Smart Networks and Services International and European Cooperation Ecosystem

D1.3 Evaluation of the acceptance for the SNS Phase 1 results

Document Summary Information

Start Date	01/01/2023	**Duration**	27 months
Project URL	https://smart-networks.europa.eu/csa-s/#SNS-ICE		
Deliverable	D1.3 Evaluation of the acceptance for the SNS Phase 1 results		
Related Work Package	WP1	**Related Task**	T1.1, T1.2, T1.3
Contractual due date	31/03/2025	**Actual submission date**	31/03/2025
Type	Report	**Dissemination Level**	Public
Deliverable Editor	Kostas Trichias (6G-IA)		

This project has received funding from the Smart Networks and Services Joint Undertaking (SNS JU) under the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101095841

Contributors and Peer Reviewers

Contributors		
Contributor Name	**Contributor email**	**Affiliation**
Kostas Trichias	Kostas.trichias@6g-ia.eu	6G-IA
Alexandros Kaloxylos	alexandros.kaloxylos@6g-ia.eu	6G-IA
Werner Mohr	werner.mohr@6g-ia.eu	6G-IA
Claudio de Majo	C.demajo@trust-itservices.com	Trust-IT Services
Raffaele de Peppe	raffaele.depeppe@telecomitalia.it	TIM
Aija Vorslava	aija.vorslava@techritory.com	VASES
Toon Norp	Toon.norp@tno.nl	TNO
Carles Antón-Haro	carles.antton@cttc.es	CTTC
Pooja Mohnani	mohnani@eurescom.eu	EUR
Peer Reviewers		
Reviewer Name	**Reviewer email**	**Reviewer Affiliation**
Raffaele de Peppe	raffaele.depeppe@telecomitalia.it	TIM
Maria Giuffrida	m.giuffrida@trust-itservices.com	Trust IT

Revision history (including peer reviewing & QA)

Version	Issue Date	% Complete	Changes	Contributor(s)
v0.1	19/11/2023	1%	Initial Deliverable Structure (Table of Contents) and section assignment	Kostas Trichias (6G-IA)
v0.2	24/01/2025	15%	Introduction, AI/ML section	Kostas Trichias (6G-IA), Alex Kaloxylos (6G-IA)
v0.3	27/01/2025	25%	Spectrum section, NTN section	Werner Mohr (6G-IA), Raffaele de Peppe (TIM)
v0.4	27/01/2025	35%	Section 3.6	Claudio de Majo (Trust-IT)
V0.5	22/02/2025	40%	Section 3.4	Toon Norp (TNO)
V0.6	28/02/2025	60%	Sections 2.2, Section 3.2	Carles Antón-Haro (CTTC)
V0.7	02/03/2025	70%	Section 3.2	Pooja Mohnani
V0.8	10/03/2025	80%	Conclusion section, Exec. Summary, consolidation of content	Kostas Trichias (6G-IA)
V0.9	24/03/2025	90%	Document review	Raffaele de Peppe (TIM), Maria Giuffrida (Trust-IT)
V1.0	31/03/2025	100%	Addressing review comments, document finalization	Kostas Trichias (6G-IA)

Legal Disclaimer

Table of Contents

List of Figures

List of Tables

Abbreviations List

Abbreviation / Term	Description
3GPP	3rd Generation Partnership Project
5GAA	5G Automotive Association
5GMAG	5G Media Action Group
5GMF	5G Mobile Communications Promotion Forum
5G PPP	5G Public Private Partnership
6G-IA	6G Smart Networks and Services – Industry Association
AI	Artificial Intelligence
AIOTI	Alliance for Internet of Things Innovation
API	Application Programming Interfaces
AR	Augmented Reality
ATIS	Alliance for Telecommunications Industry Solutions
B5PC	Beyond 5G Promotion Consortium
B6GA	Bharat 6G Alliance
CAICT	China Academy of Information and Communications Technology
CAM	Connected and Automated Mobility
CCSS	Communications, Circuits, and Sensing-Systems
CNTI	Cloud Native Telco Initiative
CPU	Central Processing Unit
CRA	Cyber Resilience Act
D2D	Device to Device
DARPA	Defence Advanced Research Projects Agency
DCI	Data-Centric Infrastructure
DNN	Deep Neural Networks
EIM	European Rail Infrastructure Managers
ERI	Electronics Resurgence Initiative
ESA	European Space Agency
ETRI	Electronics and Telecommunications Research Institute
EU	European Union
FCC	Federal Communications Commission
FSO	Free-Space Optical
GFCE	Global Forum on Cyber Expertise
GIA	Gigabit Infrastructure Act
GSMA	Global Association of Mobile Operators
HBM	High-Bandwidth Memory
HLLM	Hyper-Large Language Models
ICT	Information and Communication Technology
IITP	Institute for Information & Communications Technology Planning & Evaluation

IPCEI-CIS	Important Projects of Common European Interest in Next Generation Cloud Infrastructure and Services
ISAC	Integrated Sensing and Communication
ITS	Intelligent Transportation Systems
ITU	International Telecommunications Union
JCAS	Joint Communication and Sensing
KPI	Key Performance Indicator
KVI	Key Value Indicator
LEO	Low Earth Orbit
LFN	Linux Foundation Networking
LSTC	Leading-edge Semiconductor Technology Centre
MIMO	Multiple Input Multiple Output
ML	Machine Learning
MOST	Ministry of Science and Technology
MSIT	Ministry of Science and ICT
NDRC	National Development and Reform Commission
NGA	Next G Alliance
NIST	National Institute of Standards and Technology
NLP	Natural Language Processing
NSF	National Science Foundation
NSTC	National Semiconductor Technology Centre
NTN	Non Terrestrial Networks
OPNFV	Open Platform for Network Functions Virtualization
OWC	Optical Wireless Communication
PIC	Photonic Integrated Circuit
PSCE	Public Safety Communication Europe
R&I	Research and Innovation
RAN	Radio Access Network
RINGS	Resilient & Intelligent NextG Systems
RoF	Radio-over-Fiber
SBA	Service-Based Architecture
SDG	Sustainable Development Goals
SME	Small to Medium Enterprise
SMIC	Semiconductor Manufacturing International Corporation
SNS	Smart Networks and Services
SNS-JU	Smart Networks and Services Joint Undertaking
STEM	Science, Technology, Engineering, Math
SWIFT	Spectrum and Wireless Innovation Enabled by Future Technologies
TB	Technology Board
THz	Terahertz

TMV WG	Test, Measurement and Validation WG
TRAI	Telecom Regulatory Authority of India
TSDSI	Telecommunications Standards Development Society, India
TSN	Time Sensitive Networks
UC	Use Case
VLC	Visible Light Communication
VR	Virtual Reality
WAC	Wide Area Cloud
WG	Working Group
WP5D	Working Party 5D
WRC	World Radiocommunication Conference
XAI	explainable AI
XGMF	XG Mobile Promotion Forum
XR	Extended Reality

Executive Summary

The Smart Networks and Services Joint Undertaking (SNS-JU) launched its first phase of Research and Innovation (R&I) projects on January 1, 2023, initiating 33 projects aimed at advancing next-generation network technologies in Europe. These projects focus on key enablers for 6G development, including cutting-edge devices, novel network architectures, and software solutions. The initiative has since expanded with additional projects in 2024 (Call 2) and 2025 (Call 3), contributing to a comprehensive roadmap for Europe's leadership in future communications technology.

This document serves as the final deliverable of Work Package 1 (WP1) of the SNS ICE project, consolidating prior analyses and insights to evaluate the global impact of SNS activities to this point. WP1 has been instrumental in monitoring international 6G R&I trends, facilitating global dialogue, and ensuring alignment between European efforts and worldwide developments. Through active participation in major global fora, standardization bodies, and policy discussions, SNS ICE has positioned Europe at the forefront of 6G research.

Key findings highlight that SNS Phase 1 projects have significantly contributed to shaping the global 6G landscape. European research efforts have maintained strong alignment with international priorities, particularly in areas such as AI-driven network automation, integrated sensing and communication (ISAC), terahertz (THz) communications, and cloud-native architectures. SNS-funded projects have also played a pivotal role in advancing sustainable and energy-efficient network solutions, ensuring compliance with green technology initiatives. The role of standardization in ensuring technological coherence across regions and the importance of fostering international collaboration to drive innovation, is also highlighted.

The evaluation of SNS Phase 1 projects includes an assessment of their impact based on key performance indicators (KPIs) such as standardization contributions, scientific publications, and industry collaborations. With over 1,000 contributions to international standardization bodies like 3GPP, ETSI, and ITU, SNS projects have demonstrated substantial influence in defining future network standards. Additionally, the SNS initiative has facilitated numerous patents and intellectual property applications, reinforcing Europe's competitive position in 6G technology development.

The report provides targeted recommendations for SNS follow-up phases, including stronger industry collaboration, standardization leadership to ensure European contributions shape 6G frameworks, increase of SME Involvement and acceleration of commercialization.

By implementing these recommendations, SNS JU aims to further enhance its impact, ensuring Europe remains at the forefront of 6G development while addressing societal, economic, and environmental challenges. The continued evolution of SNS research will be instrumental in shaping the future of smart networks and services in the coming decade.

1 Introduction

On January 1, 2023, the Smart Networks and Services Joint Undertaking (SNS-JU) launched 33 Research and Innovation (R&I) projects (Phase 1), aimed at advancing next-generation network research in Europe. These projects explore innovative technologies, devices, and software for future networks and are aimed to establish experimentation facilities for trials to assess performance and shape 6G development. On January 1, 2024, 26 additional projects started (Call 2), while 16 more projects commenced their operation on January 1, 2025 (Call 3). Three more calls for SNS projects are expected to be launched by 2027, while the last SNS projects will remain operational until 2030.

This document is the final deliverable of WP1 of the SNS ICE project and it aims to wrap up the activities of WP1, by taking advantage of the work and analysis presented in previous deliverables, to set the global scene of 6G oriented Research and Innovation (R&I) and to compare it with the developments within the SNS JU and the work achieved by the ongoing projects (mostly focusing on Call 1 projects, that have been able to report on their initial findings and achievements). Based on this analysis the greater impact of the SNS JU work on the global 6G landscape is estimated, while concrete recommendations for the SNS follow up phases are provided.

1.1 Background and context

WP1 is tasked with establishing global dialogues and monitor global R&I trends and act as a bridge between the SNS JU and the rest of the world to facilitate bidirectional flow of information regarding research, policy and standardization developments. Through intense liaison activities, active presence in all major global fora, conferences and events and the organization of international workshop, sessions and speeches, SNS ICE partners have engaged with the global 6G and future networks community placing SNS on the global roadmap.

SNS ICE's international engagement strategy, first introduced in D1.1, was consistently followed throughout the project. [1]. In the same deliverable, a first analysis of the EU and global trends was presented, including relevant standardization roadmaps and a comparison with the use cases, technologies and KPIs addressed by SNS JU Call 1 projects indicated that EU 6G research efforts are well aligned with the global developments. Furthermore, the initial efforts of SNS ICE to engage in global dialogues and promote the vision and initial work of SNS stakeholders were also outlined.

In the next deliverable of WP1, i.e., D1.2 [2], a comprehensive 6G global landscape analysis was presented along with and overview of the relevant standardization developments. This deliverable highlighted the effort of the SNS ICE partners to lead the alignment of European stakeholders in terms of 6G Use Case prioritization and the eventual success of this endeavour with the common European front presented at the 3GPP SA1 meeting in May 2024. This result is a key outcome of the efforts of SNS ICE, to align EU stakeholders with the global vision and maximize the impact of the SNS work towards global standards organizations.

Based on the analysis and insights presented in D1.2, a thorough overview could be created regarding the global vision and developments and the relevant efforts taking place within the SNS JU which resulted in concrete recommendations for the different type of stakeholders engaged in the SNS JU, i.e., the Public sector and policy makers, EU telecom industry leaders, European researchers and academics, SMEs, as well as some recommendations for the next steps of the SNS JU. These recommendations were the outcome of two years of work of the SNS ICE partners and their engagement with the global community via surveys and engagement in global events.

1.2 Deliverable objective and mapping of outputs

This deliverable will continue and wrap up the work of WP1 by focusing on three main aspects:

i.) Provide an update of the 6G global landscape survey with up-to-date information on global stakeholder views and developments

ii.) Provide an analysis of global focus themes and technologies and the relevance and impact of SNS JU work for each of them

iii.) Attempt to evaluate the impact achieved by SNS Phase 1 projects based on key programme level KPIs such as standardization contributions and publications.

Table 1 below provides an overview of the contents of the deliverable and how they match the Grant Agreement contractual obligations.

Table 1: Matching of deliverable content to Grant Agreement components

GA Component Title	GA Component Outline	Respective Document Chapter(s)	Justification
TASKS			
Monitor Trends	Analysis of global B5G/6G trends	Section 2.1	An update of the results of the SNS ICE 6G global landscape survey is provided, to ensure that the latest trends and developments are captured.
	Analysis of SNS JU trends	Section 2.2	An overview of SNS JU developments is provided based on the latest available information
	Estimation of alignment between SNS JU and the rest of the world and gap analysis	Section 2.4	An estimation of the alignment and detection of possible gaps between the global trends and SNS work is performed, based on the analysis of the previous sections.
SNS Impact estimation	Capture SNS Phase 1 results	Section 2.2 Section 4	Latest technical and programmatic results from the SNS projects are captured based on available information.
	Thematic analysis & comparison to trends in other regions	Section 3	Overall trend comparison & per stakeholder performed in D1.2 [2]. In this deliverable the focus is on comparing trends per focus area.
Recommendations	Provide recommendations for the SNS follow up phases	Section 3 Section 5	Conclusions and recommendations provided based on the presented aggregate information, for the follow up of the SNS JU programme.

2 Global Trends Analysis & World vision (vs SNS)

This section provides an update on the global 6G landscape survey that was presented in deliverable D1.2 [2], based on the most recent publications of global 6G associations, and compares the results with insights gained regarding the SNS JU projects over the past year. Similarities and differences in the approach are highlighted, attempting to investigate the alignment of the EU 6G R&I approach with the rest of the world

2.1 Global vision on 6G

The evolution toward 6G represents not just an incremental advancement over 5G but a comprehensive rethinking of how communication networks can integrate seamlessly into every facet of human life, society, economy and the environment. The global vision for 6G is rooted in the ambition to build an intelligent, adaptive, and sustainable communication ecosystem that supports emerging technologies and addresses the limitations of current networks.

A key distinguishing feature of 6G is its focus on ubiquitous connectivity, ensuring that every part of the globe, including remote and underserved regions, can benefit from advanced digital services. This is facilitated through the integration of non-terrestrial networks (NTNs), such as low-earth orbit (LEO) satellites, high-altitude platforms, and unmanned aerial systems, which complement terrestrial infrastructure to achieve seamless global coverage.

Central to the 6G vision is the adoption of AI-native architectures. Unlike previous generations where AI was an add-on, 6G networks will have AI and Machine Learning (ML) embedded at their core, enabling real-time, autonomous network management, predictive maintenance, and dynamic resource allocation. This AI-driven approach will support complex, data-intensive applications like holographic communications, digital twins, and immersive virtual environments, where milliseconds of latency can make a significant difference.

Another transformative aspect is the convergence of sensing and communication (ISAC) capabilities. This integration allows networks to not only transmit data but also sense the environment, providing real-time data for applications such as autonomous vehicles, smart manufacturing, and precision healthcare. Coupled with cloud-native networking, 6G aims to deliver highly flexible, scalable, and efficient networks that can adapt to diverse user requirements and operational contexts.

Sustainability emerges as a core pillar of the 6G vision. Recognizing the environmental impact of expanding digital infrastructure, 6G prioritizes energy efficiency through innovations in hardware design, intelligent energy management, and optimized data transmission protocols. The goal is to reduce the carbon footprint of communication networks while supporting green technologies and practices.

Equally important is the emphasis on digital inclusion. 6G aspires to bridge the digital divide by making high-speed, reliable connectivity accessible to all, fostering equitable opportunities for education, healthcare, and economic participation globally. This aligns with broader societal goals of promoting social equity, resilience, and economic growth through digital transformation.

In essence, the global vision for 6G extends beyond technical specifications to encompass a holistic framework that integrates technological innovation with societal, economic, environmental, and ethical considerations. It envisions a future where communication networks are not just faster and more efficient, but also smarter, more inclusive, and sustainable, driving the next wave of human, economical and technological progress.

2.1.1 Global 6G landscape analysis & world-wide priorities: technologies and KPIs

As the SNS-JU Ambassador to the rest of the world and responsible for the bidirectional flow of information between the SNS-JU and other global associations and stakeholders, SNS ICE has carried out a comprehensive analysis of the global 6G landscape in mid-2023, providing insights and categorisation regarding the interest of global stakeholders and their respective prioritisation in terms of targeted 6G KPIs, envisioned 6G Use cases and key technological enablers. This analysis resulted in a peer-reviewed publication [3], during EuCNC 2024 and provided a comprehensive overview of the 6G R&I interests around the world. Moreover, the outcomes of this study provided proof that Europe's (and SNS-JU's) research interest are well aligned with the global priorities and that there are no significant gaps in EU's 6G Research roadmap.

Since then, the International Telecommunication Union (ITU), has published the long awaited ITU-R Recommendations for IMT 2030 (6G) [4] in November of 2023, which are considered the common baseline for the future development of 6G features and technologies around the world. Within this recommendations document, the ITU establishes, among other things: i) the high-level **usage scenarios** and overarching aspects for 6G and ii) the **targeted capabilities/KPIs for 6G**. As these recommendations represent the global consensus among key 6G stakeholders around the world, they are considered well-accepted and the research interests shift towards defining the architecture, technologies and features that will enable these targets along with more detailed definition of the Use Cases (UC) that are in need and will be served by the next generation mobile technology.

Figure 1: SNS ICE global 6G survey sources

Within the past one and a half year since the publication of the ITU-R Recommendations, most global associations and 6G stakeholders have published updated versions of their respective 6G vision, while other important milestones have also taken place, i.e., the 3GPP SA1 Workshop on IMT 2030 Use Cases. The SNS ICE partners have conducted another world-wide survey, to identify the key points emerging from these new actions and white papers, in order to be able to form an update picture of the global 6G landscape at this moment (end of 2024). Approximately 14 different source documents were identified and used for this survey, driven by the IMT 2030 Recommendations (as depicted in Figure 1) which provide the views of multiple different global stakeholders (operators, vendors) and regional 6G associations. These documents, mostly address the vision of the various stakeholders in terms of the technologies and drivers that each of them considers important for the development of the next generation of networks. While the high-level usage scenarios have already been highlighted in the IMT 2030 Recommendations, some of these documents attempt a more in-depth analysis and the definition of Use Case families that will be enabled by 6G.

The 14 source documents provide insights into the vision and priorities for 6G of **Europe** (6G-IA) [5], **North America** (ATIS-NGA) [6], **India** (Bharat) [7], **Japan** (NICT & B5G PG) [8][9], **South Korea** (SK Telecom) [10][11], **China** (IMT-2030 PG) [12][13] and **Taiwan** (TAICS) [14] as well as the targeted views of operators (**NGMN**) [15][16] and the 2 largest European vendors, i.e., Ericsson [17] and Nokia [18].

2.1.2 Key drivers, features, and technologies for 6G - outlook

All these stakeholders focus on the technologies and features that they consider as key drivers for 6G, and which should be developed as the corner stone of future 6G networks and will also enable the accomplishment of the target KPIs and use cases set forth by the ITU-R IMT 2030 recommendations. A significant degree of alignment can be detected among these global stakeholders in terms of the key enablers for 6G networks. ***Seven drivers / features*** stand out based on the SNS ICE survey as they attract almost universal acceptance among the global stakeholders as depicted in Figure 2: Prioritisation of 6G drivers across the globe according to the SNS ICE survey. Out of the 14 source documents analysed for this survey ***Sustainability / Energy Efficiency, Security/ Reliability/ Privacy/ Trust, AI-native / Network Intelligence, Integrated Sensing / ISAC and Cloud-native / Distributed Edge-Cloud***, are mentioned in all 14 sources (100% acceptance) as key drivers for 6G networks while ***Ubiquitous connectivity / NTN integration*** is mentioned in 13 out of 14 and ***Spectrum Efficiency / Spectrum Sharing*** is mentioned in 12 out of 14.

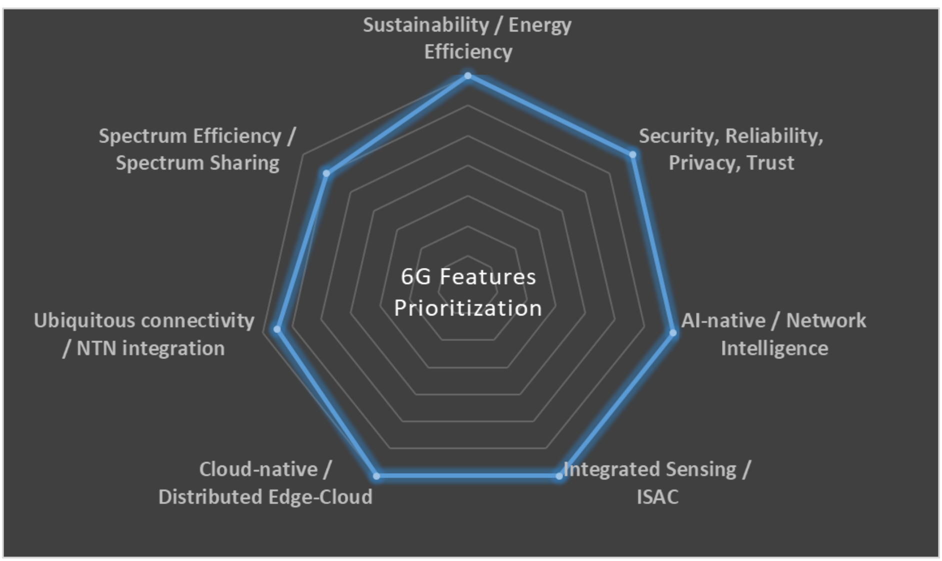


Figure 2: Prioritisation of 6G drivers across the globe according to the SNS ICE survey.

The worldwide acceptance of these features/technologies indicates that significant research efforts are already underway on a global scale, and these features /technologies are expected to be the main building blocks of future 6G networks. By analysing Figure 2 it becomes evident that there is a world-wide consensus that 6G networks should bring forth significant advances in terms of sustainability and energy efficiency and that the importance of Trustworthiness (Security, Privacy, Reliability) has increased since the 5G era. Moreover, it is globally accepted that AI will not simply be a “feature on-top” for 6G networks but rather one of the most important building blocks, along with Integrated communication and sensing capabilities. It is also globally agreed that edge-cloud integration will be much more prominent and that 6G networks should become cloud-native. Moreover, ubiquitous connectivity is a major goal of 6G which is expected to be accomplished via the seamless integration with NTN platforms and systems, while the use of new spectrum bands, the application of more spectrum efficient solutions and of new spectrum sharing methods is going to play an important role in future 6G systems, in order to cope with the continuously increases traffic.

Besides the above seven drivers, for which there seems to be almost unanimous support, several other features / technologies are highlighted by the global stakeholders as potentially important elements of future 6G networks. ***Deterministic Networking*** (Time Sensitive Networks - TSN) seems to be significantly supported by European and American stakeholders, while ***advances in Hardware*** including terminal devices, antennas, RIS, etc. are considered important by a big majority of stakeholders including Europe, India, South Korea. Moreover, ***enhanced IoT operations*** are viewed as an important part of 6G for many stakeholders including Korea, Taiwan and the global operators.

2.1.3 6G KPIs & Use Cases

It is interesting to note that most of the vision documents that were issued in the past year (within 2024), do not revisit the discussion on 6G KPIs, as the ITU-R IMT 2030 recommendations are considered the de facto target from the point of their publication onwards. Some more updates are expected in the near future, as certain regions have not had the chance to publish updated versions of their vision documents. For instance, in Japan the 5G Mobile Communications Promotion Forum (5GMF) and the Beyond 5G Promotion Consortium (B5GPC) have been merged into a new forum since April 2024, namely the XG Mobile Promotion Forum (XGMF), but have not yet published an openly accessible vision document under their new identity.

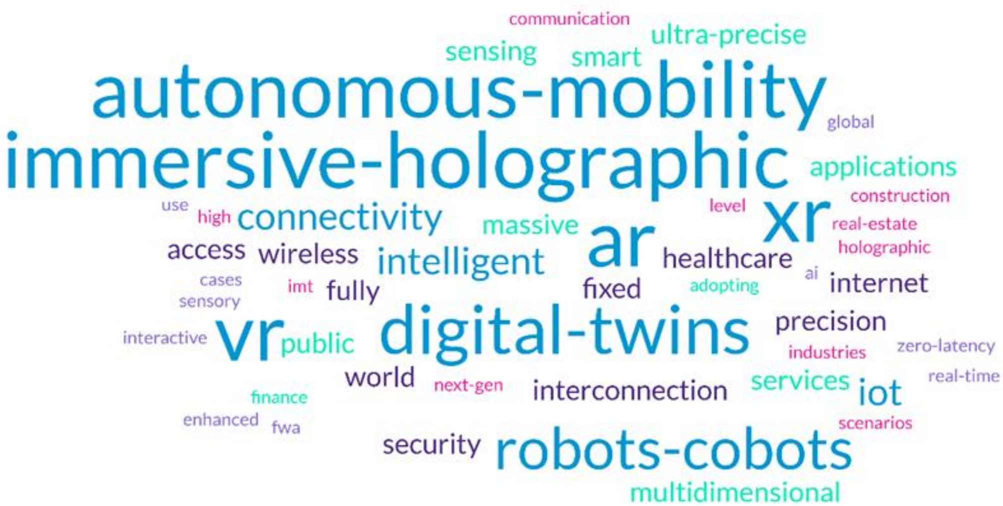


Figure 3: Word-cloud of prioritised 6G Use Cases across the globe according to the SNS ICE survey.

Based on the global survey performed by SNS ICE partners, it appears that there are clear points of convergence among the global stakeholders in terms of the most promising features / technologies that are expected to be the building blocks of future 6G networks, as well as in terms of some of the most anticipated use cases. Local needs and societal challenges do play a role in slightly differentiating the respective local vision, however the grand picture remains the same. Based on the insights provided by this analysis, European Research & Innovation activities are well aligned with the global consensus and there do not appear to be any major gaps in the EU research roadmap. Europe is even playing a pivotal role in defining the priorities for the global 6G use cases via the processes followed within 3GPP SA1, as will be further explained in the next section.

2.2 SNS Vision on 6G

The SNS-OPS Coordination & Support Action project, responsible for supporting project activities and amplifying the key messages of the SNS Joint Undertaking, conducted a comprehensive survey in the first half of 2024. This survey aimed to gather detailed insights into each project's technical aspects, vision, approach, and achievements[1]. Its primary objective was to better understand the planned work for Call 2 projects, identify shared challenges between Call 1 and Call 2 initiatives, and assess the progress made by Call 1 projects to date.

The 6G vision section of the survey comprises questions on projects' contribution to societal challenges, societal values in focus, plans and methodologies for addressing Key Value Indicators (KVIs), priorities in terms of contributions to UN's Sustainable Development Goals (SDGs), and contribution to the overall 6G Vision. The survey reveals that the minimization of energy and carbon footprint of current and future SNS technology solutions, along with the conception, development, and deployment of a European value-based approach to 6G are the top contributions to societal challenges. These are closely followed by affordability and accessibility aspects of such technologies. As for the societal values in focus, environmental, societal and economic sustainability are claimed by many projects.

Most projects plan to assess KVIs mostly by means of running trials and experiments. However, the use of questionnaires and measurements on deployed networks is also considered a valuable tool. As for SDGs, the SNS Work Programme specifically asks for contributions to four of them, namely:

- **SDG 8**: Decent Work and Economic Growth: Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all.
- **SDG 9**: Industry, Innovation, and Infrastructure: Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation.
- **SDG 11**: Sustainable Cities and Communities: Make cities and human settlements inclusive, safe, resilient, and sustainable.
- **SDG 13**: Climate Action: Take urgent action to combat climate change and its impacts.

From the survey, the top three priorities of the SNS projects include SDG 8, 9 and 11, with SDG 13 receiving a somewhat lower attention right behind strengthening the means of implementation and revitalizing the global partnership for sustainable development (SDG 17). Finally, on how projects contribute to the 6G vision included in the foundational documents of the SNS, the focus is on developing affordable and scalable technologies to ensure inclusiveness and conceiving flexible and efficient architectures for a seamless integration of communication systems and devices. Enhancing coverage and the unification of the physical, digital and human world is also regarded as a priority.

In subsequent sections, a review of the use cases, KPI targets, and technological enablers being investigated by the current portfolio of SNS JU projects is performed.

2.2.1 Use Cases

SNS ICE led the effort to align major European stakeholders from the SNS JU projects, Industry (6G-IA), EU National Initiatives and EU policy makers (SNS office, DG-CNCT), to present a common front with regards to the prioritization of 6G use cases within standardization, from EU stakeholders. As a result, at the 3GPP SA1 Workshop on 6G use cases (Rotterdam, May 2024), a European research and innovation perspective on 6G use cases was presented [19]. This perspective was derived from the Hexa-X-II use cases [20], incorporating input from various SNS projects and national 6G initiatives across European member states. The consolidated set of use cases is illustrated in Figure 4.

The identified 6G use cases are grouped into six use case families, each comprising multiple detailed use cases. Within each family, one use case has been designated as the representative case, as it best captures the key characteristics of that category. This representative use case is listed first in each family, as shown in Figure 4. For a comprehensive overview of these use cases and their associated key performance indicators (KPIs), readers are referred to SNS-ICE Deliverable D1.2 [2].

[1] The detailed results of the survey are available here: https://smart-networks.europa.eu/event/sns-ops-questionnaire-results-webinar/

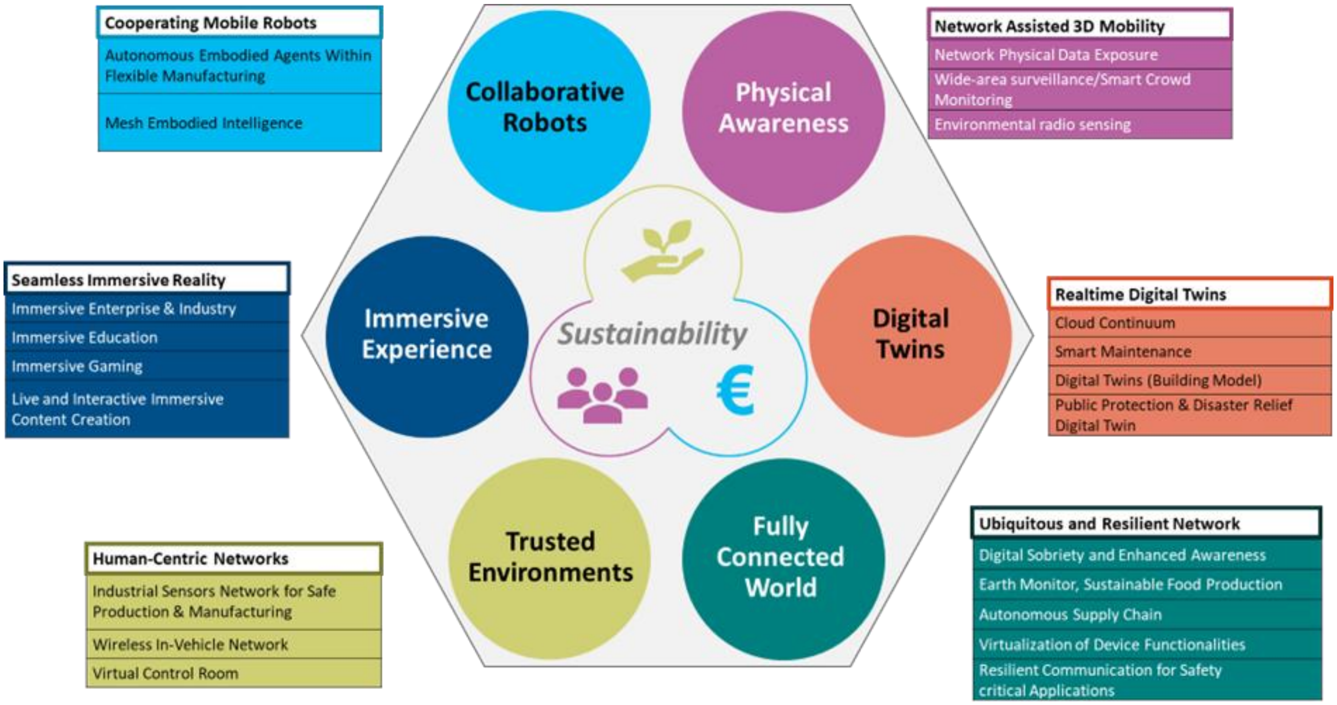


Figure 4: European consolidated R&I perspective on 6G use cases. Each circle represents a use case family, with the first use case listed serving as the representative use case for that family.

The 6G use cases presented and agreed upon in the 3GPP SA1 workshop are intimately related with those addressed within the SNS JU portfolio of projects. Figure 5 provides insights into the use cases addressed by SNS Call 1 and Call 2 projects. Collectively, the coverage of vertical sectors is very broad as it will be discussed later in this section. The coverage has significantly expanded with the launch of Call 2 projects, incorporating additional initiatives into the ecosystem. Another key aspect is that multiple projects focus on similar or closely related use cases, enabling cross-validation of experimental results and the derivation of shared insights. This collaborative approach enhances the reliability and comparability of findings, fostering a more comprehensive understanding of emerging technologies and their applications.

A closer examination of the data reveals a strong alignment with global trends. Key areas such as Industry 4.0, digital twins, robotic cooperation, and multi-sensory XR gaming continue to be among the top priorities for SNS-JU experimenters, mirroring the predominant focus observed worldwide. Notably, there is a growing interest within SNS-JU in the Transportation sector. This trend aligns with the European Union's strategic investments in Connected and Automated Mobility (CAM), aimed at enabling seamless, high-reliability connectivity across all major EU transport corridors. As Europe continues to advance its vision for intelligent, interconnected transportation networks, the emphasis on ensuring uninterrupted connectivity along key transit routes is becoming increasingly prominent in SNS research initiatives.

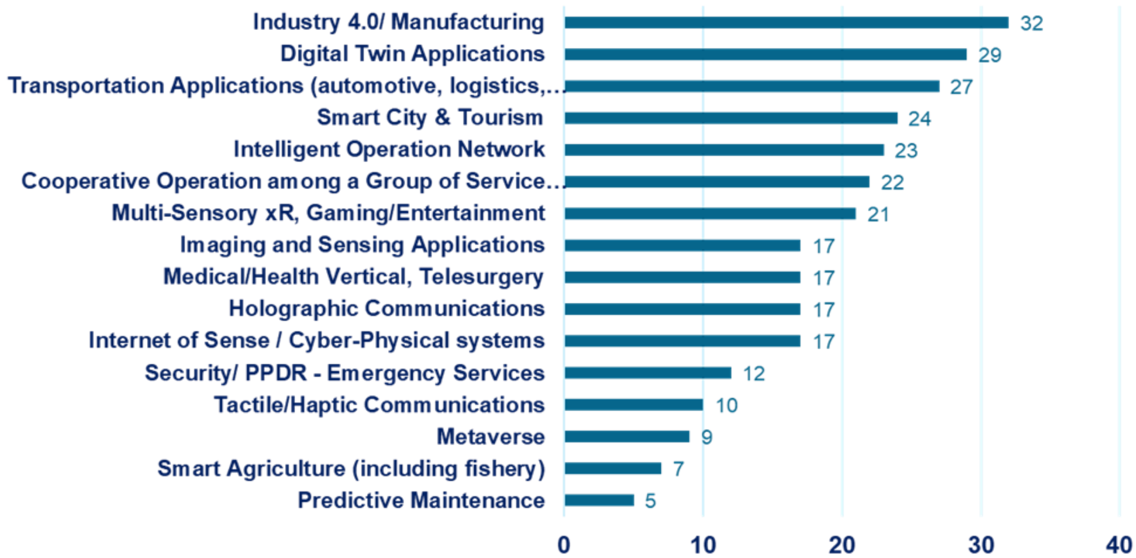


Figure 5: Use cases considered in SNS JU Call1 & Call 2 projects.

The **Vertical Engagement Tracker**[2], an on-line tool developed and evolved by the SNS ICE project (see Figure 6), aimed at mapping and monitoring 6G research and innovation use cases across industry sectors, provides further insights about the coverage of verticals by SNS projects. By the end of 2024, it documented 247 use cases from 52 SNS-funded projects in areas like Industry 4.0, Smart Cities, Smart Health, and Automotive.

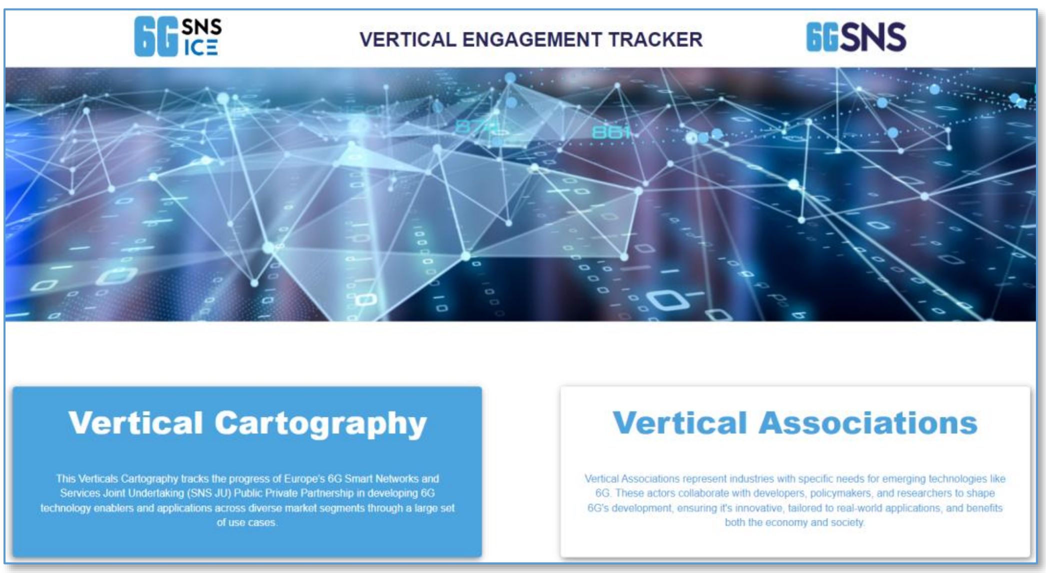


Figure 6: SNS JU Vertical Engagement Tracker landing page.

In its latest release, the VET incorporates several customizable vertical engagement charts, like Figure 7 below, from which very valuable insights can be obtained. This figure illustrates the distribution of vertical sectors across Call 1 and Call 2 projects. Industry 4.0/Manufacturing leads with 44 use cases, followed by Media/AR with 41. Automotive/Transport/Logistics comprises 31 cases, while Security/PPDR contributes 28. Smart City is represented by 19 use cases, and Smart Health by 12. Tourism & Culture records 10 cases, with Smart Agriculture and Non-Terrestrial Networks (NTN) each accounting for 6. Education and Smart Energy are less prominent, with

[2] https://sns-trackers.sns-ju.eu/vertical-engagement-tracker

4 and 5 cases, respectively. The "Other" category encompasses 40 use cases, highlighting a significant portion beyond the defined verticals.

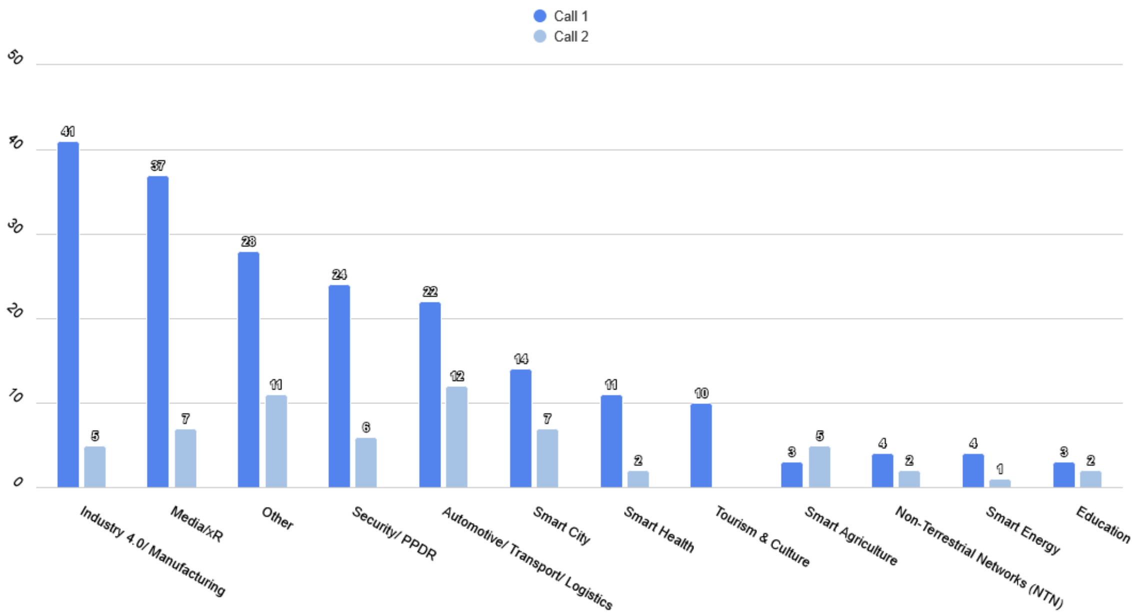


Figure 7: Verticals covered in the use cases addressed by SNS JU Call1 & Call 2 projects.

Concurrently with the efforts undertaken by projects, carrying out a detailed assessment of the relevance and prospects of 5G advanced and future 6G technologies for vertical companies is of utmost importance too. To that aim, SNS ICE recently circulated a survey among relevant vertical associations, namely, ERTICO (European Road Transport Telematics Implementation Coordination Organization), 5GAA (5G Automotive Association), PSCE (Public Safety Communication Europe), 6G Health Institute, 5G MAG (5G Media Action Group), EIM (European Rail Infrastructure Managers), ESA (European Space Agency), and AIOTI (Alliance for Internet of Things Innovation). Its objective was to examine vertical trends and use case priorities across industries by exploring key aspects of 5G and 6G adoption, application, and future expectations. The survey also offers insights into respondents' forecasts for 5G adoption rates, highlighting different levels of integration and essential factors like infrastructure availability and sector-specific requirements.

An exhaustive analysis of survey results can be found in SNS-ICE Deliverable D3.3 [21]. For the sake of completeness, the main findings are summarized here. First and foremost, the survey highlights the growing role of 5G in enabling applications across industries, such as autonomous driving, urban integration, real-time telepresence, and connected healthcare. Adoption rates, however, vary by sector, with Automotive/Transport/Logistics and Industry 4.0 leading due to their need for high-speed, reliable connectivity, while sectors like Smart Energy and Smart Health face challenges related to cost and infrastructure.

Looking ahead, respondents anticipate that 6G will address part of 5G's limitations, enabling advancements like integrated sensing, integration of satellite-terrestrial networks, and AI-driven automation. These advancements are expected to support emerging applications like real-time monitoring, advanced automation, and global connectivity. However, challenges in standardization, regulatory barriers, spectrum availability, and infrastructure costs remain. This could limit the adoption of these technologies across sectors, particularly in sectors requiring global interoperability, such as automotive and logistics.

The survey also identifies key enablers for future connectivity across multiple verticals, including cloud/edge computing, AI/ML, and cybersecurity, which are essential for scalable applications in manufacturing, healthcare, and logistics. For instance, cloud/edge computing is vital for real-time data processing in applications such as smart manufacturing and urban management, while cybersecurity plays a crucial role in ensuring the integrity and reliability of interconnected systems. Emerging technologies like digital twins and immersive communications were noted as promising but still in early adoption stages. Key challenges include infrastructure costs, regulatory hurdles, and slow standardization, particularly in globally connected sectors like automotive and logistics. Cross-industry collaboration was emphasized as crucial, for instance in healthcare, where partnerships among device manufacturers, hospitals, and connectivity providers are essential for innovations like remote surgery and real-time monitoring.

2.2.2 KPI Targets

The main KPIs addressed by SNS JU projects from Call 1 and 2, were also identified in the same survey. Figure 8 below summarizes the main findings. Interestingly, Energy Efficiency, Latency and Reliability turn out to be the most popular KPIs for both Calls. Still, peak data rate and spectrum efficiency also played a prominent role in both calls. On the contrary, positioning, mobility, user data rate, and connection density raised more interest in Call 1 projects. By aggregating results of projects from both calls (Figure 8, bottom), one concludes that the coverage of all KPIs is quite extensive, yet energy efficiency is by far the most popular KPI. Overall, three tiers can be observed in the chart:

- **1st Tier (most popular)**: Energy efficiency, reliability, and latency.
- **2nd Tier**: Peak data rate, user data rate, spectrum efficiency, and positioning.
- **3rd Tier**: Connection density, mobility, area traffic capacity, and provisioning time.

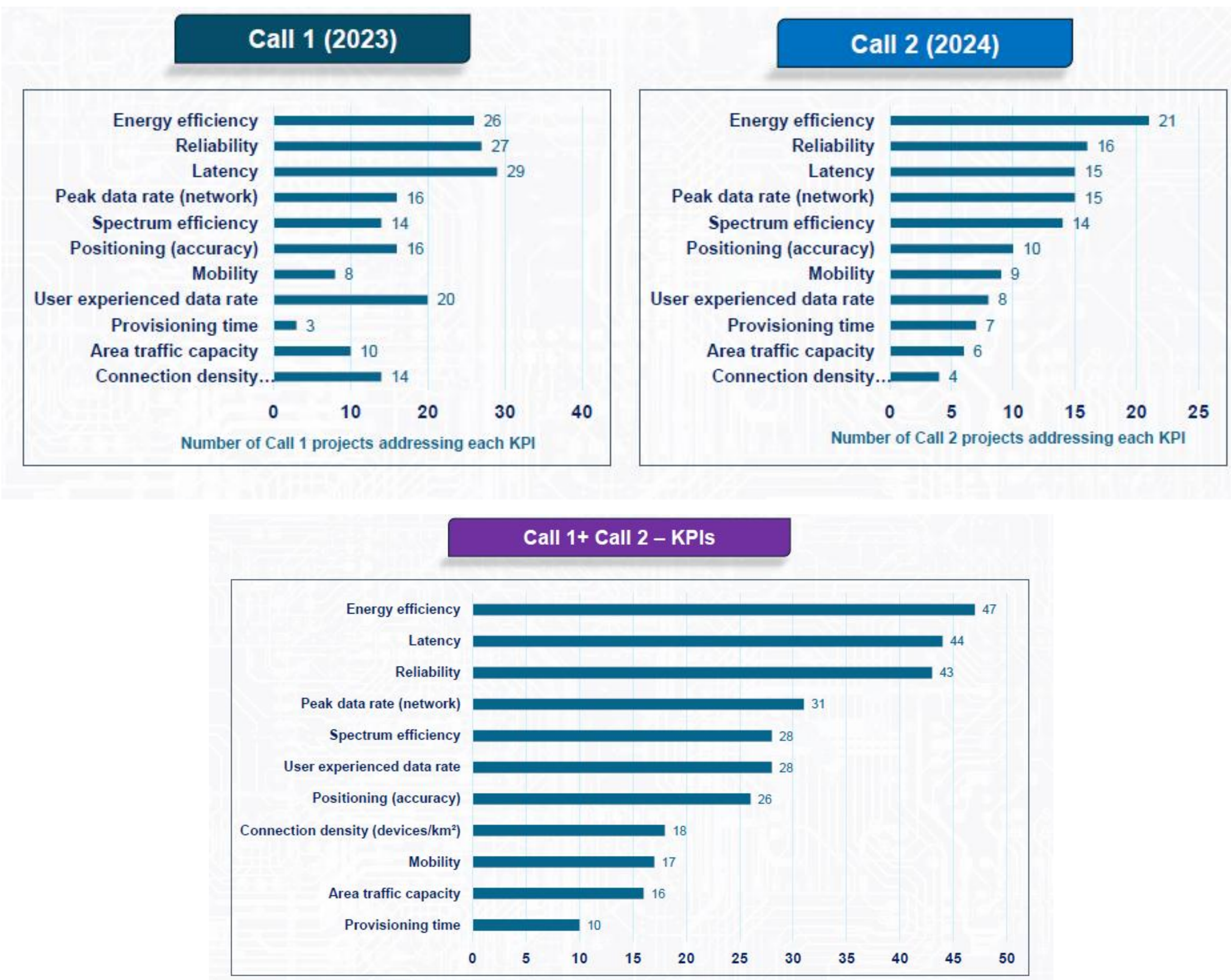


Figure 8: KPI addressed by Call 1 and Call 2 projects.

Recently, the Test, Measurement and Validation (TMV) WG of the SNS initiative has made substantial progress towards the definition of 6G KPIs with the publication of the White Paper entitled "6G KPIs – Definition and Target Values" [22]. This white paper consolidates insights from SNS JU Call 1 and Call 2 projects, defining 6G KPIs, target values, and contextual applications in trials and use cases. It aims to address gaps in 6G capability definitions, offering technical interpretations and evaluation methods for emerging, non-standardized metrics.

To align with ITU-R IMT-2030, KPI categories are structured into KPI families, merging some ITU-R categories for clarity and introducing additional families. These include (i) Data Rate and Capacity, (ii) Latency, (iii) Reliability and Availability, (iv) Mobility, (v) Compute, (vi) Sensing, (vii) AI-related Capabilities, (viii) Electromagnetic Fields (EMF) Aspects, (ix) Positioning and Localization, (x) Energy Efficiency, (xi) Coverage-related, and (xii) Other KPIs.

The key findings in this white paper are as follows:

- Traditional network KPIs (e.g., Data Rate, Latency, Mobility, Spectral Efficiency) remain essential for 6G performance evaluation. Their target values vary widely due to diverse use cases and network deployments. Compared to 5G, these KPIs will see enhanced targets, evaluated in a context-aware framework.
- 6G innovations, such as holographic communications, digital twins (DTs), XR, and collaborative robotics, introduce new capabilities (network intelligence, energy efficiency, and sensing). These require expanding and redefining traditional KPIs while incorporating cross-domain metrics to assess complex multi-layered use cases like DTs.
- KPI evaluation methodologies remain under development, with most SNS JU projects in early stages. As networks mature, harmonized measurement and validation frameworks will be needed for consistent and replicable assessments.
- Advanced testbeds and simulation platforms will play a key role in 6G KPI validation, replicating realistic environments influenced by 6G services rather than 5G benchmarks. Hybrid testbeds, integrating physical infrastructure with DT-based network simulations, will enable scalable and flexible testing.

The white paper also concludes that, for global consistency, it is key to standardize tools and metrics as well as their integration with 6G pre-standardization efforts.

2.2.3 Technological Enablers

The Smart Networks and Services Joint Undertaking (SNS JU) provides an Interactive Reference Figure[3] that showcases projects from its first two calls (see Figure 9 below). This interactive map allows users to explore various projects by clicking on them to access detailed information. The projects are categorized based on key technological areas that they address, such as Open/Disaggregated Networks, Integrated Sensing and Communication (ISAC/JCAS), High-Frequency Technologies (THz, mmWave), and more. Each category provides insights into the specific focus areas of the projects, facilitating a comprehensive understanding of the ongoing research and innovation efforts within the SNS JU framework.

[3] https://smart-networks.europa.eu/interactive-map-of-sns-projects/

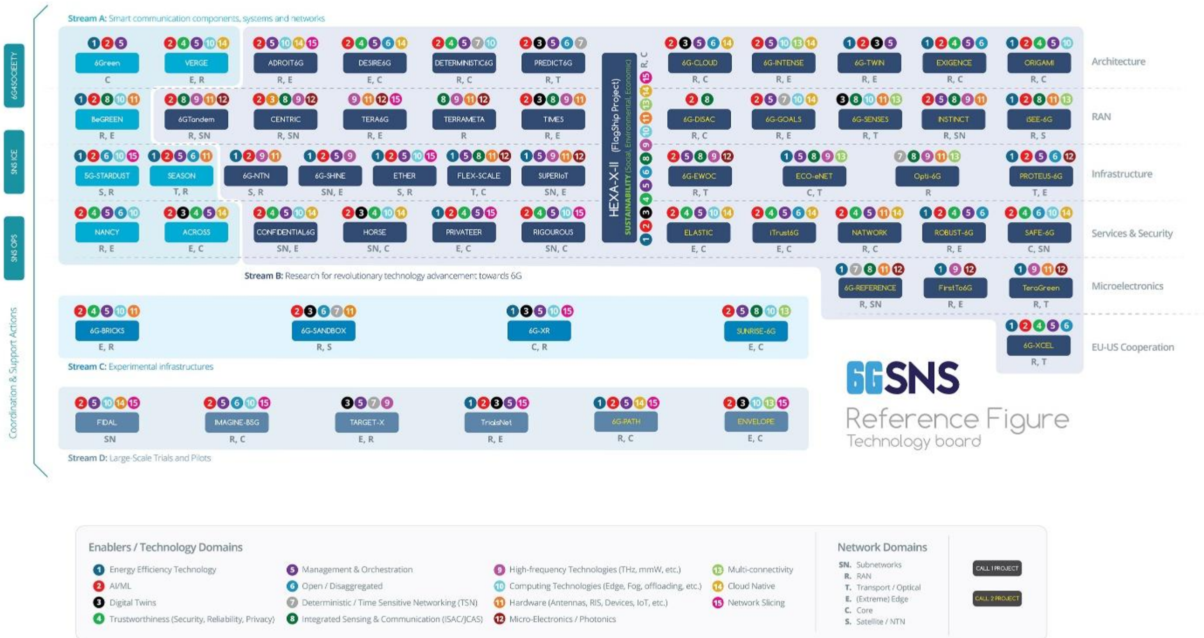


Figure 9: Interactive reference figure of SNS JU Call 1 and Call 2 projects.

An exhaustive analysis of the Interactive Reference Figure indicates that not all the enablers and technology domains are addressed at the same level. Specifically, Figure 10 reveals that AI/ML, from different standpoints, is addressed by a vast majority of projects in the portfolio, whereas deterministic communications and time sensitive networking receive less attention. In more detail, the technological areas being covered by the five most popular technology domains are as follows:

1. **Artificial Intelligence and Machine Learning (AI/ML)**: Projects developing AI/ML solutions applicable at various levels, including user equipment, network, and applications.
2. **Management and Orchestration**: Efforts aimed at automating resource planning, deployment, and orchestration of network components, including zero-touch management.
3. **Sustainable Energy**: Projects focused on integrating environmental considerations into the design, deployment, and operation of future wireless communication systems, including energy-efficient architectures, use of renewable energy sources and eco-friendly materials and policy frameworks.
4. **Computing Technologies (Edge, Fog, Offloading)**: Projects enhancing the use of cloud and edge computing functionalities, including edge offloading and cloud-native networking.
5. **Hardware Innovations (Antennas, Devices, IoT)**: Development of advanced hardware components such as antennas, reconfigurable intelligent surfaces (RIS), hardware accelerators, and transceivers.

The analysis of the most popular technological enablers used by SNS JU projects reveals that the global "hot topics" of 6G, also seem to be prioritized by SNS JU researchers, without however neglecting other technologies. The significant variety of enablers used within the SNS JU, guarantees that EU researchers will build an extensive knowledge base regarding 6G technologies, driving European competitiveness in future networks. It has to be noted, that new SNS JU projects commence every year, with a shifting focus depending on the market and technological needs and taking into account analyses such as the one below, to ensure that there are no major gaps in the EU knowledge space. As such, it is expected that almost all relevant technologies will be addressed by EU researchers (to a larger or lesser degree).

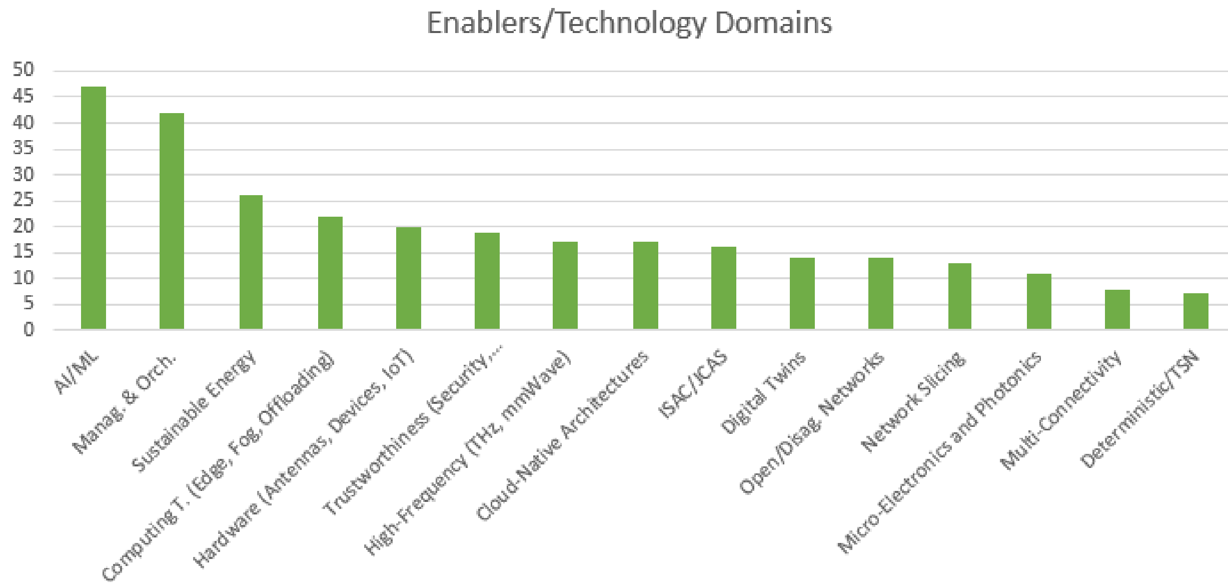


Figure 10: Enablers/Technology Domains addressed by SNS JU Call 1 and Call 2 projects.

2.3 Techritory's 6G Vision

Techritory has been established in recent years, as one of the key EU stages where Strategy and Policy issues regarding the broader telecom sector are discussed, bring together all the major stakeholders from industry and academia to discuss on the future of digital transformation and telecoms. As such, it becomes a birthing ground for the future vision on digital infrastructure, where ideas are discussed and the next steps for 6G are shaped. Techritory's 6G vision emphasizes the development of smart, sustainable ecosystems that foster collaboration between industries, governments, and academia. Their perspective highlights the importance of digital sovereignty, data security, and ethical considerations in the evolution of 6G technologies. Techritory envisions 6G as a platform to drive societal progress, focusing on human-centric applications that improve quality of life, such as smart cities, advanced healthcare systems, and intelligent transport networks. They advocate for cross-border cooperation to ensure interoperability and global standards in 6G deployment.

Techritory emphasizes collaborative innovation and practical deployments through:

- Vertical Integration: A focus on cross-industry collaborations, particularly in sectors like automotive, healthcare, and manufacturing, aligning with Europe's Smart Networks and Services Joint Undertaking (SNS-JU).
- Workshops and Insights: Discussions at Techritory prioritized sustainable and interoperable 6G ecosystems, drawing from trials and use cases to shape the future SNS R&I Work Programme.
- Key Themes: The event underscored the integration of AI, telco cloud evolution, and edge computing to achieve energy-efficient and scalable networks.

Techritory's vision, as expressed by its key stakeholders, nicely complements the global 6G vision in key aspects such as the following:

- Scope: The broad world vision, aiming for universal coverage and technological advancement on a global scale, is nicely complemented by the focused vision of Techritory, zooming in on regional collaboration and ethical governance within 6G ecosystems.
- Focus Areas: The global perspective prioritizes technical performance (speed, latency, energy efficiency), while Techritory also brings to the forefront digital sovereignty, ethical AI, and societal impact.

- Implementation Approach: Globally, the approach is driven by international standardization bodies and large tech corporations. Techritory acts as a preparatory ground for this by encouraging multi-stakeholder engagement, fostering cooperation between public and private sectors to create inclusive, sustainable 6G networks.

Summarizing, the global vision for 6G outlines a broad, ambitious roadmap focusing on technological excellence, sustainability, and global connectivity, while Techritory's vision complements this approach by providing a practical, region-specific perspective that emphasizes industry collaboration, replicable solutions, and sustainable growth. This dual approach contributes towards the holistic development of 6G as a transformative force for societies and economies worldwide.

As 6G continues to evolve, the synergy between global frameworks and regional initiatives like Techritory will be critical in shaping a connected, intelligent, and sustainable future.

2.4 Analysis & Discussion

Taking into account the global 6G vision and the EU/SNS JU vision as summarised in this section, certain interesting insights can be derived regarding the alignment of the EU/SNS JU and global visions. Overall, it can be said that the EU/SNS JU vision of 6G is well aligned with the global trends and discussions, matching to a significant degree in all researched categories (KPIs, Use Cases, Enablers) and maintaining the momentum that was built over the last couple of years. It comes as no surprise that EU/SNS JU stakeholders prioritize certain aspects of the 6G vision / research which better fit the social, economic and market needs of EU, focusing on industries and services that are traditionally strong in Europe such as Industry 4.0, Automotive, Smart City/Tourism, etc.

Moreover, SNS JU researchers seem to be expanding the current global discussions on 6G evaluation methodology and frameworks, by proposing novel KPI categories and metrics to facilitate the evaluation and validation of new technologies and/or services that did not exist before. EU/SNS researchers seem to place significant emphasis on sustainability and energy efficiency aspects of future networks, pushing the envelope in terms of sustainable architectural approaches and sustainability frameworks, proposing novel measurement frameworks and metrics such as the Key Value Indicators (KVIs).

More specifically, the following key insights regarding the alignment of the EU/SNS JU 6G vision with the global trends can be extracted based on the presented analysis:

- **Strong alignment** of the EU/SNS JU vision can be observed with the global trends and research initiatives, sharing common priorities and exploring similar avenues of development with other regions of the world.
- **No major gaps were detected** in the EU/SNS approach in terms of investigated technologies, prioritized use cases and considered 6G KPIs.
- **Significant research portfolio diversification & multi-disciplinary approach** of SNS JU projects allows for very good coverage of all major considered technologies and use cases (both popular and more obscure), facilitating EU leadership in major 6G aspects and allowing for strong validation/verification of results.
- **Alignment with major global technological trends** (AI-native, Edge/Cloud-native, ISAC, etc.) but at the same time **strong focus on EU stakeholder needs and EU societal/economical values** (Sustainability / Energy Efficiency, Security / Privacy, HW development (antennae, etc.)).
- **Alignment in prioritization of Use cases and services with the global consensus**, working on immersive / XR/AR, Digital Twins, Robots/Cobots, but also **focusing on traditional EU industries and applications** for day 1 deployments (autonomous mobility, Industry 4.0, Smart City/Tourism).
- **In pace with global consensus to focus on ITU-R defined KPI targets [4],** but at the same time working on the **development of novel KPI and KVI families and measurement frameworks** to facilitate research into EU prioritized aspects.

3 Global Focus Themes (vs SNS)

The previous section presented a high-level comparative study among the EU/SNS JU and the global 6G research priorities in terms of KPI targets, use cases and technological enablers, painting a high-level picture of the priorities in terms of 6G research around the world. This section delves a bit deeper into specific technological themes, presenting in more detail the work and vision of key global regions on specific 6G aspects and technologies and how they compare with the relevant initiatives in Europe and the SNS JU. This section helps to get a better understanding of the priorities and focus of each global region, facilitating targeted actions of common interest.

3.1 6G Architecture

One of the key aspects of the development of 6G networks is related to the design of the 6G architecture. Various activities and proposals are ongoing at the global level. This section summarizes these activities and places the European priorities at the global picture.

3.1.1 Overview of global research efforts on 6G Architecture

3.1.1.1 United States

The Alliance for Telecommunications Industry Solutions (ATIS) established the Next G Alliance (NGA) to position North America at the forefront of 6G wireless technology development. The NGA's comprehensive "Roadmap to 6G" [23] outlines key trends and priorities for the evolving 6G architecture, focusing on six critical goals:

- Trust, Security, and Resilience: Advancing these aspects to ensure future networks are fully trusted by individuals, businesses, and governments.
- Enhanced Digital World Experience: Creating immersive and integrated digital experiences that seamlessly blend the physical and virtual worlds.
- Cost Efficiency: Achieving cost efficiency across all facets of the network architecture to promote widespread adoption and sustainability.
- Distributed Cloud and Communications Systems: Developing distributed cloud infrastructures and communication systems to support diverse applications and services.
- AI-Native Future Network: Integrating artificial intelligence (AI) natively into network operations to enhance performance, adaptability, and efficiency.
- Sustainability: Ensuring that 6G technologies contribute to environmental sustainability and energy efficiency.

To support these goals, the NGA emphasizes the need for a versatile platform capable of supporting a broad spectrum of use cases. This architecture should have the means for spectrum access and sharing mechanisms [24], support of Joint Communication and Sensing (JCAS), intelligent and autonomous management and orchestration [25]. Moreover, NGA advocates for a 6G wide area cloud (WAC) encompassing intelligent and ubiquitous computing, communication, and data services, ranging from regional data centres to on-premise equipment and devices. This architecture aims to seamlessly integrate computing and communication resources, enhancing the network's adaptability and efficiency [26]. Finally, NGA is in favour of a network architecture that supports maximum disaggregation. This approach allows for tailored adaptations to meet specific requirements across various sectors, such as integrating alternative waveforms and enhancing security protocols. A flexible architecture is considered crucial for accommodating diverse applications and services in the 6G ecosystem [27].

3.1.1.2 South Korea

In South Korea various reports suggest that the 6G Architecture should follow the lessons learned from the 5G networks [10]. Thus, the 6G architecture should follow a simplified approach with a minimum number of options being supported. Also, the 6G architecture should take into account the existing networks. On their priorities one may identify:

- AI & cloud-native network
- Green-native network
- Quantum Security Networks
- Disaggregated RANs
- Integration with NTN

South Korea clearly identifies that the 6G Architecture should emphasize the importance of ubiquitous intelligence [11]. According to this view, the future telco infrastructure should evolve toward the introduction of AI at the edge where connectivity, computing, and AI capabilities will be available.

3.1.1.3 Japan

In Japan, the XG Mobile Promotion Forum (XGMF) is working to design the 6G network architecture [29]. XGMF aims to develop an end-to-end (E2E) network architecture tailored for 6G-era use cases. Central to this initiative is the implementation of a cloud-native network architecture that leverages two key technologies:

• All Photonics Network (APN): This technology focuses on utilizing photonics to enhance data transmission capabilities, aiming for ultra-low latency and high-capacity communication.

• Data-Centric Infrastructure (DCI): DCI emphasizes efficient data processing and distribution, supporting the demands of data-intensive applications in the 6G landscape.

By integrating APN and DCI, the project seeks to establish a robust infrastructure that supports advanced 6G use cases, such as AI-driven services and autonomous systems.

Moreover, Japan's Beyond 5G Promotion Consortium in its "Beyond 5G White Paper Version 3.0," [28] addresses key issues for the beyond 5G Architecture. The issues include:

- Network Resources and Computing Resources functions through the collaboration of Real-world Digital Twin for society and Network Digital Twin for infrastructure.
- Computing Resources that are distributed throughout the entire infrastructure on-demand.
- Autonomous management, optimization and fault tolerance for the entire infrastructure.
- User-centric communication, where necessary communication functions are secured from the Beyond 5G infrastructure based on User intent.
- Wide-range application of AI applies

3.1.1.4 China

The IMT-2030 Promotion Group (PG) is working on a 6G architecture and 6G key technologies, to promote consensus formation [30]. In relation to the 6G network architecture the main architectural priorities include

- Space-Air-ground integrated network
- AI native network
- Deterministic networking
- Computing aware network

- Information centric network
- Digital twin network

IMT-2030 PG also promotes the necessary security evolution (e.g., in terms of 6G blockchain technology requirements and scenarios).

3.1.1.5 India

The Telecommunications Standards Development Society, India (TSDSI) has outlined several key priorities for 6G architecture to address evolving business models and user expectations. Central to their vision is the emphasis on a distributed and hierarchical network architecture with computing integrated as a native component. This approach aims to facilitate new end-user scenarios and alleviate monetization challenges faced by operators [31]. In a recent report [32], TSDSI is focusing on the following architectural aspects:

- Framework for AI/ML operation splitting in 6G context,
- Recommendations for sustainable 6G networks
- Coreless RAN
- Rural broadband services architecture for operational framework and marketplace design
- Cloud interoperability

3.1.2 Overview of European Activities for the 6G Architecture

Very recently, 6G-IA, in collaboration with the SNS JU flagship project and various additional SNS projects, has released the European Vision for 6G networks [5]. In this document, clear trends for the European priorities for 6G networks are depicted. More specifically, the document identifies the need for 6G changes based on the identified challenges to extend IMT-2020 (e.g., unstainable RAN virtualization, poor interoperability among RAN components, extreme MIMO processing complexity, growing energy consumption, etc.), the need for ubiquitous connectivity (e.g., lack of global, open and easy to use APIs, integration of terrestrial and non-terrestrial networks, etc.), the need for native AI support across all network segments and functions and the introduction of integrated communication and sensing solutions.

For all these visions, the white paper presents an extended list of solutions that are under development in the SNS JU. The document highlights the need for 12 potential architectural innovation areas in 6G These areas aim to create a more robust, flexible, and sustainable 6G network architecture.

1) **Interoperability**: The network architecture should avoid siloed frameworks for each domain, such as access, RAN, core, and orchestration. A focus on integrating AI/ML solutions and ensuring open data circulation through APIs is key to enhancing interoperability.
2) **Resource Awareness – Resource Brokering**: With new technologies, data gathering solutions for AI/ML, and closed control loops integrated into the infrastructure, there is a need for resource-awareness in the architecture. This will enable efficient resource brokering, particularly for user-plane activities, to improve sustainability, such as reducing energy consumption in RAN.
3) **Service-Awareness**: The need for deeper integration of data, computing, and network infrastructure at the service level is critical. Extending the 5G network slicing framework to be more programmable and accessible for vertical service providers is a key focus, along with simplified APIs for seamless integration of non-communication network functions.
4) **Enriched Exposure for Multi-Tenant Federation**: Enhancing federation capabilities within the network through enriched exposure interfaces will enable better integration of external entities, such as

application service providers and other network operators. This includes the federation of network planes like CP, UP, and newer planes like sensing and NI.

5) **Deeper Integration of the UE**: Optimizing UE-driven aspects, such as mobility and authentication, and scaling data utilization from terminals will require architectural support. Extending the Service-Based Architecture (SBA) toward the UE is suggested to better integrate the UE in the network and service management.
6) **Architectural Support for AI/ML**: The architecture should support open data circulation, enabling the harvesting of data for AI/ML. Additionally, the lifecycle management of AI/ML models, including training, re-training, and reconfiguration, should be directly integrated into the architecture to enhance network functions.
7) **Support for Dependable Communications**: Reliability, dependability, and resilience must be incorporated into the 6G architecture through specific modules designed to ensure these aspects across all services and network players.
8) **Support for ISAC**: The 6G architecture should extend and support integrated sensing and communication (ISAC) systems, embracing AI-driven architectures and advanced radio technologies like multi-functional RIS and cell-free architectures to enhance performance and energy efficiency.
9) **Seamless Integration Between TN and NTN**: The integration of Non-Terrestrial Networks (NTNs) poses challenges in supporting unified 3D multi-layer and multi-connectivity paradigms. This will involve flexible onboard processing, distributed RAN deployment, and direct satellite connectivity for seamless mobility.
10) **Enhanced Support for Security, Privacy, and Trustworthiness**: Security and trustworthiness, covering safety, privacy, resilience, and reliability, must be enhanced in 6G. This includes the development of novel solutions for end-to-end security, exploring quantum-resilient encryption methods to protect against future quantum-enabled attacks.
11) **Network Simplifications**: To reduce complexity and cost, the architecture should avoid multiple deployment options and protocol splits, focusing on simplifying protocols and minimizing unnecessary signalling, especially between CU-DU splits.
12) **Sustainability**: The 6G architecture should focus on optimizing energy consumption and operational costs for enhanced sustainability. Sustainability is intertwined with the architecture and will be a major factor in its design.

These 12 innovation areas will form the foundation for designing the 6G architecture, building upon the 5G system while incorporating new design concepts, functional building blocks, and interfaces. This will enable the realization of the 6G technology enablers and use cases envisioned for the next generation of mobile networks.

Overall, and based on the information provided earlier about research priorities in other global regions, it is safe to state that the European priorities and areas covered for 6G networks, are compatible and cover all aspects identified also by other regions.

3.2 Wireless Tech (THz, JCAS, spectrum)

The development of 6G is driven by the need for unprecedented data rates, ultra-low latency, and seamless connectivity across diverse environments. To achieve these ambitious goals, key technologies such as ultra-massive multiple-input multiple-output (UM-MIMO), Terahertz (THz) communications, joint communication and sensing (JCAS), and the utilization of the Frequency Range (FR3) band (7-24 GHz) will play a crucial role. These innovations align with the stringent requirements outlined in the IMT-2030 framework, which envisions a network capable of supporting extreme capacity, ubiquitous connectivity, and native integration of AI-driven applications.

Ultra-massive MIMO significantly expands upon traditional MIMO systems by deploying large-scale antenna arrays that enhance spectral and energy efficiency, particularly in high-frequency bands. Complementing this, THz communications enable ultra-high data rates in the Tbps range, addressing the increasing demand for bandwidth in data-intensive applications such as holographic communications and extended reality (XR). Meanwhile, JCAS merges communication and sensing capabilities, allowing for advanced situational awareness and enabling applications such as high-precision localization and environmental mapping. The FR3 band, bridging the gap between sub-6 GHz and mmWave frequencies, offers a compelling mix of coverage and capacity, making it essential for enabling flexible and efficient 6G deployments. These technologies are fundamental to realizing the transformative vision of IMT-2030.

The significance of these technologies has also been recognized in the Wireless Communications and Signal Processing Workshop organized by the 6G Smart Networks and Services Industry Association (6G-IA) in April 2024 [33]. As a result, they have been identified as key priorities for inclusion in the upcoming Research & Innovation (R&I) work programmes of the SNS JU for the 2025-2027 period. Countries like the USA, South Korea, Japan, China, and India are actively engaging in research and development to pioneer these critical technologies too. The following sections are aimed to review their respective strategies and main actors involved.

3.2.1 Overview of global Wireless research efforts

3.2.1.1 United States

The **Alliance for Telecommunications Industry Solutions** (ATIS) has been instrumental in steering North America's trajectory toward 6G through its Next G Alliance. In March 2024, the Next G Alliance released a pivotal white paper titled "6G Radio Technology Part I: Basic Radio Technologies," [34] which focuses on foundational aspects of future radio technologies. This document emphasizes the need for integration of JCAS within cellular systems, highlighting its potential to foster new business opportunities in the 6G era for areas like autonomous vehicles and smart city infrastructures.

The paper also addresses the challenges of utilizing higher frequency bands. However, challenges such as significant path loss and atmospheric absorption at THz frequencies entail advanced research in materials, device fabrication, and signal processing techniques. Complementarily, the white paper also underscores the necessity for advanced MIMO designs, innovative waveform and modulation schemes, and energy-efficient network architectures to harness the full potential of these frequencies.

Regarding communications in FR3, the alliance's positioning papers highlight the necessity for regulatory advocacy to allocate and harmonize FR3 spectrum for commercial use, ensuring that the companies remain competitive in the global telecommunications landscape.

Complementarily, **NIST's "NextG Communications Research and Development Gaps Report**” [35] highlights the importance of joint communications and sensing (JCAS) in future networks. The report identifies research challenges and opportunities associated with integrating radar sensing capabilities into broadband and internet-based networks. Key focus areas include developing hardware that supports Massive MIMO antenna arrays and full-duplex circuits, as well as creating new multi-frequency spectrum processing algorithms and suitable channel models that accurately characterize joint communication and radar propagation environments. While the report outlines strategic directions rather than specific funding allocations, it serves as a foundational document guiding future investments in joint communications and sensing research.

The **Federal Communications Commission** (FCC) has also been proactive in exploring the potential of higher frequency bands. In its "6G RF Spectrum Horizons" white paper [36], the FCC discussed the possibilities of opening up spectrum above 95 GHz for experimental licenses, aiming to foster innovation in THz communications. In 2024, the FCC allocated 21.2 GHz of spectrum for unlicensed use in the 0.1 to 0.3 THz range, promoting innovation in high-frequency communication technologies. This regulatory support enables researchers and companies to explore new applications in the terahertz band, including ultra-massive MIMO technologies.

The **National Science Foundation** (NSF) has been instrumental in advancing research in next generation communications. Several NSF programs have been established to support these technologies:

- Resilient & Intelligent NextG Systems (RINGS) Program [37]: Launched in 2021, the RINGS program aims to accelerate research in areas impacting Next Generation (NextG) wireless and mobile communication, networking, sensing, and computing systems. The program focuses on enhancing resiliency and performance, including advancements in ultra-massive MIMO technologies. RINGS has allocated approximately $37.5 million to $40 million (€34.5 million to €36.8 million), anticipating 36 to 48 awards, each up to $1 million (€920,000) over three years.
- Spectrum and Wireless Innovation Enabled by Future Technologies (SWIFT) Program [38]: The SWIFT program supports research on innovative spectrum utilization and management, encompassing joint communication and sensing. It encourages exploration of large-scale MIMO systems, intelligent surfaces, and terahertz communications. The program seeks to develop novel architectures, system designs, and algorithms to improve system performance, addressing challenges such as channel and device uncertainties at higher frequencies.
- Communications, Circuits, and Sensing-Systems (CCSS) Program [39]: The CCSS program supports innovative research in circuit and system hardware, as well as signal processing techniques. It covers areas such as radio-frequency circuits and antennas for communications and sensing, communication systems and signal processing, and dynamic bio-sensing systems. The program encourages research proposals based on emerging technologies and applications, including high-speed communications at terabits per second and beyond, sensing and imaging covering microwave to terahertz frequencies, and integrated sensing and communication systems.

The **Defence Advanced Research Projects Agency (DARPA)** has a history of supporting cutting-edge research in communication and sensing technologies. These initiatives aim to develop methods for radar-communications cooperation and co-design, enhancing the performance of both systems when sharing spectrum. Recently, it has also recognized Terahertz communications and sensing as pivotal technologies with potential impacts surpassing that of the internet [40]. While specific funding amounts for individual projects were not disclosed, DARPA's investment underscores its commitment to advancing terahertz technologies for national security applications.

3.2.1.2 South Korea

South Korea's **5G Forum** has been actively engaged in outlining the roadmap for technologies beyond 5G. In its position paper "5G Evolution and 6G Strategy," [41] the forum identifies THz communications and JCAS as key components of future networks. The document emphasizes the role of THz frequencies in delivering terabit-per-second data rates, which are essential for next-generation applications such as ultra-high-definition streaming and advanced telepresence. Additionally, there is a concerted effort to develop advanced materials and components, such as high-efficiency power amplifiers and sensitive receivers, critical for the practical implementation of THz communication systems. It also discusses the convergence of communication and sensing technologies to enable new services like precise environmental monitoring and advanced driver assistance systems. The forum calls for a comprehensive approach that includes research into new materials, device technologies, and system architectures to address the challenges inherent in these high-frequency bands.

The **Electronics and Telecommunications Research Institute** (ETRI) in Korea has published a white paper entitled "Future Spectrum Strategy," which among other bands examines the prospects of utilizing the FR3 band for future wireless communications. The paper discusses the potential of the 7–24 GHz range to provide a balance between coverage and capacity, making it suitable for a variety of applications, including enhanced mobile broadband. It also highlights the technical challenges, such as spectrum sharing and coexistence with existing services, and proposes research directions to develop solutions that can effectively manage these issues.

In February 2023, the **Ministry of Science and ICT** (MSIT) unveiled the **K-Network 2030** Strategy [42] aiming to commercialize 6G services by 2028, two years ahead of the initial schedule. This strategy includes a substantial investment of KRW 625.3 billion (approximately €480 million) dedicated to research and development of core 6G technologies. The funding focuses on locally producing materials, components, and equipment essential for future 6G networks, encompassing research on ultra-massive MIMO and terahertz communications. Additionally, the strategy emphasizes the development of low-orbit satellite communication technologies to support 6G infrastructure.

The **Institute for Information & Communications Technology Planning & Evaluation** (IITP) has been instrumental in supporting fundamental research across various scientific domains. In 2024, IITP announced an investment of over KRW 172.9 billion (approximately €130 million) to secure leadership in communication growth engines and generational evolution, including the commercialization of 6G [43]. Specifically, KRW 20.6 billion (approximately €15.6 million) is allocated for developing next-generation communication network industrial technology, such as 6G, and KRW 6.2 billion (approximately €4.7 million) supports core technology development for 3GPP-based satellite communication terminals.

South Korea has also engaged in **international collaborations** to bolster its 6G research efforts. Notably, the University of Oulu in Finland and ETRI in South Korea have partnered in a collaborative research project to develop an advanced system architecture for 6G systems. This project, part of the 6G Bridge program, is funded by Business Finland and the South Korean Ministry of Science and ICT as separate yet complementary projects [44]. In the context of the SNS JU R&I Work Programme, a joint EU-KOR call was also launched in 2023.

3.2.1.3 Japan

Japan's Beyond 5G Promotion Consortium has been instrumental in shaping the country's vision for next-generation communications. In March 2024, the consortium released its "Beyond 5G White Paper Version 3.0," [28] which summarizes issues and expectations from various industries for Beyond 5G, capabilities required, and technological trends. In this whitepaper the consortium outlines strategic priorities, including the exploration of THz band communications and the development of JCAS technologies. The document underscores the necessity of THz communications to achieve data rates exceeding 100 Gbps, which are imperative for applications like real-time holographic displays and high-fidelity virtual reality. It also details ongoing research into THz wave propagation characteristics, aiming to develop models that accurately predict signal behaviour in various environments. It also discusses the integration of communication and sensing capabilities to enhance situational awareness in autonomous systems and improve the efficiency of real-time traffic monitoring and infrastructure health assessments. Regarding communications in FR3, Japan is exploring the allocation and utilization of the 7-24 GHz spectrum to enhance network capacity and support diverse applications. The consortium emphasizes the importance of international harmonization of FR3 spectrum to ensure seamless global interoperability.

The **Ministry of Internal Affairs and Communications** (MIC) of Japan has also released a position paper focusing on the utilization of the FR3 spectrum. The document, entitled "Future Vision of Radio Spectrum Policy," [45] explores the potential of the 7–24 GHz band to support enhanced mobile broadband and ultra-reliable low-latency communications. It highlights the need for technological advancements in antenna design, signal processing, and interference mitigation to fully harness the capabilities of this spectrum range. In 2022, the MIC allocated approximately ¥30 billion (around €230 million) to support various projects in the areas of interest identified in the Beyond 5G Promotion Consortium white papers. Specific areas of investigation include the development of large-scale antenna systems for ultra-massive MIMO to enhance spectral efficiency and the exploration of THz frequency bands for ultra-high-speed data transmission.

On the private side, **NTT DOCOMO** and **NTT** announced in June 2022 collaborations with leading mobile technology vendors, including Fujitsu, NEC, and Nokia, to conduct experimental trials of new mobile communication technologies aimed at the commercial launch of 6G services by around 2030 [46]. These trials focus on several key areas such as (i) ultra-massive MIMO, to develop advanced antenna systems to enhance data throughput and connectivity; (ii) THz communications, targeted at exploring the use of sub-terahertz frequency bands above 100 GHz for ultra-fast data transmission; (iii) JCAS, aimed to integrate AI-based wireless transmission methods to improve both communication and sensing capabilities; and **FR3 Communications**, with the purpose of Investigating the utilization of new 6G frequency band to expand communication coverage.

3.2.1.4 China

China's IMT-2030 (6G) Promotion Group has been at the forefront of 6G research and development. In its white paper "6G Vision and Candidate Technologies" [47] the group identifies THz communications as a cornerstone for achieving ultra-high-speed data transmission and low-latency communication. The document discusses the potential applications of THz technology, including high-capacity backhaul networks and immersive multimedia experiences. It also explores the integration of communication and sensing functionalities to support smart manufacturing, autonomous transportation, and environmental sensing.

Additionally, the **China Academy of Information and Communications Technology (CAICT)** has released a position paper titled "Mid-Band Spectrum Planning for 6G," which examines the utilization of the FR3 spectrum. The paper highlights the importance of the 7–24 GHz band in providing a compromise between coverage and capacity, making it suitable for diverse applications such as enhanced mobile broadband and mission-critical communications. It also discusses the technical considerations, including spectrum allocation strategies, interference management, and the development of compatible hardware, to fully exploit the potential of this frequency range.

Concerning research funding, the **Ministry of Science and Technology** (MOST) oversees the National Key Research and Development Program, which addresses critical scientific and technological challenges. In 2022, MOST allocated significant funding to projects under this program, focusing on advanced communication technologies, including ultra-massive MIMO and terahertz communications[4]. Complementarily, the **National Natural Science Foundation of China** (NSFC) supports fundamental research across various scientific domains. In 2022 too, the NSFC announced multiple Key Programs in the field of Information Sciences, encompassing areas such as joint communications and sensing. The average direct cost funding for these projects was approximately ¥2.85 million per project over five years, translating to about €390,000 per project [48]. Finally, The **National Development and Reform Commission** (NDRC) plays a pivotal role in strategic economic planning and technological advancement. In 2023, NDRC emphasized the promotion of research and development in 6G and other cutting-edge technologies, including terahertz communications and ultra-massive MIMO. This initiative aims to underpin the construction of a modern industrial system [49].

3.2.1.5 India

India’s efforts in next-generation communication technologies are primarily coordinated by the **Bharat 6G Alliance (B6GA)**, which was launched in 2023 under the Department of Telecommunications (DoT) [50]. India’s **6G Vision Document** [51] published by the **Telecom Regulatory Authority of India (TRAI)** and endorsed by the Prime Minister’s Office, outlines a roadmap for indigenous 6G innovation while ensuring global harmonization with international standards. The document discusses:

- THz communications: India is exploring high-frequency spectrum (100 GHz to 3 THz) for high-data-rate applications. The 6G Testbed, hosted by premier institutions such as IIT Madras, is being leveraged for channel modelling and THz system prototyping.
- Joint Communications and Sensing (JCAS/ISAC): The vision paper identifies ISAC as a key enabler for applications such as Intelligent Transportation Systems (ITS), Disaster Management, and Smart Agriculture. Researchers are working on AI-driven optimization techniques to enhance ISAC performance.

[4] https://en.most.gov.cn/programmes1/200610/t20061009_36224.htm

- FR3 spectrum utilization: India is actively participating in global spectrum discussions through the ITU-R and 3GPP, advocating for efficient FR3 spectrum allocation.

In its pursuit to lead in 6G technology, the Department of Telecommunications of the Indian government has earmarked significant funds for research and development. Specifically, via its **6G Research Funding** the government has allocated ₹10,000 crore (approximately €1.13 billion) over the next decade specifically for 6G research. This substantial investment aims to propel India to the forefront of global 6G advancements supporting, among other areas, projects across ultra-massive MIMO, joint communications and sensing, and FR3 technologies. Complementarily, in August 2024 the **Telecom Regulatory Authority of India** (TRAI) recommended the introduction of a "Terahertz Experimental Authorization" (THEA) to promote R&D and testing in the 95 GHz to 3 THz range with the purpose of encouraging innovation across academia and industry [52].

3.2.2 Spectrum

The 6G-IA Spectrum WG was re-started in August 2024 after it was dormant for some time. This was a necessary step, because the process in ITU-R WP5D towards the definition of IMT-2030 – the ITU term for 6G – is now proceeding with major milestones. The WG has set the following objectives:

- Provide expert views to the 6G-IA Board and contribute to the outcomes of 6G-IA, the 6G Initiative and the SNS JU in the spectrum area.
- Establish and promote a comprehensive and coordinated view of 6G-IA members on spectrum related issues as well as research and results from the different EU funded projects and Working Groups with respect to spectrum topics.
- Promote the view of 6G-IA in spectrum related issues.

The 6G-IA Spectrum WG is actively working towards preparing contributions for the relevant items of ITU-R.

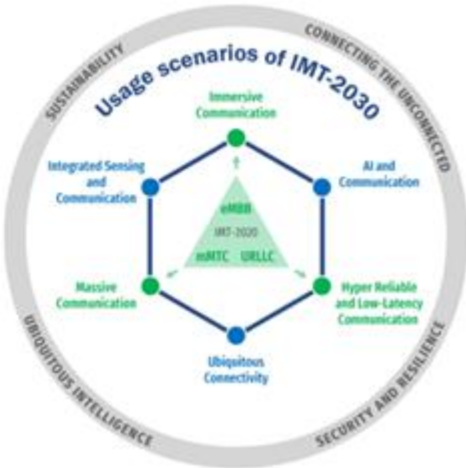
3.2.2.1 ITU-R position on IMT-2030

ITU-R WP5D has prepared its actual position on IMT-2030 in two major documents:

- Future technology trends of terrestrial International Mobile Telecommunications systems towards 2030 and beyond [53] and
- Framework and overall objectives of the future development of IMT for 2030 and beyond [4]

These documents are influencing global research activities as well as specification in international bodies such as 3GPP.

Figure 11 is summarizing the actual view of ITU-R WP5D on IMT-2030, including metrics on capabilities and **targets for research and innovation** [4], which are also compared to IMT-2020 (5G) in [54]. These targets are not yet globally agreed values for technical requirements for standardization and system implementation. They comprise targets for the research community to investigate, whether, how such targets and under which conditions may be feasible.



Usage scenarios and overarching aspects of IMT-2030

Capabilities of IMT-2030 amended by targets for research and innovation compared to IMT-2020

Figure 11: Usage scenarios and capabilities of IMT-2030 based on the actual view in ITU-R WP5D

3.2.2.2 ITU-R timeline for IMT-2030

Figure 12 summarizes the ITU-R timeline for IMT-2030 with major milestones and documents. Major discussions since 2024 are related to technical performance requirements and the forthcoming evaluation of technology proposals for IMT-2030. The research community can contribute to these activities with research results based on consensus building in the SNS JU research program.

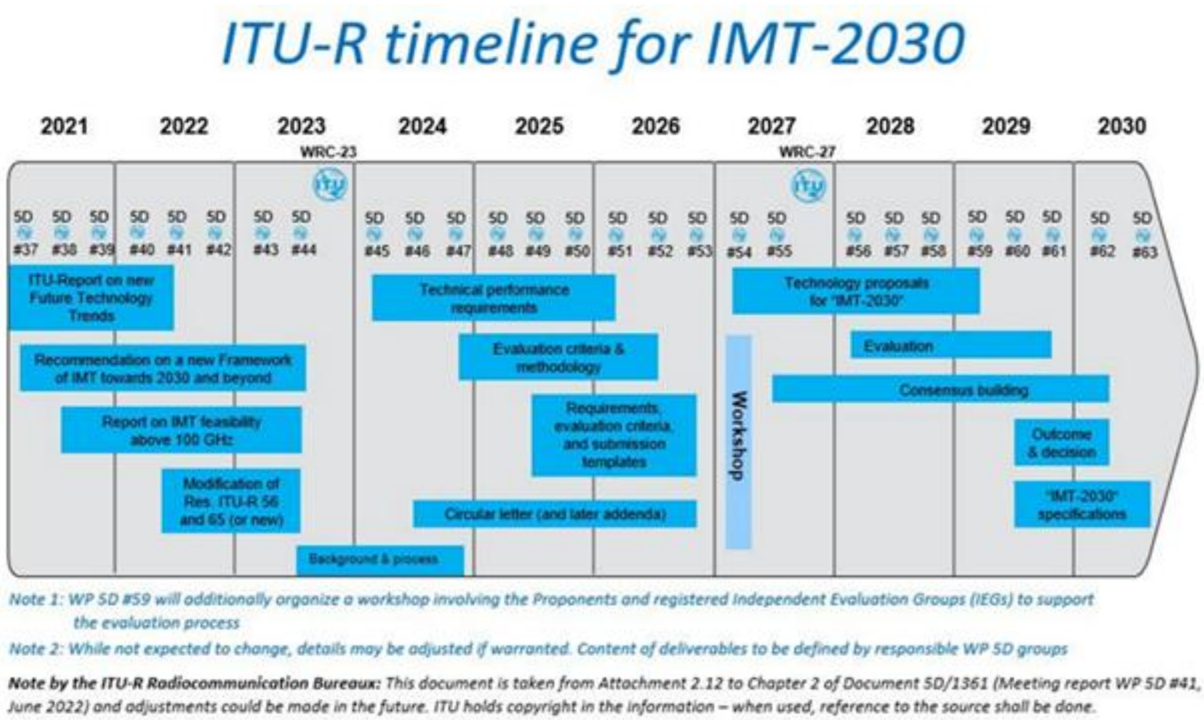


Figure 12: ITU-R timeline for IMT-2030 [4]

3.2.2.3 ITU-R WP5D status and the preparation of WRC 2027

WRC (World Radiocommunication Conference) is the global ITU body, which is discussing and agreeing the identification of frequency bands for basic wireless services, terrestrial and space services sharing frequency bands above 1 GHz**,** space services, broadcasting services, fixed service, amateur services, standard frequency and time signal service, experimental stations, radiodetermination services, radio astronomy service and radio services related to Earth observation. The allocation of frequency bands is done by national and/or regional regulations/administrations.

Currently, ITU-R Study Group 5 / WP5D is preparing WRC-2027 with four Agenda Items on Fixed, Mobile and Radiolocation:

- Agenda items
  - 1.7: 4400 – 4800 MHz / 7125 – 8400 MHz / 14.8 – 15.35 GHz – IMT spectrum
  - 1.8: 231.5 – 275 GHz / 275 – 700 GHz – Radiolocation
  - 1.9: Aeronautical mobile (OR) high frequency modernization
  - 1.10: 71 – 76 GHz / 81 – 86 GHz – Power flux-density / power limits

Only Agenda Item 1.7 supports the identification of additional IMT frequency spectrum. IMT means that spectrum could basically be applied to each IMT system and not only to IMT-2030.

The potential bandwidths of the proposed bands in Agenda Item 1.7 correspond to:

- 4400 – 4800 MHz bandwidth 400 MHz
- 7125 – 8400 MHz bandwidth 1275 MHz
- 14.8 – 15.35 GHz bandwidth 550 MHz

There are no frequency bands above 100 GHz (sub-Terahertz domain) on the agenda of WRC 2027. The next opportunity will most probably be in WRC 2031. Agenda item 1.7 is supported by industry. However, concerns are raised by several European regulators/administrations.

3.2.2.4 Ongoing activities in SNS JU and 6G-IA Spectrum WG

The 6G-IA Spectrum WG is attempting to address key questions such as:

- What is the impact of ITU-R targets for research and innovation on system design and necessary bandwidth, by considering data hungry use cases and multi-operator scenarios for competition or single-operator only
- How do these targets for research and innovation fit to available IMT spectrum and potentially additional spectrum according to WRC 2027 Agenda Item 1.7 (mid band) and which KPIs can be supported with these bands?
- How much additional frequency spectrum would be needed to support ITU-R targets for research and innovation?

Such a position will help the 6G-IA Board to make decisions, whether and how to contribute to ITU-R discussions on the ITU-R Recommendation on "Technical Performance Requirements" by beginning of 2026 and which performance KPIs should be promoted.

The SNS JU TMV WG collected material on considered frequency ranges for 6G and performance KPIs in SNS JU projects and provided this information to the Spectrum WG. SNS JU projects contributed views on Terahertz systems and potential application domains and usage scenarios and contributed to ETSI Group Report "TeraHertz technology (THz); Identification of frequency bands of interest for THz communication systems" [56]. Considered frequency bands are:

- Frequency range 100 – 275 GHz
    - 102 – 109,5 GHz
    - 141 – 148,5 GHz
    - 151,5 – 164 GHz
    - 167 – 174,8 GHz
    - 191,8 – 200 GHz
    - 209 – 226 GHz
    - 231,5 – 239,2 GHz
    - 252 – 275 GHz
    - Other frequency bands between 100 – 275 GHz
- Frequency range 275 – 1 000 GHz
    - Frequency bands 1, 3 and 5 (275 – 296 GHz, 306 – 313 GHz, 318 – 321 GHz)
    - Frequency bands 2 and 4 (296 – 306 GHz, 313 – 318 GHz)
    - Frequency bands 6 and 8 (327 – 333 GHz, 356 – 368 GHz)
    - Frequency band 7 (333 – 356 GHz)
    - Frequency band 9 (391 – 433 GHz)
    - Frequency band 10 (452 – 520 GHz)
    - Frequency band 11 (598 – 722 GHz)
    - Frequency band 12 (786 – 953 GHz)
- Frequency range above 1 000 GHz
    - Frequency band 1 000 GHz – 3 000 GHz
    - Frequency bands 3 000 GHz – 10 THz

Very wide frequency bands would only be available at rather high carrier frequencies, if such bands would be identified in future.

3.2.2.5 Contribution to ITU-R Liaison Statement on minimum requirements for IMT-2030

In October 2024 6G-IA received a "Liaison Statement to External Organizations: Minimum requirements related to technical performance for IMT-2030 radio interface(s)"[57]] with the opportunity to contribute to the definition of minimum requirements:

- *Proposed candidate items for minimum technical performance requirements based on M.2160 Usage Scenarios and Capabilities, including necessary background information and justification, which are requested to be provided preferably by WP 5D #48 (4-13 February 2025)*
- *Proposed associated target values for the above candidate items for the minimum technical performance requirements which are requested to be provided preferably by WP 5D #49 (24 June – 3 July 2025, TBC)*

RIT (Radio Interface Technology) candidates will be evaluated by ITU-R against such minimum requirements. 6G-IA decided to prepare a contribution as response to the first bullet above on items for the WP5D meeting in

February 2025. This contribution provides for each capability in Figure 1 a definition and background information and justification. The document was submitted to ITU-R WP5D in January 2025.

3.3 AI/ML Landscape

The development of 6G is a priority for researchers around the world and AI/ML is an integral part of many of the supporting funding programs. While most countries that include focused research programs on 6G include AI/ML as a component in these programs, several countries have specific programs focused on the use of AI in networks, including the US, China, Japan, South Korea and India. Significant amounts of funding are spent around the world on AI related topics, so understanding the global AI research landscape and ensuring alignment with the European efforts and the SNS JU roadmap is of critical importance.

3.3.1 Overview of global AI/ML research efforts

3.3.1.1 U.S.A

The U.S. has implemented several initiatives to bolster AI research, with considerable funding for each of them. AI-enabled solutions are clearly an important part of U.S.'s digitalization policy.

- **National AI Research Institutes [58]**: Launched by the National Science Foundation (NSF), this program funds collaborative research across various sectors. Grants average $4 million per year over five years, focusing on areas like machine learning, robotics, and AI-driven innovation. Key focus areas of this programme comprise foundational AI research in machine learning, robotics, natural language processing (NLP), AI in STEM education, AI for climate-smart agriculture, and trustworthy AI. In terms of AI Models and methodologies, the program prioritizes reinforcement learning, generative AI models like transformers, and interpretable machine learning. Research also focuses on adversarial robustness and hybrid AI systems combining symbolic and statistical methods. Collaboration with public institutions and private companies enables access to large datasets in education, climate science, healthcare, and transportation.
- **National AI R&D Strategic Plan [59]**: Updated in 2023, this plan outlines the federal government's roadmap for AI research and development, emphasizing ethical considerations and international collaboration. Key focus areas of this plan comprise Ethical AI, workforce development, and cross-disciplinary AI applications (e.g., AI for science and engineering). The plan considers scalable deep learning models and federated learning to ensure data privacy, as one of its cornerstones and it includes federal open data repositories like Data.gov, healthcare datasets, and simulation-generated data for experiments.
- **AI Safety Institute [60]**: In November 2023, the U.S. established an AI Safety Institute under the National Institute of Standards and Technology (NIST) to evaluate and ensure the safety of advanced AI models. The main focus of this institute is the evaluation of advanced models for safety, fairness, and transparency, ensuring robustness against unintended outcomes. It emphasizes safety testing for large language models (LLMs) and autonomous AI systems and they use benchmarks like OpenAI's Evals, NIST datasets, and synthetic datasets created for model testing.

3.3.1.2 China

China has made significant investments in AI research over the past years, while the interest keeps growing among researchers. Based on available information a National AI development plan could be identified as well as dedicated projects to boost computing capabilities to support AI model training and operations.

- **National AI Development Plan [61][62]**: China aims to become a global leader in AI by 2030, focusing on areas such as intelligent robotics, autonomous vehicles, and AI-driven healthcare solutions. Key Focus Areas of its National plan include AI-driven diagnostics, autonomous vehicles, urban planning, and defence technologies. The plan heavily invests in large-scale pre-trained models like WuDao 2.0, multimodal AI, and deep reinforcement learning for robotics. In terms of data sources Nationalized data collection efforts, such as government-controlled healthcare, traffic, and social media data, as well as synthetic data generated via AI models, are being sourced.
- **Exascale Computing Projects [63]**: China is developing exascale supercomputers, such as Tianhe-3 and Sunway OceanLight, to enhance AI research capabilities, with the aim to enhance computational power for large-scale AI training, focusing on exascale AI simulations for complex scientific problems. Optimization of AI training pipelines for hyper-large language models (HLLMs) and neural architecture search, seem to attract most of the interest, using simulation-generated datasets for physics, climate modelling, and genomics, supplemented by vast amounts of public data controlled by government initiatives.

3.3.1.3 Japan

Japan's government is actively promoting and heavily investing in AI research, which is considered a major building block for further technological development in other sectors as well. Japan's **AI Strategy 2023 [64][65]** is Spearheaded by the Ministry of Economy, Trade, and Industry, and focuses on integrating AI across various industries, including Manufacturing, Healthcare, and Transportation. Key focus areas include AI for societal challenges such as an aging population, disaster management, and industrial automation. Japanese researchers target developments in neuromorphic computing, energy-efficient AI models, and real-time decision-making algorithms. Data Sources include healthcare and disaster-related data, as well as smart city IoT sensor data, leveraged by the existence of public-private partnerships.

Additionally, Japan actively participates in the AI Safety Institute [60], where it contributes towards the reliable and safe operation of AI models with a focus on autonomous driving and robotics. Some of the most prominent work of Japanese researchers focuses on reliability testing for Deep Neural Networks (DNNs), particularly in safety-critical systems like drones and medical devices.

3.3.1.4 South Korea

South Korea is treating AI as a way to enhance its global competitiveness, thus investing heavily both in National AI research projects as well as on international collaborations

- **AI R&D Investment - National Strategy for Artificial Intelligence** [66][67]: In 2024, the government allocated $585 million to domestic AI research and development, focusing on areas like AI semiconductors and autonomous driving technologies and AI powered healthcare. South Korean researchers prioritize the development of edge AI, real-time NLP systems for the Korean language, and ultra-low power AI chips. In terms of data sources, they utilize national digital health databases, traffic data, and data collected from smart factories.
- **Horizon Europe Collaboration** [68]: South Korea has joined the EU's Horizon Europe program, facilitating international collaboration in AI research. This move strengthens international collaboration in AI research, focusing on shared challenges like climate change and renewable energy, while the joint research projects put their emphasis on cooperative AI systems.

3.3.1.5 India

India has launched a National Strategy for Artificial Intelligence to position itself as a global leader in AI and in parallel it has commissioned the production of an exascale computer to advance its AI research:

- **National Strategy for Artificial Intelligence [69][70]**: Launched in 2019, this strategy aims to make India a global leader in AI by 2030. Key focus areas include AI for inclusive growth in healthcare, agriculture (precision farming), and education (personalized learning). The methodology followed focuses on low-resource AI solutions, interpretable models, and AI that addresses language diversity (e.g., Indic language NLP models). Indian research leverages data from national initiatives like Aadhaar[5], AgriStack[6], and publicly available health records under the National Digital Health Mission.
- **Exascale Computing Initiative [70]**: India plans to develop an exascale supercomputer, named Param Shankh, powered by an indigenous 96-core processor, to advance AI research. This supercomputer will be used to optimize deep learning frameworks and perform simulations for climate prediction, genomics, and materials science,

3.3.2 Overview of European AI/ML research efforts

The European Union (EU) has initiated comprehensive programs to advance AI and promote AI-enabled technologies in multiple fields. A €2.6 billion research funding program running from 2021 to 2022 under **Horizon Europe**, supports AI projects that drive innovation and address global challenges while an innovation package has been established to reinforce AI research, with multiple initiatives valued up to €4 billion for the period 2021-2024 [71]. Some key focus areas for the European program comprise healthcare, energy efficiency, climate change mitigation, and smart cities. European AI research seems to prioritize explainable AI (XAI), graph neural networks, and AI-driven optimization algorithms for industrial automation. Open science cloud platforms, geospatial datasets (e.g., Copernicus Earth observation data), and patient health records under GDPR-compliant frameworks are some of the sources currently used for AI training.

Additionally, the EU is developing the AI Act [72] to establish a comprehensive legal framework for AI, aiming to foster trustworthy AI that respects fundamental rights and ethical principles. The framework is set to encourage research into bias detection and mitigation methods, ethical design practices, and regulation-compliant AI frameworks.

Recently the Smart Networks and Services Joint Undertaking (SNS JU) Technology Board (TB) issued a white paper [73] on the methodology, approach, mechanisms and data used by SNS JU R&I projects to develop AI-solutions that will optimize 6G networks functionality and/or will create new services. AI is treated as a critical building block of the future networks by SNS JU projects, as they work towards AI-native 6G networks. Based on the analysis presented in [73] there are currently approximately 200 AI-enabled mechanisms being developed by SNS JU projects targeting network and service level optimizations for 6G. 45% of these mechanisms focus on RAN optimization, addressing complex challenges such as resource allocation, interference management, and beamforming, while device optimization and network energy efficiency are also widely addressed via AI mechanisms. Explainable AI is indeed among the priorities of researchers while in terms of data sources a variety of synthetic (41%), real (33%) and mixed (16%) data sources are used.

Based on the analysis presented above, EU efforts in the field of AI/ML seem to be well aligned with the global efforts in terms of approach, methodology and utilized AI models. Data sources for training remains a significant pain point for all AI researchers and Europe should make significant efforts to create, maintain and develop datasets originating from various fields that may be safely used for AI training. European efforts appear to pay special attention to explainable AI and applications relevant with sustainability, energy-efficiency and climate

[5] https://uidai.gov.in/en/

[6] https://www.india.gov.in/agri-stack-portal

change, while each of the global regions seem to focus on their respective heavy industries, that comprise a big part of their GDP. A significant point of attention is the importance that certain global regions give to the development of supercomputers (exascale) to support the further development and training of even more advanced AI mechanisms. Europe has also set forth significant ambitions regarding High Performance Computing via the EuroHPC JU[7], however increased effort to link it with the 6G and AI development activities should take place. A common roadmap of development and convergence and close collaboration of researchers from all 3 fields, would greatly benefit innovation in all fields.

3.4 Cloud

In 6G, connectivity services and compute capabilities will be combined. Specifically, the compute capabilities will be used to support virtualised network control and AI-based network optimization. Moreover, the 6G compute capabilities will be used for all the intelligent user applications that 6G will support. While the compute for the applications can be provided at the cloud, some other tasks require processing close to the end-user or the distributed network elements. Such tasks include time critical applications and control of the network infrastructure. Therefore, a 6G telco edge-cloud continuum is required which stretches from (hyperscaler) cloud to distributed edge locations.

Currently, multiple United States based hyperscalers are dominating the market of IT-cloud services. Regarding providing edge/cloud services, European players, e.g., network operators with distributed infrastructure, could play a role. However, edge computing in Europe is still at its infancy [74], which creates a potential dependency on the large global hyperscalers. Considering that the European digital society depends amongst others on 6G, European sovereignty of telco cloud is a concern for European telco stakeholders. To support different business models, where next to hyperscalers different European providers can also play a role, it is important to create a disaggregated 6G architecture with standardized interfaces [75].

Telco cloud has been addressed by the European Commission by publishing the white paper “How to master Europe’s digital infrastructure needs?” [74]. In this white paper, the “Connected Collaborative Computing” Network (“3C Network”) is discussed, which is aimed to be a European-wide telco edge/cloud. The global association of mobile operators (GSMA) supports this initiative, as well as efforts between the public and private sectors which will provide the required developments and innovations to realise the 3C network [76]. In addition, the 6G-IA published the position paper “European Vision for the 6G Network Ecosystem” [5], to address the telco cloud sovereignty. Specifically, the European stakeholders expectations for a cloud native network are addressed and the need for solution developments to enable the edge-cloud continuum is highlighted. Finally, a workshop between cloud experts from SNS and other European research initiatives has been organized in regards to the European 6G research and its relevance to cloud [77].

3.4.1 Three roles of cloud for 6G

Cloud plays the following three roles in 6G, with each role having its own requirements and considerations:

- Supporting 6G functions

  This is the basic role of cloud in 6G, with the mobile network functions being supported in a telco edge/cloud. Already with 5G networks, the 5G service-based architecture enables the 5G core network can be deployed in the cloud. In 6G, parts of the radio functionality are also envisioned to be implemented in the edge/cloud. Due to the stringent latency requirements that radio functionalities have, a deployment in the edge is deemed appropriate. Moreover, the AI processing needed for network optimization is also envisioned to be implemented in the edge/cloud, as well as other network functions, e.g., for media processing or positioning. Additionally, functions that process or forward large amounts of data, e.g., gateways, cloud RAN, or AI optimization, may require processing capabilities beyond of

[7] https://en.wikipedia.org/wiki/European_High-Performance_Computing_Joint_Undertaking

what Central Processing Units (CPUs) offer. Network control functions such as session management rely on general cloud compute and storage capabilities.

Another aspect is that 6G networks will be multi-provider with interconnect and roaming interfaces between different network operators. The underlying cloud layer should also support a multi-provider eco-system with private cloud from network operators, local edge/cloud providers and hyperscalers. Moreover, the portability of 6G network functions between different clouds is important due to sovereignty and resilience considerations. This creates the need for standardized interfaces between network functions, regardless of in which cloud they are deployed, and between network functions and the cloud infrastructure.

- <u>Supporting 3rd party applications</u>

  This role of telco cloud is similar to the role of IT clouds, with the difference that telco cloud needs to also support applications in the edge. Some reasons that require deployment of applications at the edge include stringent latency requirements, reduction of core traffic transport, protection of data privacy and resilience. Additionally, user mobility creates the need of an application “following” the user along its route, and thus from one edge to another. The mobile operator will hide this mobility, offering the 3rd party application provider a single application interface independent of in which mobile network and edge/cloud the application is deployed. Due to the large number of applications, standardized cloud support is difficult to be provided. Finally, the application interface should be similar to the web-interfaces that the 3rd party application provides are used to.

- <u>Supporting intelligent agents</u>

  The telco cloud may also allow devices to offload their compute capabilities to the cloud. For example, this can support e.g. rendering of XR media when the device has limited compute capabilities or battery power. This is related to the concept of AI agents, which is getting significant traction in 3GPP standardization. These AI agents are applications that can run on a device but can also be offloaded into the network. AI agents can interpret intent, interact with the environment, access contextual information, make decisions, and take actions autonomously or in collaboration with other AI agents. Therefore, another role of the 6G telco cloud should be to provide an AI agent hosting ecosystem that supports AI agent interactions, such as identification and authentication of AI agents.

3.4.2 Overview of global cloud for 6G R&I efforts

Research and innovation in cloud infrastructure for 6G networks, including Telco cloud, are actively progressing across the globe, with significant contributions from countries like the United States, Japan, South Korea, India, and China.

3.4.2.1 USA

The USA dominates the cloud space in recent years with multiple “hyperscalers” being based in the US and expanding the services to various sectors including telecom. Research institutions and industry leaders are collaborating on integrating cloud computing with emerging 6G technologies. The focus is on developing cloud-native architectures that support the scalability and flexibility required for 6G networks. These efforts include exploring virtualization of network functions and enhancing the interoperability of cloud infrastructures with telecommunications networks to facilitate the deployment of Telco cloud solutions.

In the U.S., companies such as Amazon Web Services (AWS) are at the forefront of integrating cloud technologies with next-generation networks. For instance, AWS is collaborating with Telefónica Germany on a pilot project to test quantum technologies within mobile networks [78]. This initiative aims to optimize mobile tower placements, enhance network security through quantum encryption, and derive insights beneficial for 6G development. Such collaborations underscore the pivotal role of cloud computing in the evolution of 6G infrastructure.

T-Mobile has been proactive in integrating artificial intelligence (AI) and edge cloud technologies to enhance network performance and customer experience [79]. The company has partnered with organizations like OpenAI and Nvidia to develop a self-optimizing network, AI-driven Radio Access Networks (AI-RAN), and edge cloud solutions. These advancements aim to create a more responsive and efficient network infrastructure, aligning with the anticipated requirements of 6G connectivity.

Mavenir, a U.S.-based telecommunications software company, specializes in Open Radio Access Network (Open RAN) technology, which utilizes cloud-based software to reduce costs and increase flexibility for telecom operators. In November 2024, it was reported that Saudi Aramco's digital arm was negotiating a $1 billion investment for a significant minority stake in Mavenir, valuing the company at around $3 billion. This potential investment underscores the industry's recognition of Mavenir's role in advancing cloud-native network solutions essential for future 6G deployments [80] .

3.4.2.2 Japan

Japan's approach to 6G development emphasizes the integration of advanced cloud infrastructures to support future networks. The country is investing in research that focuses on network virtualization and cloud-native architectures, essential components for the evolution of Telco cloud environments. Collaborations between industry, academia, and government are central to these initiatives, aiming to create a robust ecosystem for 6G technologies.

Japan has been actively advancing Telco cloud initiatives to enhance its telecommunications infrastructure, particularly in preparation for Beyond 5G and 6G technologies. In October 2024, Rakuten Mobile commenced activities aimed at driving international standardization for advanced edge cloud technologies [81]. Supported by Japan’s National Institute of Information and Communications Technology (NICT), this initiative seeks to update existing network specifications to accommodate the demands of cloud-native networks anticipated in the Beyond 5G era. Leveraging its experience in building a fully virtualized, cloud-native mobile network in Japan, Rakuten Mobile is collaborating with international standardization bodies to establish unified standards for cloud management, including edge cloud technologies. The project also involves aligning global cloud solutions, such as Rakuten Cloud, with these international standards to promote the widespread adoption of cloud-native networks.

In December 2022, Internet Initiative Japan Inc. (IIJ) launched the IIJ Cloud Data Platform Service to facilitate data integration across on-premises and multi-cloud environments [82]. The service offers over 90 integration adapters for various cloud computing platforms and relational database management systems, enabling the development of data flows without coding. Features such as data masking and the use of closed networks ensure the secure handling of confidential data, thereby promoting digital transformation through secure and efficient data utilization.

These initiatives reflect Japan's proactive approach to integrating Telco cloud technologies, aiming to enhance network flexibility, efficiency, and security in anticipation of future communication demands.

3.4.2.3 South Korea

South Korea has launched the K-Network 2030 strategy, allocating approximately KRW 625.3 billion (around US$500 million) for 6G research and development from 2024 through 2028. A key focus of this strategy is the development of cloud-native core network software, emphasizing scalability and flexibility to meet the demands of next-generation networks. The initiative also aims to virtualize base station equipment, facilitating a transition from hardware-centric to software-oriented infrastructures, which is essential for the realization of Telco cloud environments [83].

South Korean companies are actively engaging in partnerships to advance the integration of cloud into 6G technologies. For instance, KT Corporation and LG Electronics have agreed to collaborate on 6G technology research and standardization efforts, focusing on areas such as full-duplex communication and next-generation transmission technologies [84].

3.4.2.4 China

China is actively advancing cloud initiatives to support the development of 6G networks through various strategic efforts. China Mobile has implemented the 'AI+NETWORK' strategy, focusing on integrating artificial intelligence with network operations to enhance efficiency and service quality [85]. This strategy includes the deployment of fully cloud-based 4G/5G converged core networks, establishing a foundation for future 6G infrastructure. The integration of AI aims to optimize network performance and support the anticipated demands of 6G technologies.

Moreover, Alibaba has announced plans to invest over $50 billion in artificial intelligence and cloud computing over the next three years [86]. This significant investment is directed towards enhancing cloud infrastructure and AI capabilities, which are essential components for the development and deployment of 6G networks. Alibaba's commitment underscores the importance of robust cloud services in supporting the next generation of mobile communications.

The Chinese government has expressed intentions to bolster support for artificial intelligence applications and the development of 6G technology. This initiative aims to foster technological innovation and achieve greater self-reliance in critical technology sectors. By focusing on AI and 6G, China seeks to position itself at the forefront of future technological advancements, with cloud computing serving as a pivotal element in this strategy [87].

3.4.2.5 India

India is making significant strides in enhancing its cloud infrastructure, focusing on various deployment models and technologies to support the evolving digital landscape and future advancements like 6G. Currently three main deployments are considered in India:

- Public Cloud: Major global providers such as Amazon Web Services (AWS), Microsoft Azure, and Google Cloud have established a strong presence in India. AWS plans to invest approximately $8.2 billion in Maharashtra over the coming years, aiming to deploy advanced technologies and cloud management services by 2029-2030. Similarly, Microsoft is investing $3 billion to expand its Azure cloud and AI infrastructure, including the establishment of new data centres.
- Private Cloud: Enterprises seeking greater control over their data are adopting private cloud solutions. The National Informatics Centre (NIC) has developed the 'MeghRaj' National Cloud, offering services like Infrastructure as a Service (IaaS) and Platform as a Service (PaaS) to various government departments, ensuring secure and efficient data management.
- Hybrid Cloud: A significant number of Indian enterprises are embracing hybrid cloud models, combining public and private cloud environments to balance flexibility and security. According to Forrester's 2022 Infrastructure Cloud Survey, 73% of Indian enterprise cloud decision-makers utilize hybrid cloud setups.

To enhance national security and data sovereignty, India is developing sovereign cloud infrastructure. This initiative aims to ensure that data generated within the country remains under local jurisdiction, bolstering data security and regulatory compliance. India's data centre capacity is projected to double from 870 MW in FY22 to approximately 1,700-1,800 MW by FY25, driven by increasing digitization and data localization trends. Major hubs include Mumbai, Chennai, Hyderabad, and Bangalore. Finally, the Reserve Bank of India (RBI) plans to launch a pilot program in 2025 to provide affordable local cloud data storage to financial firms, aiming to reduce reliance on global providers and support data localization in the financial sector.

While specific details on cloud infrastructure tailored for 6G are still emerging, the expansion of cloud services and data centres lays the groundwork for future 6G functionalities. The emphasis on hybrid and edge computing models will be crucial in supporting the low latency and high bandwidth requirements of 6G applications.

3.4.3 Overview of European Telco-cloud research efforts

Important Projects of Common European Interest in Next Generation Cloud Infrastructure and Services (IPCEI-CIS): The goal of IPCEI-CIS is to develop the first "Multi Provider Cloud Edge Continuum" in Europe that will be based on a distributed, openly accessible, and interoperable cloud and edge infrastructure [88]. Four primary focus areas are being addressed, namely interoperability, sustainability, cybersecurity and standardization. Additionally, to ensure the long-term support of the project results (in terms of continuity, adoption, completion, sustainability and collaboration), the 8ra initiative has been established. IPCEI-CIS consists of 120 projects that have been launched in December 2023 and that will end the latest by the end of 2031. The first results of the project are expected to be delivered by the end of 2027. The EU Member States that are contributing to IPCEI-CIS are Belgium, Croatia, France, Germany, Hungary, Italy, Latvia, Luxembourg, The Netherlands, Poland, Slovenia, and Spain. The following topics are addressed by IPCEI-CIS [89]:

- Development of the edge-cloud continuum infrastructure, including the necessary hardware and software for the network interconnections.
- Development of the "Multi Provider Cloud Edge Continuum" common reference architecture, which will serve as a guideline for the edge/cloud system deployments.
- Development of tools and services required by the applications, such that they can run and that their requirements are fulfilled.
- Development of the edge/cloud operating system and APIs.
- Development of data processing tools and services, which will enable the exploitation of the edge-cloud continuum.
- Perform a first industrial deployment to demonstrate scalability, security, and interoperability of services in different domains, including the telecommunication domain.

Alliance for Industrial Data, Edge, and Cloud: The goal of the European Alliance for Industrial Data, Edge, and Cloud is to secure innovation on cloud and edge technologies in the EU and to ensure that the requirements of processing sensitive data in the EU are met [90]. The alliance stems from the European data strategy and the declaration of EU Member States on building a European cloud. The kick-off event on the initiation of the alliance was hosted by the European Commission in December 2021. As of July 2024, the alliance comprises 56 members.

The Alliance for Industrial Data, Edge, and Cloud aims to provide:

- A platform for investment synergies.
- Recommendations and a matchmaking platform on EU investments for business and public authorities.
- A coordination platform for the European Commission and the EU Member States.
- A stakeholder consultation platform to the European Commission in regard to the EU Cloud Rulebook.
- Expertise for the public procurement of cloud services.
- A platform for synergies with Common European Data spaces.
- Strategic roadmaps, such as the "European Industrial Technology Roadmap for the Next-Generation Cloud-Edge" [91] and the "Telco Cloud Thematic Roadmap" [92].

SNS JU Policy Working Group (WG) on 3C Networks: The SNS JU Governing Board has established the WG on 3C Networks, with the following objectives:

- Discuss policy, industry and business developments relevant to the "3C network" vision.
- Identify and discuss potential synergies/coordination between SNS JU activities and other EU activities.
- Examine a potential coordination role for the SNS JU.

The WG is invitation only and its activities are confidential.

3.4.4 Overview of relevant open-source activities related to Telco cloud

Sylva [93] is an open-source project within Linux Foundation Europe. Sylva is focused on telco and edge use cases and its main goal is to develop a cloud software framework, a reference implementation and a validation programme. This will allow vendors of network functions to demonstrate their functionalities on a general purpose infrastructure. For example, the 5G core and radio cloud native network functions will run on the telco-specific Container as a Service (CaaS) that will be developed at Sylva. This CaaS can then run on top of any commercial hardware. In December 2024, Sylva announced their long-term vision to develop a cloud-native, scalable, and energy-efficient telco cloud infrastructure that supports technologies like Open RAN, edge computing, and AI-driven networks. Sylva is based on the telco ecosystem and also contributes to it. Sylva also has synergies with the O-RAN ALLIANCE, ETSI, CNTI, Anuket, and other projects and initiatives. Sylva was initiated by five European operators (Telefonica, Telecom Italia, Orange, Vodafone and Deutsche Telecom) and two telco vendors (Ericsson and Nokia). Its developments consider EU requirements such as cybersecurity, trustworthiness on data processing, service federation, and energy management. However, participation to Sylva is not limited within Europe.

Cloud Native Telco Initiative (CNTI) [94] is a project under Linux Foundation Networking (LFN). The importance of CNTI is highlighted by its evolvement from an initiative to a project in July 2024. The goal of CNTI is to accelerate the adoption of cloud native technologies within the telco sector. Specifically, CNTI aims to meet the needs of vendors and service providers by creating a conformance programme that unifies the cloud native goals and by collaborating with other telco communities. For telcos, the transition to cloud-native architectures is imperative due to the increasing demand for scalability, agility and cost efficiency. CNTI is addressing this transition in three ways. Firstly, it develops best practices for cloud native networking. Secondly, it develops a test catalogue over which the applications can be validated that they adhere to the best practices. Thirdly, it provides a certification programme that verifies that a vendor or user follows the cloud native principles and best practices.

Anuket [95] is an open-source project under LFN, created through the merger of the Cloud iNfrastructure Telco Taskforce (CNTT) and Open Platform for Network Functions Virtualization (OPNFV). The goal of Anuket is to provide standardised architectures, reference models, and conformance frameworks for cloud-native and virtualised network functions. Specifically, Anuket develops reference models, compliance tools and testing frameworks. Anuket's aim is to ensure compatibility and efficiency across multiple cloud environments and thus to reduce the costs of telecom operators and to accelerate 5G deployments. Key topics that Anuket addresses include automation, orchestration and security. Therefore, Anuket aims to enable efficient, scalable, and secure deployments in multi-vendor cloud environments through interoperability and reduced fragmentation. Furthermore, the collaboration between vendors and operators, which is facilitated, ensures that the developed standards are tested in real-world environments and the developed releases are aligned with the needs of the industry.

3.5 Non-Terrestrial Networks (NTN)

Non terrestrial networks will be fully integrated into 6G standard to provide ubiquitous coverage. Satellite integration into mobile connectivity is already taking place at fast pace, with some first movers providing basic services though integrated satellite connectivity for emergency and messaging services

According to the Global System for Mobile Communications Association (GSMA), in the last months, eight more operators moved into the satellite space, taking the total to almost 100, representing 70% or worldwide mobile connections [96]. Developments reflect increased orbital capacity from a higher number of satellites in space, and positive sentiment indicators from consumer and enterprise buyers. The relevant metrics are provided in Table 2.

Table 2: Unique operators or operator groups operating a direct Eurasia constellation or offering satellite connectivity through one or more partnerships [96]

Item	August 2024	November 2024	Variation Aug- Nov '24
Operator with satellite service*	91	99	+8
➢ **Of which live**	16	19	+3
➢ **Of which planned or testing**	75	80	+5
Mobile connections footprint (millions)	5,826	5,966	+0,14
Share of total connections base covered by satellites	67%	68%	+1 p.p.

Figure 13 depicts the regional split of telecom operators with a satellite presence. Europe has 10 operators with a satellite footprint, while Asia pacific seems to be leading this specific sector with 39 operators with a satellite footprint. Satellite connectivity has been launched at commercial level by 2 or more operators in UK while testing is taking place in Spain, Germany and Switzerland.

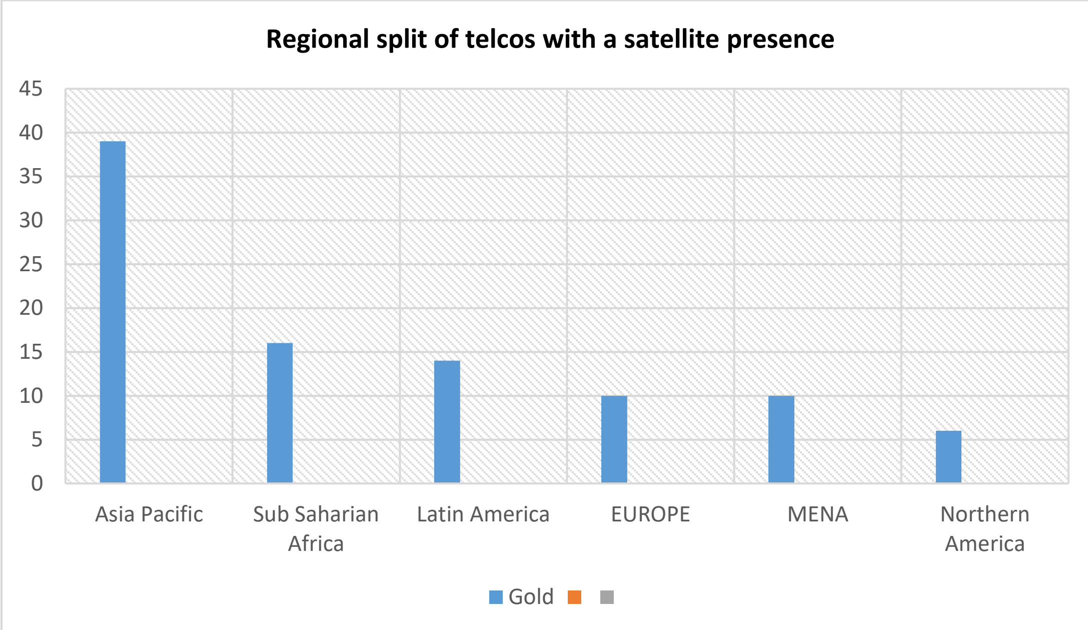


Figure 13: Regional split of Telcos with a satellite presence [96]

Nevertheless Europe, which has a very rich space industry has still a very low global satellite communications coverage provided by European satellite operators as depicted in Figure 14, despite the fact that EUTELSAT has the second larger in orbit constellation after Starlink but with 1/10 of its satellites. The IRIS 2[8] project may change this outlook around 2030.

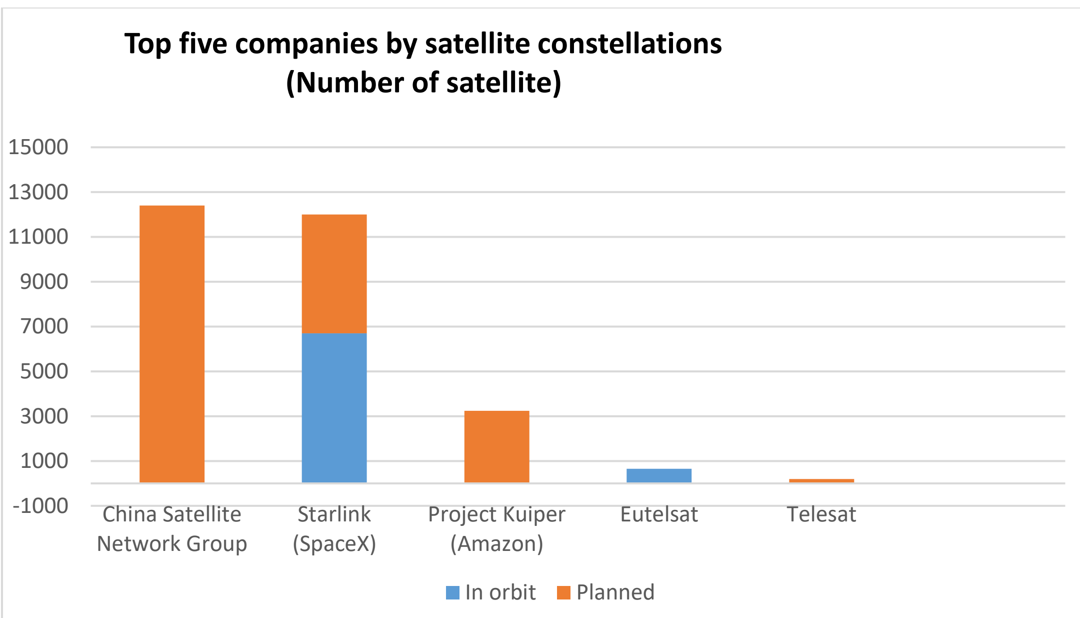


Figure 14: Top five organizations by satellite constellations [96]

[8] https://www.euspa.europa.eu/eu-space-programme/secure-satcom/iris2

Lately, interest for NTN integration with mobile networks has increased covering two different deployment options, i.e., **direct –to-device** (D2D) and **direct-to-BTS** (backhauling) connectivity. Table 3 depicts the status of partnerships between telecom operators and satellite operators according to GSMA [96].

Table 3: Satellite partnerships with telecoms operators for mobile connectivity[9] [96]

Item	Live	Planned	Direct to BTS	D2D
AST SpaceMobile	0	28	14%	86%
Starlink	3	15	56%	44%
Lynk	1	17	22%	78%
Eutelsat OneWeb	3	8	100%	
SES	3	8	100%	
Others	11	37	58%	42%
Total/Average	**21**	**113**	**56%**	**44%**

Much of the interest in satellites has come from connecting uncovered areas or providing coverage to allow ubiquitous roaming. However, the enterprises are equally interested, spanning several sectors including agriculture, trucking and logistics. GSMA Intelligence estimates there are 2–3 billion IoT devices that could be served by satellite connectivity, about 10–15% of the total [96].

At commercial level different initiatives became breaking news in the industry. Apple was the front runner with a proprietary solution for its latest iPhone to provide emergency services outside mobile coverage:

- Apple invested 1.5 B$ in Globalstar to support its satellite-based emergency service[10]
- in Spain a publicly co funded research facility will test NTN integration into mobile network using Open RAN principles[11]
- the Mobile Satellite Service Association signed an agreement with 5GAA to test mobile satellite services for the automotive sector to boost services such as autonomous driving and ITS[12].

3.6 Microelectronics

Microelectronics form the backbone of modern technology, playing a pivotal role in various sectors, including telecommunications, healthcare, and defence. They are the foundation of virtually all modern electronic devices, from smartphones and computers to medical equipment and military systems. The advent of advanced communication networks, such as 5G and the anticipated 6G, has further underscored the strategic importance of microelectronics in shaping the future of connectivity and innovation. These advanced networks demand significant enhancements in performance metrics, including exponentially higher data rates, ultra-low latency, and seamless connectivity across diverse devices and environments. Microelectronics enables these capabilities, powering critical components such as antennas, transceivers, and integrated circuits that drive wireless

[9] Where a satellite player has partnered separately with an operator group and its subsidiary, this has been counted twice. Satellite broadband services (e.g. at home, businesses or community locations) are not included.

[10] https://www.satellitetoday.com/finance/2024/11/01/apple-invests-1-5b-in-globalstar-to-fund-a-new-constellation/

[11] https://www.ericsson.com/en/news/3/2025/ericsson-grupo-oesia-and-uc3m-demonstrate-scenarios-of-integration-of-5g-and-non-terrestrial-networks-technologies

[12] https://www.businesswire.com/news/home/20250206092788/en/MSSA-and-5GAA-Agree-to-Collaborate-in-Driving-Integration-of-Terrestrial-and-Non-Terrestrial-Networks

communication. In the context of 5G, microelectronics have already facilitated breakthroughs like network slicing and massive multiple-input multiple-output (MIMO) technologies, which have revolutionised how devices connect and communicate.

Looking ahead, the transition from 5G to 6G is poised to introduce transformative technologies that will redefine the landscape of communication and sensing. These include AI-driven communications that leverage machine learning for real-time network optimisation, integrated sensing and communication systems that combine data transmission with environmental sensing, and the use of terahertz frequencies for unprecedented bandwidth and speed. These advancements hinge on significant progress in microelectronic materials, device fabrication, and design architectures. Moreover, the strategic importance of microelectronics extends beyond performance improvements. As nations and industries strive for leadership in the 6G era, the ability to develop and manufacture cutting-edge microelectronics domestically has become a critical element of economic and national security. This has led to substantial investments in semiconductor research and development globally, aimed at overcoming technological barriers and ensuring supply chain resilience.

In summary, microelectronics are integral to modern technology's functioning and key enablers of the next generation of communication networks. Their role in driving innovation and maintaining technological competitiveness makes them a cornerstone of both current and future advancements in connectivity, automation, and digital transformation.

3.6.1 Overview of global microelectronics research efforts

3.6.1.1 United States

The United States has long been a global leader in microelectronics research and development, driven by substantial investments and strategic initiatives to maintain its competitive edge in this critical sector. The U.S. government has launched a series of programmes to secure its leadership in this field, recognising the importance of microelectronics to national security, economic resilience, and technological innovation.

One of the cornerstone initiatives is the Microelectronics Commons, a national network designed to accelerate the transition of new technologies to domestic microelectronics manufacturers.[13] This programme establishes regional technology hubs to expand the nation's global leadership in microelectronics. These hubs focus on areas such as electromagnetic warfare, secure computing at the tactical edge, artificial intelligence hardware, 5G and 6G wireless, and quantum technology. Complementing this, the National Strategy on Microelectronics Research, released in March 2024 by the White House Office of Science and Technology Policy, provides a framework for federal departments, academia, industry, and international partners to address key needs in microelectronics [97]. The strategy outlines four interconnected goals to ensure that the United States remains a global microelectronics research and development leader. The United States has also strengthened collaboration between academia, industry, and government agencies to drive advancements in microelectronics. Programs like the National Semiconductor Technology Center (NSTC) aim to bridge research and development with commercialisation by fostering partnerships across the microelectronics value chain.

The CHIPS and Science Act, enacted in 2022, further reinforces these efforts by allocating over $52 billion in federal funding to support semiconductor research, development, and manufacturing. The Act also provides incentives for private sector investments in domestic chip production, addressing critical supply chain challenges and reducing reliance on foreign suppliers [98]. This initiative has catalysed significant activity within the U.S. semiconductor industry, with major companies announcing plans to establish or expand manufacturing facilities. Additionally, the Defense Advanced Research Projects Agency (DARPA) continues to play a pivotal role in microelectronics innovation through programs like the Electronics Resurgence Initiative (ERI). This initiative focuses on creating chip design and manufacturing breakthroughs to address emerging challenges in artificial intelligence, advanced computing, and quantum technologies.

[13] https://microelectronicscommons.org/

3.6.1.2 Japan

Japan is actively revitalising its microelectronics sector to reclaim its position as a leader in semiconductor technology. Recognising the strategic importance of semiconductors in the global economy and national security, the Japanese government has initiated several ambitious programs to enhance domestic production, foster innovation, and strengthen supply chain resilience. The main pillars of this strategy emphasise advanced manufacturing capabilities, substantial financial investments, cutting-edge research, and human capital development.

A cornerstone of this effort is the establishment of Rapidus Corporation in 2022, a consortium formed by eight major Japanese companies, including Denso, Kioxia, MUFG Bank, NEC, NTT, SoftBank, Sony, and Toyota. Rapidus aims to develop a mass production system for next-generation 2-nanometer (nm) chips, targeting high-speed applications essential for digitalization and decarbonization initiatives. The company plans to commence trial production in April 2025 and achieve mass production by 2027, positioning Japan at the forefront of advanced semiconductor manufacturing.[14]

Complementing this initiative, the Japanese government has unveiled a comprehensive $65 billion plan to bolster the domestic semiconductor industry. Announced in November 2024, this plan focuses on stimulating production and promoting research and development within Japan's chip sector. The investment aims to address the increasing global demand for semiconductors, driven by advancements in artificial intelligence and consumer electronics while mitigating supply chain vulnerabilities [99].

To support these endeavours, Japan has established the Leading-edge Semiconductor Technology Center (LSTC), a government-funded research institution dedicated to developing design, device, manufacturing, and equipment/material technologies for next-generation semiconductors. LSTC collaborates with domestic and international institutions to create a robust ecosystem for semiconductor innovation, focusing on 2 nm process node manufacturing technology.[15]

In addition to infrastructure and research investments, Japan is addressing the critical need for skilled talent in the semiconductor field. In November 2024, the government partnered with U.S. chip startup Tenstorrent to train up to 200 Japanese chip designers over five years. This $50 million contract, partly funded by LSTC, aims to cultivate a new generation of engineers proficient in advanced AI chip design, thereby strengthening Japan's human resources in microelectronics [100].

3.6.1.3 China

China has rapidly ascended in the global microelectronics arena, propelled by substantial investments and strategic initiatives aimed at achieving self-reliance and technological leadership in the semiconductor industry. Recognising the critical role of microelectronics in economic development and national security, the Chinese government has implemented comprehensive plans to bolster domestic capabilities and reduce dependence on foreign technology to establish a robust and self-reliant microelectronics industry. Through substantial investments, strategic policy initiatives, and talent development programs, China aims to secure its position as a leader in the global semiconductor landscape.

A pivotal component of China's strategy is the "Made in China 2025" initiative, launched in 2015, which designates semiconductors as a key sector for advancement. This policy seeks to elevate the domestic content of core materials to 70% by 2025, thereby diminishing reliance on imports [101]. The initiative encompasses substantial state funding, estimated to be hundreds of billions of dollars, including allocations for the National Integrated Circuit Industry Investment Fund, commonly known as the "Big Fund." The National Integrated Circuit Industry Investment Fund has been instrumental in channelling resources into the semiconductor sector. Established in 2014, the fund has undergone multiple phases, with the latest, Phase III, launched in May 2024

[14] https://www.japan.go.jp/kizuna/2024/03/technology_for_semiconductors.html?utm_source=chatgpt.com
[15] https://www.lstc.jp/english/

with a registered capital of approximately $47.5 billion. This phase focuses on critical areas such as large-scale manufacturing, equipment, materials, and artificial intelligence semiconductors, aiming to address bottlenecks in the industry and enhance innovation [102].

In addition to financial investments, China is actively cultivating talent to support its microelectronics ambitions. Programs like Qiming, overseen by the Ministry of Industry and Information Technology, are designed to attract overseas chip experts to bolster domestic expertise [103]. This initiative reflects China's recognition of the importance of human capital in achieving technological self-sufficiency. Chinese semiconductor firms have demonstrated resilience despite external challenges, including export controls and trade restrictions. For instance, Semiconductor Manufacturing International Corporation (SMIC) has made significant strides in advancing its manufacturing processes. In 2021, SMIC began shipping 7nm chips, marking a notable achievement in the face of global competition [104].

3.6.1.4 South Korea

South Korea stands as a key player in the global microelectronics sector, underpinned by substantial investments and strategic initiatives to bolster its semiconductor industry. Recognising the critical importance of semiconductors to its economy and technological advancement, the South Korean government and leading corporations have embarked on comprehensive plans to enhance domestic production capabilities and maintain a competitive edge.

A cornerstone of South Korea's strategy is the K-Semiconductor Strategy, launched in 2021, which aims to attract investments totalling USD 450 billion by 2030. This ambitious plan seeks to establish the world's most advanced semiconductor supply chain, encompassing the entire production process from materials and components to finished products. The strategy includes significant financial incentives, infrastructure development, and support for research and development to foster innovation within the industry [105].

In alignment with this strategy, the South Korean government announced in November 2024 a plan to provide 14 trillion won (approximately USD 10 billion) in low-interest loans starting in 2025 to support semiconductor companies. These loans, administered through state-run banks, are designed to strengthen domestic chipmakers amid intensifying global competition and geopolitical uncertainties. Notably, 1.8 trillion won is allocated for power transmission lines at a new chip complex, underscoring the government's commitment to infrastructure development in this sector [106]. A significant project under this initiative is the expedited development of the Yongin Semiconductor National Industrial Complex. Approved in December 2024, this complex spans 7.28 million square meters and is poised to become South Korea's semiconductor powerhouse. It will host six major semiconductor fabrication plants, three power plants, and over 60 small to medium-sized suppliers focusing on materials, parts, and equipment. The project anticipates KRW 360 trillion (approximately USD 246.4 billion) in private investment, potentially creating 1.6 million jobs and adding KRW 400 trillion in value [107].

Leading South Korean companies are also making substantial investments to advance semiconductor technology. SK Hynix, the world's second-largest memory chip maker, announced plans in June 2024 to invest 103 trillion won (USD 74.6 billion) by 2028, with a strong focus on artificial intelligence (AI) applications [108]. This investment aligns with the company's strategy to develop an AI value chain encompassing high-bandwidth memory (HBM) chips, AI data centers, and AI services, positioning SK Hynix at the forefront of AI-driven semiconductor innovation.

3.6.2 Overview of EU microelectronics research efforts

Advancements in the microelectronics sector are vital for the European Union's competitiveness, strategic autonomy, and industrial leadership. Microelectronics are the foundation of modern technologies such as 5G, artificial intelligence, autonomous systems, and quantum computing. The EU’s strategic focus on this sector aims to reduce dependence on non-European suppliers, strengthen supply chain resilience, and ensure its leadership in future technological advancements.

The European Chips Act, adopted in 2023, is central to the EU's efforts to build a robust microelectronics ecosystem. With a financial commitment of at least €43 billion in public and private investments, the Chips Act aims to double the EU's global semiconductor market share to 20% by 2030. This initiative focuses on increasing manufacturing capacity, fostering innovation in advanced chip technologies, and addressing supply chain vulnerabilities to ensure the EU can meet the demands of its digital economy [109].

The Smart Networks and Services Joint Undertaking (SNS JU) complements the Chips Act by integrating microelectronics research with developing next-generation telecommunications networks like 6G. The SNS Microelectronics Lighthouse project, launched under the 2024 SNS work program, exemplifies this integration. It provides test and experimental platforms to validate microelectronics innovations developed under the Chips JU, Horizon Europe, and SNS JU. This initiative focuses on technologies like THz communication, enabling ultra-high data rates and low-latency solutions required for 6G networks. These efforts bring together stakeholders from the microelectronics and telecommunications sectors to ensure alignment with Europe’s strategic goals (SNS JU).

Another pivotal initiative is the COREnect roadmap, which outlines strategic challenges and opportunities for European leadership in microelectronics and telecommunications. Developed through collaboration between the telecom and microelectronics sectors, COREnect emphasises the need for innovations in energy-efficient chips, advanced materials, and next-generation manufacturing processes. These priorities align with the EU’s technological sovereignty and environmental sustainability vision as communication infrastructures evolve toward 6G (COREnect Study) [110].

The combination of the Chips Act’s focus on manufacturing and supply chain resilience with the SNS JU’s targeted R&I efforts and COREnect’s strategic guidance, constitute the main milestone for the EU to create a comprehensive framework to advance its microelectronics sector. These initiatives, supported by substantial funding and strong collaboration between industry and academia, position Europe to lead in the global race for technological innovation while reinforcing its industrial and digital sovereignty.

3.6.2.1 Recent updates on microelectronics for telco applications

The position paper "Research Priorities on Microelectronics for 6G Networks R&I activities", co-edited by Chips JU and SNS JU, provides a blueprint for current EU efforts in microelectronics and their potential role in 5G and 6G applications [111]. Similarly to other regions like the USA, the EU has recognised microelectronics as a strategic industrial domain, critical from both economic and political perspectives. Following the enactment of the U.S. "Chips and Science Act," which allocates substantial resources to secure industrial leadership and critical supply chains, the EU adopted its own "Chips Act" in July 2023. This initiative aims to bolster EU excellence and industrial capabilities by injecting at least €43 billion in public and private investments, focusing on securing supply chains and reinforcing technological sovereignty.

While these initiatives encompass applications beyond telecommunications, the telecom sector is expected to play a pivotal role in achieving their objectives. For instance, the U.S. has allocated $1.5 billion specifically for chipsets used in wireless communication systems. In Europe, long-standing cooperation between the telecom and microelectronics sectors has already yielded the COREnect roadmap, highlighting strategic challenges for Europe as communication infrastructures transition towards 6G, anticipated by the end of this decade. The position paper outlines Europe’s 6G vision and ongoing developments, building upon discussions from a workshop held on October 16, 2023, which brought together experts from the microelectronics and communication R&I ecosystems, as well as representatives from the European Commission.

Among the potential critical use cases for 6G microelectronics development. One key area is higher frequency spectra above 71 GHz, which extends into sub-THz ranges, such as 90 GHz and beyond. These frequencies are considered for applications like high-capacity backhaul and multipoint access in industrial or high-density scenarios. The targeted spectra, including V-, E-, W-, and D-bands (60 GHz to 170 GHz), will eventually explore 300 GHz for terabit-per-second (Tbps) connectivity. This requires overcoming challenges such as minimising signal losses, improving high-power amplifiers, and integrating heterogeneous technologies like FDSOI, GaN, InP, and SiGe. These technologies are still in the early stages of development and are heavily researched in global 6G initiatives.

Another priority is the addition of upper mid-band spectrum ("FR3") between 7–24 GHz, which could be aggregated to support higher data rates for mobile devices while enabling intelligent spectrum sharing with incumbent services. Continued advancements in CMOS technology are crucial to meet demands for low power consumption, high data rates, and AI-assisted signal processing. Optimising spectrum usage through full-duplex operations and self-interference cancellation technologies is also essential. Power amplifier efficiency remains a significant factor, with current technologies achieving efficiencies of around 50%, leaving room for improvement to meet energy efficiency targets.

Joint Communication and Sensing (JCAS) emerged as a promising 6G feature, integrating communication and sensing functionalities within a single system. This requires wideband transceivers, high-precision ranging, and secure hardware integration. The convergence of communication and sensing demands innovation in front-end components, transceivers, and digital signal processing, as well as mechanisms to ensure trust and security by separating sensing and communication functions.

Industrial applications and IoT developments also drive demand for integrated sensors and RF, optical, and MEMS devices. These applications require larger data processing capabilities, ultra-low-latency AI/ML filtering, and battery-less, zero-energy IoT devices. Achieving these goals necessitates innovative RF transceiver architectures and novel low-leakage substrates to reduce power consumption, targeting energy efficiency as low as 1pJ/bit.

Lastly, higher data rates and lower latency requirements underscore the need for advanced System-on-Chip (SoC) designs. These SoCs integrate digital signal processing, memory, and power management into single chips, enhancing efficiency and reducing costs. European SoCs primarily focus on Layer 1 communication capabilities for radio access networks (RAN), with opportunities to expand into broader functionalities and support EU sovereignty in microelectronics. The workshop emphasised that very low energy consumption and trust and security are cross-domain priorities, alongside continued innovation in physical and computational aspects of microelectronics for 6G.

3.6.2.2 Next steps

The culmination of these discussions has been the call SNS-2024-STREAM-C-01-01: SNS Microelectronics Lighthouse, published in the 2024 Work Programmes for a 10 million RIA project aimed at advancing microelectronics technologies to meet the demands of next-generation 6G networks.[16] This lighthouse project is designed to bridge the gap between research innovations and practical applications, creating a platform for validating cutting-edge solutions from multiple EU initiatives. Specifically, the project will provide test and experimental platforms where solutions developed under Phase 1 of the SNS Work Program, Horizon Europe Cluster 4 projects and the Chips Joint Undertaking (Chips JU) can be evaluated. These platforms will assess the performance, scalability, and applicability of microelectronics technologies tailored for 6G networks. By focusing on technologies like THz communication and other enabling components, the project aims to address the critical requirements of 6G, such as ultra-high data rates, low latency, and efficient spectrum usage.

The SNS Microelectronics Lighthouse project also emphasises fostering synergies across Europe's research and innovation ecosystem. It will bring together stakeholders from the microelectronics and telecommunications sectors to enhance collaboration and accelerate innovation. The project's integrated approach ensures

[16] See the SNS JU 2024 Work Programme here https://smart-networks.europa.eu/wp-content/uploads/2023/11/sns-ju-annual-work-programme-2024.pdf.

alignment with broader EU strategic goals, including the objectives of the European Chips Act, which aims to reinforce Europe's leadership in semiconductor technology. Through these efforts, the initiative will not only contribute to the technological advancements necessary for 6G but will also play a pivotal role in bolstering Europe's technological sovereignty and industrial competitiveness in the global digital economy. By providing a collaborative and experimental framework, the SNS Microelectronics Lighthouse will help transition research findings into real-world applications, driving progress in 6G network development.

3.7 Security

Technology shapes our daily lives, influencing how we interact, work, and communicate. Its impact extends beyond convenience, raising critical questions about the balance between simplification and security. As we embrace technological advancements, we must also consider the level of risk we are willing to accept in exchange for innovation. This ongoing dilemma has evolved into building secure and resilient technologies—an issue that remains a primary focus for researchers worldwide. With the evolution from 5G to 6G, it is believed that 6G will experience critical challenges and complexity in securing digital infrastructures which is no longer optional but critical for global stability.

3.7.1 Overview of global research efforts on Security

Through the SNS JU whitepaper on European Vision for the 6G Network ecosystem [5], global drivers for 6G & targeted use cases around the world were identified via the 3GPP SA1 Workshop on May 2024. The workshop included participations from the leading R&I organisations from major regions of the world to provide contributions regarding their views on use cases and technological enablers that should be prioritized for the development of the 6G standard and according to that, there was an agreement on the key drivers to enable 6G networks and services and Security evolved as the top priority.

3.7.1.1 U.S.A

In the recent paper titled EU-US Beyond 5G/6G Roadmap [75] a set of critical strategic reflections and recommendations for 6G networks and services, are presented. The joint paper from Next G Alliance and the SNS JU proposed a roadmap for future opportunities through EU and US funding instruments. It also aims to provide directions for collaboration opportunities that will go beyond the scope of such funding instruments, assisting the academic and business stakeholders between the two sides of the Atlantic to identify mutually beneficial opportunities.

The US and EU are collaborating to enhance 6G resilience, security evaluation, and transparency. Trustworthiness will be built by exposing security levels, helping users to assess network safety. Confidential computing and post-quantum cryptographic readiness will ensure secure operations. Establishing common frameworks and standards is vital for security assurance, with vendors integrating security measures into development. Regulators or third parties may test solutions to ensure compliance, supporting continuous security improvements and interoperability across global 6G networks.

The US and EU plan to explore synergies to establish security expectations for equipment and software, that will help detect, prevent, and respond to threats. Data-centric security approaches, like zero-trust architecture, combined with confidential computing, to enhance operational security. The US and EU should support industry efforts to develop reliable AI-driven security solutions, ensuring a robust and adaptive cybersecurity framework for 6G networks. The enhanced co-operation actions are built on the [112] a deliverable of the EU-US Summit in October 2023, which outlines the steps for further collaboration between the Commission and relevant US regulatory agencies to prepare the ground to explore mutual recognition on cybersecurity requirements on Internet of Things (IoT) hardware and software consumer products. The Action Plan builds on the EU Cyber Resilience Act framework and the proposed US cybersecurity labelling programme Cyber Trust Mark Act.

3.7.1.2 China

On September 30, 2024, China's State Council has introduced the new Network Data Security Management Regulations [113], that came into effect on January 1, 2025. These new regulations address the increasing challenges of data security in today's digital age by providing a legal framework for managing network data processing activities. With a focus on safeguarding the rights of individuals and organizations while ensuring national security and public interests, the regulations set out comprehensive guidelines on personal data protection, cross-border data transfers, and the responsibilities of internet platform providers.

EU and China support the establishment of an inclusive and sustainable process with broad participation within the framework to deal with the issue of cybersecurity.

3.7.1.3 Japan

Japan is actively engaged in advancing the security, privacy, and trustworthiness of 6G networks through a combination of corporate initiatives, academic research, and international collaborations. SoftBank's Research Institute of Advanced Technology is at the forefront of 6G development, focusing on several key areas including security measures, by anticipating the challenges posed by quantum computing. SoftBank is investing in quantum-resistant encryption technologies to ensure secure communications in the 6G era [114].

Japanese academic institutions are also contributing significantly to 6G security research. For instance, the University of Tokyo has developed AIJack, an open-source library designed to help developers identify security and privacy vulnerabilities in AI models and systems [115]. Moreover, Researchers from Aston University and the University of Tokyo are collaborating on developing AI algorithms for malware detection in 5G, 6G, and Mobile Internet of Things (MIoT) environments [116]. Additionally, The JUNO 3 program, a joint effort between the U.S. National Science Foundation (NSF) and Japan's National Institute of Information and Communications Technology (NICT), funds projects aimed at improving network reliability and security. One such project focuses on developing a heterogeneous data plane framework to enhance security monitoring and privacy protection in 5G and future 6G networks.

The European Union and Japan expanded on their 2018 agreements with a new security and defence collaboration and signed a security and defence Partnership in Nov 2024 [117]. The foundation of this partnership is due to the fact that Europe and the Indo-Pacific are highly interconnected and interdependent thus face an increasingly challenging and interlinked security environment. This signed a Memorandum of Cooperation, paves the way for in-depth cooperation in research and development and sustainable Security via submarine connectivity. They will jointly promote actions to develop submarine cable connectivity via the Arctic, providing secure and high-quality connectivity between the EU and Japan, with the potential to extend it to Southeast Asia and the wider Pacific region.

3.7.1.4 South Korea

With the vision to create a free and safe cyberspace to support national security, promote economic prosperity, and contribute to international peace and promote cooperation across sectors, the government of South Korea has devised the nation's first National Cybersecurity Strategy [116] in line with the National Security Strategy to integrate all capabilities against cyberthreats.

The government has established a legal basis for its cybersecurity work and, to this end, has enabled the National Cybersecurity Framework Act [119]. It carries out tasks such as establishing national cybersecurity policies, detecting and responding to cyber-attacks on public sector networks, and verifying security suitability and cryptographic modules for IT products used by public institutions.

3.7.1.5 India

India has emerged as a global leader in the digital landscape and recognizing the critical importance of a secure digital environment, the Government of India has been implementing robust policies aimed at safeguarding its vast online community [51]. These measures are designed to ensure a safe, trusted, and secure cyberspace amidst the growing prevalence of cyber threats and attacks in today's interconnected world.

The National Cyber Security Policy is a crucial initiative taken by the Indian government to combat cyber threats. It provides a framework for creating a secure cyber ecosystem and aims to protect information and other critical infrastructure. Key areas of focus for India's cybersecurity strategy [120] include:

- Enhancing critical infrastructure protection: Indian critical infrastructure, particularly in sectors like finance, energy, and healthcare, needs to be better shielded from cyberattacks. Implementing stronger cyber resilience measures and ensuring continuity of services during an attack will be crucial.
- Developing a strong national cyber defence framework: India has made significant strides in cybersecurity policy, but a more unified, coherent national strategy is needed to address the evolving threats from hacktivist groups and state-sponsored actors.
- Fostering international cooperation: Expanding India's collaboration with global cybersecurity alliances, such as the Global Forum on Cyber Expertise (GFCE) and INTERPOL's Cybercrime Centre, will be an essential move to counter transnational cyber threats.

Recently, the European Commission published the evaluation of the EU-India Science and Technology Agreement of the EU-India Science and Technology Agreement for the period 2020-2025 [121]. The report confirms its vital role in fostering collaboration in key research and innovation areas. It also provides a legal and political framework for advancing joint research in ICT, and innovation.

Currently, the Global Counter-Terrorism Programme on Cybersecurity and New Technologies March 2020 – December 2026 [122] provides capacity building support to Member States, international and regional organizations for developing and implementing effective responses to challenges and opportunities that the Internet and other Information and Communications Technologies provide in countering terrorism. The programme is funded by the European Union, Germany, Japan, the Republic of Korea, the Kingdom of Saudi Arabia, the United Arab Emirates, and the Organization of American States.

3.7.2 Overview of European research efforts on Security

With EU's Digital Decade Policy Programme 2030, one of the main priorities of the current Commission is about the Secure and sustainable digital infrastructures as "Europe aims to empower businesses and people in a human-centred, sustainable and more prosperous digital future". For multiannual financial framework 2021-2027 an amount of €14.9 billion is being invested on Security and defence to create opportunities to make Europe greener, more digital and resilient [123].

In February 2024, the Commission published a whitepaper on "How to master Europe's digital infrastructure needs?" [124], the need for security in the supply and in the operation of networks is emphasized as it helps in achieving scale in EU connectivity services but is limited by lack of trusted suppliers in EU. It is also important to develop security standards covering the entire value stack, from end-to-end and from the hardware layer ensuring that such developments result in common and interoperable security standards for all key infrastructural elements underpinning sensitive communications infrastructures. In this regard EU Critical Communication System (EUCCS) is enabled to connect communication networks of all public law-enforcement, civil protection and safety responders in Europe by 2030 to allow for seamless critical communication and operational mobility across the Schengen area.

Today security is not limited to one channel but expands to the overall integration of all communication channels: terrestrial, non-terrestrial and submarine. In the Digital Decade report 2023 [125] the Commission underlined the importance of making progress towards more resilient and more sovereign networks and in particular to limit the vulnerability of the EU's key infrastructure, including submarine networks.

To build future digital networks that are secure and resilient, there is a need for cutting-edge infrastructure that delivers economic growth and societal benefits. In the coming times, quantum computers are seen to be deployed which pose a threat to existing encryption methods which are crucial in ensuring end-to end security in digital networks including electronic communication networks and critical infrastructure. EU needs to anticipate the maturing of quantum computers and start developing transition strategies towards a quantum-safe digital infrastructure now, i.e. secure against attacks from quantum computers. Thus, a coordinated and harmonized approach, ensuring consistency in the development and adoption of EU PQC standards is needed allowing systems services to function seamlessly across borders, preventing fragmentation, different levels of efficiencies in the transition, and ensure a European approach to PQC.

Security of submarine cable infrastructures is a pressing issue of EU sovereignty and poses a challenge. Hence the Commission may consider proposing a joint EU governance system on submarine cable infrastructures and may consider harmonising security requirements in international fora, which may be recognised through a dedicated EU certification scheme.

The Gigabit Infrastructure act (GIA) [126] entered into force on 11 May 2024 and will be fully applicable in November 2025. The Gigabit Infrastructure Act (GIA) responds to the growing needs for faster, reliable, data-intensive connectivity, replacing the 2014 Broadband Cost Reduction Directive. The act updates the rules to ensure faster, cheaper, and simpler rollout of Gigabit networks installation, addressing the main hurdles like cost and complex procedures for network deployment and fosters the shared use of infrastructure, Co-deployment and Coordination of Civil works, streamlining administrative procedures and equipping buildings with high speedy ready infrastructure while reducing environmental footprint of electronic communications.

Recently, The Cyber Resilience Act (CRA) [127], entered into force on December 10th, 2024. The main obligations introduced by the CRA will apply from 11 December 2027. This will contribute significantly to securing EU's digital infrastructure. It places security-by-design obligations on the manufacturers of hardware and software products, covering the entire life cycle of such products from their design and development to their maintenance. The CRA not only covers many of the products deployed in digital infrastructures, such as routers, switches or network management systems, but also requires the manufacturers of connectable hardware and software products at large to protect the confidentiality and integrity of data by state-of-the-art means.

In the most recent 6G-IA Security WG published paper on innovative approaches for 6G Security [128], cutting-edge research and innovative solutions for 6G security, emphasizing the importance of trustworthiness, privacy, and resilience in future network architectures is presented by the projects funded by EU through SNS JU calls. The envisioned 6G systems operate in dynamic and heterogeneous environments, balance safety, security, privacy, resilience, and reliability. The next generation communication relies heavily on Artificial intelligence and machine learning in advancing 6G security, enabling real-time threat detection, dynamic trust evaluation, and adaptive responses. Decentralized and scalable architectures, are needed to provide robust frameworks for secure resource management across distributed environments enhancing innovation and the ability to simulate complex scenarios, ensuring better preparedness and adaptability for 6G systems.

Overall, it is observed that Security, trust, and privacy will take on an even greater significance in 6G compared to previous generations like 5G. This shift will have substantial business implications. However, several critical challenges must be addressed to make 6G a reality. As economies and societies become increasingly reliant on telecommunications networks, the need for embedded trust is crucial. To achieve this, a comprehensive 6G security architecture must be developed, emphasizing proactive planning and stronger collaboration among security stakeholders.

3.8 Optical / Photonics

As the world anticipates the evolution from 5G to 6G networks, researchers and industry leaders are looking at cutting-edge technologies to meet the unprecedented demands of next-generation wireless communication. Among these technologies, photonics and optical communications stand out as key enablers due to their ability to support ultra-high data rates, ultra-low latency, and massive connectivity.

Photonics and optical communications are expected to play a transformative role in 6G by addressing critical challenges related to data transmission, energy efficiency, and spectrum availability. Some of the key areas where these technologies will have a significant impact include:

- **Terahertz (THz) and Free-Space Optical (FSO) Communications**: 6G networks are expected to operate in the THz band (0.1–10 THz) to support extreme data rates exceeding 1Tbps. Photonics-based transceivers and FSO communications will provide the necessary infrastructure to enable high-speed, secure, and energy-efficient transmission over long distances.
- **Optical Fiber Backbone**: While wireless links will be crucial in 6G, high-capacity optical fibre networks will form the backbone, ensuring ultra-fast data transport across core and edge networks. Integrated photonics will enhance fibre-optic performance, reducing power consumption and cost while increasing scalability.
- **Radio-over-Fiber (RoF) and Optical Wireless Communication (OWC)**: RoF technology will help distribute high-frequency wireless signals over optical fibres, reducing latency and improving network efficiency. Similarly, OWC, including visible light communication (VLC) and Li-Fi, will provide high-speed, secure communication in environments where traditional RF signals face limitations.
- **Photonics for Edge Computing and AI Integration**: Photonic computing and optical neural networks will accelerate AI-driven decision-making in 6G networks, enabling real-time processing for applications such as autonomous systems, smart cities, and immersive experiences like holography and extended reality (XR).

The integration of photonics and optical communications into 6G networks offers several advantages. Optical and photonic technologies will unlock new frequency bands, particularly in the THz and visible light spectrum, allowing for terabit-level transmission speeds. Moreover, photonic signal processing reduces the need for electronic conversions, leading to lower latencies crucial for applications such as real-time remote surgery and autonomous vehicle coordination. Optical communications also consume significantly less power compared to traditional electronic-based networks, making 6G more sustainable and cost-effective, while they also increase security as optical signals are difficult to intercept compared to RF signals, enhancing security for 6G applications requiring high levels of confidentiality, such as financial transactions and military communications.

Different regions around the world are investing heavily in research and development (R&D) to harness the potential of photonics and optical communications for 6G:

1. **Europe**: The European Union has launched multiple initiatives under the Horizon Europe and SNS JU, aiming to develop THz photonics, optical interconnects, and AI-driven photonic networks for 6G. Key focus areas in Europe include the development of energy-efficient optical components, integrated photonic circuits, and advanced fibre-optic communication systems. Institutions such as Fraunhofer, IMEC, and CEA-Leti are leading research on novel optical transceivers and quantum-enhanced optical networking for secure communications. The EU's flagship projects, such as the Photonic Integrated Circuit (PIC) program and 6G SNS Initiative, provide substantial funding to drive photonics research forward.

   Individual European states are also engaging in relevant R&I efforts. For instance, the 6G-ADLANTIK project, funded by the German Federal Ministry of Education and Research (BMBF) and coordinated by Rohde & Schwarz, focuses on developing photonic and electronic integrated components for the THz frequency range. Collaborators include TOPTICA Photonics AG, Fraunhofer HHI, Microwave Photonics GmbH, Technical University Berlin, and Spinner GmbH. The project aims to create ultra-stable, tunable THz systems based on frequency comb technology, enabling carrier frequencies well beyond 500 GHz. These advancements are crucial for 6G wireless communications, sensing, and imaging applications

2. **United States**: The U.S. Department of Defence, DARPA, and NSF are funding photonics-based 6G research through initiatives like the CHIPS and Science Act. The key areas of focus in the U.S. include the integration of silicon photonics, optical computing for AI applications, and THz communications for ultra-fast wireless networks. Companies such as Intel, IBM, and Nokia Bell Labs are developing photonic chips and optical network architectures that will underpin future 6G networks. The U.S. government is also investing in photonic quantum communications to ensure highly secure data transfer for critical infrastructure and defence applications. Additionally, GlobalFoundries has announced plans to build a $575 million advanced chip packaging and photonics centre at its Fab 8 campus in Malta, New York. Supported by a $75 million grant from the U.S. Commerce Department and an additional $20 million from New York State, this facility will focus on photonics technology, utilizing light pulses within semiconductor chips. This investment aims to enhance the domestic semiconductor supply chain, crucial for 6G infrastructure, and create over 100 jobs in the region.
3. **China**: China has been investing in 6G research through government-led programs and collaborations between Huawei, ZTE, and leading universities such as Tsinghua University and Peking University. The country is focusing on high-speed optical backhaul for 6G networks, THz-photonics integration, and quantum photonics for ultra-secure communications. Major funding initiatives, such as the National Key R&D Program and the Future Network Innovation Program, support China's ambitious goals in photonic-based 6G development. Additionally, Chinese research teams are exploring photonic crystal technologies and all-optical signal processing to enhance network performance.
4. **India**: The Indian government, through institutions like IITs and the Centre for Development of Telematics (C-DOT), is fostering research on optical and photonic technologies for 6G. India’s key research focus areas include fibre-optic enhancements for rural broadband connectivity, visible light communication (VLC) for indoor networking, and cost-effective silicon photonics for 6G applications. Government-backed initiatives such as the BharatNet program and the National Photonics Mission are driving investments in photonic technology. India is also engaging in global collaborations to accelerate the deployment of photonics-driven 6G networks.
5. **Japan**: Japanese tech giants such as NTT, Fujitsu, and NEC are investing in photonic-based 6G solutions, particularly in THz communication and photonic integrated circuits (PICs). Japan’s Beyond 5G Promotion Consortium is actively shaping the country’s 6G roadmap with a strong focus on optical communication technologies. Research efforts in Japan emphasize ultra-high-speed optical interconnects, optoelectronic computing, and advanced fibre-optic materials. The country is also heavily investing in quantum photonics for secure 6G communications, supported by initiatives such as the Moonshot R&D program and the National Institute of Information and Communications Technology (NICT) projects.

Photonics and optical communications will be instrumental in realizing the full potential of 6G networks, offering unparalleled speed, efficiency, and security. With global research and innovation accelerating in this domain, the integration of these technologies is expected to redefine the future of wireless communication, paving the way for revolutionary applications across industries. As 6G development progresses, continued collaboration between academia, industry, and governments will be essential to overcoming technological challenges and ensuring a seamless transition to the next-generation network era.

3.9 Overview of global focus themes

This section provided an analysis of several technological areas which are critical for the development of 6G networks, and the research priorities that several major global regions have established for each of these technological areas. The development of the future smart networks and services is a multi-faceted challenge which will be built on multiple technological blocks and will further require the tight integration with several other technologies and systems. Based on the analysis presented in this section, the major global regions seem to be aligned (for the most part) regarding the R&I priorities for 6G networks, however the specific socio-economic interest of each region have also affected their respective R&I roadmaps. Table 4 below, provides a summary of the analysis presented in this section, by presenting the key focus areas of each global region per technological enabler.

Table 4: Overview of key focus areas for each theme per global region

Key Themes / Region	Europe	USA	South Korea	Japan	China	India
Architecture	• Interoperability • Resource Awareness – Resource Brokering • Service-Awareness • Multi-Tenant Federation • AI-Native Network • Sustainability • Dependable Communications • TN / NTN Integration • Trustworthiness (Security, Privacy, Reliability)	• Trust, Security, and Resilience • Enhanced Digital World Experience • Cost Efficiency • Distributed Cloud and Communications • AI-Native Future Network • Sustainability	• AI & cloud-native network • Green-native network • Quantum Security Networks • Disaggregated RANs • Integration with NTN	• All Photonics Network (APN) • Data-Centric Infrastructure (DCI) • Computing Resources • Autonomous management, optimization • User-centric communication	• Space-Air-ground integrated network • AI native network • Deterministic networking • Computing aware network • Information centric network • Digital twin network	• Distributed & Hierarchical network • Integrated computing • AI native • Sustainability • Coreless RAN • Marketplace design • Cloud interoperability
Wireless Tech	• JCAS • Higher Frequencies (THz) • FR3 spectrum • Spectrum sharing • AI-native air interface • umMIMO • HW / Materials / Devices • Intelligent Surfaces (RIS)	• JCAS • Higher Frequencies (THz) • FR3 spectrum • Signal processing • umMIMO • HW / Materials / Devices • Intelligent Surfaces (RIS)	• JCAS • Higher Frequencies (THz) • FR3 spectrum • Spectrum sharing • umMIMO • HW / Materials / Devices	• JCAS • Higher Frequencies (THz) • FR3 spectrum • umMIMO • HW / Materials / Devices	• JCAS • Higher Frequencies (THz) • FR3 spectrum • Spectrum sharing / allocation • umMIMO • HW / Materials / Devices	• JCAS • Higher Frequencies (THz) • FR3 spectrum • umMIMO
AI/ML Landscape	• AI for Healthcare • AI for Energy Efficiency • AI for Climate Change • AI for Smart Cities • AI or Manufacturing/I4.0 • AI Legal Framework • Trustworthy AI • Ethical AI • AI-native 6G networks	• Natural language processing (NLP) • AI in STEM education • AI for climate-smart agriculture • Trustworthy AI • Ethical AI • Cross-disciplinary AI • AI Safety Institute	• AI semiconductors • AI Autonomous Vehicles AI powered healthcare • Edge AI • Real-time NLP • AI for Climate Change	• AI for Manufacturing/I4.0 • AI for Healthcare • AI for Transportation • AI for societal challenges • AI for disaster management • AI Safety Institute	• AI Intelligent Robotics • AI Autonomous Vehicles • AI for Healthcare • AI-driven Diagnostics • AI Defence Technologies • Exascale supercomputers	• AI for Healthcare • AI for Agriculture • AI for Education • Natural Language Processing (NLP) • AI for Climate Change • Exascale supercomputers

This project has received funding from the Smart Networks and Services Joint Undertaking (SNS JU) under the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101095841

Cloud	• Cloud-native 6G networks • Telco Cloud • Edge Cloud Continuum • Cloud interoperability • Sustainable Cloud • Cyber-secure Cloud • Multi Provider Cloud • Connected Collaborative Computing" Network (3C)	• Hyperscalers • Cloud-native 6G networks • Cloud interoperability • Quantum Technologies • Cloud Computing • Edge Cloud	• Cloud-native 6G networks • Telco Cloud • Edge Cloud • Cloud interoperability	• Cloud-native 6G networks • Telco Cloud • Edge Cloud • Cloud Management • Multi-cloud environments	• Cloud-native 6G networks • AI Cloud • Cloud Computing	• Cloud-native 6G networks • AI Cloud • Cloud Computing • Edge Cloud • Cloud Management
Micro-electronics	• Domestic chip production • Supply chain resilience • AI Hardware • 5G/6G wireless • Quantum technology • Energy-efficient chips • Next-gen semiconductors	• Domestic chip production • Supply chain resilience • Electromagnetic warfare • Secure computing at tactical edge • AI Hardware • 5G/6G wireless • Quantum technology	• Domestic chip production • Supply chain resilience • AI Hardware • Large-scale manufacturing	• Domestic chip production • Supply chain resilience • 2-nanometer (nm) chips • AI Hardware • Next-gen semiconductors • Human capital	• Domestic chip production • Supply chain resilience • AI Hardware • Large-scale manufacturing • Human capital development	• N/A
Security	• Trustworthiness • Secure and sustainable digital infrastructures • Common, interoperable security standards • Seamless critical communication • Quantum-safe digital infrastructure	• Trustworthiness • Confidential computing • Post-quantum cryptography • Data-centric security • Zero-trust architecture • AI-driven security	• National Cybersecurity Strategy • Cyber-attacks on public sector • Verifying security suitability • Cryptographic modules	• Trustworthiness • Quantum-resistant encryption • AI based security • Enhanced security monitoring • Sustainable security • National defence (submarine cables)	• National security • Personal data protection • Cross-border data transfers • Responsibilities of internet • Platform providers	• Critical infrastructure protection • National cyber defence framework • Global cybersecurity alliances
Optical / Photonics	• THz photonics • AI-driven photonics • Optical transceivers • Energy-efficient optics • Quantum-enhanced optical networking • Fibre-optic communication	• THz photonics • Silicon photonics • AI-driven photonics • Photonic quantum communications • Optical computing	• N/A	• THz photonics • Photonic Integrated Circuits • Optical transceivers • Optoelectronic computing • Advanced fibre-optic materials • Quantum photonics	• THz photonics • Quantum photonics • High-speed optical backhaul • Photonic crystal technologies • All-optical signal processing	• Fibre-optic enhancements • Visible light communication • Silicon photonics • Photonics-driven 6G networks

4 SNS Impact

The exact impact that the work of the SNS JU researchers has on the global B5G/6G community may not be easily quantifiable, as it is a multi-faceted problem, and a series of variables would need to be examined. The best approximation that can be used at this point in time to evaluate the impact of the output of the SNS projects, is via the use of certain metrics which indicate the visibility of the scientific work of the projects on the global stage, the dissemination efforts undertaken by the SNS project participants to create awareness about the project outcomes and insights of their research and the ability of SNS proponents to transform the research activities to real-life products and services via standardization and patenting. More specific, the following metrics will be examined, as they provide a multi-dimensional view of SNS JU's impact:

- Number of scientific publications by SNS project participants (visibility in the scientific community)
- Number of dissemination events organized / participated by SNS project participants (outreach)
- Number of standardization contributions by the SNS projects (contribution to shaping global standards)
- Number of patent / IPR (Intellectual Property Rights) applications submitted by SNS project participants (transformation of research into tangible innovations)

As it is not a trivial thing to collect the above metrics for the 63 projects currently operational (Call 3 projects have barely started in January 2025, and have not been able to create any impact so far), SNS ICE partners relied on the collaboration with the SNS OPS CSA project and sourced data from their annual SNS Questionnaire (2023 and 2024 editions) as well as, on data sourced directly from the EC Sygma portal[17] (official EC project portal) with the assistance of the SNS JU office. It has to be noted, that as the SNS OPS annual questionnaire tracks the achievements of the projects, a project needs to be operational at least for one year before participating in this survey. As such, for the first edition[18] of the questionnaire (2023) only Call 1 projects provided the requested metrics, while for the 2nd edition[19] of the questionnaire Call 1 and Call 2 provided metrics. A more detailed analysis of the questionnaire along with additional insights can be found in the SNS OPS deliverable D1.2 [129] and D1.4 [130].

4.1 SNS Publications

As the Research and Innovation (R&I) activities taking place under the SNS JU objectives usually address cutting-edge challenges of the telecom sector, engaging in low TRL research but also validating realistic higher-TRL solutions in the field, they may often lead to scientific publications, informing the scientific community of the challenges, solutions, measurement and achievements of the SNS JU researchers. These publications may be peer-reviewed articles in respectable journals, magazines or conferences, white or position papers (usually as a result of collaboration among multiple projects), or even book chapters. Figure 15 depicts the total number of publications successfully published by SNS JU projects, during the first 2 years of operation of the SNS JU. As expected during 2023, only Call 1 projects were mature enough to showcase some impact to the global scientific stage with ***373 publications***. This is an impressive outcome given the early stage of the SNS JU at that time and the usually long start-up time of the projects, which usually prohibits early results. In 2024 the total number of SNS JU scientific publications reached ***1102 publications***, with Call 1 projects holding the 'lion's share' as expected, as during their 2nd year of operation their results were much more mature and their labour had bear fruits, while Call 2 projects were barely in their 1st year of operation.

---

[17] https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/home
[18] https://smart-networks.europa.eu/event/sns-ops-survey-webinar/
[19] https://smart-networks.europa.eu/event/sns-ops-questionnaire-results-webinar/

This project has received funding from the Smart Networks and Services Joint Undertaking (SNS JU) under the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101095841

The picture painted by the results depicted in Figure 15 is very encouraging, as a significant impact from SNS JU researchers to the global scientific community is already visible in the first couple of years of their operation, raising expectations for the following years, when more mature results will be available.

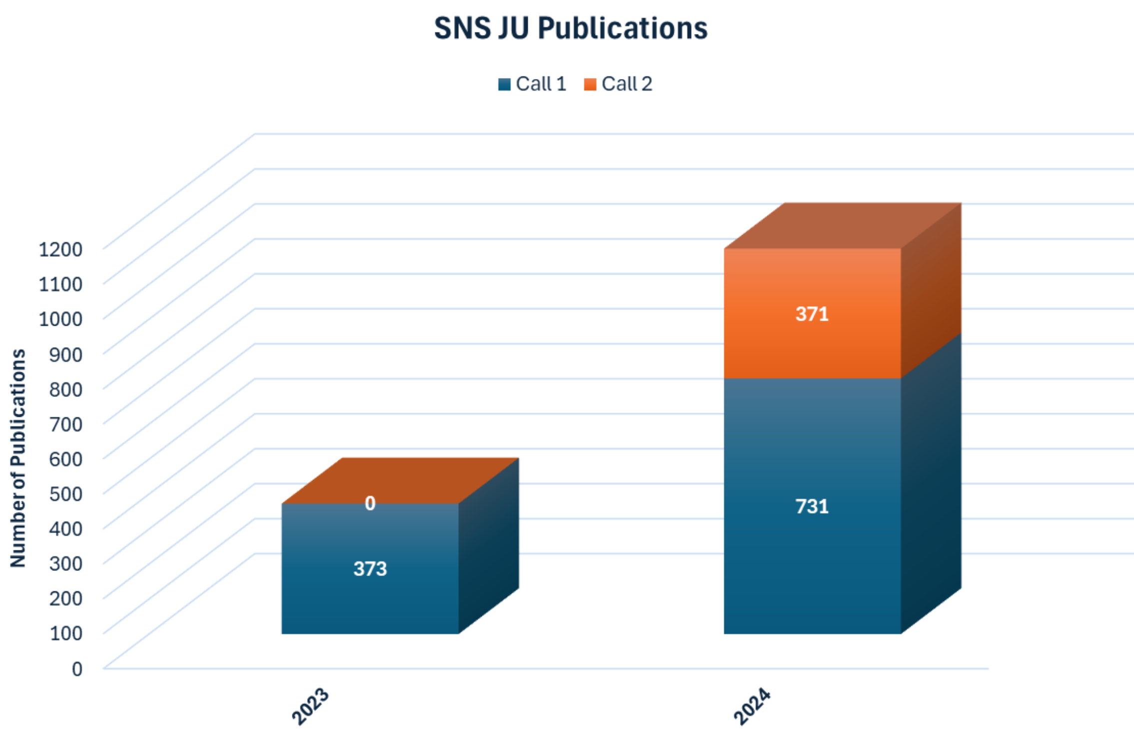


Figure 15: Number of publications from SNS JU projects.

4.2 SNS Project Events

Another metric which assists in the estimation of the produced impact by the SNS JU community, is the analysis of the number of events (workshops, sessions, webinars, panels, etc.) that SNS participants have organized and participated in. The organization and participation in such events and the corresponding conferences, exhibits, online events, etc. is the most direct way for SNS researchers to share the outcomes and insights of their work, to discuss with a broader audience in other regions and/or associations and to receive feedback from their peers, allowing them to further improve their results or develop their solutions. It is of paramount importance for all SNS JU researchers to regularly organize and participate in such events, in order to maximize the impact of their work and to stay an active member of the international telecoms research community. Figure 16 depicts the total number of events organized and participated by SNS JU project participants, during the 1st and 2nd year of SNS operation. During the 1st year, the burden of SNS representation fell exclusively on the shoulders of Call projects, which managed to have a very respectable impact with the organization and participation in ***414 events***, explaining their work, approach and methodology and even sharing early results. During 2024, the Call 1 projects matured, making interesting results and insights available and leading to the organization /participation of even more events (606). In total ***949 events*** were organized or participated in by SNS JU researchers in 2024, allowing for the broad dissemination of SNS JU work and results and increasing the global awareness of EU research on B5G and 6G networks.

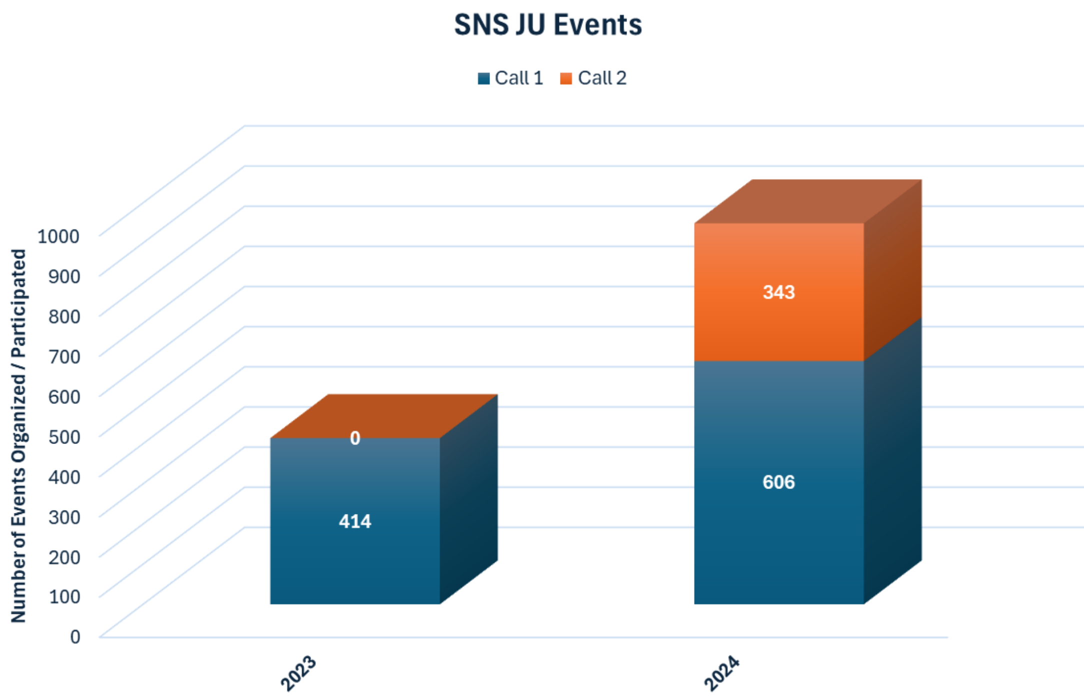


Figure 16: Number of events organized / participated from SNS JU projects.

4.3 Input to Standardization

In the years 2023 and 2024, the SNS Call 1 and Call 2 R&I projects have participated in the global standardisation roadmap for B5G and 6G, contributing to the definition of new standards within key international standardisation bodies such as 3GPP, ITU, and ETSI. These contributions have helped advance the standardisation requirements for 5G and beyond, laying the groundwork for the initial specifications leading to 6G. The SNS ICE and OPS CSA projects have implemented a robust monitoring process as part of this effort. This process leverages the 6G-IA pre-Standardisation Working Group, which collects quarterly inputs from projects participating voluntarily and publishes impact reports detailing contributions. Additionally, insights into the outcomes of 3GPP plenaries and the current state of the art are regularly shared, enhancing the community's understanding of standardisation progress and challenges.

The global roadmap for 5G and 6G standardisation represents a collaborative and dynamic effort involving various stakeholders, including academia, industry, and government entities. Within this roadmap, SNS projects have emerged as key players, bridging the gap between cutting-edge research and the practical realisation of standards.

Through the synergic and close alignment between the SNS OPS and SNS ICE consortia and the data provided directly by the SNS Office from the official EC funding and tenders (Sygma) portal, all standardisation inputs have been systematically collected and incorporated into the Standards Tracker[20] tool. This integration enables a comprehensive analysis of standardisation trends and contributions (more details in SNS OPS deliverable D4.3 [131]). For ease of reference, Figure 17 depicts a recap chart summarising the distribution of the over 1000 standardisation contributions submitted by 40 projects, according to the relevant SDO.

[20] https://verticals-tracker.sns-ju.eu/standards-tracker

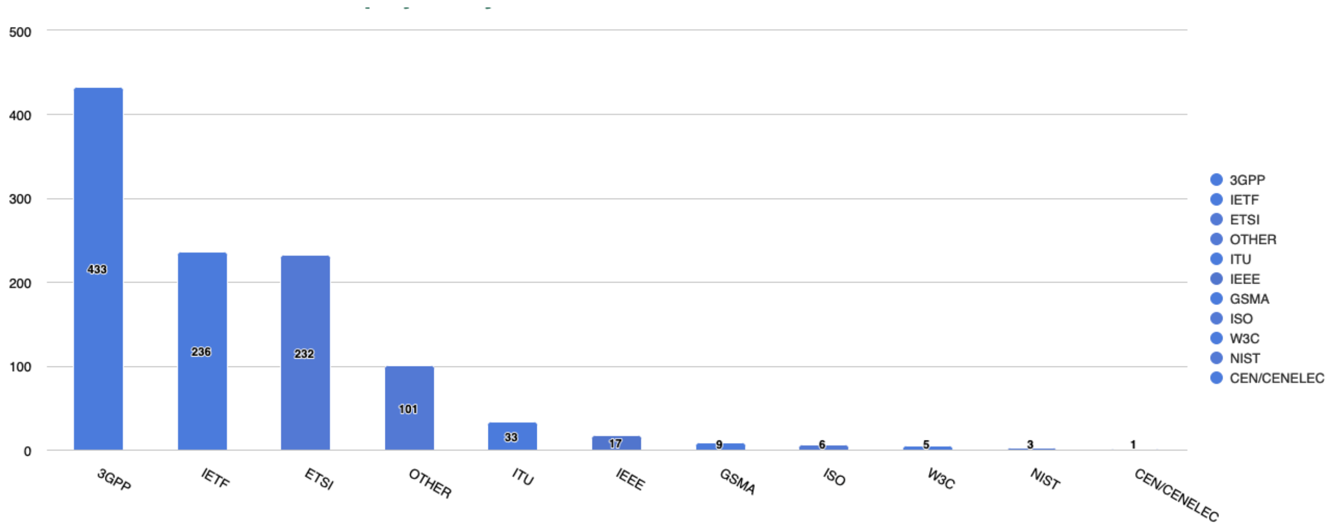


Figure 17: Standards contributions of SNS projects by SDO (Standards Tracker)

By analysing Figure 17 the focus of the SNS-funded projects in terms of standardization can be extracted, while some key insights may also be extracted:

- 3GPP leads standardisation contributions, with 433 recorded entries, reflecting its key role in mobile network evolution and future 6G standardisation.
- IETF (236) and ETSI (232) follow as major SDOs, possibly due to the importance of both internet protocol standardisation and European-driven telecommunications standardisation.
- ITU (98) and IEEE (17) show lower engagement, which suggests that European projects may be less involved in regulatory frameworks (ITU) and electrical/electronics-based standards (IEEE) compared to telecommunications-focused bodies.

The "Other" category (98 contributions) shows the existence of some level of engagement beyond the major SDOs, potentially with sector-specific or emerging standardisation groups.

4.4 SNS Patent / IPR Applications

Even though there are available metrics regarding the impact of SNS JU projects, only for the first couple of years of the SNS operation (2023 and 2024), SNS JU experimenters manged to already deliver significant advancements which led to patent / IPR applications as a direct consequence of the R&D activities that took place within the projects. This is potentially the strongest impact that SNS JU researchers can created as patents significantly strengthen the position of EU stakeholders on the global standardization stage, ensuring the EU-developed technology will find its way into the 6G standard and the global markets. Figure 18 depicts the number of patent / IPR applications submitted by SNS project participants during the first 2 years of operation of the SNS JU. In 2023 ***32 patent applications*** were submitted by SNS Call 1researchers, showcasing the strong potential of the SNS research even in this early stage. In 2024 ***74 patent applications*** were submitted in total by SNS researchers, with Call 1 getting the lion's share once again, due to their more mature results compared to Call 2.

The number of patents / IPR application sis perhaps one of the more important metrics when it comes to estimating the impact of the research conducted within the SNS JU as it essentially measures the rate of successful conversion of research ideas into actual products and services that may end up in the 6G standard.

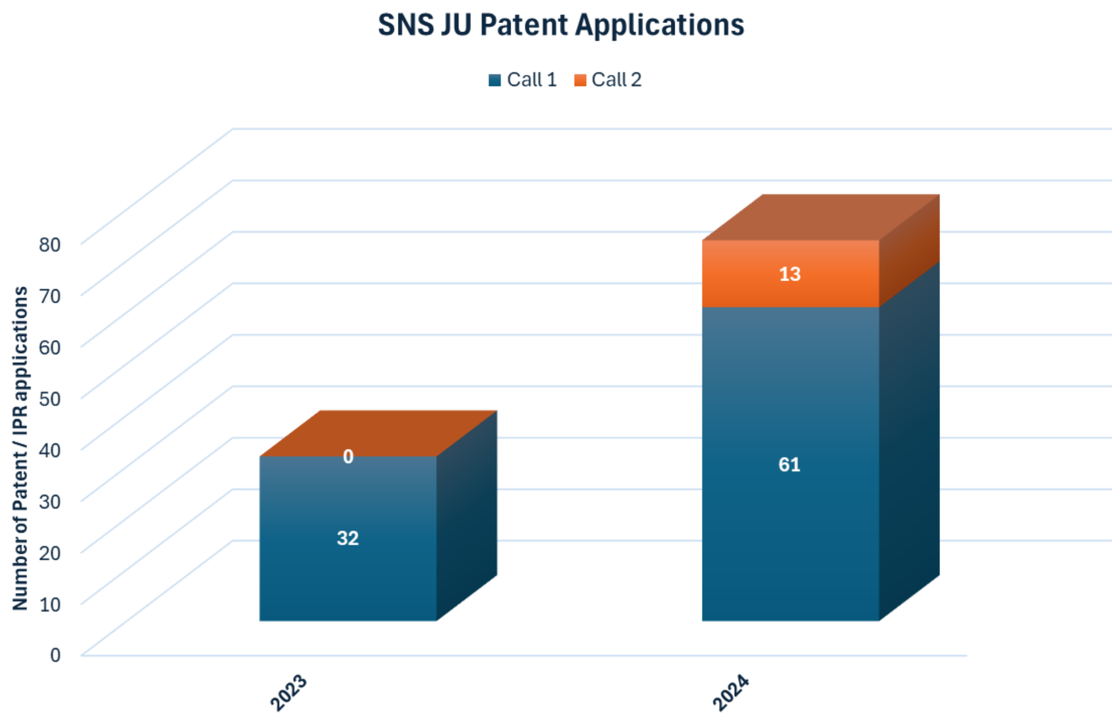


Figure 18: Number of patents / IPR applications from SNS JU projects.

5 Conclusions & Recommendations

The evaluation of the acceptance of the SNS results highlights the substantial progress made in aligning European 6G research priorities with global technological trends. The SNS JU framework has played a pivotal role in fostering innovation, facilitating collaboration, and contributing to standardization efforts. The findings demonstrate that Europe has positioned itself as a key player in 6G development, ensuring that its research outputs influence global discussions and technological advancements.

One of the critical outcomes of this evaluation is the confirmation that SNS JU research efforts align well with global 6G trends. This is evident in key technological enablers such as AI-native networking, integrated sensing and communication (ISAC), sustainability, and cloud-native architectures. The focus on these areas ensures that Europe remains competitive and at the forefront of next-generation network development. Additionally, SNS JU projects have clear goals to contribute to standardization, already actively engaging with 3GPP, ITU, and other global bodies, which has strengthened Europe's influence in defining 6G requirements.

The analysis of global focus themes provides further insights into the impact of SNS JU projects. In the domain of **6G architecture**, European initiatives emphasize interoperability, AI integration, and sustainability, mirroring global priorities while also addressing unique regional challenges. The research on **wireless technologies** highlights Europe's efforts in exploring spectrum efficiency, THz communications, and ultra-massive MIMO, aligning with international advancements to enhance data transmission capabilities. The **AI/ML landscape** in European research is focused on embedding explainable intelligence into networks, ensuring real-time adaptability and improved decision-making, which reflects broader global efforts to create AI-native networks.

In the area of **cloud technologies**, SNS JU projects support the shift towards distributed edge-cloud systems, promoting energy-efficient and scalable infrastructures. The **Non-Terrestrial Networks (NTN)** research within SNS focuses on integrating satellite and airborne communication solutions to ensure seamless connectivity, particularly for underserved regions, a goal shared by global stakeholders. Advancements in **microelectronics** play a crucial role in enabling 6G hardware, with European research addressing energy-efficient components and advanced semiconductor technologies to support the growing demands of next-generation networks. The **security** aspect remains a priority, as European efforts aim to develop robust privacy-preserving frameworks and quantum-resistant encryption methods to safeguard future communication networks. Finally, research in **optical and photonic technologies** within SNS has contributed to the development of ultra-high-speed communication and advanced sensing capabilities, reinforcing Europe's leadership in these emerging domains.

Despite these achievements, some challenges remain. While the SNS JU efforts have been largely successful, there is a need to strengthen industry participation, enhance SME engagement, and accelerate the transition from research to commercialization. Addressing these areas will be critical in maximizing the long-term impact of SNS initiatives and ensuring that European research translates into practical deployments. Based on the analysis presented in this deliverable, the following recommendations can be derived:

- **Strengthening Industry Collaboration**: Increase engagement with telecom operators, equipment vendors, and SMEs through dedicated programs and incentives to bridge the gap between research and commercial deployment.
- **Enhancing Standardization Efforts**: Maintain active participation in global standardization bodies, with structured task forces to ensure European contributions shape the 6G landscape.
- **Focus on Sustainability and Energy Efficiency**: Continue prioritizing energy-efficient solutions, green technologies, and low-carbon network infrastructure to align with global sustainability goals.
- **Supporting SME Involvement and Innovation**: Expand targeted funding schemes, mentorship programs, and access to large-scale testing facilities to encourage SME participation in SNS JU projects.

- **Accelerating Commercialization and Deployment**: Strengthen mechanisms for technology transfer through partnerships with venture capital firms, technology incubators, and public-private collaborations.
- **Global Outreach and Cooperation**: Foster international partnerships with North American, Asian, and other regional research entities to ensure mutual alignment and knowledge exchange in 6G development.
- **Enhancement of EU sovereignty**: In the current constantly shifting geo-political landscape, it is of paramount importance for Europe to enhance its digital sovereignty and limit its dependence on third party services and devices, while also pursuing significant international collaborations.

By implementing these recommendations, SNS JU can further enhance its impact, ensuring that Europe remains a leader in 6G development while addressing societal, economic, and environmental challenges. The continued evolution of SNS JU research efforts will be instrumental in shaping the future of smart networks and services in the coming decade.

6 References

[1] SNS ICE Deliverable D1.1, "Impact analysis and SNS promotional report 1.0", December 2023, https://smart-networks.europa.eu/csa-s/#SNS-ICE

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

[3] K. Trichias, A. Kaloxylos and C. Willcock, "6G Global Landscape: A Comparative Analysis of 6G Targets and Technological Trends," *2024 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit)*, Antwerp, Belgium, 2024, pp. 1-6, doi: 10.1109/EuCNC/6GSummit60053.2024.10597064, https://ieeexplore.ieee.org/document/10597064

[4] Recommendation ITU-R M.2160-0, "Framework and overall objectives of the future development of IMT for 2030 and beyond", November 2023, https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2160-0-202311-I%21%21PDF-E.pdf

[5] 6G-IA White Paper, "*European Vision for the 6G Network Ecosystem*", 6G Industry Association, November 2024. https://6g-ia.eu/wp-content/uploads/2024/11/european-vision-for-the-6g-network-ecosystem.pdf

[6] Next G Alliance White Paper, "*North American 6G Roadmap Priorities*", ATIS – NGA, June 2024, https://nextgalliance.org/white_papers/north-american-6g-roadmap-priorities/

[7] Bharat White Paper, "*6G Vision*", Government of India, Ministry of Communications, Department of Telecommunications, March 2023, https://dot.gov.in/sites/default/files/Bharat%206G%20Vision%20Statement%20-%20full.pdf

[8] NICT White Paper, "*Beyond 5G/6G White Paper*", National Institute of Information and Communication Technology, June 2022, https://beyond5g.nict.go.jp/images/download/NICT_B5G6G_WhitePaperEN_v2_0.pdf

[9] Beyond 5G White Paper, "*Message to the 2030s*", Beyond 5G Promotion Consortium, White Paper Subcommittee, March 2022, https://b5g.jp/doc/whitepaper_en_1-5.pdf

[10] SK Telecom 6G White Paper, "*5G Lessons learned, 6G Key Requirements, 6G Network Evolution and 6G Spectrum*", SK Telecom, v1.0, August 2023, https://newsroom-prd-data.s3.ap-northeast-2.amazonaws.com/wp-content/uploads/2023/11/SKT6G-White-PaperEng_v1.0_clean_20231129.pdf

[11] SK Telecom 6G White Paper, "*View on Future AI Telco Infrastructure*", SK Telecom, v1.0, October 2024, https://newsroom-prd-data.s3.ap-northeast-2.amazonaws.com/wp-content/uploads/2024/10/SKT6G-White-PaperEng_v1.0_clean_20241015.pdf

[12] IMT-2030 (6G) Promotion Group White Paper, "*6G Usage Scenarios and Key Capabilities*", IMT-2030 (6G) PG, June 2023, https://www.imt2030.org.cn/html/default/en/Publications/Whitepaper/index.html?index=2

[13] IMT-2030 (6G) Promotion Group White Paper, "*6G Wireless System Design Principles and Typical Features*", IMT-2030 (6G) PG, 2024, https://www.imt2030.org.cn/html/default/en/Publications/Whitepaper/index.html?index=2

[14] TAICS White Paper, "*White Paper on 6G technology Candidates*", TAICS TR-0021(E), v1.0, December 2023, https://www.taics.org.tw/eng/Publishing.aspx?PubCat_id=3#

[15] NGMN report, "*ITU-R Framework for IMT-2030: Review and Future Direction*", v1.0, February 2024, https://www.ngmn.org/publications/itu-r-framework-for-imt-2030.html

[16] NGMN Position Statement, "*6G Position Statement – An Operator View*", v1.0, September 2023, https://www.ngmn.org/wp-content/uploads/NGMN_6G_Position_Statement.pdf

[17] Ericsson White Paper, "*Co-Creating a Cyber-Physical World*", Ericsson, July 2024, https://www.ericsson.com/en/reports-and-papers/white-papers/co-creating-a-cyber-physical-world

[18] Nokia White Paper, "*Transforming the 6G Vision to Action*", Nokia June 2024, https://www.bell-labs.com/institute/white-papers/transforming-the-6g-vision-to-action/#gref

[19] 3GPP SWS-240025, Summary of the Workshop Report, "*3GPP Stage 1 WS on IMT 2030 Use Cases*", Rotterdam, The Netherlands, 8-10 May, 2024, https://www.3gpp.org/ftp/workshop/2024-05-08_3GPP_Stage1_IMT2030_UC_WS/Docs/

[20] Hexa-X-II, "Deliverable D1.2 – 6G Use Cases and Requirements", December 2023. https://hexa-x-ii.eu/wp-content/uploads/2024/01/Hexa-X-II_D1.2.pdf

[21] SNS ICE Deliverable D3.3, "Updated trends analysis in vertical sectors", December 2024, https://smart-networks.europa.eu/csa-s/#SNS-ICE

[22] 6G-IA White Paper, "6G KPIs – Definitions and Target Values", , January 2025. DOI: 10.5281/zenodo.14621168, Available online at: https://smart-networks.europa.eu/wp-content/uploads/2025/02/white-paper-kpis_17_2_2025_for-rel_.pdf

[23] ATIS/NGA White Paper, "Roadmap to 6G", February 2022, https://atis.org/press-releases/atis-next-g-alliance-roadmap-to-6g-positions-north-america-at-the-forefront-of-wireless-technology-development-2/?

[24] NGA Report, "Spectrum Working Group: Spectrum Access Mechanisms", November 2023, https://nextgalliance.org/white_papers/spectrum-access-mechanisms/?

[25] NGA Report, "6G Management and Orchestration (M&O)", February 2024, https://atis.org/press-releases/atis-next-g-alliance-maps-the-future-of-6g-management-and-orchestration/?

[26] NGA presentation, "NGA System Architecture – 6G Wide Area Cloud", https://hexa-x-ii.eu/wp-content/uploads/2025/02/NextG_SystemArchitecture_6GWideAreaCloud.pdf?

[27] Amitava Ghosh, Doug Castor, and Marc Grant, "National 6G Roadmap Working Group: North American 6G Roadmap Priorities", ATIS-NGA, September 2024, https://nextgalliance.org/national-6g-roadmap-working-group-north-american-6g-roadmap-priorities/?

[28] Beyond 5G Promotion Consortium, "Beyond 5G White Paper, Message to the 2030s, Version 3.0," March 2024. [Online]. Available: https://b5g.jp/en/output/

[29] XGMF, 6G Network Architecture Project, https://xgmf.jp/en/project/pj-2403

[30] Sun Shaohui, "Introduction on IMT-2030(6G) Promotion Group in China", CICT Mobile, February 2024, https://hexa-x-ii.eu/wp-content/uploads/2024/02/Introduction-on-IMT-20306G-PG-20240201.pdf

[31] TSDSI White Paper, "6G Use cases and Enabling Technologies", https://tsdsi.in/wp-content/uploads/2022/10/6G-White-Paper-12-Pages-Digital.pdf?

[32] TSDSI report, "10 Years of Developing ICT Standards – TSDSI – An Overview", January 2024, https://tsdsi.in/wp-content/uploads/2024/06/TSDSI-Overview-Slidedeck_-v0.4-20240618.pdf?

[33] 6G-IA Position Paper: Research Priorities on Wireless Technologies and Signal Processing, April 2024, https://6g-ia.eu/wp-content/uploads/2024/05/240504_6g-ia-position-paper_wireless_final.pdf

[34] "6G Radio Technology Part I: Basic Radio Technologies", White Paper of the Next G Alliance, November 2023. Available on-line at: https://nextgalliance.org/white_papers/6g-radio-technology-part-i-basic-radio-technologies

[35] "NextG Communications Research and Development Gaps Report," National Institute of Standards and Technology, NIST Special Publication 1293, 2022. Available online at: https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1293.pdf

[36] "6G RF Spectrum Horizons" , FCC Technology Advisory Council 6G Working Group Position Paper, August 17 2023. Available on-line at: https://www.fcc.gov/sites/default/files/Consolidated_6G_Paper_FCCTAC23_Final_for_Web.pdf

[37] "NSF 21-581: Resilient & Intelligent NextG Systems (RINGS)," National Science Foundation. Available online at: https://new.nsf.gov/funding/opportunities/rings-resilient-intelligent-nextg-systems/nsf21-581/solicitation

[38] "NSF 22-571: Spectrum and Wireless Innovation Enabled by Future Technologies (SWIFT)," National Science Foundation. Available online at: https://www.nsf.gov/funding/opportunities/swift-sat-spectrum-wireless-innovation-enabled-future-technologies/505858/nsf22-571/solicitation

[39] "Communications, Circuits, and Sensing-Systems (CCSS)," National Science Foundation. Available online at: https://www.nsf.gov/funding/opportunities/ccss-communications-circuits-sensing-systems

[40] "Terahertz Communications, Sensing and Security," IEEE Military Communications Conference (MILCOM) 2024. Available online at: https://milcom2024.ieee-milcom.org/program/terahertz-communications-sensing-and-security

[41] 5G Forum (Korea), Beyond 5G and 6G Strategy, 2024. Available at: https://www.5gforum.org

[42] "MSIT Launches the 2030 K-Network Strategy," Ministry of Science and ICT, Feb. 2023. Available online at: https://www.msit.go.kr/eng/bbs/view.do?bbsSeqNo=42&mId=4&mPid=2&nttSeqNo=783&sCode=eng

[43] "South Korea to Invest USD 130 Million in 5G and 6G in 2024," 6GWorld, Jan. 2024. Available online at: https://www.6gworld.com/exclusives/south-korea-to-invest-usd-130-million-in-5g-and-6g-in-2024/

[44] "Unlocking the Potential of 6G: Finland and South Korea Join Forces in the 6GBridge-6CORE Project to Develop Advanced System Architecture," 6G Flagship, Jan. 2023. Available online at: https://www.6gflagship.com/news/unlocking-the-potential-of-6g-finland-and-south-korea-join-forces-in-the-6gbridge-6core-project-to-develop-advanced-system-architecture/

[45] "Future Vision of Radio Spectrum Policy", a position paper of the Ministry of Internal Affairs and Communications, 2023. Available on-line from: https://www.soumu.go.jp

[46] "NTT DOCOMO and NTT to Collaborate on 6G Experimental Trials with World-leading Mobile Technology Vendors," NTT, June 2022. Available online at: https://group.ntt/en/newsrelease/2022/06/06/220606a.html

[47] IMT-2030 (China), 6G Vision and Candidate Technologies White Paper, 2021. Available at: https://www.imt2030.org

[48] "National Natural Science Fund Guide to Programs 2023," National Natural Science Foundation of China, 2023. Available online at: https://www.nsfc.gov.cn/english/site_1/pdf/NationalNaturalScienceFundGuidetoPrograms2023.pdf

[49] "R&D of 6G, other future tech to get high priority," The State Council of the People's Republic of China, Mar. 2023. Available online at: https://english.www.gov.cn/statecouncil/ministries/202303/02/content_WS63fff5e9c6d0a757729e7755.html

[50] "DoT Launches Bharat 6G Alliance to Drive Innovation and Collaboration in Next-Generation Wireless Technology," Press Information Bureau, July 2023. Available online at: https://pib.gov.in/PressReleasePage.aspx?PRID=1937088

[51] Bharat 6G Alliance, India's 6G Vision Document, 2023. Available at: https://www.bharat6galliance.in

[52] "India gets behind terahertz push for 6G," Light Reading, August 2024. Available online at: https://www.lightreading.com/6g/india-gets-behind-terahertz-push-for-6g

[53] ITU-R: Future technology trends of terrestrial International Mobile Telecommunications systems towards 2030 and beyond. Report ITU-R M.2516-0, (11/2022), REPORT ITU-R M.2516-0 - Future technology trends of terrestrial International Mobile Telecommunications systems towards 2030 and beyond.

[54] ITU-R: IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond. Recommendation ITU-R M.2083-0 (09/2015), IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond (itu.int).

[55] ITU: Radio Regulations – Articles. Vol. 1, Edition 2020.

[56] ETSI: ETSI Group Report "TeraHertz technology (THz); Identification of frequency bands of interest for THz communication systems", March 2024.

[57] ITU-R WP5D: Liaison Statement to External Organisations: Minimum requirements related to technical performance for IMT-2030 radio interface(s). October 2024.

[58] U.S. National Science Foundation, National Artificial Intelligence Research Institutes, https://new.nsf.gov/funding/opportunities/national-artificial-intelligence-research-institutes

[59] Article, "Breaking down global government spending on AI", HPCwire, August 2024, https://www.hpcwire.com/2024/08/26/breaking-down-global-government-spending-on-ai/

[60] Wikipedia entry, "AI Safety Institute", https://en.wikipedia.org/wiki/AI_Safety_Institute

[61] China Science & technology Newsletter, No.17, Department of International Cooperation Ministry of Science and Technology, September 2017, http://fi.china-embassy.gov.cn/eng/kxjs/201710/P020210628714286134479.pdf

[62] Online article, "China accelerates AI development to build AI innovation center", April 2024, Th State Council, The people's Republic of China, https://english.www.gov.cn/news/202404/06/content_WS6610834dc6d0868f4e8e5c57.html

[63] Wikipedia, Exascale computing, https://en.wikipedia.org/wiki/Exascale_computing

[64] OECD article. AI in Japan, National Strategies & Policies, https://oecd.ai/en/dashboards/countries/Japan

[65] White Paper, « «Japan 's AI Strategy: The challenge for AI collaboration across the trilateral security DIalogue", RMIT University, https://www.rmit.edu.au/content/dam/rmit/au/en/research/networks-centres-groups/centre-for-cyber-security/ai-trilateral-report-3-japan.pdf

[66] BankInfo Security, "South Korea Invests in AI R&D to Compete Globally", March 2024, https://www.bankinfosecurity.asia/south-korea-invests-in-ai-rd-to-compete-globally-a-24689

[67] Science.org article, "South Korea to join the European Union's research funding program", March 2024, https://www.science.org/content/article/south-korea-join-european-union-s-research-funding-program

[68] National Strategy for Artificial Intelligence, "Toward AI World Leader beyond IT", December 2019, https://www.msit.go.kr/bbs/view.do?sCode=eng&nttSeqNo=9&bbsSeqNo=46&mId=10&mPid=9

[69] Article, "The 13 Most Advanced Countries in Artificial Intelligence ", https://rejolut.com/blog/13-top-ai-countries/?utm_source=chatgpt.com

[70] National Program on Artificial Intelligence – Digital India,https://www.digitalindia.gov.in/initiative/national-program-on-artificial-intelligence/#:~:text=Government%20of%20India-,National%20Program%20on%20Artificial%20Intelligence,and%20adoption%20for%20social%20impact.

[71] European Commission, European research development and deployment of AI, https://digital-strategy.ec.europa.eu/en/policies/european-ai-research#:~:text=Horizon%20Europe%2C%20the%20primary%20EU,AI%20and%20quantum%20technology%20projects.

[72] European Commission, Shaping Europe's digital Future, AI Act, https://digital-strategy.ec.europa.eu/en/policies/regulatory-framework-ai

[73] White Paper, "AI/ML as a Key Enabler of 6G Networks: Methodology, Approach and AI-Mechanisms in SNS JU", Smart Networks and Services Joint Undertaking, Technology Board, January 2025, LINK

[74] European Commission, "How to master Europe's digital infrastructure needs?," White Paper, Feb. 2024. Online: https://digital-strategy.ec.europa.eu/en/library/white-paper-how-master-europes-digital-infrastructure-needs

[75] ATIS, 6G-IA, "EU-US beyond 5G/6G roadmap," Dec. 2023.: https://6g-ia.eu/wp-content/uploads/2024/01/eu-us-aligned-6g-roadmap-joint-paper.pdf

[76] GSMA, ``Mobile industry response to European Commission white paper: How to master Europe's digital infrastructure needs?,'' June 2024. Online: https://www.gsma.com/about-us/regions/europe/gsma_resources/the-gsma-responds-to-the-european-commission-white-paper-how-to-master-europes-digital-infrastructure-needs/

[77] 6G-IA, ``Research Priorities on Cloud and Service Provision,'' Position Paper, April 2024. Online:https://6g-ia.eu/wp-content/uploads/2024/05/6g-ia-cloud-workshop1.1.pdf

[78] Reuters article, "Telefonica Germany tests quantum technologies in pilot with AWS", November 2024, https://www.reuters.com/business/media-telecom/telefonica-germany-tests-quantum-technologies-pilot-with-aws-2024-11-28/

[79] TIME, T-Mobile US's CEO Mike Sievert on the Future of Connectivity, December 2024, https://time.com/7203701/t-mobile-us-mike-sievert-interview/

[80] Reuters article, "Exclusive: Saudi Aramco unit in talks to invest $1 billion in US software maker Mavenir, sources say", November 2024, https://www.reuters.com/world/middle-east/saudi-aramco-unit-talks-invest-1-billion-us-software-maker-mavenir-sources-say-2024-11-22/?

[81] Rakuten Mobile, Rakuten Mobile to Drive International Standardization for Advanced Edge Cloud Tech, with Funding Awarded by NICT, October 2024, https://corp.mobile.rakuten.co.jp/english/news/press/2024/1022_01/

[82] IIJ Launches IIJ Cloud Data Platform Service to Facilitate On-Premise and Multi-Cloud Data Integration, December 2022, https://www.iij.ad.jp/en/news/pressrelease/2022/1212.html?

[83] DigitimesAsia, "South Korea looks to enhance network competitiveness with K-Network 2030 strategy", July 2023, https://www.digitimes.com/news/a20230719VL209/south-korea-telecom-service-infrastructure.html?

[84] IEEE ComSoc Technology Blog, "KT and LG Electronics to cooperate on 6G technologies and standards, especially full-duplex communications", August 2024, https://techblog.comsoc.org/2024/08/13/kt-and-lg-electronics-to-cooperate-on-6g-technologies-and-standards-especially-full-duplex-communications/?

[85] Telecoms article, "China Mobile unveils 'AI+NETWORK' strategy at MWC", March 2025, https://www.telecoms.com/partner-content/china-mobile-unveils-ai-network-strategy-at-mwc

[86] The Times article, "China's Alibaba investing $50bn in AI and cloud computing", February 2025, https://www.thetimes.com/business-money/technology/article/chinas-alibaba-investing-50bn-in-ai-and-cloud-computing-xpr29lg9m

[87] Reuters article, "China says it will increase support for AI, science and tech innovation", March 2025, https://www.reuters.com/technology/china-says-it-will-increase-support-ai-science-tech-innovation-2025-03-05/

[88] Federal Ministry for Economic Affairs and Climate Action, ``IPCEI Next generation cloud infrastructure and services,'' Online: https://www.bmwk.de/Redaktion/EN/Artikel/Industry/ipcei-cis.html

[89] European Commission, ``Important project of common European interest on next generation cloud infrastructure and services (IPCEI-CIS) - RRF,'' Online: https://www.bmwk.de/Redaktion/EN/Downloads/D/decision-of-the-european-commission-regarding-the-ipcei-cis.pdf?__blob=publicationFile\&v=4

[90] European Commission, ``European alliance for industrial data, edge, and cloud,'' Online: https://digital-strategy.ec.europa.eu/en/policies/cloud-alliance

[91] European Commission, ``European alliance for industrial data, edge, and cloud presents its first deliverable,'' Online: https://digital-strategy.ec.europa.eu/en/news/european-alliance-industrial-data-edge-and-cloud-presents-its-first-deliverables

[92] European Commission, ``New telco cloud thematic roadmap from the European alliance for industrial data, edge, and cloud,'' Online: https://digital-strategy.ec.europa.eu/en/news/new-telco-cloud-thematic-roadmap-european-alliance-industrial-data-edge-and-cloud

[93] Sylva, ``Every cloud has a SYLVA lining,'' Online: https://sylvaproject.org/

[94] Cloud Native Telecom Initiative, Homepage, Online: https://lfnetworking.org/cloud-native-telecom-initiative/

[95] Akunet, Homepage. Online: https://anuket.io/

[96] GSMA Intelligence report, November 2024, https://www.gsmaintelligence.com/research/mobile-data-deck-q4-2024

[97] Subcommittee on Microelectronics Leadership Committee on Homeland and National Security, National Strategy on Microelectronics Research. March 2024. Available at https://www.nitrd.gov/pubs/National-Strategy-on-Microelectronics-Research-March-2024.pdf.

[98] Zimmerman, A. R&D Funding Breakdown: CHIPS and Science Act". American Association for the Advancement of Science. 26 August 2022. Available at https://www.aaas.org/sites/default/files/2023-01/CHIPS%20AAE.pdf?adobe_mc=MCMID%3D69209921711590814772918205876201604040%7CMCORGID%3D242B6472541199F70A4C98A6%2540AdobeOrg%7CTS%3D1701808990

[99] Wheeler, K., How Japan Proposes to Strengthen its Domestic Chip Industry. Technology Magazine. 12 November 2024. Available at https://technologymagazine.com/articles/how-japan-proposes-to-strengthen-its-domestic-chip-industry.

[100] Nellis, S. Japan taps US chip startup Tenstorrent to help train new wave of engineers. Reuters, 5 November 2024. Available at https://www.reuters.com/technology/japan-taps-us-chip-startup-tenstorrent-help-train-new-wave-engineers-2024-11-05/.

[101] Crawford, E. Made in China 2025: The Industrial Plan that China Doesn't Want Anyone Talking About". PBS. 7 May, 2019. Available at https://www.pbs.org/wgbh/frontline/article/made-in-china-2025-the-industrial-plan-that-china-doesnt-want-anyone-talking-about/.

[102] China sets up third fund with $47.5 bln to boost semiconductor sector. Reuters, 27 May 2024. Available at https://www.reuters.com/technology/china-sets-up-475-bln-state-fund-boost-semiconductor-industry-2024-05-27/.

[103] Zhu, J., Potkin, F., Baptista E., Martina M., Insight: China quietly recruits overseas chip talent as US tightens curbs, 24 August 24, 2023. Available at https://www.reuters.com/technology/china-quietly-recruits-overseas-chip-talent-us-tightens-curbs-2023-08-24/.

[104] China's Top Chipmaker Achieves Breakthrough Despite US Curbs. Bloomberg News. 21 July 2022. Available at https://www.bloomberg.com/news/articles/2022-07-21/china-s-top-chipmaker-makes-big-tech-advances-despite-us-curbs?embedded-checkout=true.

[105] Kim, Ji-H. Yoo S., Kim, J-K., South Korea's Nationwide Effort for AI Semiconductor Industry, 1 July 2023. Available at https://cacm.acm.org/research/south-koreas-nationwide-effort-for-ai-semiconductor-industry/

[106] South Korea to roll out $10 bln in loans next year to support chip industry, Reuters, 26 November 2024. Available at https://www.reuters.com/technology/south-korea-roll-out-10-bln-loans-next-year-support-chip-industry-2024-11-26/

[107] Hsiao, J. South Korea fast-tracks Yongin semiconductor complex development, aiming to be world's largest chip hub. DIGITIMES Asia, 30 December 2024. Available at https://www.digitimes.com/news/a20241230VL201/south-korea-semiconductor-industry-infrastructure-development-samsung.html

[108] South Korea's SK Hynix to invest $75 billion by 2028 in AI, chips, Reuters, 30 June 2024. Available at https://www.reuters.com/technology/south-koreas-sk-hynix-invest-75-bln-by-2028-ai-chips-2024-06-30/

[109] EU Commission, Regulation (EU) 2023/1781 of the European Parliament and of the Council of 13 September 2023 establishing a framework of measures for strengthening Europe's semiconductor ecosystem and amending Regulation (EU) 2021/694 (Chips Act). Available at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R1781.

[110] Zou. Y., European Core Technologies for future connectivity systems and components. Final COREnect Industry Roadmap. June 2022. Available at https://static1.squarespace.com/static/5f46601a7f9764175fb38f1c/t/62cfd87c20a77659f3b029a0/1657788588357/COREnect_D3.6_Final_COREnect_Industry_Roadmap.pdf.

[111] Barani, B. & Kaloxylos, A., Research Priorities on Microelectronics for 6G Networks R&I activities. Whitepaper. October 2023. Available at https://6g-ia.eu/wp-content/uploads/2024/02/6g-ia-position-paper_microelectronics-final.pdf.

[112] EU and United States enhance cooperation on cybersecurity: https://digital-strategy.ec.europa.eu/en/news/eu-and-united-states-enhance-cooperation-cybersecurity

[113] Network Data Security Management Regulations: https://www.gov.cn/zhengce/content/202409/content_6977766.htm

[114] Softbank's challenge towards realizing 6G, https://www.softbank.jp/en/corp/technology/research/story-event/053/

[115] Japanese & Canadian Research Highlights Methods to Secure 6G Incrementally, https://www.6gworld.com/exclusives/japanese-canadian-research-highlights-methods-to-secure-6g-incrementally/

[116] National Cybersecurity Strategyhttps://www.itu.int/en/ITU D/Cybersecurity/Documents/National_Strategies_Repository/National%20Cybersecurity%20Strategy_South%20Korea.pdf

[117] Security and Defence partnership between the European union and Japan https://www.eeas.europa.eu/sites/default/files/documents/2024/EU-Japan%20Security%20and%20Defence%20Partnership.pdf

[118] UK-Japan initiative tackles malware threats in 5G & 6G networks, https://telconews.co.uk/story/uk-japan-initiative-tackles-malware-threats-in-5g-6g-networks

[119] Korea's Path to Digital Leadership: https://carnegie-production-assets.s3.amazonaws.com/static/files/Feigenbaum%20Nelson_Korea%20Digital%20Leadership%201.pdf

[120] India cyber threat report Dec 2024 : https://www.dsci.in/resource/content/india-cyber-threat-report-2025

[121] Evaluation of EU-India Science & Technology Agreement highlights achievements and showcases future opportunities: https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/evaluation-eu-india-science-technology-agreement-highlights-achievements-and-showcases-future-2025-02-25_en

[122] UN office of counter-terr0rism: Cybersecurity and new technologies https://www.un.org/counterterrorism/sites/www.un.org.counterterrorism/files/240829_global_cyber_programme.pdf

[123] EU commission report on "Recovery plan for Europe" available at: https://commission.europa.eu/strategy-and-policy/recovery-plan-europe_en#introduction

[124] EU Commission, whitepaper on "How to master Europe's digital infrastructure needs?" Available at: https://digital-strategy.ec.europa.eu/en/library/white-paper-how-master-europes-digital-infrastructure-needs

[125] EU commission report on the state of the Digital Decade available at: https://digital-strategy.ec.europa.eu/en/library/2023-report-state-digital-decade

[126] Gigabit Infrastructure Act available at: https://digital-strategy.ec.europa.eu/en/policies/gigabit-infrastructure-act

[127] Cyber-resilience Act, available at: https://digital-strategy.ec.europa.eu/en/policies/cyber-resilience-act

[128] Innovative Approaches for 6G Security, Jan 2025 at: https://6g-ia.eu/wp-content/uploads/2025/01/wg_sec_position_paper-23.pdf

[129] SNS OPS Deliverable D1.2, "First Period Assessment and Planning Report", January 2024, https://smart-networks.europa.eu/csa-s/#SNS-OPS

[130] SNS OPS Deliverable D1.4, "Second Period Assessment and Planning Report", March 2025, https://smart-networks.europa.eu/csa-s/#SNS-OPS

[131] SNS OPS Deliverable D4.3, "Stakeholder Involvement and Interaction: Final Report", March 2025, https://smart-networks.europa.eu/csa-s/#SNS-OPS