EU-US

Beyond 5G/6G Roadmap

December 2023

Executive Summary

This document is a comprehensive set of critical strategic reflections and recommendations for 6G networks and services, capturing the views and priorities from Next G Alliance and the SNS JU. This document proposes 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.

This document analyzes six promising collaboration areas between the EU and the US for 2025 and beyond:

1) Work jointly to address environmental, social, and economic sustainability goals and work toward reduced footprints (Sustainable 6G) as well as enabled benefits, a.k.a. handprints (6G for sustainability) [**Refer Section 3.1**].
2) Engage in semiconductor research related to the use of microelectronics for wireless communication, especially in the mid-band to sub-THz range [**Refer Section 3.2**].
3) Enable disaggregated 6G cloud architectures with standardized interfaces between different stakeholders [**Refer Section 3.3**].
4) Strengthen a collaborative EU-US research and innovation environment for open network solutions where new results will progressively reach a higher Technology Readiness Level (TRL) [**Refer Section 3.4**].
5) Cooperate to set the main trends in AI-native air interface and network/device collaboration, including i) energy efficient AI/ML research, ii) establishment of reference datasets and AI/ML models, and iii) trustworthy AI/ML and privacy policy collaborations [**Refer Section 3.5**].
6) Join forces to institute new resilience mechanisms for 6G networks, from the supply chain to the recovery after attacks. Areas of collaboration could include developing new security expectations for 6G equipment and software, including employment of associated methods for detecting, preventing, and responding to attacks [**Refer Section 3.6**].

In addition, the document identifies the following areas for cooperation:

- Explore value creation opportunities from various vertical industries and identify common use cases between the US and the EU to maximize economies of scale and support the same standardization priorities.
- Jointly develop technology Proofs-of-Concept (PoC) targeted toward selected vertical industries that will evolve with the foundational research to conduct demonstrations, tests, and trials as technologies mature.
- Design workforce development strategies to increase the number of students graduating in STEM fields and create a talent pipeline for developing advanced 6G technologies.

The following set of specific short-term actions is proposed for the consideration of the policymakers to initiate the collaboration in the above areas:

- Organize a face-to-face EU-US workshop **in the first quarter of 2024** to discuss this document's recommendations and potential feedback from the TTC to elaborate on possible actions during 2024.
- Analyze the opportunities and create a concrete strategic collaboration agenda through collaborative R&I actions (**June 2024**).
- Organize coordinated PoC toward one or two vertical industries. The EU and US should collaboratively invest in supporting these activities (**organization until mid-June 2024 and implementation in 2025**).
- Work to identify possibilities for a shared view on the needed 6G spectrum across the EU and US (**June 2024**).

1. Context and Purpose

During the fourth Ministerial meeting of the Trade and Technology Council (TTC), which took place in Luleå, Sweden, on 31 May 2023, the EU and US administrations reaffirmed their commitment to cooperate to develop 6G networks.

As a first step, the 6G Industry Association (6G-IA), the private member of the EU Smart Networks and Services Joint Undertaking (SNS JU), and the Next G Alliance (an ATIS initiative) requested to provide an interim, joint, aligned 6G industry roadmap by the end of 2023. This collective private-sector input will then be considered for inclusion into a TTC 6G shared vision established by the US and EU governments. According to the joint statement between the two administrations, "With this TTC 6G common vision as a basis, we aim to scale up the existing R&D cooperation on 6G between the US and EU funding agencies, namely the SNS JU and the National Science Foundation (NSF), create a critical mass among like-minded partners in global regulatory and standardization bodies, and cooperate in technology trials and pilots to foster market adoption."

This document aims to fulfil that mandate. It contains a set of key strategic reflections and recommendations for 6G networks and services, capturing the views and priorities from Next G Alliance and the SNS JU. This document offers a candidate 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.

2. Guiding Principles and Key Priorities for a Common Vision

The foundational goal for the shared vision should include:

- An active collaboration plan between the private sector, academia, and government.
- A comprehensive goal built on joint 6G technology development.
- A set of strategies that will lead to rapid commercialization and adoption of 6G technologies across global markets.

Moreover, the R&D cooperation activities between the US and the EU should follow the same values and principles:

- **Trust, Security, and Resilience**: 6G will become a more integral part of everyday life and the infrastructure that society depends on. 6G networks should offer the highest levels of trustworthiness, security, and resilience.
- **Bridging the Digital Divide**: 6G should provide affordable access to services essential to the US and the EU and include policies addressing rural availability, infrastructure efficiencies, and spectrum use using both terrestrial and non-terrestrial networks.
- **AI-Native Wireless Networks**: Shape the global evolution of AI and promote critical application of trustworthy AI in wireless communications.
- **Sustainability**: Both regions should work toward reducing the ICT sector's energy consumption and decarbonizing the energy supply. One should leverage our expertise

in component design and manufacturing, advanced data modeling and optimization, power-efficient radio technologies, and carbon-neutral data center facilities.

- **Common Standards**: The US and the EU should strive to achieve one common global standard (e.g., 3GPP) for 6G. They should actively work together to realize the International Mobile Telecommunications for 2030 and Beyond (IMT-2030) vision.
- **Openness**: Open networks refer to open interfaces as well open network function definition. They both target the hardware and software disaggregation that is part of the network evolution underway in the marketplace during 2022-2023. The US and EU should work to strengthen research and innovation activities to reach sound and widely accepted conclusions. All research efforts should work under the assumption of technology-neutral regulation, not mandating any architectures but rather pursuing the most suitable and efficient solutions.
- **Verticals**: While 5G and initial 6G rollout emphasize Enhanced Mobile Broadband (eMBB) and Fixed Wireless Access (FWA) in the beginning, the EU and the US should jointly explore value creation opportunities from various vertical industries, including Industrial IoT, Automotive and Transportation, Media and Entertainment, Public Safety, Smart Cities, eHealth, and Agriculture to name a few. It would also be worth exploring possibilities to identify use cases of common interest between the US and the EU to maximize the economies of scale and to support the same standardization priorities.

3. EU-US Roadmap: Six Collaboration Areas for 6G Networks and Services

Recently, the IMT-2030 has released the overall objectives for 6G networks.[1] The motivation for IMT-2030 is "to continue to build an inclusive information society and to support the UN's sustainable development goals (SDGs)." Similar motivations have also been identified in the US[2] and in the EU, where apart from the SDGs, EU policies like the Green Deal[3] set out a target for the EU to achieve climate neutrality by 2050.

Additionally, 6G networks aim to provide environmental, societal, and business-sustainable solutions for the networking domain (i.e., "Sustainable 6G"), as well as for a variety of vertical industries (i.e., "6G for sustainability") such as media, transportation, e-health, industrial IoT, etc.

The drivers for 6G network development are not only the typical and expected **performance improvements** (e.g., throughput, latency, reliability, coverage, spectrum efficiency) but **the societal, business, and policy goals that 6G can address**. These goals will impact the technological choices for the design, development, and deployment of 6G networks.[4]

---

[1] ITU. *IMT-2030, Framework and overall objectives of the future development of IMT for 2030 and beyond*. https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2030/Pages/default.aspx

[2] NGA. (2022). *Green G: The Path Toward Sustainable 6G*. https://www.nextgalliance.org/white_papers/green-g-the-path-towards-sustainable-6g/

[3] European Commission. *The European Green Deal*. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

[4] 6G-IA. (2021). *European Vision for the 6G Network Ecosystem*, Version 1.0. https://zenodo.org/doi/10.5281/zenodo.5007670

One such important policy is the need for **technological sovereignty**. This term refers to the ability to deal with critical technologies in a way that will ensure the welfare of citizens and the prosperity of businesses, as well as the ability to decide independently while operating in a global environment. In the current challenging geopolitical environment, such a goal can be met through a combination of own capabilities and trade among trusted and reliable partners that share the same values, as is the case for the EU and the US. The following subsections focus on six key areas where the EU and the US can work together to achieve such a goal.

To better understand what 6G networks are envisioned to deliver, one needs to consider not only the motivation for a new generation of cellular networks but also **user and application trends**. As identified by IMT-2030, future networks will connect humans and machines and bridge the digital, physical, and biological worlds. Various new services enabled by ubiquitous intelligence require new solutions — including services such as immersive communications with extended reality, advances in autonomous operation of machines (e.g., vehicles, robots, etc.), and digital health and well-being. The usage scenarios as captured by IMT-2030 extend the eMBB, mMTC, and URLLC IMT-2020 vision into **six new categories**: **Immersive Communication, Hyper Reliable and Low-Latency Communication, Massive Communication, Integrated AI and Communication, Integrated Sensing and Communication, and Ubiquitous Connectivity**. These usage scenarios require that the well-known KPIs (e.g., peak data rate, user-experienced data rate, spectrum efficiency, latency, reliability, etc.) are further enhanced in values where 5G cannot deliver.

Moreover, IMT 20230 is targeting to provide enhanced capabilities compared to those identified in IMT-2020. In addition to the updated targets for well-known capabilities (including peak data rate, use-experienced data rate, spectrum efficiency, area traffic capacity, connection density, mobility, latency, reliability, security, privacy, and resilience), IMT-2030 also defines new capabilities. Among these are **coverage, sensing-related capabilities**, **AI-related capabilities, sustainability, interoperability, and positioning**. For several of these new capabilities, clearly defined metrics currently do not exist. New methodologies (*e.g.,* Key Value Indicators (KVIs)[5]) and widely accepted related frameworks must be developed.

The following subsections discuss six specific collaboration areas between the EU and the US:

- Sustainability
- Microelectronics
- Open Solutions
- Trustworthiness and Cybersecurity
- Cloud solutions
- Distributed Computing, and AI/M.

[5] 6G-IA. (2022). *What societal values will 6G address? Societal Key Values and Key Value Indicators analyzed through 6G use cases*. https://5g-ppp.eu/wp-content/uploads/2022/05/What-societal-values-will-6G-address-White-Paper-v1.0-final.pdf

Further cooperation is also required to identify spectrum opportunities that 6G networks may use to work toward **harmonizing 6G spectrum**. A recent NGMN position paper[6] recognizes the importance of considering all bands (from below 7 GHz to upper mid-band 7-24 GHz, mmWave, and up to sub-THz). The appropriate spectrum usage requires significant research efforts for spectrum and interference management, sensing, sharing, monitoring, control, prediction, adaptation, and protection.[7] Figure 1 illustrates a mapping of the EU-US collaboration areas to IMT-2030 usage scenarios and priorities.

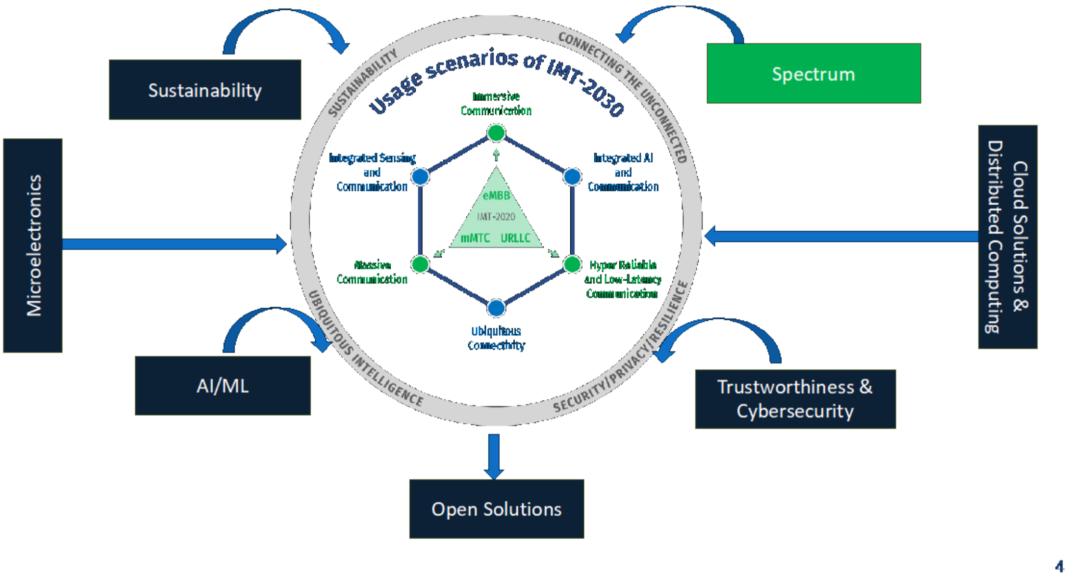

FIGURE 1 - MAPPING OF EU-US COLLABORATION AREAS TO IMT-2030 USAGE SCENARIOS

Cooperation could also be mutually beneficial in areas where global consensus is needed (*e.g.*, SDOs), where support for concepts could be strengthened following a coordinated approach from both regions, and where one side can offer on a reciprocal basis specific know-how that the other region does not have.

3.1 1st Collaboration Area: Promoting 6G Sustainable Solutions

In the 6G outlook,[8] published after the TTC2 meeting, a few guiding principles were formulated related to sustainability: "6G technologies must also be an enabler for sustainability, considering environmental, social, and economic perspectives. A reduced carbon footprint and energy efficiency will be important design goals for 6G networks. More broadly, 6G should allow for reduced energy consumption across all sectors of the economy and society. Ideally, 6G technologies will generate less pollution and reduce other environmental impacts to better contribute to long-term social sustainability while maintaining economic feasibility."

---

[6] NGMN. (2023). *6G Position Statement, An operator view*. https://www.ngmn.org/wp-content/uploads/NGMN_6G_Position_Statement.pdf

[7] Next G Alliance. (2023). *Spectrum Considerations*. https://www.nextgalliance.org/white_papers/6g-spectrum-considerations/

[8] European Commission (2023). *6G Outlook - Shaping Europe's digital future*. https://digital-strategy.ec.europa.eu/en/library/6g-outlook

These principles are expanded upon here and complemented with a set of recommendations.

Broad scope of sustainability acknowledged by ICT industry:
With the UN's Agenda 2030,[9] a global framework for sustainability is available. Naturally, the European and US ICT industries acknowledge the importance of this ambition. The 17 Sustainable Development Goals (SDGs) have a very broad scope and paint the picture of a connected world where all parts matter. In applying the SDGs to 6G development, there is consensus to divide the approach into how the 6G end-to-end system will be sustainable ("Sustainable 6G") and how it will contribute to the sustainability of other sectors ("6G for Sustainability") through enabling use cases with a positive footprint (also called enabling effect or handprint). This naturally encompasses all three pillars of sustainability (environmental, social, and economical), and specifically for network aspects of trustworthiness, privacy, and digital inclusion.

What should be addressed by the 6G R&D and standards community:
The next generation of networks must be standardized, implemented, and deployed with a positive footprint in line with the "Sustainable 6G" ambition *(i.e.*, minimizing CO2 emissions) as one of the key objectives. The focus of this ambition naturally falls on improving resource efficiency in terms of reducing the use of energy and materials, which has a solid environmental footprint. Additionally, this ambition encompasses the utilization of natural resources like land and efficient spectrum use. Efficient spectrum use may employ intelligent spectrum allocation methods.

Specifically for energy efficiency in 6G, the industry should look at the full scale of activities and optimize every step. These include all phases of the hardware lifecycle, from design and production to end of life, the design of the RAN and core architectures, sustainable use of AI and cloud services, devices, use of frequency bands, and application-level algorithms. Promoting and enabling the transition to renewable energy is also a primary goal.

Transitioning toward the circular economy is also essential. It requires incorporating elements in product design that support the reduction of material use, the repair, reuse, recycling, and recovery of products, product parts, components, and materials to circulate them in the value chain for as long as possible.[10] The 9R framework[11] (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover) can be used as a guideline to emphasize circular aspects. The overall goal for 6G networks should be delivering more services using fewer resources and creating sustainability-focused 6G standards and technologies.

The potential of 6G to transform society in a sustainable direction:

---

[9] United Nations, Department of Economic and Social Affairs, Sustainable Development. (2020). The 17 Goals. https://sdgs.un.org/goals

[10] https://www.nextgalliance.org/white_papers/green-g-the-path-towards-sustainable-6g/

[11] Potting, J., Hekkert, M. P., Worrell, E., & Hanemaaijer, A. (2017). Circular economy: measuring innovation in the product chain. *Planbureau voor de Leefomgeving*, (2544).

By supporting new use cases, 6G can also trigger and support change beyond networks themselves. This enabling effect, or “6G for sustainability,” is of great promise. To deliver this promise, careful investigation is needed, considering risks and alternative solutions.

By supporting increased electrification and digitalization, the negative footprints of businesses can be reduced. For instance, if ICT can provide coverage and stable connections everywhere (with various means), remote working, learning, and use of telepresence can be a possibility, thereby reducing commuting and transport. Such a paradigm shift can contribute to the reduction of GHG emissions.

Studies of 4G and 5G network rollouts specify that a positive effect on economic growth can be attributed to wireless connectivity. 6G thereby has the potential to strongly contribute to “green growth” and what is known as decoupling of economic activity from negative sustainability impact. Economic growth can be achieved by leveraging 6G to increase productivity, innovation, efficiency, and effectiveness by creating new value propositions, business models, and market segments.

Finally, the introduction of the 6G system has the potential to enhance the quality of life, including public services such as health care, education, safety and security, and the environment. As we seek to improve the quality of life through applications like telemedicine, remote education, and enhanced public safety, it is crucial to strike a balance between the advantages these technologies offer and the potential vulnerabilities they may introduce.

Contributing to environmental, societal, and economic resiliency is also a target of “6G for sustainability” efforts. In addition to climate change mitigation, 6G should contribute to climate change adaptation, ensuring that societies and economies are better prepared for climate-related disasters such as floods and storms and ongoing deteriorations such as water scarcity and rising sea levels and temperatures. It should also help ensure societal values such as inclusion and justice, as well as economic viability and jobs in a changing climate, helping to build resilient communities worldwide.

Additionally, while climate change, materials efficiency, and circularity challenges dominate environmental sustainability efforts, biodiversity loss is also an urgent environmental challenge. While the biodiversity footprint of ICTs in general and 6G in particular could be relatively indirect, the handprint impact of 6G in preserving biodiversity and in restoring eco-systems could be much more direct, using sensing, monitoring technologies, deploying massive IoT, as well as NTN solutions. Yet, there is much to be researched on this front, as well.

How to know we are doing the right thing:
The 6G R&D community needs guidelines and processes for steering towards a sustainable direction. One such example is the framework of KVIs, [5] which is a complementing tool to the prevailing Key Performance Indicators (KPIs) used to guide a performance-driven development. KVIs can be used in values-driven development to assess the impact on key values through dedicated metrics, especially sustainability-related ones. They can also be used by policymakers to push the development towards specific targets. In addition to KVI metrics, simple checklists and steering principles can be used when developing technology to

investigate whether there is an expected negative impact of a technology's usage and, in this case, consider how to mitigate this. It is important to have a clear definition and measurement criterion for how to effectively measure the KVIs.

Estimating the "enabling effect" of 6G, which is the positive impact of 6G on other activity sectors, remains complex. Defining a relevant KVI would be achieved only with the involvement of the concerned actors.

Another aspect to ensure that future research activities are aligned with environmental, societal, and economic priorities is to ensure alignment with policy and regulatory actions. The EU has enacted the European Green Deal,[3] while the US has enacted the Infrastructure Deal[12]. Both call for industry and research engagement.

Recommendations

- 6G should address environmental, social, and economic sustainability goals and work toward reduced footprints (Sustainable 6G) as well as enabled benefits, a.k.a. handprints (6G for sustainability).
- Promote a dual development perspective toward performance targets and to obtain sustainability value outcomes.
- Adopt a circular economy perspective by considering the whole technology lifecycle and promote using the 9R framework.
- Promote energy-efficient technologies in the design of 6G systems.
- Further define and develop the KVI methodology as a framework to quantify, measure, and estimate sustainability value outcomes related to Sustainable 6G targets and 6G for sustainability ambitions. Such KVIs should then be used in parallel with KPI requirements.
- Address 6G for climate change adaptation and resilient societies' and economies' perspectives.
- Highlight the problem of biodiversity loss and its mitigation on the 6G research agenda.
- Ensure alignment with policy and regulation requirements and roadmaps.

3.2 2nd Collaboration Area: Microelectronics and 6G

The US and the EU have recognized microelectronics as a strategic industrial domain, both from an economic and a political perspective. The US launched the "Chips and Science Act,"[13] aiming at securing a US industrial lead and critical supply chains. In July, the EU adopted

[12] White House. (2021). *FACT SHEET: The Bipartisan Infrastructure Deal Boosts Clean Energy Jobs, Strengthens Resilience, and Advances Environmental Justice*. https://www.whitehouse.gov/briefing-room/statements-releases/2021/11/08/fact-sheet-the-bipartisan-infrastructure-deal-boosts-clean-energy-jobs-strengthens-resilience-and-advances-environmental-justice/

[13] White House. (2022). FACT SHEET: CHIPS and Science Act Will Lower Costs, Create Jobs, Strengthen Supply Chains, and Counter China. https://www.whitehouse.gov/briefing-room/statements-releases/2022/08/09/fact-sheet-chips-and-science-act-will-lower-costs-create-jobs-strengthen-supply-chains-and-counter-china/

the "Chip Act,"[14] aiming at developing EU industrial capabilities by injecting at least €43 billion of private and public investments and also securing supply chains.

Although these initiatives cover the application of innovative microelectronic solutions beyond the sole communication sector, this domain will significantly contribute to these objectives. For example, the US has earmarked $1.5 billion solely for chipsets relevant to wireless communication systems. Although 5G has already largely contributed to the development of new classes and capabilities of chipsets in the mobile communications domains (e.g., for integrated RFICs capable of handling mmWave communications at low cost), 6G will push the envelope much further and create new requirements in terms of industrial capabilities to serve global markets. This is notably due to:

- Current 5G standards do not support the use of higher frequency spectrum above 71 GHz. Sub-THz communications above 90 GHz are contemplated[15] for a range of applications such as "fiber-like" backhaul (a must with network densification) or multipoint access in industrial or high-density scenarios.[16,7] This, in turn, requires the development of new technological capabilities, covering very wide bandwidth with minimal losses, frequency-dependent impairments, and high-power amplifiers with optimized non-linearities. The spectrum range to be covered also requires efficient integration of heterogeneous technologies. Although not mature today, such technologies are heavily researched in the various 6G initiatives around the world.
- The addition of the (7-24 GHz) mid-band spectrum,[17] which may be aggregated to support a higher data rate for 6G mobile devices while making possible intelligent sharing with incumbent services, will require continued progress into the "Angstrom" era of CMOS to keep up with demands for low-power computer and (AI-assisted) signal processing.
- The emergence of new technologies like Joint Communication and Sensing (JCAS) requires integration of heterogeneous technologies, very wideband transceivers (>5 GHz at baseband), and support of moderate to high spectral efficiencies.
- Sophisticated industrial applications will drive the demand for integrated sensors and RF, optical, and MEMS devices. Essential requirements in this domain include more considerable data processing capabilities to cope with the bulk of edge data, integrated AI/ML processing for low-latency filtering, and battery-less device capabilities.
- 6G further drives the need for SoCs that are designed to handle high data rates and low-latency requirements. They integrate various functions, such as digital signal processing, memory, and power management, into a single chip, making them more efficient and cost-effective.
- The emergence of AI/ML as a technology to be integrated at various levels of the 6G platform. 6G is currently being contemplated as an AI-native platform (i.e., with systematic capabilities to exploit the high data volumes generated from within or outside the platform) in the wake of the current "cloud-native transformation" being

[14] ERA Portal Austria. (2023). Council gives final approval to EU Chips Act. https://era.gv.at/news-items/council-gives-final-approval-to-eu-chips-act/.

[15] Next G Alliance. (2022). *6G Technologies*. https://www.nextgalliance.org/white_papers/6g-technologies/

[16] Hexa-X Deliverable 1.2, spectrum section. https://hexa-x.eu/wp-content/uploads/2021/05/Hexa-X_D1.2.pdf

[17] Federal Communications Commission. *Statement of Chairwoman Jessica Rosenworcel*. FCC 22-80. https://docs.fcc.gov/public/attachments/FCC-22-80A2.pdf

contemplated by the industry. This may have multiple impacts at different levels, such as: i) the need to have powerful GPU technology capable of AI/ML-assisted intelligent/reconfigurable management of radio waveforms as a function of traffic/channel characteristics, also enabling unification with NTN access capabilities; ii) processing capabilities as required to support AI/ML-assisted security from an end-to-end or local perspective; iii) processing capabilities for real-time AI/ML-assisted function placement/execution as a function of the use case scenarios, etc.

- The advent of new deployment scenarios based on Reflective Intelligent Surfaces (RIS) requires the availability of intelligent (AI/ML-driven) surfaces built using metamaterials to reduce EMF exposure to the public.
- The move toward virtualized networks that started with 5G being expected to continue and be enhanced by the emergence of 6G by the end of the decade. Microelectronics requirements are multiple and characterized by i) the need for software implementations to reach performance levels on par with classical hardware-based implementations, especially for real-time radio functions where generic purpose processors may not be enough. The need to avail from accelerators that may be incorporated in various platforms with virtualized implementations is important in that context; ii) the need to benefit from open multi-source supply chains, RISC V technology developments may be contemplated in that respect; iii) the need to optimize energy efficiency at the processor level, whilst software implementation may lead to higher energy consumption.

The above represents a non-limiting set of issues that are currently contemplated in various 6G initiatives in the world and may form the basis of further EU-US collaboration. In that context, EU-US collaboration on 6G-related microelectronics should target:

- Feasibility and de-risking of key technology building blocks needed to implement 6G vision and new demanding 6G applications.
- Reinforcing stakeholders' confidence in the key technologies to support at the standardization level.
- Identification of supply-side dependencies for these technologies.
- Enabling the emergence of a cross-Atlantic knowledge base about these technologies.

Recommendations

- Review of the supply-side capabilities of the two regions to identify gaps (sovereignty).
- Develop semiconductor research that addresses the use of microelectronics for wireless communication, especially in the mid-band to sub-THz range.
- Coordination on antenna packaging and testing (e.g., antenna-on-chip and antenna-in-package) that can improve power budgets.
- Collaboration on metamaterial research and development in the context of RIS.
- Virtualization, including application-specific accelerators (e.g., MIMO, LDPC, Packet Scheduling), and promote joint experiments for interoperability of virtual platforms.

3.3 3rd Collaboration Area: Cloud Solutions and Distributed Computing

The 6G cloud comprises both the integration of cloud concepts into the 3GPP network and the leveraging of the mobile network to integrate distributed computing resources for richer and more dynamic cloud services to applications. The goal of the former, which began in 5G, is usually to make mobile networks more efficient, reliable, and cost-effective, but not necessarily to provide new compute services. For 6G, both aspects should be part of an evolution to the integration of communications and computing with the objective of meeting the demands of new applications that require the support of distributed cloud solutions.

The 6G cloud is envisioned to operate as a cloud continuum (core, edge, and far edge) that will comprise intelligent and ubiquitous computing, communication, and data services spanning regional and metro area data centers, cell sites, on-premises equipment, and devices. The 6G system functions and applications can be supported as workloads on the 6G cloud. These workloads will be distributed to enable the processing of massive data close to the source to minimize data transport, leveraging specialized computing capabilities to improve performance, and adapting to network dynamics. In addition to communication services, computing and data planes with dedicated computing and data management functions may be introduced to cellular networks.[18]

Achieving the distributed cloud vision requires functionality to manage the inter-dependencies between computing and data aspects and the mobile system. These inter-dependencies include defining service requirements, exchanging and leveraging special capabilities (e.g., compute capabilities), and requesting transport for advanced services (e.g., chaining and pipelining). The computing management functions will need to interact directly or indirectly with the core network, RAN nodes, devices, and applications to enable communication-aware computing services.

Distributed 6G cloud should support different business models and regulatory policies,[19] from highly distributed cloud service providers that host both the applications and networks to a federation of mobile network operators with applications and networks on private edge cloud infrastructure.[20] This ubiquitous distributed computing also requires disaggregation of the services provided by functions and applications, as well as the capability of orchestrating distributed resources with various requirements across different stakeholders and business models. The cloud architecture must permit easy reservation and activation of services across multiple domains.

Distributed computing also requires the integration of mobile devices for computing and data services. Sensing, data collection, and data processing locally at the UE minimizes data transfer cost. However, the ability to do so depends on the type of device, which may range from IoT devices to powerful consumer devices that support industrial, enterprise, and extended reality (XR) applications. Therefore, it is essential to integrate device and network computing and communication capabilities to realize a ubiquitous mesh of computing and communication resources while taking into consideration security and privacy.

[18] NGA. (2022). *6G Distributed Cloud and Communications Systems*. https://www.nextgalliance.org/white_papers/6g-distributedcloud-andcommunicationssystems/

[19] European Commission. (2023). *Cloud computing.*https://digital-strategy.ec.europa.eu/en/policies/cloud-computing

[20] SYLVA Fund. https://sylvaproject.org/

Recommendations

- Support different business models and regulatory requirements and enable disaggregated 6G cloud architectures with standardized interfaces between different stakeholders.
- Work on methodologies and frameworks for end-to-end guaranteed QoS across heterogeneous platforms.

3.4 4th Collaboration Area: Open Solutions

Open networks are networks built based on open,[21] standard-based, and programmable architectures requiring the integration of various data sources and services into unified and automated platforms.

Open networks refer to open interfaces, as well as open network function definition. Open networks bring the following benefits:

- More choices for operators and manufacturers to mix and match components from different vendors, thus diversifying their dependencies.
- Greater automation and flexibility for operational efficiency in network roll-out.
- New possibilities for innovation.
- New opportunities for EU and US market players.
- Using cloudification, disaggregation, and modularization as enablers for simpler network operation and management and hardware reuse capability when replacing software or hardware vendors.

Open networks are a promising solution to support constantly growing data traffic and the need for network densification in an optimized total cost of ownership (TCO) way. The development of open networks is a complex topic, and there are important issues to consider in the envisioned solutions. This includes:

- Higher integration complexity that renders configuration, operation, and updating of networks a challenging process, while performance is not always easily met; therefore, the TCO promise is yet to be proven.
- An increased threat vector for overall network security, potentially leading to increased vulnerability in networks, which needs to be investigated and mitigated.
- Use of open architecture does not necessarily mean that proprietary components are not used. Confusion remains between open source and open interfaces/architecture. More work is needed to clarify the possibilities and expectations.
- Ensuring appropriate balance between standardization of networks to ensure interoperability, security, and scale while avoiding barriers to innovation on top of network solutions is essential.
- Energy efficiency is not easy to achieve when integrating software and hardware products from various sources.

[21] World Trade Organization. (2020). *The TBT Committee's Six Principles for the development of international standards: Are they still relevant*? https://www.wto.org/english/tratop_e/tbt_e/tbt_six_principles_e.htm

Today, open networks appear to be a significant trend where multiple stakeholders at a global level are working hard to achieve the aforementioned benefits and address the aforementioned issues.

Several prominent open network initiatives are becoming industry-wide engaged across all the network domains.

Network Domain	Open Network Initiatives	Prominent Examples
Radio Access Network (RAN)	Open RAN	3GPP, TIP OpenRAN, O-RAN
Transport	Open Transport	ONF ODTN, TIP OOPT
Platforms	Open Platforms on resource orchestration, SDN controller, and infrastructure management	ONA, OSM, CORD, OpenShift, OpenBaton, ONOS, ODL, RYU, Openstack, Kubernetes, ONAP
Core	Open Core	3GPP, OpenAirInterface OSA
Services/Use Cases	Open API	3GPP, OpenAPI, Sylva, Open Gateway, CAMARA

Although some initiatives like Open RAN are already under deployment, the area is still in ongoing development, and more research and engagement from the different industry stakeholders is needed to achieve widespread adoption in all the domains. This area clearly has potential and should be considered in current and future EU and US research activities.

An increased effort is needed to better understand the pros and cons and find the right balance between open and purpose-built solutions, as well as gain further understanding of the depth of the promise that open networks can bring.

Recommendations

- Further strengthen collaborative EU and US research and innovation so the environment for open network solutions will progressively reach a higher TRL.
- Create collaborative pan-EU and US large-scale testing facilities to transparently verify achieved results in terms of reproducibility, repeatability, and reliability of claims.
- Promote the engagement of EU/US academic and business stakeholders along the full design/development chain to generate innovative solutions/services.
- Develop a public marketplace of research and innovation facilities to determine solutions available to EU and US stakeholders for experimentation and generation of new knowledge. Leverage existing testing facilities and ensure linking and complementarity at both the European and American levels.
- Ensure a collaborative effort so that provided solutions address security and privacy while conforming to EU and US values, standards, and citizens' needs.
- Set a collaboration framework to increase the knowledge base of experts to implement, operate, and manage open network infrastructures.
- Work on further collaborative initiatives to address and promote the openness of services and use cases over the top.

- Create a joint EU-US roadmap on innovation and execute the validation and integration of its content to set common open network-related industry blueprints.

3.5 5th Collaboration Area: AI and 6G

In recent years, we have witnessed a progressive introduction of sophisticated technologies and paradigm shifts in designing 6G wireless networks that provide fundamental performance advantages and enable futuristic use cases such as holographic communications, tactile internet for remote operations, and connectivity for everything. However, complex network management solutions are needed in order to meet the stringent requirements imposed by those services. Such complexity can only be addressed by introducing increasing levels of network automation, which can be largely facilitated by the adoption of Artificial AI/ML.[22]

The transition of the air interface and other network layers to AI/ML (a.k.a. **AI-native air interface**) is underway, starting with replacing of specific functions in the network, devices, and the air interface. Before Rel-18, AI/ML-related projects in the 3GPP focused on enabling network automation or data collection for various network functions. On the contrary, the Rel-18 RAN1-led study on AI/ML for NR Air Interface[23] explores the benefits of augmenting the air interface with support of AI/ML-based algorithms for enhanced performance and/or reduced complexity or overhead. Hence, AI/ML is already on the way in the 3GPP 5G-Advanced air interface, starting from channel state prediction and feedback, beam prediction, and precise positioning, for which the use of AI/ML algorithms has been proven beneficial in improving performance. This, of course, must be accompanied by a number of functional and architectural enhancements (e.g., dedicated signaling and entities, strategies to exchange trained AI/ML models) supporting the successful deployment of AI/ML techniques. 3GPP SA2 completed a study[24] in Rel-18 on 5G system support to facilitate the application layer AI/ML operation. However, with the advent of 6G, further research on this topic is clearly needed.

In general, AI/ML excels in areas where analytically tractable and/or computationally viable mathematical models are lacking (*model* deficit) or efficient algorithms for solving the problems are either lacking or computationally infeasible leading to poor heuristics (*algorithm* deficit). Often, adopting **hybrid AI-driven/model-based approaches** turn out to be promising and allow leveraging years of engineering know-how developed to, for example, establish guarantees on QoS performance. Although 5G-Advanced addresses AI/ML-based improvement on selected aspects, 6G wireless networks are expected to natively incorporate AI/ML in the air interface design from the onset. In doing so, ensuring their harmonization with functionalities being designed in other network segments will be of utmost importance. Also, data-driven optimization across layers, such as **semantic/goal-oriented communication** protocols and architectures, is an area that will require further research.

Although AI/ML provides great opportunities for 6G, it also faces challenges. First, AI/ML model training and inference may be **computationally intensive and costly in terms of energy**

[22] NGA. (2023). *AI-Native Wireless Networks.* https://www.nextgalliance.org/white_papers/ai-native-wireless-networks/

[23] 3GPP TR38.843. *Study on Artificial Intelligence (AI)/Machine Learning (ML) for NR Air Interface*. https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3983

[24] 3GPP TR 23.700-80. (2022). *Study on 5G system support for AI/ML-based services.* V18.0.0. https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=4009

consumption. Hence, there is a pressing need for a sustainable and energy-efficient use of AI/ML in 6G networks/devices. This holds particularly true for RANs, which account for most of their energy consumption, and, notably, in resource-constrained devices such as UEs, drones, etc. Infrastructure for the **management** of datasets and the life cycle of AI/ML models, including continual data collection and monitoring/re-training the models, may also incur computational and engineering complexity, especially if AI/ML models are dynamically optimized for varying locations, network configurations, traffic conditions, and/or radio propagation conditions.

Establishing benchmark datasets and models is expected to be critical for promoting AI/ML research and standardization for 6G networks. Instrumental to this is the development of (i) methodologies for dataset acquisition, curation, association (of data from different data sources) and evaluation; (ii) metrics and models to assess the pros and cons of AI technologies in telecommunications, including aspects such as energy efficiency, explainability, reliability, security, privacy and performance; (iii) technologies and tools to adjust models to specific scenarios/setups based on, for example, continual/transfer learning; and (iv) synthetic data generation and the use of digital twins for data augmentation, model development/evaluation, and adaptation. In other words, model building and aggregation will require lifecycle management, including on-line/off-line training, development, validation, serving, monitoring, and retraining.

Last but not least, it is also key to **ensure trustworthiness in AI/ML mechanisms** for 6G networks. This includes, on one hand, making them robust against, for example, adversarial or data poisoning attacks, and, on the other hand, ensuring their explainable operation (XAI, eXplainable AI) with human-in-the-loop. This is critical for 6G because it will manage a wide range of mission-critical services (e.g., autonomous driving) and safety-critical tasks (e.g., remote surgery). On the other hand, AI must be trustable (see discussions in Section 3.6 ahead) and secure while the attack surface is widened.

Finally, there is a clear need for a **deeper understanding of the implications of existing AI policies and regulations in their use in future 6G networks**. AI, along with communication technologies, has been identified[1] as one of the Key Enabling Technologies (KET) for Europe's technological sovereignty. The use of AI in the EU will be regulated by the AI act.[25] The goal is to ensure that AI systems are safe, transparent, traceable, non-discriminatory, and environmentally friendly. The obligations of providers and users will ultimately depend on the risk level they pose to users (unacceptable, high, limited, or minimal), which must be assessed prior to product commercialization. Complementarily, the Data Governance Act[26] aims to leverage the potential of data (as an AI enabler) for the benefit of citizens and businesses. This includes the definition of good data management/sharing practices to enable industries to develop innovative products and services. In the US, The National AI Initiative Act[27] became law on January 1, 2021, providing for a coordinated program across the entire federal

[25] European Parliament. (2023). *EU AI Act: First Regulation on Artificial Intelligence.* https://www.europarl.europa.eu/news/en/headlines/society/20230601STO93804/eu-ai-act-first-regulation-on-artificial-intelligence

[26] European Commission. (2023). *European Data Governance Act*. https://digital-strategy.ec.europa.eu/en/policies/data-governance-act

[27] National Artificial Intelligence Initiative Act of 2020. 15 USC Ch. 119. https://uscode.house.gov/view.xhtml?path=/prelim@title15/chapter119&edition=prelim

government to accelerate AI research and application for US economic prosperity and national security. The National AI Initiative was established to ensure continued US leadership in AI research and development, lead the world in the development and use of trustworthy AI in the public and private sectors, and prepare the present and future US workforce for the integration of AI systems across all sectors of the economy and society.

In December 2022, the EU-US Trade and Technology Council (TTC) defined a joint roadmap[4] on evaluation and measurement tools for trustworthy AI and risk management. In order to realize the vision of TCC, we recommend following collaboration efforts for EU-US on AI and 6G.

Recommendations

- **AI-native air interface with network device collaboration**. The US and the EU should jointly develop the AI-native air interface as the defining feature of 6G with seamless integration of classical model-based network segments and new AI-driven network segments. Where relevant, hybrid data-driven/engineering approaches, along with semantic/goal-oriented communication protocols and architectures, could be adopted.
- **Energy-efficient AI/ML research**. Given the urgent global mandate on decarbonizing the energy supply in the next decade, both regions should invest in more efficient AI/ML models, which play a critical role in network infrastructure automation, to reduce the carbon footprint of the ICT sector. This includes both their conceptual design and their lifecycle management. Research of on-device, energy-efficient AI/ML could also improve device battery life and allow dynamic allocation of workload across the 6G networks.
- **Collaborations on wireless datasets and AI/ML models**. Benchmark datasets and models have fueled the exponential development of AI/ML research. Both regions must jointly develop shared wireless datasets, methodology of data management and augmentation, and assessments of AI/ML models for wireless technology in order to accelerate the 6G AI/ML development in US and EU and take the world leadership.
- **Trustworthy AI/ML and privacy policy collaboration**. The US and the EU should lead the research of robust and explainable AI/ML models to ensure 6G could meet the requirements of mission-critical and safety-critical societal needs. It is equally important that the US and the EU should collaborate on policies and regulations to ensure that AI systems are safe, transparent, non-discriminatory, and trustworthy.
- **Support global standardization of 6G AI in standards bodies such as ETSI/3GPP**. US and EU stakeholders are expected to benefit from limited AI/ML enablement in the 3GPP 5G-advanced air interface (specification in 2025). Further collaboration in global standardization of AI technology in 6G will convert the joint AI/ML research efforts into commercial products in the 2030s and directly meet the 6G societal and industry needs.

3.6 6th Collaboration Area: Trustworthiness and Cybersecurity

The US and the EU undoubtedly share a number of common objectives when it comes to the trustworthiness and security of 6G networks. At the outset, these objectives should ensure the following:[28,29]

- Business processes and supply chains are organized to ensure trust in equipment, actors, and processes associated with 6G network services.
- Diligence in developing 6G standards that can be tested and validated for consistency with well-defined security requirements.
- 6G networks and associated services that are secure, privacy-preserving, reliable, available, and resilient.
- Assurance that the 6G infrastructure, including network equipment and associated services, are interoperable across the ecosystem and that networks are deployed and operated in accordance with user expectations.

Among others, it includes the following directions:

- **Resilience of 6G infrastructure and services**: As 6G technologies are integrated into automation workflows in various societal and industrial use cases, the reliability of components, functions, and processes in the network must account for overall end-to-end performance, including reliability and resilience. The US and EU should work together to ensure that new 6G technologies and standards can improve the resilience of 6G communication and sensing functions in mission and business critical situations.
- **Building trustworthiness through evaluation and exposure of security levels provided for 6G services**: It is important for users to be able to trust that 6G networks are secure. The US and EU are working together to develop new methods for evaluating and exposing the security levels of 6G services. This will help users understand the extent to which specific solutions meet the needs of their use cases.
- **Confidential computing and strong attestation**: It will be necessary to ready 6G technologies for the introduction of post-quantum cryptographic algorithms that are vetted by organizations such as NIST. Additionally, the availability of trusted execution environments can enable greater security for cryptographic procedures, as well as edge computing environments that may need to operate on sensitive or proprietary data without exposure to attackers. Cloud computing environments and communication interfaces should be capable of using authorization and integrity verification of hardware and software components based on identity mechanisms that are derived from a chain of trust.
- **Need for common frameworks and standards for evaluation and interworking**: It is important to have common frameworks and standards for evaluating and ensuring the security of 6G networks. 6G should standardize the mechanisms by which security assurance levels are integrated by wireless vendors into their development process and by all stakeholders involved in the supply, deployment, and operations of 6G

[28] Next G Alliance. (2022). *Trust, Security, and Resilience for 6G Systems*. https://www.nextgalliance.org/white_papers/trust-security-and-resilience-for-6g-systems/

[29] 6G IA Position Paper: Key Strategies for 6G Smart Networks and Services, https://6g-ia.eu/plans-papers/

infrastructure; this ensures security by design. Vendors may seek testing of their solutions by a regulator or approved third party as part of their due diligence toward demonstrating adherence to defined assurance levels. Such actions contribute to the CI/CD processes that can respond to dynamic changes in threat surfaces and will help to ensure that 6G networks are secure and interoperable, regardless of where they are deployed.

The potential scope of cooperation between the US and EU on the trustworthiness and security of 6G is wide-ranging. Specific areas of cooperation should consider the below recommendations.

Recommendations

1. **Resilience mechanisms in the whole lifecycle of the solution and its supply chain to the recovery after attacks**: The US and EU can work together to institute new resilience mechanisms for 6G networks, from the supply chain to the recovery after attacks. This could include developing new security expectations for 6G equipment and software, including employment of associated methods for detecting, preventing, and responding to attacks.
2. **The various merits of data-centric approaches in the context of 6G**: Data-centric approaches to security, such as the zero-trust architecture, have the potential to significantly improve the security of 6G networks. Although zero-trust principles are an ideal that networks should seek to embrace, the extensive use of confidential computing and strong attestation can go a long way toward achieving the concurrent goals while still allowing data-centric automation and intelligence to improve operational security in near real time. The US and EU can work together to examine the applicability of such data-centric security solutions for 6G.
3. **The applicability of AI, including questions around critical use cases and a common definition of security levels from existing frameworks**: AI can be used to improve the security of 6G networks in a number of ways. For example, AI can be used to develop new intrusion detection systems and to automate security tasks. But AI also must be trustable and secure with widening of the attack surface. The US and EU thus should empower industry stakeholders to develop and implement trustable AI-powered security solutions for 6G.

List of Contributors

Contributor	Affiliation	Region	Role
Anton Haro Carles	CTTC	Europe	Contributor
Balachandran Kumar	Ericsson	USA	Contributor
Barani Bernard	6G-IA	Europe	Contributor
Bhatti Gagandeep	NOKIA	USA	Contributor
Bourse Didier	NOKIA	Europe	Contributor
Burger Eric	VT-ARC	USA	Contributor
Castor Doug	Interdigital	USA	Contributor
Chandramouli Devaki	NOKIA	USA	Contributor
Ciulli Nicola	Netxtworks	Europe	Contributor
Dotaro Emmanuel	Thales	Europe	Contributor
Garcia Aitor	Vodafone	Europe	Contributor
Ghosh Amitava	NOKIA	USA	Editor
Grant Marc	AT&T	USA	Contributor
Ji Tingfang	Qualcomm	USA	Contributor
Kaloxylos Alexandros	6G-IA	Europe	Editor
Mohr Werner	6G-IA	Europe	Contributor
Nawrocki Mike	ATIS	USA	Contributor
Norp Toon	TNO	Europe	Contributor
Osseiran Afif	Ericsson	Europe	Contributor
Reynolds Glenn	ATIS	USA	Contributor
Schwoerer Jean	Orange	Europe	Contributor
Wikström Gustav	Ericsson	Europe	Contributor
Young David	ATIS	USA	Contributor
Willcock Colin	6G-IA	Europe	Contributor