6G Global Landscape: A Comparative Analysis of 6G Targets and Technological Trends

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***Abstract*— The development of 6G networks and services is underway on a global scale. During 2025, the standardization process will also commence. As all regions are targeting globally accepted standards, it is essential at an early stage to identify commonalities and differences among global regions in terms of use cases, related KPIs and technological enablers. The work presented in this paper provides such a comparative study and analysis, highlighting the 6G vision of key stakeholders around the world and the ultimately adopted roadmap by ITU. Moreover, it offers key trends and insights related to the running projects of Europe's Smart Networks and Services.**

Keywords—6G landsape, KPIs, Use Cases, Enablers, Future Netorks & Services

I. Introduction

Although 5G networks are still under their final standardization process and commercial deployment, the global race for developing 6G networks has commenced for some years. In Research and Innovation (R&I) literature, a reader can already find several interesting review papers on key trends for 6G networks by numerous researchers [1][2] or key organizations like NGMN [3].

Europe has been on the front line of the 6G development process, having a concrete vision for 6G networks as produced by the 6G Smart Networks and Services Industry Association (6G-IA) [4], a detailed Strategic and Innovation Agenda (SRIA) produced by NetworldEurope [5] as well as a public-private pan-European partnership, called Smart Networks and Services Joint Undertaking (SNS JU)[1], that is operating for over two years and is currently funding more than 60 projects while organizing for additional projects on an annual basis.

Similar activities take place at a global level. As in the previous generations of cellular networks, North America, Japan, China, India, Taiwan, etc., are pretty active in the design of new cellular systems. One key objective between all these regions is to avoid fragmented 6G standards that will obstruct the broad adoption of networks and services and underachieve the desired economies of scale, endangering the success of 6G.

To achieve pre-standardization consensus among the different regions, one needs to analyze the priorities of use cases that different global regions are considering, the targeted Key Performance Indicators (KPIs) and the considered enabling technologies. In this paper, we provide such an analysis based on the latest global information that will assist the reader in quickly identifying commonalities and differences among the different regions. The paper also considers the recent IMT-2030 recommendations for 6G networks [6], allowing for a straightforward comparison with the targets of each region. Moreover, information about the primary key technological trends and insights related to the current activities of the SNS JU are provided. This collection and organization of information, which partially took place within the context of the International Collaboration activities of the SNS ICE project[2] (the SNS JU ambassador project), is the primary added value of our paper compared to other survey papers, as we identify the essential trends in terms of global regions and not specific researchers.

The rest of the paper is structured as follows. Section II discusses the key elements of the 6G vision as presented by several global regions. Section III presents information and insights related to the main activities of the SNS JU in terms of investigated use cases and currently researched technological enablers, while Section IV concludes the paper.

II. 6G Global Targets

The work presented in this paper aims to provide an aggregate, high-level view of the global 6G landscape based on the priorities, requirements, and vision expressed by key global stakeholders in various regions. The analysis focuses on three key areas: **i)** envisioned / prioritized 6G enabled Use Cases, **ii)** performance targets for the primary 6G Key Performance Indicators (KPIs), and **iii)** key 6G enabling technologies (enablers). The aggregated views of key stakeholders around the world offer unique cross-comparison capabilities, which in turn lead to significant insights regarding the commonalities and differences in 6G vision, the respective expectations around the world, and the prioritization of technologies and use cases in different regions of the world.

The information used for the analysis is sourced from publicly available documents that the various stakeholders, associations and regions have published, e.g., in the form of position or white papers, regarding their vision, priorities, and targets for the next generation of mobile networks. More specifically, the Networld Europe Strategic Research and Innovation Agenda (SRIA) [5], as updated in 2022, comprises

[1] https://smart-networks.europa.eu/

[2] https://smart-networks.europa.eu/csa-s/#SNS-ICE

one of the primary sources of the SNS JU Work Programme for R&I projects and has been used to determine the EU technological directions. Two white papers from 5G Americas [7] and the Next G Alliance [8] have been used to determine the position of US stakeholders, while the Chinese priorities have been sourced from a Huawei white paper [9]. Similarly, extensive white papers have been used to determine the priorities of Japan [10], India [11],[12] and Taiwan [13], while another extensive survey paper by S. Alraih et.al. [14], outlining the views of individual researchers around the world, has been used to compare region priorities to the latest research directions. Finally, the recently published ITU Recommendations on IMT-2030 [6] have been used to examine the proximity (or lack thereof) of the various regional priorities compared to the final ITU vision.

The following sub-sections provide the aggregated information and respective analysis of the three selected areas.

A. 6G Use Cases Targeted around the World

The comparative analysis starts with the Use Cases (UC) that the various stakeholders of the world prioritize as the most anticipated ones and the ones most likely to benefit from the advent of 6G networks. Based on the referenced source material, we have compiled an overview of the most strategic 6G-enabled UCs per global region in TABLE I. 14 UCs in total have been identified, and the interest of each stakeholder to each of them has been indicated. It cannot be excluded that stakeholders are interested in more UCs (ones not indicated in the respective column), however, such information was not available in their respective document(s).

A first takeaway from the examination of TABLE I is that there is excellent coverage of all UCs across all stakeholders, as the matching table is heavily populated. This fact indicates the anticipation of next-generation networks, which promise to enable a substantial number of applications across the globe. Most stakeholders envision a broad portfolio of use cases supported by 6G as they address eight or more UCs (up to 13 for some). At the same time, only MediaTek (Taiwan) seems to take a more focused approach, identifying five main UCs as focal points for 6G R&I activities.

Regarding specific UCs, some clear preferences emerge from observing TABLE I, as certain UCs have been prioritized by almost all the stakeholders in this study, providing insights about the most anticipated UCs globally. Those UCs are:

- *Holographic Communications*
- *Cyber-Physical Systems, Digital Twin, Manufacturing*
- *Multi-Sensory xR, Gaming/Entertainment*
- *Tactile/Haptic Communications*
- *Medical/Health Vertical, Telesurgery*
- *Cooperative Operation among a Group of Service Robots / drones*

The above-identified UCs aggregate the interest of most stakeholders on a global scale, as they comprise the most challenging scenarios and applications envisioned that still cannot be supported by existing networks. Several of the above UCs are still in development and have not yet been applied in real-life scenarios. However, it has become clear that their stringent requirements will require significant improvements from next-generation networks.

A second group of UCs closely following the previously presented “prioritized group”, that aggregated significant interest (6/8 or 5/8 matches) from the global stakeholders can be identified. Those UCs are *Imaging and Sensing, Transportation UCs (automotive, logistics, aerial, marine, etc.), Space-Terrestrial integrated UCs*, and *Intelligent Operation Network*. This second group is comprised of UCs focusing on specific vertical sectors, targeting applications with increased demands in terms of network performance and applications / services usually targeting specific network functionalities.

Finally, a third group of UCs is identified, which, although recognized as significant, do not seem to constitute priorities for most global stakeholders. Those UCs are *Critical Infrastructure, Government/National Security, First Responder / Emergency Services, Smart Buildings* and *Agriculture / Smart Farming*. These UCs remain highly relevant to the development of next-generation networks. However, they seem to attract a more *localized* interest, depending on the social needs, requirements, and cultural background of specific areas of the world. ITU also seems to prioritize eight specific UCs, mainly from the first group of UCs, which attract the interest of most global stakeholders.

B. Global Targets for 6G Key Performance Indiators (KPIs)

The analysis of the expected performance of 6G networks focuses on eight main technical KPIs: *peak data rate, user data rate, density, reliability (BLock Error Rate), user-plane latency, Energy Efficiency, mobility*, and *position accuracy*. These eight KPIs provide a well-rounded view of the expectations of the various stakeholders. Moreover, respective values have been consistently provided throughout the source material, enabling this cross-comparison study. TABLE II below depicts the aggregated information regarding the target KPI values envisioned by the world's respective regions as necessary to be achieved by 6G networks.

By observing the data presented in TABLE II, it becomes clear that even though the various stakeholders come from different backgrounds with potentially different visions of what 6G networks should accomplish, their requirements in terms of performance appear to be well aligned. Even though minor differences can be detected for certain KPIs, the overall "big picture" points towards an aligned view for these main KPIs. Moreover, the KPI targets of the regional associations and stakeholders also align well with the prevalent scientific views available in the literature [14]. Interestingly enough, some differences can be detected between the regional targets and the adopted values from ITU, which seems to have opted for a more conservative approach regarding certain KPIs such as the peak data rate, the user data rate, and positioning accuracy.

Regarding peak data rates, most stakeholders seem to agree that a value of up to 1 Tbps should be targeted, except for the B5G Consortium, which adopted a more modest target of up to 200 Gbps. Notably, ITU has adopted the same value for the IMT-2030 recommendations. On the other hand, two distinct

TABLE I. 6G USE CASES IN FOCUS IN VARIOUS REGIONS OF THE WORLD

6G Use Cases	Networld Europe SRIA 2022 [5]	5G Americas / Next G Alliance [7][8]	Huawei (China) [9]	B5G Consortium (Japan) [10]	TSDSI (India) [11][12]	MediaTek (Taiwan) [13]	Survey Paper [14]	ITU IMT-2030 [6]
Holographic Communications	√	√	√	√	√	√	√	√
Cyber-Physical Systems, Digital Twin, Manufacturing	√	√	√	√	√	√	√	√
Multi-Sensory xR, Gaming/Entertainment	√	√	√	√	√	√	√	√
Tactile/Haptic Communications	√	√	√	√	√	√		√
Medical/Health Vertical, Telesurgery	√	√	√	√	√	√	√	
Cooperative Operation among a Group of Service Robots / drones	√	√	√	√	√		√	√
Imaging and Sensing	√	√	√	√	√			√
Transportation Vertical (automotive, logistics, aerial, marine, etc.)	√	√	√	√	√		√	
Space-Terrestrial integrated network	√	√		√	√		√	√
Intelligent Operation Network	√		√		√		√	√
Critical Infra, Government/National Security	√	√		√				
First Responder/Emergency Services		√		√	√			
Smart Buildings			√	√	√			
Agriculture / Smart Farming				√	√			

TABLE II. GLOBAL TEARGETS FOR 6G KEY PERFORMANCE INDIATORS (KPIs)

Target KPI	Networld Europe SRIA 2022 [5]	5G Americas / Next G Alliance [7][8]	Huawei (China) [9]	B5G Consortium (Japan) [10]	TSDSI (India) [11][12]	MediaTek (Taiwan) [13]	Survey Paper [14]	ITU IMT-2030 [6]
Peak Data Rate	1 Tb/s	0.5-1 Tbps	1 Tbps	100-200 Gbps	0.5-1 Tbps	1 Tbps	1 Tbps	50-200 Gbps
User Data Rate	10 Gbps	DL: up to 1 Gbps UL: up to 1 Gbps	10-100 Gbps	10-100 Gbps	DL: up to 10 Gbps UL: up to 5 Gbps	> 1 Gbps	1 Gbps	300-500 Mbps
Density	10^6 devices/km2	10^6 devices/km2	10^6 devices/km2	10^6 devices/km2	10^6 devices/km2	n/a	10^6 devices/km2	10^6 - 10^8 devices/km2
Reliability [BLER]	>1-10-8	>1-10-8	>1-10-7	>1-10-7	>1-10-7	n/a	>1-10-9	~1-10-5 - 1-10-7
U-Plane Latency	<0.1 ms	0.1-1 ms	0.1 ms	0.1-1 ms	0.1-1 ms	0.5-5 ms	0.01-0.1 ms	0.1-1 ms
Energy Efficiency (Network/ Terminal)	>100% gain vs IMT-2020	Extremely low power / never charging devices	Network: 100x w.r.t 5G Device: 20 years battery	Network: 100x w.r.t 5G	Battery life-time up to 20 years	n/a	Network: 100x w.r.t 5G	n/a
Mobility	<1000 Km/h	> 500 km/h	n/a	Up to 1000 km/h	Up to 1000 km/h	n/a	Up to 1000 km/h	500 - 1000 km/h
Positioning accuracy	<1 cm	1 mm - 10 cm Six degrees of motion: (x,y,z)	Outdoor: 50 cm Indoor: 1 cm	1-2 cm	< 1 cm	n/a	1 cm	1-10 cm

groups can be observed in terms of targeted user data rates, i.e., the more ambitious group (EU, Huawei, B5G Consortium, TSDSI) that has set a target of 10 Gbps or even up to 100 Gbps, while the more modest group (US, Taiwan, Survey paper) has set a target of around 1 Gbps. In this case, the target adopted by ITU is even lower than the modest target, aiming for a user data rate of 300-500 Mbps.

Even though some differences were detected in targeted data rates, there seems to be almost exact alignment among the global stakeholders for three other main KPIs, namely *density, reliability, and user-plane latency*. All stakeholders, including the research community, agree that a 10 million devices/km^2 target is suitable for 6G. In comparison, the ITU treats this value as a minimum with an even more ambitious goal in mind (10^8 devices/km^2). In terms of reliability, expressed in targeted Block Error Rate (BLER), there is also an alignment as all stakeholders propose values between 10^{-7} – 10^{-9}. In this case, the ITU adopts a more modest target again, treating the 10^{-7} target, as the best-case scenario. Almost all stakeholders share similar targets for user-plane latency where values between 0.1-1 ms seem to be commonly desirable, except Taiwan, targeting a more modest performance of 0.5-5 ms. In this case, the ITU recommendation agrees with most stakeholders, targeting values of 0.1-1 ms.

Even though it is commonly agreed that *Energy Efficiency* is one of the primary goals of 6G, several different definitions and approaches can be detected in the literature. A significant number of global stakeholders attempt to approach this KPI in terms of expected improvement with regard to (wrt) improvement over the energy efficiency of 5G, where three stakeholders (Huawei, B5G Consortium, Survey paper) seem to consider a value of 100x wrt 5G as the most appropriate. However different values are also mentioned, while some stakeholders don't provide any specific value for this KPI. In a similar approach, ITU has not provided a specific target value for energy efficiency in the IMT 2030 recommendations.

Finally, an alignment of views can also be detected regarding *mobility* and *positioning accuracy*. In terms of mobility, all stakeholders agree that a target of supporting mobility up to 1000 km/h is appropriate for 6G networks, which is also the target set by ITU. The stakeholders' commonly accepted target for positioning accuracy is around 1 cm, with some variations mentioned per region, while once again the ITU treats this as the best-case scenario, targeting values of 1-10 cm.

It is worth noting that the network improvements in terms of KPIs usually come with a cost (complexity of equipment, additional spectrum needed, increased energy consumption etc.). This is why it is essential not only to set ambitious targets for every generation of networks but also to have a clear reasoning if the targeted use cases need these improvements.

C. 6G Global Enablers

Another interesting aspect to investigate about the global priorities on 6G is the identification of the key enabling technologies (enablers) that the various stakeholders believe will play a significant role in developing the next-generation networks to support the desired use cases and their demanding requirements. TABLE III presents the aggregated views of the eight global stakeholders in this study concerning the technological enablers that they consider crucial/strategic for the development and advancement of 6G networks.

A total of 14 enabling technologies were identified from the source material, as depicted in TABLE III. It is interesting to note that once again, an extensive coverage of these enablers is observed, as most stakeholders identify ten or more of these enablers as necessary for the development of 6G networks. This broad coverage showcases the expectation that many technologies are required to deliver on the global vision of 6G and enable the targeted use cases. With regards to the prioritization of these technologies on a global scale, a large group of enablers is clearly aggregating the interest of most stakeholders (8/8 or 7/8 matches), namely:

- *AI related enablers (Edge, RAN, AIaaS)*
- *Cloud Native Network and RAN-Core Convergence*
- *mmWave and THz Radio*
- *Communications and Sensing co-design (ISAC)*
- *Spectrum Migration*
- *Integrated Satellite hybrid infrastructures (NTN)*
- *New Antenna Technologies (e.g., RIS)*
- *Trustworthiness / Multilateral trust architecture*

The common belief across the globe that these enablers are the key to the development of 6G networks showcases the importance of these technologies and explains the interest of the global research community on these hot R&D topics. Another testament of the global consensus around these enabling technologies is the fact that the ITU recommendations document directly references all of them, as the key enablers taken into account for IMT-2030 (except for spectrum migration, which is implicitly addressed, as it is handled by the World Radiocommunication Conference).

The remaining group of enablers, consisting of *Deep Edge, Terminal and IoT device integration, Optical Wireless communication, Blockchain*, and *Quantum Computing*, attract a more localized interest by fewer stakeholders; however, they remain highly relevant to the development of specific envisioned functionalities of 6G. It is expected that these enablers will also attract more interest in the coming years as the 6G architecture solidifies, the technologies mature, and the global R&D interest shifts towards satisfying the extreme performance demands of specific stringent applications.

III. EU Smart Networks and Services Approach

After establishing the overview of the regional 6G vision worldwide, it is interesting to observe how this vision has been followed through into actual R&I activities. Focusing on the EU, the SNS JU has already funded 35 projects (Phase 1) that have been operational since January 2023, while another 28 projects (Phase 2) have commenced operation in January 2024. The SNS OPS coordination and support project has performed an in-depth survey among the 35 SNS Phase 1 projects to map their activities to specific use cases, identify the enabling technologies and KPIs used, and document the specific research outcomes. While the detailed results of the entire survey can be found in [15], in this paper, we focus on the addressed UCs and enablers of the SNS Phase 1 projects, as

TABLE III. 6G ENABLERS CONSIDERED IN VARIOUS REGIONS OF THE WORLD

6G Enablers	**Networld Europe SRIA 2022 [5]**	**5G Americas / Next G Alliance [7][8]**	**Huawei (China) [9]**	**B5G Consortium (Japan) [10]**	**TSDSI (India) [11][12]**	**MediaTek (Taiwan) [13]**	**Survey Paper** [14]	**ITU IMT-2030 [6]**
Artificial Intelligence at the Network Edge	√	√	√	√		√	√	√
AI/ML in the RAN	√	√	√	√	√	√	√	√
AI as a Service: Data / network autonomous management	√		√	√	√	√	√	√
Fully Service Based – Cloud Native Networking and RAN-Core Convergence	√	√	√	√	√	√		√
mmWave and THz Radio	√	√	√	√	√	√	√	√
Communications and Sensing co-design (ISAC)	√	√	√	√	√	√	√	√
Spectrum Migration	√	√	√	√	√	√	√	
Integrated Satellite hybrid infrastructures (NTN)	√	√	√	√	√	√	√	√
New Antenna Technologies (RIS)	√	√	√	√		√	√	√
Trustworthiness / Multilateral trust architecture		√	√	√	√	√		√
Deep Edge, Terminal and IoT device integration	√				√	√		
Optical Wireless communication	√			√	√		√	√
Blockchain	√			√	√		√	
Quantum Computing				√	√	√	√	

recorded by the SNS OPS survey and presented in the following sub-sections. Regarding KPIs, the early stage of the SNS projects, which have only been operational for a year, does not allow for specific insights or measured values. However, a preliminary analysis regarding the B5G/6G target values has taken place from the predecessor projects of 5G PPP in the context of the Test, Measurement, and KPIs Validation (TMV) Working Group and is available in [16].

A. Use Cases Addressed within SNS JU (Phase 1)

Figure 1 below depicts the number of SNS Phase 1 projects addressing a certain UC, according to [15]. At the top of the list *Digital Twinning, Manufacturing, Multi-Sensory xR* and *Cooperative Operation among a Group of Robots* can be observed, which is perfectly aligned with the global UC priorities presented in Section II. At a second tier (addressed by 10-11 Phase 1 projects, each), there are several vertical specific UCs, providing a broad coverage of key vertical sectors and offering verification and result cross-comparability capabilities. Several additional UCs are addressed by fewer projects, further widening the scope of the SNS and avoiding the creation of gaps in the EU R&I landscape.

Based on the addressed UCs of the SNS Phase 1 projects, it can be concluded that the EU R&I activities are well aligned with the global priorities while also addressing a broad range of UCs, covering all the key vertical sectors. It has to be noted that additional UCs will be addressed by the SNS Phase 1 calls, based on a planned open-call scheme for external experimenters. In contrast, any detected imbalance in missing or under-served sectors/UCs will be addressed in the follow-up calls/phases of the SNS Work Programme.

B. Key Enablers used within SNS JU (Phase 1)

Figure 2 depicts the key enabling technologies being used by the SNS Phase 1 projects to fulfill their mandate and research goals. At the very top of the list, *Artificial Intelligence (AI) and Machine Learning (ML)* functionalities are the undisputed "champions" in terms of their importance for the EU R&I work on 6G, which is perfectly aligned with the global trend detected in Section II. The *orchestration of VNFs/CNFs* is also prioritized within the Phase 1 projects, as the virtualization and softwarization of the network present significant innovation capabilities, especially in this early research phase.

Several other enabling technologies that were identified as critical for the development of 6G by the global stakeholders in Section II, such as *AI as a Service, Communication and Sensing co-design, Edge, Terminal and IoT integration, Coud-native integration, New Antenna Technologies* and more, seem to also play an essential role in the SNS projects' R&I activities. At the same time, additional -less popular- enablers are also addressed within SNS, ensuring that there will be no lack of expertise in EU in any specific domain.

Based on the above-presented focus of the SNS collaborative R&I activities, it can be concluded that EU-based research is very well aligned with the priorities set by the

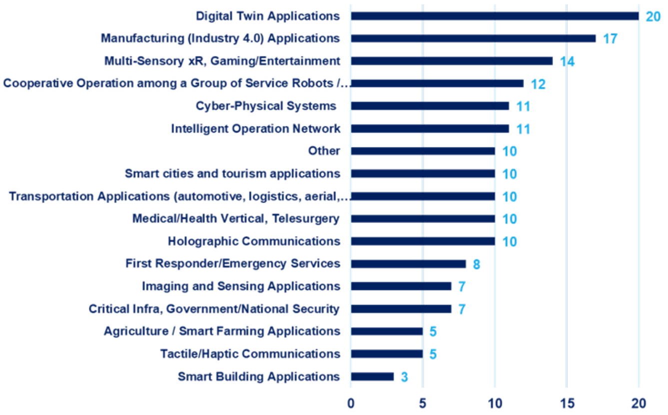

Fig. 1. SNS Phase 1 projects - Addressed Use Cases

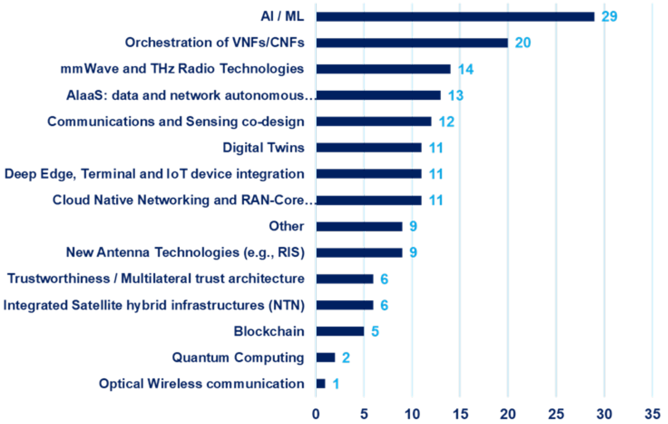

Fig. 2. SNS Phase 1 projects - Key Enablers

different regions of the world in terms of 6G research, as well as with the adopted recommendations from ITU with regards to IMT-2030. The SNS portfolio seems to offer a healthy balance of research topics, enablers, and use cases, focusing on 'day-1' scenarios but also investigating more promising technologies and scenarios that may prove fruitful in the following stages of development.

IV. Conclusions

The race for 6G networks is well underway. Beyond the expected competition among key global stakeholders and regions, it is of paramount importance that priorities in terms of use cases, target KPIs, and enabling technologies are aligned, to avoid standards and market fragmentation, which could endanger the success of the next generation of networks and services. As the standardization process in 3GPP is about to commence (in the context of SA1), the information aggregated and presented in this paper is essential.

The work presented in this paper has focused on analyzing the key trends in all main global regions and ITU IMT-2030. It has also summarized the current SNS JU activities and technological choices at the pan-European level. The overall findings suggest that there is already a significant streamlining among the different global regions but some deviations in terms of use case and performance expectations, were also detected. As the development of 6G networks is still in its infancy, these deviations need to be closely monitored.

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