstrated in relevant scenarios.

SUPERIOT

SUPERIOT aims at demonstrating, advocating and further promoting the concept of truly sustainable IoT systems.

OVERVIEW

The SUPERIOT project is focused on developing truly sustainable IoT systems. The SUPERIOT concept defines a reconfigurable IoT system based on the use of optical and radio technologies. This dual-mode optical-radio approach is exploited to provide wireless connectivity, energy harvesting as well as positioning. Printed electronics is used as a sustainable technology for the implementation of the battery-less IoT devices. The proposed IoT system is flexible to operate in different scenarios and under changing requirements, and adaptable to dynamic changes in the operating scenarios. The goals of SUPERIOT include developing and demonstrating a reconfigurable IoT system (nodes and network) that is sustainable in a wide sense (holistic sustainability). The project also aims at demonstrating that combining radio and optical technologies creates a highly capable IoT system. Four Proofs-of-Concept demonstrators are being developed.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The holistic sustainability approach of the project requires that sustainability is considered at the design, implementation, usage and disposal stages of the IoT system. Key to achieving these goals are the combined and flexible use of radio and optical technologies, the reconfiguration capabilities of node and network, as well as the use of sustainable implementation technologies. The pivotal parts of the system architecture are a) the reconfigurable radio-optical IoT nodes, b) the infrastructure providing nodes' connectivity, energy and positioning, c) network intelligence and d) services and applications. The joint use of optical and radio networks is viewed as a powerful solution for next-generation IoT systems, capable of addressing the diverse demands of modern wireless communications. The technologies selected for wireless radio and optical communications are Bluetooth Low Energy (BLE) and narrowband visible light communications (NB-VLC), respectively.

INNOVATION

The SUPERIOT project develops an innovative concept for IoT. Project innovation has been taking place in multiple fields and will continue. From the point of view of wireless connectivity, the joint use of radio and optical communications to connect the IoT nodes to access points allows dynamic and opportunistic selection of the communication technologies based on different criteria. The novelty of the SUPERIOT project, from a network architecture perspective, lies in its integration of optical and radio-based communication, wireless power transfer, and sensing/location capabilities into a single unified system. Key innovations include a holistic architecture designed for resource-constrained, sustainable IoT terminals, along with optimised algorithms for seamless handovers and operational optimisation, implemented both at the node level and within the network infrastructure. These innovations will be validated through demonstrations. The project also brings printed electronics technology in the realm of IoT, allowing sustainable implementation of IoT nodes/devices. Several printed components are being developed for the needs of the project, including

photovoltaic cells, supercapacitors and thin-film transistors. The project paves the way to future fully printed advanced IoT nodes. Such small form factor, sticker-like sustainable nodes will revolutionise IoT, creating novel use cases and operating scenarios, such as truly massive sensing and actuation with extremely low cost and minimum environmental impact.

USE CASE/ SCENARIOS

During the initial phase of the project, relevant scenarios and associated applications for the sustainable IoT concept were identified. The three main operating scenarios are summarised in the figure below. A total of 24 potential applications associated with these scenarios were also identified. The requirements for the scenarios and applications were then determined. Requirements included dual-mode connectivity, sensors/actuators, positioning, privacy/security, energy autonomy, recyclability, cost, etc. For the requirements, the project also assessed their importance, feasibility, timeline for technology matureness and possible implementation in the project demonstrators. Demonstrators 1 and 2, the most comprehensive of the project, will consider the following specific use cases: a) Industrial material flow, b) Logistics and distribution, and c) Patient monitoring.

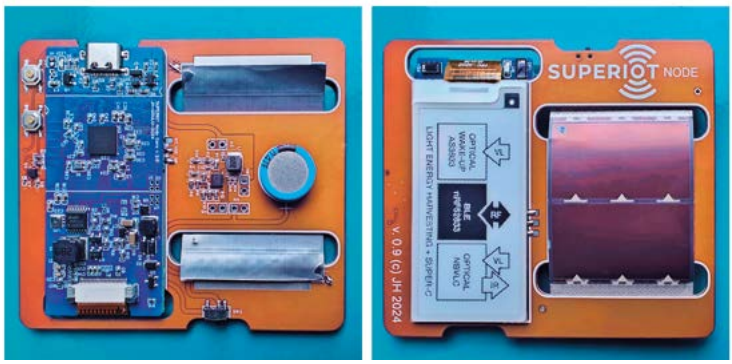
Key scenarios of the SUPERIOT project

Scenario 1: Smart tags and labels	Future smart tags and labels for identification and traceability of objects (static or moving) and people, with enhanced functionality when compared to barcodes, quick-response (QR) code or even RFID labels.
Scenario 2: Large-scale sensing and actuation	Sustainable and inexpensive devices that can be deployed in large scale for environment sensing and actuation. These devices communicate relevant parameters to the network and are also able to act in the environment.
Scenario 3: Enhanced IoT communication	Technology developments that may be used to improve many types of applications. This scenario serves as a future technology platform to enhance IoT communication capabilities in general.

RESULTS

Several key scenarios and applications for the SUPERIOT concept were identified and characterised. Reconfigurable radio-optical IoT (RIoT) nodes and their access points counterparts were developed and working prototypes were implemented. The project developed an initial reconfigurable dual-mode IoT node, called the reference node. This simpler node, based on conventional electronics, is used for preliminary testing of the concept. The figure below depicts the RIoT reference node, where the dual-mode communication board is displayed together with a flexible solar cell, e-ink display and supercapacitor. These reference designs will be further developed and used in the project demonstrators. In addition, fundamental aspects of the system at network level were investigated, including design of the network architecture, study of network selection algorithms, measurements of energy consumption for different RIoT node's operation phases, development of simulation models for radio-optical hybrid networks on network simulator 3 (ns-3) and modality optimisation algorithms for hybrid networks, joint data and energy transfer at both radio and optical domains, and others.

SUPERIOT reference radio-optical IoT node with light-based energy harvesting



Truly Sustainable Printed Electronics-based IoT Combining Optical and Radio Wireless Technologies

SUPERIOT

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TERA6G

TERA6G is advancing connectivity with cutting-edge transceivers.

OVERVIEW

TERA6G brings advanced hybrid photonic integration technology to develop groundbreaking wireless transceiver modules with Terabit-per-second data throughput capacity which can be reconfigured through network orchestration. To achieve these speeds, we reach into the frequency bands above 100 GHz and unlock massive Multiple-Input Multiple-Output (mMIMO) multi-antenna techniques to offer extremely high transport connectivity.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

TERA6G develops technologies including ultra-high frequency, wide bandwidth tunable radio transport, multi-beam and beamforming/steering concepts, flexible transport solutions, and end-to-end network architectures, aiming to unlock two key concepts for 6G.

The first is the "Fibre over the air" concept, to bring the information capacity of fibres to wireless links. Reaching into the higher end of the electromagnetic spectrum — the millimeter-wave and Terahertz ranges — where vast amounts of bandwidth are available, TERA6G aims to increase transmission speeds with low complexity coding schemes to reduce latency.

The second is the "Smart management" concept, to enable fully programmable end-to-end orchestrated communication networks, based on the reconfigurability of photonic components, unlocking network slicing and dynamic automated management of multi-beam wireless system resources.

INNOVATION

TERA6G relies on several innovations.

At the hardware level, TERA6G is developing key innovations in integration technology. One of them is the development of chiplets, functional building blocks which can be repeated and combined to scale the transmission capacity without changing the architecture. On the other hand, based on the hybrid integration approach, is the introduction of key functions such as integrated optical isolators (to avoid back-reflection issues at chip level) and 3D optical interconnects (for massive optical interfaces).

At the radiofrequency (RF) level, TERA6G develops technologies to enable large two-dimensional antenna arrays. A key innovation is avoiding dielectric silicon hyper-hemispheric lenses which prevent steering the RF beams. We introduce the use of dielectric waveguide antennas, which act as lenses for every individual element of the antenna array, to enable large, phased array antennas.

At the network level, TERA6G will take advantage of the reconfigurability of photonic components to develop wireless transceiver modules that improve user throughput and network capacity, integrating beamforming functionality to minimise misalignment impacts, and to exploit spatial discovery and network topology dynamic reconfigurability.

USE CASE/ SCENARIOS

TERA6G's use cases are focused on two main complementary scenarios:

- **The first scenario** targets outdoor public networks, in a multiple Point to Point (mPMP) X-haul mobile small cell densification scenario. This setup addresses the growing demand for scalable mobile networks in urban areas where small cells are deployed to enhance network coverage (gaps) and capacity. This scenario allows for short range transmission (especially in dense urban areas) suitable to high frequencies but being outdoor, is potentially affected by atmospheric conditions such as rain or humidity. These factors can impact system performance variables, including throughput and availability.
- **The second scenario** targets indoor private networks, in another mPMP mobile wireless scenario, enabling high-throughput connectivity in industry 4.0. Adaptive manufacturing has become an emerging trend in the field of industrial automation and production, requiring industry to deploy networks that emphasise robust and low latency connectivity for a higher density of remote nodes with changing physical layouts. As an indoor scenario, it allows for shorter ranges and is not affected by atmospheric propagation effects. However, it involves a higher density of remote nodes and requires enabling on-the-fly changeover of reconfigured production lines.

RESULTS

TERA6G results can be summarised in two main areas:

On one hand, TERA6G aims to demonstrate groundbreaking wireless transceivers, using hybrid photonic integration technology to develop the photonic integrated chiplet concept and unlock 2D phased array antennas. This will enable us to reach into the frequency bands above 100 GHz to access vast amounts of bandwidth, offering Terabit-per-second data throughput capacity on multiple wireless pencil-beams which can be steered through processing in the optical domain. These advances unlock massive Multiple-Input/ Multiple-Output (mMIMO) systems generating and controlling multiple wireless pencil-beams.

On the other hand, TERA6G aims to develop an end-to-end orchestrated communication network able to dynamically manage the network nodes within a network automation architecture, exploiting the innovative THz transceiver features. We aim at the dynamic management of the multi-beam wireless system resources through fully programmable end-to-end orchestration, to achieve energy efficiency, network resiliency and dynamically adapting the network capacity to the needs at every instant.

TERAhertz integrated systems enabling 6G Terabit-per-second ultra-massive MIMO wireless

TERA6G

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TERRAMETA

TERRAMETA aims to examine revolutionary 6G technologies and demonstrate the feasibility of multi-functional THz reconfigurable intelligent surfaces (RISs) to support very high data rates in wireless communications networks.

OVERVIEW

Over the next decade, 6G mobile communications will support novel applications, such as the internet of senses, that will capitalise on billions of wireless devices. Existing technologies simply cannot meet the requirements of such envisioned services. The TERRAMETA project aims to demonstrate the feasibility of multi-functional Terahertz (THz), Reconfigurable Intelligent Surfaces (RISs) to support very high data rates in wireless communications networks. TERRAMETA will develop hardware and advanced network analysis/optimisation methods for RISs and demonstrate them in a real factory and a telecom testing site.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

THz frequencies constitute one of the most compelling, attractive, and promising frequency bands for future wireless communications supporting potential data rates of up to 1 Tb/s, thanks to the large bandwidth available. A major contribution of TERRAMETA lies in the design and fabrication of RIS operating at 140 and 300 GHz. RISs are expected to overcome the limitations of THz communications, i.e., blockage sensitivity and high path loss, by favourably shaping electromagnetic waves to create enhanced virtual Line of Sight (LoS) paths.

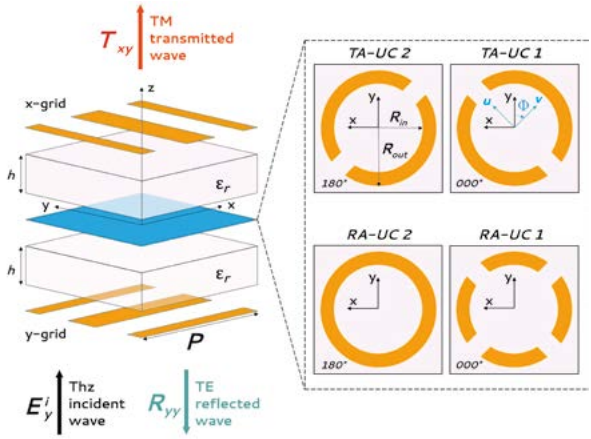
INNOVATION

Innovative unit cells were developed, incorporating memristors, Schottky diodes, and phase-change materials for non-volatile, high-frequency, and scalable designs. Additionally, sub-THz repeaters and amplitude modulators for D-band demonstrated breakthroughs in mitigating link blockage and achieving high data rates. Practical demonstrations include a high-directivity lens-Integrated Circuits (ICs) achieving 56 Gb/s, and flexible liquid metal-based unit cells with excellent phase control.

USE CASE/ SCENARIOS

TERRAMETA envisages a set of use cases and scenarios, specifically focusing on:

- **Factory Scenario**: In the context of Industry 4.0, the project demonstrates how RIS-enabled THz communication can overcome upcoming challenges in factory automation. Utilising strategically deployed RIS on pillars and mobile platforms, high-speed, low latency connections are maintained for mobile robots performing tasks like simultaneous localisation and mapping (SLAM), and AI factory digital twin modelling, which require very high mobile network data rates. This solution supports flexible factory layouts and enables efficient operations in future modular and mobile manufacturing setups. This use case will both be investigated at large-scale via ray-tracing simulation (see figure on next page), and real-world



(a) (b)

Proposed multifunctional metasurface-based transmit- and reflect-array. (a) 3-D view. (b) Geometry of the inner metallic layer

demonstration, with integration and testing of a RIS with end-user robots already completed, which is described in the next section.

- **Telecom Scenario**: The project integrates RIS with Open Radio Access Networks (O-RAN) to enhance 6G telecom infrastructure. RIS compensates for the high path loss and blockages typical of THz communications, enabling seamless Non-Line-of-Sight (NLoS) connections in urban environments. Deployment strategies include RIS on urban lamp posts for enhanced base-station-user connectivity and THz-enabled xhaul for backhaul, midhaul, and fronthaul links. Combining RIS with modular O-RAN architecture supports dynamic beam management, energy efficiency, and precise localisation, driving innovations in network densification and high-capacity connectivity.

RESULTS

TERRAMETA developed the first multi-functional RIS that can manipulate sub-THz waves simultaneously as a Transmissive RIS (T-RIS) and a Reflective RIS (R-RIS) and operating at two frequency bands, at both D-band and 300 GHz. Several prototypes are currently being designed.

TERRAMETA's first joint demonstration showcased an advanced scenario tailored for mobile robots in factory environments. Combining CEA-Leti's RF front end and four 140 GHz T-RIS', Intracom Telecom's dual-modem baseband units, and Dell Technologies robot platform and sensors, the demonstrator achieved a fully working end-to-end high-speed link via the RIS, with a data rate of up to 57.6 Gb/s. The robot sensor application was showcased a 10x+ improvement in bitrate and latency compared to Wi-Fi in the same location.

Use case demonstrator showcased live at EuMW 2024 conference. Robot is transmitting a 3D sensor map of the environment via 140 GHz link, using four RIS' including an active repeater step.

Terahertz Reconfigurable Metasurfaces for Ultra-High-Rate Wireless Communications

TERRAMETA

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January 2023-December 2025

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Verticals: Industry, Smart Cities

Partners: INESC TEC, National and Kapodistrian University of Athens, University of Oulu, Instituto de Telecomunicações, Intracom Telecom, CEA Leti, University of Luxembourg, Dell Technologies, Technical University of Braunschweig, ACST, Nova University of Lisbon, University of Hertfordshire, BT.

TIMES

The vision of TIMES is a THz-based smart radio ecosystem working in complex scenarios with many heterogeneous devices, capable of offering similar performance as wired networks in terms of data rate (Tb/s), ultra-low latency, sensing, and reliability.

OVERVIEW

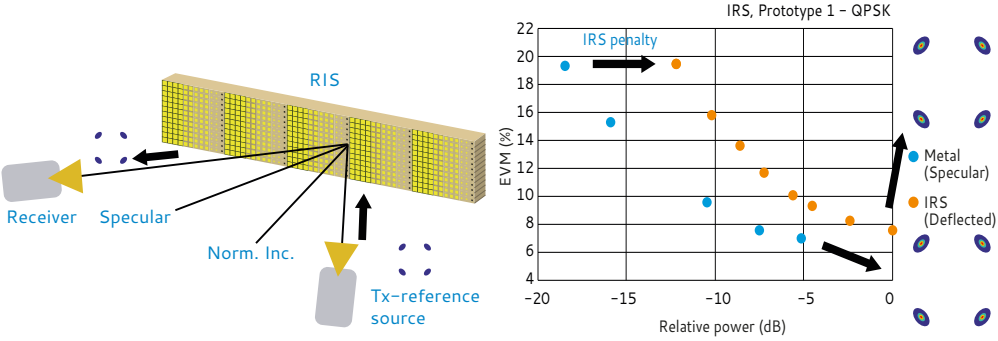
Future wireless networks aim to achieve Tb/s data rates, ultra-low latency, precise sensing, and high reliability, which current 5G technology struggles to meet. The TIMES project addresses these challenges using innovative radio channel measurements, THz spectrum bands, intelligent mesh networking, and smart sensing, focusing on industrial applications.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

TIMES addresses the challenges of future wireless networks with Tb/s data rates and ultra-low latency. It focuses on Terahertz (THz) spectrum bands, intelligent mesh networking, and smart sensing for industrial applications like cooperative robotics and predictive maintenance. Key innovation pillars include ultra-wide bandwidth, intelligent mesh networks, and high-resolution Integrated Sensing and Communication (ISAC). The project will validate two Proofs-of-Concept in industrial environments using THz wireless links and advanced antenna designs. Through precise measurements and advanced technologies, TIMES aims to integrate THz communications and ISAC systems to enhance industrial communication.

INNOVATION

The TIMES project explores the use of reflective surfaces in THz communication systems to enhance channel management. It aims to demonstrate a non-line-of-sight 300 GHz wireless link enabled by Intelligent Reflective Surfaces (IRS/RIS), involving design, fabrication, and real implementation. Due to limited experimental data, TIMES also focuses on developing characterisation techniques using channel sounding and free-space frequency-domain methods. The project has successfully demonstrated the first use of static RIS in both frequency-domain and THz data links at 300 GHz.



Demonstration of a 300 GHz link using a fixed RIS. The IQ signal (10 Gb/s) is non-specularly reflected by the reflective surface [CNRS – G. Ducournau].

TIMES is investigating a THz ultra massive multiple input multiple output system to improve communication and sensing performance. This includes developing novel waveforms for THz integrated sensing and communication systems, which offer lower peak-to-average power ratios and higher sensing accuracy. The project introduced a THz integrated sensing and communication system for object localisation and tracking in industrial environments. Research includes modelling impairments affecting THz components, developing mitigation techniques, exploring efficient beam alignment, and tracking methods using leaky wave antennas. Additionally, TIMES analyses the performance of RIS-assisted scenarios in factory settings and evaluates different network architectures and medium access control protocols to improve key performance indicators.

USE CASE/ SCENARIOS

In the manufacturing and logistics domain, TIMES has carefully outlined 15 different use cases (UCs) for THz communication systems across 6 different application areas. The project has defined UCs tailored for both stationary production machines and mobile robots within short term (up to 3 years), medium term (between 3 and 5 years) and long term (more than 5 years) time horizons. These UCs are grouped into six overarching macro classes: Mobile Robot Management; Predictive maintenance, monitoring machines/production lines with high data flow, substitute Field Bus in non Real-Time Industrial (RTI) applications; Augmented Reality (AR)/ Virtual Reality (VR) - Digital Twin - Virtual Commissioning - High-Level Maintenance; High Dynamic Control, Substitute Field Bus in RTI for Motion and Robotics; Ensuring Seamless and Secure Field Bus Substitution Process; Flexible Factory. Each of these UCs has been thoroughly analysed to determine its specific communication and sensing requirements.

RESULTS

Key components to the project include THz front ends, beam-steering antennas, and RIS technologies. The project has rigorously evaluated these designs and is fabricating initial prototypes, with two measurement campaigns conducted to assess performance.

The project is expected to significantly impact manufacturing industries by enhancing industrial communication, improving reliability and efficiency, and leading to better coordination and increased productivity. Predictive maintenance will become more accurate and responsive, resulting in cost savings and improved operational efficiency. Mobile robot management will be enhanced, contributing to more flexible and efficient manufacturing processes. Flexible and modular factory layouts will enable industries to quickly adapt to changing production needs and market demands.

THz Industrial MEsh Networks in Small Sensing and Propagation environments

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Stream C

SNS ENABLERS AND PROOFS-OF-CONCEPT (POCs)

including development of experimental infrastructure(s)

The three projects in stream C aim to develop EU-wide experimentation platforms that can incorporate promising technical 6G enablers for their further validation. Key aspects for the projects are the reusability and ability to evolve of the experimental platforms over the lifetime of the SNS programme. Accessibility and openness with well-defined and clearly documented technological and business interfaces are also considered key assets of the infrastructures to be developed.

6G-BRICKS

6G-BRICKS offers breakthrough enablers, Explainable AI models and Open interfaces for a truly modular and Open RAN compliant end-to-end 6G experimentation facility.

OVERVIEW

6G-BRICKS aims to be the first open 6G experimentation platform that integrates cell-free architecture, Open-Air Interface (OAI), and Reconfigurable Intelligent Surfaces (RIS), with a focus on modularity and scalability. It enables interdisciplinary collaboration through a "LEGO Bricks" approach, offering reusable testbed nodes.

The project leverages Software-Defined Infrastructures (SDI) to replace traditional network functions with softwarised alternatives and extends this to the Radio Access Network (RAN) via the Open Radio Access Network (O-RAN) initiative. It will launch the first open and programmable O-RAN Radio Unit (RU), the OpenRU, based on a Universal Software Radio Peripheral (USRP) platform and integrate RIS into OAI. Advanced tools will enhance current Testing as a Service (TaaS) capability, enabling device experiments via O-RAN compliant xAPPs. 6G-BRICKS supports the testing of advanced applications, the validation of breakthrough technologies, and the exploration of new architectural principles, with an emphasis on multi-tenancy and Deep Edge integration.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The 6G-BRICKS Facility features advanced architectural innovations centred around a disaggregated Management Plane and Operations Support System:

1. Experimentation Plane:

This serves as the entry point to the 6G-BRICKS Facility, enabling intent-driven, human-in-the-loop experimentation.

2. Management & Orchestration Layer:

This layer, deployed at each facility site, offers a unified controllability framework through the Domain Management and Orchestration (DMO) framework and uses Explainable AI to unify policies and provide feedback on potential issues during experiments.

3. 6G RAN Infrastructure Domain:

This domain incorporates advanced 6G RAN technologies into modular components with O-RAN interfaces for reusability.

- The KU Leuven (KUL) site features a Distributed Cell-Free RAN for enhanced network densification.
- The EURECOM (EUR) site uses the OpenAirInterface O-RAN stack, integrated with a Reconfigurable Intelligent Surface (RIS).

INNOVATION

- Integration of 6G technologies and federation of two testbeds under a unified set of experimentation tools.
- Validation and demonstration of advanced use cases.
- Support for disaggregated and programmable Software-Defined Infrastructures (SDIs) with virtualisation, softwarisation, and O-RAN compliant interfaces.

- Decentralised management plane enabling zero-touch orchestration of computing and communication resources through Explainable Artificial Intelligence (XAI).
- Compute Continuum abstraction framework supporting disaggregated wireless X-haul.
- Breakthrough 6G RAN technologies, including Distributed Cell-free and Reconfigurable Intelligent Surfaces (RIS).
- Secure and trusted Experimentation Facility and Platform.

USE CASE/ SCENARIOS

- **UC 1: Metaverse as an enable of a Modern Workplace**
- PoC 1: Holoconferencing in a Virtual Meeting room
- PoC 2: Virtual team-building activities
- **UC 2: 6G applications for Industry 4.0**
- PoC 1: Autonomous robots in Industry 4.0
- PoC 2: Augmented Reality (AR) inspection of Industry 4.0 digital twin on site

RESULTS

6G-BRICKS has delivered its final overall architecture design (D2.4), final reports on communication and sensing, cell-free distributed computation and synchronisation (D3.3), as well as the RIS controller and PaaS abstraction enablers (D3.4). D4.1 introduced the portal, testing-as-a-service and explainable, intent-driven resource management frameworks, while D4.2 detailed the end-to-end security framework and initial system integration for the experimentation facility.

Technical advancements include the e2e Open RAN-compliant CFmMIMO system and the integration of an OAI O-RAN based DU with a simplified RIS prototype. These RAN components will be made available to experimenters through standardised xApps to support the Open Call projects.

Breakthroughs in the orchestration plane, such as the AI-driven Cognitive Continuum and the 6G-BRICKS DMO include an abnormal traffic detection PoC as the first outcome (D4.1).

Building Reusable testbed Infrastructures for validating Cloud-to-device breaKthrough technologieS

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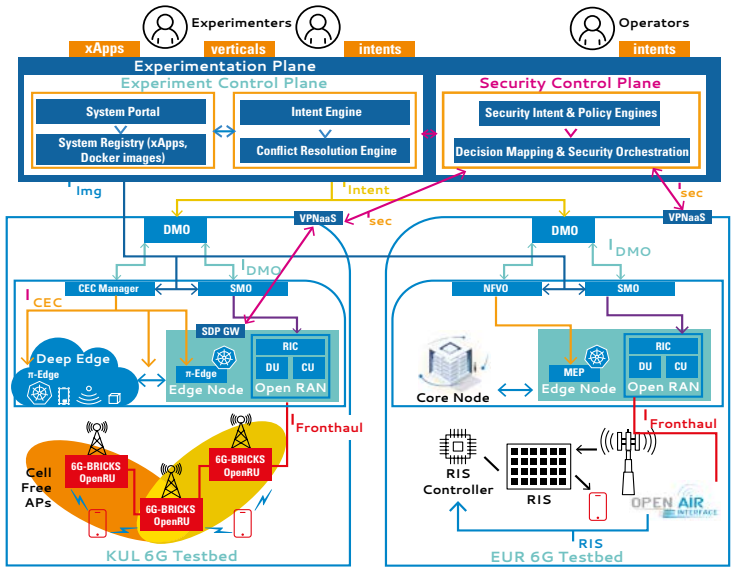


6G-BRICKS architecture

6G-SANDBOX

The 6G-SANDBOX project addresses the need for an experimentation facility that guarantees Modularity, Openness, Reusability, Innovation, and Sustainability.

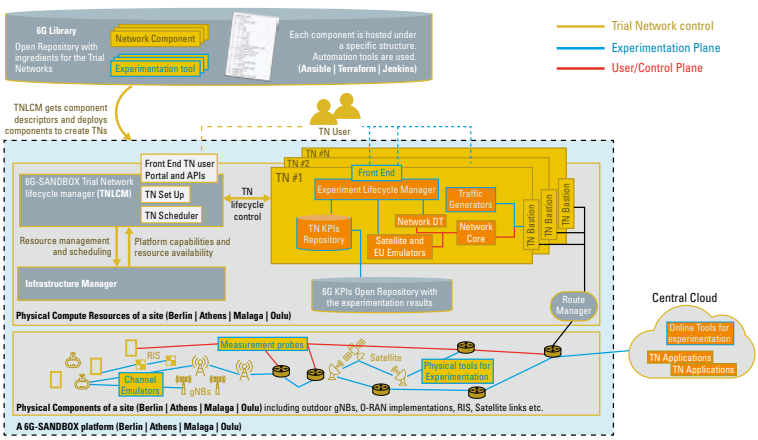
OVERVIEW

6G-SANDBOX enables the creation of testbeds designed as trial networks. A Trial Network (TN) is defined as a fully configurable, manageable, and controllable network that combines virtual, physical, and emulated resources to enable experiments for validating 6G technologies and measure 6G KPIs. Instances of Trial Networks might be offered targeting specific network domains and technologies, while within the 6G-SANDBOX project, end-to-end Trial Networks are offered by the four experimentation platforms (network and compute infrastructures). The Trial Network software components are described in a common repository, called 6G Library , which eases an experimenter to perform a modular and automatic deployment of a Trial Network by selecting on demand the required elements from the library.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

6G-SANDBOX offers an innovative experimentation approach for beyond 5G and 6G technologies based on a modular architecture (see figure below) that incorporates three primary planes: the user/control plane, managing the data transmission among the network components; the experimentation plane, facilitating the execution of experiments; and the trial network plane, handling the deployment and configuration of TNs. The three planes together form a key experimentation framework for the 6G ecosystem, incorporating already pivotal technologies beyond 5G, which are integrated and tested in the 6G-SANDBOX infrastructure. In addition, the modular and open approach followed by the project allows seamless integration of other 6G technologies during and after the project lifetime.

6G-SANDBOX reference architecture



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INNOVATION

6G-SANDBOX brings multiple innovations structured in ten technological ambitions that refer to: experimentation process and facility, disruptive wireless communications, fixed/RAN/NTN integration, deterministic networking, network openness (network core exposure), Artificial Intelligence/Machine Learning (AI/ML) network evolution, security as a service, edge-cloud continuum, digital twins, and mixed extended reality (XR)/haptic applications. For all the ambitions, the proposed innovations are reflected in software developments and/or research studies with measurable gains beyond the state of the art.

Overall, the project provides a new experimentation paradigm where isolated testbeds are generated in a network and compute infrastructure and offered to third parties for configuration, technology validation and KPI measurements. In addition, high levels of replicability and reusability of the proposed solutions have been achieved by providing all the software developments of the project open source[1]. Also, for the very first time, in a single project such a wide range of measurement tools is offered to experimenters, covering almost any kind of network KPI that a third party might request.

1. https://6g-sandbox.eu/6g-sandbox-toolkit/

USE CASE/SCENARIOS

The project develops an experimentation facility agnostic to the vertical industry that requests technology validations and 6G KPI measurements. However, to internally validate the proposed solution a demanding use case is foreseen that combines extended reality and haptic communications for immersive and touch experience to remote audience. On top of this use case, the project runs an Open Call program where third parties bring their own use cases and scenarios into the 6G-SANDBOX experimentation facility. In addition to the Open Call program, third parties can bring for validation their applications (from various vertical sectors) based on the 6G-SANDBOX third party engagement guide[2]. More specifically, 6G-SANDBOX is actively soliciting use cases like those described in FG-NET2030-Sub-G1[3] and in the scope of the ITU IMT-2030 framework[4].

2. https://6g-sandbox.eu/wp-content/uploads/2024/09/6GSANDBOX-3rd-P-Eng-Guide.pdf

3. https://www.itu.int/dms_pub/itu-t/opb/fg/T-FG-NET2030-2020-SUB.G1-PDF-E.pdf

4. https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2160-0-202311-I!!PDF-E.pdf

RESULTS

Multiple results of different types have emerged during the first two years of 6G-SANDBOX:

- **Trial Networks concept design and implementation**. The requirements and the reference architecture for the Trial Networks concept have been published. The implementation of the architectural components[5] is in progress, while a roadmap has been defined to monitor the development and integration process[6].
- **Open-source impact.** 6G-SANDBOX is the main code contributor to the ETSI SDG OpenCAPIF[7] and has published a stable version of the 6G-SANDBOX toolkit[8].
- **Experimentation tools and measurements**. Measurements of key performance indicators and technology validations have been conducted. In Deliverable D5.3[9] a benchmarking methodology and initial results are provided. Also, a new 6G experimentation lab[10] has been created and will remain active after the end of the project.
- **Standardisation inputs**. A significant number of contributions to 3GPP (SA2 & SA6 Working Groups), as well as to ITU (ITU-T Study Group) have been submitted and most of them - more than 20 - have been agreed/approved. In addition, the project is actively engaged in ETSI with the active support of ETSI SDG OCF and by hosting the ETSI MCX PLUGFEST 2023 event in Malaga.
- **Extrovertion and third-party engagement**. Collaboration Memorandum of Understandings (MoU) have been signed with associations and organisations like ESA, SLICES, ITRI, and others, while an engaging process with other SNS projects has been defined[11]. Also, 11 contributions from the open call program have expanded the project's infrastructure with new features and technologies.

5. https://github.com/6G-SANDBOX

6. https://6g-sandbox.eu/development-roadmap/

7. https://ocf.etsi.org/

8. https://6g-sandbox.eu/wp-content/uploads/2024/09/6G-SANDBOX-Toolkit_Installation-G-V1.0_F.pdf

9. https://6g-sandbox.eu/dissemination/deliverables/

10. https://www.victoria-network.eu/index.php/en/news/

11. https://6g-sandbox.eu/experimentation/

6G-XR

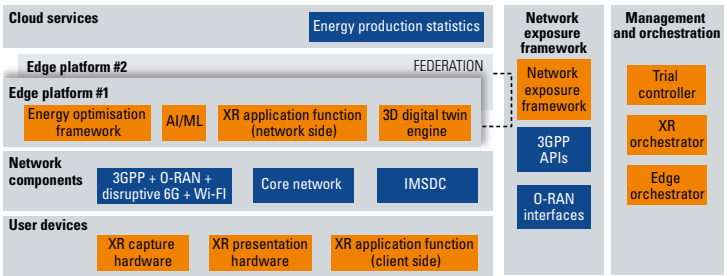
6G eXperimental Research's ambition is to strengthen European leadership in 6G technologies by enabling next-generation XR services and infrastructures that will provide beyond-state-of-the-art capabilities in the run-up to the 6G era.

OVERVIEW

6G-XR provides experimental infrastructure to **validate key B5G/6G technologies for immersive applications like holographic applications, digital twins, and Extended Reality/Virtual Reality (XR/VR)**. Through energy-efficient solutions, it demonstrates the innovative use of radio spectrum and an end-to-end B5G/6G architecture with advanced features such as network slicing, open RAN cloud implementation, and multi-access edge computing within a seamless cloud continuum. 6G-XR also contributes to standards development and showcasing impactful use cases, which provides a robust foundation for advancing 6G technologies and XR services. The activities are further complemented with an extensive cascading funding mechanism that engages third parties to deploy, test, and validate their enablers and use cases using the 6G-XR infrastructure.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

6G-XR builds on the 3GPP evolution, Open RAN, and a disruptive 6G path, incorporating innovations such as sub-Teraherz communications, Integrated Sensing and Communication (ISAC), and Reconfigurable Intelligent Surfaces (RIS). Its highly flexible architecture leverages modular components and open-standard Application Programming Interfaces (APIs) to enable seamless Artificial Intelligence (AI)-driven network management and dynamic XR applications. Spanning user devices, applications, edge/cloud platforms, and resource management, it focuses on breakthroughs like real-time holographic communication, 3D digital twins, energy optimisation, and advanced AI/Machine Learning (ML) algorithms. These advancements are validated at test sites in Spain (South Node) and Finland (North Node) to demonstrate their innovative potential.



6G-XR Reference Architecture Overview

INNOVATION

The 6G-XR project delivers innovative advancements for immersive XR experiences by combining faster, smarter, and more sustainable networks. Some of these innovations include:

- **Holographic Calls via IP Multimedia Subsystem (IMS) Data Channels**, which leverage optimised signalling and web rendering to enable seamless holographic communication.

- The Quality of Service **(QoS)-Aware Multimedia Pipeline** ensures smooth volumetric video delivery by adapting to network conditions or reserving specific resources.
- To enhance accessibility, the project introduced a user-friendly **RGBD Sensor Calibration Method**, simplifying complex setups, where the **XR Capturer** streamlines quality assurance with human-like precision
- **Thermal Compensation** for plenoptic cameras minimises distortions caused by temperature changes.
- **Non-Public Network Exposure APIs and Network as a Service (NaaS) APIs**, enabling optimised resource use, reduced latency, and efficient edge selection. Sustainability is central, with renewable energy integration and real-time monitoring reducing carbon emissions.

USE CASE/ SCENARIOS

The 6G-XR project defines five use cases (UCs) across two experimental nodes: the South Node focuses on **Real-Time Holographic Communications**, while the North Node addresses **Collaborative 3D Digital Twins and Energy Sustainability**. These ongoing UCs tackle challenges like high data rates, low latency, and dynamic resource management, enabling energy-efficient, robust XR services and demonstrating the capabilities of advanced 6G network architectures.

South Node:

- **Resolution Adaptation or Quality on Demand (QoD)** adjusts to network congestion by reducing XR media resolution or using CAMARA QoD APIs to prioritise XR traffic, ensuring smooth service.
- **Routing to the Best Edge** dynamically offloads XR processing to the optimal edge node, minimising latency and enhancing performance.
- **Control Plane Optimisations** integrates a holographic session manager into the network control plane, enabling seamless, scalable holographic communications.

North Node:

- **Collaborative 3D Digital Twin Environment** allows users to review 3D objects in a Synchronised digital twin environment. Upon approval, remote 3D printing is initiated and monitored through a robot-operated camera, enabling precise collaboration.
- **Energy Measurement Framework** integrates energy monitoring tools to optimise energy consumption and enhance sustainability across the test network.

RESULTS

The 6G-XR project has made significant progress in advancing 6G technologies tailored for extreme XR demands, surpassing 5G capabilities:

- **A sustainability experimentation framework** with real-time energy metering and a PV-hybrid power system was deployed, reducing network carbon footprints.
- **Advanced network exposure APIs** now enable third-party applications to dynamically manage slices, QoS, and traffic paths for adaptive XR networks.
- The project demonstrated **holographic calls using IMS data channels**, adapting signaling systems and integrating the MATSUKO rendering engine to WebGL.
- **A 5G New Radio StandAlone (SA) reference architecture** was defined, supporting slicing, energy optimisation, and AI-driven management for 6G.
- **Open Call 1 has led to 8 successful enabler projects** on network slicing, quality monitoring, digital twins, volumetric capture, surgical training, open-source API integration, and mobility protocol improvements, strengthening XR solutions at the North and South Nodes.

6G eXperimental Research to enable next-generation XR services

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Stream D

LARGE SCALE TRIALS AND PILOTS WITH VERTICALS

including the required infrastructure to explore and demonstrate technologies, advanced applications and services in vertical domains

Four projects are implementing large-scale SNS trials and pilots with specific verticals of high economic and societal importance. The aim is to explore and demonstrate 5G/6G technologies, advanced applications and services in vertical sectors such as energy, construction, automotive, manufacturing, eHealth, culture, and media.

Additionally, these large-scale trials aim to serve as catalysts for the creation of viable business ecosystems. Stream D projects incorporate technologies that are currently key enablers for 6G networks, including AI/ML, cybersecurity, cloud/edge and advanced IoT solutions etc.

FIDAL

FIDAL is targeting the augmentation of human capabilities, allowing vertical industry players to perform advanced technological and business validation in large-scale field trials.

OVERVIEW

FIDAL aims to advance the capabilities of 5G and beyond, enabling secure and intelligent experimentation through a comprehensive suite of tools and services. It provides an open-architecture platform enabling testing of innovative technologies in the fields of Media and Public Protection & Disaster Relief (PPDR) through large experimentation sites. These trials offer insights into the Beyond 5G (B5G) performance focusing on network efficiency, scalability, and reliability across demanding applications.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

FIDAL's architecture includes Maestro (for standardised Service Management API, OpenSlice (cross-domain slice manager) and Monitoring and Analytics Services collecting data from Testbeds, Network Applications and Use Cases (UCs). A FIDAL repository is hosted at a partner's server while the project 3 testbeds (Telenor, Patras, and Malaga) are deployed at their respective sites, connected, and configurable through exposed Application Programming Interfaces (APIs), allowing secure remote access. Artificial Intelligence as a Service (AIaaS) ensures smarter, more efficient 5G networks. To date six Network Applications have been deployed: i) Stream Selector, ii) Automatic Fire Detection, iii) Physics Service for Extended Reality (XR) Applications, iv) Remote Sensations, v) Mission Critical Multimedia Communication and Collaboration, vi) Remote scene analysis and Augmented Reality (AR) annotation.

INNOVATION

In FIDAL, each partner develops innovation paths aligned with their expertise to maximise impact. Key innovations include three FIDAL 5G testbeds for validation, experimentation, and collaboration.

Malaga Testbed: Telefónica upgrades the Málaga testbed to 5G Standalone (SA) with Network Slicing and Multi-Operator Core Network technologies, supporting beyond 5G and 6G applications.

Patras Testbed: PNET, University of Patras, and NOVA enhance private 5G SA next-generation advanced features. OpenSlice delivers AI-based end-to-end orchestration, lifecycle management, and telemetry. Maestro enables dynamic orchestration across compute and network domains, optimising scalability and performance. AIaaS introduces modular AI algorithms for detecting network threats, ensuring robust security.

Telenor Testbed: Telenor's iCORA testbed drives 5G experimentation.

These efforts cement FIDAL's role in advancing sustainable, next-generation ICT.

USE CASE/ SCENARIOS

FIDAL has defined 7 UCs targeting the verticals of Media and PPDR. Though the large-scale trials, the project is heading towards the evaluation of immersive media, emergency response, and haptic sensing, that will allow to establish key performance and value metrics, providing concrete evidence

of how advanced technologies can meet the evolving needs of society and industry, thereby facilitating the transition to 6G.

UC 1: This UC has seen important developments: the switch from local to a 5G Network, the creation of a Network application to provide the services, improved API use, and enabled multiple device connections. In the upcoming months, measurements performance for App-Device connection, Published Services and Latency will be collected during the planned large-scale trials

UC 2: UC2 enhances the detection and management capacity of forest fires through 5G. Preliminary tests conducted in lab environment have proven 5G network capacity to support the smooth operation of the UC (only a short network-induced latency of a 14-15 ms was recorded). Larger scale trails planned for the upcoming period will validate operation under heavier traffic scenarios

UC 3: UC3 completed the deployment of a complete critical multimedia communication and collaboration solution with coverage of an urban area benefiting from 5G. Dedicated slices improved quality of voice/video through Mouth-to-ear latency and Mission Critical Push To Talk access time KPIs.

UC 4: UC4 is testing the integration of advanced 5G features, that address bandwidth, latency, and scalability requirements such as: a) High-Capacity Bandwidth for seamless streaming of UHD and 360° video content, b) Ultra-Low Latency, critical for real-time video feed processing and AR applications, c) Beamforming and Network Slicing for optimal performance in high-density environments, d) Edge Computing Integration reducing latency and improving responsiveness

UC 5: UC5's 2024 enabled remote musicians to perform together achieving 50ms round over 400km

UC 6.1: This UC expects to achieve a jitter less immersive high-fidelity experience to XR users. Currently, the integration of a dissected physics engine as an accompanying Network Application has enabled shared physics calculations among XR users, while also functioning as a relay synchronisation service.

UC 6.2: Lab tests were conducted in 2024, enabling real-life testing of the Network Application over 5G, identifying gaps, and evaluating its performance. The system achieved seamless video streaming and annotation with low latency and high bandwidth, ensuring reliable real-time performance.

UC 7: The UC is exploring how smart networks and services can enable future urban and rural citizen engagement services for public services and common good. The trials are under preparation, and the initial platform and application components and capabilities have been deployed.

fidal field trials beyond 5G

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Verticals concerned :
PPDR, MEDIA

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RESULTS

FIDAL has delivered a future-proof Evolved 5G facility for rapid prototyping and large-scale validation. Three testbed labs and three large-scale Beyond 5G trial infrastructures have been integrated with end-to-end Evolved 5G facilities, ensuring seamless pre-trial integration and validation of the PPDR and media vertical UCs: 7 internal UCs and up to 28 trials from Open Calls. The FIDAL zero-touch management framework, which operates towards 6G concepts, spans network, application, and security domains, complemented by a robust security framework. A key outcome is the capability to request and provision network services and applications, facilitated by open-source contributions.

The project has further defined and applied Key Value Indicators (KVIs) to capture societal and business dimensions while ensuring the system remains dependable, secure, and easily expandable to include new stakeholders.

Looking ahead, the FIDAL repository will host training sets and data models in the next phase, underpinned by a generic, standards-aligned security framework designed to address evolving needs and sustain partner accountability.

IMAGINE-B5G

Imagine-B5G is working to provide an advanced and accessible end-to-end (E2E) 5G platform for large-scale trials and pilots in Europe.

OVERVIEW

Imagine-B5G provides an advanced and accessible end-to-end (E2E) 5G platform for large-scale trials and pilots in four 5G experimental facilities in Norway, Spain, Portugal, and France.

These support testing and experimentation of core technologies and architectures, facilitating innovative services and businesses, and will become a key enabler for future B5G vertical services and applications.

These facilities will continue to on-board third parties (e.g., SMEs, industry, and researchers) during the project's lifetime and through Open Calls (OC) to collaborate in **vertical experiments (VE)** and **platform extensions (PE)**.

USE CASE/ SCENARIOS

The Imagine-B5G project has launched its Open Calls (OCs) to engage external stakeholders, including SMEs, research institutions, and industrial players and explore innovative use cases, and address challenges in areas like energy efficiency, network sustainability, and scalability. Selected participants gain access to Imagine-B5G's platforms, resources, and mentoring.

OCs organised by the IMAGINE-B5G are successful. In the second year of the project, IMAGINE-B5g has just launched its second OC, which, similarly to the first OC, was divided into two different types of projects – vertical experiments (VE) or platform extensions (PE). Its third OC is currently running and only features vertical experiments. The OC received 68 submissions and funded 15 projects that began in 2024. The third OC had 52 submissions and also funded 15 projects, which started in the first quarter of 2025.

For the OC 2, the 15 projects had the possibility of applying to the four different facilities.

Norway Facility:

- **5G-SEDAR**: 5G Sensor Platform-Enabled Dynamic AR assistance for enhanced manufacturing, a VE, by UN-REN Institute, to increase productivity, improve safety, reduce costs and minimise human errors.
- **FUSION**: A novel Framework for Unified Sensing, Insights, Observability and Networking, a PE, by the ICCS, to provide a holistic observability and analytics framework for fusing different signals coming from the operation of such distributed applications or network services.
- **SIMONE**: Evaluating immerSIve coMmunicatiOn for eNhanced remote Education, a VE, by Karlstad University and Softcode, to empirically characterise the performance of an immersive remote education service that can enhance teacher-student communication and dynamics through B5G networks and augmented/virtual reality (AR/VR) technologies.

Spain Facility:

- **5G-VirtuFix**: Immersive Maintenance from Miles Away, a VE, by INTELLIA ICT, to focus on transforming industrial maintenance and port operations through 5G, AR, and AI.
- **FI-Veg**: Phenology and Innovation for Vegetation, a VE, by ITACyL, to integrate 5G technology with real-time sensing and analysis systems in agriculture and enhance precision

Advanced 5G Open Platform for Large Scale Trials and Pilots across Europe

Coordinated by
David Gomez-Barquero, Universitat Politecnica de València

January 2023-December 2025

Website: https://imagineb5g.eu/

X: @B5gImagine

LinkedIn: www.linkedin.com/showcase/imagine-b5g

Verticals: Agriculture and forestry, education, eHealth, industry 4.0 , Media and Entertainment, PPDR, Transport and Logistics

Partners: Polytechnical University of Valencia, Telenor, Telefonica, Altice Labs, Nokia Finland and Spain, Capgemini, Samsung UK, Keysight, Ubiwhere, Airbus, Port of Valencia, Eurecom, Telecommunications Institute (IT-UA), Oslo University, South East Technological University and Athens University of Economics and Business.

and efficiency in crop monitoring and management.

- **OpenInfra**: An Open Infrastructure Portal for facilitating operations with Large Language Models (LLMs) enhancements, a PE, by the University of Patras, to integrate and enhance infrastructure operations, through a dedicated open-source standards-based portal, including LLM framework functionalities.
- **RESCUE-5G**: Leveraging 5G and Unmanned Surface Vehicles (USVs) for Enhanced Maritime Port Surveillance and Safety, a VE, by FAVIT and LEMVOS, to enhance maritime port safety and efficiency with USVs, AI-powered image and sonar data analysis, advanced 5G communications and an immersive decision support system.
- **VM4ACADEMIA**: Vologrames for Academia, a VE by Vologrames Ltd, to explore the innovative application of volumetric video and WebAR to bring immersive educational content closer to a wider audience.

Portugal Facility:

- **CogNetCare**: Advancing Population Cognitive Health with 5G, a VE, by Neuroinova, to revolutionise cognitive healthcare by leveraging advanced 5G capabilities to deliver accurate, remote cognitive and physical assessments for early detection and monitoring of cognitive impairments.
- **N-TourXP-5G**: Enhanced Touristic Experiences with 5G, a VE, by Nomad River, to provide dynamic customised content focusing on two main areas: Augmented Tourism Experiences and Automated, Personalised Tourist Services.
- **CHHA**: Connected Home for Healthy Ageing, a VE by IEETA, to develop a connected home environment for testing innovative services like a Distributed Gamified Virtual Gym and Radar-Based Activity Monitoring.
- **OPTIMITER**: Open and Programmable Telemetry for Disaggregated Monitoring of Energy and Resource Consumption in B5G Experiments and Research, a PE, by Nextworks, to design, implement and integrate a distributed and scalable monitoring platform for collection and exposure of metrics on resource and energy consumption in experimental facilities for 5G/B5G/6G networks.
- **Project CRITICAL**: 6G Enabled Integrated Care, a VE by RedZinc Services, to integrate real-time telemedicine services via the BlueEye platform, which enables the transmission of video and biometric data from paramedics in the field to hospital specialists.

France Facility:

- **FIRESCAN**: Forest Incident Response and Emergency Security Coordination And Networking, a VE by MidGard will optimise emergency response and situational awareness through 5G-enabled rapid data transmission and coordination, improving firefighting effort.
- **FOR-5G**: FORestGuardian: 5G-powered Forest Firefighting and Surveillance System, a VE, by Rinisoft, which aims to leverage 5G technology to enable direct communication between command centres, drones, and on-ground firefighting teams.

IMAGINE-B5G is currently closing most OC 1 projects while starting to work with OC 2 winners and choosing OC 3 winners. All news regarding results, the Open Call projects and the consortium can be found on our website and social media.

RESULTS

Through the project's second year, Imagine-B5G carried out the work with its first OC winners, initially presented in last year's journal, having shared each project's goals and desired results on the project website and social media networks. The project launched its second and third OCs, having started the work with the second OC winners.

Globally with the three OCs, 45 projects have been funded out of 199 submitted proposals.

TARGET-X

The TARGET-X project is accelerating the digital transformation of four key verticals: energy, construction, automotive, and manufacturing.

OVERVIEW

The TARGET-X project investigates 5G/6G and peripheral technologies across the entire value chain, including devices, connectivity, and service delivery. The aim is to identify, assess, and propose new features targeting connected industries. TARGET-X accelerates the digital transformation of four key sectors: energy, construction, automotive, and manufacturing. Large-scale trials and pilots across Europe demonstrate, validate, and evaluate the potential of 5G/6G in real-world environments. The testbeds are located across two sites: four at the 5G-Industry Campus Europe and one at IDIADA's automotive testing grounds in Spain. These facilities enable the evaluation of cutting-edge technologies. The project's assessment focuses on Key Performance Indicators and Key Value Indicators like sustainability, safety, security, and privacy; paving the way for business models and a framework for economic and social evaluation.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

TARGET-X analyses technology elements of the 5G technology towards 6G, such as Quality of Service (QoS) to manage the growing number of services and evaluates millimeter spectrum for industrial use and the applicability of 5G indoor positioning for industrial use. The Asset Administration Shell (AAS) models the different aspects of a 5G network. TARGET-X focuses on a real-time ecosystem, where the capabilities of 5G combined with Time Sensitive Networking and Deterministic Network (DetNet) are explored. The project provides financial support to third parties: the budget is allocated across two Open Calls, each addressing a variety of topics that outline challenges to be tackled by third parties.

INNOVATION

TARGET-X is developing a Methodological Assessment Framework using User Key Performance Indicator (UserKPI) and User Key Value Indicator (UserKVI) to quantify the value of use cases across different sectors. evaluating them from techno-economic and societal perspectives. The AAS is used as an enabler for vertical use cases and to realise automation through interoperability. It provides a standardised digital representation of assets, supporting Industry 4.0 interoperability. Combined with 5G networks and 5G-enabled devices, AAS allows flexible interaction between network and Information Technology (IT)/Operational Technology (OT) domains, promoting efficient resource use and intelligent manufacturing environments. In the automotive testbed, the focus is on predictive QoS for tele-operated driving. By utilising network data, the system predicts potential issues and alerts the driver in advance, enabling timely actions to avoid unnecessary stops and improve the driving experience, preventing disruptions caused by network performance issues.

USE CASE/ SCENARIOS

TARGET-X explores twelve use cases from four verticals on two sites offering unique testing possibilities.

Use Case	Description
Inline Quality Assurance for Machining	Focuses on real-time quality assurance in machining using a vibration sensor and 5G-Time Sensitive Network (5G-TSN) to analyse data for improved process stability and control.
Environmental Condition Monitoring	Develops a sensor platform for sustainability data collection in milling processes, enhancing insights for environmental footprint calculations.
Trace and Tracking of Workpieces	Enables end-to-end tracking of workpieces throughout production, facilitating optimisation of manufacturing processes.
Edge-Controlled Automation with Mobile Manipulation	Implements mobile robotics for assembly tasks, leveraging 5G for efficient communication, aiming to reduce execution time.
Energy Monitoring and Energy Consumption Awareness	Develops tools for high-resolution energy measurements to improve grid monitoring and identify potential malfunctions, enhancing energy management.
Cooperative Perception	Implements a safety feature in vehicles for collision avoidance through cooperative communication, enhancing situational awareness.
Digital Twin	Creates a digital representation of traffic scenarios to simulate and develop safety features for vehicles, improving operational reliability.
Predictive Quality of Service for Tele-operated Vehicles	Predicts network QoS to prevent vehicles from entering low coverage areas, enhancing operational reliability in tele-operated scenarios.
5G for Automation of Deconstruction Processes	Automates deconstruction tasks through collaboration between humans and robots, improving efficiency with 5G communication.
5G for Mixed Reality Supported Deconstruction Planning	Utilises mixed reality for enhanced planning and documentation of deconstruction tasks, improving operational efficiency.
5G for Energy Analytics	Creates energy consumption profiles for construction processes, providing insights for optimising energy use.
5G for Safety Assistant System	Develops a monitoring system using mobile robots to supervise safety zones on construction sites, enhancing worker safety.

Trial PlAtform foR 5G EvoluTion – Cross-Industry On Large Scale Identity card

Coordinated by Niels König, Fraunhofer Institute for Production Technology IPT

January 2023-June 2025

Website: https://target-x.eu

LinkedIn: www.linkedin.com/showcase/target-x/

Verticals: Automotive, Construction, Energy and Manufacturing

Partners: Fraunhofer Institute for Production Technology IPT, Ericsson Germany and Turkey, RWTH Aachen University, IDIADA Automotive Technology, Centre Construction Robotics, i2CAT, Marposs, FundingBox Accelerator, 5G Communications for Future Industry Verticals, Marposs Monitoring Solutions, Neutroon, Mitsubishi Electric, Fundingbox Communities, Qualcomm.

RESULTS

TARGET-X expects to:

- Enable future use cases through self-adapting communication networks.
- Be able to dynamically allocate communication and computation resources across IT/OT.
- Generate KPI and KVI from real business cases and provide a Methodological Assessment Framework.
- Identify requirements and recommendations for future mobile networks to facilitate the deployment of connected vehicles and related applications.

TRIALSNET

TrialsNet is deploying B5G large-scale trials over wide coverage areas and with the involvement of extended sets of real users targeting a holistic evaluation of the KPIs and KVIs of 6G applications in different domains, encompassing various network deployments and solutions.

OVERVIEW

TrialsNet focuses on improving technical, performance, and productivity aspects that strongly impact the move from 5G to 6G. The project has two main goals: identifying the limitations of current network technologies to define future requirements, and assessing how users accept new applications by involving different industry sectors. This will help strengthen and expand 5G and future network solutions. The main objectives can be summarised as follows: a) Trialling of 6G Applications, b) Enhance B5G networks to support 6G applications, c) Introduce societal benefits in different areas, thanks to 6G Apps, d) Large scale deployment of B5G Networks, e) Achieve Industrial Impact, f) Achieve Scientific and Standardisation Impact, and g) Create an ecosystem of verticals and technology providers in the trial sites and beyond.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

TrialsNet has established two distinct technological frameworks within its platform and network solutions: TrialsNet Baseline 5G Technology (Bs5G) as the initial project's infrastructures deployment and TrialsNet Advanced 5G Technology (A5G). The project is currently completing the A5G phase providing bleeding-edge network technology to support the project use cases. For instance, TrialsNet is deploying a fully millimetre wave standalone solution for the use cases in Spain and is supporting the use cases in Romania through the Zero Touch Management Service solution. Finally, TrialsNet also developed innovations that are specifically related to sustainability, improving metrics such as energy consumption, a fundamental objective when performing large scale trials.

INNOVATION

The underpinning architectural approach for the project is 5G-Advanced networks with the early realisation of 6G-like use cases and experiences. The project applies an innovation pipeline method tracking and maturing over 25 innovation candidates to a smaller list at the end of the project. With the addition of an Open Call cohort there is significant diversity in use cases (UCs) applications, locations and thus innovation. The value propositions of the innovations are assessed against the number of UCs that are enabled by the innovation as well as the Key Value Indicator (KVI) performance which ultimately aims to frame the potential for impact against the Sustainable Development Goals.

Trial of UC5 "Control Room in Metaverse". The shared Control Room with information and officers (left), and emergency field intervention (right).

Innovations are present across all 3 industrial sectors of interest to the project. Innovations are categorised into a) horizontal covering transversal aspects of B5G systems such as zero-touch management, B5G application framework, and Digital Twins for next-generation mobile networks, and b) vertical, related to specific UCs such as Artificial Intelligence mechanisms for diagnostic and resources efficiency, and automatic orchestration of slice resources to ensure the QoS in mobility).

USE CASE/ SCENARIOS

TrialsNet is implementing 13 innovative core use cases plus 24 others coming from the Open Call. They span across three key domains within Europe's urban ecosystems: a) Infrastructure, Transportation, Security, and Safety, b) eHealth and Emergency, and c) Culture, Tourism, and Entertainment. These use cases are tested over large coverage areas, engaging diverse sets of real users across four geographical clusters: Italy, Spain, Greece, and Romania, plus 12 different sites for the use cases of the Open Call. TrialsNet leverages advanced platform and network solutions, incorporating cutting-edge functionalities such as dynamic network slice management, End-to-End (E2E) orchestration, Network Function Virtualisation (NFV), Mobile Edge Computing (MEC), and Artificial Intelligence/Machine Learning-based methodologies. Additionally, sustainability and affordability are prioritised in both the design and operational phases of the project's solutions.

RESULTS

During the first phase of TrialsNet, the design and development of use-case applications, platform and network solutions, their integration and lab testing, and end-user engagement were successfully completed. The project also defined a proper Key Performance Indicators (KPIs) and KVIs evaluation framework and process to enable uniform and comparable data collection and analysis across trials.

Currently, the project is conducting an extensive trial campaign, including Open Call UCs, to gather data on network performance, user feedback, to validate the UC requirements. These activities aim to identify limitations of current network technologies, evaluates user acceptance, and helps shape the project's contributions to the 6G ecosystem.

Three trials have already been completed: UC 5 "Control Room in Metaverse", enabling agents collaborative real-time coordination during emergencies (see figure on the previous page); UC 12 "City Parks in Metaverse", offering an interactive adventure based on historic sites (see figure below); and Turin5Games, an Open Call use case allowing users to play popular video games on remote servers. These trials engaged hundreds of users, with measured KPIs and KVIs meeting expectations, confirming their success. The results also highlighted limitations to address in future developments and essential features for next-generation networks to ensure long-term adaptability.

Meanwhile, trials for UC 1 "Smart Crowd Monitoring" and UC 4 "Smart Traffic Management" are ongoing in Iasi, utilising 5G NonStandAlone (NSA) and 5G SA networks to measure KPIs under varying scenarios.

Trial of UC 12 "City Parks in Metaverse". A user (left) and Virtual Reality characters (right).

Trials Supported By Smart Networks Beyond 5G

Coordinated by
Silvia Provvedi, Ericsson

January 2023-December 2025

Website: www.trialsnet.eu

X: @trialsnet

LinkedIn : www.linkedin.com/company/trialsnet/

Verticals: Infrastructures, Transport, Security and Safety/eHealth and Emergency/Culture, Tourism and Entertainment

Partners: Ericsson Italy and Spain, Telecom Italia, Orange Romania, Nextworks, Wings ICT,Information & Communication Technologies IKE, University Carlos III of Madrid, Interuniversitais Micro-Electronica Centrum, Yerba Buena VR, CNIT, Telefonica ID, Italian Institute of Technology Foundation, Athens International Airport, Santa Anna School, PIIU, City of Torino, Gheorghe Asachi University of Iasi, Prosegur, Crossmedia, DAEM, CNR, Hellenic Institute of Transport, Real Wireless

COORDINATION AND SUPPORT ACTIONS (CSAs)

The project portfolio includes two Coordination and Support Actions focussed on internal operational aspects of the SNS Partnership as well as on establishing dialogues with EU initiatives (e.g., related partnerships, national initiatives, etc.) and promote SNS results and achievements at a global level while working towards the formation of global standards.

SNS ICE

The SNS ICE project provides the collaboration environment for dialogue amongst European and global stakeholders involved in the preparation of 6G smart networks and services.

OVERVIEW

The SNS ICE project serves as a coordination and support action initiative under the SNS JU, advancing Europe's vision for 6G networks on a global scale. It facilitates collaboration and knowledge exchange among European, Vertical and international stakeholders preparing for 6G smart networks and services. The project captures and analyses emerging technological trends and reports on B5G and 6G research and innovation (R&I) activities within the SNS community. Additionally, it disseminates the outcomes of SNS projects globally, creating a collaborative platform for dialogue and exchange. The work of SNS ICE aims to strengthen Europe's leadership in next-generation networks and to foster a unified approach to global 6G development.

PROJECT ACTIVITIES / HIGHLIGHTS / INNOVATION

The SNS ICE project has engaged in strategic activities to capture the latest innovations and discussions in B5G/6G development, analysing global and vertical landscapes while promoting the vision of SNS JU. Key highlights for 2024 include:

- **Alignment on EU stakeholder priorities for 6G Use Cases & common EU front in Standardisation**

  SNS ICE led efforts to unify European stakeholders (Industry, Academia, SMEs, SNS JU Projects, National Initiatives) on 6G Use Cases (UCs) prioritisation within standardisation bodies. Through multiple alignment meetings and feedback rounds, detailed UCs (families, requirements, KPIs) were defined. For the first time, EU stakeholders presented a unified front at a 3GPP SA1 Workshop in May 2024, significantly boosting European influence and impact on future 6G standards.

- **Vertical Engagement & Trends Analysis**

  Over the last two years, the SNS ICE project has actively engaged stakeholders from vertical sectors, associations, standardisation and regulatory bodies, aiming to understand the trends and the uptake of technology developed for the benefit of society. Memorandums of Understanding/Letters of Intent (MoUs/LoIs) fostered joint actions and events, including a 2024 questionnaire for vertical associations which helped refine the 2023 SNS ICE trend analysis[1]. The Vertical Engagement Tracker (VET)[2] tool developed in 2023 to systematically map and monitor SNS JU use cases, was updated with 247 use cases from 52 SNS JU projects, and allows to draw a comprehensive birds-eye view of the current state of the art of the SNS JU research landscape while identifying gaps and guiding future policy[3].

- **Global 6G Landscape Analysis & Worldwide Collaboration**

  SNS ICE has been instrumental in strengthening the SNS JU's position in global fora, through the organisation of more than 20 international events & conferences[4] in 2024, realising the commitments of the 8 MoUs that have been signed

Smart Networks and Services International and European Cooperation Ecosystem

Coordinated by
Kostas Trichias, 6G-IA

January 2023-March 2025

Website: smart-networks.europa.eu/csa-s/#SNS-ICE

X: @sns_ice

LinkedIn : www.linkedin.com/company/93155360/

Partners: 6G-IA, CTTC, TNO, Trust-IT/COMMpla, Telecom Italia, Nokia Solutions and Networks Germany, Eurescom, VASES

with International associations. Moreover, project partners further enhanced and updated the SNS ICE 6G global landscape survey[4] focusing on: i) envisioned / prioritised 6G enabled UCs, ii) key 6G enabling technologies (enablers) and iii) performance targets for the primary 6G Key Performance Indicators (KPIs). The extracted insights suggest that Europe's 6G roadmap is well aligned with global priorities, including key enablers like AI-native networks, energy efficiency, and integrated sensing.

- **EU Research Environment & National Initiatives**

SNS ICE further advanced collaborations with European National initiatives in 2024, analysing research priorities across nine EU initiatives and capturing stakeholders' views on 6G. The project also provided a thorough analysis of the EU cloud initiatives around Europe which has been highlighted as a key collaboration topic by almost all EU stakeholders[5].

RESULTS

The SNS ICE partners facilitated meaningful connections with the SNS and the global community and engaged in extensive outreach activities throughout 2023/24[3] to raise awareness about SNS JU activities and promote the results of the Phase 1 and 2 projects, in order to maximise the programme's impact. The figure below depicts SNS ICE's outreach in numbers, including:

- **Workshops/Webinars**:30+ focused workshops and/or webinars were (co)organised by SNS ICE
- **Event organisation/participation**: 45+ physical events in 13 different countries/locations worldwide were (co)organised with impactful efforts from SNS ICE partners in strategic conferences, symposia, workshops, etc.
- **Podcasts**: 20 podcast episodes have been published on the SNS ICE channels , offering valuable technical insights and engaging discussions with leading EU and global 6G experts.
- **Videos**: 23 videos have been produced and published on the project channels, providing summaries of key activities, expert interviews and insights from events.
- **Other Dissemination and Communication material**: A multitude of creative and engaging dissemination and communication material such as press-releases, newsletters, infographics, roll-ups, flyers, and social media posts were produced to spread critical information about SNS ICE and SNS JU activities.

SNS ICE outreach in numbers

1. SNS ICE Deliverable D3.2, Initial Trends Analysis in Vertical Sectors, January 2024, https://smart-networks.europa.eu/csa-s/#SNS-ICE

2. https://verticals-tracker.sns-ju.eu/

3. SNS ICE Deliverable D3.3 Updated Trends Analysis in Vertical Sectors, January 2025, https://smart-networks.europa.eu/csa-s/#SNS-ICE

4. SNS ICE Deliverable D4.3, Final Dissemination Communication and Exploitation Report, March 2025, https://smart-networks.europa.eu/csa-s/#SNS-ICE

5. SNS ICE Deliverable D1.2, Impact analysis and SNS promotional report 2.0, December 2024, https://smart-networks.europa.eu/csa-s/#SNS-ICE

6. SNS ICE Deliverable D2.2, Findings and Trends from European 6G R&I initiatives, December 2024, https://smart-networks.europa.eu/csa-s/#SNS-ICE

SNS OPS

The SNS OPS project is devoted to supporting the operations of the 6G Smart Networks and Services Joint Undertaking (SNS JU).

VISION/ KEY OBJECTIVES

The SNS OPS project is devoted to supporting the operations of the SNS JU. The planned work is to facilitate the activities of the European SNS Initiative. This includes:

- **Support for the Smart Networks Services (SNS)** institutionalised European partnership and the related programmatic organisation.
- **Organisation of the SNS as a coherent programme** with clear links to the 6G Infrastructure Association and the European Commission / the SNS JU Office.
- **Maximise output and exploitation of SNS project results** in key domains, e.g., standardisation and spectrum, through managed cooperation between projects.
- **Inter JU coordination and joint actions.**

APPROACH

The approach and structure of the SNS OPS project is designed around operating the SNS JU infrastructure and facilities while maintaining and taking over many European ICT research leadership activities from the 5G PPP to the 6G SNS JU. This builds on the achievements of the predecessor CSA 6GStart and aims at bringing the European momentum and leadership developed in 5G PPP into the new challenges of the SNS JU under Horizon Europe.

The project is divided into 5 core streams of work that maintain a continuous dialogue with each other, and with the peer CSA SNS ICE, to ensure that a clear picture of the progress of the SNS community is obtained and regularly fed back into the actions to improve the programme for each successive phase.

RESULTS

SNS OPS has in its second year continued to work on all 5 core streams of activities and achieved all planned results, even going beyond target KPIs.

In the **SNS assessment and planning stream**, a "monitoring and analysis framework" has been developed to track technological KPIs, societal KVIs, and other key work aspects targeted across SNS projects. Questionnaires were created for Call 1 and 2 projects. **New projects provided insights on positioning and plans, while Call 1 projects reported on first-year progress.** A thorough analysis of responses yielded valuable insights, published and presented in a webinar and further used e.g. in the SNS Work Programme generation process which SNS OPS partners have supported and made various contributions to. Findings indicate that all SNS Work Programme objectives are well matched by the projects, showing a healthy balance and complementarity among the projects.

In the second stream **SNS Outreach: Dissemination and Communication**, SNS OPS has reinforced the SNS brand and online efforts. The SNS JU website maintained by SNS OPS remains a central hub with strong community engagement. SNS outreach has

Supporting the SNS JU Operations

Coordinated by
Uwe Herzog, Eurescom

January 2023–March 2025

Website: https://smart-networks.europa.eu/csa-s/#SNS-OPS

Partners: Eurescom, 6G-IA, Nokia Solutions and Networks, Ericsson, Thalès France, Telenor, Orange, IDATE, Nokia Networks France, South East Technological University, Australo, Trust-IT/COMMpla Instituto de Telecomunicaçoes, Martel, University of Surrey.

expanded on LinkedIn and X, with a SNS JU Mastodon channel to reach out new audiences, demonstrating growing engagement.

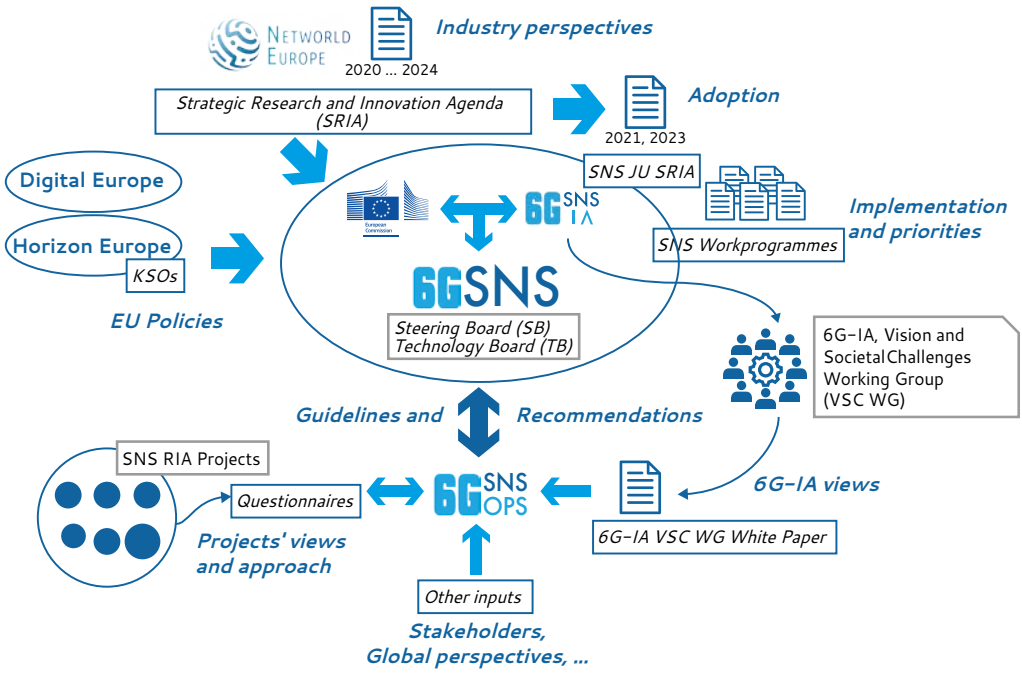
In the third stream **SNS programme organisation and orchestration**, SNS OPS supports the key SNS initiative bodies, including the Steering and Technology Boards, ensuring efficient project collaboration. With the adding of Call 2 projects, these Boards do now have 63 SNS project members, significantly increasing coordination efforts. SNS OPS also continued to manage the SNS Collaboration Agreement among SNS JU projects, integrating SNS Call 2 and Call 3 projects.

The fourth stream **Stakeholder Engagement and Working Group Support** focuses on global stakeholder involvement and interactions. To optimise the value and impact of the SNS JU programme, the strategy includes tailored activities for core groups of stakeholders, such as verticals and complementary domains, SMEs, Working Groups, and peer Partnerships, Initiatives and Associations. Several Events have been organised – e.g. for Digital Innovation Hubs, on Microelectronics and on Security –to assess SNS JU's impact and to gather feedback.

The fifth stream – **Events logistics and IT infrastructure** – ensures professional event preparation and IT support. Highlights include the EuCNC & 6G Summit 2024 and SNS Sessions at MWC 2024 and 2025. In terms of "IT infrastructure", SNS OPS has also taken care of the organisation, production and provision of the SNS JU working IT infrastructure, covering mail servers and repositories over the brokerage service to the SNS JU website at https://smart-networks.europa.eu.

SNS OPS will continue its activities on all streams until March 2025 when it will hand over them to the follow up CSA SNS CO-OP project.

SNS Vision and Programme process, stakeholders and reference documents



Call 2 Projects

The 28 SNS Call 2 projects started in January 2024 or March 2024 in three streams or sub-streams and one CSA.

Stream B

WIRELESS COMMUNICATION TECHNOLOGIES AND SIGNAL PROCESSING

The stream B covers research for revolutionary technology advancements, in preparation for 6G and revolutionary advancements for IoT, devices and software.
The stream targets low to medium Technology Readiness Level in WP2023, with the objective of delivering innovative solutions towards real life networks, in a long-term time-period.
It also includes targeted international cooperation with the USA centred on Artificial Intelligence.

The stream B is broken down into six sub-sections encompassing i)System Architecture (B1, 5 projects), ii)Wireless Communications Technologies and Signal Processing (B2, 6 projects), iii)Communication Infrastructure Technologies and Devices (B3, 4 projects), iv)Reliable Services and Smart Security (B4, 4 projects), v)Microelectronics-based solutions for 6G networks (B5, 3 projects), and vi)the EU-USA 6G R&I Cooperation (B6, 1 project).

Stream B1

SYSTEM ARCHITECTURE

The selected projects demonstrate complementarity and have been selected in such a way as to strengthen the structure of 6G networks for increased robustness, adaptability, and efficiency to cater for the expected extreme 6G use cases and their requirements.

6G-CLOUD

An initiative aimed at developing an AI-driven and cloud-compatible architecture for 6G networks.

OVERVIEW

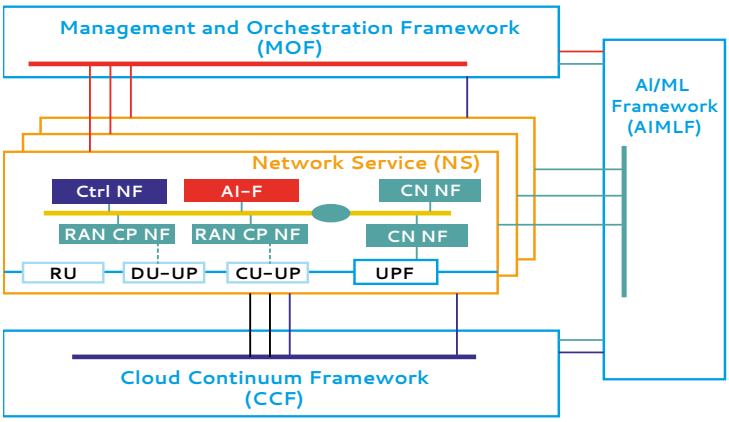
6G-Cloud aims to research, develop and test key technologies to achieve an AI-native and cloud-friendly 6G system architecture on top of the cloud continuum. It seeks to go far beyond the current 5G architecture design with disruptive, innovative approaches and solutions, providing the blueprint for the overall service-oriented 6G system architecture design, composed of basic network functionalities and multiple control and management frameworks over a multistakeholder cloud environment spanning from extreme edge to central clouds.

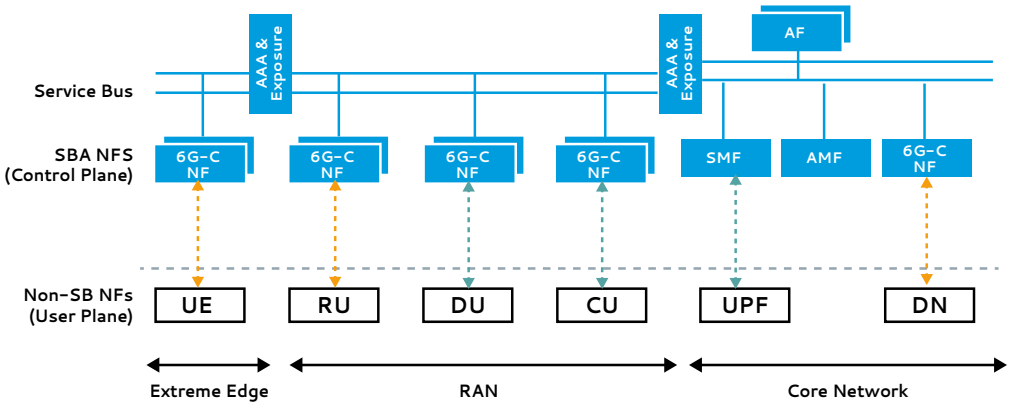
CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The 6G-Cloud architecture emphasises flexibility and dynamic deployment to adapt to varying connectivity needs, infrastructure resources, and optimisation goals. It enables novel network concepts through service-based Radio Access Networks (RAN), RAN-core Convergence, and enhanced service delivery, emphasising reduced latency, scalability, energy efficiency, and sustainability. The design integrates cloud-native principles with distributed, programmable control, ensuring seamless orchestration across hybrid environments. Native Artificial Intelligence (AI)/Machine Learning (ML) support enhances performance, cost-efficiency, and energy optimisation while managing the complexity of heterogeneous, multi-vendor networks. The Cloud Continuum concept underpins the architecture, enabling the dynamic allocation of compute/storage resources across public and private clouds.

6G-Cloud is working towards offering a divergent framework of multiple innovative technologies related to system architectures focused on flexible network service composition, native AI support, integration of

6G-Cloud management and infrastructure frameworks





SBA RAN design in 6G-Cloud

resources from multiple providers, extreme control programmability, and network digital twin. 6G-Cloud fully aligns with Europe's 6G vision to strengthen Europe's leadership on next-generation mobile network technologies and services.

6G-Cloud work was showcased in MWC 2024, Open RAN Summit 2024, and reflected in ten standard contributions.

INNOVATION

6G-Cloud addresses the following key innovations:

- Developing a comprehensive, AI-native service-oriented 6G system architecture on top of a cloud continuum.
- Creating AI-driven cloud continuum and management frameworks and business interfaces for a multistakeholder environment.
- Establishing an AI/ML framework for native-AI support in the 6G system.
- Enabling the 6G "network-of-networks" concept using service-oriented network design.

RESULTS

As two major results from the first year, 6G-Cloud has developed an orchestration framework and an initial service-based RAN architecture. The orchestration framework uses a separation-of-concern approach, splitting the system into frameworks that can be independently updated. The cloud continuum framework manages resources from multiple providers, enabling dynamic resource pooling for network services. The management and orchestration framework works with cloud continuum framework to manage cloud resources and network functions. The AI/ML framework monitors and orchestrates AI/ML-driven functions using a network digital twin to enhance decision-making. These frameworks offer a flexible, scalable, and intelligent base for 6G networks.

The service-based RAN architecture introduces a control fabric to enhance performance in disaggregated RAN. It integrates with Service-Based Architecture (SBA) in domains like 5G core and extreme edge, supporting end-to-end services with specific Quality of Service (QoS) needs. A logical message bus allows efficient communication between Network Functions (NF) and RAN apps. Non-SBA NFs, crucial for user data flows, remain outside the SBA to meet latency demands, while 6G-C NFs bridge non-SBA and SBA functions. These NFs translate SBA Application Programming Interfaces (APIs) into infrastructure commands and offer control endpoints for flexible configurations, such as network slicing. The architecture is adaptable for future 6G applications.

Service-oriented 6G network architecture for distributed, intelligent, and sustainable cloud-native communication systems

6G CLOUD

Coordinated by Tao Chen, VTT Technical Research Centre of Finland

January 2024 - June 2026

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Partners: Partners: VTT, Warsaw University of Technology, National Centre for Scientific Research "Demokritos", University of Murcia, Orange Poland, ATOS Spain, BULL, Thales Six GTS France, Lenovo, BubbleRAN, Ubiwhere, Four Dot Infinity, University of Bern

6G-INTENSE

Shaping the Future of 6G with Sustainable, AI-Powered Smart Services and Advanced Network-Compute Integration.

OVERVIEW

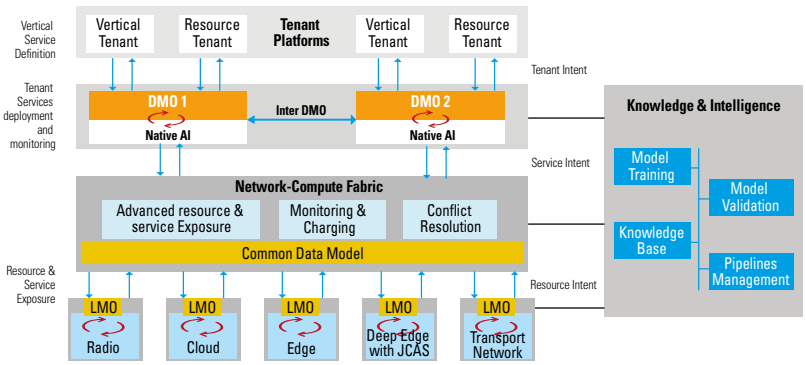
The 6G-INTENSE project aims to revolutionise future 6G networks through intent-driven Artificial Intelligence (AI) innovations and collaborative ecosystems. Its objectives include developing a distributed management and orchestration plane for reconciling multi-stakeholder intents, an abstraction framework for 6G network-compute fabric, and a scalable compute interconnection solution using Software Defined Wide Area Network (SD-WAN) for autonomous service mesh deployments. The project will also deliver the first AI-native toolkit and federated AI plane, supporting privacy-preserving joint communication and sensing at the edge, while maximising impact through extensive dissemination, exploitation, and standardisation activities.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The 6G-INTENSE project proposes a revolutionary system architecture to deliver the "6G as a Smart Service Execution Platform." Its Distributed Intent-driven Management and Orchestration (DIMO) framework integrates a Native AI toolkit for intent declaration, negotiation, and automation. As described in the figure, the architecture separates service and resource management via Domain Management Orchestrators (DMOs) and Local Management Orchestrators (LMOs), supported by a unified Network-Compute Fabric with a Common Data Model. Sensing enhances dependability at the Deep Edge, while scalable tenant management enables zero-touch orchestration. Programmable overlay networking via SD-WAN ensures efficient Compute Inter-Connection (CIC), advancing sustainable, collaborative infrastructure sharing.

INNOVATION

The new system architecture for the "6G as a Smart Service Execution Platform" ranks among main innovations. It is fully in line with the vision of sustainable infrastructure sharing to reduce space and energy



Architecture overview of 6G-INTENSE

costs and encouraging collaboration among all members of the value chain under a unified Network-Compute fabric. A key contribution is a novel automation architecture with a Native AI toolkit facilitating intent declaration, negotiation, and decision automation across autonomous domains, termed Distributed Intent-driven Management and Orchestration (DIMO).

The project also leverages sensing capabilities to bolster resilience and dependability at the Deep Edge. Additionally, it introduces a hierarchical tenant management layer, incorporating the concept of DMO to enable zero-touch service management.

A Native AI toolkit powers the cognitive intent lifecycle, utilising techniques like Large Language Models (LLM), reasoning functions, and Reinforcement Learning with Human Feedback (RLHF). The project also pioneers programmable overlay networking technologies for Compute Inter-Connection (CIC) via SD-WAN.

USE CASES/ SCENARIOS

Intent-driven NaTive AI architecturE supporting Network-Compute abstraction and Sensing at the Deep Edge

Coordinated by Coordinated by Christos Verikoukis (ISI/ATH)

January 2024 – December 2026

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Partners: ISI/ATH, EURECOM, L.M. Ericsson, Intracom, Orange Romania, OTE, Consiglio Nazionale delle Ricerche, Iquadrat, University of Oulu, eBOS, Realworld

The 6G-INTENSE project features two use cases (Proofs-of-Concept, PoCs) to demonstrate innovations. The first, Distributed Continuum for Pervasive Computing aims to validate the Abstraction Framework through deployment, model training, and integration with southbound Compute and Communication platforms. This includes two scenarios:

Pervasive Computing in a Distributed Continuum Scenario:

- Manage micro-service deployment as an Orchestration Continuum by the Network-Compute Fabric, after training its Generative AI models.
- Demonstrate Joint Communication and Sensing (JCS) of the Deep Edge infrastructure, such as monitoring links and performance.

Edge Intelligence and Compute Interconnection Scenario:

- Demonstrate SD-WAN usage for PoP interconnection and dynamic resource integration into the Network-Compute Fabric.
- Provide SLA guarantees through intent monitoring and use Edge intelligence for training distributed ML models.

The second use case focuses on the Metaverse, with two scenarios:

Joint Communication and Sensing for Optimal User Tracking:

- Demonstrate JCS functions for location awareness within the Metaverse and explore trade-offs between sensing accuracy and energy efficiency.

Fully Autonomous Metaverse Fault Configuration Accounting Performance Security (FACPS), Sensing, and Continuum Abstraction:

- Showcase how Native AI drives intent (re-)negotiation at the Tenant domain.
- Implement Orchestration Continuum at the Service domain and demonstrate adaptation based on Sensing inputs.

The use cases target Performance KPIs such as high-throughput, low latency connectivity, and reliable orchestration across distributed resources. Business KPIs focus on new business models, market disruption through native AI-driven service management, and SLA guarantees via automation.

RESULTS

6G requires scalable, distributed orchestration to manage diverse resources like clouds, edge networks, and IoT devices. Deliverable D2.1 outlines PoC scenarios, business KPIs, and technical specs, while D2.2 defines initial architecture requirements and zero-touch automation. 6G-INTENSE leverages DIMOs and the Network Compute Fabric with AI for Zero-Touch Service Management, enabling dynamic, intent-driven orchestration, ensuring high throughput, low latency, and massive IoT—boosting Europe's 6G leadership and Intellectual Property Rights generation.

6G-TWIN

AI-based architecture for the upcoming 6G network, focusing on using Network Digital Twins (NDTs) for real-time optimisation.

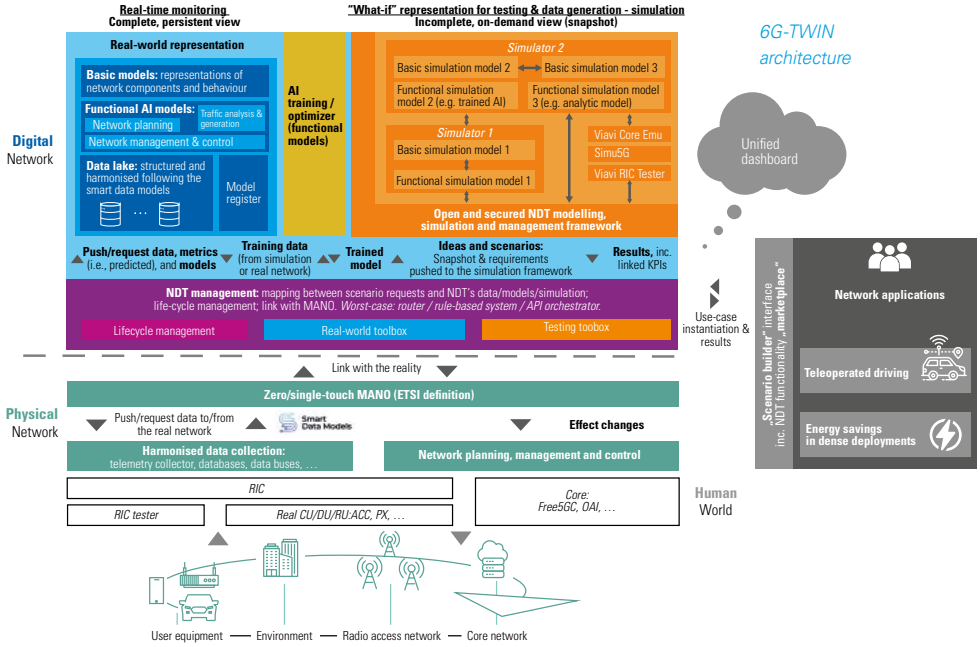
OVERVIEW

Networks are becoming increasingly complex and distributed, relying on a wide variety of technologies to operate effectively. With 6G expected around 2030, it is crucial to design, experiment with, and standardise network architectures that embed greater intelligence and automation. In this context, Network Digital Twin (NDT) is emerging as an essential concept for predicting, testing, and refining network scenarios before deployment, as well as supporting real-time adaptability during operation.

6G-TWIN establishes the foundation for the design, implementation and validation of an AI-native reference architecture for 6G systems that incorporates NDT as a core mechanism for the end-to-end, real-time optimisation, management and control of highly dynamic and complex network scenarios.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

6G-TWIN develops methods, modelling, and simulation solutions for designing, creating, and managing multi-layered virtual representations of future 6G systems. These representations incorporate heterogeneous domains (e.g., edge, fog, and cloud) and diverse communication technologies (e.g., cellular, optical, and non-terrestrial networks). The



project's functional architecture, illustrated above, combines key components, including real-time data collection from the physical network, NDT data and model management, AI training, and an on-demand simulation framework. These elements are orchestrated through a unified management layer that ensures seamless integration, lifecycle management, and feedback loops between real-world operations and simulation-driven insights.

INNOVATION

The 6G-TWIN NDT framework introduces a multi-layered architecture bridging real-world network operations with predictive and simulation-driven decision-making. In this context, a key innovation is the formalisation of the NDT concept: while digital twin is increasingly applied across various sectors, this project establishes a structured, AI-native framework specifically for 6G networks, ensuring clarity, scalability, and scientific rigour in its implementation. This NDT provides a dynamic and controlled environment to test and optimise network scenarios. This approach accelerates the development of intelligent, scalable, and cost-effective systems, setting a new standard for NDT use in 6G.

USE CASES/ SCENARIOS

The project's solutions will be validated through two use cases (UCs) tackling mobility and energy-efficiency challenges:

- Teleoperated driving: predictive NDT solutions will anticipate network behaviour before a vehicle's departure, ensuring extreme quality of service and resource availability throughout its journey.
- Energy savings: reactive NDT solutions will optimise end-to-end network energy efficiency in real time.

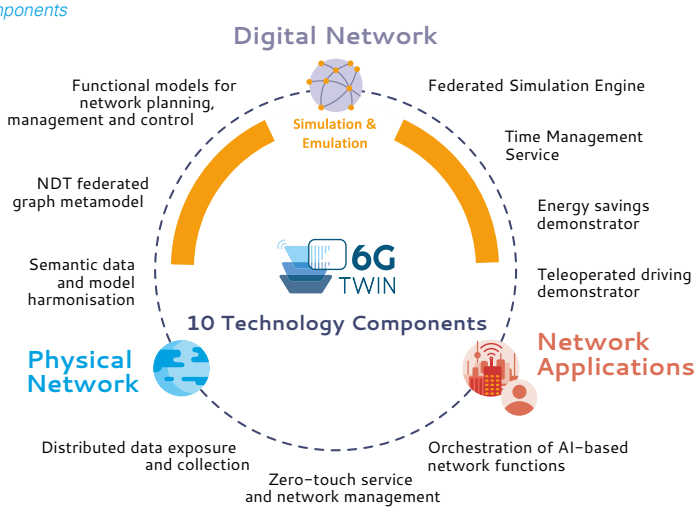
Both UCs will leverage low-TRL, lab-scale demonstrators and open approaches (e.g., O-RAN) to maximise the project's impact.

RESULTS

The project will deliver a total of ten technology components, including:

- An AI-native network reference architecture that integrates multiple NDTs.
- On-the-fly AI approaches for orchestrating network functions (NF) and services (NS).
- Functional models to optimise network performance.
- An open modelling and simulation framework.

6G-TWIN's technology components



Integrating Network Digital Twinning into Future AI-based 6G Systems

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Partners: LIST, IMEC, Polytechnical University of Bari, Technical University of Dresden, Bourgogne University, Accelleran, Ericsson, Proximus NXT, R2M Solution, Ubiwhere, VIAVI Solutions.

EXIGENCE

Devise & explore a novel approach for energy consumption and carbon footprint reduction of ICT services in the era of next-generation mobile telecommunications (6G).

OVERVIEW

EXIGENCE aims to create a novel approach for reducing energy consumption and carbon footprints in ICT services in the 6G era. This approach focuses on ICT service layer energy consumption, measurement, analysis, and optimisation, explicitly involving service users into the overall reduction task. Cross-domain exchange of energy information (or ecodata) raises new standardisation requirements in 3GPP, ETSI, IETF, and other Standard Development Organisations. By addressing energy consumption across multiple domains, EXIGENCE seeks to provide a scalable, future-proof solution for sustainable ICT operations. The project envisions a future where energy information awareness of both users and providers is integral to the design and operation of next-generation telecom infrastructures.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The project aims to enhance ICT service exchanges by incorporating corresponding ecodata exchanges and leveraging this ecodata to optimise each domain within the service delivery pathway. EXIGENCE introduces the Measure, Optimise, Incentivise (MOI) concept and follows the Service Function Chain (SFC) model. The architecture represents each subservice domain (technology or administrative) with an agent capable of collecting and exposing ecodata for each service session. These agents are equipped with inter-domain eco-data exchange capabilities, defining reference points for agent-to-agent communication, including metrics, service descriptors, and optimisation hints. Interfaces for these reference points and agents will be showcased in testbeds. The agent integration into domains imposes new requirements, such as 3GPP's need to measure session-level energy consumption.

INNOVATION

The project has contributed to standardisation with a focus on energy consumption (EC) and carbon emissions (CO_2e), emphasising the need for mobile networks to collect EC and CO_2e data linked to subscribers in charging information and support energy-efficient, carbon-aware content downloads (3GPP TR 22.883, Sections 5.3 and 5.8). Key contributions include use cases on EC and CO_2e transparency, carbon emission charging, energy-efficient content download, energy-aware Network Function (NF) selection, EC-aware slice admission control, network optimisation for energy saving, and EC Exposure and Control in the Mobile Core Network, all submitted to 3GPP SA1 and SA2. The project also created a new work item in ETSI ISG to study energy consumption data sharing using a permissioned distributed ledger and an IETF draft on intent for energy-aware services. Innovations include extending the qMON suite to monitor energy consumption and developing a green orchestrator to optimise load distribution and energy reduction. EXIGENCE is also exploring carbon markets by leveraging ecodata exposure and developing related use cases for submission to 3GPP SA1.

USE CASES/ SCENARIOS

EXIGENCE identified fourteen use cases (UCs), all based on an end-to-end approach, from which requirements were derived. Of the 14 use cases, here are six:

- **UC 1: Media Streaming Carbon Footprint Transparency**, proposes including metrics like "Instant Carbon Footprint" and "Total Daily CO_2" during video streaming services. This relies on energy measurements and interoperability across different domains in the end-to-end chain.
- **UC 2: Digital Sobriety**, builds on UC1 by applying carbon footprint measurements to help users take actionable steps to reduce their environmental impact.
- **UC 4: Behavioural Incentive for Digital Sobriety**, extends UC2 by focusing on non-economic incentives to motivate users to lower their carbon footprint effectively.
- **UC 9: Physical Security**, involves Artificial Intelligence (AI)-backed surveillance cameras connected over private 5G/6G networks. These cameras are designed to detect emergency situations while minimising energy consumption without sacrificing service quality.
- **UC 10: Carbon-aware AI Service Provisioning and Control**, involves distributing and constructing AI models over various computational and energy resources. This UC introduces new architectural entities, interfaces, and service scheduling mechanisms to enable AI services over renewable energy resources, helping to lower their carbon footprint.
- **UC 14: Green Network Orchestration in the Edge**, enables third parties to request ecodata predictions for specific processing loads at edge locations. This allows tasks to be scheduled on "greener" locations to optimise energy use.

These UCs are integral to the project's goal of promoting sustainability through innovative, energy-aware solutions across various domains.

RESULTS

EXIGENCE integrates energy consumption reduction as a core principle, ensuring that the ecological impact of the consumed ICT services is a central consideration for all stakeholders and fosters the creation of green service composition, where net energy expenditure and CO_2e become key factors in decision-making alongside traditional Service Level Agreement-based approaches. In essence, the project develops live eco-labels for ICT services, domain-specific resource management mechanisms, and supports user involvement by defining user incentives to reduce energy and CO_2e impacts during service invocation. EXIGENCE's outcomes aim to verifiably reduce energy consumption and carbon footprints, particularly in the context of 6G, where energy-efficient domain orchestration is essential yet probably insufficient. EXIGENCE promotes sustainable ICT service usage, contributing to the development of greener and more resource-efficient ICT ecosystems. It ensures that future generations of mobile systems foster innovation while maintaining environmental responsibility.

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January 2024 – June 2026

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Partners: F6S Network Ireland, Telefonica ID, Instituto de Telecomunicaoes; National and Kapodistrian University of Athens, TNO, Internet Institute, Atos Spain, Huawei technologies Germany, Athens University of Economics and Business – Research Centre, Detecon International.

ORIGAMI

ORIGAMI aims at advancing the architectural models of next-generation mobile networks by exploring Global Service-Based Architecture, Zero-Trust Exposure Layer and Compute Continuum Layer.

OVERVIEW

ORIGAMI ORIGAMI aims to advance mobile network technology by enhancing current 5G architectures, thereby setting the stage for 6G. When the 5G architectural model is severely lacking at both extremes: it has outdated support for global operations among network infrastructure providers and restricts the full potential of virtualisation and programmability in the underlying physical infrastructure. If not addressed, these architectural deficiencies will impose clear limitations on 6G system operations. The main goal of ORIGAMI is to develop a novel cross-plane architecture for 6G networks, which removes practical barriers towards 6G, enables sustainable and energy-efficient systems, and promotes new disruptive business models.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

ORIGAMI aims at achieving this goal by designing:

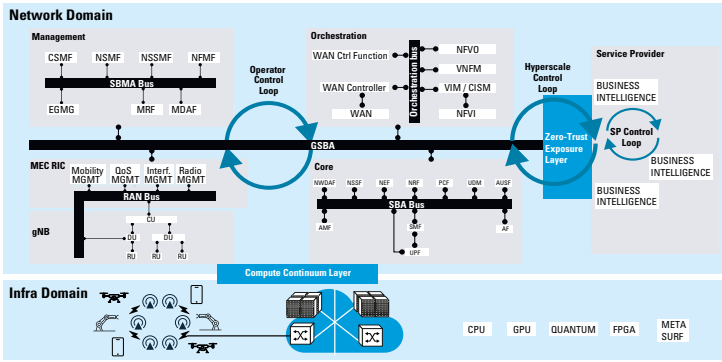
- Global Service-Based Architecture (GSBA) model that fosters inter-operability across data, control, management, orchestration, and Network Intelligence (NI) planes,
- Zero-Trust exposure Layer (ZTL) that supports unprecedented levels of network customisation driven by verticals that include other Mobile Network Operators,
- Compute Continuum Layer (CCL) that unlocks streamlined control over virtualised functions at very fast timescales.

These enablers enhance the network architecture beyond the current 5G SBA. On top of such innovations illustrated in the figure next page, ORIGAMI will develop novel, tangible, verifiable, and measurable NI solutions and digital services that will demonstrate the viability of its vision in realistic use cases.

INNOVATION

ORIGAMI aims to collaboratively design and develop innovative network architectural extensions that ensure synergistic operation, address challenges, and utilise them by specific NI algorithms that capitalise on the newly created closed loops. On the one hand, ORIGAMI's **Operator Control Loop** extends existing domain-specific control loops, like those in the RAN or core domain, to achieve a holistic network view. The GSBA unifies these domains, allowing intelligent algorithms to cooperate under Network Operator policies. This enables operations like global RAN resource orchestration, which standard 5G architecture can't support due to the need for tight interdomain coordination. On the other hand, the ZTL introduces the **Hyperscale Control Loop**, enhancing service providers and network operators' collaboration. This enables a broader range of network capabilities and service customisation, allowing operators to offer services and monetisation models like those of SaaS companies. To effectively enable this vision, several NI functionalities and services will exploit these closed loops on top of ORIGAMI's architectural innovations.

The ORIGAMI architecture innovations enables next-generation global services and NI functionalities



USE CASES/ SCENARIOS

ORIGAMI addresses technological barriers through these use cases:

Data-driven task offloading for reliable vRAN acceleration. Addressing Barrier 1 (Unsustainable RAN virtualisation), ORIGAMI proposes a vRAN approach, focusing on resource pooling and opportunistic offloading.

Enhancing management, stability, and security in 6G architecture. ORIGAMI targets advanced Machine Learning (ML) models for network management in Open RAN architectures, addressing Barrier 2 (Poor interoperability of RAN components).

Integration of novel compute paradigms and robust NI. ORIGAMI develops an NI toolbox for 6G, focusing on Quantum computing-aided optimisation, scalable, and hybrid learning approaches to address Barrier 3 (High latency and unreliable NI).

Effective, distributed, and streamlined access to u-plane computing. Addressing Barrier 4 (Underutilised modern programmable transport), ORIGAMI proposes integrating ML models into u-plane programmable hardware, developing distributed solutions for heterogeneous user planes, and streamlining user-plane intelligence development and deployment.

Enabling global operator model. ORIGAMI leverages Distributed Ledger Technology for dynamic partnerships in the ecosystem, proposing a blockchain solution for direct interaction among mobile operators, tackling Barriers 5 (Lack of global service APIs) and 6 (Obsolete trust model hinders performance).

Anomaly detection. ORIGAMI integrates real-time anomaly detection functionalities addressing Barrier 7 (Inadequate networking data representation).

Network Core traffic analysis and optimisation. ORIGAMI aims to reduce Barrier 8 (high volume of control plane signalling) through SCP-enabled 6G network core, using ML for traffic optimisation.

Optimised Resource Integration and Global Architecture for Mobile Infrastructure for 6G

ORIGAMI

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January 2024 – December 2026

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Verticals: ORIGAMI provides horizontal solutions and innovations to all verticals but will realise implementation in the IoT vertical.

Partners: Telefonica ID, NEC Laboratories Europe, Telecom Italia, EMnify, Fogus Innovations & Services, Cumucore, ISRD, NET AI TECH, University Carlos III of Madrid, IMDEA, i2CAT, Technical University of Delft.

RESULTS

In its first year, ORIGAMI made strong progress in developing a new cross-plane architecture for 6G, including key components like GSBA, ZTL, and CCL. These aim to overcome limitations in 5G and support the transition to 6G. Major achievements include creating infrastructure-aware virtualised RAN functions, improving open RAN interoperability, and using advanced computing methods for low latency network processing.

CloudRIC, an intelligent abstraction layer that forms the basis for ORIGAMI's CCL, aims to be a ground breaking architectural component for 6G systems that tailors network operations to the underlying infrastructure, supports diverse computing resources, and preserves virtualisation layer abstractions. These achievements directly contribute to the project's goals of enabling energy- and cost-efficient utilisation of radio, networking, and computing resources while also supporting the global deployment of services with performance guarantees. ORIGAMI also made strides in decoupling authentication and billing from connectivity, ensuring reliable global operations through new global data exposure and representation.

Stream B2

WIRELESS COMMUNICATION TECHNOLOGIES AND SIGNAL PROCESSING

The selected projects explore advances such as novel 6G RAN technologies and integrated communication–sensing paradigms.

6G-DISAC

The 6G-DISAC project is aimed at realising Integrated Sensing and Communication (ISAC), surpassing typical standalone scenarios.

OVERVIEW

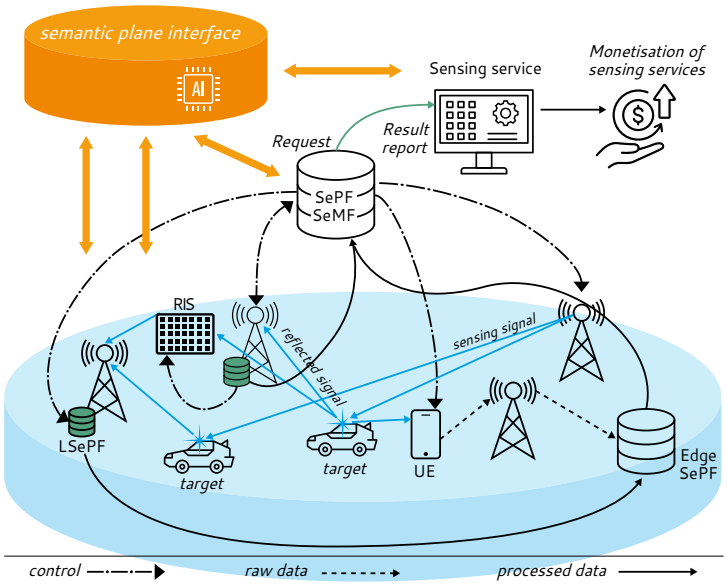
Integrated Sensing And Communications (ISAC) is a key and transformative feature of next-generation wireless systems, enabling 6G networks to not only communicate but also sense the environment, localise, and track users and objects. The 6G-DISAC project advances ISAC by developing a distributed, intelligent framework for 6G networks. It combines energy-efficient, large-scale sensing with a semantic processing approach, focusing on precise tracking, optimised resource usage, and the seamless integration of diverse sensors to address scalability, and intelligent data analysis challenges.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The 6G-DISAC architecture integrates distributed sensing with a semantic framework for efficient signal processing and resource allocation while enabling technologies and methodologies such as Reconfigurable Intelligent Surfaces (RISs), semantic waveforms, tracking and handover of passive targets.

Sensing Management Function (SeMF) is the central entity in charge of the management and control functions related to sensing. Sensing Processing Function (SePF) provides the distributed processing capability and also multi-node fusion at the core.

6G-DISAC architecture



INNOVATION

Significant technological advancements include: i) Distributed Sensing and Processing: Combines data from multiple nodes and heterogeneous sensors for high-resolution object detection and tracking; ii) Semantic and Goal-Oriented Approach: Incorporates AI/ML for efficient signal processing, adaptive waveform design, and resource allocation tailored to application needs iii) Physical Layer Enhancements: Leverages distributed MIMO, RISs, and EXtremely Large Multiple Input Multiple Output (XL-MIMO) for high-resolution sensing and efficient communication iv) Resource-Efficient Operations: Intelligent allocation of bandwidth, power, and computing resources using semantic reasoning via the introduction of local SePF, which plays a key role in decentralisation, ensuring efficiency and reducing bottlenecks. v) Advanced Signal Processing: Includes context-aware sensing and semantic fusion to process multi-modal data, enabling robust, dynamic network operation.

USE CASES/ SCENARIOS

The 6G-DISAC has identified use cases based on three criteria: DISAC benefit, business potential, and demonstration potential in precise localisation, detection, identification with high reliability, robustness, and resilience.

- **UC 1: DISAC for Smart Factory Shop Floors**

  Motivation: Enhance Automatic Guided Vehicles (AGVs) operational capabilities using 6G technology for communication and high-resolution sensing.

  Implementation: AGVs communicate with a base station and sense surroundings, managed by a network controller.

  Dynamic Scenario: AGVs navigate safely around humans, requiring real-time sensing and low latency communication.

- **UC 2: Vulnerable Road User (VRU) Protection at a Smart Intersection**

  Motivation: Enhance traffic management and VRU safety at intersections using DISAC, 6G, IoT, and AI.

  Implementation: Integrates IoT sensors, 6G network, traffic control centre, and connected vehicles/ smartphones.

  Dynamic Scenario: Ensures VRU safety while maintaining traffic flow with real-time sensing and low latency communication.

RESULTS

Technical outcomes include methods for enhanced spatial-temporal resolution, energy efficiency, and multi-modal learning. New transmission schemes are provided for collection of distributed sensing data and optimised adaptive waveform shaping simultaneous operations. Several results have been provided on receiver-side processing regarding these operations that differ on synchronisation, channels and devices. Scenarios including dynamic handover management, full-duplex communication, beamforming and beam tracking have been investigated, along the trade-offs between sensing and communication at physical layer level.

Cooperative sensing schemes are implemented for both active and passive users, addressing the management of computational, communication, and computational resources. The semantic framework reduces communication overhead and resource consumption by focusing on context-relevant information. Novel protocols enable distributed sensing operations with minimal control overhead, while accommodating for the heterogeneous devices.

6G for Distributed Intelligent Sensing and Communication

6G DISAC

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January 2024 - December 2026

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6G-GOALS

6G-GOALS marks a leap towards intelligent and goal-oriented communication, integrating AI to revolutionise network design and data transmission.

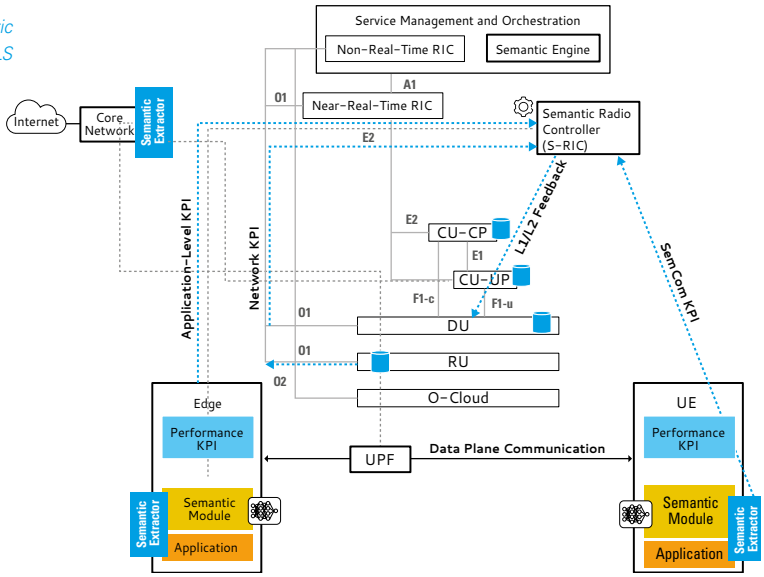
OVERVIEW

The 6G-GOALS project focuses on semantic and goal-driven communication, leveraging AI-powered architectures, protocols, and services, aiming to embed this intelligence directly into network design.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

A key outcome of the project is the development of innovative Radio Access Network (RAN) solutions that incorporate multi-band operations and advanced sensing techniques. Semantic-awareness connects the RAN with various network domains, forming the foundation of the 6G-GOALS architecture and driving the transition toward an AI-native, programmable, and knowledge-driven design. The project introduces intelligent network functions, including the Semantic Engine (SE) and the Semantic Radio Intelligent Controller (S-RIC) bridging existing Open RAN technology with semantic-enhanced and distributed and radio units. In the 6G-GOALS SemCom-enabled O-RAN architecture n (figure below), the S-RIC is envisioned as an advanced extension of the RAN Intelligent Controller concept within the Open RAN framework. This goes beyond raw data exchange by interpreting data meaning to enhance network management and orchestration, enabling semantic awareness across L1/L2 layers and at the application level. To ensure efficient operation, key semantic management loops are designed to handle performance monitoring, resource orchestration, model lifecycle management, knowledge base handling, and energy efficiency.

Goal-oriented and semantic Open RAN of 6G-GOALS



INNOVATION

The 6G-GOALS framework revolutionises communication by leveraging AI-driven semantic technologies to enhance efficiency, adaptability, and sustainability in 6G systems. The main pillars are in semantic data representation, timing-aware communication, and sustainable network management to overcome the limitations of traditional systems. Key innovations include AI-powered methods for efficient data acquisition, compression, and joint source-channel coding, minimising transmission needs while optimising performance. Timing-aware communication enhances distributed reasoning through advanced metrics, domain adaptation, and causal learning to ensure timely and accurate data exchange. Sustainability is addressed via semantic-driven Radio Access Networks, integrating energy-efficient resource management and real-time AI-powered control mechanisms within Open RAN architectures. These advancements position 6G-GOALS as a transformative framework for smarter, more efficient, and sustainable next-generation networks.

USE CASES/ SCENARIOS

The 6G-GOALS approach integrating semantic, goal-oriented communication with cutting-edge advancements in AI and ML, has been applied across various use cases, including robotic teleoperation, autonomous driving, collaborative robotics, and core network management. In robotic teleoperation, semantic communication ensures the efficient transmission of critical data, such as sensor readings and video feeds, enabling real-time decision-making. For autonomous vehicles, the use of semantic networks enhances Vehicle-to-Everything communication, improving vehicle safety by enabling accurate prediction of potential hazards. Edge inference systems leverage this approach to process data locally, minimising latency while preserving the semantic integrity of transmitted information. Additionally, digital twins optimise network performance by simulating the impact of system changes using semantic data, while the Semantic State Representation Function (SSRF) adapts core network operations, enhancing resource management.

RESULTS

The 6G-GOALS project has validated several key UCs through simulations and experiments, demonstrating performance improvements. The simulation of deep joint source and channel coding (DeepJSCC) for image transmission in MIMO and Rayleigh fading channels highlighted efficient multiplexing and error resilience. Edge image classification using adaptive token selection outperformed JPEG compression in low Signal-to-Noise Ratio conditions. Goal-aware neural network splitting at the edge resulted in relevant energy saving with minimal accuracy loss compared to full offloading. Experiments with the SSRF in the core network achieved satisfying accuracy in adapting network operations. IoT simulations leveraging Low Power and Wide Access mode demonstrated improved energy efficiency, supporting relevant image transmissions in challenging network conditions. Finally, demonstrations include hardware implementations of semantic-aware systems for efficient wireless model transmission and cooperative robotics that optimise operations using semantic communication. 6G seeks to bridge the digital divide by providing universal, high-speed internet access, while ensuring networks to remain resilient and adaptable to disruptions. In essence, 6G is foundational to the 6G-GOALS project for advancing communication technology, ensuring high performance, sustainability, and widespread connectivity.

Oriented Ai-Enabled Learning And Semantic Communication Networks

Coordinated by Emilio Calvanese-Strinati, CEA-Leti

January 2024 - December 2026

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Partners: CEA-Leti, CNIT, NEC, TOSHIBA, University of Aalborg, Eurecom, Imperial College London, TIM, HPE, HPE IT, University of Singapore

6G-MUSICAL

6G-MUSICAL explores innovative approaches for tightly integrating communication and radio-sensing, paving the way for a paradigm shift towards a perceptive network.

OVERVIEW

6G-MUSICAL integrates radio sensing, communication technologies and localisation solutions to pioneer new Radio Frequency communication paradigms advancing beyond 5G and 6G capabilities. The project is structured around several objectives to meet societal and industrial needs with enhanced reliability, sustainability, and performance, including:

- Defining the network architecture, with physical and logical network architecture and framework that combines communication and radio sensing networks, incorporating both connected and unconnected devices
- Defining the essential space-time-frequency localisation and latency and analysing the effectiveness of these waveforms
- Designing and developing stable reference sources of clock and RF/mm-Wave frequencies, cooperative MIMO (multiple input, multiple output) multi-static sensing algorithms
- Developing dynamic resource allocation schemes
- Developing UCs and conduct appropriate experimentation

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The 6G-MUSICAL project integrates communication and sensing to shape future 6G networks. Its architecture equips edge nodes with RF/radar-based sensing elements that work alongside communication components, enabling precise localisation, object tracking, and 3D imaging. Innovations like RIS, JC&S, THz frequencies, and AI-driven network management enhance reliability, low latency, and energy efficiency. This flexible, scalable approach supports diverse UCs while advancing green and digital transformation goals.

INNOVATION

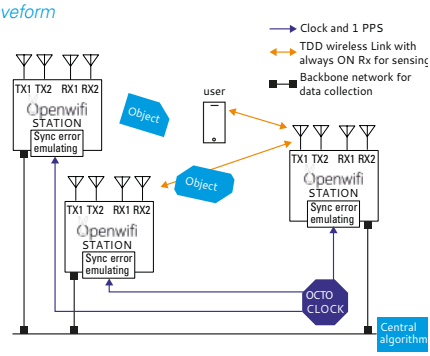
6G-MUSICAL aligns with EC programs, advancing integrated communication and sensing in 6G networks. As a pre-standardisation project, it benefits from ongoing projects. Key technologies include: i) **Joint Communication and Sensing (JC&S)**: enhancing performance, enabling context-aware services, and optimising resources. ii) **Dynamic Spectrum Management**: AI-driven spectrum allocation and interference control for seamless connectivity. iii) **Reconfigurable Intelligent Surfaces (RIS)**: Improving signal quality and coverage, especially in challenging environments. iv) **Energy-Efficient Design**: optimised hardware/software solutions to reduce power consumption for sustainable networks. v) **Advanced Localisation**: high-precision positioning for industrial automation, logistics, and smart mobility.

USE CASES/ SCENARIOS

- **UC 1: "Cooperative communication and multi-static sensing based on OFDM waveform"**

This scenario aims to show Integrated Sensing and Communication (ISAC) in a cell-free wireless network context with a Wi-Fi Orthogonal Frequency-Division Multiplexing (OFDM) waveform. One Wi-Fi station communicates with user equipment running some local/ internet traffic. Two stations (could be the receiver of the same station involved in the communication or a new station) decode the reflections from the transmission and generate range-Doppler maps combined to create a multi-static view of the environment, the typical setup of this Proof-of-Concept (PoC), as illustrated below.

PoC typical setup for ISAC in a cell-free wireless network context with Wi-Fi OFDM waveform



- **UC 2: "Generation and Robust Distribution of References to Synchronise Network"**

The work will include experimental testing of all the subsystems of the data and clock distribution to the Remote ISAC transceivers depicted, including the Master Optical Clock, the multichannel TRx and Rx transceivers designed and structured as Photonic Integrated Circuits and the Remote ISAC transceivers. The synchronisation and data transmission of point-to-multipoint ISAC signals will be experimentally tested. The Lab will experimentally emulate a massive MIMO edge network with more than 1000 edges.

- **UC 3: "Integrated Communication and Sensing with Planar Phased Array Antennas"**

This scenario will test the communication between a commercial base station and a mobile user (end terminal, vehicle, or drone) using the planar phased array antenna designed by FRH with eBOS testbed facilities. The PoC will be able to localise, track the user, and transmit the information. The figure below illustrates a potential scenario (sensing and transmission simultaneously).

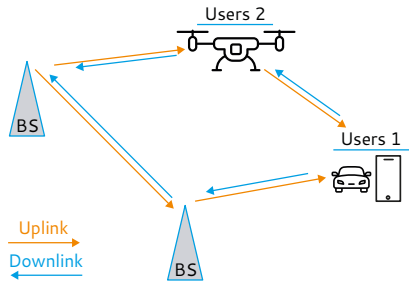
RESULTS

The final phase of 6G-MUSICAL focuses on iterative Proofs-of-Concept for three key use cases in industrial and societal domains, tested in controlled labs to validate capabilities and reach TRL4.

Expected outcomes include: i) **Reliability**: ultra-reliable communications with under 1 millisecond and 99.9% availability. ii) **Energy Efficiency**: up to a 30% lower energy consumption than 5G. iii) **Throughput**: data rates exceeding 10 Gb/s. iv)Scalability: flexible architecture for diverse applications. iv) **Interoperability**: seamless integration with existing systems. v) **User-Centric Design**: enhanced quality of service for reliability, accessibility, and energy savings.

6G-MUSICAL aims to drive industrial innovation, societal progress, and sustainability, enabling applications like precision manufacturing, smart healthcare, and urban development through AI-driven network management and advanced sensing. It also supports Europe's digital and green transitions, fostering growth, bridging digital divides, and enhancing global competitiveness.

PoC3 scenario illustration



6G MUltiband Wireless and Optical Signalling for Integrated CommunicAtions, Sensing and Localisation

6G-MUSICAL

Coordinated by Atílio Gameiro, Instituto de Telecomunicações

January 2024 – December 2026

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6G-SENSES

6G-SENSES proposes Cell-Free Massive MIMO and Integrated Communication and Sensing for advanced 6G connectivity.

OVERVIEW

6G-SENSES designs and develops a next generation RAN infrastructure that aims to achieve advanced performance towards the IMT-2030 and to progress the Integrated Sensing and Communication (ISAC) paradigm towards fully perceptive networks. To this end, research is focused on integrating Cell-Free massive Multiple-Input Multiple-Output (CF-mMIMO) networks, Reconfigurable Intelligent Surface (RIS)-based infrastructures, as well as ISAC, using as baseline beyond state-of-the-art Open RAN (O-RAN) and 3GPP specifications for the 5G protocol stack, and developing a sensing and a network intelligence plane spanning across network segments.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

6G-SENSES proposes a 6G architecture that interconnects a multi-technology RAN able to offer sensing functionalities with core network domains. New 6G capabilities such as CF-mMIMO and ISAC will be implemented to support the 6G vision. The goal of 6G-SENSES is to facilitate service/network providers' activities (mapped to IMT-2030 New Capabilities) to then tackle vertical-related use cases.

The considered technologies that are expected to offer sensing functionalities comprise Wi-Fi, mmWave and 5G New Radio (5GNR), which will coexist in an ISAC framework that jointly supports sensing and communication services. Sensing information stemming from these technologies will be pushed to the O-RAN framework for network optimisation and service provisioning purposes.

INNOVATION

6G-SENSES is grounded on the disaggregation of RAN functionalities, along with the development of an intelligent control and management plane exclusively operating on top of the RAN, as well as the inclusion of parallel data streams enabled by RAN sensing (including RIS).

6G-SENSES proposes emerging ISAC platforms to enable new applications, such as precise location tracking and environmental monitoring, and introduces innovative techniques like Orthogonal Time Frequency Space (OTFS)-based ISAC[1]. A cross-layer approach will be developed to enhance edge caching mechanisms and integrating various features into an Artificial Intelligence (AI) / Machine Learning (ML) model for traffic prediction and characterisation[2]. Multi-mode ultra-low power mmWave front ends will be provided to the platforms for indoor scanning of potential high-speed communication users and high-resolution tracking of active users' locations.

The work in the field of CF-mMIMO addresses distributed and scalable signal processing techniques and algorithms to support efficient operation, and its associated practical challenges[3]. The proposed implementations aim to optimise multiple access techniques and improve system efficiency.

1. Deliverable D3.1 "Initial report on the development of 6G-SENSES infrastructure building blocks"

2. Deliverable D4.1: "Initial SoTA and design of wireless edge caching solutions" - https://6g-senses.eu/wp-content/uploads/2025/02/2025-01-15-6G-SENSES_Deliverable_4.1_MAIN_FINAL.pdf

3. Deliverable D3.1 "Initial report on the development of 6G-SENSES infrastructure building blocks"

USE CASES/ SCENARIOS

Service provisioning use cases are in the focus of 6G-SENSES (in line with the IMT-2030 new usage scenarios), paying special attention to ISAC, as well as AI and Communication. These 6G Use Cases (UCs), requirements and KPIs represent the starting point for technology design and subsequent implementation of 6G-SENSES technologies (D2.1)[3]. These features enable various RAN provisioning approaches: 1) RAN as raw infrastructure resources, 2) RAN as virtualised resources, or/and 3) RAN -captured, -processed -exposed data to Network Operators (NOPs) or (even) service customers. In this context, the technology advancements make room for an extended ecosystem model (cf. orange modules in the figure) compared to that of 5G[4].

In **ISAC** UCs, RAN sensing is used to obtain information about the surroundings. The edge segment captures and intelligently processes the sensing information streams that are parallel to the data communication ones. From the figure, sensing information is captured and/or processed by the RAN/O-RAN/RIS operator role and is communicated to the NOP, which uses this information to adjust the RAN.

In **AI and Communication** UCs, an AI layer that can be dynamically distributed across edge and core computing resources is envisioned, both for network and application purposes. We then consider AI processing as an integral part of the resources (of various segments and layers) and it belongs to the corresponding service provisioning layer, depending on the data to be captured and the specific capabilities to be enabled.

3. Deliverable D2.1: "Report on 6G-SENSES use cases, requirements and KPIs and key technological advancements" - https://6g-senses.eu/wp-content/uploads/2024/10/2024-09-30-6G-SENSES_Deliverable_2_1_vf.pdf

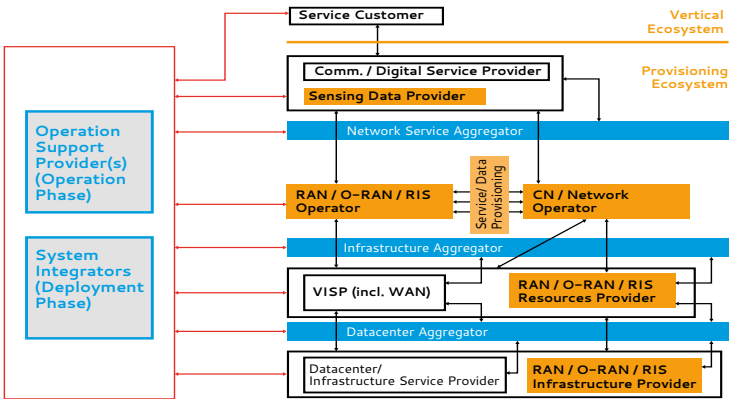
4. H. K Hallingby, S. Fletcher, V. Frascolla, A. Gavras, I. Mesogiti, & F. Parzysz, (2021). 5G Ecosystems. Zenodo. https://doi.org/10.5281/zenodo.5094340, acc. February. 2024.

RESULTS

The 6G-SENSES results thus far comprise a description of three UCs[5], i.e. **1) Sensing enabled Services**, focusing on exploiting sensing information to improve communication services (sensing-aided communication), **2) Ubiquitous Connectivity & Immersive Services**, focusing on storylines exploiting the CF-mMIMO and RIS capabilities combined with sensing, and **3) Network Digital Twin (NDT)**, focusing on storylines enabling Network Optimisation and Energy Saving, exploiting Network Intelligence. These use cases are described in terms of value and capabilities offered both for the various service provisioning roles and stakeholders of future 6G ecosystems and for the envisioned 6G end-user (vertical or individual) application services. In addition, the description of the use cases includes aspects of their technical realisation (given the above mentioned 6G-SENSES technologies and innovations proposed), along with the requirements and KPIs.

5. Deliverable D2.1: "Report on 6G-SENSES use cases, requirements and KPIs and key technological advancements" - https://6g-senses.eu/wp-content/uploads/2024/10/2024-09-30-6G-SENSES_Deliverable_2_1_vf.pdf

Revised Ecosystem view enabled by 6G-SENSES enhancements



SEamless integrationN of efficient 6G wirelesS tEchnologies for communication and Sensing

Coordinated by
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January 2024 – June 2026

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Verticals: Health, Industry, Vehicular

Partners: IHP – Leibniz Institute for High Performance Microelectronics, Institute of Accelerating Systems & Applications, University of Cantabria, Accelleran, OTE, Sapienza University of Rome, Technical University of Braunschweig, BubbleRAN, Barkhausen Institute, INTEL Germany, Nottingham Trent University.

INSTINCT

INSTINCT focuses on developing three technological pillars to achieve a more sustainable, interactive, and intelligent 6G connectivity.

OVERVIEW

The INSTINCT project is aimed to enable globally sustainable, interactive, immersive, and intelligent 'beyond communications' 6G connectivity by developing three complementary but critical breakthrough technology pillars:

i) "Sense-to-communicate": to improve radio spectrum usage by leveraging sensing information for supporting of 'beyond communications' use cases. ii) "Communicate-to-sense": to transform the wireless network into a smart 'sense the world' platform, capable of providing Joint Communication and Sensing (JCAS)-as-a-service functionalities towards a wireless radio 'beyond transmitting bits', capable of sensing, detecting, mapping, and 'understanding' semantics. iii) Multi-functional JCAS Network Intelligence: to optimise the architecture, resources, propagation and waveforms aided by AI for wireless JCAS systems.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

INSTINCT aspires to deliver the theoretical framework and relevant Key Performance Indicators (KPIs), waveforms, protocols and Hardware (HW) design of an innovative beyond communications 6G architecture, which combines the benefits of Sensing-assisted Communications, Communications-assisted Sensing and the Co-design of Sensing and Communications, leveraging Intelligent Surfaces and AI/ML.

INSTINCT, by means of its 3 pillars, will establish the foundations, invent the enablers and devise new architectures and, thus, offer the cornerstones of a new Information Communications and Sensing Technologies (ICST) era, where IoT meets ICT.

INNOVATION

INSTINCT develops **sensing-assisted communication technologies** thus allowing localisation, tracking, mapping, monitoring, imaging, incident detection and semantics become integral parts of connectivity services. (Pillar i)

INSTINCT leverages the **capabilities of intelligent surfaces**, holographic radios and cell free systems, which offer wavefront engineering functionalities, tunability and programmability of the wireless environment and can act as reconfigurable and intelligent sensors. (Pillar ii)

INSTINCT employs **Machine Learning (ML) techniques and structured optimisation** to incorporate the co-design of Sensing and Communications as main ingredient of multi-functional 6G network intelligence. (Pillar iii)

INSTINCT interdisciplinary approach comprises the 3-phase methodology (theoretical studies, ecosystem development, demonstration and KPI evaluation) and will provide 2 HW and 1 software (SW) demo for interactive, immersive and intelligent connectivity in three 6G usage scenarios.

The timeliness and pertinence of INSTINCT impact originates from its relevance to 6G technologies and to recent developments in regulation and standardisation, specially to address the gaps, especially in recent European-funded research.

USE CASES/ SCENARIOS

The use cases in INSTINCT are classified in three general categories, namely sensing-aided connectivity, sensing-able connectivity and multi-functional JCAS intelligence. To allow their simulative evaluation, available deterministic and statistical channel models will be upgraded, focusing on the integration of Reconfigurable Intelligent Surface (RIS) models and JCAS performance metrics. The outcomes will allow to quantify the achievable performance of JCAS wireless networks and to benchmark the final demonstrations.

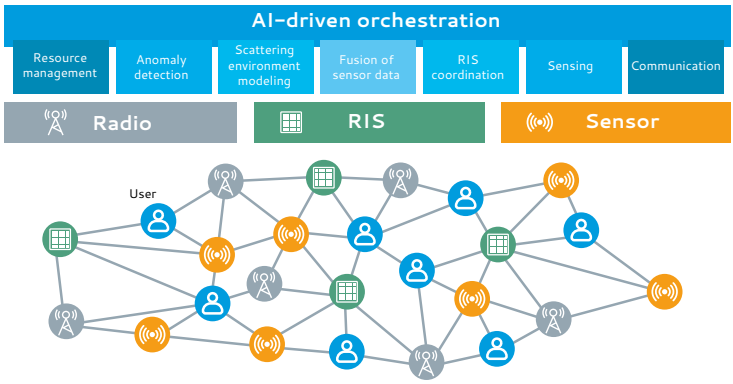
Work Package (WP) 4 includes plans for indoor and outdoor scenarios, such as industrial manufacturing and large campus logistics, to demonstrate the project's outcomes. This will involve evaluating relevant KPIs including object detection probability, localisation accuracy, range and angular resolution, service latency, maximum guaranteed data rate, etc. The demonstrations will showcase the benefits of the project by combining different techniques such as JCAS, RIS, Global Navigation Satellite System (GNSS), etc.

RESULTS

Work Package (WP) 2 provides the technology enablers for the three pillars of the project as well as derives fundamental research, algorithms and performance results and benchmarks. WP2 also aims at hardware implementation aspects and to address that, mitigation of hardware impairments in JCAS transceivers are studied. In the first year, waveforms for vehicular use cases and designs/control methodologies for RIS usage are also developed.

WP3 focuses on developing a network architecture that fully supports JCAS operations. Its primary goals include designing efficient resource allocation strategies, managing coordination among multiple sensors and RISs, implementing an AI-driven orchestration layer, and crafting a flexible management system to address diverse service requirements. The outcomes of the Work Package will encompass architectures, protocols, and software solutions.

INSTINCT Results



Joint Sensing and Communications for Future Interactive, Immersive, and Intelligent Connectivity Beyond Communications

INSTINCT

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January 2024 – December 2026

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iSEE-6G

iSEE-6G aims to integrate Communications, Computation, Sensing, and Power Transfer into a unified 6G RAN framework.

OVERVIEW

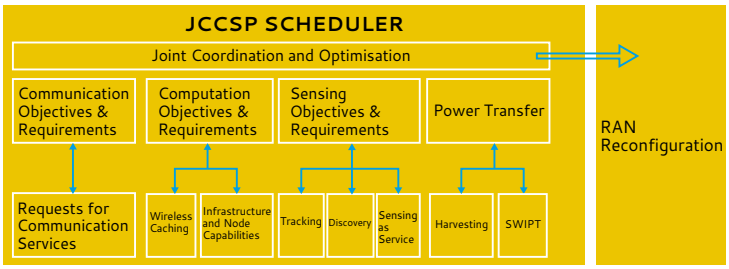
Joint Communication and Sensing (JCS), or Integrated Sensing and Communications (ISAC), is set to transform wireless system operation and Radio Access Networks (RANs). iSEE-6G takes this further, developing a unified Joint Communication, Computation, Sensing, and Power Transfer (JCCSP) radio platform, leveraging 6G technologies. The iSEE-6G framework includes novel antenna surface solutions with reconfiguration capabilities, a JCCSP-optimised physical layer aligned with Open RAN, cross-layer design for service-oriented architecture, and system-level JCCSP solutions for cell-free 6G networks. The PoC plan investigates JCCSP for Unmanned aerial corridors and vehicular scenarios, using edge computing for improved positioning and mapping in Public Protection and Disaster Relief (PPDR) scenarios.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

iSEE-6G integrates **Communications, Computation** (RAN disaggregation and edge offloading for cumbersome functions), Sensing (object and motion detection through radio), and wireless/ RF **Power Transfer** into a unified 6G JCCSP RAN framework, focusing on:

- Radio channel evaluation.
- Intelligent surface and antenna array design.
- Waveform and transmission optimisation.
- Network sensing and ORAN-based beamforming.
- Cross-layer designs of content placement methods, Rate Splitting Multiple Access (RSMA), sensing schemes, and stochastic geometry-based system-level performance analysis.
- AI application for modelling, optimisation, and decision-making.
- New service components for edge-based positioning and topology management.
- An intelligent unit to coordinate the operation of the system model and the components, the JCCSP scheduler.

JSCCP Scheduler



Integrated SEnsing, Energy and communication for 6G networks

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Verticals: agriculture, automotive, smart-city, drone OEMs, health, telecommunication, industrial automation, PPDR

Partners: IMST, University of Piraeus Research Centre , Technical University Berlin , Airbus DS , IMEC, University of Leuven, WINGS ICT, University of Cyprus, Orange Romania, Agricloud, NVIDIA, Direk.

INNOVATION

iSEE-6G introduces a groundbreaking framework for JCCSP, extending traditional ISAC capabilities by:

- Proposing novel physical layer designs, including optimised waveform designs, and intelligent beamforming techniques.
- Performing advanced channel modelling tailored for the ISAC channel particularities.
- Integrating cutting-edge technologies such as reconfigurable/holographic intelligent surfaces, mmWave and multi-band communication, and full-duplex operation for JCCSP operation.
- Investigating novel emerging services of JCCSP for PPDR applications.

iSEE-6G emphasises on Unmanned Aerial Vehicular (UAV) applications, enabling energy-efficient Wireless Power Transfer (WPT), enhanced sensing, and secure communications.

It incorporates machine learning for dynamic network optimisation and promotes multi-band operations for seamless service delivery across diverse environments.

USE CASES/ SCENARIOS

iSEE-6G investigates six use cases of JCCSP enhancing the system's efficiency and performance:

- **JCS in a 6G Cell-free environment** effectively exhibiting the applicability of network Multiple Input Multiple Output (MIMO) and underscoring the practical advantages of the O-RAN architectural paradigm by showcasing its seamless integration into sensing and communications frameworks.
- **UAV corridors** managing and coordinating UAVs with various networking and functional roles
- **Safety enhancement**: utilising 6G technology, JCCSP and and Unmanned Aerial Vehicles (UAVs) amalgamate the cutting-edge multi-functional 6G capabilities with the versatility and agility of UAVs to create proactive safety measures.
- **Agricultural industrial IoT**: showcasing the effectiveness of UAVs in collecting agricultural data for environmental sensing, and precision interventions, enhancing agricultural productivity, resource utilisation, and sustainability.
- **Connected and cooperative autonomous mobility**: UAVs equipped with advanced sensing capabilities and B5G/6G communication technology that enhance coordination and collaboration among autonomous vehicles.
- **Energy harvesting**: The exploitation of UAV acting as RF signals outlet stands out as a key-enabler for the lifespan sustainability of the Internet of Everything (IoE) networks introducing an extra degree of freedom to the emerging WPT technology.

RESULTS

The expected JCCSP outcomes of iSEE-6G include:

- 6G-enabled use case scenarios with aerial corridors.
- Channel models for aerial systems.
- New types of modulation, multiple-access and physical layer framing schemes.
- New hybrid beamforming schemes exploiting achievable Degrees of Freedom.
- Novel wireless edge caching techniques for JCCSP-enabled 6G networks.
- Multi-Access Edge Computing enhanced positioning and mapping.
- AI-enabled collaborative positioning algorithms with European Global Navigation System fusion and exploitation of results for PPDR operations.
- mmWave beam-scanning antenna arrays and RIS prototypes for the UAV and the terrestrial Radio Units.
- Proof-of-Concept demonstration testbeds.

Stream B3

COMMUNICATION INFRASTRUCTURE TECHNOLOGIES AND DEVICES

The projects have been selected to fortify and expand the physical and virtual infrastructure to support 6G technologies, e.g. on optical and wireless.

6G-EWOC

6G-EWOC focuses on advancing 6G for autonomous driving, improving road safety and efficiency.

OVERVIEW

6G-EWOC focuses on autonomous driving, connecting vehicles and sharing their collected information instantaneously among traffic participants. 6G-EWOC supports democratised safety and efficient transport as it contributes critical technologies:

- Optical wireless communications & sensing for situational awareness and connectivity.
- Seamless access to edge data centres through high-capacity fibre fronthaul.
- Real-time processing collected roadside data.
- Orchestration of constituents of 6G-enabled vehicular connectivity through AI.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

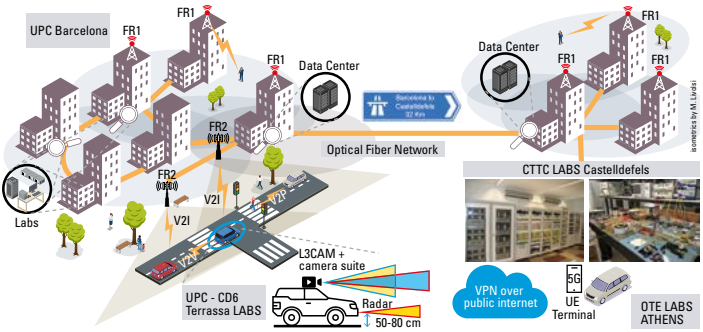
6G-EWOC's architecture introduces optical communications, sensing and AI for connected and automated driving, curating and sharing vast information to all traffic participants.

Radio access is enhanced by Optical Wireless Communication (OWC) with up to 10 Gb/s access rates, and direct communication between road-users through connected sensors. Fronthaul connectivity and aggregation by 100 Gb/s low latency coherent fibre comms, permitting instantaneous access to near- and far-edge data centres to fuse – in real-time – the vast amounts of data generated along the roadside scenery. Software-defined networking (SDN) in close interplay with AI enables 6G-EWOC to provision its resources in the most efficient way.

INNOVATION

Several innovations are foreseen:

- **Optical wireless**: Gb/s access to roadside users via beamformers and free-space optical links, plus VLC for vehicle-to-vehicle data exchange.
- **Connected LiDAR/RaDAR**: laser/radio-based detection and ranging for high-quality data and instant information exchange.
- **High-capacity fronthaul**: 100 Gb/s connectivity using Photonic Integrated Circuit (PIC) technology and advanced Application-Specific Integrated Circuits (ASIC).
- **Software-Defined Networking orchestration**: device programmability and rapid service provisioning with AI algorithms for efficient orchestration and energy optimisation.
- **AI-based sensor applications** crowdsourced data fusion for



Tentative 6G network test-bed in Barcelona (UPC/CTTC) and Athens (OTE)

accurate Simultaneous Localisation and Mapping (SLAM) and informed decision-making in autonomous driving systems.

USE CASES/ SCENARIOS

The migration to advanced mobile and road infrastructure networks with improved performance and reliability supports fully autonomous vehicles with collective perception capabilities. 6G-EWOC addresses selected use-cases for road transportation:

- **Safety**: Navigation through complex/busy intersections seamlessly and collision-free, despite the presence of other road participants including vehicles with similar, lower or no autonomy, vulnerable road-users such as pedestrians, cyclists or e-scooters, and obstacles – in a dynamically changing environment. 6G enables traffic participants to gain a comprehensive understanding of their surroundings, including the capability to see through obstructions to capture hidden objects and to be informed and predict trajectories. 6G further contributes through fast data processing close to the "event" to minimise delays and enable a realistic digital-twin representation of the traffic scenario. Network slicing guarantees quality-of-service to ensure the prioritisation of traffic related to vulnerable road users over less critical ones.
- **Transportation efficiency**: Optimising road traffic flow in smart cities requires effective control—or at least influence—of vehicle movement by leveraging collective perception. This reduces congestion, travel time, and CO_2 emissions, ultimately enhancing citizens' quality of life. City-level information processing powered by AI enables more coordinated traffic patterns and large-scale rerouting to minimise delays and prevent congestion.
- **Response to emergency situations** is supported by achieving route prioritisation for emergency vehicles, enabling them to reach their destination the soonest possible – even though this might involve several busy road intersections.

RESULTS

The wireless and wired communication modes contributed by 6G-EWOC will be demonstrated in access and fronthaul scenarios. Regarding OWC, initial outdoor demonstrations featuring optical beamformers for a 10 Gb/s/λ Fi-Wi-Fi bridge have successfully showcased a simplified yet reliable deployment of optical remote radio heads for infrastructure-to-infrastructure connectivity – further including the effective mitigation of optical turbulence. Moreover, LiDAR point-cloud transmission through Ethernet-over-Visible Light Communications (VLC) has been demonstrated over a 100m LED-based vehicle-to-vehicle link.

AI-based applications for autonomous vehicles will demonstrate an efficient data fusion sensor suite, utilising connected LiDAR and RaDAR systems for joint communication and sensing on an instrumented vehicle. This setup will enable the reconstruction of traffic scenes from multiple perspectives and ensure precise identification of dynamic elements.

Data fusion will occur early or late in the processing pipeline, depending on connectivity, and will be performed at the far edge (customer side) or near/far edge.

The foreseen 6G network testbed will include a fully operational 5G distributed network supported by an optical network providing connectivity between the UPC (Barcelona) and CTTC laboratories (Castelldefels) and the connectivity with the OTE Labs (Athens).

AI-Enhanced Fibre-Wireless Optical 6G Network in Support for Connected Mobility

Coordinated by José Antonio Lázaro, Polytechnical University of Catalunya

January 2024 – December 2026

Website: 6G-ewoc.eu

LinkedIn: www.linkedin.com/in/6g-ewoc-project/

Verticals: Connected and future autonomous vehicles employing multiple sensor technologies

Partners: Polytechnical University of Catalunya-BarcelonaTech, CTTC, Austrian Institute of Technology, III-V Lab, Ligentec, Beamagine, Bifrost Communications, Nokia Bell Labs, NVIDIA, Magna, Cosmote.

ECO-eNET

The ECO-eNET project pioneers in 6G transmission technologies, merging optical and radio transport for an efficient edge network.

OVERVIEW

The ECO-eNET project pioneers research in emerging transmission technologies to create a confluent edge network, integrating optical and radio transport for 6G efficiency and capacity. It combines confluent xhaul with cell-free and Distributed Multiple Input Multiple Output (D-MIMO)-based access networks. Photonic Radio Fixed Wireless (RFW) and Free-Space Optical (FSO) transmission enable an edge mesh network. New monitoring and slice-aware control protocols unify radio intelligent controllers with transport Software Defined Network (SDN) for optimal service delivery. Leveraging wired and wireless transport, an AI layer enhances network functions and user applications. Led by industry and academia, it advances 6G's capacity, energy efficiency, low latency, and robustness.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

ECO-eNET's confluent networking integrates RFW, FSO, and Flex-grid Dense Wavelength Division Multiplexing (DWDM) fibre optics for xhaul networks, focusing on confluent mesh networking. The goal (figure next page) is to develop a confluent mesh edge network interoperating with Radio Access Network (RAN) structures (Cell Free/D-MIMO, O-RAN) to meet 6G's reliability, peak data rate, and low latency needs. This involves a layered architecture advancing infrastructure, control, sensing, and management, integrating fibre, optical wireless, and radio fixed wireless. Beyond simple convergence, it enables flexible interoperation via AI-driven orchestration, forming a scalable 6G platform. This "network confluence" is the core of ECO-eNET's vision.

INNOVATION

The ECO-eNET project will transform 6G networks with advanced access solutions, including 3D coverage and a 1 Tb/s Terahertz (THz) fixed wireless link over 1 km. This breakthrough boosts capacity 100x-1000x over mmWave, bridging connectivity gaps and enabling denser access points. A key goal is ultra-low energy and high-capacity connectivity through seamless optical-wireless integration. Key innovations include plasmonic components that achieve 1 Tb/s at 10 pJ/bit, next-gen photodetectors for optical-to-wireless conversion, and optimised Digital Signal Processing (DSP) for free-space optics and radio-over-fibre links. ECO-eNET will validate these advances through trials in real-world environments using testbeds and field scenarios. Trinity College Dublin will provide access to the OpenIreland infrastructure, featuring a metro lab testbed linked via the Dublin HEAnet metro network. Demonstrations will integrate THz wireless and FSO transmissions, achieving 1 Tb/s over 1 km, seamlessly merging into metro and access networks via optical heterodyning and analogue radio-over-fibre techniques. The trials will showcase confluent networking for capacity-optimised X-haul, including dynamic optical modulation, Flex Ethernet aggregation, and fibre sensing for enhanced quality and resilience. ECO-eNET will define next-generation high-capacity, energy-efficient networks where optical and wireless technologies converge intelligently.

Efficient Confluent Edge Networks

Coordinated by Paolo Monti, Chalmers University of Technology

January 2024 - December 2026

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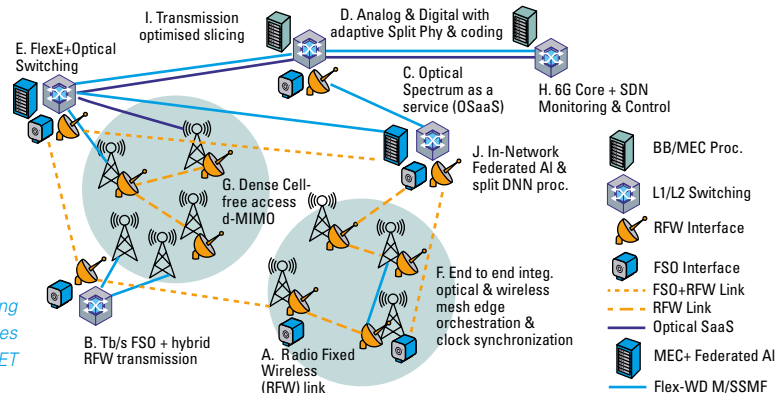
Partners: Chalmers University of Technology, Trinity College Dublin, Institute of Accelerating Systems and Applications, OTE, Accelleran , mBryonics Limited, Tallinn University of Technology, Adtran Networks, ETH Zürich, Polariton Technologies, University of Bristol



Confluent mesh networking including ten technologies investigated in ECO-eNET

USE CASES/ SCENARIOS

ECO-eNET use cases (UCs) cover various service provisioning roles, stakeholders, and envisioned vertical services:

- **UC 1: Optical Network for Hyper Reliable Low Latency Communication (HRLLC) Scenarios** focuses on a confluent network in the 6G transport segment, leveraging sensing technologies to predict malfunctions, outages, and intrusions in fibre optical networks. Trials will emulate transport network conditions and assess the network's response.
- **UC 2: Wireless Transport Network for High Capacity & HRLLC** explores extended confluent solutions using sub-THz and FSO bands for high-capacity, low latency networks. It integrates transport communication and sensing to detect link failures and enables confluent mesh networking for enhanced reliability via an intelligent management plane. Trials will evaluate complex transport network deployments.
- **UC 3: CF/D-MIMO Structures for IC & HRLLC** integrates CF/D-MIMO RAN structures into the ECO-eNET mesh transport network, enhancing scalability and flexibility. This supports "Seamless Immersive Reality" and "Ubiquitous and Resilient Networks." Trials will assess 6G technologies in an End-to-End deployment.
- **UC 4: AI-Optimised Confluent Mesh for Energy & Latency** develops AI/ML algorithms to optimise energy efficiency and minimise latency in 6G X-haul networks, balancing energy efficiency, computational overhead, and prediction accuracy for Integrated Sensing and Communication (ISAC) services. Trials will assess the intelligence of the complete ECO-eNET solution.

RESULTS

ECO-eNET's innovative confluent networking technologies will unlock new supply chains and markets by delivering terabit-per-second capacities without increasing energy consumption. These advancements also significantly reduce latency for next-generation applications.

A key milestone in this vision was reached with the development of FSO and RFW components for high-capacity wireless links. Notable achievements include the design of a turbulence-resistant FSO system that integrates a photonic lantern and a phasing Photonic Integrated Circuit (PIC). Additionally, advancements were made in sub-THz technologies using graphene photodetectors, plasmonic modulators, and high-gain antennas.

Rigorous modelling has validated the feasibility of achieving 1 Tb/s transmission over 1 km, and well-defined specifications are guiding the implementation of these cutting-edge solutions. This transformation will extend high-speed, intelligent network services across Europe, improving accessibility in previously underserved areas.

OPTI-6G

OPTI-6G's ambition is to design, develop and exhibit the operation of a radio optical 6G.

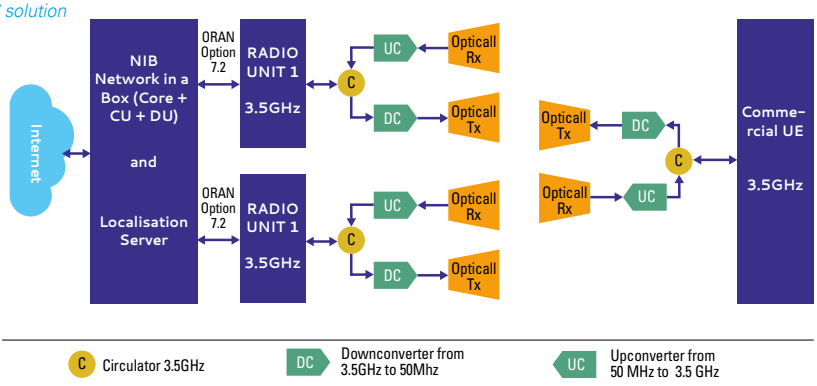
OVERVIEW

The OPTI-6G project introduces a broadband Optical Wireless 6G Communications (OWC) solution using vertical cavity surface-emitting laser (VCSEL) arrays operating at a near Infrared (IR) wavelength of 1550 nm. This wavelength offers favorable propagation and high resistance to interference. Additionally, the system ensures seamless indoor broadband coverage through a cell free network of OWC access points, strategically distributed within buildings. The broadband system is designated to deliver data rates of 1 Gb/s over distances of up to 5 m, with a 25° field of emission. Furthermore, it will be complemented by a high precision localisation and sensing solution, which has already been demonstrated an accuracy of less than 5 cm at 3.5 GHz.

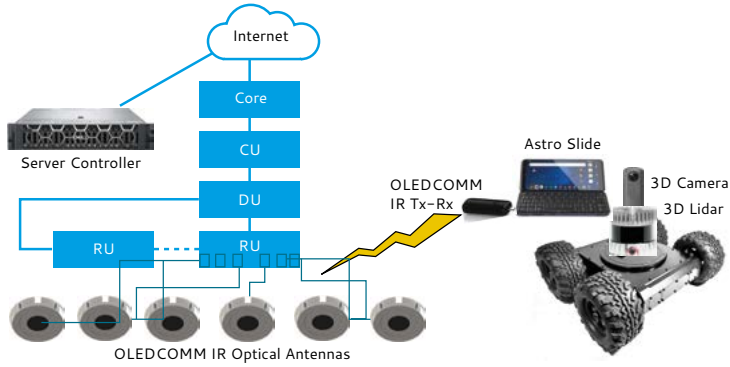
CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

A Private 5G Network (P5N) is a compact solution designed for deployment in dedicated areas, offering high performance URLLC applications. This P5N architecture incorporates the Sparq-2025- Network in a Box (NIB) and the Sparq-2025-Open RAN Radio Unit (ORU), operating in 3.5GHz/ mmWave bands. The system will be enhanced by replacing its air interfaces with OWC infrared (IR) ones. The network supports the O-RAN split PHY architecture option 7.2 category B with O-RAN Interface between the ORU and the NIB. The NIB integrates all key 5G network components including O-RAN Distributed Unit (O-DU), Central Unit, Next Generation Core and Multi-Access Edge Computing, covering functionalities from the High PHY (OSI layer-1) to the Application Layer (OSI Layer-7). The motivation for using this architecture is to evaluate the advantages of a cell free 5G network operating in the optical domain, rather than the conventional microwave domain, typically at 3.5GHz (n78 band).

OPTI-6G OWC solution



OPTI-6G use case architecture



INNOVATION

In the project, the P5N architecture will be transformed into an OWC cell free 5G Network by replacing the 3.5GHz/mmWave transmit and receive units to OWC IR transmitters and detectors using 5G numerology (OFDMA). The motivation is to evaluate the benefits of the cell free 5G network operating in the optical domain rather than the traditional microwave domain, typically at 3.5GHz. Expected improvements include enhanced coverage area, increased throughput to and from downlink and uplink communication, and reduced handover time between cells.

USE CASES/ SCENARIOS

The position of a User Equipment (UE) on an automated guided vehicle (AGV) will be determined by either measuring the distance and angle of the UE from photodiode (PD) at an OWC access point (AP) or by measuring the distance of the UE from four PDs at four OWC APs.

The angle is estimated by adjusting the PD receiver at the OWC AP using a gimbal so that the Received Signal Strength (RSS) reaches its maximum value.

The distance is determined by measuring the RSS and/or Time of Arrival (ToA) of the IR signal emitted by the UE at the OWC AP.

By combining distance and angle measurements, or by using four distance measurements, the exact position of the UE can be calculated. This positioning information will be used to navigate the AGV along predefined routes within its environment.

RESULTS

The OPTI-6G project aims to implement three distinct OWP localisation methods and combine them to achieve a more accurate and robust aggregate estimate of the UE location.

- **The Time Difference of Arrival (TDoA) method**: measures the TDoA from multiple APs. Its innovation is achieving picosecond-level resolution for centimetre-accurate, real-time UE localisation, surpassing current state-of-the-art methods.
- **Received Signal Strength (RSS) method**: determines location by measuring the RSS from multiple APs. By conducting RSS measurements simultaneously with TDoA measurements using uplink transmissions at OWC antennas, the system can integrate these data points without requiring time synchronisation, enhancing overall accuracy.
- **Hybrid RSS and Angle of Arrival method**: leverages beamsteering to modulate the orientation of one or several optical sources. It enables 2D positioning with just a single optical source (i.e. a single AP) and a single PD at the UE level, while 3D positioning can be achieved with only two APs.

By integrating these three methods, the project aims to significantly improve localisation precision and reliability for next-generation wireless networks.

OPTI-6G

Optical 6G Cell-Free Networks (OPTI-6G)

Coordinated by
Adam Kapovits, Eurescom

January 2024 - December 2026

Website: https://opti-6g.sns-ju.eu/

Verticals: Industry 4.0

Partners: Eurescom, BRUNEL University of London, Versailles Saint Quentin en Y University, RunEL NGMT, Oledcomm.

PROTEUS-6G

PROTEUS-6G aims to design and develop a dynamic, flexible, scalable, cost-effective, high-bandwidth, and low latency packet-optical fronthaul and midhaul for 6G networks.

OVERVIEW

PROTEUS-6G aims to conduct groundbreaking research on complementary technologies that focus on scaling the fronthaul and midhaul (X-haul) segments of 6G networks. The goal is to fully support the potential of emerging 6G services through the introduction of three main innovations: i) A novel Spatially-Diverse Point-to-Multi-Point (SDPtMP) optical fronthaul distribution network ii) The development of ultra-high-speed, low latency, cost-effective, and power-efficient Lite-Coherent (LITECOH) transceivers (TXR), iii) A novel service management, orchestration and control system.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

PROTEUS-6G focuses on developing an advanced packet-optical X-haul networking infrastructure, leveraging a novel software-programmable photonic-integrated-circuit based subsystems and technologies. These will be operated under intelligent software management architecture, designed to simplify and optimise network operations. The project aims to support future **ultra-high capacity, low latency, and energy-efficient 6G cellular and cell-free MIMO radio access networks**.

INNOVATION

To fully support the emerging 6G services, PROTEUS-6G considers the introduction of three main innovations:

- **A SDPtMP optical fronthaul distribution network**, enabled by an innovative optical device that optically extracts transmitted digital subcarriers using an array of sharp optical interleaving filters. These filters function as circular subcarrier multiplexers/demultiplexers. Next-generation Digital Subcarrier Multiplexing (DSCM) transceivers will support dynamic functional split up to option 7-2.
- **Development of ultra-high-speed, low latency, cost-effective, and power-efficient Lite-Coherent (LITECOH) TXR** as key enablers for cell-free Multiple Input Multiple Output (MIMO). These transceivers will achieve ultra-high fronthaul capacities, as required for functional split option 8, delivering 6.4 Tb/s per fibre over 8 wavelengths (0.8 Tb/s/λ).
- **A novel service management, orchestration and control system**, designed to enable dynamic reconfiguration of functional splits in the Radio Unit; Distributed Unit and Central Unit, ensuring greater flexibility and efficiency.

Programmable Reconfigurable Optical Transport for Efficiently offering Unconstrained Services in 6G

PROTEUS 6G

Coordinated by Tomkos Ioannis, University of Patras

January 2023 - December 2025

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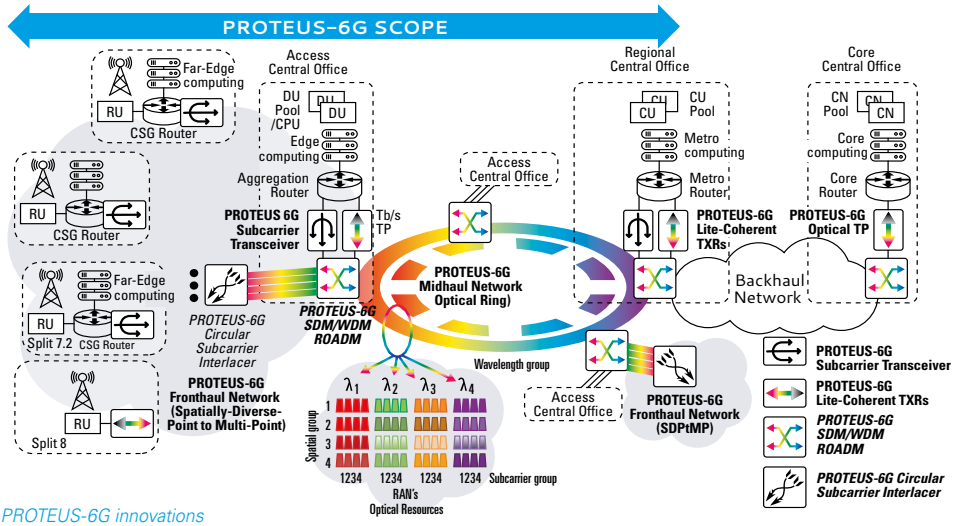
Partners: University of Patras, Hebrew University of Jerusalem, Telefonica ID, LioniX International, PICadvanced, Ubitech, Opsys Technologies, Infinera, CNIT, ETH Zürich, CTTC, Polariton Technologies, University of Carlos III de Madrid, Fraunhofer HHI.



The PROTEUS-6G innovations and supported scenarios.

USE CASES/ SCENARIOS

Scenario i) will demonstrate **dynamic functional splits**, adapting in real-time to changes in traffic, new services, and network demands. The options envisioned split option range from 1 up to option 7.2. Implementing this scenario **requires highly flexible and reconfigurable photonic transport technologies, including point-to-multipoint transponders, SDM/WDM ROADMs, and subcarrier multiplexers and demultiplexers**.

Scenario ii): will focus on **functional split option 7.1 and -8**, which impose **high-capacity requirements** on the fronthaul photonic distribution network. These requirements scale with the number of distributed antenna arrays while also demanding **ultra-low and nearly deterministic latency**. In PROTEUS-6G, this will be achieved through the deployment of **high-capacity lite-coherent transceivers**.

RESULTS

PROTEUS-6G focuses on eight main expected results:

1. **Expending 6G Access**: Developing diverse access networks to support various devices, while extending 6G reach and minimising environmental impact.
2. **Long Distance Communications**: Advancing flexible, ultra-fast, and energy-efficient transceivers based on coherent detection with simplified Digital Signal Processing.
3. **Reconfigurable Fronthaul**: Implementing PROTEUS-6G's fronthaul SDPtMP network with digital subcarrier-based granularity for low latency 6G O-RAN.
4. **Ultra-Low Energy Devices**: Developing battery free devices and ultra efficient solutions for energy conservation.
5. **Sustainable, High-capacity Networks**: Evolving 6G into an intelligent, energy-efficient system that enhances capacity, reduces latency, and measures reliability. This shift integrates lossless subsystems and distributed big data processing across multiple data centres.
6. **Efficient Interleaver Network**: Designing energy-efficient lattice structures and sharper filters for the fronthaul/midhaul networks.
7. **High-speed Transmitters**: Integrating the 0.8Tb/s transmitter module with an all-optical chromatic dispersion equalisation filter for improved performance.
8. **Standardisation Efforts**: Enhancing standardisation through XR-400 transceiver compatibility testing (XR-Forum) and PROTEUS-6G filter fronthaul network evaluations.

Stream B4

RELIABLE SERVICES AND SMART SECURITY

The projects have been selected in such a way as to ensure a secure transition to 6G that prioritises user data protection and privacy, reliability, trust and resilience.

ELASTIC

ELASTIC targets enhancing security and efficiency in 6G network management

OVERVIEW

ELASTIC enhances efficiency and security in service orchestration within the highly distributed and heterogeneous context of the cloud-fog-edge continuum. By leveraging modern cloud-native ecosystems to improve service orchestration and security over 6G networks, ELASTIC focuses on:

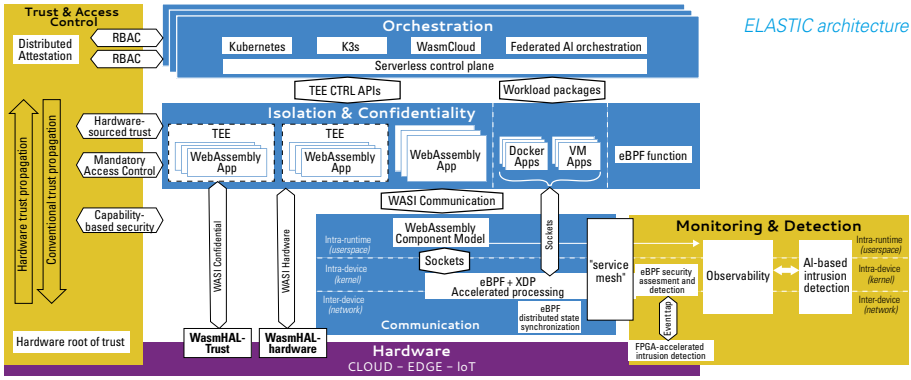
- Optimising executable isolation for secure and efficient cloud and edge computing.
- Designing a secure, architecture-agnostic Function as a Service (FaaS) framework for artifact management and trusted interactions.
- Developing privacy-preserving execution environments using confidential computing and privacy-enhancing technologies.
- Implementing efficient, secure orchestration for IoT and edge workloads in 6G infrastructures.
- Promoting 6G standardisation and European-aligned secure service frameworks.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The ELASTIC architecture has five key blocks for secure, resource-efficient service orchestration over for 6G networks. The **Orchestration** block manages services across cloud-fog-edge infrastructures enhancing scalability and security. The **Isolation & Confidentiality** block protects data from Web Assembly (Wasm) and extended Berkeley Packet Filter (eBPF) tools using Trusted Execution Environment (TEE) and hardware abstraction frameworks. The **Communication** block ensures secure, efficient data exchange, encryption, and accelerated microservices. The **Monitoring & Detection block** provides continuous security monitoring and cybersecurity issue reporting. The **Trust & Access Control block** ensures authorised access to sensitive data via remote attestation platforms.

INNOVATION

The ELASTIC project introduces key innovations addressing critical challenges in distributed systems, enabling secure and efficient next-generation solutions. Highlights include: **1. Wasm Hardware Abstraction Layer (HAL) for TEE**: Seamless TEE functionalities access via WebAssembly; **2. Edge Device Security**: Lightweight Wasm-based orchestration for secure constrained edge devices; **3. Remote Attestation & Access Control**: Secure VM migration, multi-platform attestation and lightweight Attribute Based Access Control (ABAC) for constrained environments; **4. Serverless Orchestration**: Low latency Wasm-based serverless orchestration; **5. Decentralised Federated Learning (FL) Optimisation**: Advanced algorithms enhancing privacy, security, and efficiency in FL models; **6. eBPF Security**: Early detection of eBPF vulnerabilities for improved security and developer experience; **7. Wasm Integration**: Scalable Kubernetes control plane framework minimising overhead; **8. FL Toolbox**: First Wasm-based orchestration tool for secure and traceable FL on edge nodes; **9. Data Protection**: Public Key Cryptography (PKC) standards for secure operations; **10. Microservices Acceleration**: Low latency communication using eBPF and Remote Direct Memory Access (RDMA) technologies.



ELASTIC architecture

USE CASES/ SCENARIOS

The ELASTIC solution will be validated and assessed through real-life demonstrations, focusing on two distinct use cases (UCs):

1. **Smart Connected Factory of the Future**: This UC will evaluate the portability, usability, and security of various ELASTIC technologies. Static analysis algorithms will facilitate early detection of security vulnerabilities in eBPF code during its development phase. The observability framework for Wasm-based serverless/FaaS workloads in Kubernetes will be validated to enhance attack detection and prevention within the serverless ecosystem. Integrating cross-platform, portable drivers for the data fabric will simplify deployment across diverse hardware platforms. Stateless IoT data processing elements, such as data transformation and validation, will leverage the FaaS paradigm and be deployed near devices for efficiency. ELASTIC's low latency, real-time monitoring, equipped with embedded low-power, hardware-based modules, will effectively detect security issues. TEEs and remote attestation will enable secure execution of data fabric components within attested TEEs, enhancing overall system security.
2. **Privacy-Preserving IT Service Migration**: This UC will demonstrate the migration of sensitive IT services and associated data from private data centres to the cloud using the defined framework, ensuring compliance with cybersecurity rules, IT standards, and privacy regulations. The automation and portability of the confidential computing hardware-independent platform will be validated, with a focus on the abstraction layer's handling of remote attestation. The solution will also be tested for its ability to extend secure IT service migration to edge and far-edge clouds, meeting performance and high-availability objectives.

Efficient, portabLe And Secure orchesTration for reliable servICes

elastic

Coordinated by Sotiris Ioannidis, Technical University of Crete

March 2024 – February 2027

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X: @ElasticProject_

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Verticals : Industry

Partners: Technical University of Crete, Ericsson Finland, Ericsson Sweden, Telefonica ID, Thalès SIX, Thalès DIS, IMEC, Ultraviolet, Aalto University, Lunds University, Abstract Machines, Zentrix Lab, University of Turin

RESULTS

With 6G wireless communication networks expected to drive a substantial expansion in the scope and capabilities of networked services, ELASTIC has achieved notable progress emphasising on the optimisation of comprehensive 6G service orchestration and the development of robust security frameworks. ELASTIC has defined its architecture, incorporating 29 distinct tools that focus on tackling the challenges of securing and orchestrating the diverse array of services and resources in 6G networks. ELASTIC first analysed modern security and orchestration frameworks, focusing on Wasm and eBPF, to assess their capabilities, limitations, and potential for 6G networks. ELASTIC has also explored and developed lightweight and efficient service orchestration frameworks within the scope of Confidential Computing, leveraging TEEs and hardware Central Processing Unit extensions. The outcomes of these efforts will be made publicly available in the coming months.

iTRUST6G

Revolutionising 6G security with a zero-trust architecture, employing AI/ML for dynamic threat management, and improving trust through innovative identity models and advanced security policies.

OVERVIEW

The iTrust6G project is pioneering zero-trust (ZT) architecture for 6G, leveraging AI/ML to enhance trust, manage threats, clarify security policies, and track assets. The project aims to improve trust establishment, optimise security procedures, and reduce network resource overhead. AI/ML will be applied to threat mitigation, focusing on continuous monitoring and programmable security. Intent-based security policies will enable automated end-to-end security orchestration. Novel Trust Algorithms will be developed for trust management, addressing service design, stakeholder identity, and software supply chain security. iTrust6G will also create an identity management model to strengthen stakeholder trust and improve 6G service decisions using cyber-threat intelligence.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The iTrust6G architecture consists of five layers, each supporting ZT:

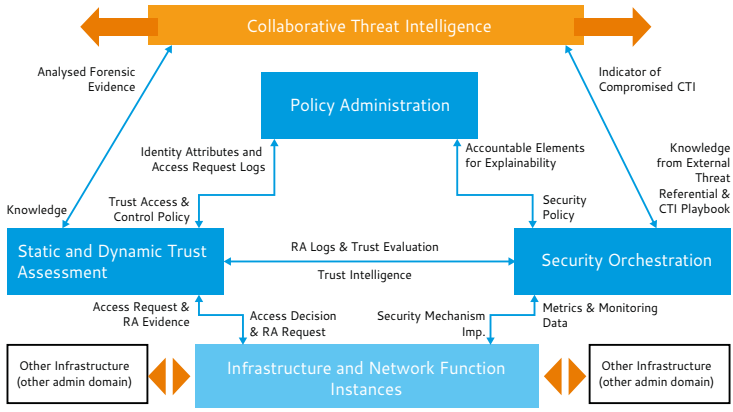
- **Collaborative Threat Intelligence Layer**: Coordinates knowledge sharing for trust evaluations, shares threat insights, and supports remediation with Cyber Threat Intelligence (CTI) playbooks.
- **Policy Administration Layer**: Manages tenant-specific policies, enabling intent-based security and trust, interacting with trust and orchestration layers.
- **Static & Dynamic Trust Layer**: Evaluates asset posture, supports ZT access decisions, and interfaces with CTI, policy, and orchestration layers.
- **Security Orchestration Layer**: Automates threat response with AI, generates remediation playbooks, and integrates tools for tenant-specific security.
- **Infrastructure Layer**: Unifies diverse 6G network environments, simplifies complexity, and enables multi-tenant collaboration.

INNOVATION

As networks expand in complexity, so does the potential for breaches and data compromise, demanding innovative solutions. The envisioned innovation of iTrust6G lies in creating a paradigm shift in securing next-generation networks through trust-centric, adaptive, collaborative and intelligent solutions. The project will enact a secure management of diverse set of resources and of multiplicity of criteria and data source to evaluate trust. iTrust6G policy framework will support operator security compliance and to account for potential threats, at design and run time. To that extent, advanced technologies such as Federated ML, AI-driven threat detection, intent-based and real-time trust inference will be leveraged as core building blocks of the platform.

These approaches for managing cybersecurity in dynamic and complex environments will permit ensuring intelligent and secure service orchestration in 6G network operations. This vision positions iTrust6G to redefine trust and security in the era of hyper-connected, multi-stakeholder digital ecosystems.

iTRUST6G architecture



USE CASES/ SCENARIOS

iTrust6G will integrate design, specification, and testbed demonstrations, targeting key use cases in telecom and cybersecurity specific verticals. and corresponding validation scenarios emulating anticipated security & trust needs of 6G stakeholders:

- **UC 1**: Dynamic Security Orchestration and Trust Establishment in Multi-Stakeholder Environments
- **UC 2**: Operational Security and Trust Re-evaluation
- **UC 3**: Programmable Security as a Service

The use cases and scenarios outlined aim to refine and validate iTrust6G's ability to handle complex security threats and maintain trust in dynamic, programmable environments, paving the way for more resilient and secure 6G networks.

RESULTS

The iTrust6G project has established a solid foundation for the development of secure and trustworthy 6G networks. Some key milestones and results from the first year of the project are:

- Defining project's use cases, requirements and architecture.
- Designing Federated ML for threat classification and integrated CTI platform, and developing AI-driven threat detection, risk assessment models, and real-time trust inference.
- Analysis and proposing a dynamic trust evaluation score for the iTrust6G platform.
- Progress on the programmability model, CTI automation playbook, the Secure Service Orchestrator, and the Security Capability Model and Policies Language.

Intelligent Trust and Security Orchestration for 6G Distributed Cloud Environments

Coordinated by Mir Ghoraishi, Gigasys Solutions

January 2024 - June 2026

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Partners: Gigasys Solutions, i2CAT, Telefonica, Lenovo, National Technical University of Athens , Politécnico de Torino, PDMFC , Adrestia

NATWORK

NATWORK aims to establish and implement the first economically feasible, energy-efficient, and effective bio-inspired, AI-driven cybersecurity and resilience framework specifically designed for 6G networks.

OVERVIEW

NATWORK presents the first economically viable, energy-efficient, bio-inspired and AI-powered cybersecurity and resilience framework designed for 6G. Its objective is to enable intelligent networking and services with minimum energy consumption while ensuring enhanced high trustworthiness, adaptability, and security. By integrating bio-inspired mechanisms and AI, NATWORK achieves real-time self-adaptability and resilience, including protection against Physical Layer threats. It also addresses the unique complexities and challenges of cross-sector business environments within 6G ecosystems. The project also focuses on critical cybersecurity use cases tailored to 6G networks.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

NATWORK's architecture mimics the stepwise operation of the biological immune system. Its first defense layer (figure) uses AI-based proactive mechanisms that dynamically alter the attack surface, deterring potential intruders. The second layer employs adaptive AI/ML models to classify detected threats, trigger mitigation actions, and continuously learn from past security incidents to predict and counter future threats. This approach enhances situational awareness and adaptability, creating an AI-driven cybersecurity autoimmunity system. Threat management operations are orchestrated with a focus on energy efficiency, security requirements, performance optimisation, ensuring seamless and uninterrupted network functionality.

	Biological processes	NATWORK components	
Physical barriers and innate immunity	Physical barriers (Skin, mucous, membrane, etc.)	AI-based MTD	Continually modifies attack surface to disrupt attackers Uses deep RL to optimise MTD strategies
	Prevent and kill invaders (phagocytes, iron sequestration, etc.		
Adaptive immunity (identification)	Antigen (feature) extraction by Antigen-Presenting Cells (APCs)	P4-based network analytics	Threat identification/classification
		AI-based intrusion detection	Continually modifies attack surface to disrupt attackers Uses deep RL to optimise MTD strategies
		Security monitoring	AI-based Intrusion detection Anomaly detection and classification
Adaptive immunity (mitigation)	T-cells (CD4+ Th1) clear infected cells	AI-based RIS configuration	Jammer detection and mitigation
	T-cells (CD4+ Th2) and B cells produce antibodies	ML-based MIMO	MIMO antennas and signal processing Jamming detection and mitigation
	Production of memory lyphocytes to remember invaders	AI-based anti-jamming	Detect, classify and respond to jamming attacks Learn from data and optimise response strategies
Laboratory-based acquired immunity	Vaccines for faster response	AI-based behavioural analysis	Controlled test environment Deploy, observe and analyze a Mirai botnet Train effective machine learning model
Situational awareness and cooperation of diverse components/ individuals	Situation awareness and cooperation (cytokines, lymphatic system	Security-compliant slice management	Cluster monitoring and evaluation of security requirements
	Genetic diversity to adapt better to invaders	Distributed federated learning across the continuum	Intelligence-driven information sharing within multi-tenant telecommunication networks
Immunity orchestration and regulation	Regulation/selective distribution of oxygen, glucose, fat, etc.	Energy efficient orchestration	AI-driven scheduling
		Attack resilient orchestration	Lightweight Kubernetes at the edge
	Balance immune response and overaction/inflammation	Security-by-design orchestration	Resource and workload management
		Security-performance balancer	Balances risks in radio interface vs. performance requirements due to traffic
		SecaaS	Security-as-a-Service Payload management Integrity and confidentiality

Mapping the biological immune system operations to the NATWORK architectural components

INNOVATION

NATWORK introduces modular architecture designed for secure, sustainable, and resilient 6G. It combines orchestration tools, advanced network and security functions, and AI-based Federated Learning agents, deployed across the cloud-to-edge continuum to enable bio-inspired security, resilience, and net-zero energy management. This is built upon a microservices-based paradigm to support dynamic resource distribution and meet the performance, scalability, security and interoperability requirements. NATWORK advances by employing Decentralised orchestration powered by AI/ML models for rapid decision-making, efficient threat mitigation, and energy optimisation. It utilises bespoke AI/ML-enhanced network cross-domain orchestration in core and radio domains, but also at large-scale deployments, to enable dynamic adaptation, optimised resource allocation, and enhanced performance. An open-source Proof-of-Concept framework is envisioned supporting a set of innovative features, such as extended service catalogues, advanced optimisation algorithms and cross-domain services.

USE CASES/ SCENARIOS

NATWORK will implement four use cases (UCs) to address critical 6G security challenges:

UC 1: Sustainability and Reliability of 6G Slices and Services- Focuses on: i) resilient orchestration of 6G Slices against denial of sustainability attacks, ii) Security-as-a-Service via with remote attestation, Web Assembly (Wasm) runtime verification, anti-cloning, and execution monitoring, and iii) intelligent green energy-aware payload placement for net-zero services. Key Performance Indicators (KPIs) include energy waste and latency per security operation.

UC 2: Anti-Jamming Technologies for Autonomous Vehicles – Protects Vehicle to Everything (V2X) networks from jamming attacks using multi-antenna/Reconfigurable Intelligent Service (RIS) setups and AI-driven detection and mitigation mechanisms. Enhancements include traffic re-routing, AI-powered adaptive modulation for autonomous recovery, and AI-based physical layer key generation for securing 6G bands. KPIs include attack detection/mitigation rates, recovery times, and downtime prevention.

UC 3: IoT security – Shields IoT networks from Distributed Denial of Service (DDoS) attacks with AI-powered anomaly detection and penetration testing. Distributed technologies will establish a secure and decentralised trust and access framework for 6G. KPIs include detection accuracy, mitigation time, network performance, trust establishment time.

UC 4: Continuous Security for Network Variability – Involves i) AI-driven optimisation of security function placement, ii) AI-aware Network slicing, iii) software-defined radio for agile payload communication, iv) AI-driven orchestration of microservices for high Quality of Service, v) explainable Moving Target Defense Strategies and vi) software control flow monitoring for DoS attacks detection. KPIs include processing latency, computational and energy efficiency, and resource utilisation.

Net-Zero self-adaptive activation of distributed self-resilient augmented services

NAT WORK

Coordinated by
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January 2024 – December 2026

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RESULTS

With expanded network coverage, 6G is set expected to revolutionise communication and support time-critical applications that benefit society. Security is a key concern in the 6G era, and NATWORK embraces this vision by introducing a bio-inspired cybersecurity system that integrates AI-driven security management and sustainable security solutions. It prioritises physical layer security with advanced anti-jamming technologies, while maintaining energy efficiency for net-zero operation in line with EU environmental goals. NATWORK's four innovative use cases tackle critical security challenges ensuring compliance with EU regulations such as General Data Protection Regulation and the Cybersecurity Act. By fostering a secure, sustainable and high-performance 6G ecosystem, NATWORK strengthens Europe's global leadership in 6G innovation.

ROBUST-6G

ROBUST-6G aims to address the new concerns posed by the dynamic nature of forthcoming 6G services and networks in the future cyber-physical continuum by developing data-driven, AI/ML-based security solutions.

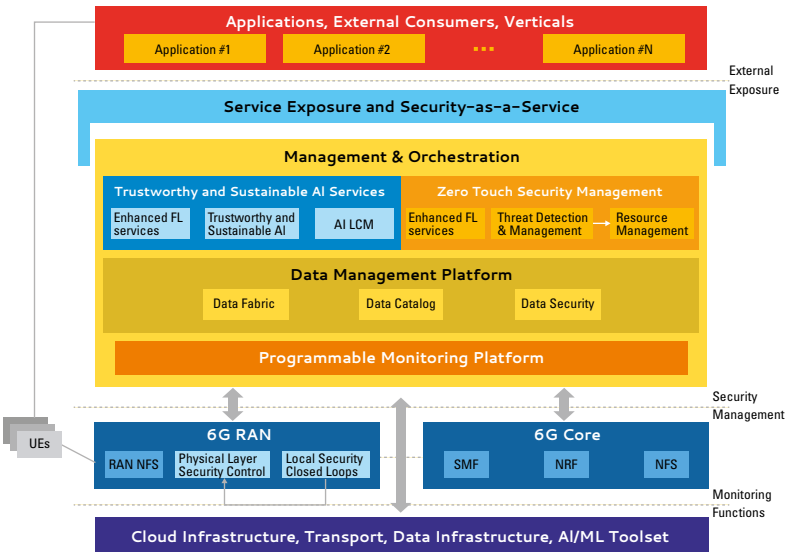
OVERVIEW

ROBUST-6G tackles the evolving security challenges of dynamic 6G network with AI/ML-based solutions. It enhances security and robustness of distributed intelligence while ensuring privacy and transparency. It promotes sustainable AI to optimise computation and minimise energy consumption without compromising performance of AI/ML based security solutions. The project enables zero-touch security and resource management for trusted services across multiple stakeholders. Additionally, it pioneers AI/ML-enabled techniques to counter physical layer (PHY) attacks and proposes novel security schemes tailored for 6G's low latency, low-energy and low-complexity requirements.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

ROBUST-6G's architecture consists of five core components: **1) The Data Management Platform** ensures secure data access and management, incorporating Data Fabric for processing and exposure, and Data Governance for access policies. **2) The Programmable Monitoring Platform** collects monitoring data from infrastructure and network functions to detect anomalies. **3) The Trustworthy and Sustainable AI Services Layer** integrates components to provide distributed, secure, privacy-preserved, and explainable AI services. **4) The Zero-Touch Security Platform** leverages AI-driven closed loops for autonomous threat response. **5) The PHY Security** utilising AI-based solutions for trustworthy PHY for 6G.

ROBUST-6G



Smart, Automated And Reliable Security Service Platform For 6G

ROBUST-6G

Coordinated by Güneş Kesik, Ericsson Turkey

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INNOVATION

ROBUST-6G has introduced key security innovations for 6G: 1) Federated learning-based IDS: Detects security threats via federated learning on network traffic and IoT data while preserving privacy. 2) Data Fabric: Manages secure collection, processing, storage, and exposure of security data. 3) Data Governance: Enables data cataloguing and access authorisation. 4) Security Capabilities Exposure via Network-Security-as-a-Service (NetSecaaS): Exposes ROBUST-6G's security services as a service for third-party applications. 5) PHY Authentication Module: Develops low latency AKA solutions, including false base station authentication. 6) Spiking Neural Networks simulator: Simulates spiking neural networks using PyTorch optimisers. 7) Robust Intrusion Detection System (IDS) Framework: Enhances IDS to detect/respond to PHY attacks. 8) Signal Identification as Attack Detection: Uses signal processing for cyber-attack detection. 9) Privacy-preserving Federated Learning (FL): Prevents data leakage and poisoning attacks. 10) Robust AI/ML against adversarial attacks: Defends AI models from evasion and poisoning. 11) Architecture and Signalling for Network Security: Automates security services like trustworthy AI and PHY security.

USE CASES/ SCENARIOS

ROBUST-6G innovations will be demonstrated through three use case (UC) scenarios.

1. **AI Model Trustworthiness Evaluation in 6G Distributed Scenarios**: This UC focuses on Distributed Federated Learning (DFL) for AI/ML training, incorporating trust dimensions such as robustness, sustainability, explainability, and fairness, alongside Physical Layer Security (PLS) measures. The goal is to develop AI/ML models that are robust to cyber threats, privacy-friendly and adaptable to dynamic 6G environments.
2. **Automatic Threat Detection and Mitigation in 6G-Enabled IoT Environments**: This UC addresses security needs in extreme edge IoT scenarios, leveraging advanced AI-driven, closed-loop security mechanisms for proactive, reactive, and predictive threat response. The ROBUST-6G's Zero-touch Security management and Orchestration Platform will ensure a resilient and self-adaptive IoT ecosystem.
3. **Security Capability Exposure via Network Security as a Service**: This UC builds on the GSMA Open Gateway framework to provide NetSecaaS and expands its functionalities by enabling application developers and enterprises to seamlessly integrate security policies by applying ROBUST-6G's advanced security capabilities. This UC will demonstrate how ROBUST-6G capabilities can effectively address diverse security needs, showcasing the seamless integration of advanced security measures into the network infrastructure.

RESULTS

ROBUST-6G has developed an advanced security architecture that integrates AI-driven security, automated threat detection, and zero-touch security management. The project includes a Threat Matrix, which analyses potential threats in 6G while analysing reviewing existing key threat detection and mitigation solutions. The DFL Framework enhances privacy-preserving AI training, enabling secure and decentralised learning while mitigating adversarial threats. ROBUST-6G has released a Library of Known PHY Attacks and PLS Datasets, addressing 6G PHY security. It maps datasets to key threats—like spoofing, tampering, and DoS—and introduces the RF Fingerprinting Migration Dataset for better authentication and anomaly detection.

To ensure a secure, resilient, and privacy-preserving 6G networks, integrated security automation across all layers is required. ROBUST-6G focuses on Trustworthy and Sustainable AI/ML for 6G Security, Zero-Touch Security Management, and AI/ML-Enabled PHY Security, ensuring real-time threat detection and response across all layers.

SAFE-6G

SAFE-6G pioneers a holistic research approach, situating a native trustworthiness framework atop the open and distributed USN/NSN-based 6G core, leveraging (X)AI/ML techniques to coordinate user-centric safety, security, privacy, resilience, and reliability functions, strategically optimising the Level of Trust (LoT).

OVERVIEW

The SAFE-6G project aims to develop a trust-driven, user-centric 6G ecosystem using cognitive frameworks, AI/ML techniques, and distributed architectures. Its objectives include:

1. Defining trustworthiness requirements for a human-centric, zero-touch 6G framework using distributed AI/ML across the edge-cloud continuum.
2. Developing cognitive coordination frameworks and Machine Learning operations (MLOps) tools for trust management and AI/ML optimisation.
3. Designing AI-assisted functions for safety, security, privacy, resilience, and reliability with a zero-trust approach.
4. Adopting cloud-native paradigms for compatibility with 5G/6G networks and edge-cloud systems like aerOS.
5. Validating SAFE-6G via Metaverse pilots to test configurations, trust levels, and AI/ML methods under security threats.
6. Promoting results via dissemination, standardisation, and stakeholder engagement for industry and regulatory adoption.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The SAFE-6G project aims to create a user-centric 6G network framework that provides a trustworthiness level based on user intent. By integrating AI and ML techniques, it coordinates novel functions for safety, security, privacy, resilience, and reliability, which reflect various trust dimensions. The architecture is adaptive, using a cloud continuum to deploy network functions close to users for efficient trust provisioning, tailored to individual needs. SAFE-6G avoids the "one-size-fits-all" approach and optimises the Level of Trustworthiness (LoT) as a key performance indicator for 6G.

INNOVATION

The SAFE-6G project introduces innovations to next-gen network architecture, enhancing user control, security, and adaptability. Key advancements include:

1. **User-Centric Architecture**: Shifts to user-focused models with User Service Nodes (USNs) and Network Service Nodes (NSNs) for personalised services.
2. **Edge-Cloud Continuum**: Scalable, low latency service deployment across edge and cloud environments.
3. **Enhanced Trust & Security**: Implements a zero-trust framework, AI-driven anomaly detection, and differential privacy.
4. **AI-Driven Optimisation**: Uses federated learning and MLOps for efficient AI/ML model management.
5. **Cloud-Native Design**: Modular, microservices-based architecture.
6. **Identity Security**: Blockchain and federated identity for secure access.

USE CASES/ SCENARIOS

To validate the SAFE-6G framework, two metaverse use cases (UCs) will be deployed on a small-scale SAFE-6G prototype for user-centric 6G service provision.

- **UC 1:** focuses on a Digital Twin (DT) of an industrial production line, enhancing trustworthiness with secure, resilient access in eXtended Reality (XR). This enables real-time updates and secure changes in production processes.
- **UC 2:** explores 6G's potential for hybrid education in XR+AI, improving hands-on learning with seamless collaboration and strong personal data security.

Both UCs will enable tailored trust aspects through real-time user interactions.

RESULTS

The SAFE-6G project introduces a user-centric, end-to-end cognitive trustworthiness framework to enhance trust in 6G networks. Unlike 5G, which focuses on security, SAFE-6G integrates safety, security, privacy, resilience, and reliability across the edge-cloud continuum, redefining trust holistically. The project outcomes include comprehensive reference architecture and key components for developing adaptive 6G systems that meet user needs. Features include dynamic orchestration, user-intent-driven configurations, and AI-powered trust functions, ensuring high performance and trust. These advancements aim to create trustworthy, adaptive 6G environments for complex use cases and AI-driven applications, addressing the limitations of 5G in scalability, trust, and adaptability.

SAFE-6G

Smart and Adaptive Framework for Enhancing Trust in 6G Networks

Coordinated by
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January 2024 - December 2026

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Verticals: Industry, Education and Training

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Stream B5

MICROELECTRONICS-BASED SOLUTIONS FOR 6G NETWORKS

Call 2 B5 projects will contribute to the strong push towards the advancement of European microelectronics in providing solutions for next-generation communication networks and devices at various levels of the device data processing chain, from baseband and mixed-signal processing to RF and antenna systems covering frequencies from sub-6 GHz to THz.

6G-REFERENCE

6G-REFERENCE targets transceiver hardware innovations enabling 6G densely distributed systems exploiting Distributed MIMO (D-MIMO).

OVERVIEW

The aim of 6G-REFERENCE is to develop hardware enablers constituting a reference design of distributed radios for a cell-free joint communication and sensing system operating in FR3 bands.

To allow for flexible deployment, fibre access cannot be taken for granted. Synchronisation in frequency and time over the air then becomes a key challenge. Moreover, improvements in data capacity are wanted, while also supporting distributed sensing functionality. Realising all this functionality in practical Integrated Circuit (IC) hardware with low complexity, cost, and power consumption is a key research and design challenge. We aim to show this is possible focussing on

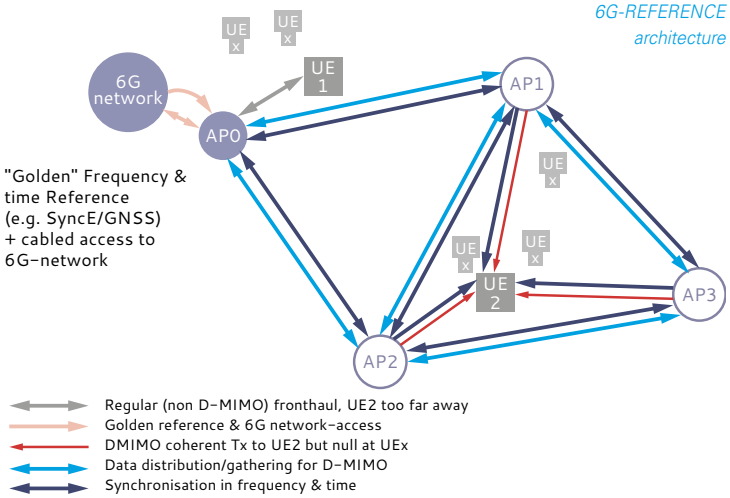
5 key project goals:

1. Coherent cooperative transmission to user terminals from a group of distributed RUs and efficient over-the-air (OTA) fronthaul data distribution amongst them.
2. Accurate Over-the-Air Synchronisation (OAS) of distributed Radio Units (Rus).
3. Accurate sensing and localisation using the same RU hardware platform.
4. Selectivity in the frequency and spatial dimension, to co-exist with other services in FR3 bands.
5. Sustainability in economic and ecologic sense, focussing of low power cost effective solutions.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The figure below shows simplified representation of the architecture with a cluster of D-MIMO wireless Access Points (AP) serving a single UE, while also providing fronthaul functionality. For flexible deployment, it is assumed that only one node (AP0) has high-speed fibre access.

6G-REFERENCE architecture



6G haRdware Enablers For cEll fRee cohEreNt Communications & sEnsing

Coordinated by Ignacio Llamas-Garro, Centre Tecnologic de Telecomunicacions de Catalunya

January 2021 - December 2026

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Partners: CTTC, Ericsson, University of Twente, CEA, Anteral, MTU Australo Alpha Lab, IMEC, Polytechnical university of Zurich, Advanced Circuit Pursuit AG, University of Birmingham.

INNOVATION

6G-REFERENCE explores the feasibility of Radio Frequency hardware concepts and develops IC hardware in Fully Depleted Silicon-On-Insulator (FDSOI) Complementary Metal-Oxide-Semiconductor (CMOS) technology and FR3-band Antenna Arrays to demonstrate functionality and assess achievable performance. The following innovations are explored:

1. In-Band MIMO full duplex transceivers and antenna arrays targeting:

- Enhancing Data capacity
- Solving scheduling challenges
- Enabling monostatic radar
- Reducing latency for communication and synchronisation

2. Novel synchronisation solutions to:

- Synchronise (SYNC) accurately in phase, frequency and time
- Synchronise quickly and continuously (FDSYNC)

3. Novel RF and antenna components:

- Time Modulated Arrays (TMA) to reduce power, complexity and cost
- Frequency Modulated Arrays (FDA) to increase positioning accuracy
- Reconfigurable Intelligent Surface (RIS) solution for beam steering, e.g. to reduce interference
- Antenna Arrays including environmental sensors

4. Dynamic filtering (Intermediate Frequency and antenna):

- Programmable Frequency selectivity exploring analogue Finite Impulse Reponse solutions
- Spectrum coexistence (10-15 GHz)

USE CASES/ SCENARIOS

In the first year, 6G use cases were reviewed and deployment scenarios proposed by key industrial associations and standardisation bodies. We examined the fit between 3GPP initial steps for 6G and the 6G-REFERENCE baseline scenario and RU architectures. Partly based on results from the HEXA-x-II project, the following best fitting use cases we identified for 6G-REFERENCE:

- Immersive communications
- Integrated sensing and localisation
- Time sensitive networks applications

We also define user scenarios fitting to the use cases:

- An urban square communication scenario with densely distributed RUs (Distributed Multiple Input Multiple Output deployment) for cell-free uniform coverage, while incorporating basic sensing capabilities
- A factory hall scenario with a more regular deployment grid supporting communication but also higher performance sensing capabilities
- A timing focused use scenario (Time Sensitive Network) with special focus on low latency, accurate frequency and phase synchronisation and high accuracy time stamping to UTC.

RESULTS

Based on the use cases and scenarios, initial system specifications were derived for main communication, sensing and timing synchronisation functionalities. Some initial results include:

- Selection of the 14.8-15.35GHz cm-wave band as target band with 50-400MHz channel bandwidths
- Definition of a deployment grid with about 25 m spacing between access points (urban and factory)
- Assessment of minimum antenna array sizes for communication and sensing applications
- Communication KPIs: 480 Mb/s per user, 43 Mb/s per m^2, 105 devices/km^2, 0.1-1 ms latency to fibre
- Sensing KPIs for industrial warehouse: 0.5m and 0.5m/s range/velocity resolution, 0.1s refresh time
- Synchronisation KPIs: resolution <2 ppb in frequency, <22.5° in phase, <100nsec in UTC time

FirstTo6G

FirstTo6G brings together European SMEs, universities, and consultancy to create a revolutionary 6G transceiver microchip technology.

OVERVIEW

FirstTo6G is developing the world's first 6G transceiver microchip technology, i.e. data converters and corresponding millimetre-wave front ends that fulfil the extreme requirements to make 6G a widespread reality. The consortium brings together European SMEs InCirT, Sivers Semiconductors AB and Argo Semi as well as leading universities RWTH Aachen and Yeditepe University and consultancy SCIPROM.

The project is designing and creating energy-efficient data converters with up to 16GHz instantaneous bandwidth and state-of-the-art frontend technology. They will be integrated into two full millimetre-wave transceiver chipsets.

FirstTo6G addresses key technological challenges related to the global introduction of 6G by 2030. Its results will contribute to 6G standardisation, and its demonstrators can be used in experimental radio devices for 6G trials.

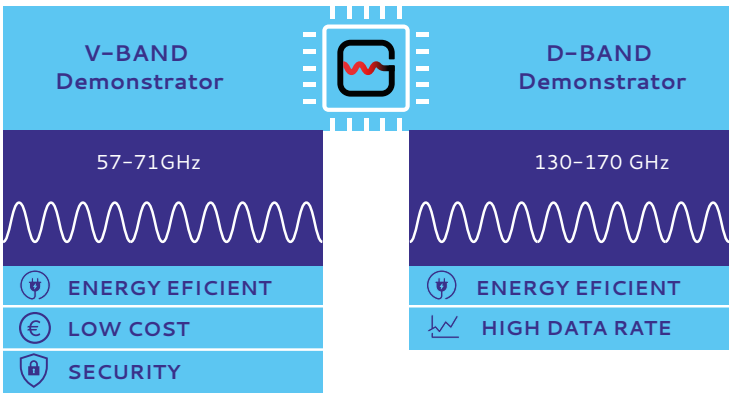
CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

FirstTo6G is working on Transcription and Reception Units (TRx) solutions for the V-band and D-band frequencies.

The project's architecture involves integrating breakthrough Fourier Domain Digital-to-Analog and Analog-to-Digital Converters (FDDACs/FDADCs) with new frontend technologies. The proposed V-band solution targets to integrate the complete transceiver in a single 22 nm-Fully Depleted Silicon On Insulator (FDSOI)-based chip and achieve a total instantaneous bandwidth of 8GHz. The proposed D-band solution targets a two-chip solution with data converters in 22 nm FDSOI and the frontend in silicon-based and III-V semiconductor technologies, achieving an instantaneous bandwidth of 16GHz.

With this project FirstTo6G addresses some of the biggest challenges in 6G.

The two demonstrators to be developed in FirstTo6G



INNOVATION

InCirT has invented a completely new and disruptive approach to data conversion called the Fourier-Domain DAC and the Fourier-Domain ADC. The key innovation lies in the data converter architecture, which allows to completely eliminate oversampling and digital filtering. Therefore, performance improvements are not any more reliant on the availability of more advanced semiconductor technology. In particular, this new approach allows achieving up to 100x higher instantaneous bandwidth than state-of-the-art with an up to 10x higher energy efficiency!

The 8-GHz DAC / ADC which will be developed for the V-band solution will already be a factor of >4x above today's state-of-the-art in terms of coherent instantaneous bandwidth. It will at the same time be much lower in energy consumption and cost. The cost reduction will be achieved by implementing the chip in the mature and cost-effective 22FDX technology. The 16-GHz DAC / ADC developed for the D-band will further double this performance!

USE CASES/ SCENARIOS

A successful adaptation of the technology developed in this project will contribute to the widespread adoption of 6G and therefore the availability of ultrahigh-speed wireless connectivity anytime anywhere. Smart cities will be equipped to optimise traffic by constantly exchanging data between vehicles, roads, pedestrians and traffic lights. Smart energy grids will be qualified to on-demand energy-based distribution and autonomous drones monitor infrastructure. AR/VR applications will reach new levels of resolution and realism, benefit from new sensing functionality and thus, become an integral part of our everyday live providing ultrarealistic mixed-reality applications wherever.

RESULTS

FirstTo6G will generate critical connectivity 6G chipset technology, which will overcome key technical barriers in terms of instantaneous bandwidth, energy efficiency and chipset cost. This technology will help to enable the widespread establishment of 6G networks.

In particular, the project will deliver two demonstrators for 8GHz and 16GHz modulation bandwidth systems for the V- and D-band frequencies. It will additionally yield novel automated circuit design software for frontend chips.

In its first year, FirstTo6G worked on design, system analysis and link budget, defined the exact architectures of the data converters, validate performance targets through model and worked on component design. The first prototype production date has been set for May-25.

FirstTo6G will contribute towards widespread availability of 6G networks, which will enable economic growth, increased productivity and thus, increased wealth and prosperity of society. It will further strengthen the European high-tech communication microelectronics ecosystem improving European technological sovereignty, independence, and security.

Fourier-Domain TRx solutions enabling widespread realisation of 6G

FirstTo6G

Coordinated by
Sebastian Waters, InCirt

January 2024 – June 2027

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Partners: InCirT, Sivers Wireless, Argo Semiconductors, Yeditepe University, RWTH Aachen University, SCIPROM

TERAGREEN

Towards Energy-Efficient High-Speed Wireless Links

OVERVIEW

TeraGreen will establish the foundations for future Tbit/sec communications systems by providing the understanding and Proof-of-Concept demonstrations of how the generation, detection and multiplexing of multiple ultra-wideband signals in the H-band can be realised with highly energy-efficient and scalable technological solutions. TeraGreen targets high-speed, energy-efficient wireless communication systems for line-of-sight backhauling and purpose-built fixed wireless access applications in future 6G networks. TeraGreen aims at two link demonstrations to show >200Gb/s capacities in medium-range links and a practical path towards >Tb/s capacities with an energy-efficient solution for the first time.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

TeraGreen is composed of a multi-disciplinary team assembled to deliver integrated Terahertz (THz) transmitter and receivers for Tb/s wireless point-to-point links with all the essential RF-hardware development capabilities to exploit the 252-325GHz band. In particular, the focus is on the:

- Development of THz transceivers with a new silicon technology reaching 500GHz cut-off frequencies to address the lack of commercial THz technology bottleneck.
- Development of quasi-optical antennas with ultra-high gain and alignment capabilities to address the high free space spreading loss bottleneck.
- Development of multi-beam lens arrays to reach spatial multiplexing enabling, for the first time, a path to achieve Tb/s links.
- Development of wideband waveforms suitable for energy-efficient 1-bit Analog to Digital (A/D) conversion with temporal oversampling for the exploitation of 100GHz bandwidth to address the A/D conversion power efficiency bottleneck.

INNOVATION

Europe does not currently dominate the entire connectivity vertical, including the smartphone industry. However, establishing a leading position in infrastructure and key service areas would provide Europe with unique opportunities to leverage its competitive expertise. This would enable Europe to shape future 6G infrastructures, standards, environmental strategies, and regulations in the communication-computing domain.

TeraGreen will contribute to this mission by ensuring that:

1. the project outcomes deliver key technologies with a long-term impact on RAN evolution, making it more energy-efficient, flexible and scalable than current deployments,
2. the project outcomes support EU suppliers in the communication and computing markets, enhancing their global competitiveness by providing hardware solutions and software algorithms that achieve cutting-edge performance in capacity, cost-, spectrum- and energy efficiency.

Towards Energy-Efficient Tb/s Wireless Links

TeraGreen

Coordinated by Marta Kluba, Delft University of Technology

January 2024 - December 2026

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USE CASES/ SCENARIOS

TeraGreen focuses on four use cases:

- **UC 1: Fronthaul in ultra-dense small cell networks**

  In ultra-dense small cell networks, TeraGreen tackles the challenge of delivering energy-efficient, high-capacity fronthaul solutions using THz communication. Small cells are essential for delivering high data rates and low latency in 6G networks, particularly in dense urban environments. However, the fronthaul links must handle massive amounts of data traffic. TeraGreen's THz-based solutions provide ultra-high bandwidth for these links, ensuring seamless communication while significantly reducing energy consumption.

- **UC 2: High throughput Fixed Wireless Access (FWA)**

  TeraGreen's high throughput FWA use case aims to provide ultra-fast, energy-efficient internet connectivity to homes, businesses, and remote areas using THz communication.

  By leveraging THz spectrum, TeraGreen enables multi- (Gb/s data rates, allowing users to experience fibre-like speeds wirelessly without the need for costly physical infrastructure.

- **UC 3: Live immersive Extended Reality (XR) at large-scale events**

  TeraGreen's XR use case focuses on delivering seamless, high-bandwidth experiences for large events, allowing participants to interact with virtual elements in real time, regardless the audience size. By using THz communication, TeraGreen ensures the ultra-low latency and high data rates required to support immersive technologies such as augmented reality and virtual reality at concerts, sports games, and conferences.

- **UC 4: Wireless data centres.**

  Finally, TeraGreen's wireless data centre use case aims to enhance efficiency and scalability innext-generation data centres by utilising THz communications. As demand for cloud computing, AI, and big data analytics grows, , traditional wired infrastructure can become a bottleneck in terms of speed, flexibility, and energy consumption. TeraGreen offers ultra-high throughput, low latency wireless links that can replace or complement fibre-optic connections within data centres, enabling faster data transmission between servers, storage units, and other critical components.

RESULTS

TeraGreen will position European telecommunications and microelectronics industries at the forefront over the next decade, reinforcing their already strong standing. Europe must regain leadership in semiconductors development and manufacturing while securing a stable supply of electronics equipment – both essential for critical societal functions and competitiveness in emerging business sectors. The project brings together cutting-edge disruptive technology with leading European expertseach contributing complementary skills and knowledge.

TeraGreen's success will drive significant advancements in the evolution of 6G communication networks. Specifically, it will act as a key enabler for long-term time developments, with an impact expected 5-10 years after project completion. TeraGreen can serve as a comprehensive backhaul solution for dense small-cell urban networks and purpose-built FWA applications supporting backhaul capacities ranging from 200-1000Gb/s. Its backhaul technology offers a viable alternative to wired fibre or microwave backhaul links for dense cells and microcells. By reducing the need to deploy extensive wired deployments – reserving them only for small-cell base stations without Line of Sight – TeraGreen enables cost-effective network densification. Additionally, thanks to its energy efficiency technologies, this densification can be achieved in a power-and eco-friendly manner.

Stream B6

EU-US 6G R&I COOPERATION: 6G-XCEL

The aim of 6G-XCEL is to seamlessly integrate AI to enhance the capabilities of the 6G network, while also ensuring the collaboration between EU and US stakeholders is concrete and productive.

6G-XCEL

The 6G-XCEL project aims to integrate AI into the development of 6G networks, focusing on decentralised AI controls in edge network use cases.

OVERVIEW

The 6G-XCEL project is leveraging AI to advance the design and operation of 6G networks and envisions addressing critical challenges in edge network use cases (UC).

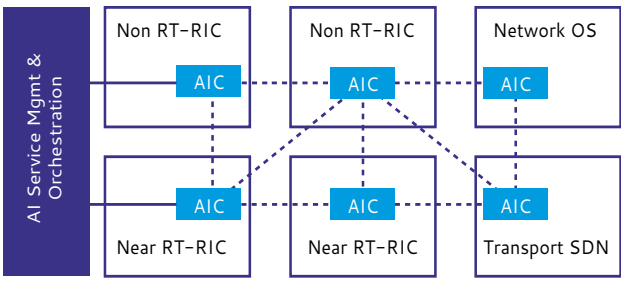
Its primary objective is developing a **Decentralised Multi-party, Multi-network AI** (DMMAI) framework to coordinate controls across radio and optical networks. This framework promotes global validation, standardisation, and sustainable AI-based network solutions. It also supports the creation of reference use cases, data repositories, curated training datasets, and benchmarking platforms for AI/ML solutions in 6G networks. To achieve this, 6G-XCEL unites EU and US researchers to validate and integrate the DMMAI framework into various testbeds and programs.

CONCEPT/ ARCHITECTURE

The 6G-XCEL project will provide a framework and tools for research and development of decentralised AI methods for network control extending across radio and optical networks and network domains. It builds on the O-RAN architecture as an open platform supporting multi-party applications (xApps/rApps) in a Radio Access Network Intelligent Controller (RIC).

It studies the application of AI-driven controls and their potential for 6G networks, enhancing the O-RAN architecture by extending its capabilities from the RAN to the optical domain, enabling AI-based control across the entire network spectrum. It focuses on benchmarking functionality across testbeds providing initial studies on the DMMAI framework addressing research critical challenges: energy efficiency, AI control loop time scales, scalable management of large-scale time series data, security and privacy in multi-party scenarios, and integration with AI orchestration platforms.

DMMAI Framework



INNOVATION

The 6G-XCEL project introduces cutting-edge innovations to drive the development of AI-powered 6G networks. Key advancements include a Decentralised AI framework for network control in radio and optical networks leveraging the O-RAN architecture to support multi-network applications and provide open tools for AI-driven 6G solutions across testbeds. The project also focuses on benchmarking of Zero-Touch End-to-End AI service orchestration platforms to automate and optimise 6G networks, enhancing resource efficiency, energy usage, and service quality for both aerial and terrestrial edge networks.

The project also focuses on energy-efficient transformers and online learning algorithms for processing large-scale 6G data while ensuring trust and explainability. Mechanisms for validating third-party AI models are being developed to enhance security in AI-native mobile networks. Additionally, energy-optimised DMMAI models, privacy-preserving federated learning, and real-time control over distributed RICs are advancing network intelligence, reliability, and sustainability.

USE CASES/ SCENARIOS

The 6G-XCEL project explores AI-driven spectrum and energy-efficient network management through two key UCs. In the first UC, researchers focus on AI-powered spectrum management across testbeds in OpenIreland, IMEC's CityLab, and the US-based COSMOS. Using the DMMAI framework, multiple independent networks can cooperate and coordinate spectrum usage via peer-to-peer and hierarchical AI/ML models. This approach creates a "spectrum control plane", optimising spectrum allocation, predicting traffic patterns, and adapting to real-time changes. Additionally, studies on mmWave communications will evaluate their performance under varying weather and environmental conditions, combining insights from radio and optical networks to develop smarter, adaptable systems for 6G infrastructure. These efforts highlight AI's potential to enhance connectivity, reduce interference, and ensure reliable communication in dense urban settings.

In the second UC, tested at the University of Patras, AI/ML models aim to optimise energy efficiency across network infrastructure while enabling seamless mobility between private and public networks. Leveraging Juniper's RIC, AI tools will analyse usage patterns to minimise power consumption and improve resource allocation. A custom translation layer integrates legacy network equipment with AI systems, enhancing control and coordination. The project prioritises secure interoperability between network providers during transitions for reliable connectivity.

These use cases demonstrate how AI and ML can tackle key challenges in future 6G networks. By developing intelligent spectrum management and energy-efficient solutions, the project is paving the way for faster, smarter, and sustainable wireless ecosystems, capable of meeting the demands of next-generation connectivity.

RESULTS

The 6G-XCEL framework will define network functions, design principles, and requirements for DMMAI control scenarios, ensuring flexibility for various implementations. It will develop and benchmark several reference implementations across its testbeds. Use case datasets, measurement methods, and results will be made available to support further research and standards creation. A major achievement will be fostering a transatlantic research network on AI and 6G, building a foundation for future advancements.

The project is developing an integrated AI control framework for future 6G networks, offering a flexible, scalable design with a publish-subscribe communication model for efficient control across fibre and wireless network segments. A publish subscribe architecture was presented at SIGCOMM 2024 and provides a basis for initial implementations and analyses.

Overall, the project will drive AI adoption in 6G networks while collaborating with standardisation bodies for global implementation.

6G Trans-Continental Edge Learning

Coordinated by Daniel Kilper, Trinity College Dublin

January 2024 – December 2026

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Verticals: Telecommunications (e.g. IoT) - Connected Vehicles (e.g., Transport and Logistics) – Healthcare – Education - Robotics

Partners: University of Patras, IMEC, Aalborg University, Sorbonne University, Fraunhofer HHI, IBM Ireland, Deutsche Telekom, Juniper, Dienekes

Stream C

COMPLEMENTARY SNS EXPERIMENTAL PAN-EU FEDERATED INFRASTRUCTURE: SUNRISE-6G

The stream C focuses on SNS system Enablers and PoCs with a target to further develop and consolidate Europe wide experimental infrastructure(s), in support of the various phases of the SNS. Federation of EU platforms is also targeted with capabilities to extend to non SNS test platforms, either at national level or with third countries.
SUNRISE-6G is the SNS Call 2 flagship project in this field.

SUNRISE-6G

SUNRISE-6G aims to develop an open, scalable approach for experimenting and deploying vertical applications within a Europe-wide 6G infrastructure network.

OVERVIEW

The SUNRISE-6G project aims to advance the development of 6G by integrating leading-edge technologies, ensuring seamless connectivity, and addressing societal and environmental challenges. It focuses on pioneering communication and sensing solutions, driving innovation in network architecture, and enhancing performance and sustainability with transformative UCs that underpin Europe's leadership in next-generation wireless networks. SUNRISE-6G aims to deliver a sustainable and evolvable Experimentation facility for 6G, federating Beyond-5G platforms and enablers from all over Europe under a common test, validation and vertical application deployment infrastructure.

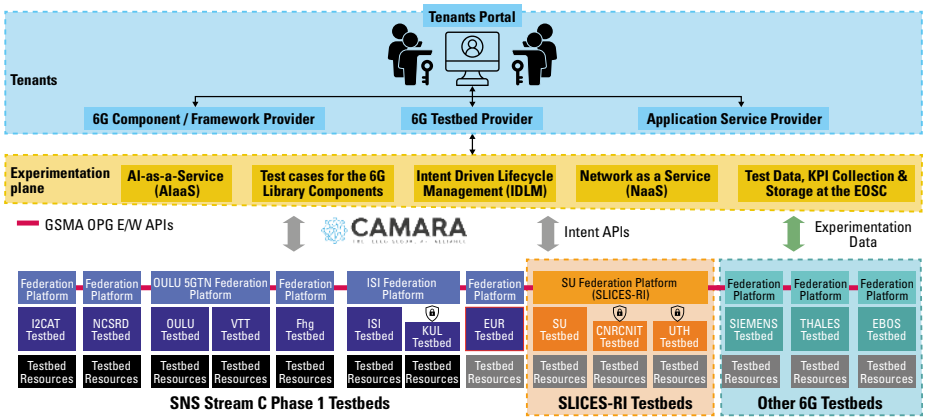
CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The SUNRISE-6G project envisions a novel architecture integrating communication, sensing, and computation into a unified ecosystem. SUNRISE-6G aspires to create a federation of 6G test infrastructures in a pan-European facility that will support converged Testing as a Service workflows and tools, a unified catalogue of 6G enablers publicly accessible by experimenters, and cross-domain vertical application onboarding. The architecture supports dynamic scalability, ultra-low latency, and energy efficiency, ensuring adaptability to diverse applications and industries. Core technologies include advanced network orchestration, multi-access edge computing, and enhanced spectrum management, setting the foundation for transformative 6G services.

INNOVATION

SUNRISE-6G embraces the "network of networks" vision of 6G, aiming to unify public and private infrastructures under a scalable, internet-like

SUNRISE-6G architecture design



architecture. It will deliver a pan-European experimentation platform featuring Integrated Sensing and Communication for context-aware services, AI-driven network management, a modular end-to-end 6G architecture adaptable to diverse needs, seamless integration of non-terrestrial networks, and energy-efficient, sustainable solutions.

USE CASES/ SCENARIOS

- **UC 1: "Federated Metaverse"**

  Real-time holographic communications in eXtended Reality (XR) environments promise to become a dominant social interaction, collaboration and communication medium in the years to come and an essential enabler towards the Metaverse. SUNRISE-6G will count on a worldwide pioneering platform, "HoloMIT", which can provide real-time multiuser holographic communications with realistic and volumetric user (self and others) representations using low-cost and off-the-shelf XR capture and rendering hardware.

- **UC 2: "Collaborative Robotic Exploration of Mining Environments"**

  The federation of Private Networks within an overarching 6G ecosystem ("Network of Networks" concept) with applications in harsh and demanding mining environments. This scenario showcases the AI Plane federation concept, allowing the testbed to operate as the AI as a Service "Supernode". Thus, it can assist the resource-constrained site in zero-touch infrastructure optimisation tasks.

- **UC 3: "Federated NTN" (Non-Terrestrial Networks)**

  Experiment 1: Mobile Industrial Assets supported by NTN Edge Cloud and Communications

  Experiment 2: Multi-Operator and Multi-Access in NTN

  Integrating NTNs with terrestrial networks ensures service continuity and scalability for Beyond 5G.

  Experiment 2 explores:

1. Inter-PLMN handover—UE transitions from terrestrial (Operator A) to satellite (Operator B) 3GPP access, maintaining session continuity.
2. Dual-connectivity using MultiPath TCP to merge terrestrial and emulated satellite paths into a single connection.

RESULTS

SUstainable federation of Research Infrastructures for Scaling-up Experimentation in 6G

Coordinated by
Christos Verikoukis,
ISI/Athena Research Centre

January 2024 - December 2026

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Partners: ISI/ATH, IQuadrat, Siemens, Thalès, IBM Ireland, INTRACOM, Juniper, UOULU, NCSR "DEMOKRITOS", KU Leuven, Eurecom, Fraunhofer, i2CAT, Greenerwave, Infolysis, Fogus, Sorbonne University, CNR, University of Thessaly, OTE, eBOS, NH APPART, Lulea University of Technology, VTT, Lenovo, Altice Labs, CNIT, ISRD

Project Phase 2 started with the implementation of the 6G Library of components and the main frameworks of the Facility, which are part of the Experimentation and the Federation Plane. The implementation of breakthrough components (e.g., Joint Communication and Sensing, Near-Field RIS) follows an iterative process of scientific innovation and measurement-based analysis at testbeds that will generate the first high-quality datasets for the E2EAI framework. Phase 2 concludes with integration and federation, where 6G components are integrated with the UCs and Test cases, and the testbeds are federated in an E2E facility and the Experimentation and AI Plane.

Through the final year, we will proceed with the establishment and setup of the validation of the Federated Experimentation platform and the different assets of the 6G library with iterative and parallel execution of targeted UCs initially and via 2 hackathons to be performed and to ensure that potential feedback improvements are applied to all SUNRISE-6G components, thus enabling iterative refinements to ensure target KPIs are met.

SUNRISE-6G envisions transformative outcomes in connectivity, sustainability, and societal impact. It aims to deliver ultra-fast, low latency networks for applications ranging from smart cities to healthcare while cutting energy consumption. 6G will meet future demands for ubiquitous, high-speed, real-time connectivity, supporting Europe's digital and green transition and driving innovation, efficiency, and economic growth.

Stream D

LARGE SCALE TRIALS AND PILOTS WITH VERTICALS-FOCUSED TOPIC

The stream D targets large-scale SNS Trials and Pilots with Verticals, including the required infrastructure. Projects are expected to explore and demonstrate technologies and advanced applications and services for the vertical domains focusing on two priorities less covered in the previous call, namely i) Automotive and ii) Health, Smart Cities, Farming or Education.

6G-PATH

6G-PATH focuses on developing innovative infrastructures, delivering and refining an experimentation platform, expanding user communities, and shaping the future of 6G through research and standardisation efforts.

OVERVIEW

In the B5G/6G transition it is vital that requirements are set and new and demanding Use Cases (UCs) are specified, as a means of setting 6G challenges and for supporting validation in realistic and market-oriented scenarios. Against this backdrop, 6G-PATH's main goal is to help foster the development and integration of new and improved tools/products from EU companies within B5G/6G, while also measuring relevant KPIs & KVIs. 7 testbeds are part of the consortium, which are used by 10 use cases across the 4 "key" verticals.

A portion of the budget is used for FSTP, where the goal is the integration of 2 new Pilot Sites, extension of the testbeds with 10 additional technologies, as well as 30 new UCs through Open Calls, to further involve the community and obtain more metrics and outcomes.

6G-PATH works closely with other ongoing/starting Stream B and Stream C projects to this aim.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The core architecture is on the 6G-PATH platform, offering a unified environment for UC partners to configure, schedule, execute and analyse experiments, abstracting testbed operations through middleware and backend tools. Pilots and UCs define service compositions, schedule experiments and analyse collected metrics. Northbound APIs ensure programmability, flexibility and interoperability, using open-source standards. The Portal allows UC owners to plan, execute and monitor experiments via tools like the Experiment Scheduler, AAA and the KPI/KVI Dashboard. Backend manages testbed operations through Southbound APIs, by integrating components like Infrastructure Management, AIaaS, Security aaS and Monitoring. Southbound APIs standardise backend operations for seamless communication with diverse testbed infrastructures enable experimentation with potential expansion through Open Calls.

6G-Path

6G Pilots and TriAls Through Europe

Coordinated by Ioannis Chochliouros, Hellenic Telecommunications Organisation S.A. (OTE), Greece

January 2024 – December 2026

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Verticals: Smart Cities, Education, Health, Farming

Partners: OTE, Telefonica ID, Orange Romania, Airbus DS, HPE- Italy, University of Malaga, Karlstads University, Charité – University Hospital of Berlin, University of the West of Scotland, University of Bradford, Altice Labs, Fraunhofer FOKUS, Instituto de Telecomunicaçoes, ICT-Ficial, OneSource Consultoria Informática, RedZinc Services, Odin Solutions, eBOS, Apart AE, F6S Network Ireland, Orange Romania Foundation, MCS Data Labs, ACTA, Terraview, CloudSigma,

INNOVATION

6G-PATH builds on results previous research, advancing low Technology Readiness Level developments into a state-of-the-art experimentation platform. It integrates with testbeds and evolves alongside internal use cases and Open Call innovations. Key integrated innovations include AI-driven networks, intelligent cross-domain continuum management and 6G RAN prediction capabilities, aiming to move from centralised processing to ubiquitous intelligence, using distributed and federated learning. Localisation innovations, with precision moving from 10 cm 2D to 1 cm 3D, will support XR technologies, the Internet of Senses and ultra-precision manufacturing. Testbed developments will be complemented by selected UCs in 6G-PATH verticals. The UCs will evaluate the integration of AI, Edge-Cloud computing, XR, ultra-low latency and high-bandwidth capabilities, supporting applications such as smart farming, immersive education, healthcare monitoring, large-scale IoT, and the resilience, safety and security required for public safety and emergency applications. 6G-PATH will "enable" ground-breaking advances in network capabilities, fostering innovation across various sectors.

USE CASES/ SCENARIOS

6G-PATH encompasses 10 UCs spread across 4 verticals.

- **Smart Cities:** i) Connected and sensing city; ii) automated logistics, and; iii) security coordination. This vertical focuses upon large-scale IoT-Edge-Cloud integration to support, inter-alia, mission-critical communications (MCX), extreme video/data streaming and high quality of service (QoS) features such as URLLC and mMTC. These UCs will evaluate deterministic, reliable and high-resolution services as well as resilience and security for next-generation networks, particularly in the context of Public Protection and Disaster Relief and for emergency-related applications.
- **Education:** i) XR rural schools; ii) the classroom of the future, and; iii) XR Health Training. It is devoted to immersive XR (incl. AR, VR and MR), holographic-based education and training scenarios. Specific focus is set on leveraging edge computing, location-sensitive processing and AI-driven capabilities for advanced video and data processing to support KPIs and QoE measurement. The main goal is to revolutionise education by providing innovative and interactive AI-based learning experiences.
- **Health:** i) 3D hydrogel patches, and; ii) elderly monitoring. It examines micro and nomadic edge nodes and networks to enable ultra-high bandwidth, ultra-low latency communication as well as secure data exchange between edge-core and core networks. The UCs are designed to support advancements in healthcare through secure, real-time monitoring and precision treatments.
- **Farming:** i) Water-saving techniques and; ii) smart vineyards. It assesses off-grid, intermittent and interconnected deployments with focus on network slicing via the support of different types of QoS (eMBB, URLLC, eMTC) and AI-driven edge-cloud computing integration to optimise agricultural practices and improve sustainability.

RESULTS

6G-PATH aims to refine E2E 5G Advanced and 6G test infrastructures. It will validate key technologies and architectures. For this, the project has carefully selected UCs of real market interest in relevant verticals. 6G-PATH will promote viable business models and will provide contributions to standardisation bodies, thus driving progress and highlighting advancements/ breakthroughs at a global scale. 6G-PATH will stimulate large industrial stakeholders to engage in experimental activities, fostering collaboration and industry-driven innovation. It will contribute to open-source tools for reuse and create a repository of requirements and lessons learned to guide future resilient next-generation network developments.

ENVELOPE

ENVELOPE aims to advance and open up a reference 5G advanced architecture and transform it into a vertical-oriented one.

OVERVIEW

The main objective of ENVELOPE is to advance and open up the reference 5G advanced architecture, transforming it into a vertical-oriented system with the necessary interfaces for Connected and Automated Mobility (CAM) Use Cases (UCs) that i) expose network capabilities to verticals, ii) provide vertical-information to the network; iii) allow verticals to dynamically request and modify certain network aspects in an open, transparent and semi-automated way. ENVELOPE aims to deliver three large-scale Beyond 5G trial sites in Italy, Netherlands and Greece, implementing features tailored to the CAM services and advanced exposure capabilities. While focused on CAM, the developments will be reusable by other verticals. ENVELOPE capabilities will be demonstrated through the project's CAM UCs and at least nine open call projects.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

ENVELOPE aims to advance the reference 5G advanced (B5GS) architecture by making it more tailored to specific verticals This is achieved by integrating interfaces that expose advanced network capabilities to verticals, provide the network with information from verticals and allow verticals to dynamically request and adjust certain network features. The figure next page illustrates the project's architectural approach of the project to achieving this goal. ENVELOPE enablers offer important network capabilities to CAM applications: ENVELOPE APIs simplify/abstract access to the corresponding complicated 5GS interfaces and services. A MANO layer enables the Experimentation as a Service framework which formalises testing and experimentation across available resources, including the Far Edge.

INNOVATION

ENVELOPE introduces innovative support for advanced network features while simplifying interactions between vertical services and 5GS. Although applicable to various industries, these features are designed with a focus on automotive services.

Key features include Dynamic Slicing, applications can request or release network resources on demand; Predictive QoS, Provide performance forecasts, enabling applications to take proactive actions; Traffic management, supports applications managing traffic between 3GPP and non-3GPP interfaces (Access Traffic Steering-Switching-Splitting (ATSSS); Service & session continuity, including edge service level solutions such as Service Migration; Automated (zero-touch) control loops, reduces manual intervention by automating network adjustments. ENVELOPE aims to deliver these features via user-friendly APIs that hide the complexity of the underlying 5GS APIs.

Evaluation and validation of connected mobility in real open systems beyond 5GS

ENVELOPE

Coordinated by
Angelos Amditis, ICCS

January 2024 - December 2026

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Verticals: Automotive: Connected car – V2X and Autonomous driving

Partners: ICCS, Commsignia, LINKS Foundation, NCSRD, University of Duisburg-Essen, TNO, Athena Research Centre, VICOMTECH, OTE, KPN, TIM, Teoresi, ISFM, HPE, Siemens, Lenovo, Nextworks, FOGUS, IQuadrat, eBOS , InCites, ERTICO

USE CASES/ SCENARIOS

ENVELOPE's technological innovations will be validated in three large-scale trials.

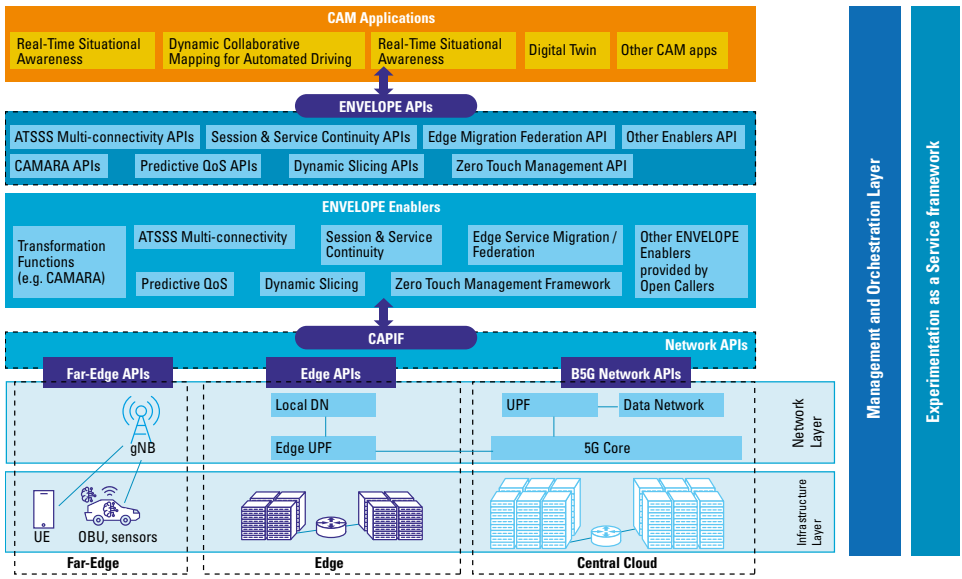
The Italian site considers two UCs focusing on advanced in-service reporting for Automated driving Vehicles (AVs) and dynamic collaborative mapping for automated driving, emphasising real-time accident data reporting and continuous High-Definition map updates. In both UCs, vehicles send raw sensor data to edge applications during specific events, requiring network reconfiguration for data sharing and processing.

The Dutch site investigates three UCs focusing on periodic vehicle data collection for improving digital twins (DT), vehicle testing with mixed reality, and teleoperated driving aided by DT. Combined with advanced V2X/V2N communications, DT enables the study and optimisation of real-world UCs in a virtual environment.

The Greek site focuses on Multi-Access Edge Computing (MEC) service handover between multiple mobile network operators, ensuring seamless service continuity and exploring data sharing for real-time situation awareness. The UC falls under the scope of Local Hazard and Traffic Information 5GAA CAM UCs category.

RESULTS

ENVELOPE aims to provide the community with a well-defined set of technology enablers and vertical-friendly APIs that support a more flexible interaction with the network. The project places significant focus on sharing and extensively validating these advancements both through open-source solutions and the establishment of three experimental facilities. The latter will enable extensive experimentation and technology solution validation in the context of the ENVELOPE Cooperative CAM UCs, offering valuable insights on the functionality and use of the corresponding features in realistic conditions. Building on these established facilities, the project's Open Calls will create a feature-rich experimentation environment. This allows third-parties to validate the provided solutions in various conditions or industries, and test additional technology enablers and interfaces.



ENVELOPE Architecture -- The ENVELOPE APIs simplify the interaction of vertical services with a series of advanced technological enablers delivered by the project. The Experimentation as a Service framework facilitates extensive testing.

SNS SOCIETAL CHALLENGES

The three Streams of the Call 2 are complemented by the SNS Coordination and Support Action (CSA) 6G4Society which aims at dealing with societal challenges related to SNS technologies.

6G4SOCIETY

Bridging Technology and Societal Values in 6G Development.

OVERVIEW

The 6G4Society project aims to address the challenge of balancing two competing needs in the technological development of 6G: **securing technology performance objectives while ensuring that societal and sustainability values are properly embedded into technology**.

The main objectives are:

- Generating a better understanding and shared knowledge on the aspects influencing public acceptance of 6G technologies.
- Supporting the conception and development of a unified EU consensus framework centred on a value-based, sustainable, and ethics-driven approach of 6G, promoting it throughout the European and international standardisation and regulation domains.
- Engaging and reaching out to public audiences to build 6G social acceptance, while engaging technological players in accounting by design for equity, diversity, inclusion and sustainability.
- Empowering the 6G community to reflect EU policy and legislation in technology solutions for the development of future human-centred and sustainable networks and services.

Acting as a hub within the 6G SNS community to help all ongoing projects align on common societal and environmental priorities, Key Value Indicators (KVIs) and Key Sustainability Indicators (KSIs).

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

6G4Society aims to promote a multidisciplinary, complementary approach to future technology development. The project applies methodologies from ethics, legal, and social science and humanities (SSH) disciplines, allowing the comprehension of socio-cultural aspects and mechanisms behind 6G technology and laying the foundation for responsible research and innovation of 6G technology. Based on these methodologies, 6G4Society provides frameworks, models, guidelines, policy suggestions and operational recommendations to develop sustainable and socially accepted 6G technology and applications.

INNOVATION

6G4Society conveys these complementary and multidisciplinary aspects operating on three main layers of action, interwoven throughout the comprehensive project work plan:

1. **Content**: Creating knowledge and providing advice on social and ethical thematic aspects relevant to 6G development, working especially on KVIs/KSIs, and on the definition of a Technology Acceptance Model.
2. **Processes**: Contributing to key innovation processes within the 6G ecosystems exploitation and uptake (such as engaging in standardisation discussions, project pilots, living labs, and working groups), thereby channeling knowledge and multidisciplinary perspectives.
3. **Social Dynamics**: Addressing barriers and challenges related to the information and communication context through targeted communication and engagement activities.

USE CASES/ SCENARIOS

Given that societal acceptance and environmental sustainability are crucial for the successful development and adoption of any technology, the work 6G4Society will undertake is of relevance across multiple verticals. It will offer valuable insights into 6G deployment, applicable to a wide range of use cases and scenarios. By collaborating closely with other ongoing 6G SNS projects—such as through the 6G SNS Sustainability Task Force and the 6G SNS Vision, specifically within the Societal Needs and Value Creation (SNVC) sub-group—the goal is to communicate in a transparent way the potential benefits and trade-offs 6G can bring to market players and society.

RESULTS

The 6G4Society planned results include a **Social Acceptance Model for Technology (SAT) tailored for 6G technology,** a **framework outlining Key Sustainability Indicators,** along with **policy and operational briefs**, providing recommendations to other players in the 6G SNS ecosystem and beyond. They will be validated with all 6G-SNS JU projects by adopting a public and user engagement methodology, alongside the 6G-IA Working Groups and their connected projects.

These efforts pave the way for wider scale and longer-term impacts, notably the **downstream exploitation of 6G**, the **ethical and sustainable development of 6G, larger public validation**, and wider social acceptance. Central to achieving these impacts is **increased awareness**, promoted across diverse stakeholder groups through various means and on different aspects depending on the issues and barriers addressed. This awareness, in turn, is expected to facilitate **openness and acceptance** across the different stakeholders, leading to the longer impacts mentioned above.

The long-term impact of 6G4Society

Briging Technology and Societal Values in 6G Development

6G4SOCIETY

Coordinated by Monique Calisti, Martel Innovate

January 2024 – December 2025

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Verticals: The project will explore societal and sustainability values across numerous verticals

Partners: Martel, Digital for Planet, eBOS, NOVA, CyberEthics Lab, PSCEurope

Call 3 Projects

The SNS JU Call 3 received an enthusiastic response, with requested grants totalling €863 million, more than 7 times the available funding. The 16 selected projects in Call 3 support 301 beneficiaries from 25 countries in developing and deploying next-generation network infrastructure, platforms, and services.

Stream B

WIRELESS COMMUNICATION TECHNOLOGIES

The focus of stream B is on wireless communication technologies. It is divided in eight sub-sections for a total of twelve projects.

Stream B1

SYSTEM ARCHITECTURE

FLECON-6G

Enabling Scalable, Intelligent, and Collaborative 6G Networks.

OVERVIEW

The FLECON-6G project envisions an Intelligent 6G Network of Networks that seamlessly integrates Native and Trustworthy AI and empowers the automated and scalable orchestration of services and capabilities across diverse networks, subsystems, and technological domains, fostering collaboration among multiple stakeholders.

The project aims to i) develop and deploy an innovative 6G architecture integrating public/private sectors & terrestrial/non-terrestrial components ii) develop native AI algorithms for intent-driven, multi-stakeholder networks, ensuring generalisability and uncertainty quantification iii) enable sustainable resource sharing through a Smart Marketplace for MNOs, infrastructure owners, and developers iv) develop and integrate a multi-layer Network Digital Twin (NDT) framework within a Zero-Touch 6G network architecture v) develop innovative data transfer paradigms with advanced techniques and deep Edge integration vi) establish a collaborative, distributed framework for dynamic, multi-domain 6G networks of networks vii) validate FLECON-6G innovations through targeted experimentation and testing in Proofs-of-Concept (PoCs).

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The FLECON-6G project introduces a modular, distributed 6G architecture with NDT for real-time monitoring and efficient resource management. It integrates Native AI for zero-touch operations and intelligent service composition, with intent-based Application Programming Interfaces (APIs) enabling seamless automation for stakeholders.

Key technologies include AI-as-a-Service (AIaaS), Digital Twin-as-a-Service (DTaaS), edge computing, and network slicing. Moreover, the Smart Marketplace improves access to resources and supports sustainable business models. These innovations create a high-performance "Network of Networks", supporting use cases in automotive, industry, healthcare, and public safety.

INNOVATION

The project introduces Multi-layer NDTs for real-time monitoring and analytics, optimising multi-domain 6G networks. Intent-Based APIs enable scalable service orchestration and seamless resource management.

The Smart Marketplace facilitates resource sharing through models like AIaaS and DTaaS. Native AI ensures zero-touch, self-optimising operations using trustworthy algorithms.

A Collaborative Architecture supports multi-domain coordination, while advanced data transfer paradigms enhance efficiency with edge integration. The integration of Non-Terrestrial Networks (NTNs) combines terrestrial and satellite systems, offering scalable connectivity for underserved areas. The user-centric design ensures accessibility and usability through responsive, inclusive interfaces.

USE CASES/ SCENARIOS

The FLECON-6G project includes four PoCs showcasing advanced 6G technologies:

- **PoC 1: Seamless Immersive Reality (SIR).** Combines Virtual, Augmented and Extended Reality (VR, AR, XR) to create multi-sensory experiences, enhancing entertainment and education through real-time, interactive environments. Focuses on high-bandwidth, low latency communication for seamless integration. Provides services in many fields from entertainment to education.
- **PoC 2: Machine Inspection with Autonomous Robots and VR**. Uses VR-enabled robots for efficient anomaly detection during inspections. Ensures reliable video quality in varying wireless conditions, enabling effective remote operations.
- **PoC 3: Network Digital Twin with Non-Terrestrial Networks**. Integrates NDTs with NTNs for real-time monitoring and control in remote areas. Allows immediate configuration adjustments for consistent connectivity.
- **PoC 4: Public Safety Services**. Improves emergency communication systems with low latency, secure solutions. Addresses infrastructure limitations to ensure reliable performance in critical scenarios. Provides public safety solutions to meet high-performance demands during emergencies.

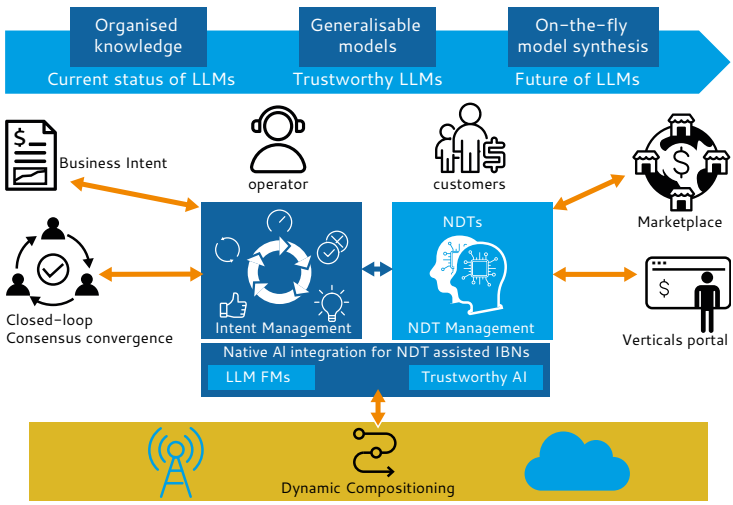
ENVISIONED RESULTS

The FLECON-6G project aims to develop a modular, distributed 6G architecture featuring multi-layer Network Digital Twins for real-time monitoring and optimisation. It introduces a Smart Marketplace to enable resource sharing and supports innovative models like AIaaS and DTaaS. Native AI integration ensures scalable, automated service orchestration, enhancing communication systems' efficiency and adaptability.

These advancements will be validated through targeted PoCs.

6G is critical to addressing limitations in current networks regarding trustworthiness, sustainability, and interoperability. It meets rising demands for ultra-reliable, low latency communication in key sectors like healthcare, industry, and public safety while enabling advanced applications such as immersive reality and autonomous systems.

FLECON-6G high-level Vision



Flexible Open Architecture and AI-driven Enabling Technologies for a Novel 6G Connectivity Platform

FLECON-6G

Coordinated by
Christos Verikoukis, ISI/ATH

January 2025 – December 2027

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Verticals: Automotive, Industry, Media and Entertainment, PPDR, Health

Partners: ISI/ATH, EURECOM, CNIT, Technical University of Delft, UCLAN Cyprus, EBOS Technologies, IQuadrat, NeXtworks, Brainstorm Multimedia, E-Lighthouse Network Solutions, Real World Eastern Europe, Airbus DS, Ericsson, LENOVO Germany , NVIDIA Denmark , Siemens , Orange Romania, OTE, Telefonica ID

UNITY-6G

Pioneering Sustainable, Scalable, Intelligent and Integrated 6G Networks.

OVERVIEW

UNITY-6G project aims to transform 6G network development by integrating cutting-edge technologies and innovative architectures. It emphasises scalability and sustainability across integrated networks, including Non-Terrestrial and Terrestrial Networks, xhaul, Open RAN, Non-Public Networks, Edge, Core and Cloud. Key advancements will include; i) **AI-native architectures** that leverage machine learning to automate and optimise network operations, enhancing performance and reliability, ii) **Digital twin technology** for real-time simulations and network management of, improving adaptability and resilience, iii) **Renewable energy integration** via smart grid interfaces to enhance efficiency and reduce environmental impact. By addressing the evolving demands of next-generation telecommunications, UNITY-6G lays the foundation for a sustainable, scalable, intelligent, and trustworthy 6G network infrastructure supporting future digital applications.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The UNITY-6G architecture embodies a sophisticated, multi-layered approach to building an integrated and intelligent 6G network, **Infrastructure layer**: Comprising both traditional and integrated network components, it also includes Virtual Power Plants (VPP) and Time-Sensitive Networking (TSN) elements, ensuring efficient energy management and precise timing across the network, **Edge-Cloud Continuum layer**: bridges centralised and edge processing, enabling faster and more efficient data processing and storage closer to the end-users, **Management and Control layer**: using AI-driven smart service orchestration, it automates complex decision-making processes and dynamically optimises network resources for improved efficiency and service quality, **Digital Twin layer**: creates virtual replicas of network resources allowing real-time simulation and testing of network scenarios, improving predictive maintenance and operational resilience.

INNOVATION

UNITY-6G stands out for its innovative contributions to 6G networks development, focusing on sustainable, scalable and intelligent operations. It utilises AI-native architectures for dynamic resource management and predictive maintenance to increase network efficiency and reliability, especially in dynamic and challenging conditions and develops a service-based architecture that supports seamless interaction across heterogeneous network domains including Non-Terrestrial Networks, xhaul, Open RAN, and Edge, Core, and Cloud systems. It also introduces digital twinning for network management, enabling real-time performance simulations and proactive adjustments to improve resilience and service delivery focusing on creating common interfaces and protocols for seamless communication across different domains. Additionally, UNITY-6G integrates renewable energy sources with smart grid interfaces, advancing sustainable grid operations and improving resilience to natural disasters.

USE CASES/ SCENARIOS

UNITY-6G has identified four key use cases aligned with its ambitious goals:

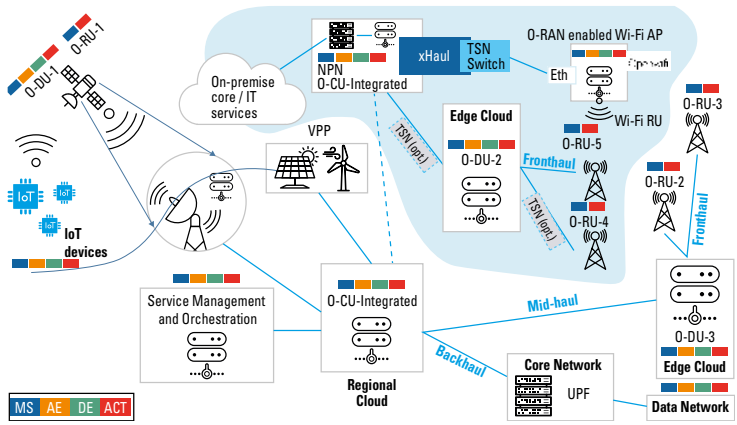
- **UC 1: Sustainable networks for disaster handling**. Developing sustainable networks that maximise alternative power sources (solar, wind) through coordination with local microgrids. These networks leverage service-based architecture for efficient resource use and flexible service deployment,
- **UC 2: Immersive experience with real-time Extended Reality (XR)/holographic communications**. Designing a semantic-aware 6G network optimised for real-time holographic communications. The focus is on performance, minimal latency, high-quality user experience, and energy efficiency,
- **UC 3: Digital Twin for integrated 6G network evaluation**. Leveraging Digital Twin for testing and rapid deployment of novel 6G services, assessing future scenarios and deployment options, testing the impact of configuration and function changes in 6G communication systems, simplifying and accelerating site deployment configuration, enhancing transport, satellite, and radio resource management, enhancing operations of edge-cloud continuum, tackling issues of trustworthiness and resiliency, and effective network orchestration and management in 6G communication networks,
- **UC 4: Multi-RAT O-RAN enabled NPN for supporting time sensitive application for Industry 4.0**. Developing a multi-Radio Access Technology (RAT) RAN tailored to 6G NPN architectures, integrating cellular and IEEE 802.11 technologies. The goal is to support low latency and high reliability communication in an industrial setting, where industrial automation application span in end-to-end wired-wireless and across different RATs domains.

ENVISIONED RESULTS

UNITY-6G envisions groundbreaking advancements in 6G networks, emphasising sustainability, intelligence, scalability and trustworthiness. Key technologies include i) **AI-native architectures** that dynamically optimise operations enhancing efficiency and reliability, ii) **digital twin technology** for real-time simulations and proactive management, improving resilience and adaptability, iii) **distributed ledger technology** to ensure secure and transparent resource sharing, fostering trust among network participants, iv) **Sustainable network solutions** that integrate renewable energy sources to minimise environmental impact.

These innovations redefine performance, efficiency, and security standards, positioning UNITY-6G as a foundational pillar of future global digital infrastructure.

UNITY-6G architecture



UNified archITecture for Open RAN-enabled Distributed, Scalable and SustainabilitY enhanced 6G Networks

Coordinated by
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January 2025 – December 2027

Website: www.unity-6g.eu

LinkedIn: www.linkedin.com/company/unity-6g/

Verticals: PPDR, Industry, Media and Entertainment, Energy

Partners: CTTC, Telefonica ID, Keysight Denmark, Orange France, Nokia Solutions and Networks Germany, Software Radio Systems, Independent Power Transmission Operator, Rimedo, Ceragon Networks, Hispasat, Nearby Computing, Holo-industry 4.0 Software, Alma Mater Studiorum, University of Bologna, German Aerospace Centre, Four Dot Infinity Information and Telecommunications Solutions, Interuniversitair Microelectronica Centrum, Fondazione Links, National Centre for Scientific Research "Demokritos", Martel, HES-SO

Stream B2

WIRELESS COMMUNICATION TECHNOLOGIES AND SIGNAL PROCESSING

6G-LEADER

AI-Driven and Open RAN Innovations for Next-Generation 6G Networks.

OVERVIEW

6G-LEADER is built on a strong and multidisciplinary consortium, that includes leading vendors, Radio Frequency experts, a mobile operator, system integrators, and innovative Small Medium Enterprises (SMEs) within the Open RAN ecosystem. It also brings together top academic and research institutions specialising in AI/ML-driven wireless networks, semantics empowered communications, and advanced antenna concepts. Additionally, two large-scale infrastructure providers will support the deployment of five Proofs-of-Concepts (PoCs) alongside partners focused on driving the adoption of project outcomes within the 6G ecosystem.

These carefully selected PoCs will demonstrate key innovations designed to meet the needs of 6G stakeholders and emerging service requirements. They will leverage predictive AI/ML capabilities for RAN optimisation, in-network wireless AI, advanced antenna technologies, semantically aware control and user planes, and real-time RAN control with efficient conflict management.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

6G-LEADER aims at developing AI/ML-driven and semantics-empowered wireless communications and signal processing solutions, comprising novel antenna concepts in the form of Fluid Antennas (FAs) and Reconfigurable Intelligent Surfaces (RIS) based beamformers, leveraging new 6G spectrum in the FR3 band, and designing spectral efficient multiple access techniques and in-network Wireless for AI schemes. These innovations will be integrated into an O-RAN-based architecture with real-time control and efficient conflict management.

INNOVATION

6G-LEADER plans to evolve the 6G RAN by adopting an AI/ML-driven approach for accurate prediction and optimisation of network parameters, enhancing multiple access through novel random and non-orthogonal schemes and supporting in-network Wireless for AI applications.

Furthermore, the project aims for a significant shift from current 5G/B5G deployments by leveraging novel antenna concepts and new spectrum bands. This approach enables mobile operators to deploy networks while integrating semantics principles to optimise both the control and user planes of the 6G RAN.

To support a thriving ecosystem for European SMEs and industrial stakeholders, the project adopts an open RAN architecture enhanced with a real-time control loop and efficient conflict resolution. This framework follows multi-parameter optimisation processes essential for the seamless development of next generation 6G networks.

USE CASES/ SCENARIOS

This objective aims at deploying and validating all 6G-LEADER key innovations, including predictive AI/ML PHY solutions, Wireless for AI, random and non-orthogonal multiple access schemes, enhanced prototypes of FAs and RIS-based beamformers, FR1/FR3 coexistence, semantically enhanced control and user planes, and O-RAN-compliant RAN control and conflict mitigation in five PoCs.

Each PoC will integrate a different set of 6G-LEADER innovations, driven by real-world issues faced by the PoC owners, such as the lack of spectrum faced by mobile operators, the need for real-time RAN control, limitations by current 5G systems to accommodate ultra-low latency, mass connectivity, and in-network AI computing.

Towards this end, 6G-LEADER will leverage three large-scale testbeds to deploy its key innovations. Through this process, the open, disaggregated and interoperable AI/ML-driven RAN design, proposed in 6G-LEADER will be thoroughly studied and evaluated, and the added value of 6G-LEADER to address current limitations and weaknesses in 5G/B5G communication systems will be highlighted.

ENVISIONED RESULTS

While striving to develop novel 6G technologies offering cost reduction, and network and service deployment simplification, lower Electro Magnetic Field (EMF) exposure should be targeted as well. With these overarching goals, 6G-LEADER aims at technologies that will have a clear impact on future RAN standardisation in different domains, from PHY and multiple access, Wireless for AI, coexistence of FR1 and FR3 bands, novel antenna designs, and the incorporation of semantics principles to both the control and user planes. Targeted standardisation efforts will be continuously performed by project partners with strong experience and expertise in the field, targeting consensus building and reinforcing Europe's role in shaping the future mobile communication standards.

LEArning-Driven and Evolved Radio for 6G Communication Systems

Coordinated by Ana Luísa Alves, F6S Network Ireland

January 2025 – December 2027

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LinkedIn: www.linkedin.com/company/6g-leader/

Verticals: Industry, PPDR, Health, Smart Cities, and Transport & Logistics.

Partners: F6S Network Ireland, University of Cyprus, Four Dot Infinity Information and Telecommunications Solutions, Aalto University, Polytechnical University of Catalunya, Atos Spain, Linköping University, Accelleran, University of Granada, Software Radio Systems, ICCS, Digital Catapult, Samsung Electronics, Nokia UK, CNIT, Massive Beams, University Carlos III of Madrid, Telefónica

MULTIX

The project aims to revolutionise 6G RAN design by developing a MultiX fusion Perceptive 6G-RAN system (MP6R) that integrates multi-sensor, multi-band, multi-static, and multi-technology capabilities.

OVERVIEW

This will enable Integrated Sensing and Communication (ISAC), enhancing situational awareness and localisation accuracy for 6G applications. The project focuses on three innovation pillars: i) **MultiX Perception System** (MPS), embedding sensing functions into the Radio Access Network (RAN) stack; ii) **MP6R Controller** (MP6RC), coordinating multi-technology sensing and mobility; and iii) **Data Access and Security Hub** (DASH), ensuring secure multi-sensor data aggregation and exposure. MultiX will validate its innovations through two Proofs-of-Concept (PoCs): 1) Multi-layer Network Digital Twin for Industrial Manufacturing and 2) Contact-free eHealth Monitoring at Home Environment, contributing to 6G standardisation efforts.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

MultiX introduces a flexible, intelligent 6G RAN that integrates sensing and communication in a unified architecture. The MultiX Perception System embeds sensing capabilities into the RAN stack using a functional split architecture, allowing multi-sensor, multi-band, multi-static, and multi-technology ISAC deployments. The MP6R Controller extends RAN control to manage 3GPP and non-3GPP technologies, including radar, LiDAR, and cameras, enabling seamless coordination. The Data Access and Security Hub provides secure, distributed data processing, ensuring real-time access, privacy, and trust. The architecture supports dynamic reconfigurability, optimising network resources for high-accuracy localisation, environment perception, and adaptive communications essential for next-generation 6G applications.

INNOVATION

MultiX introduces several groundbreaking innovations that enhance the capabilities of next-generation 6G networks. By embedding perception directly into the RAN stack, the project shifts from traditional communication-centric architectures to a fully integrated ISAC framework. The functional split approach allows vendors to extend their RAN capabilities in a plug-and-play manner, enabling seamless sensing and communication convergence. The MP6R Controller facilitates the coordination of multi-technology sensing, optimising performance across diverse radio environments. A key innovation is DASH, which ensures privacy-aware and secure multi-sensor data aggregation, enabling real-time situational awareness while maintaining data protection standards. Additionally, MultiX leverages AI-driven sensing orchestration to dynamically adapt network parameters based on environmental changes, improving accuracy, efficiency, and scalability. These innovations position MultiX as a key enabler for 6G standardisation efforts, shaping the future of ISAC networks.

USE CASES/ SCENARIOS

MultiX validates its 6G Perceptive RAN through two Technology Readiness Levels (TRL) 4–5 PoCs addressing industrial automation and healthcare:

i) **Multi-layer Network Digital Twin for Industrial Manufacturing**: MultiX enables real-time sensing and digital twinning of industrial processes. By integrating radar, LiDAR, and AI-driven analytics, it enhances predictive maintenance, safety monitoring, and process optimisation. Robots and autonomous vehicles benefit from ultra-precise localisation and navigation, improving efficiency and reducing downtime. This PoC also explores adaptive network slicing to support latency-sensitive control loops in Industry 4.0.

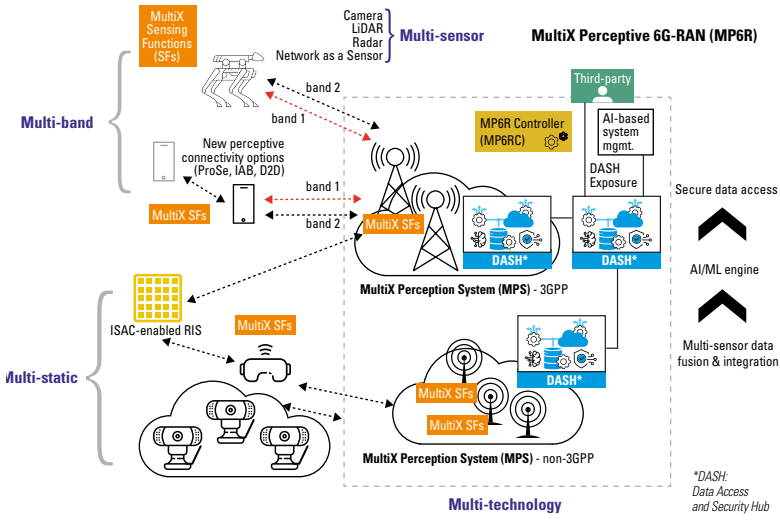
ii) **Contact-free eHealth Monitoring at Home Environment**: MultiX enables privacy-preserving, real-time health monitoring using RF, vision, and bio signal sensors to track vital signs, posture, and fall detection. It integrates edge AI for continuous assessment of physiological conditions, reducing hospital visits while improving elderly and chronic disease patient care. The system ensures secure, encrypted health data transmission, complying with regulatory requirements.

Additionally, MultiX supports autonomous systems, urban mobility, and smart cities by enhancing object tracking, localisation, and environment awareness. The architecture can be applied to autonomous vehicles, enabling collaborative perception, improved collision avoidance, and context-aware navigation. Other use cases include mission-critical applications such as emergency response and disaster recovery, where enhanced sensing and communication can assist in search and rescue operations.

ENVISIONED RESULTS

MultiX will deliver a scalable, AI-driven 6G RAN with native sensing and communication capabilities, enabling ultra-precise localisation, adaptive networks, and secure multi-sensor fusion. A key outcome is shaping 6G standardisation, actively contributing to 3GPP, IEEE, and ETSI ISAC working groups by defining ISAC architectures, functional splits, and security frameworks for next-generation RANs. The PoCs will validate low latency industrial automation and privacy-aware eHealth solutions, accelerating the 6G adoption. 6G is essential to support high-density, high-mobility scenarios with real-time perception and communication, enhancing autonomous systems, smart cities, and Industry 4.0, while ensuring standardised interoperability and global impact.

MultiX vision



MULTIX

Advancing 6G-RAN through multi-technology, multi-sensor fusion, multi-band and multi-static perception

Coordinated by
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January 2025 – June 2027

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Verticals: Industry 4.0, Logistics, Health, Smart Cities

Partners: University Carlos III of Madrid, Apple, BubbleRAN, CNIT, INTEL, InterDigital Europe, IHP – Leibniz Institute for High Performance Microelectronics, i2CAT, IMDEA Networks, Institute of Accelerating Systems & Applications, Catholic University of Leuven, NEC Laboratories Europe, Nextworks, OTE, Siemens, Telefónica University of Cantabria

Stream B3

COMMUNICATION INFRASTRUCTURE TECHNOLOGIES AND DEVICES

AMBIENT-6G

AMBIENT-6G will develop standardised enablers to integrate ambiently powered energy neutral devices into the 6G network infrastructure.

OVERVIEW

AMBIENT-6G aims to address the growing e-waste problem in the Internet of Things (IoT) by introducing a new class of ultra-low-power, Energy Neutral Devices (ENDs). Powered by ambient energy harvesting or Radio Frequency Wireless Power Transfer (RF-WPT), these devices can operate autonomously for decades, greatly reducing battery-related e-waste.

The project's main challenge is ensuring ENDs match the performance of battery-powered devices while operating on much lower energy budgets. AMBIENT-6G covers a broad range of ENDs, including rechargeable and battery-less types, and supports both active radios and backscatter communication.

By adopting an inclusive view of ENDs, AMBIENT-6G aims to broaden deployment options, use cases, and technical enablers—helping shape the standardisation of ambient-powered IoT devices in 3GPP and other bodies.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The overall project objective of AMBIENT-6G is to design, prototype, validate, and standardise hardware and software technology solutions for ENDs, as well as the 6G network infrastructure that connects them to the Internet. The project targets the secure integration of both active and passive (i.e., backscatter-based) devices in the 6G network architecture and end-to-end cloud-edge-device continuum. Active devices will make use of novel Low-Power Wide Area Network (LPWAN) protocols, targeting orders of magnitude lower power consumption than current 5G LPWAN options, such as NB-IoT and LTE-M. The protocols will be lightweight, secure, and energy aware. The network will offer backscatter capabilities to support communication with passive devices, as well as RF-WPT to provide remote recharging. The devices will be integrated into a Cloud-Edge-Device continuum, enabling distributed and federated AI, with low-power on-device inference and training, energy-aware computational offloading to edge and cloud, and over-the-air model updating capabilities.

INNOVATION

AMBIENT-6G introduces transformative innovations for sustainable IoT, targeting three innovation areas. The first innovation area targets **a holistic hardware/software device architecture**, encompassing performance vs. cost vs. materials trade-offs, as well as circuits for energy storage, harvesting, and management, and transceiver solutions for RF-WPT, backscatter, and wake-up radios.

The second innovation area focuses on **a 6G LPWAN for ultra-low-power devices in general and ENDs** specifically. It encompasses infrastructure enablers for backscatter and RF-WPT, as well as secure and lightweight protocols, with reduced signalling overhead and energy-aware transmission scheduling.

The third innovation area will investigate **enablers for end-to-end intelligence**, including predictive mechanisms

to support energy-awareness, distributed and on-device AI (including inference and training), and cloud-edge-device orchestration and offloading.

USE CASES/ SCENARIOS

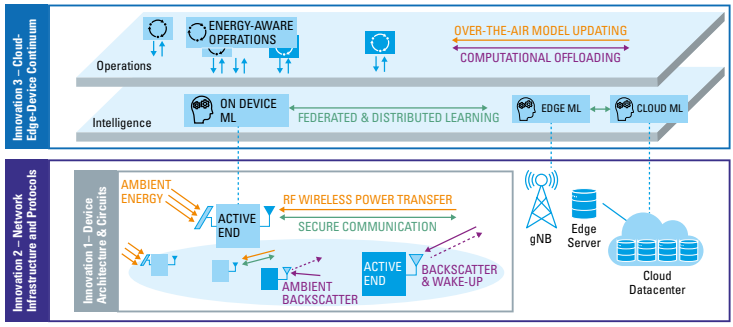
The AMBIENT-6G project enables transformative use cases across multiple IoT verticals by leveraging ENDs and 6G infrastructure.

Potential applications include: i) **Hard-to-Reach Devices**: ENDs embedded in materials, deployed in remote or hazardous locations, or requiring long maintenance-free lifespans, such as implants in living tissues, remote monitoring in mountainous regions, or worldwide tracking; ii) **Massive-Scale Sensor Networks**: Enabling deployments with thousands of devices for applications like fine-grained environmental monitoring in cities, tracking goods in warehouses, or monitoring air quality in smart buildings; iii) **Extreme-Lifetime Applications**: Devices requiring minimal maintenance, such as smart utility meters, wearables for elderly users, or devices where manual maintenance is economically or practically infeasible; iv) **Logistics and Supply Chain**: Battery-less tagging for goods to improve warehouse efficiency, tracking mobile medical instruments, and updating electronic shelf labels remotely in retail environments; v) Health Monitoring: Tracking and monitoring patients using battery-less and low-maintenance devices in hospitals or home-care settings; vi) **Environmental Monitoring**: ENDs for monitoring parameters like oil leakages, environmental pollutants, or disaster detection through event-triggered data transmission; and vii) **Industrial Applications**: Supporting IoT in manufacturing and predictive maintenance in industrial environments using ENDs integrated with low-power and low latency protocols.

ENVISIONED RESULTS

AMBIENT-6G will deliver new hardware and software designs for ENDs and LPWAN 6G network solutions, including circuits, protocols, resource allocation algorithms, and low-power AI frameworks. The project will contribute to standardisation, including 3GPP Ambient-IoT, and IEEE 802.11 ambient power. Moreover, the project will identify viable use cases and business opportunities for ENDs and 6G LPWAN solutions. The technical outcomes will be validated through several integrated Proofs-of-Concept (PoCs), grouped into four demonstrations: i) device combining ambient energy harvesting, backscatter, and low-power channel access, ii) energy-aware computing and offloading capabilities, iii) a life cycle assessment tool for END design, and iv) end-to-end federated learning and resource allocation framework.

The AMBIENT-6G project targets innovations for energy neutral devices in 3 areas: i) device architecture and circuits, ii) network infrastructure and protocols, and iii) cloud-edge-device continuum



Towards standardised 6G connectivity for ambiently-powered energy neutral IoT devices

AMBIENT-6G

Coordinated by
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January 2025 – December 2027

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Partners: imec, Aalto university, University of Oulu, Ericsson Finland, Sequans, WINGS-ICT, KU Leuven, QUICKSAND, NXP, Technical university of Graz, Telefonica

NEXASPHERE

NexGen 3D Networks Spin Harmonies across 6G, AI, and unified TN/NTN.

OVERVIEW

NexaSphere aims to develop a system enabling a 3D network of networks (see figure next page), seamlessly integrating multi-path transmission to enhance multi-connectivity while conserving energy. It unites space-borne, airborne, and terrestrial platforms, with a focus on aviation, rail, and automotive.

Its main objective is to design advanced hardware prototypes and software algorithms for a sustainable, multi-connected 3D network. This network will combine radio and wireless-optical technologies, with AI-driven programmability for orchestration. NexaSphere also plans to extend the edge-cloud continuum into space, forming a Radio and Wireless-Optical Continuum. By integrating scalable simulation and emulation models and performing in-lab and real-world validation, the project aims to demonstrate Proofs-of-Concept (PoCs) for this unified Terrestrial/Non-Terrestrial (TN/NTN) architecture, targeting a Technology Readiness Level of 4–5.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

NexaSphere envisions a highly reliable and flexible 3D network fabric designed for high-mobility, long-range, and 6G-NTN verticals. Leveraging advanced multi-connectivity strategies, it integrates optical and radio interfaces for seamless indoor and outdoor tropospheric communications. By unifying air- and space-borne assets (e.g., GEO or NGSO) with terrestrial 5G/6G cores, NexaSphere ensures end-to-end connectivity for critical applications. Moreover, AI/ML models enhance predictive scheduling and 3D mobility management to anticipate 3D communication maps in environments with relative hight velocity. Another NexaSphere's feature is its extended edge-cloud framework, where space nodes also perform edge computing. Finally, a dedicated network orchestration ensures seamless coordination across both TN & NTN domains, enabling resilient, adaptive, and intelligent 6G networks.

INNOVATION

The vision of NexaSphere is a unified 6G ecosystem with automated networking and communication enabled by an intelligent, sustainable, and distributed 3D architecture spanning space and terrestrial domains. Thus, key innovation pillars include: i) On-Board Processing (OBP) satellite with Free Space Optical and RF links, ii) Distributed gNB in space, iii) Energy-efficient wireless optics, iv) High-efficiency NTN antenna for mobility, v) AI/ML-driven resource and mobility management in 3D networks, vi) Multi-connectivity across TN/NTN, and vii) Unified TN/NTN edge-cloud orchestration.

USE CASES/ SCENARIOS

NexaSphere will demonstrate three key PoCs across transportation sectors, including aviation, automotive, and railways. These PoCs validate NexaSphere's advanced Innovation approaches.

- **PoC 1: Seamless In-Flight 6G-NTN Connectivity for Aviation**

  PoC 1 focuses on enhancing In-Flight Connectivity (IFC) by

leveraging multi-band, multi-connectivity architectures with electronically steerable antennas. Through AI-driven predictive models, the system will dynamically optimise communication paths based on power consumption, latency, and data rate, to use the best of efficient resource allocation throughout a flight. The integration of a distributed edge-cloud infrastructure further enhances real-time data processing, reducing latency while maintaining seamless connectivity for passengers and airline operations.

- **PoC 2: AI-Driven Data Optimisation for Connected Vehicles**

  PoC 2 addresses data hoarding challenges in automotive applications, to guarantee efficient data exchange over 6G TN/NTN networks. AI-driven strategies will determine essential data subsets for transmission using dimensionality reduction techniques and edge-offloading approaches. This bi-directional data optimisation enhances safety-critical and non-critical applications, reducing unnecessary data loads while maintaining real-time access to road traffic updates, High-Definition maps, and infotainment services.

- **PoC 3: 6G-NTN Integration for Railway Connectivity**

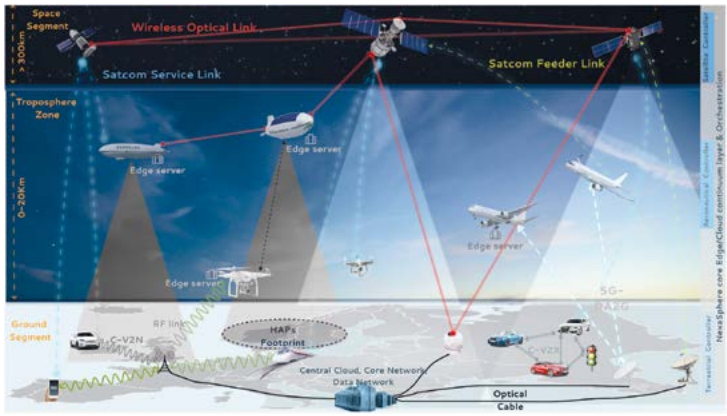
  PoC 3 focuses on enhancing connectivity for railway, providing high reliability, safety, and efficiency through TN/NTN integration. It targets critical applications like signalling, emergency communication, and automated train operations through technologies such as predictive maintenance and real-time monitoring for cost-effective operations. AI-based traffic steering and multi-path connectivity enable smooth TN/NTN integration to provide uninterrupted service even in challenging environments.

ENVISIONED RESULTS

NexaSphere defines a 3D TN-NTN system architecture with energy-efficient multi-technology connectivity, integrating 5G/6G TN and NTN with wireless-optical technologies (e.g., Free-Space Optics (FSO) & LiFi). It envisions a meshed space network with onboard gNBs, RF/FSO links, edge computing for orchestration, and AI-driven multi-connectivity optimisation. It surpasses 5G by integrating Radio-Optics in a 3D network.

Custom antennas for aviation, automotive, and rail will enhance energy efficiency and performance. NexaSphere will validate its innovations through TRL 4-5, -integrating wireless-optical, NTN, core network, and 3D edge-cloud components - and promote them actively. AI-based algorithms will optimise resource allocation to achieve seamless connectivity in transportation.

NexaSphere vision of a unified TN/NTN for aviation, automotive, and trains connectivity



NexaSphere

Coordinated by Babak Mafakheri, Safran Passenger Innovations

January 2025 - December 2027

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Verticals: Transport and logistics

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Stream B4

RELIABLE SERVICES AND SMART SECURITY

MARE

A reliable 6G services provisioning platform through the definition of a novel security plane.

OVERVIEW

The transition to 6G communications introduces new security and privacy challenges, including, protecting sensitive user data, securing ultra-low latency communication, defending against emerging cyber threats, and maintaining the integrity of the network infrastructure.

MARE will address these challenges by creating a reliable 6G services provisioning platform conceptually supported by the definition of a security plane, becoming the recipient for all envisioned security related functionalities.

The platform will be built on a well-defined set of open, editable and programmable security functions, delivered as enablers to the 6G architecture, offering transparent, multi-domain/stakeholder security and privacy provisioning, aimed at proactively proposing and assessing candidate strategies to automatically handle attacks and threats in 6G networks.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

MARE will enrich the 6G ecosystem by defining the MARE Security Plane. This Security Plane will consist of a set of open and extendable programmable functions that will be designed to address the specific challenges driven by the new attack surface both on the control and management planes.

In MARE's solution, Security Functions are dynamically composed to adapt to the specific attacks to be addressed. They are independent and modular blocks of software, offering specific security functionalities, in the form of microservices to be easily extendable and connected among them, making MARE Security Plane to be the right strategy to face known but also not yet foreseen threats. These functions are composed by selecting and connecting the appropriate set of primitive components (security assets, including tools, algorithms, or any atomic security elements that may contribute to deliver a security capability) to address a specific threat.

INNOVATION

A key innovation of MARE is the modular approach to security, implementing each function as a set of atomic components ("DOTs"). These building blocks can be reconfigured and reused across different functions, enabling a fully-flexibleand expandable security framework, where new functions can easily be composed and customised. To ensure the effectiveness of security functions before deployment, MARE will deliver a pre-assessment environment based on network modelling and digital twinning, serving as a sandbox for testing security solutions. Additionally, MARE will contribute to 6G architecture and standardisation efforts by defining security functions tailored to safeguard the performance of 6G networks in distributed architectures and complex operational environments.

USE CASES/ SCENARIOS

MARE will focus extensively on verifying and testing its security concepts across a wide range of 6G scenarios. The project will demonstrate and validate its solutions through a series of Proofs-of-Concept (PoCs), each aligned with specific attack vectors identified in key thematic areas. Additionally, MARE will assess potential risks introduced by its own security framework by including a dedicated PoC that examines threats targeting the MARE Security Plane components.

The PoCs will be tested in near-real-world scenarios within lab environments, leveraging real 5G/B5G equipment to deploy the core network and the necessary computational infrastructure. These setups will integrate Digital Twin technology to support realistic emulation and testing.

The PoCs will address a variety of security threats, including:

- Critical network attacks
- AI/ML-driven threat protection, detection, and response for the 6G core network
- Full-plane threat detection targeting critical network control elements
- Man-in-the-middle attacks on AI models
- Detection of data and intent tampering
- Zero-touch mitigation of security risks from tampered data ingestion
- Ensuring trustworthy AI operations
- Secure implementation of Network Digital Twins
- DDoS attacks originating from X-Edge
- Secure exposure of network capabilities
- Cross-network security attestations and shared protections in multi-network infrastructures

Through these efforts, MARE aims to establish a comprehensive security framework that strengthens the resilience of 6G networks against evolving cyber threats.

ENVISIONED RESULTS

MARE will provide:

- A set of enriched security functions built upon basic primitives (DOTs), that are composed into programmable security services to maximise security, turning into the MARE Security Plane proposed in the project.
- A smart "pre-assessment" environment, including simulation, emulation and real infrastructure for systems, users, etc., where security related services and functions are analysed.

To optimise the scope and coverage of its security enablers, MARE will study and implement a systematic Attacks Modelling Reference Framework for the identification and categorization of the evolving 6G ecosystem threat landscape.

The MARE solution will be built on – and will be compliant with – the architectural concepts for 6G, as defined by European and International initiatives, such as the Hexa-X I/II flagship projects.

MARE, Programmable, Modular and Disaggregated Security Plane for 6G Ecosystems

Coordinated by Dr. Andreas Zalonis, Space Hellas

January 2025 – December 2027

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Partners: Space Hellas, Security Systems and Services, Telefonica ID, Atos Spain, Ericsson Italy, Thalès Six GTS, HP Italy, Orange France, Airbus Defense and Space, National Centre for Scientific Research "Demokritos", Braunschweig Technical University, Polytechnical University of Catalunya, CNIT, University College Dublin, Nextworks, Four Dot Infinity, XLAB, Accelleran, 8Bells, Ubitech

XTRUST-6G

Extended zero-trust and intelligent security for resilient and quantum-safe 6G networks and services.

OVERVIEW

The XTRUST-6G establishes a zero-trust security framework for 6G ecosystems, focusing on resilience, privacy and dependability. It enhances security through dynamic, risk-based access control, AI-driven intrusion detection-response and blockchain-powered identity verification. By integrating advanced privacy-preserving AI/ML techniques and physical layer security, it guarantees secure data sharing, trusted AI training and End-to-End (E2E) protection in 5G+/6G networks.

Key objectives include:

- Develop a zero-trust security architecture to increase resilience
- Provide risk-based situational awareness with proactive security tools
- Implement AI-based zero-touch E2E protection
- Enhance visibility, control, monitoring and security orchestration
- Ensure trustworthy operations using blockchain for identity verification, lifecycle management & compliance
- Secure the 5G+/6G supply chain by establishing an Operation Support System (OSS) security framework and AI-driven risk-based detection and remediation
- Provide quantum-safe solutions, physical layer security, advanced techniques for 6G privacy, secure data sharing and trusted AI/ML training

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The architecture of XTRUST-6G is built on a cloud platform hosting the developed tools, mechanisms and AI services. It integrates intelligent security orchestration, quantum-safe technologies and zero-trust security and features collaborative eXtended Detection and Response (C-XDR) for real-time monitoring, federated User Interface & dashboards and automated security enforcement.

Endpoint security is strengthened through runtime integrity analysis, dynamic risk management, and Distributed Ledger Technology (DLT)-based asset discovery.

The 6G security layer leverages federated learning intrusion detection, intelligent intrusion response, and cyber deception techniques.

Collaborative Threat Intelligence (CTI) enhances situational awareness by enabling real-time cyber-threat data exchange. Quantum-safe tools (Quantum Key Distribution or QKD, Post Quantum Cryptography or PQC) and O-RAN security with x/rApp, cloud workload protection and posture management ensure a resilient, adaptive and privacy-preserving 6G ecosystem.

XTRUST-6G

Coordinated by
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Verticals: Automotive, Energy

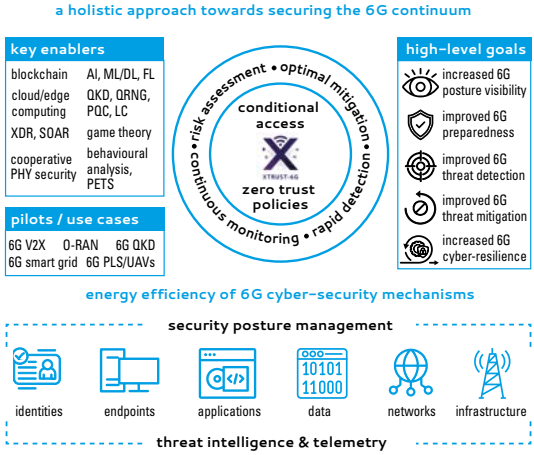
Partners: Greek Centre for Research and Technology (CERTH-ITI) European Dynamics, Information Technologies Institute, University of Portsmouth, University of Thessaly, University of Peloponnese, TalTech, K3Y, InCites Consulting, IQuadrat, SUMMiT-TAL TECH, ADDITESS, Sphynx, University of Luxemburg, Ericsson Italy, Cyentific, Telefonica ID, Telekom Slovenije, Hellenic Data Protection Authority.

INNOVATION

The XTRUST-6G introduces six key innovations to revolutionise the security of 5G+/6G networks:

- Zero-trust security, enabling real-time risk-based access control to strengthen 6G resilience, reduce cyber breaches, and enhance public trust
- C-XDR improving situational awareness, reducing attack response time and safeguarding European supply chains
- Blockchain-powered identity verification ensuring tamper-proof digital identities and secure O-RAN asset lifecycle management and reinforcing European (EU) digital sovereignty
- Quantum-safe cryptography (QKD, PQC) safeguarding 6G networks against physical layer attacks
- Cyber deception techniques, such as AI-driven honeypots, enhancing intrusion detection and preventing costly data breaches
- Federated learning and graph-based threat modelling enabling privacy-preserving AI security and collaborative threat intelligence sharing, while AI-powered automation optimises energy efficiency, aligning with EU Green Deal's objectives

High level architecture



USE CASES/ SCENARIOS

The XTRUST-6G project includes five pilots:

- **Pilot 1**: Integrates 5G/6G into Electric Vehicle charging with zero-trust and zero-touch security, ensuring reliable network slices, congestion prevention and enhanced communication via O-RAN mechanisms
- **Pilot 2**: Enables AI-driven cyber-attack assessment in Autonomous Vehicles and secures smart mobility by protecting 5G+/6G infrastructure with encrypted communication, policy-based authorisation and collaborative security
- **Pilot 3**: Ensures 6G security through QKD-based encryption for authenticated E2E communication and secure backhaul links
- **Pilot 4**: Enhances Unmanned Aerial Vehicle (UAV) security in 5G+/6G with encrypted communication, audit mechanisms and physical-layer protection strengthening resilience against attacks
- **Pilot 5**: Protects O-RAN systems with intrusion detection, zero-touch security orchestration and software supply chain security for cloud and edge applications

ENVISIONED RESULTS

The evolution towards 6G must be accomplished considering 6G security and privacy needs. XTRUST-6G aims at delivering next-generation cyber-security tools and services for 6G communications by relying on contemporary zero-trust security principles, including AI-driven security and service deployment beyond perimetric strategies, addressing disruptive security, reliability, and energy efficiency. It supports secure, privacy-preserving services, zero-touch security, quantum cryptography for 6G, and efficient multi-stakeholder service development. It advances trustworthiness, resilience, openness, transparency, and dependability under EU regulations. Finally, it strengthens EU cybersecurity, digital sovereignty, supply chain security, security assurance, resilient infrastructures, disruptive technologies, and international standardisation.

Stream B5

INTERNATIONAL COLLABORATIONS EU-JP, 6G-MIRAI

Stream B6

INTERNATIONAL COLLABORATION EU-ROK, 6GARROW

6G-MIRAI

6G Machine Intelligence based Radio Access Infrastructure

OVERVIEW

The 6G-MIRAI project, in partnership with Japan's HARMONY project, aims to develop AI/ML solutions through a joint effort involving top industry and academic experts from Japan and the EU. 6G-MIRAI targets the development of future-proof 6G physical layer technologies and RAN architectures, with particular emphasis on advanced multi-antenna technologies such as user-centric cell-free massive Multiple Input Multiple Output (MIMO), natively supported by practical, reliable, and robust AI/ML techniques.

The project has four main objectives:

- **Reliable and robust AI/ML for future wireless**. Targets the development of channel and hardware models to enhance offline AI/ML design, focusing on low-physical layer enablers crucial for user-centric cell-free massive MIMO systems.
- **Practical AI-native design of next-gen Radio Access Networks**. Explores which functions should run on which network elements and based on what data. Focuses on architecture, functional splits, protocols, and data handling to enable user-centric cell-free networks.
- **Common platform for data, benchmarking, and validation**. Establishes a unified framework for testing, benchmarking, data management, and validating AI-driven techniques and protocols.
- **Aligned strategy on future standardisation**. Building on initial 3GPP efforts to promote using realistic data for training, evaluating, and testing AI/ML models.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

To achieve the above objectives, the consortium will focus on five Research and Technology Items (RTIs):

- Develop models and datasets for the considered technological solutions. 6G-MIRAI will propose novel generative AI-based channel models; fuse synthetic and real measurement data to evaluate the performance of, for example, channel state information compression and beam management algorithms; model hardware impairments in distributed MIMO systems to train AI/ML algorithms; and investigate methods for scalable synchronisation and reciprocity calibration.
- Decrease the resource requirements of AI/ML techniques to enable reliable, scalable, and real-time learning. To this end, hybrid model and data techniques for multi-antenna technologies will be developed, with potential applications in beamforming, channel estimation, and pilot design.
- Implement AI-based algorithms in user-centric cell-free massive MIMO networks for decentralised coordination, resource allocation, scheduling, and QoS-aware adaptive protocols and network configurations.
- Provide guidelines for AI-ready 6G-RAN architectures, aligning with 3GPP and O-RAN developments.
- Investigate methodologies for data management, testing, and validation methodologies in collaboration with other RTIs.

INNOVATION

The project's key innovations are categorised into four main impact areas. First, it focuses on future-proofing 6G physical layer technologies and open RAN architecture, with a strong emphasis on advanced multi-antenna technologies such as user-centric cell-free massive MIMO, which is natively supported by AI/ML techniques. Second, it aims to develop "AI-native" solutions across multiple layers of the protocol stack while establishing a comprehensive architectural framework for AI-native-driven RAN. Third, the project seeks to advance 6G radio access network solutions capable of meeting the key performance indicators in cell-free and extreme MIMO, joint communication and sensing, and critical RAN functionalities such as modulation, coding, synchronisation, and multiple access. It also focuses ML and ensuring seamless integration of multiple frequency bands. Lastly, the initiative is dedicated to strengthening European expertise in key enabling technologies, particularly in AI/ML and advanced signal processing techniques, fostering innovation and leadership in the development of next-generation systems.

USE CASES/ SCENARIOS

6G-MIRAI aims to expand existing 3GPP use cases by extending the scope of 3GPP Release 19. The project will explore advanced complex joint CSI compression and prediction schemes, as well as joint Tx/Rx beam pair prediction techniques. Additionally, it will introduce new use cases, such as reducing pilot overhead and enhancing cell-free MIMO designs using AI/ML-based techniques. For all relevant use cases, lifecycle management considerations will be addressed across 3GPP RAN1/2/4 and potentially within O-RAN.

Due to the lack of standardisation for AI/ML integration within cell-free RANs, 6G-MIRAI is expected to drive innovation in key areas, including signalling exchanges among nodes in 3GPP RAN3, network architecture design, fronthaul splits, and function distribution specified in 3GPP and O-RAN frameworks.

ENVISIONED RESULTS

In the area of hybrid model-based data-driven learning, 6G-MIRAI will advance expertise on key MIMO processing blocks for the 6G baseband. Specifically, it will design beamforming and resource allocation methods that integrate realistic hardware and channel models, while addressing practical constraints such as limited computational capabilities, partial channel state information, and scarce training data. By assessing the capabilities of AI/ML in balancing performance and energy efficiency trade-offs, 6G-MIRAI will contribute valuable insights to future 6G standardisation efforts.

Additionally, 6G-MIRAI will produce and publicly release realistic and diverse datasets for cellular and cell-free massive MIMO systems. These datasets will be accompanied by a standardised validation and benchmarking methodology significantly enhancing the capabilities of the scientific community's ability to assess and refine AI/ML techniques for next-generation wireless systems.

6G Machine Intelligence based Radio Access Infrastructure

Coordinated by Tobias Ley, Ericsson Research

April 2025-April 2028

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6GARROW

Unlocking new levels of efficiency, flexibility, and performance with AI-native Radio Access Networks and integrated device-network approaches.

OVERVIEW

The 6GARROW project is an international collaboration between the European Union (EU) and the Republic of Korea (ROK) to advance Radio Access Networks (RANs) and develop integrated device-network approaches for AI-native 6G mobile networks. It aims to enhance RAN performance and efficiency by integrating AI/ML-based components, while enabling external devices to access AI/ML resources via Application Programming Interfaces (APIs).

By embedding AI/ML into the network stack, 6GARROW will streamline base station management, improve energy efficiency, enhance terminal autonomy, and simplify user device hardware. The project also focuses on network-wide energy savings, failure recovery, and interoperability by leveraging centralised AI/ML resources and internal network data. The innovativations from 6GARROW will drive automation, sustainability, and improved network performance in the future mobile networks.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The 6GARROW AI-native system architecture (see figure) integrates AI and ML across the entire 6G network, comprising User Equipment (UE), Radio Access Network (RAN), and Core Network (CN), all connected via standardised interfaces for seamless communication. Data from all components is exposed to network management via APIs, enabling advanced service placement and external control.

AI nativeness ensures low latency, intelligent edge access for latency-sensitive applications. 6GARROW also provides AI-as-a-Service (AIaaS), improving scalability and flexibility. The architecture supports semantic communication and sensing by exposing AI/ML resources to external devices, addressing challenges like orchestration and energy efficiency.

INNOVATION

The innovation of 6GARROW lies in its seamless integration of AI and ML across the entire 6G network, including devices, enabling intelligent, adaptive, and context-aware operations. It introduces an AI-native architecture that enhances network performance by embedding AI/ML into the RAN and CN, using distributed agents and data collection mechanisms across all components. The system enables low latency, edge-based AI access, for real-time network management and automation, particularly for latency-sensitive applications. Additionally, 6GARROW facilitates external service placement and orchestration via APIs, offering AIaaS for scalable and flexible intelligent services. By exposing AI/ML resources to external devices and users it supports semantic communication and sensing, improving system efficiency and driving network innovation.

USE CASES/ SCENARIOS

6G AI-native integrated RAN-Core networks

6GARROW

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January 2025 – December 2027

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Verticals: Automotive, Industry, Media and entertainment, PPDR, Health, Energy,Smart Cities, Transport and logistics

Partners: CEA-Leti, Fraunhofer HHI, Aalto University, University of Oulu, Intel Germany, Hewlett-Packard Enterpriseltaliana , Grenoble Ecole De Management, Orange, Yonsei University, Seoul National University, Korea University Research and Business Foundation, ETRI, LG Electronics

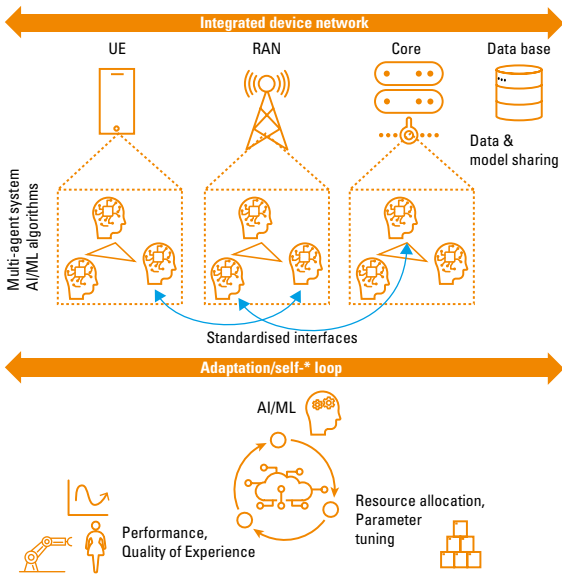
6GARROW will demonstrate its innovative AI-native and integrated device-network technologies through four functional demonstrations, highlighting the potential of these approaches in 6G wireless communication.

The first demo, **Semantic-aware device-edge co-inference**, features gesture recognition in a robotic control setup, using edge intelligence apps with semantic-aware encoding and inference to provide real-time, Personalised feedback, showcasing practical advancements in 6G applications. The second demo, **6G cross-domain network intelligence framework**, demonstrates AI coordination across the RAN and CN domains, validating end-to-end network slicing requirements and resolving conflicts through cross-domain inference coordination. The third demo, **Physical layer AI/ML techniques**, evaluates AI/ML techniques such as Channel State Information (CSI) feedback and beam management using Open-RAN components in a lab setting, promoting flexibility and efficiency in utilising radio resources. Finally, the AI/ML-based CSI and Channel Quality Indicator (CQI) compression demo validates compression algorithms on an edge intelligence platform using an enhanced MIMO testbed, assessing performance through real-world channel measurements.

The integration of AI and device-network approaches in 6GARROW offers significant benefits for mobile operators and end-users. It reduces operational expenditures by optimising radio resources and lowering energy consumption, while also cutting capital expenditures by enabling new services without additional hardware investments. For end-users, 6GARROW improves Quality of Experience by dynamically adjusting to channel conditions, ensuring stable service, and extends device lifespan, particularly in IoT, by enabling flexible service adoption. It also creates new business opportunities through seamless connectivity and energy-efficient solutions across industries.

ENVISIONED RESULTS

The 6GARROW project envisions several key outcomes, including the development of innovative demonstration tools, algorithms, and methods for AI-native and integrated device-network approaches. 6GARROW will amplify its impact through strategic standardisation and intellectual property management, complementing its extensive publication efforts. The collaboration between the European Union and the Republic of Korea ensures a shared vision of advancing AI technologies, enabling seamless connectivity, and addressing global challenges in mobile network optimisation. This joint effort will strengthen the EU-ROK relationship while highlighting their mutual commitment to leading the way in the development of 6G technologies.



6GARROW AI-native 6G system with integrated device-network approach

Stream B7

SUSTAINABILITY LIGHTHOUSE, SUSTAIN-6G

Stream B8

RELIABLE AI FOR 6G COMMUNICATIONS SYSTEMS AND SERVICES, 6G-DALI

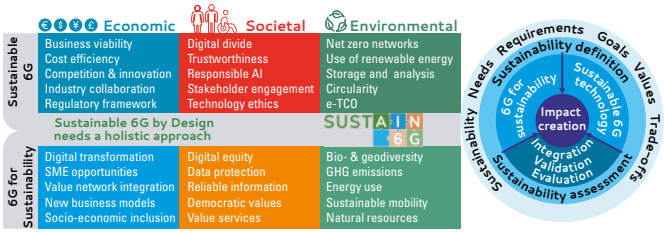
SUSTAIN-6G

European Sustainability Lighthouse Project – The holistic perspective on Sustainable 6G and 6G for Sustainable Applications.

OVERVIEW

SUSTAIN-6G implements a holistic approach to sustainability addressing societal, environmental, economic challenges, to achieve a unified European view embracing different stakeholders. The project contributes with technology enablers for 6G ("Sustainable 6G") and vertical solutions and applications integrating 6G technology ("6G for sustainability"). The goal is to consider the multitude of sustainability needs and trade-offs as depicted in the figure below in an End-to-End (E2E) manner, and to take the full lifecycle of assets into account. The project further consolidates processes and methodologies to define and assess sustainability impact qualitatively and quantitatively and makes them applicable. Through Proof-of-Concept implementations and integration testing the project validates and evaluates the developed solutions. By acting as a hub to exchange, develop, consolidate and evaluate innovation and concepts on sustainability across SNS and beyond, SUSTAIN-6G is a driving impact force for "Sustainability by Design" in 6G and vertical systems, providing guidelines, implementation best practice recommendations, roadmaps, new sustainable business models, and standards contributions.

Sustainability dimensions and SUSTAIN-6G objectives



CONCEPT/ INNOVATION/ USE CASES

The 6G ecosystem encompasses heterogeneous technologies including ubiquitous computing, advanced radio and optical solutions, (edge) AI, new security, trust and privacy enablers, integration of sensing and communication, and non-terrestrial component incorporation. Vertical sectors take key technology steps forward through digitalisation, softwarisation, and data- and AI-based autonomous operation, and 6G communication technology is a central enabler for this transformation. Across these ecosystems, sustainability goals and values play a key role, driven through economic, customer and societal demands as well as regulatory requirements.

However, sustainability goals of the different stakeholders might call for trade-offs e.g. between accessibility (coverage), energy efficiency and security. SUSTAIN-6G foresees a holistic 6G ecosystem design to approach the respective technologies and solutions jointly, simultaneously minimising negative and enhancing positive sustainability impacts. Creating an E2E perspective from device via network and service infrastructure to the (vertical) application enables balancing sustainability values. The respective methodology (figure next page) starts with analysing existing 6G candidate technologies (from previous and current research initiatives) and distilling use cases within the SUSTAIN-6G targeted vertical scenarios and beyond. This step includes understanding reference sustainability scenarios and needs, involving European and global

SUSTainability Advanced and Innovative Networking with 6G

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Verticals: Agriculture & farming technologies

Partners: b-com, CEA-Leti, CCyberSocialLab , Deutsche Telekom, Ericsson Sweden, EDF, Eurescom, John Deere, KU Leuven, MDCREATE, Nokia Networks France, Nokia Solutions and Networks Germany, Orange France, University of Oulu, P-NET, Polytechnic university of Turin, QAMPO, Qualtek , Real Wireless, Siemens Germany and Austria, Telecom Italia, University Carlos III of Madrid, WINGS-ICT

projects and frameworks, ethics and regulation, and collecting direct inputs from stakeholders. With this baseline, the work on technology enablers for "Sustainable 6G" and vertical solutions and applications integrating 6G technology ("6G for sustainability") is launched.

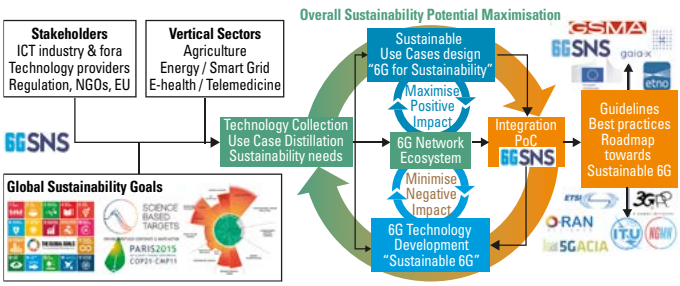
The project aims to develop at least 16 innovations in radio access, core, cloud, optical and E2E (network management, AI, privacy/security) domains. These innovations are evaluated with focus on reducing the negative impact of the communication network and enabled use cases on sustainability values, through an iterative process ("Minimise Negative Impact" loop). A set of at least 9 vertical use cases are studied in detail in terms of maximising their positive impact to environment, society and economy. Through an iterative process of integrating 6G technology enablers with each of the use cases ("Maximise Positive Impact" loop) this impact is evaluated and conclusions on the use case specific 6G enablers are drawn. The selected use cases—agriculture, e-health/telemedicine, and energy smart grid—demand diverse communication requirements (e.g., coverage, latency, reliability, security) and support a wide range of sustainability goals. Thereby, results and insights can be extrapolated to other sectors such as smart cities or education.

Towards the ultimate SUSTAIN-6G objective of a holistic E2E perspective on sustainability, the integration, joint validation and evaluation, and impact quantification of 6G technology enablers with vertical use cases plays is central. This is achieved through Proof-of-Concept (PoC) implementations ("Overall Sustainability Potential Maximisation" loop) and supported by introducing a Sustainability Management Plane concept. The latter interfaces network, service providers and vertical ecosystems to enable e.g. data and policy exchange and exposure, and to manage trade-offs towards an E2E optimisation of sustainability goals and values. Major efforts are made by the project on defining and improving the processes and methodologies for sustainability definition and assessment / evaluation towards a framework that can be applied to the whole 6G ecosystem including network, services and vertical domains.

ENVISIONED RESULTS

The key results of the project will include innovative solutions on 6G technology enablers and their application to vertical use cases. The evaluation of their sustainability impact and the lessons learned throughout their integration will be baseline for relevant standards contributions. Together with the processes and methodologies defined for E2E sustainability definition and assessment, the results will be leveraged to define guidelines and best practice recommendations for the design and implementation of sustainable 6G ecosystems. This will be complemented by creating recommendations for new and innovative business models that take advantage of the opportunities provided through the paradigm of "Sustainable 6G by Design". Finally, a strategic roadmap will provide guidance for the full adoption of sustainability principles in 6G and beyond standards, regulation and policies, addressing stakeholders within and outside the communication technology domain.

SUSTAIN-6G overall concept and methodology



6G-DALI

User-friendly e2e AI framework for DataOps and MLOps in 6G.

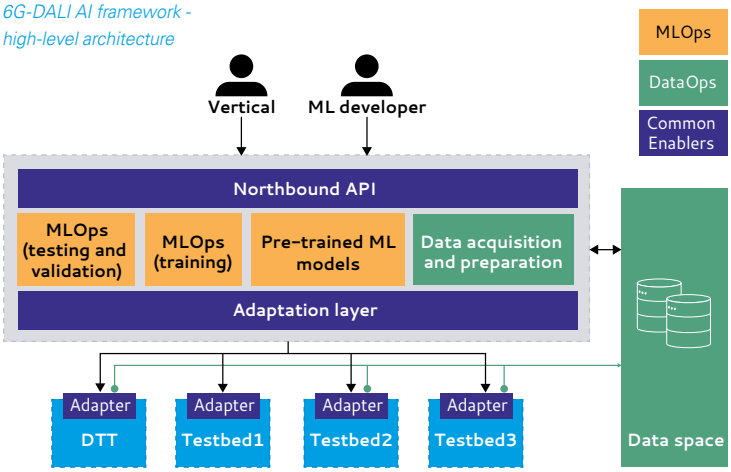
OVERVIEW

6G-DALI develops an AI framework linking 6G data with verticals, Machine Learning (ML) developers, and experimenters. It leverages 6G testbeds from the SNS C phase 2 (SUNRISE-6G) project, uniting experts in 6G, AI/Machine Leaning Operations (AI/MLOps), and Data Operations (DataOps). This collaboration ensures an efficient, trustworthy AI/ML experimentation framework. The goals are to: i) deliver an End-to-End (E2E) AI framework, ii) integrate Gaia-X and Extract Load Transform (ELT), iii) enhance MLOps, iv) enable 6G testbed integration, v) build a Digital Twin (DT) Testbed, vi) ensure ethical compliance and vii) drive dissemination and standardisation.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The 6G-DALI architecture, as depicted in the figure below, defines an AI framework supporting i) AI experimentation via MLOps and ii) data analytics via DataOps. It automates workflows, linking ML developers improving 6G with vertical users optimising services. It connects to 6G testbeds (Radio Access Network or RAN, Core Network or CN, edge/cloud), where some sites offer Digital Twins. The framework establishes the first 6G Dataspace, enabling secure data sharing among ML developers, operators, and vendors using International Data Space (IDS) and Gaia-X to drive 6G data economies.

6G-DALI AI framework - high-level architecture



6G DAta and ML operations automation via an end-to-end AI framework

Coordinated by
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January 2025 – December 2027

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Partners: ISI/ATH, Intracom, IBM Ireland, VIAVI, EURECOM, KU Leuven, IQuadrat, Spark Works, CyberEthics Labs,Nextworks, OTE, Technical University of Delft

INNOVATION

6G-DALI drives innovation across key areas:

1. AI-based data cleaning – Enhances data quality, retrieval, and governance in 6G data lakes.
2. Collaborative MLOps & Reinforcement Learning (RLOps) – Orchestrates ML pipelines via a unified framework.
3. Trustworthy AI – Detects ML model drift and improves unseen scenario accuracy by 20%.
4. Explainable Reinforcement Learning (RL) – Uses Large Language Models (LLMs) for a 2× improvement in RL explainability.
5. Digital Twin – Builds the first DT for Radio Access Network and Core Network (CN).
6. Knowledge Transfer Automation – Simplifies integration and maximises insights.
7. Federated Learning – Ensures 6G privacy and efficiency with NetWork Data Analytics Function (NWDAF) operations.
8. LLM-enabled AI & High Parameter Optimisation – First European AI experimentation and data generation platform for 6G-as-a-Service.

USE CASES/ SCENARIOS

This section summarises the Proofs-of-Concept (PoCs) validating 6G-DALI's enablers: DataOps (PoC 1) and MLOps (PoC 2), along with their experimentation platforms.

- **PoC 1: Data management & experiment on demand**

  Showcases the 6G-DALI AI framework's ability to fulfill user data requests via the 6G Data Space. Objectives are to:

i) Integrate the AI framework with 6G Data Space and Gaia-X for trust and service cataloging.

ii) Use LLMs to translate user requests into datasets and experiments.

iii) Implement an Extract, Load and Transform (ELT) pipeline for data cleaning, augmentation, and storage.

- **PoC 2: AI as a Service (AIaaS) for CDN apps via cross-testbed Decentralised MLOps**

  Validates 6G-DALI's AI framework, including Decentralised MLOps, meta-orchestration, and AI services. It assesses cooperative ML model management and demonstrates applicability in a Content Delivery Network use case.

- **PoC 3: Digital Twins for large and medium-scale 6G experiments**

  Addresses the lack of representative datasets for RAN and CN. It enables large-scale experiments using Digital Twins, aiming to:

i) Generate and integrate datasets into the 6G Dataspace via 6G-DALI ELT.

ii) Implement RLOps for testing and validating trained RL agents.

ENVISIONED RESULTS

AI in 6G enables large-scale deployment, federated learning, model re-training, standardisation impact and interpretability via compliance testing thanks to a good mix of industry and academic experience.

6G-DALI will deliver open datasets, a 6G Dataspace for dataset storage and secure sharing, and a Digital Twin testbed for data generation on demand.

Stream C

SNS MICROELECTRONICS LIGHTHOUSE, X-TREME 6G

The goal of Stream C is to provide a foundational open microelectronics platform in Europe and to validate some 6G candidate technologies.

X-TREME 6G

X Transceivers & RF front-ends made in Europe's Microelectronics light house to Enable new 6G use cases.

OVERVIEW

X-TREME 6G aims to create a Microelectronic LightHouse (MLH) in Europe, serving as an open platform to design next-generation chiplets-chipsets for 6G applications. It leverages advanced Silicon BiCMOS, III-V InP, and 3D integration for high-capacity radio access technologies like wireless backhauling (>140GHz), Joint Communication And Sensing (JCAS), Non-Terrestrial Networks (NTN), and Network as a Sensor (NaS). The project supports the SNS program and emerging Chips Joint Undertaking (JU) pilot lines. X-TREME 6G will establish a 6G experimentation ecosystem in Europe, demonstrating the benefits of new chipsets and supporting the 6G ecosystem's growth. The initiative targets Technology Readiness Level 5-6 (TRL 5-6) maturity for pilot lines and technologies. Additionally, it will develop resource-efficient 6G algorithms and software, including ML/AL algorithms for basebands and new beam tracking for SATCOM applications, enhancing the capabilities for new end-users.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

CORENECT report highlights Europe's strong position in solid-state technologies for Analog-Radio Frequency (RF), and the urgent need for trained RF and millimetre wave (mmWave) engineers. This project aims to develop mixed RF-mmWave and digital technologies to enable high data rates, exploring Silicium-Germanium (SiGe) & Indium-Phosphide (InP) technologies for 6G. It also aims to integrate heterogeneous mmWave components into a single System-in-Package (SiP) with industrial scalability and low-cost packaging strategy.

To address Europe's lack of advanced Complementary Metal-Oxide-Semiconductor (CMOS) technologies, the project will implement baseband functions in Field Programmable Gate Arrays (FPGAs), while awaiting future European Chips-JU initiatives.

X-TREME 6G aims to enhance performance in **mmWave antenna arrays** using high-performance SiGe and InP Integrated Circuits (ICs), developing D-band and H-band phased arrays received and transmitters for X-haul, JCAS, and Q/V-band SATCOM arrays with advanced calibration and beam-forming capabilities.

In 5G/6G **Multiple Input Multiple Output (MIMO) systems**, more antennas increase failure risks, affecting radiation patterns. Addressing this issue, new cost effective approaches using Fourier Function Transfer (FFT), neural networks, and compressed sensing are proposed. X-TREME 6G also aims to advance by using JCAS for detecting and mitigating faulty elements in generalized arrays, integrating mono and multi-static radar images for improved accuracy.

X-TREME 6G will enhance NaS by leveraging real field data from microwave networks for environmental monitoring tasks, developing ML-based algorithms for weather forecasting to improve response to environmental changes.

X-TREME 6G

Coordinated by Didier Belot, STMicroelectronics
January 2025 - June 2028

Website: https://x-treme6g.eu/

LinkedIn: www.linkedin.com/company/x-treme-6g/

Partners: STMicroelectronics, Fraunhofer IZM, III-V Lab, Nokia Solutions and Networks Italy, Nokia Networks France, Institute for Technology of Karlsruhe, University of Bordeaux, CNRS, Denmark Technical University, CEA, AMIRES, IMST, Politecnico di Milano, University of Patras, P-Net, Orange Poland, ETH Zurich, Argus Space

INNOVATION

The project aims to provide SiGe BiCMOS (Fmax 500GHz, qualified up to 300GHz, TRL6-7), and InP HBT (Fmax 600GHz, qualified up to 300GHz, TRL 4-5) platforms for 6G. X-TREME 6G will lead in component fabrication and heterogeneous integration up to H-band, optimising RF performance, heat dissipation, and reliability.

Full hardware demonstrators will be developed for phased array receivers and transmitters at Q/V Bands for NTN and D-Band for X-haul and JCAS scenarios. We aim for high dynamic range improvement using developped process platforms including antennas integration. Architecture will be adapted for NTN, JCAS and X-haul scenarios, with specific configurations for Q/V-band SATCOM.

X-TREME 6G proposes tasks beyond state-of-the-art by for faulty antenna elements detection, using JCAS functionality.

Transition to 6G communications is revolutionising microwave networks, not only improving data rates, reliability, and latency but also unlocking new capabilities, for environmental sensing under the "Network as a Sensor" (NaS) paradigm. Recent studies show that microwave networks, combined with machine learning have potential as integrated sensing infrastructures.

USE CASE/ SCENARIOS

In recent years, several 6G testbeds have been proposed to design and validate emerging technologies. However, most focus on specific aspects such as mmWave and THz links, or Reconfigurable Intelligent Surfaces (RIS), with few open platforms enabling full-scale network application and deployment testing. Many remain limited to 5G scenarios.

Current Wireless Backhauling (WBH) solutions can achieve up to 10 Gb/s using 2 GHz channels, adaptive modulation and frequency reuse (XPIC). Future 6G WBH solutions will target frequencies above 100 GHz (D-Band, and H-Band), providing over 70 GHz of spectrum and enabling very high capacity (10-25 Gb/s) links.

The X-TREME 6G project aims to provide open, advanced testbeds and platforms for third-party research and development, including:

- Broadband massive MIMO testbed: featuring tens of channels and mmWave heads up to 140 GHz.
- Network as a Sensor (NaS) platform: utilising microwave/mmWave network data for environmental sensing.
- Broadband NTN testbed: supporting SATCOM ground terminals with large-scaled receivers and transmitters arrays at Ka-band and/or Q/V-band.
- Joint communication and sensing platforms: operating at Sub-6 GHz, 26 GHz, and 140 GHz.

These testbeds will enable realistic hardware implementations and experimentation, accelerating the development of new-generation 6G applications and technologies.

ENVISIONED RESULTS

This project will validate the microelectronics technology platforms of ST, III-V Lab, and IZM with a D-band hardware demonstrator and H-band building blocks, addressing antenna array integration above 100 GHz. The hardware will integrate into the existing 28 GHz testbed and expand to D-band, enabling further 6G research. It will develop heterogeneous integration of 6G components using Pinted Circuit Board embedding technology and validate 5G-NR extensions, promoting results to 3GPP RAN-1. Both ST's and III-V Labs' technology will be fully exploited, using developped packaging platform. ST, III-V Lab with UBx, and IZM will contribute with process components up to TRL 6-7. Nokia, P-NET, UPAT, CEA, DTU, POLIMI and ORANGE will implement COREnect's strategy to strengthen European 6G leadership. IMST and KIT will contribute with expertise in smart networks, AI, and chip design. The NTN Testbed will enable ETHZ and Argus Space to investigate satellite communications. Platforms will be available for future SNS projects development.

Stream D

SNS LARGE SCALE TRIALS AND PILOTS WITH VERTICALS (IA)

Stream D targets large-scale SNS Trials and Pilots with Verticals, including the required infrastructure. This third call is to explore sustainability in these new 6G verticals.

6G-VERSUS

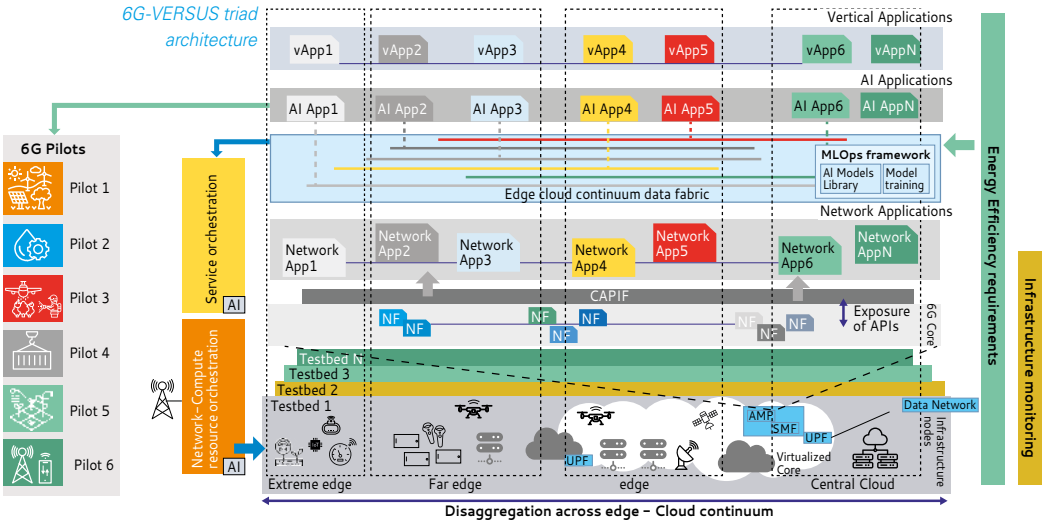
6G Vertical trials for Sustainability.

OVERVIEW

6G-VERSUS is a pioneering initiative designed to bridge technological innovation with strategic experimentation to achieve tangible sustainability outcomes. Leveraging six advanced 6G research platforms across Europe, the project conducts large-scale trials and pilots to explore sustainable solutions in five environmentally conscious vertical industries. The project introduces a novel methodology that transforms existing use cases into 6G applications, structured as Vertical Apps (V-Apps), Network Apps (N-Apps), and AI-assisted Apps (AI-Apps). 6G-VERSUS aims to demonstrate the profound sustainable, economic and societal impact of 6G technology, propelling towards a more sustainable and prosperous society.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

The 6G-VERSUS triad architecture model consists of three components: the **V-App, AI-App, and N-App**. The V-App poses user interface tailored to domain-specific requirements, providing context awareness including real-time data insights for vertical applications. The AI-App leverages machine learning and data analytics to transform raw data into intelligence-based actionable insights, optimising service quality and energy efficiency. The N-App lies at the boarder-line between the 6G-VERSUS architecture and 6G-Application, utilising native 5G/6G APIs to mediate between the V-App and the AI-App through exposing business APIs for optimised decision-making.**The 6G infrastructure** consists of six testbeds forming the physical layer and above the infrastructure lies a layer of core Network Functions (NFs) and a layer NApps, mediated by a Common API Framework (CAPIF), which serves as a standardised, unified and secure API exposure mechanism between the two, enabling their seamless integration,



authentication, and access control. A **Data Fabric Layer** spans the far-edge cloud continuum, incorporating a Machine Learning-Operations framework to enhance AI/ML-driven network optimisation.

INNOVATION

6G-VERSUS innovations will transform the currently existing use cases and services into 6G applications. The project pioneers in AI-driven advancements, such as network slicing for dynamic resource allocation, autonomous optimisation for self-healing and predictive maintenance, and real-time cybersecurity improvements. It prioritises sustainability through energy-efficient networks, renewable energy integration, and AI-assisted power management. By merging technological innovations with strategic planning, 6G-VERSUS seeks to produce practical outcomes that benefit the environment and offer societal and economic advantages, redefining interoperability and end-to-end testing across both public and private networks.

USE CASES/ SCENARIOS

6G-VERSUS

6G vertical applications for sustainability

Coordinated by Sanna Tuomela, University of Oulu

January 2025 - December 2027

Website: http://6g-versus.eu/

X: @6G_VERSUS

LinkedIn: www.linkedin.com/company/6g-versus/

Verticals: PPDR, agriculture, logistics, energy, transport and logistics

Partners: Universities of Bradford, Oulu, Cyprus, Valencia, Malaga, Kingston, and Coimbra, CSIC, A1 Bulgaria, Porto de Aveiro, Entra Energy, Envolve, ICCS, Incites, Infolysis, Pedro Nunes Institute, Instituto de Telecomunicacoes, Keysight Technologies, National Centre for Scientific Research "DEMOKRITOS", One Source, OTE, Telefonica ID, 8Bells, Nokia, Altice Labs, JSIO, Eurecom, Thalès Six GTS, Hellenic Rescue Team of Attica, Software Company, Greencitizen, HP Italy, HiDRALiA, CETAQUA

The 6G-VERSUS is structured around six distinct 6G pilots. 6G-VERSUS realises a three-step methodology by 1) **Transforming the currently existing use cases and services into 6G applications** 2) **Testing and validating the 6G applications of each use-case/pilot at the six 6G SNS and non-SNS Experimentation Platforms** that are supporting the project, properly enhanced with energy efficiency tools and components, 3) **Assessing both qualitatively and quantitatively the sustainable impact** of each 6G Application per use-case/pilot on the environment, the society, the economy, the industry and the European market. With the support of six 6G platforms/testbeds6G-VERSUS is poised to demonstrate the transformative sustainable impact of 6G. The Greek pilot employs collaborative robotics for Search and Rescue (SaR) operations, improving response times and safety of disaster response efforts, minimising human risk and environmental impact. The Spanish pilot develops immersive telepresence actuators for field operations, reducing the need for physical travel and its associated carbon emissions. The French pilot implements data-driven strategies for water and waste management in critical infrastructures, enhancing efficiency and reducing environmental footprint. The Portuguese pilot focuses on creating sustainable and safe port infrastructures, contributing to economic growth and environmental conservation. The Bulgarian pilot utilises AI to monitor, and control distributed renewable energy sources, optimising energy production and distribution. The Finnish pilot innovates with a self-sustainable 5G base station, paving the way for energy-autonomous communication networks.

ENVISIONED RESULTS

6G-VERSUS will demonstrate the feasibility, viability and sustainability of 6G vertical applications and generates new knowledge and insights of the capabilities of 6G technology for verticals. Advanced frameworks for network interaction, vertical application transformation, and energy efficiency will foster 6G vertical solutions that enhance the performance, reliability, and sustainability of communication networks. Engagement with stakeholders will raise awareness of the sustainability and business benefits of 6G technology and inspire broader adoption and investment in sustainable 6G infrastructure. Contributions to standardisation efforts and policy recommendations will influence the development of policies and regulations that support the deployment of sustainable 6G technologies.

AMAZING-6G

Evaluation and validation of B5G/6G sustainability and performance via large-scale trials in the vertical domains of Health, Public Safety, Energy, Transport.

OVERVIEW

AMAZING-6G explores Beyond 5G (B5G) and 6G networks through large-scale trials, assessing their performance, sustainability, and real-world applicability. These trials not only validate key technologies but also reveal new use cases across various sectors including healthcare, public safety, energy, and transport. The project prioritises sustainability in environmental, social, and economic aspects, applying value-driven methodologies to enhance technical specifications and business models. By promoting collaboration among industry stakeholders, researchers, and policymakers, AMAZING-6G aims to drive innovation, standardisation, and scalability. This initiative will highlight the European Union's contribution to developing intelligent, sustainable, and secure 6G networks, in line with key design principles such as resilience, trust, and inclusion. Ultimately, AMAZING-6G will demonstrate the transformative potential of 6G in facilitating advanced applications like IoT, AI, Extended Reality (XR), and smart cities, bridging the gap between theory and practice for a hyper-connected future.

CONCEPT/ ARCHITECTURE/ TECHNOLOGIES

AMAZING-6G outlines a unified architecture aimed at integrating various vertical applications including Energy, eHealth, PPDR, and Transportation—promoting a shared vision and technical coherence. This architecture is organised into distinct system perspectives, that encompass functional, informational, and deployment aspects, while also focusing on key performance factors such as resilience, scalability, and efficiency. A rigorous requirements engineering process captures both functional and non-functional requirements, ensuring they are systematically tracked and integrated into the design.

The architecture features a Communication Continuum that includes both legacy and advanced networking, alongside a Compute Continuum that integrates cloud, edge, and far edge services., It also includes additional layers for IoT, Service Level Agreement (SLA) enforcement, and localisation. Security and management functions form integral pillars, addressing risk mitigation and vertical-specific needs. Sustainability is a guiding principle, driving energy-efficient designs and resource optimisation. This modular and scalable approach ensures adaptability within the evolving 6G ecosystems.

INNOVATION

AMAZING-6G drives B5G/6G innovation across multiple domains, significantly enhancing connectivity, intelligence, and sustainability. In the healthcare sector, AI-powered ultrasound imaging and wearable sensors facilitate continuous monitoring and post-surgical care. Public safety benefits from fast private network provisioning, end-to-end slicing, and the collaboration of autonomous drones for enhanced situational awareness.

Energy solutions are augmented with AI-driven optimisation for renewable

sources and modelling of user behaviours. In transportation advances include real-time digital twins, seamless mission-critical connectivity, and network slicing for railway signalling. Furthermore, AI-driven zero-touch management guarantees dynamic orchestration of teleoperations and automated mobility.

Through cutting-edge edge computing, seamless IoT integration, and designs focused on sustainability, AMAZING-6G is transforming industries, optimising efficiency, resilience, and inclusivity in next-generation networks.

USE CASES/ SCENARIOS

Amazing Large-Scale Trials and Pilots for Verticals in 6G

Coordinated by
Andreas Georgakopoulos, Panagiotis Demestichas, WINGS ICT.

January 2025 – December 2027

Website: https://amazing6g.eu/

X: @Amazing6G

LinkedIn: www.linkedin.com/company/amazing-6g/

Verticals: Automotive, PPDR, Health, Energy, Smart Cities, Transport and Logistics

Partners: WINGS ICT, University of Patras, Centre for Research and Technology Hellas, Port of Thessaloniki, P-Net , Telecom Italia Nextworks, LINKS, City of Turin, HP Italy Bellantenna, TNO, Oslo University Hospital, VTT, Finnish Meteorological Institute, Aurora Power Trains, imec , ISRD, Orange Romania , SIMTEL, Custom Soft Solutions, STS, University of Technology Chemnitz, Smart Rail Connectivity Campus, Universities of Surrey and Carlos III of Madrid, CAPGEMINI, Portugal Acromove Europe, Telefonica ID, Telefonica, OQ Technology

AMAZING-6G explores a wide range of use cases in Health, Public Safety, Energy, and Transport, by using B5G/6G technologies to enhance connectivity, intelligence, and sustainability. Large-scale trials and pilot projects will validate these solutions in real-world environments, ensuring they effectively address sector-specific challenges.

In the healthcare sector, continuous wearable ultrasound monitoring allows for real-time assessment of heart function, which decreases the need for hospital visits, improves patient outcomes, and reduces healthcare costs. Additionally, AI-driven analysis enhances diagnostic accuracy, benefitting both prehospital and perioperative care.

B5G/6G communication, private networks, and network slicing are vital for Public Protection and Disaster Relief operations. These technologies support seamless interoperability for mission-critical services, such as Augmented Reality (AR) and Virtual Reality (VR)-assisted control centres, search and rescue in extreme conditions, and mobile emergency response units. Benefits include increased situational awareness, improved safety for both victims and responders, and more cost-effective disaster management.

In the **Energy sector**, innovations focus on optimising the use of renewable energy and improve infrastructure maintenance. Key use cases include autonomous offshore wind turbine inspections, solar energy monitoring using edge-cloud intelligence, and real-time energy consumption analysis in Renewable Energy Communities (RECs). These solutions enhance sustainability, reduce carbon emissions, and increase grid efficiency through AI-driven forecasting and coordination of energy resources.

Transportation applications focus on improving urban mobility, logistics, and safety. Use cases include protecting vulnerable road users, enhancing railway signalling with B5G/6G networks, and enabling the teleoperation of autonomous vehicles for increased reliability. Ports also benefit from advanced logistics and operations management, ensuring the seamless movement of goods while minimising environmental impact.

ENVISIONED RESULTS

AMAZING-6G will generate groundbreaking scientific insights by addressing performance trade-offs in critical areas such as Health, Public Safety, Energy, and Transport—domains where B5G/6G adoption remains minimal. By leveraging interdisciplinary expertise, the project seeks to advance AI-driven networking and communications, bridging knowledge gaps and laying foundations for future research.

Large-scale trials, open-access datasets, and upgraded testbeds will be used to accelerate the global understanding of B5G/6G infrastructure.

6G is essential for achieving ultra-reliable, low latency, and high-capacity connectivity in mission-critical applications. Additionally, 6G-powered digital inclusion will provide ubiquitous access in underserved regions, fostering sustainability, economic growth, and societal resilience.

CSA: SNS CO-OP

SNS CO-OP

Supporting and coordinating the activities of the European SNS JU.

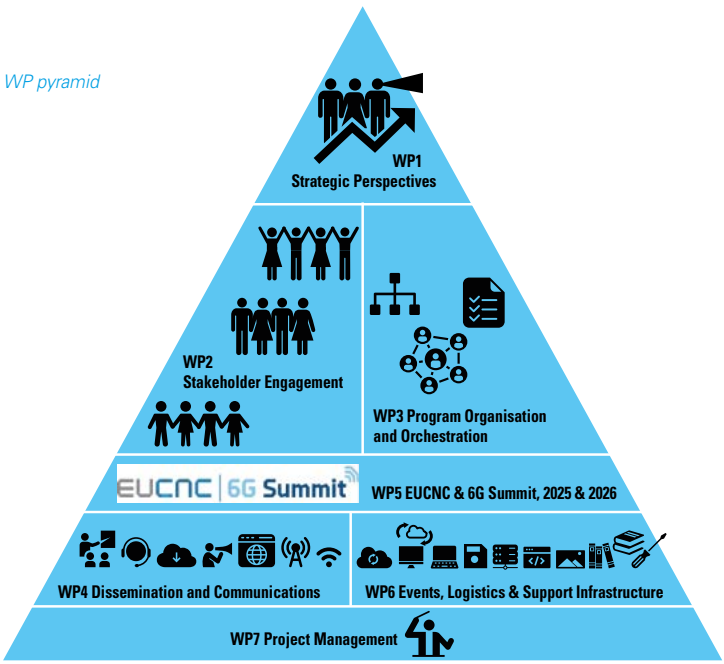
PRIME OBJECTIVES

The SNS CO-OP project prime objective is devoted to supporting and coordinating the activities of the European SNS JU community and its related Work Programmes, building on the first phase activities, to integrate the second phase activities and prepare for subsequent phases. During the life of the SNS CO-OP project the SNS JU will grow to be an initiative of approximately 80 projects running in parallel and all these projects need to be equally supported in terms of their integration into the SNS Support infrastructure, participation in the SNS initiative management boards, working groups and events, and, critically to be facilitated to be an active contributor to the SNS JU goals as a whole.

CONCEPT/ APPROACH

SNS CO-OP will provide programme coordination services and support, shared information spaces and increased stakeholder involvement by building on the strengths and assets of the platforms and communities established through the SNS OPS and SNS ICE work. During the first year of SNS CO-OP, the project will take over all SNS JU support activities from SNS OPS and SNS ICE and, in addition it will take over the EuCNC support for the events in 2025 and 2026 (building on the 6GStart EUCNC support).

WP pyramid



During the life of SNS CO-OP, the project activities of the SNS JU will involve over 80 projects running in parallel. These projects, and their participants, will be integrated into the SNS JU operational structure, signed up for the program level collaboration agreement and invited into the various cross-project workgroups and other programme level activities as is relevant to their workplans and the goals of the SNS JU. In addition to this, SNS CO-OP will assist the preparation work for subsequent phases of the SNS JU whereby analysis of the program coverage and emerging project results can be fed back into the preparation work for future phases of the SNS JU.

The activities will be structured into six Workpackages: WP1 Strategic Perspectives, WP2 Stakeholder Engagement, WP3 Program Organisation and Orchestration, WP4 Dissemination and Communications, WP5 EuCNC & 6G Summit - 2025 & 2026 and WP6 Events, Logistics & Support Infrastructure.

ENVISIONED IMPACT AND RESULTS

SNS CO-OP will facilitate the achievement of the SNS JU impact by operating, maintaining and improving the mechanisms to facilitate and foster the necessary knowledge sharing, collaboration, exploitation, and consolidation among the new SNS JU actions, the affected communities and relevant vertical sectors to help reach the digital targets. The programme volume for the period will involve an average of 80 SNS projects running in parallel for the entire period, which means each assembly of project views, consolidation of opinions and event working meetings will involve many players and require significant actions to ensure fair inclusion of all perspectives. The work towards achieving the potential impact of the SNS Initiative will also involve working in close partnership with the SNS JU Office. Strategic promotion activities will be jointly done and also aligned with evolving goals of the European Commission through the SNS JU Governing Board. The SNS CO-OP impact goals will be distributed across the project activities and will include among others:

- Enhancement of the 6G SNS Vision
- Measurable Programme Progress and Key Performance Indicators (KPIs) / Key Value Indicators (KVIs)
- Maintaining the holistic view of progress on implementing SNS and 6G in Europe
- Widespread dissemination of European achievements
- Growing the 6G SNS constituency
- Supporting early exploitation of results
- Supporting relevant Key Values and Policies

The strength and experience of the SNS CO-OP consortium will allow to achieve the envisioned impacts in a professional, efficient and effective way. The SNS CO-OP consortium has 19 members and affiliates of members of the 6G-IA active in its work, as well as the 6G-IA itself, and six of those organisations are elected to the board of the 6G-IA. This high level of involvement will ensure there is a close alignment between the SNS CO-OP project and the private member of the JU.

SNS Collaborative Operations and Output Optimisation

6G SNS CO-OP

Coordinated by
Uwe Herzog, Eurescom

January 2025 - March 2027

Website: https://smart-networks.europa.eu/call-3-stream-csa/#SNS-CO-OP

LinkedIn: www.linkedin.com/groups/12011028/

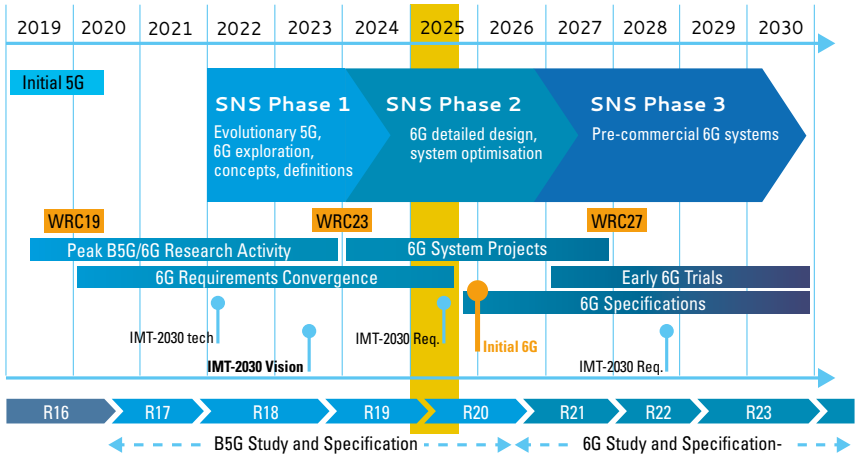
Partners: Eurescom, 6G-IA, Nokia Solutions and Networks Germany, Ericsson, Thalès Six GTS, Telenor, Telecom Italia, IDATE, Nokia Networks France, South East Technological University, Australo, Trust-IT/COMMpla, Instituto de Telecomunicacoes, TNO, CTTC, Vases, INOV, University of Oulu, Poznan University of Technology, University of Malaga, Telefonica ID.

SNS PROGRESS ASSESSMENT

The global development of 6G networks and services is progressing, with standardisation set to begin in 2025. As regions work toward globally accepted standards, early identification of commonalities and differences in use cases, KPIs, and technological enablers is crucial.

The SNS programme to date

The SNS Initiative Steering Board (SB) and Technology Board (TB) act as the main governance bodies for coordination of activities between projects and driving project roadmap and technological alignment. The SB is comprised of the project coordinators and representatives from the public and private sides of the SNS JU along with a selection of key support personnel, while the TB is composed of the technical managers and key support personnel.



SNS Programme – Phased Approach

The SB provides SNS Initiative guidance, such as engagement with the TB and the formation, tracking and closing of SNS Project Working Groups (WGs). The SB also fosters co-operation around general project engagement and events and other actions, to ensure that relevant expertise available from the SNS Initiative when international workshops or liaisons require it.

SNS Project WGs are coordinating bodies for activities relating to specific technical scopes of interest. Among other things, the WGs produce White Papers on topics such as 6G KPIs – Definitions and Target Values; Network and Service Management Advancements; and Towards 6G Architecture[1]. There are currently WGs in place on Architecture, on Test, Measurement and KPI Validation (TMV), on Reliable Software Network, and on Hardware Technologies[2].

The TB fosters technical discussions where technical results and insights are shared, common technical issues are resolved and SNS technical milestones and achievements are tracked, while new topics to collaborate on are also identified. Key findings and insights are shared in various formats such as joint publications, like the recent TB AI/ML White Paper[3] based on a survey of 33 SNS JU projects devoted to the development of AI-based solutions, or the interactive overview of all Call 1 & 2 SNS JU projects in the Reference Figure 2025[4].

1. https://smart-networks.europa.eu/sns-publications/

2. https://smart-networks.europa.eu/sns-ju-working-groups/

3. https://eur02.safelinks.protection.outlook.com/?url=https://smart-networks.europa.eu/wp-content/uploads/2025/02/ai_ml_white-paper-

4. https://eur02.safelinks.protection.outlook.com/?url=https://smart-networks.europa.eu/wp-content/uploads/2025/02/ai_ml_white-paper-

The SNS programme began in 2022 and is organised in three main phases, as depicted in the figure on the previous page, with a first call for projects based on the first SNS Work Programme WP2021-22, followed by annual calls for dedicated WPs.

The SNS programme and its projects are steadily making outstanding progress and a concrete impact, as regularly highlighted in the SNS programme and projects websites and news[1,2]. Seventy-nine projects have been contracted thus far (35 projects in Call 1, 28 projects in Call 2 and 16 projects in Call 3), creating a very strong momentum and sense of dynamism, as depicted in the figure below.

1,244 entities from 33 countries have been funded, of which 505 are unique entities. SMEs account for 26% of entities funded. They attract 24% of the total fundings.

1. https://smart-networks.europa.eu/
2. https://6g-ia.eu/

The Call 4 has opened on May 22, 2025. Participants can submit their proposals online until 18 September 2025.

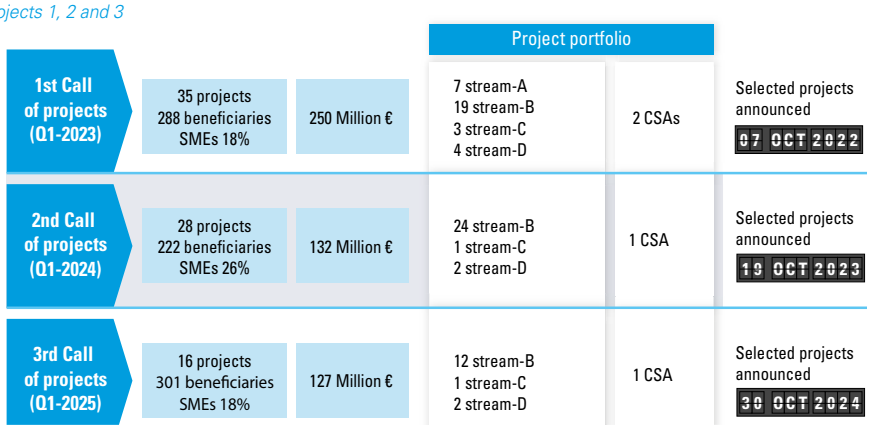
Retained projects from this Call will support research and innovation activities through two complementary streams:

Stream B: Advanced research for revolutionary and evolutionary technology advancements, including Topics on 6G Disruptive Technologies.

Stream C: Development of a 6G Telco Cloud and service platform experimental infrastructure.

Large-scale trials and pilots with vertical sectors with a focus on Industry/Manufacturing, Media, Transportation/Logistics, Emergency and Safety Services, and Health will be implemented through Stream D via a later Call within 2025. The Call for Stream D Proposals will be subject to an amended SNS JU R&I Work Program 2025 to be published in 2025.

SNS Programme and Calls for Projects 1, 2 and 3



Innovations and achievements

The previous section of this SNS Journal highlighted the key information and achievements from Call 1 and 2 projects and the key information and objectives/plans from Call 3 projects. The SNS OPS Monitoring Framework created the ability to map out the SNS Call 1 and 2 projects on technical, vision and market perspectives. The SNS Call 1 and 2 projects were asked to provide detailed input for the next round of data collection pertaining to (non-exhaustive list) events hosted and participated

in (webinars, workshops, sessions, panels, keynotes), co-authored and peer-reviewed journal/magazine articles, conference papers, book chapters, White Papers, standards contributions (from project partners), IPR (e.g. patents), trials and experiments (Proofs-of-Concept, lab tests, trials and pilots), use of and contribution to open source. All the collected data was analysed and consolidated by the SNS OPS project at programme level for further use by Steering Board (SB), Technical Board (TB) and SNS- and Working Groups (WGs) overall.

All SNS Call 1 and 2 projects already contribute actively to the SB, TB and different SNS WGs, while Call 3 projects are currently onboarded as well. A significant achievement within 2024 was the release of the 2nd edition of the SNS projects Reference Figure[1] developed by the TB, providing an interactive map of the 63 Call 1 and Call 2 projects with a set of 15 technological enablers and 6 networks domains that they are working on.

Moreover, the coordination and support action (CSA) projects SNS OPS and SNS ICE have developed and delivered significant tools to facilitate SNS researchers as well as the public to classify and categorise the research taking place within SNS and to link it with associated partnerships and SDOs via the SNS JU trackers suite[2], which comprises three distinct tools, namely the Vertical Engagement Tracker, the Standards Tracker and the KPI Radars. Through these tools, a comprehensive analysis of the different Trials taking place within SNS and the addressed vertical sectors can be obtained, as well as a full list of the standardisation contributions of SNS JU researchers and an overview of the achieved technical and programme level KPIs.

At every step along the way, the 79 contracted projects are having a significant technical and dissemination impact, directly at the project level and at the programme level, through cross-cutting projects and WG actions. The projects' achievements are detailed in the previous section of this SNS Journal. Regarding key achievements at the programme level, the following (non-exhaustive) list testifies to the SNS programme's tremendous momentum and dynamism, as detailed as well in SNS Newsflashes and Newsletters[3]:

- The unified EU front presented at 3GPP SA1 meetings regarding the standardisation and prioritisation of 6G use cases from EU stakeholders (SNS projects, National Initiatives, industry, academia, SMEs), impacting the direction of 6G standardisation, led by SNS ICE and Hexa-X-II.
- The Open Calls Task Force operating under the SB, coordinating the participation of 3rd party experimenters within the SNS JU, and synchronising 145 experimenters from 22 different countries executing experiments addressing 15 different vertical sectors.
- The Sustainability TF operating under the TB, coordinating the work of 27 Call 1 and Call 2 projects actively working on Sustainability solutions for 6G and 6G for sustainability, analysing the methodologies, approaches and metrics used by the researchers.
- The impactful SNS publications[4] (White and position papers) that provide insights into the key findings and insights gained by SNS experimenters and help shape the future of 6G on a global scale. Thus far, three major white papers have been published on AI/ML mechanisms in SNS, Network and Service Management advances and KPI definitions and targets, aggregating the lessons learned and insights from the majority of SNS projects.

1. https://smart-networks.europa.eu/interactive-map-of-sns-projects/
2. https://sns-trackers.sns-ju.eu/
3. https://smart-networks.europa.eu/sns-newsflash-newsletters/
4. https://smart-networks.europa.eu/sns-publications/

- International MoUs/Joint Research and Innovation signed with 28 entities or associations.
- Projects' significant contributions to the ETSI Security Conference 2024[1], the EuCNC & 6GS 2024[2], 5G Techritory 2024, Global 5G Event 2024, Globecom 2024, etc.
- Several cross-cutting project workshops, e.g. SAFE-6G, 6G-SANDBOX, ENVELOPPE, ECOeNET, ORIGAMI and 6G-EWOC at ATHENA 2024[3], 6G-TWIN, BeGreen, CENTRIC, 6Green, 6G4Society[4] and Hexa-X-II 6G Series Virtual Workshops[5] including SNS projects and international presentations from the different regions.
- SNS programme and projects' strong contributions to MWC 2024[6] including SNS Session and exposure for 20+ projects at partners/organisations' booths and stands.
- Programmes' and projects' significant contributions to the forthcoming EuCNC & 6GS 2025[7].

1. https://www.etsi.org/events/2445-etsi-security-conference-2024
2. https://www.eucnc.eu/2024/www.eucnc.eu/index.html
3. https://smart-networks.europa.eu/event/sns-projects-1st-workshop-on-advancements-in-research-infrastructures-adaptive-frameworks-and-global-architectural-evolution-athena-2024/
4. https://smart-networks.europa.eu/event/sns-ju-projects-and-others-at-sustainable-places-2024-workshop-towards-sustainable-6g-mobile-networks-in-luxembourg/
5. https://hexa-x-ii.eu/6g-series-workshop-by-hexa-x-ii/
6. https://smart-networks.europa.eu/event/sns-ju-at-mwc-6g-horizon-session/#:~:text=The%20Smart%20and%20Services%20Joint%20Undertaking%20%28SNS%20JU%29,the%20next%20frontier%20of%20wireless%20communication%20technology%3A%206G.
7. https://www.eucnc.eu/

Vision

The SNS 6G Vision has been shaped through extensive collaboration between EU policymakers, industry leaders, and research communities, with strong private sector involvement via NetworldEurope and 6G-IA. This vision integrates technological, societal, business, and policy considerations to ensure a comprehensive approach. Key focus areas include AI-driven architectures, security, sustainability across social, economic, and environmental areas, and the transition from 5G to smart, interoperable 6G networks. The 6G-IA Vision and Societal Challenges Working Group (VSC WG) and the SNS JU have been instrumental in refining Key Values (KVs) and Key Value Indicators (KVIs) to track societal impacts. Efforts are ongoing to define beyond-connectivity services, emphasising service enablers and ecosystem collaboration. Fundamental needs identified include convergence, security, privacy, resilience, and sustainability, alongside fostering a strong expert community. The SNS CO-OP CSA will further update the vision, ensuring alignment with global developments while guiding future R&I actions and project pipelines.

Cooperation and collaboration

The European Commission promotes international cooperation and seeks to achieve a global consensus on the development of mobile standards and requirements, and especially on 5G and 6G. To this end, agreements have already been signed with many other regions around the globe to support 6G deployment and adoption.

The 6G Smart Networks and Services Industry Association (6G-IA) persistently and diligently engaged in the formalisation of other MoUs. These strategic partnerships and collaborations, marked by the signing of MoUs, are indicative of 6G-IA's commitment to fostering strong relationships and alliances within the industry.

Twenty-eight Memoranda of Understanding (MoUs) and Letters of Interest/Intent (LoI) have been signed with organisations and associations of strategic importance, including the Next G Alliance (USA), 5GForum (South Korea), the Beyond 5G Promotion Consortium (Japan), TSDSI (India), the NGMN Alliance, ESA, 5G-ACIA, AENEAS, 5G-MAG, Taiwan Association of Information and Communication Standards (TAICS), the Bharat 6G Alliance and the European Rail Infrastructure Managers Association (EIM) among others.

Targeted 6G use cases and 6G trials around the world

6G collaboration and competition are already underway. Region-wide initiatives are taking shape, including national efforts in North America, Europe, and Asia-Pacific. In particular, national and international 6G programmes have already begun to generate demand and develop use cases (UCs) and applications.

Given the high stakes, a comparative analysis[1] of UCs prioritised by the various stakeholders reveals that a substantial number of applications, between five and thirteen – an average of around eight for many and up to thirteen for some – are anticipated according to the paper released by the 6G-Infrastructure Association and the SNS-ICE project in June 2024.

Six UCs aggregate the greatest amount of interest but cannot be supported by current networks: i) Holographic Communications, ii) Cyber-Physical Systems, Digital Twin, Manufacturing, iii) Multi-Sensory xR, Gaming/Entertainment, iv) Tactile/Haptic Communications, v) Medical/Health Vertical, Telesurgery, vi) Cooperation Operation among a Group of Service Robots/Drones.

A second group of UCs that carry increased demand for network performance and applications from verticals are attracting significant interest: i) Imaging and Sensing, Transportation UCs including automotive, logistics, aerial, marine, ii) Space-Terrestrial integrated UCs, iii) Intelligent Networks.

A third group is identified as relevant but not a priority based on local

1. 6G Global Landscape: A Comparative Analysis of 6G Targets and Technological Trends, Kostas Trichias, Alexandros Kaloxylos, and Colin Willcock 6G-IA/SNS-ICE, June 2024 - https://smart-networks.europa.eu/wp-content/uploads/2024/07/eucnc24_paper_6g-global-landscape_ucs_kpis_enablers_v1.0-2.pdf

interest UCs: i) Critical Infrastructure ii) Government/National Security iii) First Responder/Emergency Services iv) Smart Buildings and Agriculture/Smart Farming

Group#	6G UCs	Networld Europe SRIA 2022	5GAmericas Next G Alliance	Huawei	B5G Consortium	TSDSI	MediaTek	ITU IMT-2030
1	Holographic Communications	✓	✓	✓	✓	✓	✓	✓
	Cyber Physical Systems, Digital Twin, Manufacturing	✓	✓	✓	✓	✓	✓	✓
	Multi-Sensory xR, Gaming/Entertainment	✓	✓	✓	✓	✓	✓	✓
	Tactile/Haptic Communications	✓	✓	✓	✓	✓	✓	✓
	Medical/Health Vertical, Telesurgery	✓	✓	✓	✓	✓	✓	
	Cooperative Operation among a Group of Service Robots/ Drones	✓	✓	✓	✓	✓		✓
2	Imaging and Sensing	✓	✓	✓	✓	✓		✓
	Transportation Vertical	✓	✓	✓	✓	✓		
	Space-Terrestrial integrated network	✓	✓		✓	✓		✓
	Intelligent Operation Network	✓		✓		✓		✓
3	Critical Infra, Government/National Security	✓	✓		✓			
	First Responder/ Emergency Services		✓		✓	✓		
	Smart Buildings			✓	✓	✓		
	Agriculture/Smart Farming				✓	✓		

Source: 6G Global Landscape: A Comparative Analysis of 6G Targets and Technological Trends, Kostas Trichias, Alexandros Kaloxylos, and Colin Willcock 6G-IA/SNS-ICE, June 2024 - https://smart-networks.europa.eu/wp-content/uploads/2024/07/eucnc24_paper_6g-global-landscape_ucs_kpis_enablers_v1.0-2.pdf

6G trials are also gaining momentum worldwide, with key initiatives exploring advanced technologies and real-world applications. In Europe, SNS Stream B and D projects and Open Calls projects are conducting large-scale trials to validate 6G use cases, including URLLC, AI-driven network automation, and joint communication and sensing. These projects aim to bridge the gap between research and deployment by testing advanced radio technologies, Open RAN architectures, and integrated AI solutions.

Beyond Europe, other regions are also advancing 6G trials. China has conducted successful Terahertz communication tests in satellite-based and urban environments, demonstrating high-speed, low latency capabilities. South Korea is trialling AI-native networks and ultra-dense networking, leveraging its leadership in 5G to accelerate 6G development. Japan is focusing on sustainable 6G infrastructure, testing energy-efficient networks and advanced MIMO technologies. In North America, 6G Americas is leading industry-driven trials on next-gen spectrum utilisation and edge AI, while Brasil6G is exploring 6G applications in smart agriculture and remote healthcare. These global trials are collectively forging the path toward 6G, refining its technologies and ensuring real-world feasibility.

SNS projects address industry challenges

The industry faces a trifecta of challenges centred around Key Value (KV) and Key Value Indicators (KVI): sustainability, inclusion and cybersecurity. SNS projects are addressing these issues.

KEY VALUE INDICATORS/KEY PERFORMANCE INDICATORS (KVIS/KPIS)

For 6G systems, technology assessments must incorporate environmental, social, and economic Key Values (KVs), aligning with global goals such as the UN SDGs. These values are measured through Key Value Indicators (KVIs), which guide the SNS 6G initiative by ensuring that technological advancements address sustainability, digital inclusion, and economic impacts.

Through the SNS JU, Europe is leading efforts to integrate KVs and KVIs into 6G discussions alongside traditional KPIs. Various SNS projects, including those within the 6G-IA Societal Needs and Value Creation (SNVC) Sub-Group and the 6G4Society Support Action, are working to define, evaluate, and implement KVIs.

While some projects have begun measuring KVIs, challenges remain, including prioritisation issues, measurement gaps, and ensuring practical applicability. Engagement with KVIs is nevertheless fostering responsible innovation, helping align 6G development with societal needs, improving public acceptance, and broadening the scope beyond purely technical design considerations.

SUSTAINABILITY

Sustainability is a core principle of the Smart Network and Services (SNS) programme, extending beyond energy efficiency to encompass environmental, social, and economic dimensions. The initiative emphasises reducing

energy consumption and carbon emissions through optimised system designs, AI-driven network management, and energy-aware service provisioning. A key focus is establishing standardised metrics for measuring ICT-related energy usage and carbon footprints, ensuring transparency and accountability. The SNS programme also advocates for integrating sustainability at the service level, enabling real-time energy monitoring and efficient resource allocation. Additionally, fostering user awareness and incentivising green technology adoption are seen as essential steps toward a more sustainable 6G ecosystem.

The 6G-IA Vision published a White Paper on "Sustainability of 6G: Ways to reduce energy Consumption, in December 2024. This White Paper identifies 6G's main operational sustainability challenges in by contrasting the European Industry's consensus vision for 6G and the expected evolution of services and the mobile ecosystem with the lessons learned from 5G, in terms of the main sources of energy consumption and the reasons for it. In trying to address these challenges, this White Paper identifies several candidate enabling technologies and more general approaches to energy consumption and carbon dioxide emission reduction. It also identifies potential current research and standardisation gaps, to be considered in future work on the path to more sustainable 6G.

INCLUSION

Inclusion is a core principle in all SNS projects, ensuring that next-generation networks are designed to be accessible, equitable, and beneficial for all. SNS projects actively promote diversity by fostering inclusive research environments, encouraging gender balance, and addressing digital accessibility for underserved communities. The WiTaR (Women in Telecoms and Research) Working Group has continuously championed gender diversity and inclusion in the telecom and research sectors in 2024. WiTaR was actively fostering mentorship programmes, networking events, and leadership training to empower women in these fields. The initiative has also driven visibility through panel discussions at major industry conferences, such as EuCNC & 6G Summit 2024 and MWC 2024, highlighting female experts and role models. Additionally, WiTaR is collaborating with academic institutions and industry leaders to promote equal opportunities, encourage Science Technology Engineering and Mathematics education for young women, and advocate for policies that support gender balance in tech and research careers.

CYBERSECURITY: A CORNERSTONE FOR SECURE AND RESILIENT 6G DEPLOYMENT

The emergence of 6G marks a transformative shift in digital infrastructure, promising to support an extensive range of future services and applications. From immersive extended reality to ubiquitous pervasive sensing, 6G is set to revolutionise industries and societies. However, its full potential depends on the security and resilience of the underlying infrastructure. Cybersecurity of 6G is not merely a technical requirement; it is a fundamental necessity for the seamless integration of 6G into daily life. Aligned with European values, 6G developments prioritise security and resilience, incorporating societal, ethical, and environmental considerations that extend beyond technological autonomy and economic benefits.

6G cybersecurity faces many challenges, including:

- **Evolving Threat Landscape**: the cybersecurity threat landscape continues to evolve, becoming extremely complex. The heightened connectivity, massive data flows from billions of objects, and the deep integration of Artificial Intelligence (AI) introduce new attack vectors and amplify existing vulnerabilities. Addressing these risks requires a proactive and adaptive cybersecurity strategy, guided by European policies that embed security as a fundamental aspect of technological evolution. These imperative drives extensive research and innovation across multiple cybersecurity domains, aiming to develop solutions capable of tackling 6G's unique challenges.
- **Securing the 6G Cloud Continuum**: the 6G architecture will rely heavily on a distributed cloud continuum, extending from centralised data centres to network edges. This shift demands innovative security frameworks capable of safeguarding resources across a highly dynamic and decentralised environment. AI-powered analytics will be crucial for real-time threat detection, anomaly detection, and automated incident response. Security orchestration mechanisms must be highly adaptable, ensuring real-time attack detection and response. Additionally, decentralised security solutions will be essential to maintain resilience, even during network disruptions.
- **Leveraging AI for Physical Layer Security**: AI's intensive integration into 6G presents both opportunities and challenges for cybersecurity. While AI introduces potential security risks, it can also be leveraged to enhance protection. Technologies like Reconfigurable Intelligent Surfaces (RIS) can dynamically control wireless propagation, improving security at the physical layer. AI-driven algorithms can also detect and mitigate jamming and eavesdropping attacks, ensuring the confidentiality and integrity of wireless communications.
- **Securing the AI Lifecycle**: Given AI's pervasive role in 6G, a comprehensive security approach is required, throughout the entire AI lifecycle. Security must be embedded at every stage, from data acquisition and preprocessing to model deployment and monitoring. This includes addressing threats such as data poisoning, adversarial attacks, and model extraction. Robust Machine Learning Operations (MLOps) practices are essential to ensure the AI model integrity and security. Additionally, validating AI inferences and authenticating AI components will be critical in building trust in AI-driven systems.
- **The Shift Towards Zero Trust and Data-Centric Security**: traditional perimeter-based security models are inadequate for 6G's highly dynamic and distributed nature. A Zero Trust approach, where trust is never assumed and access is continuously verified based on context and identity, is essential. This paradigm enforces the principle of "never trust, always verify," ensuring rigorous authentication and authorisation for all users and devices, both inside and outside the network. This involves: **i) Advanced data protection**: Implementing robust confidentiality, integrity, and availability safeguards throughout the data lifecycle. Confidential Computing enables secure data processing in encrypted environments, preventing unauthorised access even during computation. **ii) Revised Identity, Credential, and Access Management (ICAM)**: adopting dynamic, Attribute-Based Access Control (ABAC) to enforce fine-grained access policies based on user identity, device attributes, and contextual information. **iii) Metadata-driven compliance and security**: processing and analysing metadata associated with data to enforce usage policies and ensure regulatory compliance. Metadata provide valuable insights into data provenance, lineage, and sensitivity.

Cybersecurity is not an afterthought but rather a fundamental requirement for the successful deployment of 6G. By adopting Zero Trust principles, data-centric security, and advanced technologies such as AI and Confidential Computing, global technology and security communities can build a secure, resilient and innovative 6G infrastructure. A strong cybersecurity foundation will not only safeguard digital ecosystems but also unlock the full potential of 6G to drive the next wave of technological advancements.

Main recurring activities

SNS OPS MONITORING FRAMEWORK – 2ND EDITION (2024)

The SNS OPS Monitoring & Analysis Framework is one of the key sources of information regarding the targets, methodologies and achievements of SNS JU projects. Based on an annual questionnaire sent to all SNS JU Research & Innovation (R&I) projects, insights have been gained into the direction of research and innovation within the JU, KPIs/KVIs, the projects' market goals and visions, as well as programme-level KPIs concerning the impact of the SNS JU as a whole. The 2024 edition of the SNS OPS questionnaire was completed by all 33 R&I Call 1 projects and 27 Research and Innovation (R&I) Call 2 projects, and the analysis from the SNS OPS partners provided significant insights regarding the ongoing work, the expected results and the impact achieved thus far. The detailed results of the 2024 SNS OPS questionnaire were presented to the SNS community during a webinar on 27 June 2024, and can be accessed on the SNS JU website: https://smart-networks.europa.eu/event/sns-ops-questionnaire-results-webinar/"

SMALL AND MEDIUM ENTERPRISES' (SMES) INVOLVEMENT AND SUCCESS STORIES

The NetworldEurope SME WG advocates for SMEs in the telecommunications sector. Throughout 2024, the WG continued to promote its members' skills and experience, boosting their visibility amongst larger companies, research organisations and other stakeholders. It also remained dedicated to supporting SMEs' involvement in research and innovation projects.

Exploring R&I opportunities

Since the launch of the first SNS calls, more than 100 SMEs across 27 countries have participated in projects and cascade funding. The WG accounts for more than 60% of those SMEs. Although slightly lower in the 2024 SNS call, the involvement of SMEs has consistently surpassed the 20% SME participation recommended by SNS JU.

SMEs have proven their value in advancing SNS innovation and research and across verticals. Many have consolidated their position in the ecosystem thanks to their agility, their ability to innovate and their skillsets, which gives them a unique competitive edge.

In addition, the WG hosted relevant projects featuring Open Calls such as the aeROS project EUCloudEdgeIoT, STAND.ICT.eu and PQ-REACT, as well as SME-focused initiatives such as the European Cluster Collaboration Platform.

Building connections and enhancing SMEs' visibility

The **"European SME expertise in 5G and beyond 2024"** brochure was released in February 2025. It includes more than 80 company profiles, detailing each SME's expertise, achievements and main areas of focus for future RDI collaboration. The brochure also contains the latest SME success stories, showcasing how their work in R&I projects contributes to enhancing and developing groundbreaking solutions and services.

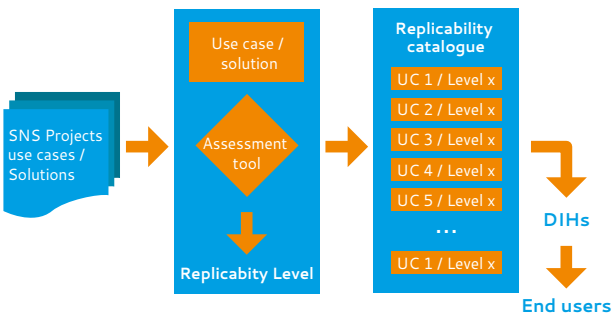
Facilitating networking is at the centre of the SME WG. In 2024, a new initiative was launched to encourage collaboration amongst WG members in R&I projects. A roundtable was also organised to share insights about issues specific to SMEs when applying for R&I projects, including networking, balancing limited resources, and more. The SME WG participation in the EuCNC & 6G Summit was another highlight in 2024. SMEs used the event to present their innovations and explore meaningful collaborations with industry leaders and other players.

In 2025, the SME WG will remain committed to representing SMEs' interests in the electronic communications sector. It will work to strengthen and expand the community, solidifying its position in the ecosystem. The WG will also continue to promote SMEs' skills and experience, to further their participation in R&I projects and to facilitate collaboration with other players.

REPLICABILITY INITIATIVES

The Replicability initiative that has been initiated several years ago with the AIOTI Large Scale Pilots and the 5G PPP projects now includes replicable use cases and solutions developed by SNS JU Call 1 and Call 2 projects.

replicability initiative



The SNS OPS survey was conducted again in 2024, and additional replicable use cases have been collected. In addition, Call 1 projects, which have developed and trialled these use cases, have used the replicability assessment tool to measure a replicability level. The catalogue has compiled more than 130 use cases thus far, covering most verticals with a particular focus on Industry 4.0 (25). There are also multiple "generic" solutions that can be used by different verticals. Stream C and Stream D projects are the largest providers of use cases targeting verticals, as Stream A and Stream B projects provide most of the "generic" solutions, chiefly enablers giving end users greater connectivity power.

In addition to the initial cooperation with the Horizon Result Platform and the Horizon Booster project, a new cooperation has been set up with the techfinders.io project whose objective is similar but covers the full spectrum of digital tech. The cooperation's goal is to align the replicability level to provide DIHs and integrators with a consistent indicator for the ease of replication for a given use case/solution. The updated replicability catalogue currently contains more than 130 use cases, which will be supplemented by the new Call 3 projects following the 2025 survey.

OPEN CALLS

In the SNS JU programme, Open Call projects utilising the Financial Support to Third Parties (FSTP) model play a crucial role in expanding research collaboration and accelerating innovation in 6G. These projects provide opportunities for external stakeholders, including SMEs, universities, and research institutions, to contribute cutting-edge solutions to the broader SNS ecosystem. The Open Calls focus on various aspects of 6G development, such as network automation, AI-driven orchestration, security, joint communication and sensing, use cases and verticals, large scale trials and pilots, and sustainable network design. Selected projects integrate their research into ongoing SNS initiatives, ensuring alignment with European 6G priorities and fostering a diverse, multi-stakeholder approach. The Open Calls launched by Stream C/D projects also support experimental validation through SNS testbeds and large-scale trials, allowing participants to test their technologies in real-world use cases and conditions. These projects significantly enhance the collaborative and competitive landscape of 6G research, ensuring that Europe remains at the forefront of next-generation network development.

6G-SANDBOX, 6G-XR, TARGET-X, Imagine-B5G, FIDAL, 6G-BRICKS, 6G-PATH and TrialsNet, launched Open Calls, which meanwhile have all closed. Open Calls have been very successful, attracting many applicants from a wide range of countries. 180+ Trials and Pilots have been launched by 200+ subprojects with a budget of more than €26 million for 20 Open Calls (3 per project except only 1 for 6G-PATH and 2 for 6G-BRICKS) and 280+ third parties involved. Initial figures, statistics, and insights are being collected by the SNS Open Calls Task Force.

Other 6G initiatives

2024 has been rich in events, cooperation agreements, workshops, and White Papers. This section provides a global overview and reports on major milestones.

MAJOR EVENTS

The past several months has been eventful ones.

Global 5G event 2024

Global 5G events serve as a significant platform for sharing the latest trends in 5G achievements and discussing various topics related to mobile communication, global unified B5G technology standards, and industrial ecosystems. The events also cover discussions on 6G issues, in addition to 5G.

Hosted by TSDSI, the successful 11th Global 5G Event was held in New Delhi, India on August 29-30 2024. The event provided a platform for experts from Brazil, China, Europe, Japan, South Korea, the US and India to discuss topics related to current AI and cloud implementation models in 5G Networks, Multi-Access Edge Computing Use

Cases with AI, regional experiences from 5G deployments, and the path to 6G with AI and the cloud over four technical sessions. It helped deepen understanding of regional views on the potential 5G and 6G AI and cloud computing opportunities, challenges, standardisation and deployment strategies.

EuCNC 2024

The EuCNC 2024 conference, which took place from 3 to 6 June in Antwerp, Belgium, was a remarkable success, once again bringing together leading experts, researchers, and industry professionals to discuss the latest advancements in electronic communications and 6G development. The event featured insightful keynotes, dynamic panel discussions and cutting-edge demonstrations, fostering collaboration across academia and the industry.

With a strong focus on innovation, sustainability and societal impacts, EuCNC 2024 provided a valuable platform for networking and knowledge sharing, reinforcing Europe's leadership in next-generation connectivity. The high level of engagement and the quality of discussions highlighted the conference's role in shaping the future of communication networks.

Many ongoing 5G PPP and SNS projects had a booth, presented a paper, or hosted a session, making this the event of the year for research projects in Europe. SMEs took centre stage, presenting their innovations, networking with industry leaders, and exploring emerging technologies.

The 2025 edition of the EuCNC will be held in Poznan, Poland from 3 to 6 June 2025.

MWC2024

The Mobile World Congress 2024 took place in Barcelona, Spain from 26-29 February. In addition to new smartphones and other innovative devices, emerging technologies to help 5G advanced come true were on display, including revolutionary devices and specialties such as APIs, AI and the Cloud. AI was ubiquitous, in multiple Generative AI applications for various sectors, and for smartphones and wearables. The AI-RAN alliance was announced with the goal of integrating AI into cellular networks to enhance RANs. Another AI-based alliance, the Global Telco Alliance including SK Telecom, Deutsche Telekom, SoftBank was penned to develop dedicated AI models for telcos.

MWC 2024 attracted many SNS projects, including 5G-STARDUST, ADROIT6G, 6G-BRICKS, INTENSE-6G, SUNRISE-6G, 6G-SANDBOX, CENTRIC, 6G-XR, TARGET-X, 6G-SHINE, VERGE, HEXA-X-II; 6G-NTN, 6Green, 6G-EWOC, OPTI-6G, 6G-CLOUD, FirstTo6G, 6G-XCEL, 6G-REFERENCE, and 6G-TWIN.

The SNS JU hosted the "6G Horizon" session, to explore the future of wireless communication, focusing on the theme of "Bridging Perspectives for a Sustainable Future." This 90-minute session brought together industry leaders, policymakers, and researchers to align on the vision for 6G. It emphasised Europe's strong focus on public-private collaboration, the integration of 6G with various industries, and its potential impact on sustainability and cybersecurity. As society moves towards a data-driven future, 6G aims to address new challenges with innovative solutions for resource optimisation and data sovereignty.

OTHER PAST EVENTS AND INITIATIVES

Workshops and webinars

Major workshops took place in 2024 and early 2025, which included:

Impact Assessment and Facilitation Actions (IAFA)

These events are part of a series of SNS OPS coordination and support actions (CSA) targeting relevant partnerships, initiatives and associations to raise awareness about the work of the SNS JU and its projects.

Pre-standardisation

This online workshop series, organised by SNS OPS in collaboration with ETSI and HSbooster.eu, tackled relevant topics linked to challenges in standardisation in the context of 5G/6G developments. The events featured the participation of experts sponsored through HSbooster.eu premium service programme and tackled topics such as SDOs' future 6G Agendas, SDOs 6G Work Items, verticals and standardisation, including the advancements and support of services enabled by 5G and 6G. IAFA#4 was a series of three events addressing this issue, held online in the first half 2024.

6G-IA series of workshops

The 6G-IA has organised six workshops on the following topics: Photonics, NTN, Security, Wireless and Cloud/Service Provision. The purpose of these workshops was to identify possible future strategic directions for the SNS JU for the remaining years. These reports should trigger further discussions with the 6G-IA members (through the 6G-IA consultations), the European Commission, related Horizon Europe Joint Undertakings (JU) and Public Private Partnerships (PPPs), and the Strategic Research Group (SRG). These reports are intended to serve as a springboard to discussions. The various position papers on 6G research priorities address key areas critical to the development of next-generation networks: cloud, microelectronics, photonics, 6G security, wireless communication & signal processing, NTNs.

"How advanced communications can support sustainability goals?"

On 21 January 2025, NetworldEurope and AIOTI – the Alliance for AI, IoT and Edge Continuum Innovation – co-hosted a webinar to explore the transformative potential of advanced communications to drive sustainability.

The workshop created a collaborative space to examine current practices and future visions for integrating sustainability into advanced communication systems. Participants were encouraged to consider how innovations in electronic communications, IoT, and AI can be leveraged to reduce carbon emissions, optimise resource efficiency, and foster a greener digital economy.

Future Services

SNS OPS has initiated a IAFA activity with focus on "Future Services" and how to facilitate, strengthen, and engage with the so-called "5G/6G Provisioning ecosystem", with particular focus on network service provider stakeholders (NSPs, including incumbent carriers, or Communication Service Providers, CSPs). The central purpose is to focus on aligning the relevant 5G/6G SNS industry stakeholders to drive developments in common and future multi-stakeholder services. This requires standardisation, coordination, and incentive-compatible alignment to develop the needed future of interoperable smart network services and service enablers, including capturing insights on current stumbling blocks, pain-points, and challenges.

The importance of Media verticals in 6G

The 15th edition of the NEM Summit, under the topic "Emerging virtual worlds for a new digital society", was organised in Brussels on

23-24 October 2024. SNS OPS partners South East Technological University and Nokia were able to collaborate with the organisers of this prestigious annual event to promote the work and opportunities in SNS to the NEM community and, vice versa, to gather significant contributions from the NEM Community to SNS activities.

Indeed, it was underlined that media is a vertical of significance and highlighted as a main vertical in the four SNS Stream D projects – FIDAL, TrialsNet, IMAGINE-B5G and Target-X - that are implementing large-scale SNS trials and pilots with specific verticals of high economic and societal importance.

6G-IA Workshop on national initiatives

6G-IA will organise a series of webinars where various national initiatives will showcase their key achievements and share information about their experimental platforms.

The first webinar in this series was "UK's 6G Achievements and Experimental Platforms". It took place on 24 January 2025.

in a compute-connectivity continuum environment encompassing different network segments / providers / domains and enabled by softwarisation coupled with new advanced architectures, frameworks, and models. This will allow greater flexibility, reliability, adaptability, and efficiency for both network operations and service deployments for the benefit of an ecosystem of different application layers/developers/components. This will also lay the foundation to move beyond the current inter-networking capabilities in Future Internet architectures and to further convergence between internetworking and IP layer re-engineering. Around 150 participants attended. More information about the event can be found on the website: https://netsoft2023.ieee-netsoft.org/. Rui Aguiar (ITAV) participated as a speaker and member of the distinguished expert panel. The event helped to disseminate of ideas coming from NetworldEurope SRIA.

5G Techritory

5G Techritory has become a major event on the connectivity conference calendar. 5G Techritory 2024 gathered 1,800+ participants from 40+ countries, with 108 speakers delivering invaluable insights across 26 panel discussions and keynote speeches.

In 2024, Quantum, AI, and 6G took centre stage, and the forum has long evolved to cover connectivity. Consequently, on the first day of the event, "5G Techritory" was rebranded to "Techritory" to better reflect the conference's broadening scope and the diversity of their community.

Over the course of the two days, the SNS ICE project has co-hosted five events: i) on diversity in Telecoms R&D with the WiTaR working Group, ii) on key trends and 5G evolutions for vertical sectors where 6G-IA members shared results on trials to validate vertical uses cases, while industrial players shared their experience to bring 5G to real world iii) on the European priorities highlighting lessons learned from 5G and the role of sustainability beyond just energy efficiency iv) on Synergies among NI and the SNS JU activities v) on the SNS projects and tools developed by the SNS JU and CSAs.

The SNS JU brokerage event

The SNS R&I WP for 2025 was announced in the Annual Work Programme (AWP) 2025.

A SNS JU Brokerage Event was held on 29 January 2025 to allow any organisation in the wider SNS JU community to present their organisation profile and/or interests to their peers – as an introduction for possible future collaboration(s).

Presentation of Call 3 SNS projects launched early 2025

In January 2025, the third set of SNS projects was launched, critical in establishing a solid European research and innovation (R&I) foundation, defining

the next-generation networks. The recently launched projects were presented in two webinars on 14 and 17 February 2025, to give an overview of their planned activities and ambitions.

The 6G series workshop by Hexa-X-II (11-12 February 2025)

On February 11-12, 2025, Hexa-X-II and other SNS JU European projects organised the third version of fully virtual workshops open to all. It followed a first version hosted by Hexa-x which took place in June 2023.

The 6Gseries workshop was supported by the European Commission and the SNS JU Office. In addition to insights from the European 6G view, insights were gained into regional perspectives on 6G development from Asia and North America. The workshop aimed to provide valuable information about 6G innovation areas, such as sustainability, system architecture, smart network management, and future devices.

SNS Stream B/D Projects Workshop on KPIs and KVIs

The webinar brought together a diverse group of experts and project representatives to discuss the critical performance and value indicators for 6G technology. Participants included projects from both Stream D (TrialsNet, FIDAL, TARGET-X, IMAGINE-B5G) and Stream B (ORIGAMI, PRIVATEER, Deterministic6G, Hexa-X-II, SAFE-6G, 6GTandem, PREDICT-6G).

WHITE PAPERS AND REPORTS

In 2024, 50+ White Papers and reports were produced by SNS projects and 6G-IA WG projects. All of the White Papers are publicly accessible via the SNS[1] website and the 6G-IA website[2]. An overview is provided below.

- **AI/ML as a Key Enabler for 6G Networks: Methodology, Approach and AI-Mechanisms in the SNS JU (January 2025)**. Produced by the SNS JU Technical Board, the White Paper provides details and statistics about the AI/ML-based solutions developed within the SNS JU, including the goal of the AI mechanisms, the learning type and method, the network segment they are implemented on, characteristics of the AI models used and information about the training data sets and the output of the mechanisms.
- **6G-IA Security WG Position Paper: Innovative Approaches for 6G Security (January 2025).** This paper addresses cutting-edge research and innovative solutions in the realm of 6G security, emphasising the importance of trustworthiness, privacy, and resilience in future network architectures. Looking at collaborative projects funded by EU through SNS JU calls, it provides a comprehensive overview of 6G security research challenges in scope ranging from distributed cloud systems to physical layer protection. This paper is organised around the following key pillars depicting research clusters covered by projects:
·Innovative Security Frameworks;
-Decentralised and Adaptive Solutions;
- Advanced Technologies for Future-Ready Networks;
-Scalable and Zero-Touch Approaches.
- **6G-IA Vision WG White Paper: Sustainability of 6G: Ways to reduce energy consumption (December 2024**). This White Paper identifies the main challenges in the area of the operational sustainability of 6G by contrasting the European Industry's consensus vision for 6G and the expected evolution of services and the mobile ecosystem with the lessons learned from 5G, in terms of the

1. https://smart-networks.europa.eu/sns-publications/
2. https://6g-ia.eu/plans-papers/

main sources of energy consumption and the reasons for it. In trying to address these challenges, this White Paper identifies several candidate enabling technologies, and more general approaches to energy consumption and carbon dioxide emission reduction. It also identifies potential current research and standardisation gaps, to be considered in future work on the path to more sustainable 6G.

- **SNS JU Reliable Software Networks WG White Paper: Network and Service Management advancements (December 2024)**. This White Paper investigates key frameworks and interfaces for achieving open, intelligent and reliable 6G networks. These aspects are implemented in software, which has therefore emerged as an essential component of mobile telecommunication networks, tasked with ensuring the efficient and effective operation of the 5G and 6G systems. 6G Software, with APIs, frameworks, enablers, as well as advanced and bespoke security, will transform 6G networks into a dynamic, intelligent, and secure platform capable of meeting the demands of future applications.

- **6G-IA Vision WG White Paper: European Vision for the 6G network Ecosystem (November 2024)**. This White Paper focuses on the ongoing global efforts to develop and standardise 6G networks, aiming for a commercial launch around 2030. It highlights the importance of creating a unified 6G vision, driven by key stakeholders worldwide, towards a single global consensus.

- **6G SNS IA Report: Smart city trials in Europe – Summary of activities in smart city vertical segments/use cases (June 2024).** This document concentrates on 5G and communication systems when designing Smart City verticals, a basic requirement and expectation amongst multiple stakeholders for future communication infrastructure. The report provides a summary of the key 5G PPP Phase 3 projects devoted to smart city use case trials and validations.

Appendices

Working Groups, Task Forces and Advisory Group

The SNS Initiative Steering Board (SB) and Technology Board (TB) act as the main governance bodies for coordination of activities between projects and drive project alignment on roadmap and technological levels.

STEERING BOARD, CHAIR AND VICE-CHAIR	TECHNICAL BOARD, CHAIR
Mikael Fallgren, Ericsson Anastasius Gavras, Eurescom	Kostas Trichias, 6G-IA

Three types of WGs have also been formed to address certain issues and publish consolidated views established within the SNS Community: i) SNS Industry Working Groups (6G-IA WGs), established under a mandate from the 6G-IA, ii) SNS JU Project Working Groups (SNS JU WGs), established under the mandate of the inter-project SB) and iii) SNS Strategic Working Groups (SNS GB WGs) established under the mandate of the SNS JU Governing Board (GB).

Other WGs work under the mandate of NetworldEurope.

WGS AND LEADERS	ORIGIN
5G/6G for Connected and Automated Mobility (CAM) Pouria Sayyad Khodashenas, i2CAT Konstantinos V. Katsaros, I-SENSE	6G-IA
6G Architecture Ömer Bulakci, Nokia Xi Li, NEC Lab	SNS JU
Enabling Technologies for Future Vertical Ecosystem Transformation Prof. Maziar Nekovee, University of Sussex Dr. Xueli An, Huawei European Research Centre	NetworldEurope
Hardware Technologies Alexios Birbas, University of Patras Luis Manuel Pessoa, INESC TEC	SNS JU
Pre-Standardisation Ricardo Trivisonno, Huawei Veronica Vuotto, Trust-IT	6G-IA
Reliable Software Networks David Artuñedo Guillen, Telefonica ID Dimitris Tsolkas, Fogus Innovations and Services	SNS JU
SatCom Alessandro Guidotti, CNIT Joan A. Ruiz-de-Azua, i2CAT Foundation	NetworldEurope
Open Smart Networks and Services Aitor Garcia Vinas, Vodafone	6G-IA
Security Antonio Skarmeta, University of Murcia Dhouha Ayed, Thales	NetworldEurope
SME Jessica Carneiro, Australo Nicola Ciulli, Nextworks	6G-IA
Spectrum Maria Teresa Aparicio Pena, Telefonica ID	SNS JU

WGS AND LEADERS	ORIGIN
Test, Measurement and KPIs Validation **-Test Data Reusability sub-WG:** Michael Dieudonne, Keysight Technologies **-KVI sub-WG:** Ioannis Patsouras, WINGS ICT **-KPI sub-WG:** Ioanna Mesogiti, Cosmote	6G-IA
Trials Carles Antón-Haro, CTTC Paul Harris, Viavi Solutions	6G-IA
Vision and Societal Challenges Patrik Rugeland, Ericsson Håkon Lønsethagen, Telenor	6G-IA
Women in Telecommunication and Research (WiTaR) Bahare Masood Khorsandi, Nokia Marie-Hélène Hamon, Orange	6G-IA

TASK FORCES / ADVISORY GROUP LEADERS	ORIGIN
Open Calls Task Force Ioannis Markopoulos, NOVA	SNS-I SB
Verticals Task Force Raffaele De Peppe, Telecom Italia	6G-IA
Expert Advisory Group Jyrki Huusko, VTT Artur Hecker, Huawei	NetworldEurope

Acronyms and abbreviations

3D	three-dimensional
5G	5th Generation Wireless Systems
5G PPP	5G Public Private Partnership
5GS	5G System
6G	6th Generation Wireless Systems
6G-IA	6G Smart Networks and Services Industry Association
ABS	Anti-lock Braking System
ADAS	Advanced Driver-Assisted Systems
AI/AI4Edge/AI-AI/AIML	Artificial Intelligence/AI for edge/AI-native Air Interface/Artificial Intelligence/Machine Learning
AP	Access point
API	Application programming interface
AR, VR, XR	Augmented, Virtual, Extended Reality
ASIC	Application-specific Integrated Circuit
B5G	Beyond 5G
BiCMOS	Bipolar Complementary Metal-Oxide Semi-Conductor
B-RAN	blockchain RAN
BS	Base station
CapEx	Capital Expenditure
CoMP	Coordinated Multipoint
Coordination and Support Actions	CSAs
CORENect	European Core Technologies for future connectivity systems and components CORENect
CPS	Cyber Physical Systems
CPU	Central Processing Unit
CU	Centralised Unit
D2D	Device-to-Device
DaaS	Desktop as-a-Service
DDoS	Distributed Denial of Service
DIDs	Decentralised Identifiers
DIH	Digital Innovation Hub
DIMO	Distributed Intent-Driven Management and Orchestration
DLT	Distributed Ledger Technology
DPD	Digital Predistortion
DPU	Data Processing Unit
DSA	Decarbonisation Service Agreement
DSP	Digital Signal Processing
DU	Distributed Unit
E2E	End-to-end
EAS	Edge Application Service
Edge4AI	edge for AI
eFBB	Enhanced Fibre Broadband
ELT	Extract, Load, Transform
eMBB	enhanced mobile broadband
ETSI	European Telecommunications Standards Institute
EU	European Union
FFBC	Full Fibre Broadband Connection
FFC	Full Fibre Connection
FFGRB	Full Fibre Guaranteed Reliable Broadband
FHE	Fully Homomorphic Encryption
FL	Federated Learning
FPGA	Field Programmable Gate Array
GEO	Geosynchronous Earth Orbit
GEO/NGSO/LEO	Geosynchronous Equatorial Orbit/Non Geosynchronous Equatorial Orbit/Low Geostationary Earth Orbit
GHG	Greenhouse Gas
GHz	Gigahertz
gNB	Next-Generation Node B
GPU	Graphics Processing Unit
GRE	Guaranteed Reliable Experience
GRFB	Guaranteed Reliable Fibre Broadband
GRFFE	Guaranteed Reliable Full Fibre Experience
HAP(S)	High Altitude Platform (Station)
HPC	High Performance Computing
HPC	High Performance Computing
IAFA	Impact Assessment and Facilitation Actions
ICT	Information and Communication Technology
IIoT	Industrial Internet of Things
IoT	Internet of Things
ISAC	Instance-specific Algorithm Configuration
ITU/ITU-R	International Telecommunication Union/ITU Radiocommunication sector
J	Joules
JCAS	Joint Communications And Sensing
KCL	King's College London
KPI/KV/KVI	Key Performance Indicator/Key Value/Key Value Indicator
LLM	Large Language Model
LoI	Letter of Intent
M&O	Management & Orchestration
M2MP	point-to-multipoint
MAC	medium access control
MAS	Managed Access System
MB	Multi Band
MBoSDM	Multi Band over Space Division Multiplexing
MEC	Multi-Access Edge Computing
MIMO	Multiple-Input Multiple-Output
ML	Machine Learning
mMIMO	Massive MIMO
mMTC	massive Machine-Type Communication
mmWave	Millimetre wave
ms	millisecond
NBI	Northbound Interface
NGSO	Non-geostationary
NIC	Interface Card
NOS	Network Operating System
NPN	Non-Public Network
NTN	Non-Terrestrial Networks
O/E/O	Optical to Electrical to Optical
ON	Optical Node
Open RAN	Open Radio Access Network
OpEx	Operating Expense
P2MP	Point-to-MultiPoint
P2P	point-to-point
PHY	physical layer
PoC	Proof-of-Concept
PON	Passive Optical Networks
QO	Quasi-Optical
QoE	Quality of Experience
R&D	Research and Development
R&I	Research and Innovation
RAN	Radio Access Network
rApps	robotic Applications
Rel.	Release
RF	Radio Frequency
RIS	Reconfigurable Intelligent Surfaces
RRM	Radio Resource Management
RRM	Radio Resource Management
RSU	radio-side unit
RT RIC	Real-Time RAN Intelligent Controller
RTO	Radio Transmission Operator
RU	Radio Unit
SatCom	Satellite communication
SB	Steering Board
SBA	Service-Based Architecture
S-BVTs	sliceable Bandwidth Variable Transceiver
SCoDIHNet	Smart Connectivity Digital Innovation Hub Network
SDM	Space Division Multiplexing
SDN	Software Defined Network
SDO	Standard Development Organisation
SME	Small and medium-sized enterprise
SMPC	Secure Multi-Party Computation
SNS/SNS JU	Smart Networks and Services/SNS Joint Undertaking
SPT4AI	Secure, Private and Trustworthy AI
TB	Technology Board
TEE	Trusted Execution Environment
THz	Terahertz
TN/NTN	Terrestrial Network/Non-Terrestrial Network
TRL	Technology readiness level
TX/RX	transmitters/receivers
UAV	Unmanned aerial vehicle
UC	Use Case
UI	User Interface
UN	United Nations
UP	User Plane
UPF	User Plane Function
URLLC	Ultra-Reliable Low Latency communications
V2V	vehicle-to-vehicle
VC	verifiable credentials
VIM	Virtual Infrastructure Manager
VNF/NF	Virtual network function/Network Function
vRAN	virtualised RAN
WBSS	Wave Band Selective Switch
xAI	Explainable Artificial Intelligence
xApps	Cross Applications
ZSM	Zero-touch network and Service Management

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More information at
https://smart-networks.europa.eu