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SNS OPS – Supporting the SNS JU Operations

SNS JOURNAL/2023

Table of Contents

Foreword from the European Commission

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Interim Executive Director of the Smart Networks and Services Joint Undertaking and Head of Unit, Future Connectivity Systems at European Commission

In January 2023 the Smart Networks and Services Joint Undertaking (SNS JU) launched its first portfolio of 35 research, innovation, and trial projects. Selected after the first SNS JU Call in early 2022, these projects enable the evolution of 5G (5th Generation Wireless Systems) technology and ecosystems and promote 6G research in Europe.

With a combined funding of around 250 million EUR under Horizon Europe, this projects portfolio aims to build a first-class European supply chain for advanced 5G systems and Europe's 6G (6th Generation Wireless Systems) technology capacities.

The Research and Innovation (R&I) projects will develop smart communication components, systems, and networks for 6G, tracing both an evolutionary path through further enhancements of 5G advanced technology (Stream A[1]), as well as a more revolutionary path by investigating the benefits of promising technological enablers (Stream B[2]). Technology validation initiatives will develop SNS experimental infrastructures (Stream C[3]) and carry out large-scale SNS trials and pilots (Stream D[4]) in several business and industrial vertical sectors.

1. https://smart-networks.europa.eu/stream-a-smart-communication-components-systems-and-networks-for-5g-mid-term-evolution-systems
2. https://smart-networks.europa.eu/stream-b-research-for-revolutionary-technology-advancement-towards-6g/
3. https://smart-networks.europa.eu/stream-c-sns-experimental-infrastructures/
4. https://smart-networks.europa.eu/stream-d-large-scale-sns-trials-and-pilots/

Stream A selected projects (7) cover research on energy-efficient radio networks, adaptive Open Radio Access Network (Open RAN), integrated 5G Non-Terrestrial Networks (NTN), Artificial Intelligence (AI)-based edge platforms, and intelligent resource management ensuring security, privacy and trustworthiness.

The 19 Stream B projects focus on novel technologies that are expected to be adopted in commercial networks in a mid- and/or long-term timeframe. The projects research novel 6G system architectures, advanced wireless and optical communication technologies, advances in NTN, secure development of ultra-reliable and low-latency communications (URLLC) applications. Hexa-X-II, the flagship initiative, will provide a complete system perspective of future 6G SNS platform, from an End-to-End (E2E) architectural and functional perspective, address sustainability and societal aspects and consolidate 6G Key Performance Indicators (KPIs) and European Key Value-based indicators (KVIs).

While the three Stream C projects develop European Union (EU)-wide experimentation platforms that can incorporate promising technical 6G enablers (e.g., from Stream B) for their further validation, Stream D four projects are implementing large-scale SNS trials and pilots with specific verticals of high economic and societal importance. They are exploring and demonstrating 5G/6G technologies, advanced applications, and services in vertical sectors such as media, industrial Internet of Things (IoT), energy, construction, automotive, manufacturing, eHealth, culture, agriculture and education, also thanks to open calls in which third parties, including small and medium-sized enterprises (SMEs), start-ups and scale-ups can participate. These large-scale trials incorporate key enablers for 6G networks, such as AI/Machine Learning (ML), cybersecurity, cloud/edge and advanced IoT solutions, and aim to become the catalyst for the creation of viable business ecosystems.

Success in 6G will depend on the extent to which regions succeed in building a solid 5G infrastructure, on which 6G technology experiments and, later, 6G deployments can build. Which is why building 5G ecosystems is so critical. The SNS JU encapsulates this rationale in its two-pillar approach[5], coordinating the 5G Strategic Deployment Agenda and fostering 5G deployment projects under the Connecting Europe Facility Digital and other programmes, while fostering Europe's technology and industrial capacities in 6G.

Building on the 5G Public Private Partnership (5G PPP), the first set of 6G projects and on the Hexa-X flagship, the SNS projects did play an active role, introducing the first wave of projects and projecting their impact in dedicated SNS lunch webinars and by presenting their standardisation roadmap and ambitions at the ETSI Research conference last February.

Europe's objective is clear: leading the design and standardisation of 6G technologies, with a holistic industrial approach that focuses on connectivity but also tackles edge cloud environments and future chips for 6G, as set out in the European Core Technologies for future connectivity systems and components (CORENect) roadmap for positioning Europe in 6G chips.

With the Second SNS JU Call that closed last April, the Smart Networks and Services Joint Undertaking is committed to ensuring that Europe builds a value-based 6G vision, collaborates with other leading regions around the world, promotes a global 6G standard and onboards verticals as early as possible to drive new technological requirements and build the needed infrastructure.

With earmarked public funding of 132 million EUR, SNS Call 2 kicked off SNS Phase 2 and, once again, attracted a large number of proposals. For Call 2 we also called on multidisciplinary teams to address the societal challenges surrounding SNS technologies.

Good luck to all the SNS First Call projects that will soon be joined by new ones!

We look forward to continuing to work with the growing SNS community!

5. *smart-networks.europa.eu/missions-and-objectives/*

Introduction from the 6G-IA

The start of the first SNS-JU projects in January 2023 as described in this journal is a very significant milestone. As well as marking the beginning of the real work of this important research programme, it also represents the culmination of many activities over many years to make it possible. We should remember the work of the Information and Communication Technologies (ICT)-52 projects in the previous5G PPP partnership. This set of projects began the work on 6G research and built a technological bridge from the 5G to the 6G era. Their work fed into the definition of the SNS-JU proposal in terms of technological goals and requirements and was instrumental in the creation of the European 6G vision[6].

We should also remember the many people and organisations who were involved in setting up the SNS-JU from the first discussions in 2017 to the present day. When we started this journey, it was far from clear that any research partnership for mobile communications would be part of Horizon Europe. Through the hard work of those on the private and public side, we have created the SNS proposal and steered it through the path to approval and implementation. Having been a part of this process from Day one, I can honestly say it is a pleasure to be writing this foreword as it is indicative of how far we have come and indeed how far we still aim to go.

As this journal shows, the first calls of the SNS-JU have laid a strong foundation for 6G research in Europe. The scope and breadth of the research encapsulated in these projects is unique, as is the broad spectrum of participating organisations. We need to build on these first steps to create a dynamic and inclusive 6G research community around SNS. We will work on creating relevant working groups to share knowledge and discuss solutions so that true collaborative activities across the whole SNS community can begin.

Colin Willcock,

Chairman of the SNS JU Governing Board and 6G-IA Board

6. https://5g-ppp.eu/wp-content/uploads/2021/06/WhitePaper-6G-Europe.pdf

Moving to 6G

5G deployment will continue on over the next few years. 6G will be its successor, and be faster, more accurate and more ubiquitous. 6G networks will use very high frequencies, higher than 5G networks, ranging from 100 Gigahertz (GHz) to 30 THz (Terahertz). Cloud-based network technology will offer substantially higher capacity and much lower latency. Basic requirements for 6G include 1 Tbps speeds with latency below one millisecond, compared to 1 Gbps for 5G, and latencies below 5 milliseconds (ms).

6G networks will also be distributed, decentralised, and smart to achieve a truly trustworthy infrastructure and reduce the networks' footprint on energy, resources, and carbon emissions.

The development of 6G involves several key enablers, including Terahertz communications, AI, 3D communication infrastructure to incorporate both terrestrial and wireless access points, sensors, a High level of Security, and an energy-efficient air interface.

The focus on optimising performance – which has always been the main driver for the telecom industry – has started to shift. The impact of networks and sustainability have become an increasingly large priority in discussions and research.

Call #1 presentation

In November 2021, the SNS JU was established as a legal and funding entity, and one of the European Partnerships aimed at accelerating the Green and digital transition. This Partnership is led jointly by the European Commission and the 6G Smart Networks and Services Industry Association (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 stakeholders, including operators, manufacturers, research institutes, universities, verticals, SMEs and ICT associations.

The SNS JU promotes alignment with Member States on 6G Research and Innovation and the deployment of advanced 5G networks. It sets out an ambitious mission with an EU budget of 900 million EUR for 2021 to 2027. The private sector will contribute to SNS JU activities with at least equal resources (i.e., 900 million EUR).

The SNS JU has two main ambitions:

Foster Europe's technological sovereignty on 6G by implementing the related R&I programme, leading to design and standardisation around 2025.

Boost 5G deployment in Europe with a view to developing leading digital markets and enabling the digital and Green transitions of the economy and society. To this end, the SNS JU coordinates strategic guidance for the relevant programmes under the Connecting Europe Facility, in particular for 5G Corridors.

The first SNS call for proposals under Horizon Europe was published on 18 January 2022, and closed on 26 April 2022. The 35 first SNS-JU projects were launched in January 2023 in four main complementary workstreams and backed by two CSAs (Communication Support Actions):

Stream A: Smart communication components, systems, and networks for 5G Evolution systems – 7 projects

Stream B: Research for radical technology advancement (in preparation for 6G and radical advancements of IoT, devices and software) – 19 projects

Stream C: SNS Enablers and Proof of Concept (PoCs), including development of experimental infrastructure(s) – 3 projects

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 – 4 projects

The 35 projects are critical to establishing a solid R&I foundation for Europe, defining next-generation networks. The second SNS call for proposals opened in January 2023 with a submission deadline set for April 2023.

This section provides details on CFP 1 SNS-JU projects, stream by stream.

The seven projects in this stream trace 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 and trustworthiness.

Stream A

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

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.

PROJECT OVERVIEW

To this end, the project will design, develop, and demonstrate a **flexible satellite system** integrated with the terrestrial infrastructure by means of self-organised network architecture, and will deliver an **innovative framework to support the operation of multi-orbit constellations**, with transparent and regenerative space nodes, to deliver 5G/6G NTN services.

OBJECTIVES

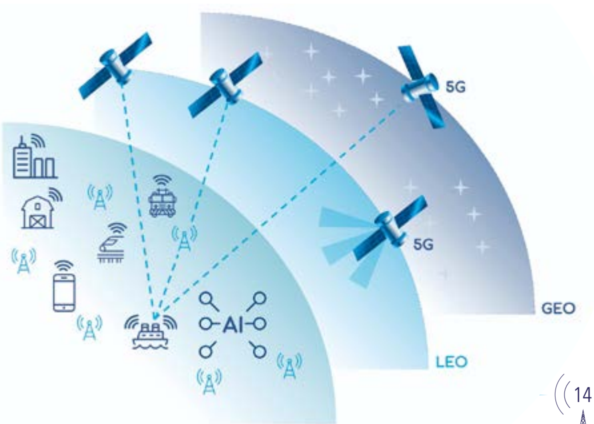
A full-fledged AI-based network architecture concept will be taken as baseline to enable a self-organising network paradigm, whereby multi-connectivity and radio resource management will be data driven and allow for rapid auto-tuning of the end-to-end system according to the varying operating conditions.

In order to develop such an ambitious system concept, the project will pursue the following specific objectives:

- Study, design and develop a **5G-based satellite network**, implementing onboard processing and storage capabilities towards effective networking and mobile computing in the sky.
- Define and design **data-driven management system components**, building on AI/ML based solutions for resource allocation and service provision in highly dynamic integrated hybrid networks.
- Design, implement, and demonstrate **E2E services over a fully integrated Terrestrial Networks (TN)-NTN** advanced network architecture with regenerative space nodes.
- Contribute to the development of a **European Research and Technology roadmap** to ensure strategic positioning and global competitiveness of Europe in integrated TN-NTN communications

KEY TECHNOLOGIES

- Regenerative payloads for Geostationary Earth Orbit (GEO) and Non-Geostationary (NGSO) systems
- Unified radio interface for cost-effective converged TN/NTN multi-tenant networks
- Softwarised self-organised network architecture
- E2E AI-Driven Network Design



5G-STARDUST key technologies

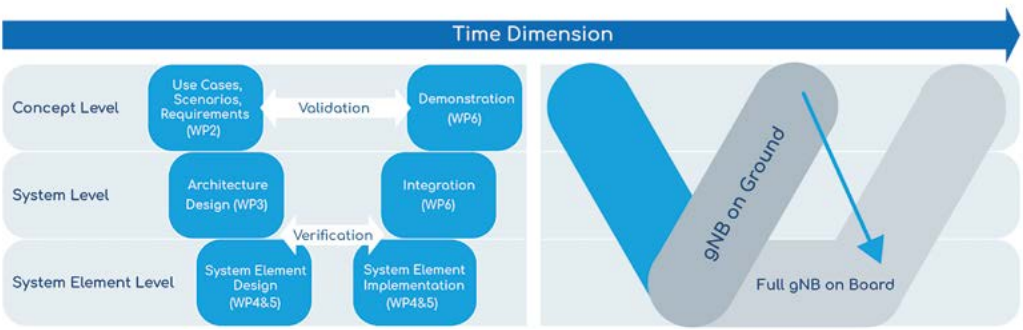
CONCEPT AND APPROACH

5G-STARDUST will enable ubiquitous 5G coverage with special focus on low-density areas through a deeper integration of TN and NTN. In order to provide coverage and services to a wide area economically, 5G-STARDUST will investigate the use of space-borne components, namely satellite communication (SatCom) from Low- and Geostationary Earth Orbit (LEO and GEO).

The challenging objectives of 5G-STARDUST will be achieved by implementing an incremental system engineering approach relying on the Vee model and consisting of two phases, as depicted below, whereby the system will be progressively expanded through the concept, system, and system element level towards the system demonstration.

The baseline used for such an approach will consider the next-generation Node B (gNB) located at the ground segment (step 0), as addressed in the current state of the art following 3GPP-Release 17. The first phase (1) will then consist in moving some gNB functionalities to the space segment according to widely accepted RAN Centralised Unit (CU)/Distributed Unit (DU) functional splitting. Finally, the second and last phase (2) will be aimed at moving the gNB entirely to the space segment, hence giving a more futuristic view of the so-called **Satellite-as-a-Service concept**, while also offering new services such as edge computing in space

5G-STARDUST concept and approach



TRL 5 PLANNED DEMONSTRATION

The aforementioned incremental approach (from steps 0 to 2) will be pivotal to achieving effective demonstration of the system designed in the course of the project. As such, intermediate demonstrations will be possible until the system being designed reaches full maturity, after which it will be demonstrated as part of a final project dissemination event.

Satellite And Terrestrial Access For Distributed, Ubiquitous And Smart Telecommunications

5G stardust

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January 2023-December 2025

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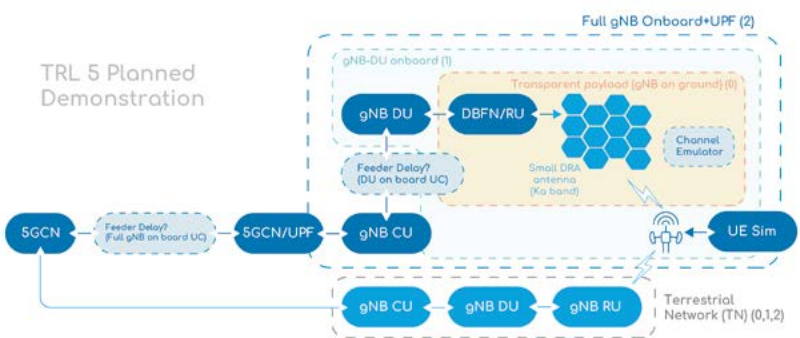

Incremental gNB in space implementation towards the final demonstration

6GREEN

The 6Green project aims to conceive, design, and realize an innovative service-based and holistic ecosystem.

CONTEXT

The 5G aspect of radio mobile networks and edge computing technologies are the two key enablers transforming the cloud into a flexible communication and compute continuum, creating the possibility of introducing radically new applications in any vertical industrial domain. Recent studies indicate that the intrinsic distributed and pervasive nature of 5/6G and edge computing are going to cause a noticeable usage and deployment increase for computing resources, driving up associated infrastructure operating expense (OpEx) and capital expenditures (CapEx), and, consequently, their carbon footprint and energy requirements.

The rise of edge computing is further affecting the infrastructure and its impact on energy consumption and Greenhouse Gas (GHG) emissions, leading to an edge-cloud continuum composed of a large number of public/private micro/small/medium datacentres. Since, in 5G, edge facilities should be dimensioned in accordance with the workload produced by locally connected mobile users and their (edge) applications, the edge component of the 5/6G continuum cannot benefit from workload aggregation, and it will significantly affect the ecosystem's sustainability.

To tackle this problem and meet the sustainable growth targets of both the United Nations (UN) 2030 Agenda and the European Green Deal, the 5/6G continuum needs to develop new foundational paradigms rapidly, specifically addressing the overall ecosystem's energy and carbon footprints.

OBJECTIVES

The 6Green project aims to conceive, design, and realize an innovative service-based and holistic ecosystem, able to extend the communication infrastructure into a sustainable, interconnected, greener end-to-end integrated computing system, supporting all types of services and interconnected networks, and promote energy efficiency across the whole 5/6G value chain. The ultimate objective of the project is to enable and to foster 5/6G networks and vertical applications, reducing their carbon footprint by a factor of 10 or more compared to business-as-usual scenarios.

To achieve this ultimate goal, the project will exploit and extend state-of-the-art cloud-native technologies and the Beyond 5G (B5G) Service-Based Architecture (SBA) with new cross-domain enablers to boost the global ecosystem's flexibility, scalability and sustainability, and to have 5/6G stakeholders (from the ones acting at the infrastructure and network platform levels to vertical industries) reduce their carbon footprint by becoming integral parts of a win-win Green economy business, and fulfilling a Decarbonisation Service Agreement (DSA). The interactions among stakeholders will create the ability to achieve a successful trade-off between the dynamic and geographically distributed (mobile) workload produced by vertical applications and network slices, and the energy consumption/carbon footprint induced to the evolved SNS network and computing infrastructure.

DESCRIPTION AND METHODOLOGIES

The 6Green project envisions the 5/6G ecosystem as a sustainable, interconnected, greener, flexible end-to-end integrated computing system, able to properly interface stakeholders by means of the latest generation internet-based and cloud-native paradigms, and facilitating their interactions according to the aforementioned Green economy business models and agreements. This will enable 5/6G vertical applications and network slices to be autonomically placed in the edge-cloud continuum in a dynamic, and scalable fashion, and to instantiated, modified, dimensioned, migrated, and released in a coordinated fashion, when and where needed by end-users to minimise the resulting impact in the infrastructure layer.

In order to shift from the current, flat/semi-static lifecycle management of network slices and applications to novel and real-time adaptive operations, three ground-breaking technological innovations have been identified that reflect the structure of the Project activities:

1. **Edge Agility**: a form of handover procedure providing smart, fast, and automated horizontal scalability to vertical application and related slices across the 5/6G edge-cloud continuum. The workload, as well as the latency budget, are redistributed according to user or infrastructure-driven events, (e.g., user mobility, seamless workload replacement/migrations, etc.). The slice/vertical application footprint is rapidly scaled to zero in all unused continuum areas and quickly resumes the operating capacity when needed.
2. **Green Elasticity**: the provision of energy-aware, hardware-assisted acceleration to network functions and vertical applications to enable smart vertical scalability across the whole 5/6G ecosystem. Relying on hardware acceleration engines, which exhibit low power-consumption dependency against their usage, enabling lower processing latency with respect to pure software artefacts and reduced consumption by exploiting standby/low power modes joint with optimal configurations/deployments.
3. **Energy-Aware Backpressure**: the design of a set of cross-domain observability mechanisms and analytics, fed by hardware-level energy consumption metrics, to evaluate the energy and the carbon footprint ascribable to a vertical application or a slice. The introduction of Green business models is seen as a catalyst to motivate all the stakeholders to adopt environmentally conscious behaviours through economic incentives.

Three future-proof vertical applications have been identified as project use cases, not only because they represent future-proof 5/6G applications extremely relevant to energy- and carbon-awareness, but also because they provide challenging requirements on network slices and (edge) computing and storage facilities, which can vary according to the Energy-Aware Backpressure information flows and activated application functionalities, and that can differently trigger Edge Agility and Green Elasticity zero-touch operations.

Use-Case #1: **Critical Operation Maintenance during Energy-Constraint Disaster Scenarios**. Evaluation of the consequences of a disaster for the infrastructure essential for the functioning of a society and economy), and identification of countermeasures to preserve stability and reduce negative impact for society and economy.

Use-Case #2: **Energy-Efficient Augmented Reality Remote Assistance System**. Evolution of a Remote Visual Assistance from a remote optimisation tool for manufacturers towards a key solution for verticals to get closer to carbon neutrality, with the introduction of Augmented Reality features to collect live data and share it remotely to improve energy-efficiency.

Use-Case #3: **Zero-Carbon Clientless Virtual Enterprise Desktop as-a-Service** (DaaS). Shift most DaaS tasks from clients to servers to provide native 5/6G benefits such as security, slice integration with the private enterprise network infrastructure, and reduce GHG emissions.

Green Technologies for 5/6G Service-Based Architectures

6Green

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BeGREEN

BeGREEN brings forward the design of energy-efficient solutions into radio access, edge, network functions and management.

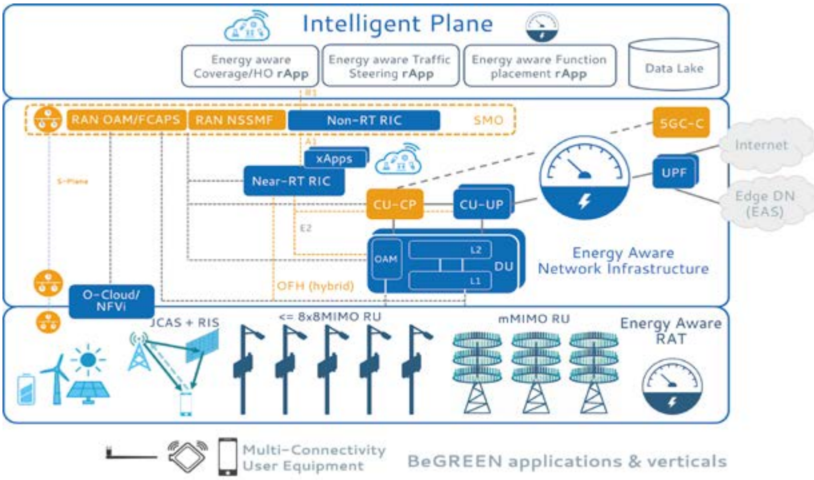
PROJECT OVERVIEW

The project takes a holistic view to providing evolving radio networks that not only accommodate increasing traffic and service levels but also consider power consumption as a factor. BeGREEN aims to establish a solid techno-economic basis for assessment of technology choices where energy efficiency is an explicit characteristic rather than an afterthought. The project will take an evidence-based assessment of current and emerging radio access technology choices to expose the practical energy cost of cutting-edge technologies to help community achieve energy consumption targets.

ARCHITECTURE

The proposed architecture, based on massive Multiple-Input Multiple-Output (mMIMO) as well as lower order MIMO scenarios assisted with Joint Communications And Sensing (JCAS) and Reconfigurable Intelligent Surfaces (RIS), uses the advantage of an O-RAN Near-RT RIC (Real-Time RAN Intelligent Controller) and AI/ML cross applications (xApps) to provide extra features to B5G/6G RAN energy efficiency. Primarily, the project provides an analysis of mMIMO and cell-free distributed MIMO architectures, and their impact on energy utilisation in the network. With near-future deployments allowing many antennas to achieve cell-free connectivity, the proper utilisation of spectrum resources, energy transmission and interference mitigation becomes essential. A small difference in the utilised joules (J) per bit per user would have a huge impact from the operator's perspective. As such, BeGREEN's aim is to quantify the combined energy and spectral efficiency impact of practical constraints that conventional and emerging base-stations and mobile devices experience in providing data services to end users. Defining the energy efficiency of a radio network requires consideration of several factors.

The BeGREEN proposed architecture, as shown in the figure, includes distributed unit (DU) hardware acceleration using a graphics processing unit (GPU)-based offloading engine as a fundamental technology component to achieve energy efficiency for offloading heavy data processing to enable large scale mMIMO radio-access complex data processing, as well as centralised processing units for cell-free distributed MIMO control. In addition, direct interaction of Near-Real-Time RAN Intelligent Controller (Near-RT RIC) with RU to improve energy efficiency by means of robotic applications(rApps)/ (xApps) controlling of radio unit (RU) functions, as well as AI-assisted digital predistortion (DPD) and envelope tracking solutions are being considered. To enable longer RAN resource deactivation times (macro-sleeps), an appropriate management of the carriers and channels (antennas) according to traffic distributions and demands at a macro-time, e.g., minutes or even hours, can avoid the resource waste emanating from the over-dimensioning of the network to meet peak hour requirements. For the xApp control algorithms, depending on RU capabilities, functionalities such as reduction of transmit power at idle times and switching between MIMO scenarios (e.g., switching 4x4 to 2x2 or vice versa) are considered.



BeGREEN Architecture

BeGREEN proposes an AI-assisted energy-aware "Intelligent Plane" as an additional plane along with user plane and data plane, that allows the data, model, and inference to be seamlessly exchanged between network functions. This "Intelligent Plane" will evolve O-RAN components and interfaces to enhance power consumption monitoring and control in the RAN infrastructure. Furthermore, while O-RAN is currently focused solely on the RAN, BeGREEN will tackle beyond state-of-the-art evolution towards the infrastructure for the mobile core user-plane, for radio Edge located applications (Edge Application Service (EAS), with user plane function, User Plane Function (UPF) and CU-user plane), Central Unit-User Plane (CU-UP), instances), including specific Edge AI services. BeGREEN's Intelligent Plane aims to address innovations and challenges such as:

- **Energy-aware interfaces**: The designed architecture will extend O-RAN interfaces to enhance the exposure of energy-related metrics and control services to the envisioned energy-aware rAPPs and xAPPs. The exposed data and services will leverage the findings of the project related to the definition of energy efficiency KPIs, and to the monitoring and optimisation of CU/DU/RU components (E2 and O1 interfaces) and the O-Cloud (O2 interface).
- **AI Engine**: The AI Engine will consist of an execution environment that can host AI/ML models and will manage their lifecycle and access to data, where training and inference is envisioned to be performed by AI-driven rAPPs and xAPPs.
- **AI-driven energy-efficient management of user plane network functions**: BeGREEN will introduce AI/ML algorithms that dynamically select central processing unit (CPU) power saving modes (e.g., C-states) and orchestrate the number of Virtual network functions (VNF) instances to minimise energy consumption according to the network's utilisation patterns and without affecting virtualised RAN (vRAN) and User Plane Function (UPF) performance. Moreover, BeGREEN will study the impact of federated learning approaches to the energy efficiency of AI/ML algorithms and its lifecycle management.
- **AI-driven energy optimisation for edge computing applications**: BeGREEN will conduct an in-depth evaluation of the impact of AI services' energy consumption on a mobile network.
- **O-RAN-based control of innovative wireless technologies**: BeGREEN will study the benefits of innovative technologies like intelligent reconfigurable surfaces (RIS), cell-free distributed MIMO, and relay-enhanced RAN (e.g., Mobile Integrated Access and Backhaul) on energy efficiency, targeting its integration with O-RAN architectures.

At the end of project, BeGREEN's solutions will be implemented and demonstrated in a real-time end-to-end scenario, on BT's testbed in Adastral Park, Ipswich, UK.

BEGREEN

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ACROSS

ACROSS offers a secure E2E network and service management platform that is poised to tame the emerging dynamicity, complexity, performance, and scalability requirements of modern and futuristic end-user oriented 6G services over an ever-expanding cloud processing continuum.

OVERALL VISION / PROJECT GOALS

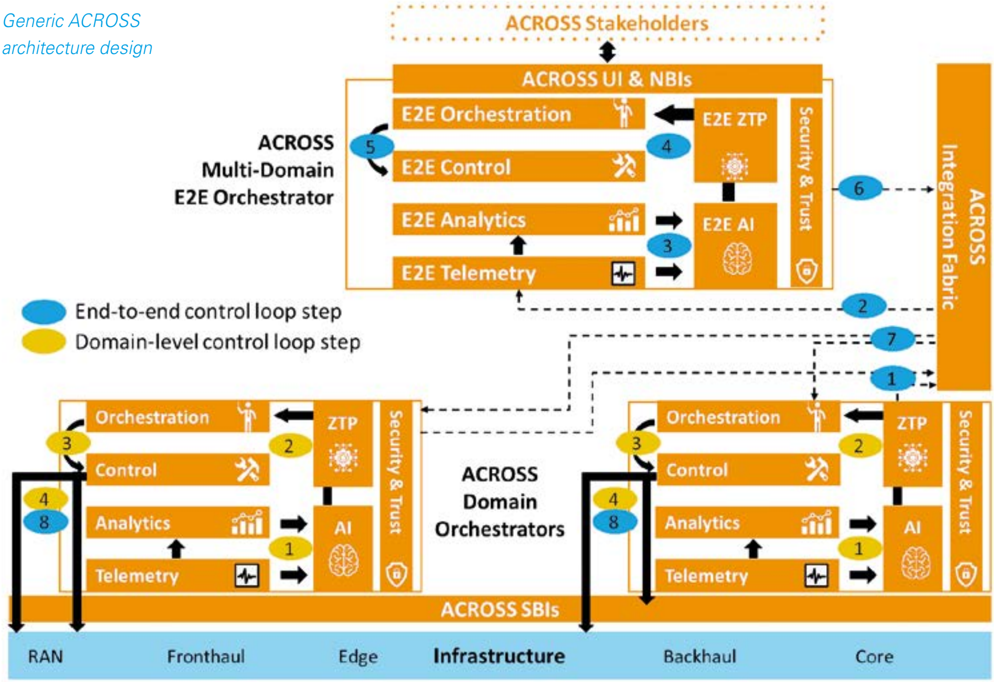
The ACROSS developments provide: an ultra-scalable service orchestration stratum, built as an ensemble of a highly distributed grid of individual and distributed domain orchestration instances, managed by an overlay cloud-native service orchestrator capable to deal with multi-X (i.e., domain, technology, vendor, and tenant) infrastructures, across geo-distributed edge-to-core deployments. The platform includes security and trust solutions over the underlying swarm of devices and ad-hoc data sources, advance monitoring and data analytics from both the infrastructure and the deployed application components, and AI-assisted processing of data to generate optimised series of service orchestration events. This enables the required vertical and horizontal zero-touch mechanisms, offering multi-objective service management optimisations in the presence of trade-offs between performance, energy consumption, and cost.

ACROSS is expected to be the first of a new breed of AI-driven zero-touch service deployment and management platforms, fully compliant with existing standards in zero-touch network and service management. For this reason, the project invests considerably in contributions towards standardisation, through a concrete roadmap of tangible proof-of-concept demonstrations to selected bodies (i.e., European Telecommunications Standards Institute (ETSI) Zero-touch network and Service Management (ZSM) and with the goal to further advance standardisation in the face of the emerging 6G requirements.

DEVELOPMENT OBJECTIVES

- The development of the service deployment and runtime orchestration platform framework including the horizontal (RAN to Core) orchestration across multi-X domains and the vertical (infrastructure to app layer) orchestration within a single domain.
- The development of open E2E telemetry infrastructure, featuring zero-touch reporting and data collection at the speed of the underlying hardware, along with standardised telemetry reports and visualisation mechanisms.
- The development of an ultra-instinct unsupervised AI stratum that turns deep E2E telemetry data into automated and proactive actionable decisions, empowering the control loops of the cross-domain orchestration platform in a fully automated fashion.
- The development of a broad range of zero-touch operations as programmable "hooks" in response to events originating from infrastructure telemetry data and/or produced intelligence translated into actionable decisions to the ACROSS orchestrator.
- The development of security and trust mechanisms providing device integrity, secure data acquisition and dissemination, and secure AI against attacks (e.g., Distributed Denial of Service (DDoS) heavy hitters, adversarial attacks).

Generic ACROSS architecture design



ARCHITECTURE AND KEY FUNCTIONALITIES

The previous figure depicts the generic ACROSS architecture design. In the lower part, several physically distributed domain-level orchestrator instances are deployed, each dedicated to the management of a particular domain infrastructure capable of managing resources across the entire cloud continuum ranging from mobile RANs, transport and datacentre networks, as well as edge and core clouds. An overlay multi-domain E2E orchestration on top is a logically centralised cloud-managed entity that ensures E2E service and network continuity across domains, constituting the entire edge-to-core cloud continuum. An essential development is the cross-domain integration fabric which bridges the orchestration levels (following modern standardised approaches), while fostering separation of concerns through a scalable message bus between domain-specific and cross-domain functions and technology and vendor agnosticism through open standardised Application programming interface (APIs). Atop, the ACROSS User Interface (UI) and Northbound Interface (NBI) exposes a powerful frontend UI along with management APIs for orchestration, policy management, service management, AI, data generation, and telemetry towards a broad set of relevant stakeholders, such as operators, service providers, open-source communities, data scientists, and third parties.

Two individual levels of control loops are supported (yellow and blue circles in figure). At a single domain level (Yellow circles), the domain orchestrator employs telemetry and analytics functions. Next, the data are exploited by a domain-level AI engine to produce local intelligence which feeds the zero-touch operations that trigger in turn the necessary reconfigurations/reactions. Once an automated orchestration reaction is triggered, the orchestrator interfaces with the control block of the ACROSS domain orchestrator, i.e., the Virtual Infrastructure Manager (VIM), RAN intelligent controller, Software Defined Network (SDN) controller etc., to realise the necessary underlying hardware reconfigurations. In a similar fashion, the ACROSS multi-domain E2E orchestrator (purple circles) uses the interfaces and message bus of the integration fabric to aggregate telemetry data across the underlying domains, produce end-to-end analytics and intelligence, which then trigger end-to-end automation functions that involve tuning of inter-domain orchestration loops. To enforce the necessary reconfiguration at an end-to-end level, the multi-domain E2E orchestrator calls control functions of the various domain-level orchestrators through the ACROSS integration fabric.

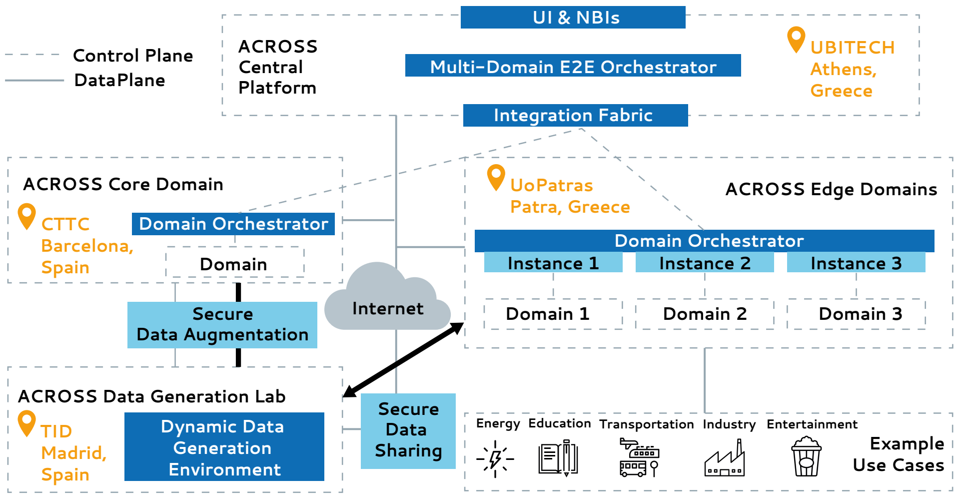
EXPERIMENTATION ACTIVITIES

ACROSS promotes a federated validation and demonstration environment built as a combination of heterogeneous geo-distributed testbeds, spread through four locations across Southern Europe. The Central Platform located in Athens hosts the multi-domain E2E orchestrator and connects to various distributed edge and 5G domains in Patras area and a core domain in Barcelona. Also, the Data Generation Environment is an auxiliary but utterly important testbed for validating key ACROSS concepts and AI model solutions.

The platform is validated through four generic test cases, with the following aims:

- **Test case 1** – The end-user/application-driven zero-touch orchestration capabilities, where runtime configuration requests initiate through the UI and determined by the network status and implied policy criteria.
- **Test case 2** – The infrastructure-driven zero-touch orchestration, where changes are imposed in response to events generated form device monitoring data in the network.
- **Test case 3** – The intelligence-driven zero-touch automation, where the AI mechanism suggests reconfigurations based on data that are analysed by both application and infrastructure monitoring events.
- **Test case 4** – The holistic zero-touch orchestration, where all the above cases are combined to a fully automated platform, able to optimally handle diverse type of events.

Overview of the ACROSS validation platform



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

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NANCY

The primary objective of NANCY is to introduce a secure and intelligent architecture for the B5G wireless network.

OBJECTIVES

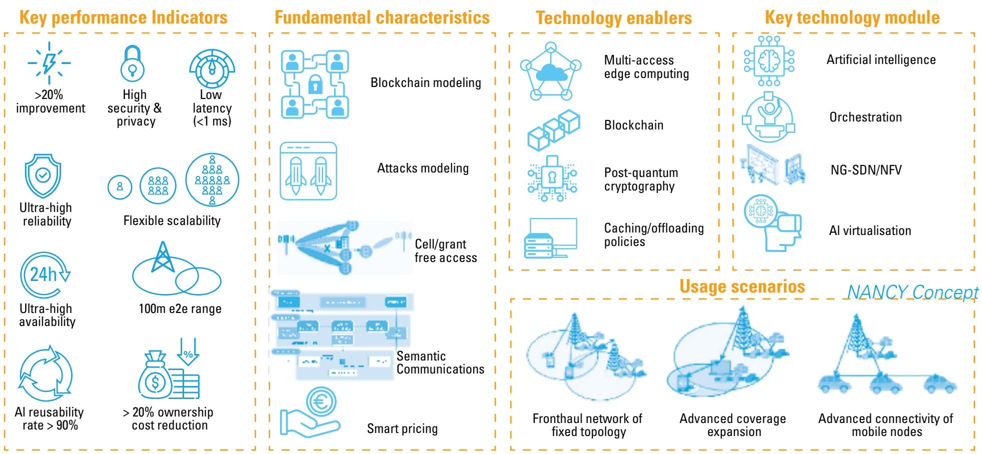
This will be achieved by utilising cutting-edge technologies such as AI and blockchain to facilitate secure and intelligent resource management, flexible networking, and orchestration. To realize this vision, innovative architectures, including point-to-point (P2P) connectivity for device-to-device communication, mesh networking, and relay-based communications, as well as protocols for medium access, mobility management, and resource allocation, will be developed. These architectures and protocols will be jointly optimised to make the most efficient use of the mid-haul and fronthaul, thereby enabling truly distributed intelligence and transforming the network into a low-power computing unit. Furthermore, NANCY will follow a holistic optimisation approach, leveraging developments in blockchain, to support end-to-end personalised, multi-tenant, and perpetual protection. Finally, in order to account for the unique characteristics of the new radio access network (RAN) arising from the use of novel building blocks such as blockchain, multi-access edge computing, and AI, NANCY will present a new experimentally verified network information-theoretic framework.

To realize the concept of AI-assisted blockchain RAN (B-RAN) for B5G wireless networks, a powerful, scalable, and flexible machine learning-based orchestration framework, advanced blockchain and attack models, and a pioneering network information theory approach will be leveraged. Furthermore, NANCY will devise an appropriate experimental-driven performance evaluation and assessment framework by selecting relevant usage scenarios and metrics. Additionally, NANCY aims to identify critical technology gaps and create, optimise, demonstrate, and assess key enablers for the B-RAN. To achieve these objectives, the NANCY approach is based on three distinct pillars:

I. **Designing a distributed B-RAN** solution that offers dynamic scalability, high security, and privacy in a heterogeneous environment. This will be achieved by implementing distributed and decentralised blockchain, as well as cell-free radio access mechanisms. The objective is to improve the utilisation of radio resources by introducing novel strategies for range and service expansion, supporting new use cases and killer apps, and exploiting the underutilised spectrum.

II. **Achieving Pareto-optimal AI-based wireless B-RAN orchestration**. This aims to maximise energy efficiency and trustworthiness, support ultra-high availability and applications with diverse requirements, optimise network topology and management, enable device collaboration and collaborative sensing, and allow for the reproducibility and explainability of the system and network-level AI models. This approach will transform B5G RANs into intelligent platforms, opening up new service models to telecom and individual providers and operators.

III. Developing a distributed Multi-Access Edge Computing (MEC) that offers almost-zero latency and high-computational capabilities at the edge, where data is generated. This will be achieved by implementing social-aware data and AI model caching and task offloading strategies. The goal is to transform B5G verticals into intelligent, real-time, flexible, and reliable platforms.



USAGE SCENARIOS

The Figure depicts a high-level view of the NANCY concept, including the identified key performance indicators, the fundamental characteristics, the technology enablers, and the key technologies that will be explored and adopted by NANCY, as well as the three usage scenarios that will demonstrate and validate the envisioned AI-assisted B-RAN for B5G networks.

Usage Scenario #1: Fronthaul network of fixed topology

In this context, each device is tasked with a computation-intensive and delay-sensitive job, such as navigation, video streaming, virtual reality, etc. The Base Stations (BSs)/Access Points (APs) owned by the same or different providers are equipped with MEC capabilities, allowing them to execute AI functions and possess high-availability computation resources. Resource-constrained mobile devices can offload their tasks to the heterogeneous edge infrastructures that employ fine-grained computational resource allocation policies for processing offloaded tasks. Furthermore, since the user device is within range of at least two BS/APs, coordinated multipoint (CoMP) connectivity can be employed to enhance system reliability and energy efficiency. Finally, spectrum aggregation can be utilised to increase the achievable data rate on the device. Given that the interactions between devices and BS/APs are not trust-based, the need for a B-RAN approach is identified. In such scenarios, critical system parameters include the aggregated data rate, which is expected to exceed 100 Gbps, energy efficiency, and network latency. Therefore, an AI-based orchestrator is required to jointly optimise infrastructure selection, resource allocation, and network function allocation.

Usage Scenario #2: Advanced coverage expansion

In situations where ultra-dense connectivity demands and mobility environments exist, individual static or moving infrastructures can function as relay nodes to provide reliable and high data rate connectivity. In addition, dynamic (ad hoc) midhaul node topologies can expand network range and reliability in an energy-efficient manner, supporting multi-hop, ad-hoc mesh, and multipoint-to-multipoint (M2MP) connectivity. Offloading device tasks to midhaul nodes with high computational capabilities can significantly reduce network latency. The interactions between the device-midhaul node and midhaul node-BS/AP are not trust-based, hence UE must use pseudonyms when sharing content to enhance security and privacy. In this regard, blockchains are deployed to midhaul-nodes and BS/AP. Lastly, a smart pricing policy should be developed for the midhaul-node services. Critical parameters in such scenarios include security and privacy, reliability and availability, and energy efficiency.

Usage Scenario #3: Advanced connectivity of mobile nodes

This scenario aims to facilitate communication between vehicles-to-radio-side units (RSUs), vehicle-to-vehicle (V2V), Unmanned Aerial Vehicle (UAV)-to-BS, and UAV-to-UAV. Sharing content among these entities is possible; however, as trust may not be established, pseudonyms must be utilised to enhance security and privacy. Blockchain technology is deployed on RSUs, vehicles, and UAVs with robust computational capabilities to achieve this. In addition to high security and privacy, the key parameters for this scenario include energy efficiency, latency, high data rate, mobility management, and scalable flexibility.

*an artificial i*N*telligent*
*A*ided *unified* N*etwork*
*for se*C*ure* B*e*Y*ond*
5G long term evolution

NANCY

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SEASON

The goal of the SEASON project is to design and validate a transport network infrastructure able to support beyond 5G and new emerging services.

PROJECT GOALS

the SEASON project is relying on the joint usage of Multi-Band and Space Division Multiplexing (SDM), spanning the access, aggregation, and metro/long-haul segments, supporting the requirements for x-haul, further integrating the packet/optical and computing layers, and targeting efficient networks in terms of capacity and energy efficiency.

ARCHITECTURE

The target SEASON architecture considers joint Multi Band (MB) and Space Division Multiplexing (MBoSDM) and SDM-Passive Optical Networks (PON) networking, in terms of both transmission and switching.

SEASON will address innovation in terms of sliceable Bandwidth Variable Transceivers (S-BVTs) enabling Point-to-MultiPoint (P2MP) along with the integration of (coherent) pluggable optical modules on open packet/optical white boxes (open devices with hardware and software – referred to as the Network Operating System (NOS) – decoupling and providing open control and management interfaces), smart Network Interface Cards (NICs) or the latest generation Data Processing Units (DPU).

A critical objective of such architecture is to ensure energy efficiency, relying on advanced Digital Signal Processing (DSP) applied also to SDM/Multicore fibres, and MBoSDM optical switching and P2MP S-BVTs allowing traffic aggregation/router bypassing, and reducing the number of Optical to Electrical to Optical (O/E/O) conversions.

SEASON follows an *Open Disaggregated Transport Network* design, which means adopting open standards (e.g., data models within a model-driven development methodology) and aligning with key Standard Development Organisations (SDOs) in the scope of Optical Transport Networks.

Such complex infrastructure requires rethinking the *control and orchestration systems* towards autonomous optical networks, addressing not only the integration – in overarching control systems – of the RAN, access and transport segments but also adopting more agile DevOps methodologies.

The community has widely accepted that the complexity of the underlying optical technology, resulting in several interdependent configuration parameters, will likely require cognitive networks powered by streaming telemetry, real-time network measurements and AI/ML-aided service management and orchestration for near-real time network operation. This includes not only the development of multi-objective techniques to find the optimal allocation of resources and service functionality in the infrastructure (core, edge, far-edge) – including optimal functional splits to be applied – but also moving intelligence as close as possible to the data plane, and devising a distributed system based on multiple communicating agents and data-driven closed control loops.

The increase in available capacity shall not only address traffic growth, but it also enables increased reliability and agility e.g., in disaster recovery scenarios. Given the importance of reliability, SEASON will develop an optical layer Digital Twin for use cases such as soft-failure and anomaly detection, localisation, and identification.

METHODOLOGY

The SEASON methodology is organised in four phases, namely systems design and specification; systems development and preliminary tests; early integration and focused experimental activities and final Integration and development of demonstrations, aiming at showcasing the essential project technological visions and solutions.

SEASON will have a clear impact on the society, in a context with increased needs of connectivity and higher capacity demand required for services such as Virtual Reality (VR)//Augmented Reality (AR) or holographic telepresence facing new network planning and optimisation challenges due to new patterns situations, emerging from a post-Covid19 world.

The SEASON consortium includes major European telecom operators (Telefonica, Telecom Italia), major vendors (ADVA, Infinera P/G, Ericsson), three consolidated SMEs (Accelleran, Wings and West Aquila) and four major highly reputed research centres and academic institutions (CNIT, CTTC, Fraunhofer HHI, and UPC).

Self-Managed Sustainable high-capacity Optical Networks

SEASON

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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.

PROJECT GOALS

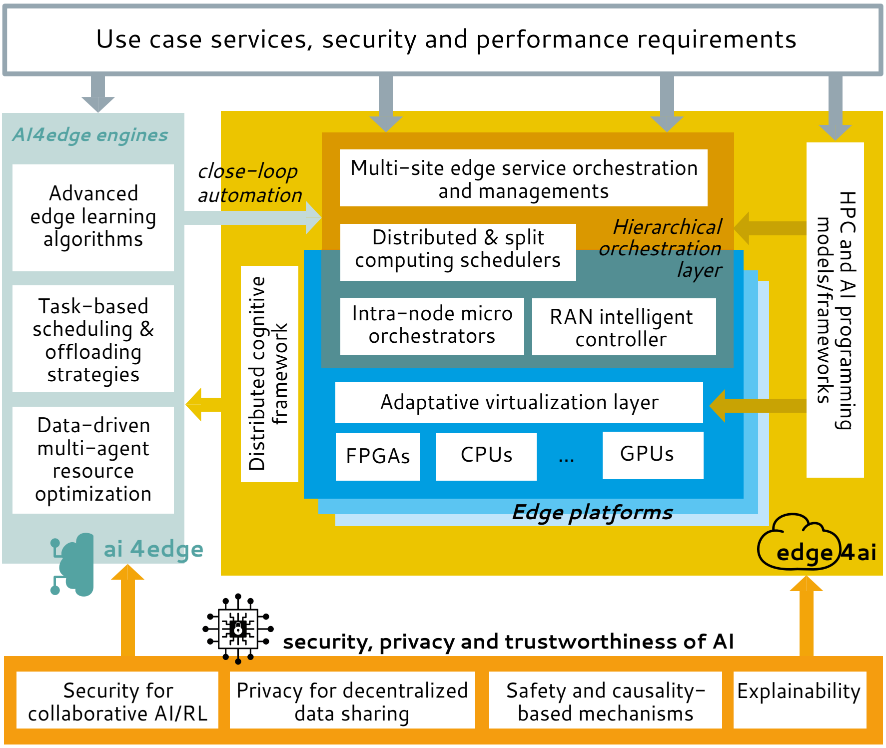
Innovative immersive and real-time vertical services, leveraging AI and big data workflows to process massive volumes of generated IoT data, are becoming increasingly demanding in terms of latency and computation. The synergy between edge computing and B5G networks is expected to meet these requirements, but it has not yet achieved the required level of maturity level, and many challenges lie ahead. It is within this context that the EU-funded research project VERGE (AI-powered evolution towards open and secure edge architectures) 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. To achieve this vision, the project will address several obstacles currently standing in the way of the edge computing evolution, including:

- The efficient management and utilisation of the highly heterogeneous and distributed processing elements available anywhere across the edge to cloud path, each having different performance and power consumption budgets, memory solutions and interconnectivity standards.
- The need to optimise on-the-fly the network performance and allocate computing and communication resources in highly heterogeneous and rapidly changing scenarios, taking into account a multitude of parameters, monitored data and optimisation goals that may often be conflicting among them.
- The importance of ensuring the trustworthiness of AI models used for decision-making processes and maintaining the privacy of sensitive data transferred across the network for model training.

By adopting an interdisciplinary approach to converge techniques from multiple areas, including telecommunications, edge and cloud technologies, embedded and distributed computing, cybersecurity and AI, VERGE will achieve its vision by:

- Building an "edge for AI" (Edge4AI) framework, to support the flexible and efficient deployment and execution of B5G AI-enabled applications across a jointly orchestrated compute and communication continuum, while fully exploiting the capabilities of multi-core/multi-accelerator platforms for ultra-high computational performance;
- Developing an "AI for edge" (AI4Edge) portfolio of AI solutions, by employing cutting-edge AI methods and novel distributed learning algorithms that are able to automate and optimise the network operation through intelligent decisions and that are coherently integrated in a collision-free and efficient manner for addressing different optimisation problems;
- Providing the necessary methods for Secure, Private and Trustworthy

AI (SPT4AI), to address the relevant challenges that specifically emerge due to the decentralised edge computing environment and the extensive use of distributed AI methodologies in a dynamic and heterogeneous network structure.



INNOVATIONS

The key innovative features of VERGE, as shown in the figure, include:

- A **hierarchical orchestration layer** managing the lifecycle of both network and application services, and considering different levels of intelligent control, from the orchestration of distributed workflows across multiple edge sites to the micro-orchestration of tasks within a single HW-accelerated node.
- An **adaptive virtualisation layer** specifically targeting programmable accelerated HW platforms, which, in combination with the most suitable **programming models** from the embedded, High-Performance Computing (HPC) and AI domains, will enable the full exploitation of the inner parallelism capabilities of the underlying infrastructure.
- A **distributed cognitive framework**, responsible for collecting in real-time a wide range of system, network and application parameters with both local and global scope and making them available to decision-making entities (AI4Edge engines) at the right granularity.
- A set of **AI-powered data-driven multi-agent resource optimisation solutions and task-based scheduling strategies** (AI4Edge engines), optimising the allocation of communication and computation resources across the network edge in a scalable and synergic manner, handling tasks such as dynamic computation offloading, optimal splitting of network (e.g., CU –DU), AI functions (e.g., deep learning layers), end-to-end slicing, etc.

- **Advanced learning algorithms** optimised for operation at the edge under constrained resources, bringing down the training time and increasing the algorithms' robustness under highly distributed and heterogeneous scenarios.
- Novel mechanisms for **security and privacy**, offering efficient and robust mitigation methods against adversarial attacks in collaborative AI and ensuring the required privacy in distributed and decentralised data sharing processes.
- Solutions to enhance the **safety and explainability** of AI models, including causality-based methodologies and techniques based on knowledge graphs for obtaining semantically rich explanations for the decisions made by AI techniques.

USE CASES

VERGE innovations will be showcased in use cases targeting two vertical domains: (i) smart manufacturing and industry through novel extended reality (XR) applications for collaborative inter-factory design and virtual prototyping of products, and teleoperation of robotic systems, and (ii) smart and sustainable transportation through IoT-driven autonomous tram services. Each use case consists of several user stories, each with different KPIs and demonstrating different VERGE capabilities.

XR-enabled industrial use case

The XR-enabled industrial use case will focus on delivering immersive XR services with minimal latency and overall high Quality of Experience (QoE) 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. Edge computing will play a key role in such scenarios, bringing the computation-intensive XR rendering service closer to the end users and enabling novel AI-based predictive schemes to optimise the content delivery to the end users. This use case will be demonstrated live in two remotely located industrial sites in Turkey, provided by Arçelik, whereas small-scale experiments will leverage a lab-controlled environment at King's College London (KCL)'s premises.

Autonomous tram use case

The second use case is built around the concept of the autonomous tram, focusing on safety services running on-board the tram and at the edge infrastructure and fusing the input of multiple sensors (e.g., cameras, Lidars, radars, etc.) to augment the situational awareness of the driver by detecting hazardous situations across the tram path. The use case demonstrations will showcase several VERGE features such as predictive slicing and RAN reconfiguration, following the tram trajectory and meeting the communication requirements on-the-fly, multi-layer orchestration across the edge-cloud compute continuum to support distributed and split computing, as well as secure, safe and explainable learning at the edge. This use case will be demonstrated in the 5G-enabled communication laboratory of GTSI (Italy and France), as well as in complementary facilities in Barcelona, leveraging real datasets provided by the GTSI sensorised tram fleet.

AI-powered eVolution towards opEn and secuRe edGe architEctures

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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.

Stream B

RESEARCH FOR RADICAL TECHNOLOGY ADVANCEMENT

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

6G-NTN

The 6G-NTN project brings together high-level representatives from the mobile communication, satellite, and research communities to address users' needs in telecommunication networks.

PROJECT OVERVIEW

The 6G-NTN project brings together high-level representatives from the mobile communication, satellite, and research communities to address users' needs in telecommunication networks. The goal is to research and develop innovative technical, business, regulatory, and standardisation requirements for the **full and seamless unification of the Non-Terrestrial and Terrestrial components in future 6G telecommunication networks**. This will be key to extending the coverage, resilience, and sustainability of next-generation mobile networks, and to better meeting the needs and expectations of both vertical and consumer market segments, while unlocking new value chains and delivering a broad societal impact. By achieving its objectives, 6G-NTN will contribute significantly to **strengthening Europe's industrial leadership in wireless communications and services infrastructure**.

OBJECTIVES

The goal of 6G-NTN is to develop an NTN component fully integrated with the 6G infrastructure able to provide connectivity services to vertical industries and consumer terminals in indoor/in-vehicle and outdoor conditions.

The main objectives include:

1. Identify the **target services and operational requirements** for the 6G Non-Terrestrial Network component.
2. Design/sizing of a **3D non-terrestrial network** component (space and ground segments) to meet the target user requirements.
3. Design **trade-off and assessment** of compact terminals targeted by the 3D NTN component.
4. Design **flexible software-defined** payload across flying platforms and frequency bands.
5. Identify and design the key characteristics/features of a **flexible waveform for 6G's integrated Radio Access Network.**
6. Design and evaluate **AI data-enhanced multi-orbit multi-connectivity** radio intelligent controllers.
7. Design and development of the dynamic orchestration of **Virtual Network Functions** in the 3D network for 6G.
8. Design of a reliable and accurate positioning function for the 6G system achieving a **precision below 10 cm**.
9. Design of features enabling **spectrum usage optimisation** (coexistence and possibly sharing) between the different network nodes of the three-dimensional (3D) architecture, including NTN and TN nodes, operating in the considered frequency bands.
10. Lay the groundwork for the broad and lasting impact of 6G-NTN, while contributing to the growth of the **European 6G ecosystem** surrounding the **SNS JU**.

CONCEPT AND APPROACH

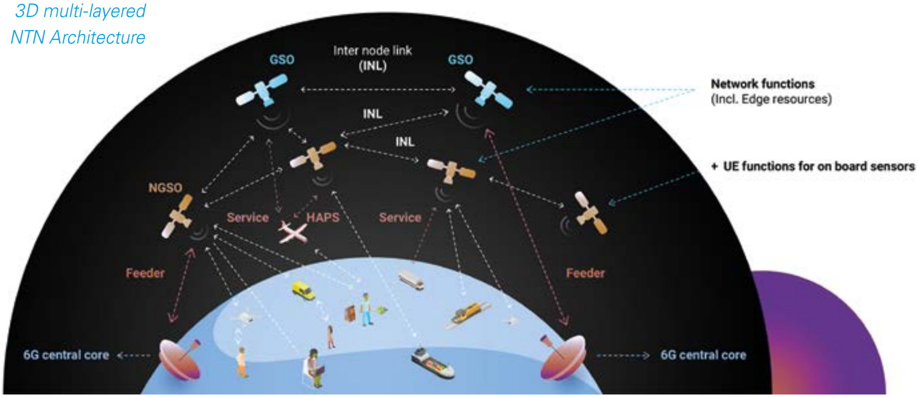
The revolutionary novelty brought by the 6G-NTN approach stems from holistic approach to designing the overall 3D multi-layered infrastructure. The "3D" characteristic refers to the full integration of the NT component with the terrestrial one, while the "multi-layered" feature relates to the integration into the NT component of different layers of communication nodes, e.g., satellites and/or drones, flying at different and multiple altitudes. By defining such a comprehensive architecture, 6G-NTN will create the ideal framework for innovative concepts, mechanisms, and technologies to be conceived, developed, and validated, while producing important outcomes in terms of standardisation, regulation and R&I level which are key to: i) addressing the described major goals in a variety of vertical markets; and ii) opening up new research avenues in which Europe should invest to ensure its technological sovereignty.

KEY VALUE INDICATORS

The 6G-NTN project aims to contribute directly to important Key Value Indicators, namely:

- **Inclusiveness** provided through a global coverage, achieved with the 3D NTN component, to deploy 6G services to areas where terrestrial solutions deployment is not economically viable.
- **Efficiency** obtained by optimised spectrum use based on efficient spectrum coexistence and, if possible, by taking advantage of spectrum sharing techniques between the different network node service links.
- **Sustainability** through Artificial Intelligence-driven Radio Resource Management, mobility, and traffic routing, to reduce/minimise the carbon footprint and energy consumption.
- **Resilience** provided through massive redundancy in terms of connectivity between multi-layer network nodes at different altitudes, all interconnected via free space optical and/or radio links.
- **Interoperability** provided by a standardised flexible waveform for 6G integrated Radio Access Network, which will pave the way for the broad adoption of the vast majority of devices.

3D multi-layered NTN Architecture



6G Non-Terrestrial Networks

6GNTN

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6G-SHINE

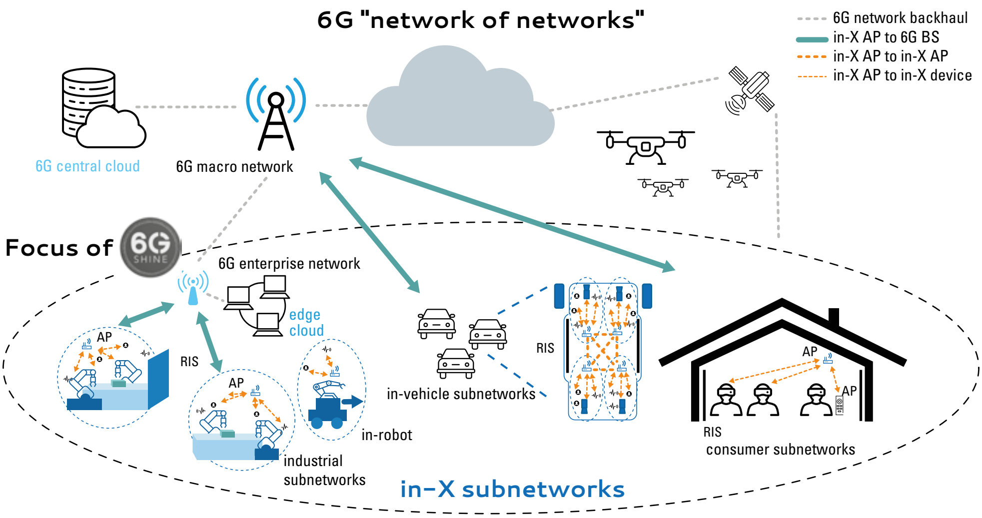
The 6G-SHINE project will pioneer the main technology components for wireless in-X subnetworks, short range low-power radio cells to be installed in industrial and consumer entities.

PROJECT OVERVIEW

6G is expected to take the form of a "network of networks". It will integrate subnetworks with diverse characteristics in terms of coverage, operational purpose, and spectrum, including cellular, non-terrestrial, drone, campus and private networks.

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 and consumer entities like robots, vehicles, production modules and classrooms. *In-X subnetworks* are located at the very end of the 6G 'network of networks' to support highly localised and high-performance connectivity. For example, in-vehicle wireless subnetworks may replace the wired infrastructure for the anti-lock braking system (ABS), motor control and advanced driver-assisted systems (ADAS); in-robot subnetworks can wirelessly support fast closed loop control, e.g., force control; in-classrooms subnetworks can be used for XR applications for educational purposes. These use cases may be demanding extremely high data rates, or low latencies and high reliability – especially for life-critical applications.

In-X subnetworks may spontaneously become very crowded, such as those installed in vehicles on a congested road, or in robots in a matrix production setup, therefore suffering from a potentially strong mutual interference. Given the need of supporting services that may be life-critical, In-X subnetworks must be able to perform their operations autonomously, while still benefiting from connection with a broader 6G umbrella network, which may aid traffic and radio resource management for subnetworks in its coverage area.



CONCEPT AND APPROACH

The 6G-SHINE technology components will leverage the opportunities offered by the specific in-X short range deployments to ensure low-cost high-performance connectivity while dealing with major challenges such as signal blocking, interference due to densification, and proneness to malicious attacks.

The main objectives of the 6G-SHINE project are the following:

- Define relevant application scenarios, use cases and architectures for in-X subnetworks, and analyse related performance requirements.
- Characterize the radio propagation characteristics in short-range scenarios and frequency bands of interest, considering <10 GHz, millimetre wave (mmWave) and sub-THz spectrum regions.
- Design new physical layer (PHY) and medium access control (MAC) enablers for scalable requirements in terms of latency, reliability or data rate, leveraging the opportunities offered by the short-range deployments. Envisioned PHY/MAC enablers include short range beam-focusing techniques for constrained devices, reflective intelligent surfaces, intra-subnetwork macro diversity, uRLLC enhancements, predictive schedulers, flexible/full duplex schedulers.
- Develop cost effective radio resource management techniques (considering both legitimate and malicious interferers) in dense dynamic subnetwork crowds. The project will explore fully distributed solutions – where subnetworks perform their decisions independently – as well as centralised and hybrid approaches, where an umbrella 6G network can aid operations of subnetworks in its coverage area. Modern artificial intelligence approaches for radio resource management will be studied.
- Develop new methods for integrating subnetworks in the 6G architecture and efficient orchestration of traffic, radio and computational resources among in-X subnetworks and wider 6G 'network of networks'.

Performance of the designed solutions will be verified via simulations and – for selected components – via demonstration platforms in laboratories. In this respect, the project targets a technology readiness level (TRL) in the 2-4 range.

The innovative 6G-SHINE solutions will advance the state-of-the-art of high-performance short-range connectivity, bringing the pervasiveness of wireless to a level that has never been reached before. The project will also result in a large portfolio of technology components that will contribute to future 6G standardisation. Targeted standardisation bodies are 3GPP, IEEE, ETSI, as well as industry fora such as 5G-ACIA and 5G-AA.

6G* SH*ort range extreme communication* IN E*ntities

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6GTANDEM

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

PROJECT DESCRIPTION

6G is expected to transform today's society, enhance businesses, increase research possibilities, create new technologies, advance communication systems and address the needs of a broad spectrum of sectors.

6GTandem represents a salient part of this crucial transformation. By co-designing novel dual-frequency operation and an innovative highly integrated and distributed radio stripe system, 6G Tandem will create superior value in energy consumption, service availability and system cost.

The 6GTandem project will focus on high-performance and reliable wireless services based on two main innovative and mutually reinforcing concepts:

1. Dual-frequency distributed MIMO operation whereby favourable deployments enable drastic energy savings, and the low/high frequency bands offer both redundancy and mutual support.
2. Co-design of signals, algorithms, and transmission schemes with an easily deployable architecture – i.e., radio stripe – for extended sub-THz coverage.

Together we aim to advance dual-frequency distributed MIMO networks that have the potential to enable services offering ultra-high reliability and high-resolution position information in a sustainable way and thereby effect positive change in European society.

The project will focus primarily on the advancement of the combined low-frequency and sub-THz distributed MIMO system to enable new applications that require an unprecedented combination of performance factors. It will pull novel networks forward with joined expertise on wireless 6GTandem (101096302) European 6G Annual Journal 2 communication system and innovative hardware solutions, creating new opportunities for highly energy-efficient operation and low-cost deployment.

With our robust team of industrial, academic and research partners, we will deliver unique results in the highly promising new area of dual-frequency networks with distributed deployments, which will fuel Research and Development (R&D) output and eventual new products.

The consortium is driven by the goal of providing uniform ultra-high throughput coverage, off-load lower frequency bands and a gateway to new services – and thereby contribute new insights for the whole European 6G community.

GOALS AND OBJECTIVES

6GTandem aims to gain a competitive advantage by defining and shaping the future of 6G infrastructures in Europe and contributing to the long-term impact of smart, flexible, and scalable (RAN) evolution, while offering hardware products that will deliver unprecedented performances in terms of Radio Frequency (RF) management, cost-, spectrum- and energy-efficiency in the global market.

In particular, 6GTandem will focus on the following objectives:

- Develop the **6GTandem system** concept presenting an **optimised** combination of a lower-frequency infrastructure and a **sub-THz radio stripe**.
- Develop **models for the tandem system** in terms of hardware impairment, propagation in the plastic fibre waveguide, and impact of the radio environment.
- Design **waveforms for dual-frequency systems** with control information.
- Develop **fully integrated communication links** at sub-THz frequencies based on plastic microwave fibres.
- Demonstrate and validate the proposed concept, to identify performance bottlenecks, and to **guide the future research** directions in- and **beyond the project lifetime**.

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

6GTandem

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January 2023–June 2026

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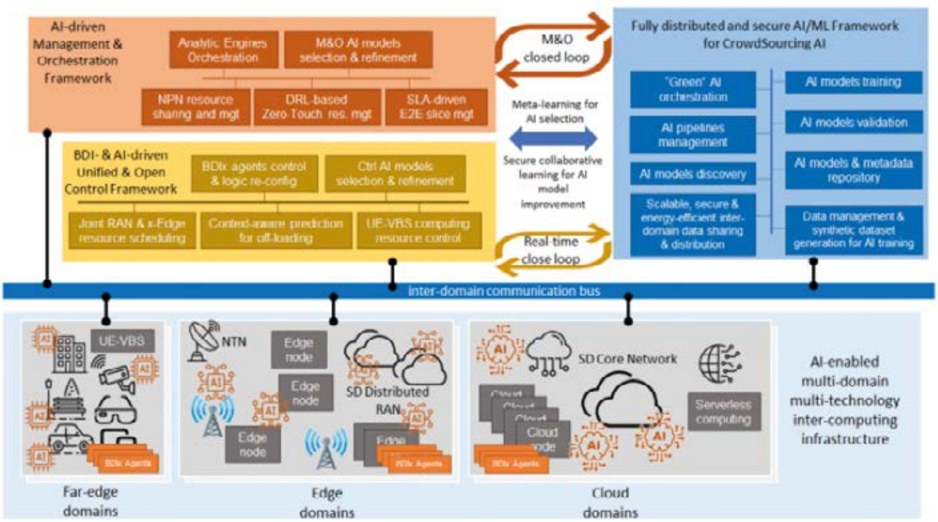
ADROIT6G

ADROIT6G's overall project goal is to provide revolutionary research foundations for low TRL, technological advancements in preparation for upcoming 6G network architectures.

GOALS OF THE PROJECT

As the world moves from the 5G to the 6G era, the mobile communications fabric needs to be architected to accommodate the emerging stringent requirements of innovative, extreme, future-looking applications that cannot be served by existing 5G mobile networks. ADROIT6G's overall project goal is to provide revolutionary research foundations for low TRL, technological advancements in preparation for upcoming 6G network architectures. The proposed architectures will make fundamental changes to the way networks are designed, implemented, operated, and maintained. As illustrated in the figure below, 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 with their own characteristics and capabilities – are used to deploy virtual functions of software-defined, disaggregated RAN and core networks, virtual applications as well as AI agents, which are orchestrated dynamically as part of the overall network control and management strategies.

ADROIT6G conceptual architecture



OBJECTIVES

ADROIT6G focuses on the following key objectives:

1. Design and implement a novel 6G system architecture that integrates a distributed AI framework for combined communication, computation and control, and empowers the convergence of networks and IT systems to enable new future digital services.
2. Create an AI-driven Management and Orchestration (M&O) and control framework for 6G Networks.
3. Architect a distributed and secure Crowdsourcing AI.
4. Develop energy-aware models for multimodal Representation Learning.
5. Evolve the cellular infrastructure to allow the true integration of deep-edge devices in communication and computation functions.
6. Enable Non-Terrestrial Networks connectivity for highly reliable Industrial Internet of Things Services.
7. Extend and demonstrate the use of decentralised AI for Device-to-Device (D2D) communications.
8. Support data plane acceleration.
9. Integrate and demonstrate the potential and user value of ADROIT6G through relevant experimentation, testing, and validation of its innovations in PoCs in lab settings.
10. High-value exploitation and business.
11. Contribute to standardisation, open source, and communities.
12. Dissemination, outreach, and capacity building.
13. Make significant contributions to the establishment of a set of globally accepted KVIs.

PROOFS OF CONCEPTS

ADROIT6G aims to define, validate and affirm reference, network-level, 6G KPIs and KVIs in extreme 6G UCs, thus establishing the frontiers of 6G technology and bringing them one step closer to future exploitation. The applicability, performance, and viability of the ADROIT6G technological solution will be validated across the following PoCs:

PoC 1: Extreme enhanced mobile broadband (eMBB) for immersive Extended Reality

One of the greatest promises of the next decade is that immersive communication, holographic telepresence and XR will become our default way of communication. PoC 1 will emulate a scenario where the teacher delivers their lecture from their home/university office/etc., while the students attending the class physically can watch the teacher's holographic entity giving the lesson.

PoC 1 Extreme eMBB for immersive Extended Reality

PoC 2: Extreme URLLC for collaborative robots

PoC 2a will emulate a scenario in

PoC2a Extreme URLLC for collaborative robots

which multiple robots are operating and collaborating with each other in an automotive manufacturing process production line, requiring real-time supply chain optimisation via large-scale Industrial Internet of Things (IIoT) sensing and predictive analytics, involving a massive number of sensors and actuators.

PoC 2b will validate ADROIT6G in exploiting satellite-based communication for augmenting terrestrial 6G networks in areas where infrastructure is weak or non-existent.

PoC2b Extreme URLLC for collaborative robots

PoC 3: Extreme massive Machine-Type Communication (mMTC) for Industrial IoT, also demonstrating the capabilities of NTN interworking with terrestrial 6G networks.

PoC 3 emulates a robotic construction scenario with multiple robots and drones as described above. The scenario covers robots and drones that need to coordinate with one another on a construction site, in which different types of autonomous robots and drones need to sync/coordinate their movements – with and without human involvement – to perform joint tasks, lifting and unloading/loading construction material between robot cranes, mobile robots, drones, etc.

PoC 3 Extreme (mMTC) for Industrial IoT, also demonstrating the capabilities of NTN interworking with terrestrial 6G networks

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

ADROIT6G

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CENTRIC

CENTRIC proposes leveraging AI techniques through a top-down, modular approach to wireless connectivity that puts users' communication needs and environmental constraints at the centre of network stack design.

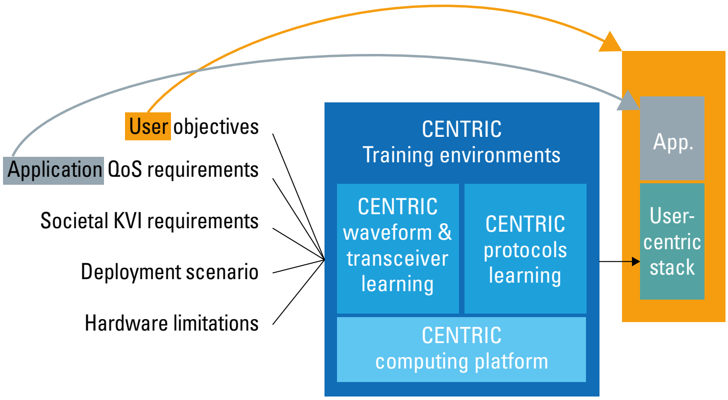
PROJECT VISION

Current networks are built around the concept of universal service offering, where the network's resources are configured to carry information bits of a specific traffic type according to their specific performance requirements. This has enabled wireless networks to address the exponential traffic growth of the previous decade through careful quality of service management. However, this approach has also reduced traffic categories to a small set of KPI profiles that reflect the network limitations rather than users' real needs. Today's wireless networks are thus service-centric, built bottom-up, starting from the protocol stack with applications deployed over the stack. But this one-size-fits-all design philosophy runs counter to the growing diversity of users, applications, and environments of the future wireless ecosystem.

As illustrated in the figure below, based on users' communication needs and application-specific requirements, the tailor-made waveforms, transceivers, signalling, protocols, and hardware implementations are optimised adaptively and on-demand. CENTRIC will make this possible by advancing theory, algorithms, hardware co-design, and training and monitoring environments for future 6G use-cases. The project will focus on providing the desired quality of experience to a given user, or type of users, while minimising the required spectrum usage and energy consumption.

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 a degree of physical layer and protocol stack customisation that is unprecedented 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 they need it. 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



OBJECTIVES AND INNOVATIONS

1. **To develop AI methods for the discovery of novel and efficient waveforms** – enabling the discovery and optimisation of tailor-made waveforms.

2. **To develop AI methods for the discovery of novel and efficient transceivers** – for large-scale extreme MIMO deployments and beam-based communications in mmWave spectrum.

3. **To develop AI methods for the discovery of customised lightweight communication protocols** – targeting the design of layer-2 and RRM (Radio Resource Management) protocols tailored to the users' and service needs, as well as network topology and communication scenario.

4. **To introduce novel end-to-end hardware co-design solutions for energy-efficient AI-native transceivers**

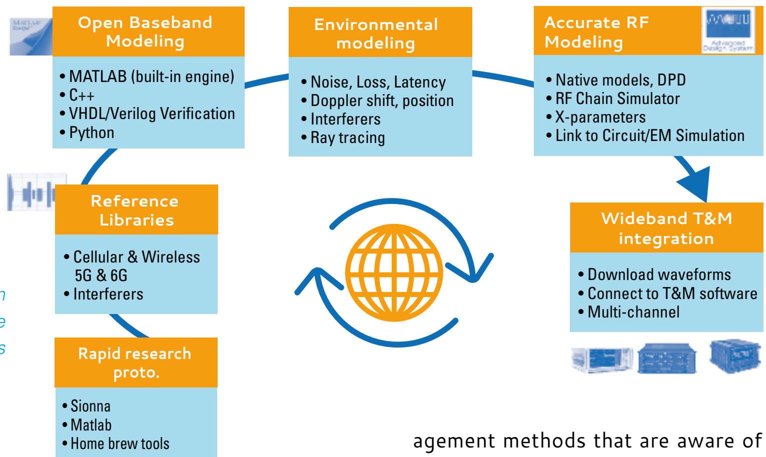
5. **To develop training and monitoring environments as enablers for AI-AI deployments** – development of Digital Twin based methods that enable initial training, deployment, adaptation, monitoring, modularisation, and retraining.

6. **To validate user-centric AI-AI solutions in lab setting**

7. **To demonstrate and disseminate AI-AI concepts**

To attain these objectives, CENTRIC will develop novel AI-based concepts for physical layer, medium-access protocols, and radio-resource management of 6G networks, including: methods for data-driven learning of novel waveforms using deep neural networks, AI techniques for joint sensing and communications, multi-agent reinforcement learning frameworks for emerging novel communication protocols, or radio-resource management methods that are aware of energy efficiency and electromagnetic field emissions. Additionally, the project will explore the suitability of novel computational paradigms, such as neuromorphic computing, to overcome the computational burden of large AI models. Last but not least, the project's research scope will include fundamental statistical methods to monitor and orchestrate the different modules that make up CENTRIC's AI-AI vision.

The study of the 6G AI-AI concepts in CENTRIC will focus first on simulation then, based on the results obtained, a selection of the algorithms developed by the project will be implemented in a proof-of-concept tabletop demonstrator. This tabletop demonstrator will serve to validate the AI-AI concepts over the air in realistic conditions. The combination of the overall CENTRIC development chain, from a rapid prototyping simulation environment, through detailed modelling in a joint co-simulation environment for benchmarking and ending in a tabletop demonstrator is summarised in the figure above.



CENTRIC's cycle from simulation to hardware proof of concepts

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

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CONFIDENTIAL6G

CONFIDENTIAL6G will develop cryptographic quantum-resistant protocols and security proofs, tools, libraries, mechanism and architectural blueprints for confidentiality in 6G.

PROJECT OVERVIEW

The main ambition of the CONFIDENTIAL6G project is to enable secure and privacy-preserving computation via novel, modern cryptographic techniques and operations across the cloud-edge continuum that will be necessary in 6G. Prerequisite for implementation of privacy preservation and security of data in these heterogeneous environments and different contexts is robust modern cryptographic techniques, tools and libraries. This is why it is essential to focus the research on these security enablers as well, especially with the awareness of danger that can be posed by near-future quantum computers and their capabilities to break the contemporary encryptions.

PROJECTS PILLARS

The project is conceptualised around three main pillars:

- **Pillar A – Cryptography**

  Cryptographic enablers for confidential computing (Fully Homomorphic Encryption (FHE), Secure Multi-Party Computation (SMPC), Trusted Execution Environment (TEE) and post-quantum networking. Distributed Ledger Technology (DLT) privacy enablers (Zero-Knowledge Proofs (ZPK). Support for embedded edge devices and HW.

- **Pillar B – Confidential computing**

  Confidential computing via FHE, SMPC and HW TEEs. Collaborative AI/ML. Confidential containers. Remote attestations. Secure enclave abstractions. Secure key distribution.

- **Pillar C – Confidential Networking**

  Post-quantum secure network protocols. Secure data sharing and access control. Private blockchain Smart Contracts, Decentralised Identifiers (DIDs) and Verifiable Credentials (VCs). Federated AI/ML orchestration.

CONFIDENTIAL6G will research post-quantum cryptography (PQC) in order to create tools, libraries, Software Development Kits (SDKs) and other artifacts needed for future 6G technologies:

- Domain #1: Confidential Computing enablers: Lattice-based cryptography for Fully Homomorphic Encryption, Secure Multi-party Computation, TEE attestation handling, collaborative AI/ML
- Domain #2: Confidential Communication enablers: PQC Transport Layer Security (TLS) and other protocols10, Blockchain-based data exchange, Zero-Knowledge Proofs (ZKPs), confidential Smart Contracts, DIDs and VCs, and a new concept of Anonymous Credentials (AC)
- Domain #3: Confidential Edge and IoT enablers: embedded FHE, PQC for constrained devices, large-scale networks of connected devices involved in federated learning and cryptography necessary to support this.

USE CASES

Use Case 1: Predictive maintenance for airline consortium using blockchain-based data sharing platform and federated AI/ML orchestration

The key validation: (i) confidential Smart Contracts and transactions in DLT in order to hide information about asset metadata in the data marketplace for aviation consortiums; (ii) blockchain-enhanced access control layer that would enable immutable logs and traces of consent, coupled with blockchain-configured proxy mechanisms; (iii) secure and encrypted metadata transfer to the orchestration layer based on Kubernetes, distributed between aviation companies; (iv) federated AI/ML orchestration that will ensure that computation is brought to the data sets in the edge data centres near the airports in a secure manner; (v) remote attestation and result handling for the applied algorithm for predictive maintenance.

Use Case 2: Privacy-preserving confidential computing platform that enables mitigation of internal threats for telecom cloud providers

The key validation: (i) automated handling of confidential VMs, including their creation and initialisation in a programmable manner and using cloud APIs; (ii) TEE abstractions to help cloud providers enable TEEs in the cloud; (iii) software framework for handling remote attestations; (iv) Software Management Agent (SMA) for management of secure VMs and enablement of secure TLS connections within enclaves; (v) confidential container framework and Kubernetes support.

Use Case 3: Intelligent connected vehicle, mission-critical services, Over-The-Air (OTA) updates, FL/ML and vehicle to infrastructure communication

The key validation: (i) OTA updates to help manufacturers securely transfer software updates as part of "Connected Car" systems; (ii) adaptive asynchronous distributed learning (ADL)-based scheme will be used for model uploading and downloading car data; (iii) use blockchain to guarantee the security of and tamper-proof the shared ADL models that are important for safety and driving applications; (iv) blockchain to protect sensitive data from manipulation and to guarantee immutability of software (SW) updates (the hash is on the ledger and the car can verify that it is getting the right one; (v) Vehicle digital identity creates the ability to verify which car needs updates and those already updated (i.e. a credential certifying the performed update); (vi) evaluate secured and privacy-preserving communication and aggregation of the models in the Federated Learning (FL) server, and how to protect these from FL attacks such as membership inference, attribute inference, data reconstruction attacks, or data poisoning attacks, and potentially side-channel attacks.

Confidential Computing and Privacy-preserving Technologies for 6G

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DESIRE6G

Promoting the 6G vision, the DESIRE6G project will design and develop a novel zero-touch control, management, and orchestration platform, with native integration of AI, to support verticals with extreme requirements.

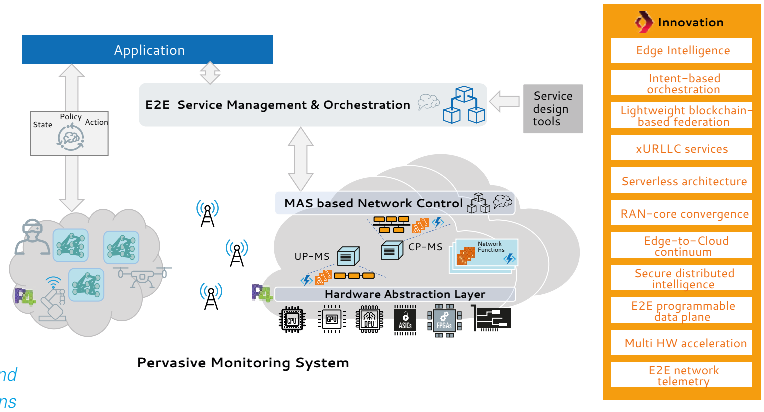
DESIRE6G supports verticals with extreme requirements (e.g., eXtreme URLLC services) over a performant, measurable and programmable data plane. From zero power to extreme low latency or ultra-high reliability: the 6G system should not limit our future use cases, yet it should be simpler and more autonomous than the previous generation. The two key components that will allow us to achieve these goals are the following: 1. A lightweight centralised Service Management and Orchestration (SMO) layer, with distributed and coordinated intelligent control employing Multi-Agent Systems (MAS). This functional split promotes service assurance by enabling faster control loops, ensuring the scalability of the system as its self- operation* relies mainly on the autonomous coordinated operation of the agents. 2. An end-to-end programmable user plane supporting multitenancy, using a hardware abstraction layer to interact with the heterogenous devices e.g., GPUs, Tensor Processing Units (TPUs), Field Programmable Gate Arrays (FPGAs), System-on-a-Chip (SoCs). This will facilitate increased flexibility in function placement and offloading while using simple and abstract control plane APIs. It will also enable simpler customisation of end-to-end network behaviour without sacrificing performance and power efficiency.

SYSTEM ARCHITECTURE

As illustrated in the figure next page, the ***E2E SMO*** Layer oversees all orchestration and lifecycle management aspects, generating the needed guidelines for the agents, allowing the desired degree of freedom for their autonomous operation. The Intent-Based Networking (IBN) approach starts with the ***Service Design Tools*** defining the service and the Intent in terms of policy rules that guide the service behaviour e.g., goals related to quality of service, performance etc. By natively accommodating distributed network intelligence closer to the user plane through ***MAS-based Network Control***, we expect fast and coordinated decision-making across the Far Edge, Edge, Transport, and Core domains.

Because of the envisaged distribution of intelligence, DESIRE6G leverages DLT as a basis for securing agent interactions (*Secure Distributed Intelligence*). Specifically, an infrastructure-agnostic software security DLT-powered framework is introduced that combines automatic security enforcement by binary rewriting and the needed trustworthiness and traceability brought by the DLT structure. To support the seamless execution of services across multiple, heterogeneous administrative domains (e.g., Public Network Integrated Non-Public Network deployment), DESIRE6G will employ *Lightweight blockchain-based federation* at the SMO level.

At the data plane, the DESIRE6G cloud-native mobile network promotes *RAN-core convergence* for 6G. Furthermore, by investigating the *Serverless* approach for network and application-specific function deployment, we aim to take advantage of their programming simplicity and automatic scaling and operation migration capabilities across the *Edge-to-Cloud continuum*.



System architecture and key innovations

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

DESIRE6G

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DESIRE6G will further provide the architectural elements and APIs to support the seamless offloading of network functions and application computations to the network. To unify application/network function (e.g., AI/ML processing, RAN network functions, real-time computations) development and deployment on heterogeneous systems a ***Hardware Abstraction Layer*** will be defined. In this context, we introduce "in-network computing as a service", where application developers, Over-The-Top (OTT) service providers etc., will be able to benefit from in-network acceleration and optimisation without the need of domain specific knowledge. Furthermore, by promoting multi-tenancy in the E2E programmable data plane, DESIRE6G promotes deep slicing, allowing slice-specific protocol stacks utilising multi-HW accelerators over the shared infrastructure. On a per-service basis, this can be the market differentiator, enabling novel application-network interactions and enhanced performance.

The system architecture will be complemented by a ***Pervasive Monitoring System*** to support the DESIRE6G architecture. The data plane will be observable and measurable from the user terminals to the cloud, leveraging on E2E in-band *network telemetry* solutions, providing high accuracy and sub-ms granularity. Telemetry data will feed AI/ML algorithms for training, inference and detection or forecasting of anomalies and performance degradations, which will make the data plane highly predictable and reliable. Finally, DESIRE6G will employ distributed, privacy preserving AI/ML approaches, while considering application-level requirements, communication, and compute resource constraints to further support *Edge Intelligence*. For this purpose, a spectrum of AI/ML techniques ranging from federated and collaborative learning will be investigated covering both theoretical and practical aspects. Moreover, data scrambling and normalisation techniques, stemming from privacy preserving image processing, will be exploited to provide third-party intelligent algorithms with required data while preserving confidentiality and privacy.

USE CASES

The developed solutions will be demonstrated and tested through experiments in laboratory environments, and larger field evaluations utilising diverse trialling facilities, namely the 5TONIC laboratory (https://www.5tonic.org) in Spain and the ARNO testbed (http://arnotestbed.santannapisa.it) in Italy. DESIRE6G focuses on two representative 6G use cases: augmented/virtual reality and digital twin industrial applications, targeting extreme key performance indicators. In the context of a factory maintenance application, multiple video streams rendered by UAVs will be merged/processed and delivered to the AR/VR headset, which will allow for tilt and pan of the virtual landscape to be controlled by the maintenance operator's head movements. In the context of industrial robotics applications, the operational factory floor digital twin involving (i) the remote control of a robotic arm and (ii) autonomous navigation and control of a robot dog using Simultaneous Localisation and Mapping (SLAM) algorithms.

DETERMINISTIC6G

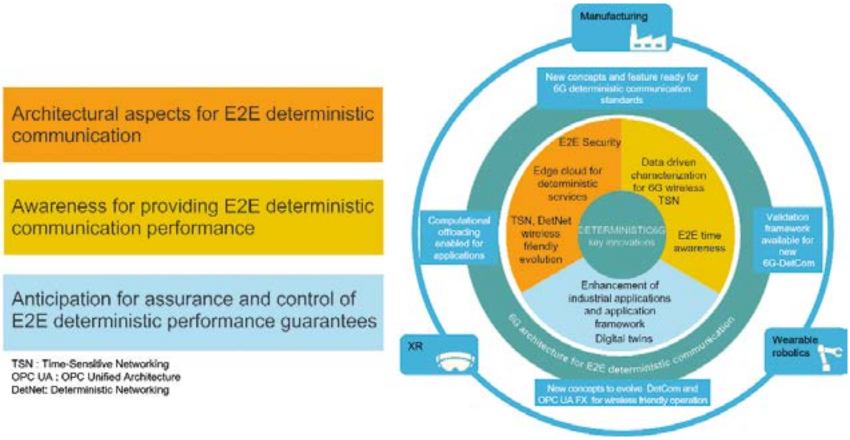
DETERMINISTIC6G aims to develop an end-to-end deterministic communication architecture enabling innovative 6G use cases.

OBJECTIVES

The concept of deterministic communication to guarantee communication latency and reliability is central to the project. Ensuring sufficient end-to-end communication reliability remains a challenge for cellular networks in an industrial context. The new project will develop the technology enablers that are essential to building the "time-sensitive" communication needed for 6G. A primary focus of the project will be on the interplay between future 6G networks and highly time-synchronised networks called Time Sensitive Networking (TSN). The challenge in these settings is that wireless systems like 6G can be subject to strong random variations, which are incompatible with technologies like TSN. DETERMINISTIC6G will tackle this problem through a combination of new wireless transmission design and advanced machine learning algorithms, leading to 6G wireless transmission with deterministic latency behaviour. In addition, the project will consider consequences and novel approaches for time synchronisation, network security as well as the integration of computational nodes into 6G systems.

PROJECT DESCRIPTION

DETERMINITIC6G results will play a vital role in defining future 6G deterministic technology standards and solutions. The current deterministic communication standards are driven by Standards Development Organisations (SDOs) for wired communication systems. IEEE 802.1 TSN plays a central role, as it makes it possible to provide guaranteed high performance connectivity services for certain traffic flows on a common Layer-2 bridged Ethernet infrastructure. Similarly, Deterministic Networking (DetNet) as a deterministic transport solution that ensures bounded latency and low data loss over a Layer-3 routed network is being specified by the Internet Engineering Task Force (IETF). 5G support for TSN and DetNet builds on the 5G capabilities for uRLLC which is included in the 5G Releases 15 to 17 specifications. TSN, DetNet, and 5G technologies are currently viewed as complementary technologies in deterministic communication networks, paving the way for future advanced manufacturing systems. An interworking and integration of these technologies is key to supporting the deterministic communication services over the heterogeneous infrastructure and multiple application domains required for network convergence. By the same token, the Open Platform Communications (OPC) Foundation's Field Level Communications (FLC) initiative develops one common multi-vendor middleware framework for a converged network infrastructure based on TSN, as well as DetNet and 5G/6G down the road. It standardises interoperable data models and common procedures across a variety of industrial use cases with multi-vendor components. This includes the specification and usage of deterministic communication from applications, by activating and configuring the underlying deterministic communication infrastructure.



DETERMINISTIC6G Overview

DETERMINISTIC6G

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DETERMINISTIC6G builds on the wired deterministic communication standards to support end-to-end deterministic communication over heterogeneous networks. The expected outcomes of the project include:

- 6G architecture for deterministic communication and interfaces allowing dynamic interactions in integrated heterogenous infrastructure
- Integration and interworking with deterministic standards over wired (TSN and DetNet) and wireless communication infrastructure
- Design of an open controllability framework for time-critical services operating dynamically over multiple heterogeneous domains including edge computing as well as wired and wireless domains
- An architecture for innovative 6G use cases based on security-by-design principles that provide capabilities to support deterministic wireless 6G transmission
- New data-driven ML methods for 6G system providing probabilistic latency guarantees at run-time
- E2E time awareness for supporting the deterministic operations
- Unified service provisioning through integration with an advanced industrial application framework (Open Platform Communications Unified Architecture Field eXchange (OPC UA FX) to provide service to several industry verticals.
- Algorithms that leverage the information base of 6G digital twins and Cyber-Physical Systems (CPS) digital twin in order to maintain E2E guarantees but also application-layer features such as safety

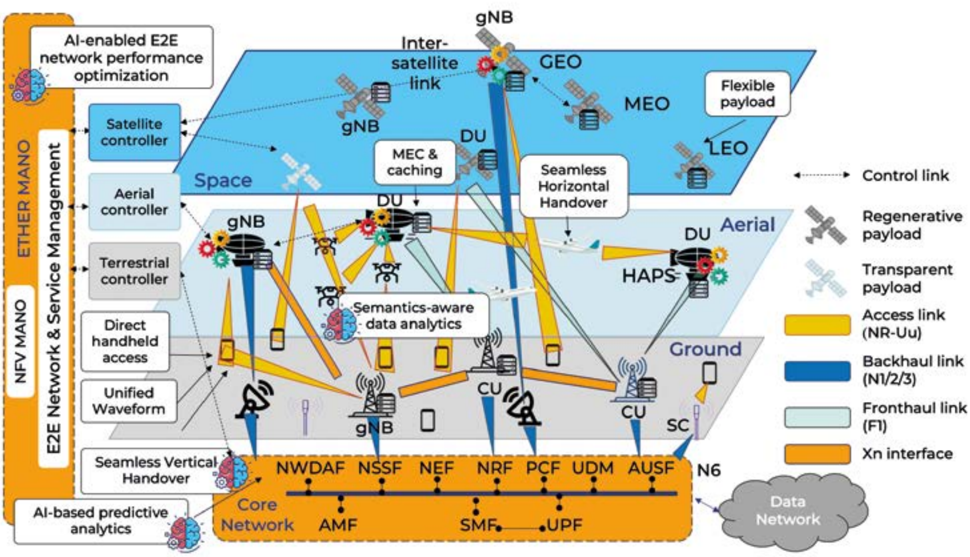
ETHER

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.

PROJECT OVERVIEW

ETHER relies on the following innovations:

- Unified RAN advancements that enable broadband connectivity from every corner of the world, even with handheld devices.
- Intelligent management of the 3D network resources for meeting predefined KPIs, enabling the network to self-adapt to rapidly evolving traffic conditions and situations on the ground without human intervention.
- A distributed 3D computing and caching medium enabling the reduction of response delays by alleviating congestions towards cloud data centre.



PROJECT ARCHITECTURE

To realize this novel system concept, ETHER relies on a multi-layered and unified space-aerial-terrestrial architecture, leveraging the benefits of AI/ML for the optimisation of the highly complex and heterogeneous "network of networks" and optimised by means of:

- **Collection and processing of a massive amount of data** that spans terrestrial, aerial, and space networks. These data will be generated, e.g., by satellites, High Altitude Platform Station (HAPS), UAVs, airplanes, small cells, and User Equipment (UE)/Internet-of-Things (IoT) devices and can reveal hidden trends, thus, proactive network adaptation to foreseen requirements can be achieved.

- AI/ML advances for self-evolving network capability leveraging a multitude of learning concepts that have proven to be highly effective in solving complex problems, such as reinforcement learning, federated learning, meta learning, and deep transfer learning.
- **Full-scale softwarisation across the network layers** by separating the data and control planes and enabling its remote programmability, e.g., by means of a software-defined payload, paving the way for full-scale intelligent decisions.
- **Direct handheld device access in the Ka band and unified waveform design together with seamless horizontal/vertical handovers** for smooth user connectivity to a multitude of terrestrial and aerial/space base stations.
- **Edge computing and caching capabilities** for optimally allocating the processing of data produced by various IoT devices, sensors, UEs close to where the data is produced, and for running distributed ML algorithms in conjunction with centralised approaches.

USE CASES

ETHER is going to experimentally showcase the following 3 use cases that integrate its technical innovations:

- **Use case 1-ETHER flexible payload-enabled service provisioning to semantics aware and delay-tolerant IoT applications:** The provision of the Narrowband Internet of things (NB-IoT) service as deployed in a satellite system will be achieved by means of a flexible payload. This payload will play a crucial role in the execution of the demonstration. Specifically, the payload will enable management of the NB-IoT service over a target region across the different satellites. This management will be orchestrated by a ground Management and Orchestration (MANO) system that will instruct the satellites to activate and deactivate services in a coordinated manner, exchanging status and context with satellites to come. To this end, capabilities will be demonstrated in the following three areas: a) management of infrastructure resources from different domains such as registration of cloud/edge and RAN resources, b) slice management capability through which reserved resources per slice are registered and configured, where each slice is composed of cloud/edge compute chunks, RAN chunks, and 5G Core Network (5GCN)/Cloud/edge network chunks, and c) management of network services including service instantiation/termination/migration, service update, and service recovery. Additionally, two other IoT services will be deployed alongside NB-IoT in the flexible payload, to demonstrate the possibility of executing them simultaneously. With this execution, it is expected to verify that the design and development of the flexible payload is capable of autonomously managing internal software-based payloads and propagating their status amongst the satellites to ensure service continuity.
- **Use case 2-ETHER unified RAN for direct handheld device access in the Ka band:** We assume that a mobile handheld device is initially connected to a terrestrial site. As the device is moving, the received signal from the terrestrial site starts deteriorating due to an obstacle in its vicinity. Based on reported measurements from the handheld device regarding signal strength from other terrestrial sites and from non-terrestrial platforms, such as LEO satellites, a handover process will be triggered through intelligent algorithms that target maximised energy efficiency – according to availability constraints, flow conservation constraints, power and capacity constraints. In the case of connecting to a non-terrestrial platform, the ability to use AI

sElf-evolving terrestrial/ non-Terrestrial Hybrid nEtwoRks

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to choose whether to deploy OFDM or OTFS, according to the resulting Doppler spread and its impact on performance, is also leveraged.

- **Use case 3-ETHER architecture demonstration for air-space safety critical operations:** The handover and multilink features are key enablers for safety-critical Urban Air Mobility (UAM) and U-SPACE operations. Safety-critical operation is important because it avoids human injury and death, damage to property and the environment, and financial loss. To meet the safety goal, the communication system needs to be reliable, resilient, and ubiquitous. It must also satisfy emerging standards for command-and-control links and metrics pertaining to packet latency, availability, integrity, and redundancy. In this use case, one or more UAVs move across multiple ground-based network cells covered by LEO satellites. This includes the horizontal handover between terrestrial network cells and vertical handover from ground network to satellite using a unified waveform and access technology. In network layer, smart multilink capability that manages the dissimilar data links and guarantees the safety-critical service performance through network redundancy will be demonstrated. They ensure continuous andresilient data links for the aircraft while meeting the service requirement. In these evaluations, the network environment and wireless channel must be emulated realistically. For the edge computing demo, UAM and U-SPACE applications requiring short-latency and resilient services will be demonstrated. This MEC component will support evaluation of hosting data distribution for deconfliction and other airspace management services within each network layer, particularly to support evaluation of latency and backhaul performance requirements. Other key criteria to be demonstrated include dynamic synchronisation and migration of data at the network edge to follow aircraft users as they move across the network, guaranteeing service continuity.

FLEX-SCALE

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

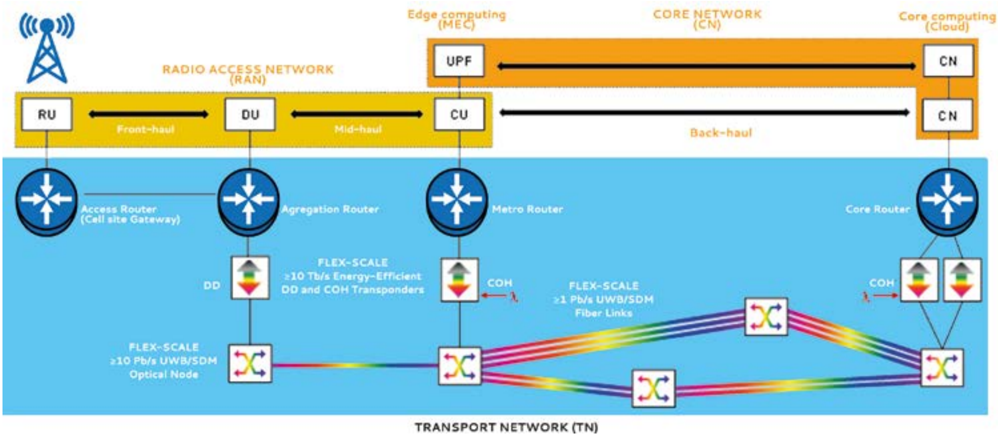
CONTEXT

Each will operate at higher frequencies to deliver greater bandwidth to mobile end-users (humans and machines), while the overall network will utilise the latest technologies that are still at the research and exploration stage. No matter which technologies will be chosen to build the RAN portion of 6G networks, one thing is certain: each antenna site will eventually connect to the optical communication networks at the aggregation and core levels. To put things into perspective, a future beyond-5G mobile network deployment scenario utilising 200-MHz carrier-aggregated signals and 64×64 massive-MIMO requires 240×10 Gb/s Common Public Radio Interface (CPRI) (splitting option 7) front-haul interfaces to connect the remote radio units (RRUs) at the antenna sites with the centralised baseband units (BBUs) in cloud radio-access networks (C-RAN). This brings the data capacity requirement to a staggering 2.4 Tb/s per massive-MIMO antenna sector. As a single BBU can support multiple RRUs, the access network needs to handle such demanding operating scenarios. Wavelength Division Multiplexing (WDM)/SDM schemes per spectral channels/spatial lanes, building upon higher rate interfaces per channel/lane (beyond current 1 Tb/s single-lane Input/Output (I/O) interfaces) need to be utilised.

FLEX-SCALE TRANSPORT NETWORK

As shown in the figure below, the end-to-end 6G network spans many segments from the 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 (labelled as FLEX-SCALE in the figure). 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 particular network segment. By introducing the ONs, we can expect the requirements for router capacities, as well as their number of ports, to decrease, saving energy and cost (routers cost more and consume far more power per bit processed). As we move deeper into the core network, the capacity of the ONs increases and, as discussed below, can exceed 10 Pb/s. The corresponding optoelectronic interfaces for each of the connections between the 6G cell sites and the ONs, as well as between the ONs, need to support rates ranging from a few hundred Gb/s to ≥1 Tb/s in a single lane (either spectral or spatial). To scale the capacity of the optical links between the ONs, it is foreseen that multiplexing approaches utilising a combination of spectral multiplexing (i.e., Ultra-Wide-Band WDM – UWB) and spatial multiplexing (i.e., Space Division Multiplexing – SDM) will be employed, thus scaling link capacities to 1 Pb/s and beyond. Since multiple such UWB/SDM multiplexed optical links will be networked to neighbouring ONs, the ONs' throughput should scale to ˜tens Pb/s. The 6G transport network, formed by the ONs and UWB/SDM links, is arranged in intercon-

FLEX-SCALE high-capacity, UWB+SDM transport network for 6G



nected rings and mesh architectures to support network resilience and higher reliability/availability for the 6G services. Depending on the 6G segment where the ONs are deployed, their switching speeds is also an important parameter to be engineered according to the corresponding requirements. Switches deep in the Backbone network support the largest throughputs but their switching speeds may be less demanding. ONs that are closer to the network edge need to switch faster to support the low latency requirements, but their capacities will be smaller. Future ONs will rely increasingly on faster and higher capacity reconfigurable optical add-drop multiplexers (ROADMs) and optical cross-connects (OXCs), but a new breed of transmission and switching technologies needs to be developed to satisfy the diverging requirements across the network.

The FLEX-SCALE network will efficiently support IP traffic provisioning through intelligent bandwidth assignments per segment from the edge/access to the core, using the reconfiguration capabilities of the optical switches that should afford Pb/s throughput and fine switching granularities depending on their location across the network. For such a demanding scenario, a new breed of optical switching nodes needs to be developed with the ability to dynamically reconfigure its operation, scale its throughput on demand, at faster speeds than current technologies dictate and at smaller physical volume and lower cost. Today's ROADMs operate at spectral super-channel level and OXCs at fibre-level. In the future, as the capacities of optical communication systems will further scale with the use of UWB/SDM schemes, the ONs should route and add/drop at the spectral and spatial domains. The emergence of UWB demands the development of new optical nodes that will be capable of performing switching at wave-band level – *flexibly defined (i.e., the size of the band can be variable)* – besides spectral super-channel and fibre level switching. Such optical network nodes, that presently do not exist, should have common features with today's Wavelength Selective Switches (WSSs) supporting route-and-select topologies, but additionally be capable of operating efficiently at the Waveband level. The Wavebands' size should be flexibly configurable to cover the range from a super-channel to the entire C+L+S-bands and everything in between, enabling WDM

FLEX-SCALE

Flexibly Scalable Energy Efficient Networking

FLEX-SCALE

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provisioning or full fibre routing. FLEX-SCALE, among other innovations, will develop a highly performing WaveBand Selective Switch (WBSS) which will be a key element in the ONs. It will be implemented on a PIC platform that scales down its overall footprint and cost. The WBSS will operate alongside enhanced WSSs and OXCs arranged in a novel *SDN-controlled Multi-Granular (MG) Optical Switching Node* that the consortium will develop and demonstrate its operation experimentally. Its operation is described in the Ambition section and its implementation in the Methodology section. This FLEX-SCALE reconfigurable Multi-Pb/s UWB/SDM Multi-Granularity Optical Network (MG-ON) will provision capacities on demand, serving the needs of Aggregation/Metro/Core Routers across the front-, mid- and back-haul 6G network segments, in a way that optimises the cost and power consumption of the entire network, while serving the needs of the bandwidth-hungry and latency-sensitive 6G applications. These FLEX-SCALE MG-ONs will be equipped with a new generation of high-rate and low-power optoelectronic interfaces, patented by consortium partners, that rely on novel transceiver designs and new photonic technologies for their fabrication. The innovative FLEX-SCALE transceiver designs avoid the use of bandwidth-limited, power-hungry and costly electronics circuitry, like electronic Digital to Analogue Converters (DACs), replacing them with plasmonic-based optical ones, and optical Digital-to-Analogue Converters (oDACs) that perform direct Digital-to-Optical (D/O) conversion. Such novelty will result in much higher bit-rate scalability of the optical transmitters and much lower power consumption per transmitted bit.

It is worth pointing out that, aside from network capacity scaling, our society is struggling to find ways to reduce its overall energy footprint, and particularly ICT's footprint, since many studies predict that electricity used by ICT could exceed 20% of the worldwide total by 2030. To this end, energy and cost-efficient optical networks with greater throughput and versatility are vital for the sustained growth of converged fixed-wireless infrastructures in the context of emerging 6G networks. As a result, transformational optical communications technologies and devices (e.g., novel optical switches and transceivers) with new capabilities and high performance are required and will be developed within the FLEX-SCALE project.

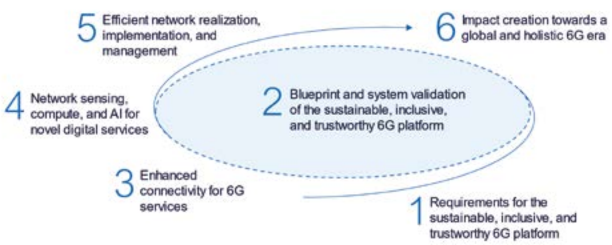
In conclusion, the FLEX-SCALE consortium has devised a plan to develop solutions that will enable: (i) the optoelectronic interfaces to scale to ≥10 Tb/s, (ii) network link capacity to scale ≥1 Pb/s by UWB/SDM (iii) the ONs capacities to scale to ~tens Pb/s while enabling flexibility to reduce the costs and energy consumption, and (iv) manage the network using SDN while introducing efficient and dynamic allocation of network resources across the 6G network. These envisioned advancements are in sync with industry trends towards full-band transceivers, multi-band transmission, and upcoming SDM solutions.

HEXA-X-II

The Hexa-X-II project is a continuation of the Horizon 2020 ICT-52 6G flagship Hexa-X project, and endeavours to continue the research on 6G components as well design an end-to-end 6G system capable of delivering the future 6G digital services.

OBJECTIVES

The main goal of the Hexa-X-II project is to develop and describe the 6G platform on a system level and design a blueprint and system validation aiming at a sustainable, inclusive, and trustworthy 6G platform in time for the expected technical standardisation of 6G in e.g., 3GPP.



To achieve this, the Hexa-X-II project will evaluate and develop the values, requirements, and use cases for 6G, with a keen focus on the economic, societal, and environmental sustainability of 6G and dedicated efforts to anchor the 6G vision in society to foster the acceptability of the next generation of mobile networks.

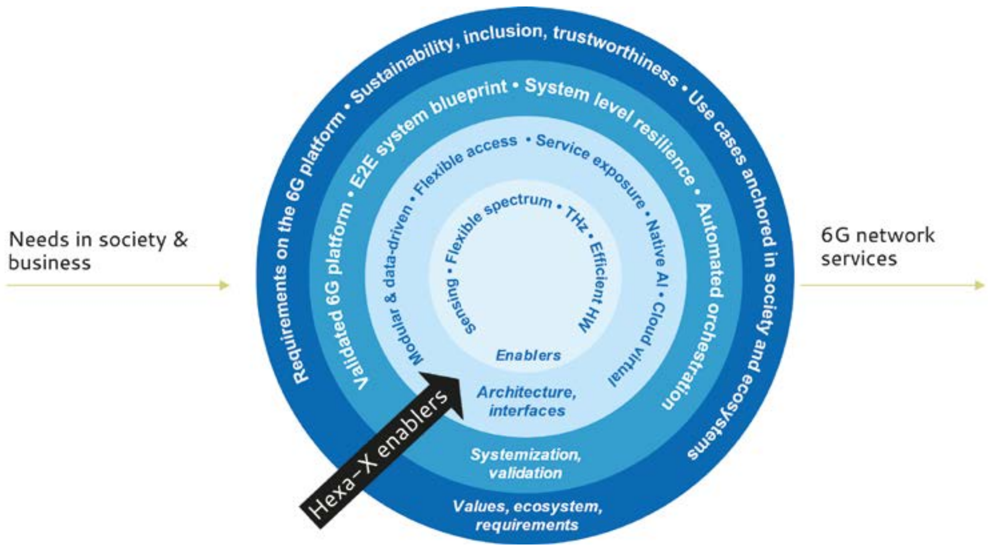
Furthermore, to design the 6G system, Hexa-X-II will develop and evaluate the technological components that will constitute the 6G platform and explore techniques to enhance the connectivity, incorporate capabilities beyond communication (e.g., sensing, computational offloading, or AI services), and develop the network architecture to improve the efficiency and sustainability of the networks.

Finally, Hexa-X-II aims to continue Hexa-X's role as the focal point of 6G research in Europe and foster regional and global collaborations striving for a harmonised 6G view going into standardisation in the coming years.

TECHNICAL SCOPE

As a holistic 6G flagship project, the technical scope of Hexa-X-II runs the gamut from 6G devices to radio interface, to network architecture, to network orchestration, to transport, all the way to the application layer.

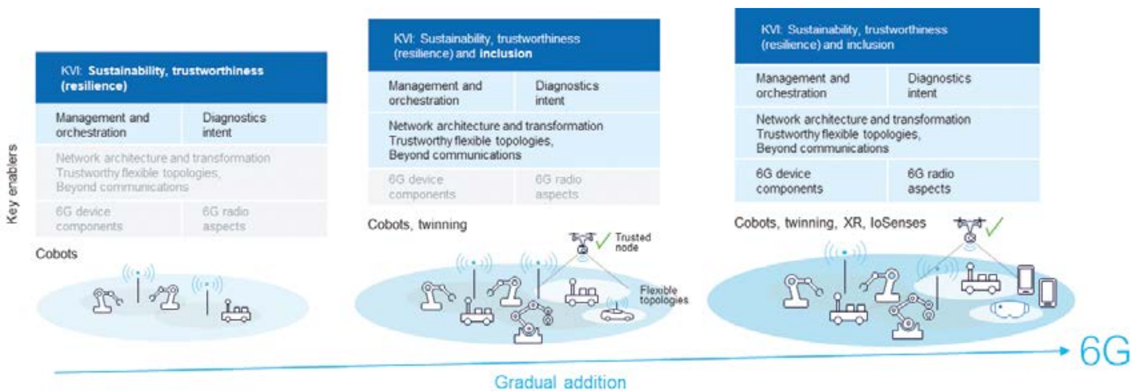
Based on this, the 6G platform will deliver a wide range of digital services, ranging from extreme connectivity with minimal latencies, to extremely efficient energy-neutral devices, as well as incorporating novel capabilities such as sensing or compute while ensuring that the technologies and development are sustainable, inclusive, and trustworthy.



PROOFS OF CONCEPT

The Hexa-X-II project will develop a series of system-level proof of concepts (PoCs) in three iterations, that will gradually incorporate features and components from eight smaller PoCs.

In the first iteration, the PoCs will showcase a smart network and orchestration in a device-cloud continuum, managing collaborative robots (cobots) solving simple tasks.



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The second iteration of the PoC will incorporate flexible topologies ensuring connectivity and latency requirements of the cobots, as well as introducing computational offloading capabilities and using distributed machine learning models to optimise the system.

In the third and final iterations, novel 6G devices will be introduced to emulate a full end-to-end system, using AI models to optimise the air-interface, as well as using the air interface to conduct accurate localisation and sensing of the human operators and cobots. The human operator will employ end-to-end extended reality capabilities to monitor, control, and interact with the cobots.

HORSE

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

CONTEXT AND OBJECTIVES

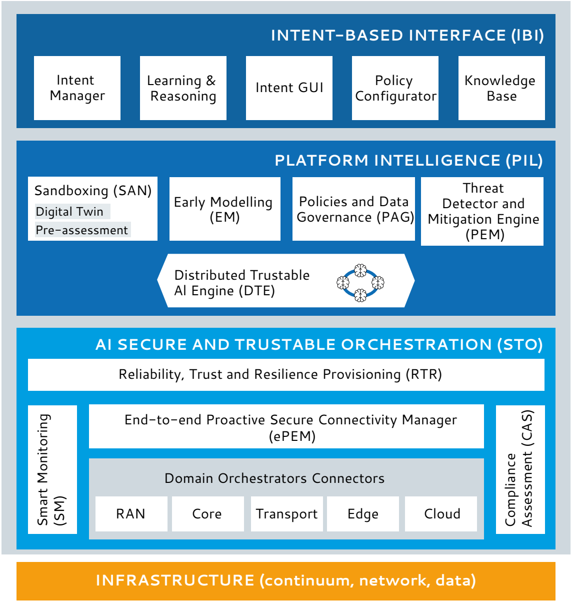
6G technologies, benefitting from softwarisation, Gb/s speed and sub-THz communications paradigms, open up opportunities for developing new and innovative network management strategies, while navigating the evolution toward disaggregation, new software-based paradigms in architecting and operating future connectivity platforms, and embracing features of computing, automation and smartness, trust, privacy and security. Supported by this technology evolution, as the vision of new, smart and innovative capabilities is becoming a reality, superb user experience is expected even in the presence of mobility and resource volatility.

However, the fundamentally new and unknown features of advanced, disaggregated, virtualised and multi-vendor 6G-based infrastructures take the security and resilience design challenge to the next level, by managing unknown, complex and highly versatile infrastructures as they evolve. Indeed, the future deployment of 6G networks is inextricably connected to the integration of diverse hardware elements and infrastructures, thus leading not only to a highly heterogeneous environment, but also to functions and features that cannot be anticipated at the time of design. In this complex scenario, the HORSE vision is to navigate as yet unforeseen technology solutions, and system evaluation, towards an omnipresent, smart and secure network service provisioning in the future network-of-networks landscape.

To this end, **HORSE proposes a novel human-centric, open-source, Green, sustainable, coordinated provisioning and protection evolutionary platform, which can inclusively yet seamlessly combine advancements in several domains, as they are added to the system (e.g., predictive threats detection, proactive business-wise threats and breaches mitigation actions, programmable networking, semantic communications, Network Function Virtualisation (NFV), intent-based networking, AI-based techniques, cross-layer management of physical layer features, etc.).**

HORSE is funded under the SNS Phase 1 (2022) Stream B of projects and began in January 2023. These projects will perform research on revolutionary technology advancements, in preparation for 6G and revolutionary advancements of IoT, devices and software. These projects will attempt to address 6G system fundamental principles, which form the basis of technology standardisation. Their find-

Key Technologies and System Architecture



ings are likely to significantly affect initial 6G discussions (use case/system requirements, KPIs, interfaces, etc.) in various standardisation bodies, which is why concrete plans are needed for close synchronisation with the relevant standardisation activities.

USE CASES

Secure, smart LRT system scenario

Remote Rendering to Power XR Industrial scenario

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

HORSE

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Use Case 1

Secure Smart LRT Systems (SS-LRT)

Background: LRT (light Rail Transit) or Metro Operation involves the management and orchestration, with high availability, of several systems, applications and end-to-end services, supported by equipment that typically are deployed on tram stops, trams and in the Command Centre. Usually, these Command Centres are deployed in private networks, for security reasons, and are located on the Operator premises, for latency reasons. The 6G capabilities, particularly the ones that are addressed in the HORSE project, will leverage the introduction of new paradigms related to communications, disaster recovery, security, resilience, with geographically and distributed operation (even supported by cloud solutions) with several impacts on overall availability and decision support.

Main scenarios: Based on Dublin and Bergen LRT/Metro scenarios, deployed by EFACEC, it is intended to compare the system performance that is being achieved now with the one achieved by the HORSE solution, with respect to the following main performance objectives:

- Disaster recovery,
- Remote operation, including cloud solution,
- Operation statistics,
- Security vulnerabilities and threats,
- Communication performance for data exchange between trams, stops and the Command Centre,
- Applications and services performance.

Use-Case 2

Remote Rendering to Power XR Industrial (R22XRI)

Background: Multiuser XR (Extended Reality) multi-sites collaboration provides Industry 4.0 professionals with the means to solve complex issues in a much easier and efficient way, giving them the opportunity to meet in a virtual common space to collaborate and share virtual 3D objects. Furthermore, and most importantly, thanks to VR and AR processes can be monitored and experienced in 3D for future research. Providing a reliable and secure communication system (as a backbone for information exchange), especially when collaboration is between different sites, is an emerging challenge that needs to be tackled.

Added to which, industrial espionage is a growing threat, forcing manufacturers to take a more proactive approach to securing their intellectual property. A proactive, resilient and secure system is extremely important to protect valuable data and intellectual property from unauthorised access ensuring a free flow of information throughout all actors involved (engineers, specialists, and supply chain). Virtual remote collaboration, security, in the communication improvement and process monitoring are this key challenges that this pilot use case aims to explore.

Main scenarios: The HORSE project will develop and operate a multiuser environment where different professional stakeholders can interact and teleport to another context that is either fully virtual or mixed. The service will offer a resilient and secure environment that professional users located at different sites and leveraging XR technology can benefit from. The main characteristics will be:

- Endless cloud and edge processing power to stream big data,
- Global availability on all XR devices,
- High data sharing security with regarding to peer-to-peer communication, human-machine interaction and 3D assets sharing,
- Infrastructure flexibility,
- Fast Adoption by simple integration,
- Empowering teams with efficient app development and time savings.

PREDICT6G

PREDICT-6G will develop a novel Multi-technology Multi-domain Data-Plane (MDP) overhauling the reliability and time sensitiveness design features existing in current wired and wireless standards.

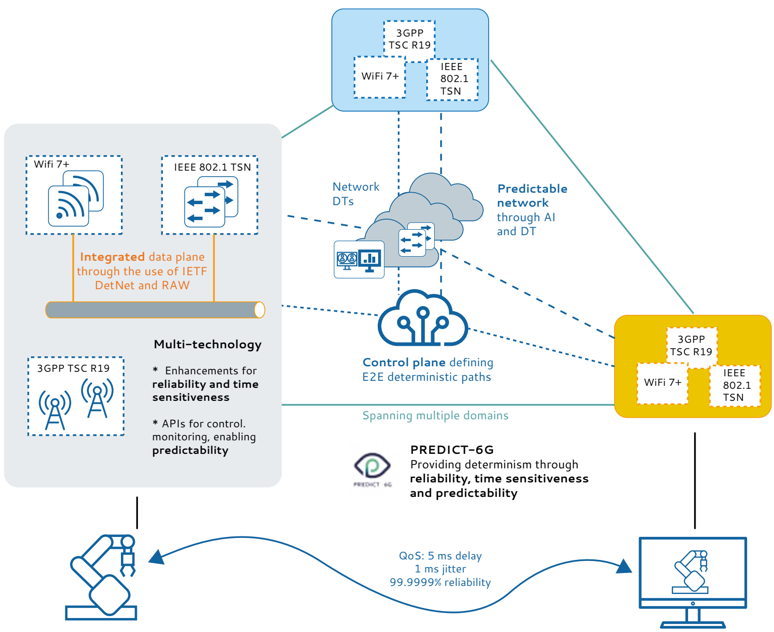
CONTEXT AND VISION

6G is expected to accelerate the path begun with 5G for catering to the needs of a wide variety of vertical use cases, both current and emerging. This will require major enhancements of current 5G capabilities, especially in terms of bandwidth, latency, reliability, security, and energy efficiency.

PREDICT-6G's mission is therefore geared towards *the development of an end-to-end 6G (E2E) solution including architecture and protocols that can guarantee seamless provisioning of services for vertical use cases requiring extremely tight timing and reliability constraints.* To succeed, the solution will target determinism network infrastructures at large, including wired and wireless segments and their interconnections. PREDICT-6G will develop a novel **Multi-technology Multi-domain Data-Plane (MDP)** overhauling the **reliability and time sensitiveness** design features existing in current wired and wireless standards.

OBJECTIVES

PREDICT-6G aims to create a secure, modular, interoperable, and extensible deterministic network and management framework that automates the definition, provisioning, monitoring, fulfilment, and life-cycle management of end-to-end (E2E) deterministic services over multiple network domains, hiding the complexity of continuously balancing and re-configuring the constituent domain specific enablers to maintain a consistent E2E determinism.



As shown in the figure, **PREDICT-6G builds on three pillars**:

- Extend the **reliability and time sensitiveness** features of IEEE 802.11 (targeting WiFi7/8) and 3GPP (targeting contributions to R19/20) networks, including APIs for the monitoring and control of such capabilities, enabling predictability. This pillar also considers the provision of a certain level of determinism (for specific applications) involving links or networks without native support (at layer 2) of deterministic features or not capable of guaranteeing a certain level of time sensitiveness, reliability, or predictability.
- Develop an **MDP** jointly with an **AI-driven multi-stakeholder inter-domain Control-Plane** (AICP). This will enable the creation of E2E deterministic paths, by leveraging on IETF Deterministic Networking (DetNet) and Reliable and Available Wireless (RAW) mechanisms.
- Enhance the predictability of the network through intelligence, enabling the forecasting of the occupancy of network resources and the effect of accepting a new flow into the network. This feature will be enabled through **AI and network digital twining** approaches.

There are several ***significant technical challenges*** that must be overcome to achieve a seamless end-to-end deterministic service. These include inconsistencies in the definition and explanation of determinism across different domains, as well as the lack of standardised APIs to attain determinism in the data plane. In addition, the various link layer technologies result in different inherent network capabilities, and there are incompatible control- and management-plane interfaces that hinder the provision of determinism.

PROOFS OF CONCEPT

To address these technical challenges, and trial and deploy PoCs, **PREDICT-6G** intends to leverage and expand the capabilities of two Open-Labs: the **5TONIC Innovation Lab in Madrid and the Nokia Open Lab in Budapest (5G Innovation Network)**. Both labs offer pre-commercial hardware and the participation of various industries in various scenarios (such as Vehicle-to-Everything (V2X) and smart manufacturing) to enable innovation in the control- and data-planes in realistic network environments. The data, control and management plane components developed in **PREDICT-6G** will be proven through working prototypes implementing the services, functionalities and workflows specified in the system architecture. The system integration will be performed in iterative cycles, taking as input the HW and SW modules continuously delivered from data plane mechanism as well as control/management-plane and providing back the required feedbacks in terms of bug fixing, missing features or potential improvements. The testing environment will progressively move from the initial labs where the single modules have been developed to the target open labs in Madrid and Budapest.

In summary, **PREDICT-6G offers several benefits** by providing a system architecture that spans data, control, and management frameworks for deterministic networks. These benefits include improving the reliability and time sensitivity of wireless network domains, extending the concept of determinism to non-deterministic network infrastructures, and providing a control and management framework that automates and autonomously operates the network infrastructure while simplifying provisioning, control, and monitoring workflows. Additionally, PREDICT-6G incorporates an **AI-powered network Digital twin (DT) infrastructure** that enables the implementation of advanced provisioning, diagnosis, and prognosis algorithms for the fulfilment of deterministic network services. The overall goal is to achieve a frictionless data path with a deterministic behaviour at the data-plane level and to automate the full life cycle of service provisioning over multiple administrative/technological network domains, while ensuring interoperability and extensibility.

PRogrammable AI-Enabled DeterminIstiC neTworking for 6G

PREDICT-6G

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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.

CONTEXT AND OBJECTIVES

The emergence of 6G, which is currently being envisaged as a set of new technology enablers, is expected to widen the 5G threat landscape further, by including aspects such as heterogeneous radio, RAN softwarisation, multi-vendor deployments, AI-driven network management. It is thus evident that the current vision for 6G calls for even stricter and more sophisticated security controls.

At the same time, privacy is considered a key pillar in EU research and development activities in the run-up to 6G, as privacy enablement is considered a top societal priority in the EU 6G vision. 6G is anticipated to comprise a decentralised, zero-trust, globally connected continuum of heterogeneous environments involving several actors across the service chain (core/edge/RAN infrastructure providers, service providers). In such a pluralistic environment, privacy is crucial, not only for the end users but for all stakeholders, and it needs to be considered as a critical requirement in all technologies of the network stack, including security mechanisms.

In other words, the challenge for security enablers in future networks is, on the one hand, to address the significantly widened 6G threat landscape while, on the other hand, protecting the privacy of all actors in the 6G chain. Intrusive security can no longer be considered acceptable.

In this context, the aim of PRIVATEER will be 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 General Data Protection Regulation (GDPR) and the upcoming ePrivacy regulation. To that end, 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.

To achieve this mission, PRIVATEER will:

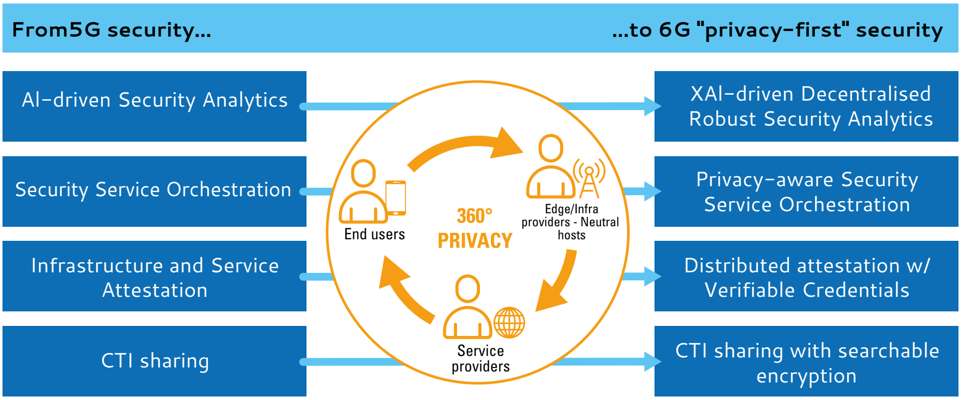
- decentralise the security analytics process and engage anti-adversarial AI techniques to create more robust models. Decentralisation will leverage edge/fog computing assets as well as federated AI techniques to distribute both the storage and processing of data. Explainable AI (XAI) will also be employed, so the human operator can directly align operations with privacy constraints.
- enable privacy-aware slicing and security service orchestration, taking into account the user's "privacy intent" and constraints as input for intent-based networking – for example, by placing core and edge VNFs only on trusted infrastructure domains and by verifying the integrity of the traffic path (proof-of-transit).
- distribute the infrastructure/service identification and authentication process and enable each 6G stakeholder to prove the integrity of its assets by means of verifiable credentials, exploiting the Decentralised IDentifier (DID) concept.

For this purpose, a permissioned blockchain will be used as a decentralised storage, where stakeholder certificates and proofs of authentication will be recorded.

- promote Cyber Threat Intelligence (CTI) sharing (which is significantly hindered due to privacy concerns) by applying searchable encryption and distributed indexing mechanisms, enabling CTI sharing with fine-grained control over information exposure.

APPROACH

By addressing the above-mentioned challenges, PRIVATEER takes the concept of privacy preservation beyond just end users, embracing all 6G ecosystem actors, including infrastructure and service providers. The project thus achieves "360-degree privacy" as depicted in Figure below.



The PRIVATEER approach for "privacy-first" security in 6G

The PRIVATEER framework will be deployed and evaluated in a campus-wide ever-evolving B5G test network, initially developed as part of the H2020 5GENESIS project. The demonstration will involve specific use case scenarios associated with two verticals with solid security and privacy requirements, namely Intelligent Transportation Systems (ITS) and Smart Cities.

It must be stressed that the security enablers developed in PRIVATEER will complement (and be compatible with) "native" 5G/6G security controls as standardised by 3GPP for basic functionalities (network attachment, authentication, authorisation etc.) in order to achieve a holistic, privacy-friendly security solution for future networks.

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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 AND OBJECTIVES

RIGOUROUS targets:

- Holistic Smart Service framework for securing the IoT-Edge-Cloud continuum lifecycle management.
- Human-Centric DevSecOps.
- Model-based and AI-driven Automated Security Orchestration, Trust Management and deployment.
- Advanced AI-driven Anomaly Detection, decision and Mitigation Strategies.
- Demonstration of a Set of Industrially Relevant Use Cases in Operational Environments.

INNOVATIONS AND ADVANCEMENT

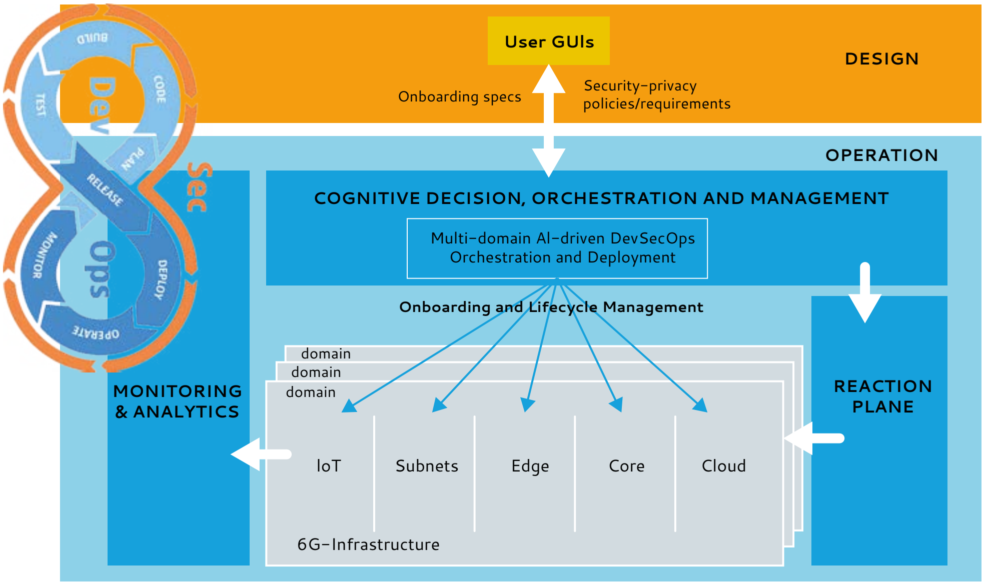
RIGOUROUS will allow several innovations:

- Intent-based Security and Privacy Formal Modelling and Onboarding Specification
- AI-based Security Orchestration across Network Segments
- Privacy-preserving AI for Anomaly Detection in B5G
- End-to-End Multidomain 6G Slicing over Zero-touch Security Network Management
- 6G Zero Trust Security Adaptations
- Continuum SOAR Loop Reaction and Mitigation
- IoT Device Bootstrapping and Trusted Application Onboarding
- Intelligent Detection and Mitigation of Economical Denial of Sustainability (EDoS) Attacks against 6G Network Slicing
- MTD-based Robust Mechanisms for Enabling Trustable Autonomic Security
- End-to-End Threat Risk Assessment
- Dynamic and Automated Software Composition
- AI-driven Decision-Making Mitigation Framework

EXPECTED OUTCOMES

RIGOUROUS expects:

- Identification/characterisation of the threat landscape applied to the envisioned end-to-end 6G connectivity and service systems and the technologies and architecture to mitigate them.
- Availability of technologies supporting the necessary levels of trustworthiness, resilience, openness, transparency, and dependability expected under the EU regulations (such as GDPR and Cyber Security Act, including associated provisions including new certification processes, etc.) across a complete continuum incorporating the human-cyber-physical system including connectivity-service provision.



RIGOUROUS high-level vision

- Availability of technologies ensuring secure, privacy-preserving, and trustworthy services in the context of a programmable platform accessed by multi-stakeholders and tenants, including vertical industries as users.
- Availability of security technologies and processes addressing the challenge of open-source solutions developed in the context of multi-vendor interoperability.
- Secure the host-neutral infrastructure where multiple infrastructure providers are involved in the network service's deployment, hosting, and orchestration.
- Identify the life cycle of smart services security and trust requirements, including development, provision, operation, maintenance, and their business impact on the stakeholders' ecosystem.
- AI technology is applied to security in two ways: i) correct application of AI to enhance security in 6G; ii) consideration of potential security threats using AI.

secuRe desIGn and deplOyment of trUsthwoRthy cOntinUum computing 6G Services

RIGOUROUS

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SUPERIOT

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

PROJECT OBJECTIVES AND VISION

The key objectives of SUPERIOT are to: a) demonstrate that dual-mode IoT (radio/light-based) is not only feasible but also results in a highly flexible and adaptable solution; b) demonstrate dual-mode (radio/light) energy harvesting; c) demonstrate dual-mode positioning as a part of the SUPERIOT concept; d) demonstrate that printed electronics is a key technology for the implementation of sustainable IoT nodes; e) implement and demonstrate a reconfigurable IoT node (RIoT) supporting the radio-light dual modes and using printed electronics technologies; f) implement and demonstrate a reconfigurable IoT network supporting radio-light dual mode operation; g) develop several technology demonstrators (see below). These objectives support a fundamental goal of SUPERIOT: to demonstrate, advocate and further promote the concept of *truly sustainable IoT systems*.

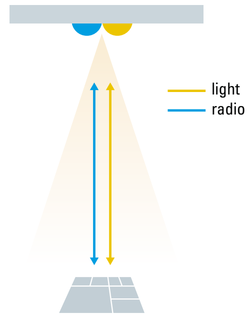
Project vision: We expect that the project will pave the way for further developments, particularly as printed electronics technology progresses. In the future and based on the SUPERIOT concept we anticipate: a) fully printed reconfigurable optical-radio IoT nodes; b) extremely inexpensive nodes supporting their massive use; c) use of biodegradable electronics supporting even more environmentally friendly nodes; d) nodes and networks with enhanced capabilities and e) operation in novel scenarios such as inside the human body, underwater, mining as well as any scenario requiring massive sensing and actuation.

CONCEPT

The project will create an IoT system that is sustainable from multiple perspectives, advocating three principles: 1) sustainable by design, 2) sustainable by implementation and 3) sustainable by usage. SUPERIOT will exploit multimodality in several domains, using light and radio signals to provide wireless connectivity, to harvest energy and to provide positioning. Reconfigurability will be a key characteristic of the concept. Both nodes and the network can

Sustainability by design

Multi-mode **communications**:	light-and radio-based wireless connectivity
Multi-mode energy **harvesting**:	light-and radio based
Multi-mode **positioning**:	light- and radio-based
Reconfigurability:	node and network
Sustainable implementation:	printed electronics technology (node)
Sustainable use:	smart energy harvesting and management

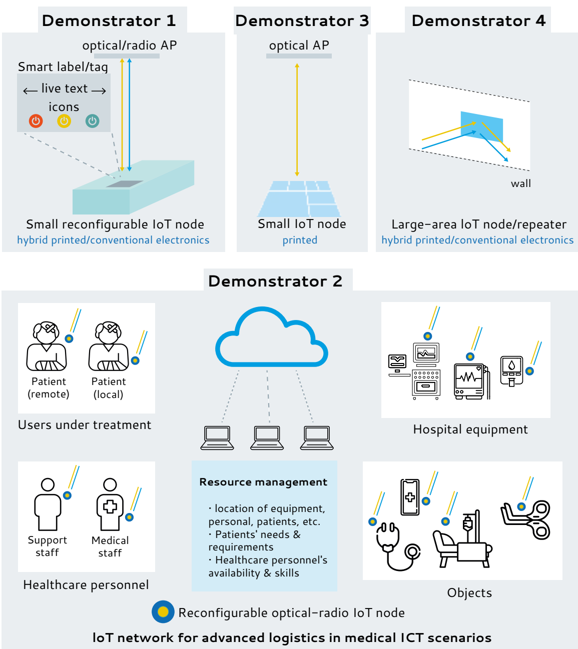


Printed electronics-based energy autonomous reconfigurable ToT node (RIoT) be dynamically reconfigured to create a versatile system that is adaptable to the dynamics of the environment as well as to different operating scenarios. Since IoT in general involves the massive use of nodes or devices, particular care will be put in designing highly sustainable IoT nodes. The project will consider energy autonomous IoT nodes (i.e., battery-less) that are implemented with environmentally friendly technology such as printed electronics. The figure summarises the key characteristics of the SUPERIOT concept.

SUPERIOT DEMONSTRATORS

Four demonstrators will be developed at the final stage of the project, including: a) reconfigurable optical-radio IoT node implemented with printed and conventional electronics technologies (application: smart tags and labels); b) reconfigurable optical-radio IoT network (application: logistics in medical ICT scenarios); c) limited capability IoT node implemented with printed electronics technology only, and d) large-area IoT node/repeater. The SUPERIOT demonstrators will prove the project's unique holistic approach to developing truly sustainable IoT systems based on three principles: sustainable by design, sustainable by implementation and sustainable by usage. The figure illustrates the demonstrators to be developed.

Demonstrators of the SUPERIOT project



In summary, SUPERIOT aims to develop a truly sustainable and highly flexible IoT system based on the use of optical and radio communications, and the exploitation of printed electronics technology for the implementation of sustainable IoT nodes. The dual-mode optical-radio approach confers unique characteristics to the IoT system. The system can be dynamically reconfigured to use optical, radio, or both connectivity approaches. The hybrid optical-radio system allows very efficient use of resources while combining the advantages of both wireless communication methods. Energy autonomous nodes will be designed to harvest energy from both light and radio sources, resulting in an efficient and reliable energy system. Moreover, positioning reliability and accuracy will be improved by jointly exploiting optical and radio signals. The multimodal operation results in a highly flexible and adaptable communication system, that can operate efficiently under changing conditions and in different scenarios. The implementation of the IoT nodes will use as much printed electronics technology as possible, resulting in a cost-efficient, environmentally friendly solution. Nodes will have essential IoT functionalities such as sensing, actuating and computational capabilities. As important as the development of a sustainable and flexible IoT node will be the development of its networking capabilities. The project will also identify, develop, and demonstrate applications for the proposed concept. As a proof-of-concept, the SUPERIOT project will develop four demonstrators.

Towards a Truly Sustainable IoT System

SUPERIOT

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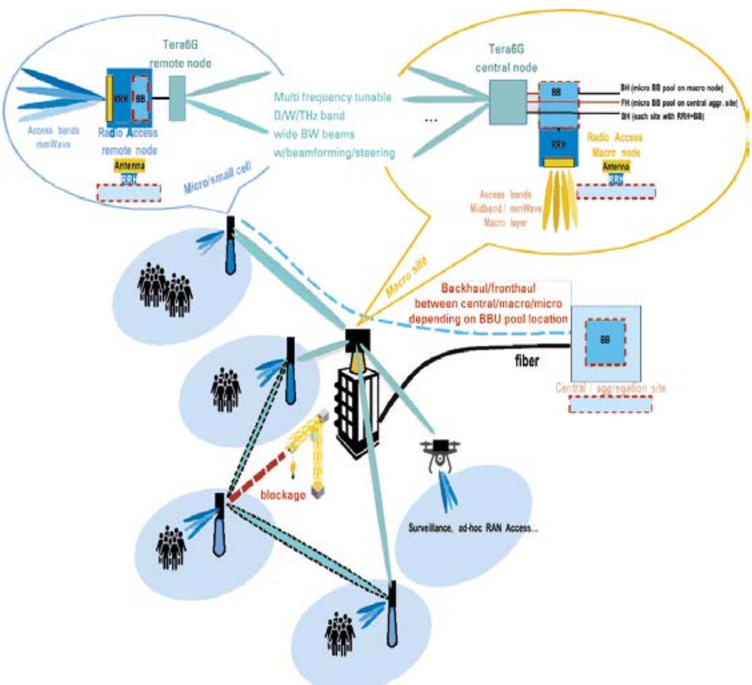
TERA6G

The TERA6G is an enabler of the Fibre-over-the-air concept. The objective is to develop new generation wireless links with Terabit-per-second data throughput capacity using hybrid photonic integration technology advances unlocking disruptive wireless transceivers employing massive MIMO for beyond-5G networks.

KEY CHARACTERISTICS

- **Agility**: Ultra-wide bandwidth (up to 30 GHz per channel, handling any modulation scheme) and continuous frequency tuning of the carrier frequency from 30 GHz to 450 GHz, reaching into the Terahertz (THz) range.
- **Scalability**: Development of scalable MIMO capable of handling a large number of beams with 2-dimensional antenna arrays with beamforming and beam-steering
- **Reconfigurability**: TERA6G modules frequency agility and number of available wireless pencil-beams unlock implementing a variety of functions, from wireless data transmission to channel sounding and radar ranging.

TERA6G wireless transceiver modules create the ability to unlock various potential deployment scenarios for ultra-high throughput transport connectivity to multiple remote ends as radio sites.



OBJECTIVES

A goal enabled by a key set of objectives:

- Scalable **multi-MIMO Blass Matrix Transmitter** module handling up to four beams transmitted from a 2D array with 16 antenna elements in a 4x4 array.
- Scalable **multi-MIMO incoherent multi-band Receiver** module handling four beams with four different LO oscillators received at a 4x4 antenna array.
- **Reconfigurable transceiver modules,** capable of implementing different independent functionalities on each beam.
- **"Fibre over the air" and THz smart management**, integrating THz wireless technologies and systems, and designing Network Functions allowing their management as part of network slicing functionality aiming at dynamic automated management of multi-beam wireless system resources, fully programmable end-to-end orchestrated communication networks.
- Dynamic networks based on **adaptive, energy-efficient, multi-beam nodes**, developing methods and algorithms to maximise system energy efficiency adapting dynamically physical layer resources.

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.

GOALS AND OBJECTIVES

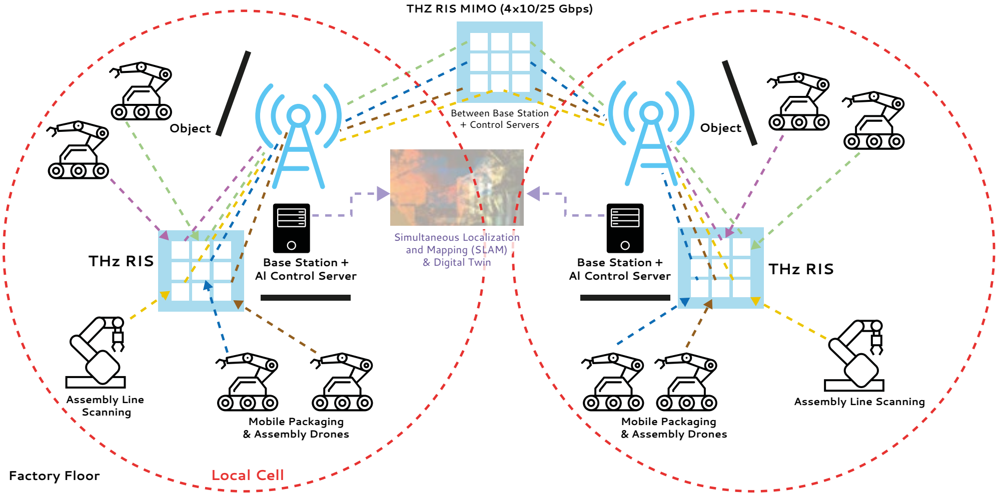
- Novel THz hardware development and testing at 140 GHz and 300 GHz.
- Development of THz-tailored network architectures with realistic models.
- Development of signal processing techniques for THz communications, localisation, and sensing with various forms of reconfigurable metasurfaces.
- Demonstrate THz metasurfaces in an "Industrial Edge" environment and an outdoor Telecom scenario with real-world equipment.
- Actively influence 6G and THz communications standardisation and regulation.

PROJECT DESCRIPTION

This project encompasses materials, components, devices, algorithms, and applications within its scope.

- Materials and electronics components that can support the THz operation frequency with appropriate performance, cost-efficient fabrication and low power consumption will be investigated.

Figure 1: "Industrial Edge" environment



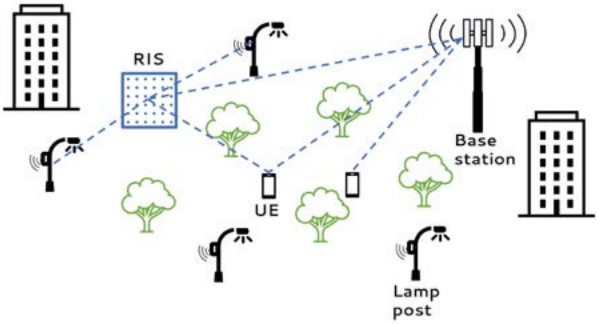


Figure 2: Outdoor telecom scenario

- Two types of THz RIS, reflective-RIS (140 GHz) and transmissive-RIS (300 GHz), will be developed by exploring multiple THz capable reconfigurable micro-electronics technologies (e.g., memristors, BiCMOS and microfluidics).
- Signal processing techniques for THz RIS communications, localisation, and sensing, including channel modelling, channel estimation, beam management, baseband processing and THz-tailored network architectures including Ultra-Massive MIMO techniques will be developed.

Using the developed THz hardware, advanced signal processing algorithms, and cutting-edge network analysis/optimisation methods, the target use cases for TERRAMETA are:

- "Industrial Edge" environment (Figure 1)
- Outdoor Telecom scenario (Figure 2)
- Indoor and outdoor-to-indoor test scenario (Figure 3)

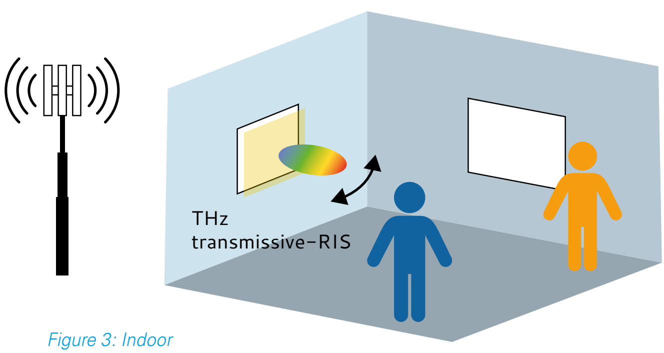


Figure 3: Indoor and outdoor-to-indoor test scenario

Terahertz Reconfigurable Metasurfaces for Ultra-High-Rate Wireless Communications

TERRAMETA

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TIMES

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

CONTEXT AND VISION

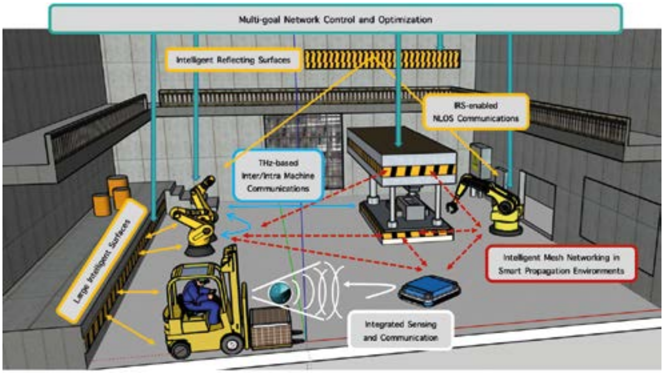
Future wireless networks are envisioned to provide unprecedented performance, not only by targeting *Tbps data rates, but also by inherently supporting a large range of novel applications that combine Tbps data rates with agility, reliability, security and extremely low response time and latency*. Virtual avatar presence, traffic control and autonomous driving, remote health monitoring services, cyber physical systems for intelligent transport, digital twins, and industrial automation are just a few examples of highly challenging anticipated use cases imposing new KPIs for throughput, reliability, E2E latency, and network robustness. **These KPIs raise several new challenges, which are all critical for a practical implementation "beyond 5G"**. Direct human/robot interaction in complex manufacturing processes set very stringent requirements in terms of reliability (up to the order of 10ˆ-9), real-time inter- and intra-machine communication requires communication latencies below 150μs and jitter below 2μs, high precision localisation and imaging accuracy (1 mm in line-of-sight (LoS) and < 10 cm in non-LoS (NLoS), and could involve thousands of nodes generating Gbps of aggregate data (massive capacity). **These KPIs by far exceed the performance of current and near-future wireless technologies, such as the ones defined in the 5G standard**. Moreover, they become even more critical in complex indoor environments, which will interconnect thousands of machines, wearable devices, and fixed terminals exchanging information at extremely high data rates, in a dynamic fashion. Although large bandwidths are available at higher frequencies (mmWave/THz), their exploitation in industrial environments adds an important obstacle to the connection (harsh propagation conditions (e.g., metallic obstacles, unforeseeable attenuation, multipath, and potential interference) that must be continuously compensated for at network level. Innovative technological concepts, components, and architectures are required to lift these barriers. Inspired by this, TIMES will theoretically analyse, design, develop, and showcase in a Proof-of-Concept (PoC) demonstrator, innovative wireless communications concepts addressing networks beyond 5G.

The vision of TIMES is a THz-based smart radio ecosystem working in complex scenarios with a large number of heterogeneous devices, capable of offering similar performance as wired networks in terms of data rate (Tbps), ultra-low-latency, sensing, and reliability, thus beyond the capability of current wireless networks.

INNOVATION PILLARS

To achieve such a long-term vision, TIMES will **combine three (3) innovation pillars**:

- **Pillar 1** Exploiting ultra-wide bandwidth and sensing-friendly characteristics of THz communications.
- **Pillar 2** Deploying intelligent mesh networks in smart propagation environments.
- **Pillar 3** Enabling high-definition integrated sensing and communications (ISAC).



TIMES concept illustration for industrial scenarios and key technological enablers.

In the figure, the TIMES concept for an industrial scenario is illustrated along with its key technical components. The long-term vision of TIMES will enable wireless networks **to replicate the functionality of wired systems** and create the opportunity to make wireless networks an integral part of industrial automation. This in turn will dramatically improve the range of applications supported by wireless networks, thus enabling far *more commercial opportunities for operators and enterprises, driving the growth of diverse and high-performance use cases*. The main application areas and use cases of interest include predictive maintenance, digital twinning, motion control, collaborative robots, and control-to-control, to name but a few. These applications require performance levels that can be reached only by using very large communications bandwidths that are not available to 5G. Such bandwidths are available at radio frequencies significantly higher than the ones currently used by 5G (e.g., THz). However, such high frequencies pose challenging issues when seeking to ensure industrial-level reliability, due to complex propagation environments and the presence of heterogeneous devices with different complexity requirements.

OBJECTIVES AND APPROACH

Such challenges require the design of novel wireless technologies to realise smart radio environments with high spatial-temporal sensing capabilities. The solutions that will be developed in the context of TIMES will represent technological enablers for future wireless networks (6G) and will enable the support of novel use cases. These use cases are even beyond the specific scenarios considered in TIMES. TIMES intends to pursue its targeted breakthrough by focusing on eight (8) *constituent objectives*:

1. Derivation of new THz channel models based on measurements in industrial scenarios
2. Design of novel solutions at the physical (PHY) and medium access control (MAC) layers
3. Design and implementation of THz front ends and antennas
4. Design of a multi-goal mesh-based RAN composed of active nodes and intelligent reflecting surfaces (IRSs)
5. Design and fabrication of IRSs operating at THz frequencies
6. Integration of sensing and communications functionalities
7. Definition of use cases and requirements for future industrial applications
8. Objective 8 Realisation and validation of a PoC in real industrial environments.

TIMES will deliver a pre-commercial prototype, which will be demonstrated in a relevant Industry 4.0 test environment (TRL 4). The successful demonstration at BIREX – one of the *Italian Industry 4.0 Competence Centres* equipped with the latest network technologies – and at AETNA – one of more complete producer of packaging machines for secondary and tertiary packaging with over 10,000 machines installed in several industrial sectors involved in I4.0 Industrial applications – will be the fundamental and key-enabling result of the TIMES impact strategy. Upon successful completion, the TIMES concept will improve sustainability and scalability through the significant reduction of costly and energy-hungry active communication nodes in the radio access network. It will have a disruptive impact on the deployment of THz communication in 6G radio access networks in general, and 6G reconfigurable industrial mesh networks in particular. *This is expected to generate a sustainable impact far beyond the TIMES project.*

THz Industrial MEsh Networks in Small Sensing and Propagation environments

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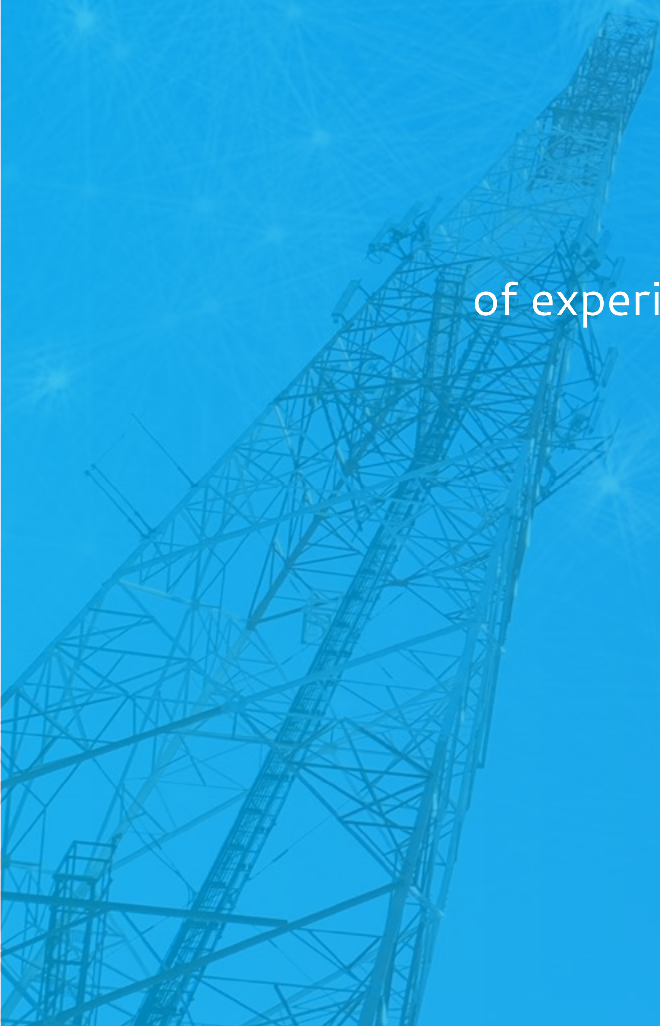
The three projects in stream C aim to develop EU-wide experimentation platforms that can incorporate promising technical 6G enablers for their further validation. Key aspects for the projects are the reusability and ability to evolve of the experimental platforms over the lifetime of the SNS programme.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

Stream C

SNS ENABLERS AND PROOF OF CONCEPT (POCS)

including development of experimental infrastructure(s)



6G-BRICKS

Key participants from four 5G PPP projects (MonB5G, MARSAL, REINDEER, HEXA-X) have joined forces to pursue the federation of their efforts in the 6G-BRICKS experimentation facility, leveraging on a mature set of experimentation tools from the 5GMediaHUB 5G PPP project.

GENERAL DESCRIPTION

6G-BRICKS will be the first open 6G experimentation platform that combines cell-free, Open-Air Interface (OAI) and Reconfigurable Intelligent Surfaces (RIS), while adopting the proven principles of softwarisation, Open Interfaces (O-RAN), and Open-Source software stacks, putting future expansion and evolvability at its core. However, experience from previous 5G PPP efforts has shown that the enormous complexity of the standards and software stacks makes evolvability and scaling-out efforts extremely challenging, requiring interdisciplinary efforts and big investments in integration.

This is where 6G-BRICKS steps in, bringing together specialists in breakthrough 6G technologies, such as cell-free networking, distributed processing and RIS, and adopting principles of modularity and softwarisation to deliver the first truly modular end-to-end 6G experimentation platform in Europe. 6G-BRICKS will structure the various architecture tiers around the concept of "LEGO Bricks", delivering self-contained testbed nodes that can be reused across testbed infrastructures. This significantly lowers the barrier of entry to an end-to-end experimentation platform for specialists to bring their breakthrough technologies for validation and experimentation.

6G-BRICKS will adopt the trend of Software-Defined Infrastructures (SDI) and Software Networks that replace "black boxes" (i.e., physical network functions, such as firewalls) with their softwarised equivalents. This trend will be extended to the Radio Access Network (RAN) via the Open Radio Access Network (O-RAN) initiative, aiming to evolve O-RAN elements in the 6G era via the integration of breakthrough technologies. To this end, 6G-BRICKS will deliver **the first open and programmable O-RAN Radio Unit (RU) for 6G networks**, termed the **OpenRU**, based on an NI USRP-based platform. Moreover, 6G-BRICKS will integrate the RIS concept into the OAI. In addition, 6G-BRICKS will deliver breakthrough experimentation tools, going well beyond the current Testing as a Service (TaaS) capabilities of current initiatives, and allowing experiments also on devices via O-RAN compliant xAPPs. Thus, the 6G-BRICKS experimentation facility aims to serve a dual role, both as a playground for testing advanced vertical applications and for validation testing and showcasing of the clear benefits and capabilities of 6G breakthrough technologies and devices. Moreover, it will deliver and test new architecture principles, with multi-tenancy, disaggregated Operations Support Systems (OSS) and Deep Edge integration at the forefront.

OBJECTIVES

1: To deliver an evolvable 6G experimentation facility that will integrate breakthrough 6G technologies and federate two testbeds under a common set of experimentation tools.

2: To validate and showcase advanced use cases in holographic communication, metaverse and digital twinning, showcasing the benefits of 6G breakthrough technologies and architecture.

3: To support disaggregated and programmable Software-Defined Infrastructures (SDIs), adopting virtualisation, softwarisation and O-RAN compliant interfaces to promote modularity and reusability.

4: To offer a fully decentralised management plane, supporting zero-touch orchestration of computing and communication resources based on **Explainable Artificial Intelligence**.

5: To offer a Compute Continuum abstraction framework supporting a disaggregated wireless X-Haul.

6: To deliver breakthrough technologies towards a 6G RAN via Distributed Cell-free and RIS.

7: To provide a secure and trusted Experimentation Facility for multiple concurrent tenants and experimentation platforms.

8: To maximise the impact created by the project through wide means of dissemination, communication, standardisation and exploitation activities.

USE CASES

Use case 1: The Metaverse as an enable of a Modern Workplace

This Use Case (UC) will demonstrate how network densification via distributed cell-free can make untethered Metaverse UCs a reality, offering an acceptable quality of experience, and the ability of immersive social interactions.

- **PoC 1**: Holoconferencing in a Virtual Meeting room

  This PoC will demonstrate an evolutionary "holoconference" scenario, showcasing ultrahigh-speed with low-latency communication (uHSLLC) that is made possible with distributed cell-free technologies.

- **PoC 2**: Virtual Team Building activities

  This PoC will demonstrate a revolutionary scenario, showcasing ultra-high data density (uHDD) communications and Joint Communication and Sensing enablers.

Use case 2: 6G applications for Industry 4.0

This Use Case will focus on Industry 4.0 applications and demonstrate how 6G enablers can contribute to creating more efficient operators, leveraging autonomous robots, digital twinning and XR.

- **PoC 1**: Autonomous robots in Industry 4.0

  The PoC-1 of this use case will show how 6G will support autonomous robots for industry 4.0. The autonomous robot will move around the factory while having low-latency communication. It will move objects from positions A to B according to the request received from a server.

- **PoC 2**: AR inspection of Industry 4.0 digital twin on site

  PoC 2 will show how 6G support remote Digital Twin visualisation through an Augmented Reality (AR) interface, by superposing SCADA data on the real object. The Proof of Concept (PoC) will exploit Artificial Intelligence (AR) to enable an inspection feature for discovering malfunctioning elements in indoor Oil and Gas systems.

6G BRICKS

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6G-SANDBOX

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

GOALS AND OBJECTIVES

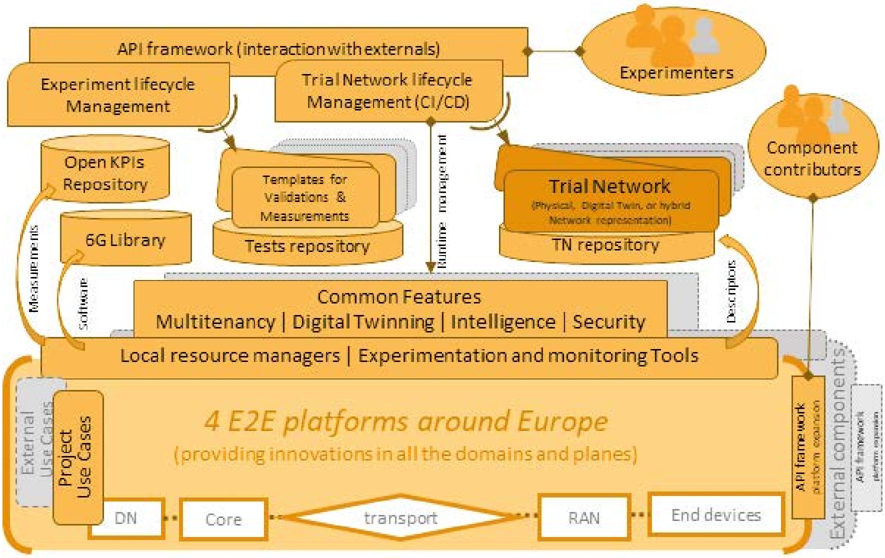
The potential of experimentation facilities has been demonstrated in the context of 5G, by pan-European facilities, such as 5GENESIS, 5G-VINNI, or 5G-EVE. In the beyond-5G era, the key objectives of the European Smart Networks and Services (SNS) research and innovation program are formulated around the development of experimentation infrastructures for validation of 6G technologies and use cases. In this context, the 6G-SANDBOX project will provide an open facility for the validation of new technologies towards 6G as part of the emerging European 6G ecosystem.

The 6G-SANDBOX project addresses the need for an experimentation facility that guarantees Modularity, Openness, Reusability, Innovation, and Sustainability (MORIS). The project introduces the concept of Trial Networks and adopts a standardised API framework for internal and external interaction with the facility. It retains existing approaches for experimentation lifecycle management and provides experimenters with capabilities for Trial Network (TN) lifecycle management. More specifically the project objectives are the following:

- Define and release the architecture and the processes/methodology of an experimentation facility towards 6G.
- Develop and integrate the 6G-SANDBOX end-to-end physical connectivity infrastructure across Europe, which incorporates 6G technologies.
- Develop and integrate the 6G-SANDBOX resource management framework to efficiently deploy trial networks and to control multi-domain virtualised resources – "Infrastructure-as-a-Code".
- Develop and integrate a framework for performing automated experimentation as a service on 6G-SANDBOX trial networks tailored to the 6G KPIs and KVIs.
- Create an ecosystem under the SNS JU umbrella, that will allow the adoption of innovative components from Stream B projects and also enable the hosting of 6G use cases (open calls and Stream D projects).
- Create a tangible socioeconomical impact as well as maximise technological and business potential through targeted communication, dissemination, and standardisation.

PROJECT ACTIVITIES AND MAIN OUTPUTS

Considering the MORIS characteristics in the project, *modularity* is supported through the "infrastructure as a code" approach for creating the experimentation infrastructures that compose the testbed, and through the adoption of standardised APIs and API managers. The *openness* guarantee is introduced at multiple levels, from opening the experimentation results to releasing innovative software developments and integrations to an open reposi-



Conceptual Architecture of 6G-SANDBOX

tory, named the Open 6G Library. To maximise *reusability*, common testing methodologies and test templates are adopted to produce self-defined and easily comparable KPI/KVI results. Based on the concept of Trial Networks, as explained later in this section, the facility is *innovative* by design; however, there are specific innovative aspects at the connectivity, management, and application/use case levels that are presented as project ambitions later in this section. Finally, regarding the *sustainability* factor, the evolution beyond the project lifetime tailored with i) the evolution plans of its build-in components (especially the experimentation toolbox form Keysight and the developments that will be open sourced) and ii) the close commitment to SNS JU program level objectives. The figure above illustrates the 6G-SANDBOX concept.

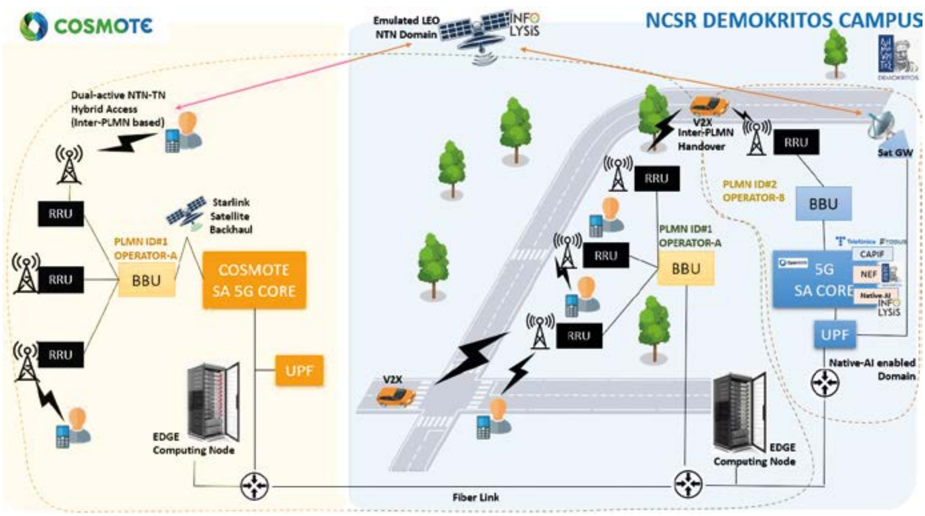
Trial Networks concept

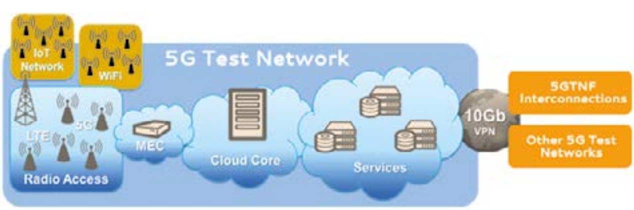
6G-SANDBOX provides the means for the generation of testbeds in the form of *Trial Networks*. A TN is defined as a fully configurable, manageable, and controllable network that combines virtual, physical and emulated resources (i.e., digital twins) and enables experiments for validating 6G technologies 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 will be offered by the project's four experimentation platforms. By definition, a Trial Network is an abstraction of an actual testbed, and is able to be reserved through multi-tenancy solutions by experimenters that have secure access to the TN. The experimenters are provided with both experiment and network lifecycle management tools. The 6G-SANDBOX project will provide a description language and APIs to define the TNs. Based on the Infrastructure-as-a-code model the project will implement a fully automated multi-tenant infrastructure to expand 6G experimentation to multiple experimenters with different needs in terms of technologies, use cases, and test duration.

In-project target technologies

6G-SANDBOX will research several technologies that will subsequently be subjected to experimentation and the validation of uses cases and KPIs/KVIs. The technologies include:

- 28 GHz Reflective Intelligent Surfaces (RIS),
- THz communication with measurement facilities up to 170 GHz,
- Innovative vRAN disaggregation playground,





Illustrations of the platforms

- Edge-cloud continuum-oriented deployments,
- Integration of Non-Terrestrial Networks (NTN),
- Network programmability (realised through P4 language on switches) towards deterministic networks,
- AI/ML and Security as a Service,
- Advance experimentation toolbox, including the availability of the Keysight portfolio that supports Network Twining, and Monitoring capabilities,
- Extended Reality enablers (XR),
- Haptic communications enablers.

E2E Experimentation platforms

The 6G-SANDBOX testbed includes four end-to-end platforms that are composed of: i) components from mature experimentation testbeds around Europe; ii) components from commercial public networks; iii) emulation/twinning components; and iv) any additional components that will be provided by external sources.

- The Malaga Platform covers areas in the University of Malaga Campus (UMA), the cities of Málaga and Torremolinos, Málaga Tech Park, Malaga Port and the La Mayora research farm. The spectrum used combines experimental licenses (26-28GHz) along with commercial spectrum shared by Telefónica (2.8GHz and 3.5GHz). During trials, the 6G-SANDBOX platform will be enhanced with the Keysight's portfolio for testing and measurement, disaggregated RAN, mmwave RIS, access to Satellite, deterministic networking using P4 language, and support for extended reality and haptic communications.

- The Athens platform is a large-scale experimental facility created by two 5G Standalone (SA) systems in Attika region in Greece. The first 5G SA System is spread across the COSMOTE and NCSR Demokritos campus, supplemented by two edge nodes for performance optimisation, while the latter 5G SA system is located only in the National Centre for Scientific Research (NCSR) Demokritos campus, providing an open 5G core implementation with exposure capabilities and native-AI enablers. The scope of the 6G-SANDBOX platform includes support for experiments related to inter- Public Land Mobile Network (PLMN) connectivity, as well as dual-connectivity between terrestrial and satellite access link, experiments related to V2X experiments, and the realisation of Common API Framework CAPIF/Network Exposure Function (NEF) APIs, and native-AI driven use-cases.

- The Berlin platform is an evolution of the FOKUS 5G-Playground as enhanced within the 5GENESIS project. The platform features a multi-vendor 5G campus network test environment as a key driver for 5&6G innovations. Using the 3700 – 3800 MHz spectrum. It provides indoor and outdoor coverage at the FOKUS laboratories and parking deck, as well as at a remotely integrated factory shopfloor. For 6G-SANDBOX, the Berlin platform will be enhanced with Open RAN disaggregated radio access technologies, an evolution of the FOKUS Open5GCore towards a 6G, and the Keysight software-based testing portfolio.

- The Oulu platform is part of the 5G Test Network Finland (5GTNF) program. It includes thirty LTE small cells operating at different frequencies (700 MHz, 2.1, 2.3, 2.6, and 3.5 GHz), two macro cells operating at 2.3 GHz, and two 5G New Radio (NR) base stations operating at 3.5 GHz. The network is currently being enhanced by 1) mmWave 5G NR base stations (24-28 GHz) with Remote Radio Head (RRH) based cloud RAN 5G NR devices and 2) a wireless sensor network with an estimated 2,000 different types of sensors with wireless connectivity via NB-IoT, Long Term Evolution for Machines (LTE-M), and Long-Range Radio (LoRa)

Large-scale showcasing event

For an extensive and full-range utilisation of the 6G-SANDBOX testbed, when services and enablers specific to use cases are involved, the 6G-SANDBOX project will host a large showcasing event for a use case that combines telepresence technology from Nokia XR Lab with haptics in a theatre where the experience provided from the stage to the live audience is also offered to a remote audience connected through XR devices. The event will be a live demonstration of the capabilities of XR technology, including remote presence and haptics, through a live entertainment show. This is an innovative and yet unstudied approach to entertainment, since the aim is not only to provide the audience (local and remote) with multimedia content from the theatre (passive receivers of the show), but also to provide them with a real-time sense of touch (Figure).

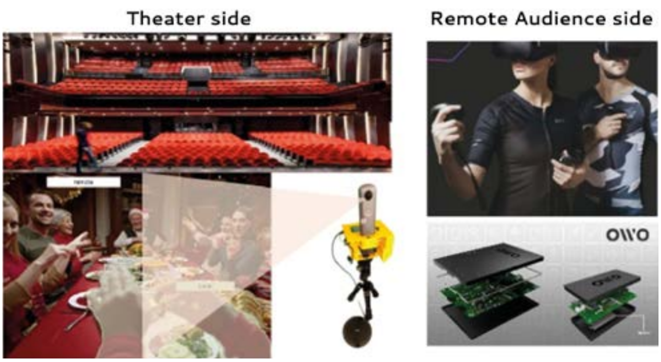


Illustration of the expected large-scale showcasing event

Cascade funding with open calls

The 6G-SANDBOX facility will provide both experimental and TN management services to externals using open calls. Additional open calls will also serve to integrate new technologies and sites into the facility as a whole.

SAND BOX

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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.

PROJECT OVERVIEW

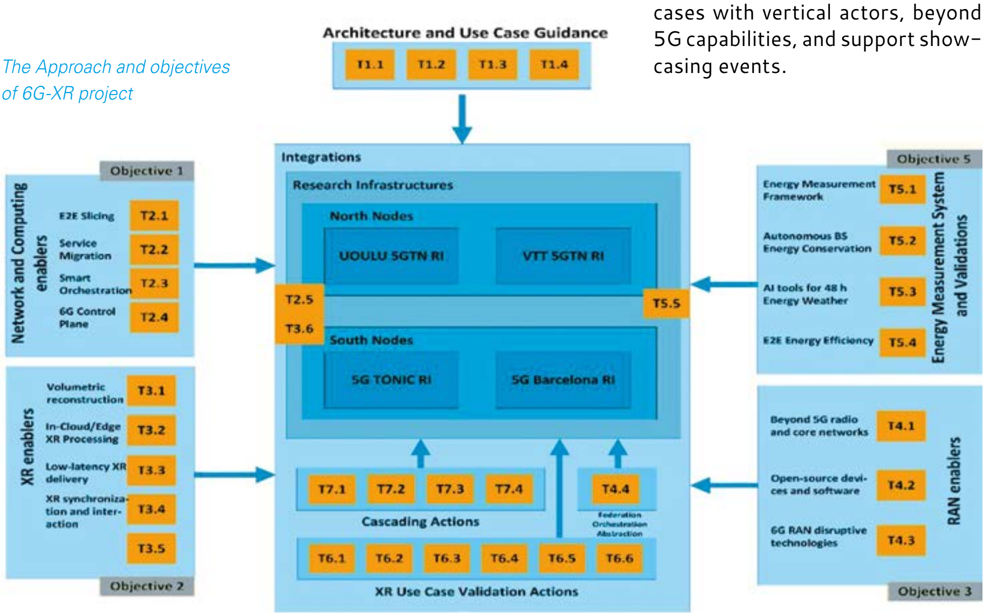
The project will develop an experimental multisite Research Infrastructure (RI) to provide a validation platform for various 6G-use cases by developing enablers for networking and computing, radio access technologies beyond 5G, enablers for XR services with in-build federation, trial management, abstraction tools as well as energy measurement frameworks.

OBJECTIVES AND APPROACH

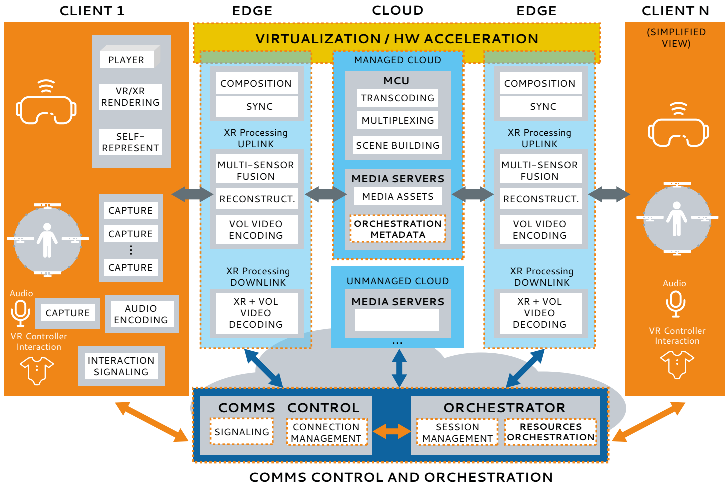
6G-XR is building its objectives, ambition, and methodology on top of four state-of-the-art research (SoTA) RIs, namely 5GTN UOULU, 5GTN VTT, 5TONIC, and 5GBarcelona. These well-developed RIs represent the most evolved open environments for communications research in Europe. The 6G-XR project will enhance the capabilities of these research infrastructures to provide beyond-state-of-the-art (BSoTA) capabilities towards 6G.

- **Build a multisite Research Infrastructure (RI)** that can provide a validation platform for multitude of foreseen (extreme) 6G use cases by developing enablers for networking and computing, radio access technologies beyond 5G, enablers for XR services with in-build federation, trial management, abstraction tools as well as energy measurement framework.
- **Validate multi-access edge computing scenarios** and their integration into a complete cloud continuum, support innovative use cases with vertical actors, beyond 5G capabilities, and support showcasing events.

The Approach and objectives of 6G-XR project



Envisioned evolution of HoloMIT in 6G-XR (newly envisioned components and components to be significantly evolved represented as boxes with red dashed lines)

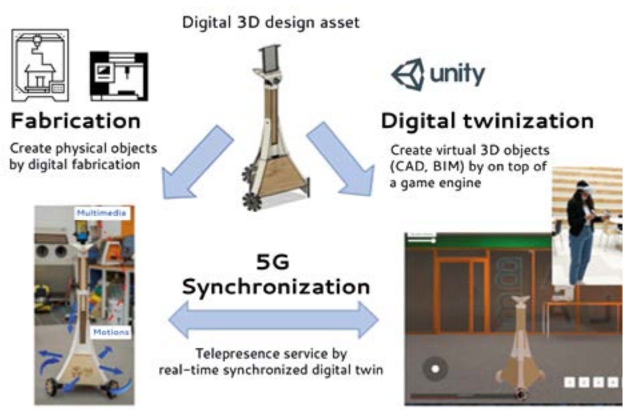


- **Demonstrate and validate performance of innovative 6G applications** with a focus on demanding immersive applications such as holographics, digital twins and XR/VR.

Initial Use Case 1: Real-time holographic communications – Key challenges are addressed to successfully deliver real-time multi-party holographic communication services at scale and over heterogeneous environments. 6G-XR will go beyond the state-of-the-art in this field with the goal of increasing the visual resolution of holograms, as well as the performance, scalability, interoperability and efficiency of such services. The envisioned next-generation holographic services will adopt many new features fully compliant with 6G architectural and communication paradigms, and it will be expected to contribute to the maturity, robustness, and wide adoption of high-quality, scalable, and affordable holographic communication services.

Initial Use Case 2: Collaborative 3D Digital Twin Environments – The scale of blending digital and physical in VR is still narrow, restricted to simple application areas, and the full potential of XR has not yet been achieved. There are, however, some state-of-the-art systems that aim to extend the virtual across the XR spectrum, in addition to increasing the intermeshing of the digital and physical. Interestingly, collaborative 3D digital twin environments take advantage of existing 3D material for building a mirror world like VR and enhance this environment with remote operation capabilities for robotics and computer mediated collaboration e.g., using private 5G advanced and emerging 6G devices and networks.

Digital Twin like environment, a cyber-physical system that leverages 5G combining teleoperation of robots via virtual environments and IoT



6G eXperimental Research to enable next-generation XR services

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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.

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

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.

CONTEXT AND OBJECTIVES

It is the convergence of the cyber and physical worlds that could be achieved with the very low latency and high data capacity of beyond 5G and 6G networks, thus enabling the creation of services such as **digital twins** and **internet of senses/haptic applications**. This is where **FIDAL comes in, targeting the augmentation of human capabilities**, allowing vertical industry players to **perform advanced technological and business validation in large-scale field trials** of highly innovative and advanced applications that exploit beyond 5G technologies. This, in turn, will provide extensive and valuable feedback to the broader industry, academia, innovators and stakeholder community before the broad commercial deployments of **Beyond 5G** networks throughout Europe.

The overall objective of FIDAL is to validate Beyond 5G technologies in a user context to maximise downstream take up, thus laying the groundwork for 6G. Key FIDAL objectives are:

- To extend and deliver (i) an advanced future-proof Evolved 5G facility, anticipating evolution into next SNS phase, (ii) open and accessible to support 3rd party vertical experiments, (iii) a test environment for rapid prototyping and large-scale validation of advanced, forward-looking applications.
- To leverage, develop and extend innovative, next-generation and business-relevant services, and applications (including digital twins and internet of senses) in the Media and Public Protection and Disaster Relief (PPDR) domains, showcasing the clear benefit of 5G evolution and preparing the ground for the introduction of 6G.
- To implement a unified framework for automatically driving end-to-end network (device, edge, core, cloud continuum, etc.) and service management decisions via a zero-touch engine, leveraging Distributed Deep Reinforcement learning-based control algorithms.
- To contribute a repository of Network Applications, AI-driven tools, open-source applications, open training sets, and data models, to be leveraged by FIDAL vertical applications, 3rd party projects from Open Calls and future SNS projects
- To implement an end-to-end Security Framework for the operations including Artificial Intelligence as a Service (AIaaS).
- Exploitation, contribution to standards, outreach and clustering activities, dissemination, communication, and Open Calls.

APPROACH

The FIDAL project will be executed over three contiguous and sequentially aligned phases of development. This will allow the project to address the requirement analysis and methodologies and prepare in detail the vertical use case scenarios and associated target KPIs and KVIs towards the large-scale trials. Our approach will: i) design the detailed FIDAL architecture, develop processes and interfaces to interwork and obtain data from the facilities at orchestration, management and infrastructure levels, ii) design, and develop the **innovation streams and technological enablers**, i.e. the **FIDAL experimentation framework**, such as the AI as a Service, the Zero-Touch Automaton and related APIs, and iii) integrating these enablers to the testbeds and validating the use cases of the vertical industries in a series of "preparatory" lab trials and large-scale trials. Cascaded calls – aka Open Calls – processes, contracting and assistance are scheduled while respective onboarding to the test facilities is performed. Business analysis, Intellectual Property (IP) management and international networking, standardisation, KVI and societal impact, and dissemination, communication, and community-building activities are performed. With the above well-defined and pragmatic approach FIDAL will cover **the technological, societal, and business perspectives in each use case**.

Moreover, FIDAL has the ambition to demonstrate beyond 5G connectivity and associated management and zero-touch management within the set of KPI requirements that arise from specific vertical domains. In particular, from one hand the Media and Entertainment use cases represent the **Enhanced Media** and on the other hand the **PPDR** use cases represent the envisaged **Advanced Safety**. This will be achieved through the three defined phases.

Phase 1: the requirements, specification, and adaptation of the experimentation framework with the participation of the vendors, vertical owners and key stakeholders.

Phase 2: the setup of the labs and large-scale infrastructures in close collaboration with key vendors. Furthermore, a corresponding parallel evaluation and/or re-design/upgrade improvements to ensure a smooth and aligned evolution of the lab validations through the defined realistic FIDAL use cases and initial Open Calls use cases.

Phase 3: 2 cycles of iterative large-scale trials and third-party SME trials through open calls aiming at validating extreme beyond 5G vertical KPIs and KVIs, while contributing to FIDAL repositories of Network Apps, creating open-source applications, deriving new requirements from the verticals and presenting lessons learnt.

FIDAL

USE CASES

FIDAL will deploy three testbeds and three large scale infrastructures in Greece, Norway and Spain. All facilities will be upgraded to meet 5G Evolved requirements.

The testing and validation methodology in FIDAL follows the effective well-established DevOps continuous Testing methodology that combines software development (Dev) with automated information technology operations (Ops) participating together in the entire service lifecycle, from design through the development process to production and monitoring. FIDAL will rely on the Experimentation Tools layer, that delivers a fully managed DevOps driven Testing as a Service (TaaS) pipeline for the definition and implementation of test cases. Test cases define a test (or experimentation pipeline) targeting a specific KPI measurement via industry-standard DevOps processes and tooling (e.g., Jenkins Continuous Integration (CI)/Continuous Delivery (CD) server and Robot framework). During the project, each use case will deploy a layered testing practice to drive development, involving significant industry representative tests, verifications, and validations. The FIDAL experimentation framework will be deployed in all trial sites enabling consistent update and validation across all infrastructures.

Three types of trial will be conducted:

a) **Lab validation tests**: Lab validation of all UCs will be performed in three testbeds. Advanced 5G functionalities, such as 5G New Radio (5G NR) and extreme coverage in the testbeds will be performed. FIDAL will introduce a logical separation between experimentation facility development taking place within the testbeds themselves for the addition of new or updated Network Apps and their associated VNFs.

b) **Large-scale trials**: FIDAL will validate 5G evolution enabling technologies' features and capabilities in significant portions of stadia, city centres, etc. Please refer to the UCs section for the detailed description. Such large-scale trials will be supported by 5G evolution infrastructure as well as the FIDAL framework that will be deployed in collaboration with the technology vendors thus being able to validate the technology in near commercial conditions.

c) **Open call trials**: A consistent methodology will be deployed to onboard and perform trials with the selected open calls contractors. FIDAL experimentation framework supports open interfaces and modules to accommodate both in project and open calls UCs.

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VERTICALS ADDRESSED

Media and Entertainment

PPDR

IMAGINE-B5G

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

PROJECT OVERVIEW AND GOALS

The project has already shortlisted seven verticals and corresponding stakeholders related to **PPDR, media, education, smart agriculture and forestry, eHealth, transportation and logistics, and Industry 4.0**, which will experience and test their use cases on the IMAGINE-B5G platform.

IMAGINE-B5G brings together four advanced 5G experimental facilities, located in Norway, Spain, Portugal and France. These facilities will capitalise on the previous 5G PPP infrastructure and vertical trial projects by drawing analogies and reusing the platform components as much as possible.

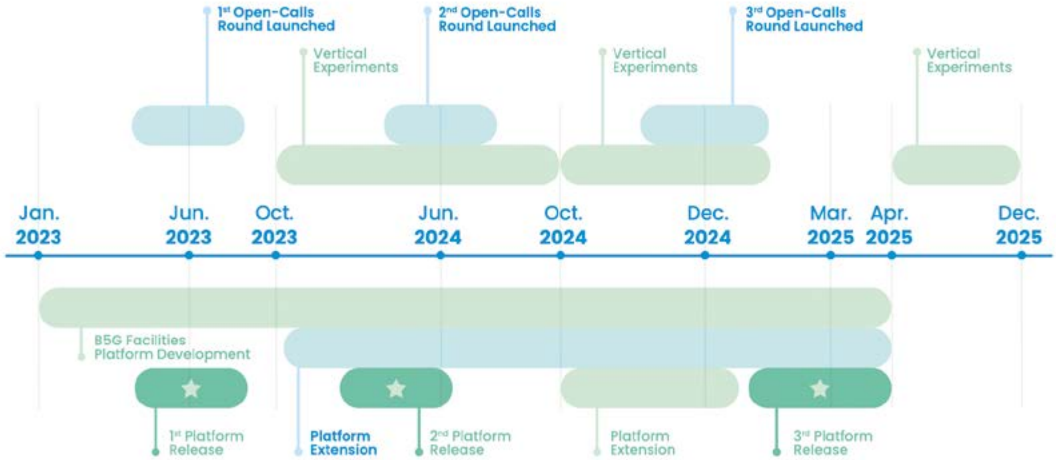
The goal is to have these facilities support a set of Beyond 5G applications enabled by the integration of advanced 5G technologies, including 5G positioning, zero-touch solutions, network capability exposure, edge computing, advanced IoT solutions, network data analytics, mmWave frequencies, advanced combinations of private and public networks, and open architectures.

The functionalities built into the B5G platform will enable IMAGINE-B5G vertical applications to be **demonstrated at scale**. Those include immersive holographic, haptic and telepresence communications for enhanced human interaction enabled by the integration of **advanced 5G technologies**, such as zero-touch solutions, network capability exposure, edge computing, advanced IoT solutions, network data analytics, millimetre wave frequencies, advanced combinations of private and public networks, and open architectures. They will allow the project to **identify and validate new 5G KPIs** (Key Performance Indicators) and KVIs (Key Value Indicators) across three fundamental domains – **societal, application, and management**.

The IMAGINE-B5G E2E facility will fuel testing and experimentation of core technologies and architectures, facilitating innovative services and businesses, and become a key enabler for future B5G vertical services and applications.

The IMAGINE-B5G project expects to have a huge impact worldwide among vertical industries by:

- equipping European verticals with facilities that will increase their capacity for innovation, digitalisation, and driving European economies;
- deploying concurrent trials which will serve to prove that operators are able to deliver on the stringent technical requirements of new B5G/6G applications;
- using its pilots with verticals and cross-vertical industries to demonstrate Europe's B5G evolution and leadership in advanced 5G technologies and architectures;
- preparing and maximising widespread acceptance and adoption by end-users of B5G solutions in European economies.



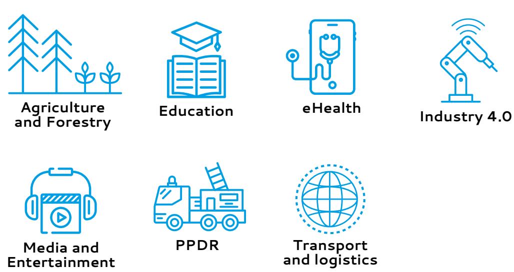
Project timeline

OPEN CALLS

Additionally, through three open calls over its lifetime, IMAGINE-B5G will on-board third parties (e.g., SMEs, industry, and researchers) to collaborate in vertical experiments and platform extensions through pilots and trials in the IMAGINE-B5G platform facilities. Collectively, the facilities will support a set of B5G applications (including immersive holographic, haptic and telepresence communications for enhanced human interaction) enabled by the integration of advanced 5G technologies, including 5G positioning, zero-touch solutions, network capability exposure, edge computing, advanced IoT solutions, network data analytics, mmWave frequencies, advanced combinations of private and public networks, and open architectures. The infrastructure of the facilities in Norway, Spain and Portugal will be based on industry equipment and components. The French facility will bring a completely open-source E2E 5G implementation. The different facilities of IMAGINE-B5G will have a diverse set of advanced 5G technologies.

IMAGINE-B5G allocated a budget of 4.4 MEUR for its open calls, and the participation of SMEs, scaleups and start-ups in the open calls will be strongly supported by targeting a minimum budget of 2.2 MEUR allocated for them (50% of the total open-call budget).

VERTICALS ADDRESSED



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

Imagine B5G

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TARGET-X

The TARGET-X project was launched to accelerate the digital transformation of four key verticals: energy, construction, automotive, and manufacturing.

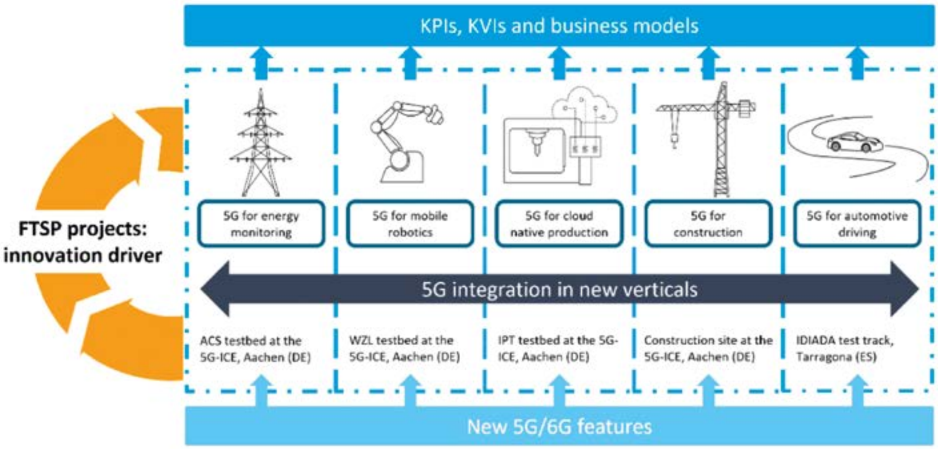
CONTEXT AND OVERVIEW

The fifth generation of wireless technology, also known as 5G, has been a significant development and currently being rolled out globally. With its potential for ubiquitous connectivity, 5G's capabilities have been tested in various industrial sectors, such as manufacturing, showcasing its impressive potential. Moving beyond 5G towards 6G will bring even more advanced features, improved performance, and functional benefits to several industrial sectors.

The TARGET-X project was launched to accelerate the digital transformation of four key verticals: energy, construction, automotive, and manufacturing. This will be achieved through large-scale trials in multiple testbeds, which will demonstrate, validate, and evaluate the potential of 5G/6G in real environments. This approach will enable testing and evaluating the most advanced 5G/6G technologies, such as real-time communication, localisation, self-description, digital twinning, and sensor-network data fusion.

To assess the effectiveness of the developed technologies, the project's evaluation will focus on Key Performance Indicators (KPIs) and Key Value Indicators (KVIs), such as sustainability, safety, security, and privacy. This will open the way to establishing new business models and a methodological assessment framework for economic and societal evaluation. The development of these solutions will be supported and guided by the TARGET-X consortium, which includes SMEs, Information Technology (IT), and Operational Technology (OT) partners, and up to 100 Financial Support to Third Parties (FSTP) entities. This strong consortium brings together SMEs and innovation drivers to create a collaborative environment.

Overall concept of TARGET-X



USE CASES

TARGET-X will establish a selection of use cases for all verticals in the existing 5G testbeds at the 5G-Industry Campus Europe and IDIADA to achieve its goals. New 5G/6G features will be developed, integrated into the testbeds, and validated in evolved use cases. The FSTP projects will deliver new use cases and technical contributions, which will strengthen the 5G/6G ecosystem by involving a large number of participants. The project results will be discussed with 6G-SNS projects and used for standardisation in different verticals.

In conclusion, the TARGET-X project is an ambitious initiative to bring about significant advancements in wireless communication technology. Through large-scale trials and evaluations, this project aims to demonstrate the potential of 5G/6G in rea-world environments and develop new business models that can benefit various industrial sectors. With its focus on KPIs and KVIs, this project is expected to bring innovative solutions to improve sustainability, safety, security, and privacy while strengthening the 5G/6G ecosystem.

VERTICALS ADDRESSED

Automotive

Construction

Energy

Industry 4.0

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

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TRIALSNET

The TrialsNet project will deploy full large-scale trials to implement a heterogenous and comprehensive set of innovative 6G applications based on various technologies such as cobots, metaverse, massive twinning, Internet of Senses.

PROJECT OVERVIEW

The project will cover three key areas of European urban ecosystems, namely:

i) Infrastructure, Transportation, Security and Safety,

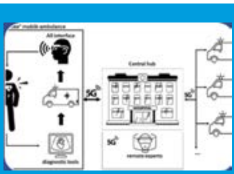
ii) eHealth and Emergency,

iii) Culture, Tourism and Entertainment.

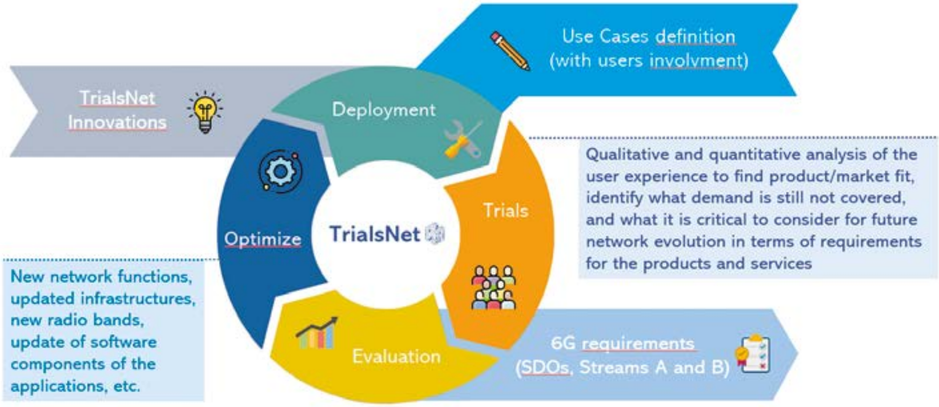
USE CASES

In the three abovementioned areas, TrialsNet will design and implement **13 use cases** according to the following mapping.

The use cases will be developed over wide coverage areas with the involvement of extended sets of real users in **four geographical clusters**, in Italy, Spain, Greece and Romania. The use cases will be cross-cutting, each single use case will be potentially implementable over different clusters, thus allowing for a holistic evaluation of the network **KPIs** and **KVIs** of the 6G applications in different contexts and scenarios, including different network deployments and solutions.



Infrastructure, Transportation, Security & Safety	eHealth & Emergency	Culture, Tourism & Entertainment
UC1: Smart Crowd Monitoring UC2: Proactive Public Infrastructure Assets Management UC3: Autonomous APRON UC4: Smart Traffic Management UC5: Control Room in Metaverse	UC6: MCI and Emergency Rescue in Populated Area UC7: Remote Proctoring UC8: Smart Ambulance UC9: Adaptive Control of Hannes Prosthetic Device	UC10: Immersive Fan Engagement UC11: Service Robots for Enhanced Passengers' Experience UC12: City Parks in Metaverse UC13: Extended XR Museums Experience



APPROACH

To achieve this, TrialsNet will design and deploy **platforms and network solutions with advanced functionalities** based on dynamic slicing management (E2E orchestration, NFV, MEC and AI/ML methods) to be trialled on **different network architectures** (3GPP and O-RAN). Design objectives of sustainability and affordability of the deployed systems will be also treated with the highest priority.

Finally, TrialsNet will also develop appropriate technical and **socio-economical assessment frameworks** mapping quantitative and qualitative measures and visualising the dynamics of the use cases for societal acceptance. Proper **KVIs** will be monitored, tested and refined to provide a socio-technical vision for early adoption of 6G solutions.

Based on the above activities and with a view to making the urban environment more liveable, through improvements in the different areas, TrialsNet will then pursue the objectives of:

i) understanding where **current networks fall short of ensuring the performance** needed by the use cases, and

ii) **establishing the new requirements** for next generation mobile networks.

To this end, TrialsNet has defined the methodology depicted below, creating value from the trialling of the specific UCs, evaluating where the supporting network infrastructure can be improved, optimising thanks to specific innovations developed in the project, and defining new requirements when needed.

During the project's lifetime, TrialsNet will launch an **Open Call** that will bring new key stakeholders onboard to implement additional, diversified and heterogeneous vertical use cases, supporting the deployment of new trials over the project platforms and network solutions, and to extend its infrastructures dimension in other parts of Europe. The Open Call will then maximise the impact of the TrialsNet's activities and accelerate the adoption of its solutions by demonstrating their flexibility, user acceptance and technology transfer.

The launch of the Open Call is planned for November 2023. New partners are expected to be onboarded into TrialsNet's activities in early June 2024.

Trials Supported By Smart Networks Beyond 5G

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

COMMUNICATION SUPPORT ACTIONS (CSAS)

SNS ICE

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

VISION

It will be the instrument to **present, leverage, and position SNS JU activities** and achievements in major European and global fora. As such, the project will become the *de-facto* ambassador of the SNS JU programme and its R&I projects by establishing dialogues with:

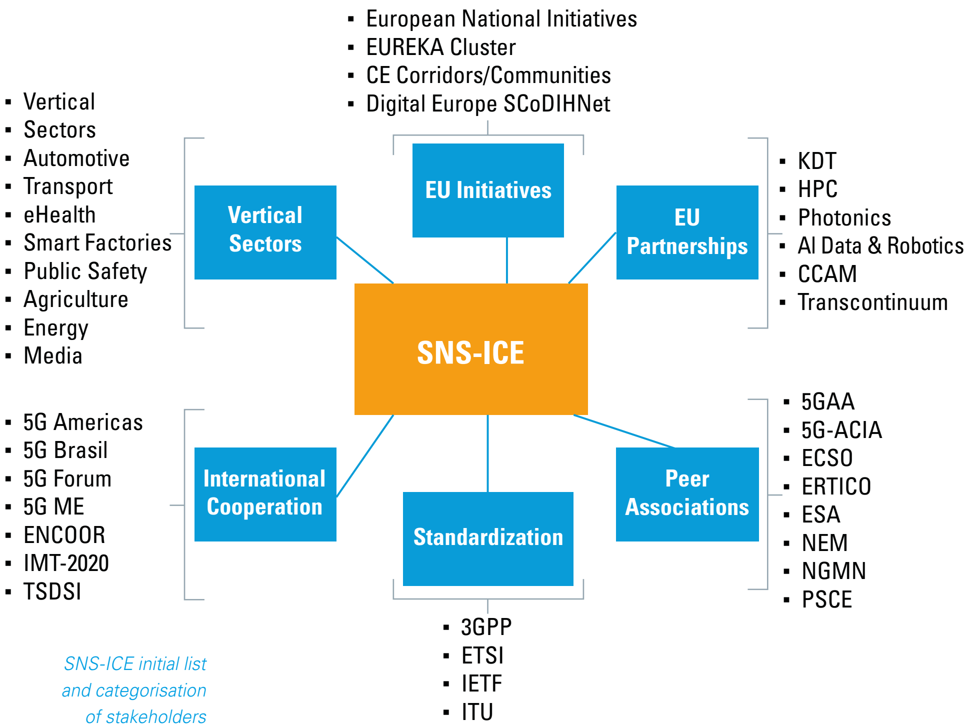
- peer Horizon Europe Partnerships,
- national initiatives,
- research and development clusters,
- key vertical industries,
- international associations;

KEY OBJECTIVES

The above vision of SNS ICE will be achieved through the realisation of three specific key objectives, namely:

- Establish relationships and create a framework for dialogues and cooperation,
- Promote SNS activities and achievements, identify potential target areas and provide feedback from global initiatives to the SNS JU,
- Target consensus building and create a roadmap for future steps.

This ambassadorial role of the SNS ICE project will be a key to meeting the abovementioned objectives and securing European ICT stakeholders' competitiveness on the global stage. It is imperative that SNS JU projects be constantly aware of global standardisation priorities, trends, and activities. SNS ICE objectives directly address the creation of a collaboration ecosystem (working closely with SNS OPS) and the establishment of fruitful dialogue amongst stakeholders (i.e., SNS research and innovation projects) at the European and international levels, as well as supporting their cooperation with vertical industries and entities outside of the SNS JU. The SNS ICE will also play a key role in supporting the SNS presence in future Global 6G Events. The initial planned list of relevant stakeholders for SNS ICE is presented in the figure.



SNS-ICE initial list and categorisation of stakeholders

APPROACH

SNS ICE plans to achieve the objectives listed above by working towards a diverse portfolio of outcomes, including delivery of global 6G R&I trend reports and alignment analysis with the SNS 6G roadmap, evaluation of the acceptance and impact analysis of SNS Phase 1 results, evaluation of 6G collaboration in Europe and worldwide, trend analysis in vertical sectors, dissemination and promotion of SNS exploitable results and more. SNS ICE will also target the organisation of multiple physical and virtual 6G oriented events targeting stakeholders on a European and global level and even dedicated vertical events SNS OPS.

Smart Networks and Services International and European Cooperation Ecosystem

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January 2023–March 2025

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SNS OPS

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

VISION AND KEY OBJECTIVES

The planned work is to facilitate the activities of the European SNS Initiative, as outlined in the SNS contractual partnership. This includes:

- Support for the Smart Networks Services (SNS) institutionalised European partnership and the related programmatic organisation through cross SNS projects coordination.
- Organisation of the SNS as a coherent programme with clear links to the 6G Infrastructure Association and the EC via the partnership board and the JU Office and their strategic policies.
- Maximised output and exploitation of SNS project results in key domains (e.g., standardisation, spectrum) through managed cooperation between projects on horizontal issues.
- Inter JU coordination and joint actions.

APPROACH

The SNS OPS project will also orchestrate and organise strategic activities to capture and promote the European view on 6G, the achievements of the 6G SNS and will start the process of monitoring the development and impact of these results on the evolution of 6G in Europe over the period of life of the 6G SNS initiative.

At a strategic level, there is a close relation between the planned activities of the SNS OPS project, in terms of the expected outcomes, and the ambitions of the SNS JU.

The size and scale of the SNS JU will mean that the programme involves many participants, hence a need to involve these players – through the projects and the 6G-IA membership – in the ongoing SNS assessments of the programme, its progress, future directions and how to steadily improve programme activities to create more value and impact. To achieve this, the SNS OPS project will consolidate and present the value and relevance of SNS activities to a wide community of stakeholders on an ongoing basis throughout the life of the project. The SNS OPS project will facilitate the following outcomes using the skills and experience of the SNS OPS project team.

SNS OPS will also look to the future and consider what additional actions are necessary to maintain European momentum and leadership in 6G and facilitate the 6G take-up in Europe's vertical sectors.

During the life of the SNS OPS project, the SNS JU will be launching and expanding its first phase activities and preparing for subsequent phases.

Supporting the SNS JU Operations

Coordinated by
Uwe Herzog (Eurescom)

January 2023–March 2025

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

ACRONYMS AND ABBREVIATIONS

5G CN	5G Core Network
5G NR	5G New Radio
5G PPP	5G Public Private Partnership
5G SA	5G Standalone
5GTNF	5G Test Network Finland
5GTNF	5G Test Network Finland
5G	5th Generation Wireless Systems
6G-IA	6G Smart Networks and Services Industry Association
6G	6th Generation Wireless Systems
AP	Access Point
ADAS	Advanced Driver-Assisted Systems
AI4Edge	AI for Edge
AICP	AI-driven Multi-stakeholder Inter-domain Control-Plane
AC	Anonymous Credential
ABS	Anti-lock Braking System
API	Application programming interface
AI	Artificial intelligence
AIaaS	Artificial Intelligence as a Service
ADL	Asynchronous Distributed Learning
AR	Augmented Reality
BS	Base Station
BBU	BaseBand Unit
B5G	Beyond 5G
B-RAN	Blockchain RAN
CapEx	Capital Expenditure
CPU	Central Processing Unit
CU	Centralised Unit
C-RAN	Cloud Radio-Access Network
CAPIF	Common API Framework
CPRI	Common Public Radio Interface
CSA	Communication and Support Action
CSAs	Communication Support Actions
CD	Continuous Delivery
CI	Continuous Integration
CoMP	Coordinated Multipoint
xApps	Cross Applications
CTI	Cyber Threat Intelligence
CPS	Cyber-Physical System
DPU	Data Processing Unit
DSA	Decarbonisation Service Agreement
DID	Decentralised IDentifier
DID	Decentralised IDentifiers
DaaS	Desktop as-a-Service
DetNet	Deterministic Networking
Dev	Development
D2D	Device-to-Device
DPD	Digital Predistortion
DSP	Digital Signal Processing
DAC	Digital to Analog Converter
DT	Digital Twin
D/O	Digital-to-Optical
DDoS	Distributed Denial of Service
DLT	Distributed Ledger Technology
DU	Distributed Unit
EDoS	Economical Denial of Sustain-ability
EAS	Edge Application Service
Edge4AI	Edge for AI
E2E	End-To-end
eMBB	enhanced Mobile Broadband
CORENect	European Core Technologies for future connectivity systems and components
ETSI	European Telecommunications Standards Institute
EU	European Union
XAI	Explainable AI
XR	Extended Reality
FL	Federated Learning
FPGA	Field Programmable Gate Arrays
FSTP	Financial Support to Third Parties
FLC	Foundation's Field Level Com-munication
FOKUS	Fraunhofer Institute for Open Communication Systems
FHE	Fully Homomorphic Encryption
GDPR	General Data Protection Regulation
GEO	Geosynchronous Earth Orbit
Gbyte/s	Gigabyte Per second
GHz	Gigahertz
GPU	Graphics Processing Unit
GHG	Greenhouse Gas
HAPS	High Altitude Platform Station
HPC	High Performance Computing
IIoT	Industrial Internet of Things
ICT	Information and Communication Technologies
IT	Information Technology
I/O	Input/Output
ISAC	Integrated Sensing and Com-munication
IP	Intellectual Property
IRS	Intelligent Reflecting Surfaces
ITS	Intelligent Transportation Systems
NIC	Interface Card
IETF	Internet Engineering Task Force
IoT	Internet of Things
JCAS	Joint Communications And Sensing
J	Joules
KPI	Key Performance Indicator
KVI	Key Value-based indicator
KCL	King's College London
LRT	Light Rail Transit
LoS	Line-of-Sight
LoRa	Long Range Radio
LTE-M	Long Term Evolution for Machines
LEO	Low Geostationary Earth Orbit
ML	Machine Learning
M&O	Management and Orchestration
MANO	Management and Orchestration
mMTC	massive Machine-Type Com-munication
mMIMO	Massive MIMO
MAC	Medium Access Control
mmWave	millimetre Wave
ms	Millisecond
MORIS	Mobile Robot Operating System for Industry 4.0 Scenarios
MB	Multi Band
MBoSDM	Multi Band and Space Division Multiplexing
MEC	Multi-Access Edge Computing
MAS	Multi-Agent Systems
MDP	Multi-domain Data-Plane
MG-ON	Multi-Granularity Optical Network
MIMO	Multiple-Input Multiple-Output
NB-IoT	Narrowband Internet of things
NCSR	National Centre for Scientific Research
NI	National Instrument
AI-AI	AI native Air Interface
NEF	Network Exposure Function
NEF	Network Exposure Function
NOS	Network Operating System
gNB	next Generation Node B
NGSO	Non-geostationary

NTN	Non-Terrestrial Networks
NBI	Northbound Interface
OPC	Open Platform Communications
OPC UA FX	Open Platform Communications Unified Architecture Field eXchange
Open RAN	Open Radio Access Network
OAI	Open-Air Interface
OpEx	Operating Expense
OT	Operational Technology
Ops	Operations
OXC	Optical Cross-Connect
oDAC	optical Digital-to-Analog Converter
ON	Optical Node
O/E/O	Optical to Electrical to Optical
OpenRU	O-RAN Radio Unit
OTA	Over-The-Air
OTT	Over-The-Top
PON	Passive Optical Networks
PHY	Physical Layer
M2MP	Multipoint-To-Multipoint
P2MP	Point-to-MultiPoint
P2P	Point-To-Point
PQC	Post-Quantum Cryptography
PoC	Proof of Concept
PLMN	Public Land Mobile Network
PPDR	Public Protection and Disaster Relief
QoE	Quality of Experience
RAN	Radio Access Network
RF	Radio Frequency
RRM	Radio Resource Management
RU	Radio Unit
RSU	Radio-Side Unit
RT RIC	Real-Time RAN Intelligent Controller
RIS	Reconfigurable Intelligent Surface
RIS	Reconfigurable Intelligent Surfaces

RIoT	Reconfigurable IoT Node
RIoT	Reconfigurable IoT node
ROADM	Reconfigurable Optical Add-Drop Multiplexer
RIS	Reconfigurable Surfaces
RIS	Reflective Intelligent Surfaces
RAW	Reliable and Available Wireless
RRU	Remote Radio Unit
R&D	Research and Development
R&I	Research and Innovation
RI	Research Infrastructure
rApps	Robotic Applications
SatCom	Satellite communication
SMPC	Secure Multi-Party Computation
SPT4AI	Secure, Private and Trustworthy AI
SMO	Service Management and Orchestration
SBA	Service-Based Architecture
SLAM	Simultaneous Localisation and Mapping
S-BVT	Sliceable Bandwidth Variable Transceiver
SME	Small and Medium-sized Enterprise
SNS JU	Smart Networks and Services Joint Undertaking
SW	Software
SDN	Software Defined Network
SDK	Software Development Kit
SMA	Software Management Agent
SDI	Software-Defined Infrastructures
SDM	Space Division Multiplexing
SDM	Space Division Multiplexing
SDO	Standards Development Organisations
SoTA	State-of-The-Art research
SOC	System-on-a-Chip
TRL	Technology Readiness Level
TPU	Tensor Processing Units

THz	Terahertz
TN	Terrestrial Networks
TaaS	Testing as a Service
3D	Three-Dimensional
TSN	Time Sensitive Networking
TN	Trial Network
TEE	Trusted Execution Environment
URLLC	Ultra-Low-Latency Communications
uHDD	Ultra-High Data Density
uHSLLC	Ultra-High-speed with Low-latency Communication
UWB	Ultra-Wide-Band
UN	United Nations
USRP	Universal Software Radio Peripheral
UMA	University of Malaga Campus
UAV	Unmanned Aerial Vehicle
UAM	Urban Air Mobility
UC	Use Case
UE	User Equipment
UI	User Interface
UP	User Plane
UPF	User Plane Function
V2X	Vehicle-to-Everything
V2V	Vehicle-To-Vehicle
VC	Verifiable Credential
VIM	Virtual Infrastructure Manager
VNF	Virtual network function
VR	Virtual Reality
vRAN	Virtualised RAN
WBSS	WaveBand Selective Switch
WDM	Wavelength Division Multiplexing
ZPK	Zero-Knowledge Proofs
ZSM	Zero-touch network and Service Management
XR	Extended Reality
ZSM	Zero Service Management

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More information at
https://smart-networks.europa.eu

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