On 6G Visions and Requirements

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Abstract

6G represents standardized communication systems that will be commercially available in 2030s. Even if the initial 5G networks, basing on the 3GPP Release 15, have hardly started become commercially available gradually as of 2019 and their large-scale deployment is still years away, industry is already keen to envision the justification and performance of the forthcoming generation. While there are no concrete 6G standards produced at this stage, their planning will benefit from realistic indications of the requirements and type of usage. The task is not straightforward as users, including a variety of verticals with their rather different communication environments, are sometimes not capable of expressing their future needs in technical terms nor industry might be able to prognosticate the demand that has not yet equivalence in preceding systems. This paper analyses some of the most important current visions of key standardization bodies and assesses indications of the industry for the potential requirements, service types, use cases, and architectural and functional models that can serve as a building block for the actual realization of the visions. This paper also presents means that can be applied in further interpretation and assessment of the vertical

needs and priorities, with examples reflecting the benefits of Network Slice requirements that the GSMA North Americas Network Slicing Taskforce studied for foreseen near future environment and that may be extended to be utilized also in exploration of 6G requirements.

Keywords: Vertical needs, IMT-2030 standardization, 6G performance, 6G requirements.

1 Introduction

Since the very first mobile communication generation – which refers to the now obsolete analogue mobile systems of 1980s with mainly wireless voice call service capability – each of the posterior decade has witnessed the arise of a new generation. 2G, 3G, 4G, and now 5G are all evolving in a parallel fashion as for the standardization is considered. Each generation has their evolving use base. In practice, the regional scenarios of the deployment and utilization of different generations can be considered to be either parallel or overlapping, depending on the varying market segments. Figure 1 presents the foreseen global development of the relative utilization of 2G–5G. [1] As can be seen, the importance of least spectral-efficient 2G, predominantly repre-sented by Global System for Mobile Communications (GSM), will decrease although it serves still especially IoT devices and developing markets for
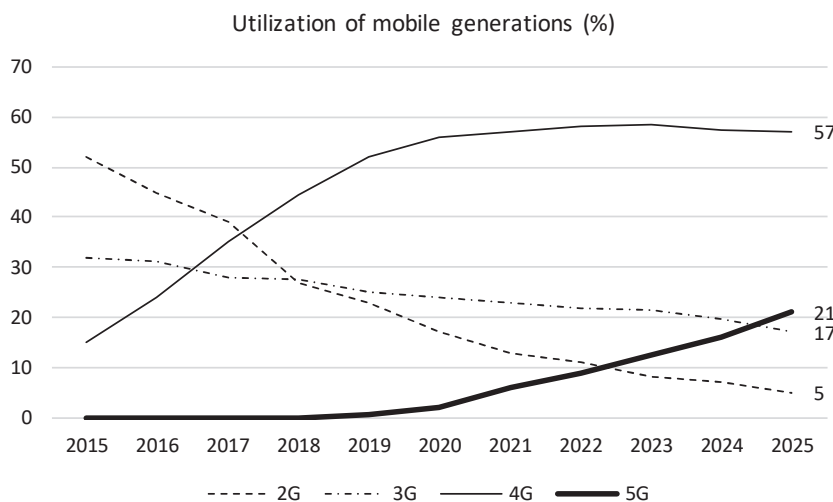

Figure 1 Relative utilization of mobile communication generations [1].

years to come. As for 5G, its deployment will take place gradually, and by 2025, it will serve an estimated 21% share of the global use base while in developed markets such as in the USA, Europe and Asia the regional utilization may be close to 50%. Still in 2025, 4G is clearly the most dominant generation.

Meanwhile, 6G is still under early visioning. Of the most active entities considering the foreseen requirements and form of the next generation, the most relevant is the International Telecommunication Union (ITU), which is preparing high-level performance statements for 6G systems in a form of the IMS (International Mobile Telecommunications).

The ITU has performed this task since the production of IMT-2000 of 3G, proceeded by the IMT-Advanced for 4G, and IMT-2020 for 5G. As has been the case previously, also the global requirements for 6G, referred most probably to as IMT-2030, will be an iterative joint effort with the industry and standardization bodies such as the Standard Setting Organizations (SDOs) of the Third Generation Partnership Project (3GPP).

As an example of the globally recognized 5G, the ITU approved three new technologies that conform with the IMT-2020 vision and strict performance requirements: 5G-SRIT and 3GPP 5G-RIT of the 3GPP and 5Gi of the Telecommunications Standards Development Society India (TSDSI). The IMT vision requires that the candidate technologies are sufficiently detailed to enable worldwide compatibility of operation and equipment, including roaming. As a result of the ITU evaluation process, the first release of IMT-2020 supporting 5G is now a set of terrestrial radio interface specifications incorporated into a global standard of the ITU-R Recommendation "Detailed specifications of the radio interfaces of IMT-2020." This same process will be applied to 6G, too, and the 3GPP among other contributors will take it into account in their Technical Specification (TS) development in suitable Releases well before 2030, supported by preceding 6G-related Technical Reports (TR) [2].

2 Entities Forming the Base for 6G

Although the IMT will be elemental for 6G, the work of the ITU is still in the initial phase and relates merely to discussions of visions. As an example, the TS "Architecture Framework" of the Study Group SG13 produced such outlook in 2020. Meanwhile, industry is advancing with ideas to concretize the visions and early candidate technologies. This is an iterative process, which helps ITU form the concrete IMT requirements for 6G.

Table 1   Example of entities considering and contributing to 6G development

Entity	Role, Source
ITU-T SG13	The Future Networks Study Group of ITU-T considers candidate ideas for IMT-2030 requirements [3].
ITU-R	Definition of requirements for 6G radio technologies. ITU-R Working Party 5D has invited organizations to provide inputs for its June and October meetings in 2021 to develop "Future Technology Trends towards 2030 and beyond" report [4].
ITU-R WRC	The future Word Radiocommunication Conferences will discuss radio band extensions that aim to serve 6G in 2030 and beyond.
3GPP	The role of 3GPP, as an entity representing various globally significant SDOs, will be essential in a form of concrete candidate proposal of the forthcoming ITU IMT for 6G.
European Commission	European Union, through the EC, has established various research programs for 5G and is preparing the same for 6G. Examples of the latter are Hexa-X and SNS-PPP [5].
Next G Alliance	ATIS-lead initiative in North America region to discuss and promote solutions for 6G era with industry representatives.
US Government	The US government, through agencies such as Federal Communications Commission (FCC), is emphasizing the need for regional participation in the standardization and technical development of future communications technologies.
Ministry of Internal Affairs and Communication, Japan	Has produced vision for the 6G goals indicating comparative attributes with 5G.

Table 1 summarizes some of the entities contributing to this process, based on the publicly available information.

3 Current 6G Visions

The 6G era is still rather far away from the commercial deployment, which can be estimated to begin gradually approx. 2030. In fact, there are no commonly agreed visions yet available regardless of many forums discussing the ideas. Of the various sources of information, some statements commonly indicate that 6G will be connecting physical and digital words, and serves as a platform to make digital twin a reality. Digital twin in this context refers to the ability of the system to represent the real-world objects in a

digital form in a near-real time. What can be interpreted from the statements of various sources, such as ITU NET-2030 [3] and Next G Alliance [6] is, that 6G requirements are driven predominately on use case basis that widen the previously applied principle of presenting performance characteristics in terms of technical attributes and their values.

As stated in [7], 6G will integrate physical, biological, and digital worlds along with the evolved radio frequency communication, to facilitate the inclusion of variety of components such as robots, digital twins, artificial intelligence, emotion-driven devices, and brain-machine interface. This setup is capable of enabling a complete cyber-physical-biological communication experience.

The ITU-T SG13 is one of the most concrete sources of information as it paves the way for the forthcoming ITU IMT requirements for 6G. It considers the development of the 5G capabilities and presents opportunity areas for the further development and some probable use cases such as holographic communication that indicates the respective requirements beyond the capabilities of 5G. The contents of, e.g., Architecture Framework Specification produced by the SG13 in June 2020, the following indications can be presented: 6G needs to tackle 10–100 times higher data speeds, considerably higher system capacity, spectrum efficiency, and terminal velocities, better radio service coverage, and lower latency. Furthermore, 6G is expected to better interconnect things.

Table 2 presents some of the publicly available, concrete 6G vision statements of industry and standardization, and comparative statements of the ITU-T SG13 Network 2030 visions.

The indications of the 6G visions in Table 2 represent needs that may not be feasible to comply with even further evolved 5G. These indications, among other entities forming such statements via academic research and practical investigation, will be useful information sources for forming the ITU IMT-2030 requirements for the forthcoming 6G systems.

Table 2 presents a snapshot of the high-level visions whereas the various current and future initiatives will produce concrete proof of concepts. This is a long-term effort and the process will be rather similar to the applied research of the various items that were candidate options for the 5G requirements and standardization. This effort is thus an iterative process so that the ITU will evaluate the realistic expectations produced by the numerous concepts for technical performance of the future radio and core functions, architecture models, and other relevant aspects forming the IMT-2030 requirements.

Table 2   Assessment of selected 6G vision statements

Vision Statement	Relevancy assessment	Ref.
ITU NET-2030 requirements include: simplicity; native programmability and soft re-architecting; backward compatibility; heterogeneous communication, compute, storage, service and their integration; native slicing; unambiguous naming network functions and services; Intrinsic anonymity and security support for all network operations; resilience; network determinism.	– Along with virtualized network, adding service may increase complexity and result failures – the solutions must be kept simple; – architecture must be highly flexible; – Network 2030 must support service and network device decoupling; – heterogeneity must be multi-dimensional; – native slices should enable efficient use of many types of Network 2030 services; – user and systems will not access a specific server but rather the hosted content, function or service; – Network 2030 will be a critical national infrastructure for security and economy; – To avoid future cyber-attacks, the Network 2030 must have adequate means to mitigate the respective impact through appropriate controls on all the planes of the telecommunication network that are under risk. – Network 2030 must be adaptive to accommodate both deterministic and non-deterministic service requirements.	FG-NET-2030 [8]
6G needs to solve limitations of 5G, e.g., system coverage and IoE; 6G must serve Ubiquitous Intelligent Mobile Society.	This statement indicates the high expectations of the ecosystem for the 6G technologies, and the need for future technologies to serve as a platform in evolving society.	Shanzhi Chen [9]
Holographic media and multi-sense including haptic communication services will be examples of the typical representatives of 6G according to ITU-T.	Current 5G use cases often mention multimedia through Augmented Reality and Virtual Reality (AR/VR), but 5G performance will be limited for near-real-time holographic communications. 6G can be expected to provide engaging and realistic user experiences via true rendering of an object. Holographic applications include many realms such as entertainment, teleconferencing, tele-surgery, and remote holographic presence.	ITU-T [10]

(*Continued*)

Table 2   Continued

Vision Statement	Relevancy assessment	Ref.
The Hexa-X vision is to connect human, physical, and digital worlds with a fabric of 6G key enablers.	European Union – founded Hexa-X has connectivity industry stakeholders and research entities considering development towards 6G. The Hexa-X project includes developing key technology enablers of new radio access technologies at high frequencies and high-resolution localization and sensing; connected intelligence through AI-driven air interface and governance for future networks, and 6G architectural enablers for network disaggregation and dynamic dependability. This activity considers the overall visions in practice.	EU Hexa-X [5]
Next G Alliance aims to advance North American leadership over the 5G evolutionary path and 6G early development, and to create Next G development roadmap promoting a marketplace for 6G.	Next G Alliance can be assumed to have important role in regional 6G preparedness. It focuses on technology commercialization encompassing the lifecycle of research and development, manufacturing, standardization and market readiness. Through its member organizations representing key stakeholders of the mobile communications, the influence for forthcoming standards can be significant.	Next G Alliance [6]

4 Possible Enablers for 6G

According to [4], 6G will be a set of technologies forming the complete architecture. Thus, it can be expected that 6G is a combination of terrestrial, aerial (aircraft-mounted base stations) and space (satellite) systems. Reflecting the current development, it can be estimated that some of the technologies such as network functions virtualization (NFV) and software defined networking (SDN) keep evolving and serve in 6G era, too. This means that the related services such as Network Slicing (NS) will play important role in 6G.

Table 3   Some of the potential, further evolving enablers in 6G

Enabler	Estimated Role in 6G
Network Slicing	Along with the Network Functions Virtualization, Network Slicing will be more granular and serves the varying needs of multitude of verticals optimizing the network resources.
Common APIs	Further evolved Common APIs for Northbound Interfaces of the 3GPP SA6 has potential to extend the developers' opportunities to better access and utilize the network resources. 6G will benefit from the concept.
SEAL	Service Enabler Architecture Layer for Verticals as defined by the 3GPP SA6 supports vertical applications in V2X and other domains. The application and signalling plane entities for application-enabling services can relate to, e.g., group, configuration, location, identity and key, as well as network resource management in a reusable way across vertical applications. SEAL can turn out to be relevant enabler in 6G.
V2XAPP	Application layer support for V2X services enables use and deployment of V2X services over 3GPP systems. The V2X Application Enabler layer resides on top of the SEAL architecture. The V2XAPP provides capabilities in 4G such as V2X message distribution, service continuity, application resource management, and dynamic group management via the 4G system capabilities, and can pave the way for similar tasks in 6G.
Radio interface	OFDM has served as a feasible base technology for LTE downlink and 5G NR by adjusting its parameters to cope with the technological performance goals. OFDM in its further evolved form can serve as a feasible candidate technology also for 6G although many other variants can emerge, too.
Open RAN	Open Radio Access Network is currently evolving concept for the abstraction of the RAN modules, that provides the execution of functions also on cloud. It is relevant candidate enabler also in 6G.

Table 3 summarizes some of the current enablers planned or utilized in 4G and 5G, and that can be strong candidate items evolving further in 6G era, too.

5 Network Slice Assessment of Vertical Requirements

5.1 Network Slicing as a 6G Enabler

One of the most logical current and future solutions to optimize vertical-specific performance of the networks resources is Network Slicing (NS).

The development of 5G has already indicated the importance to understand end-user requirements along with the new service models that NS facilitates. NS provides ecosystem means for extending business models, and serves as technical base for advanced optimization for the operators in terms of available network resources and how to dedicate them to users, which in general are verticals with a diversity of needs. Along with the technical evolution, NS also provides new business opportunities. Thus, a Network Slicing Provider (NSP) can typically be a telecommunication service provider, which is the owner or tenant of the network infrastructures from which NSs are created. NSP can thus be a separate entity from the network infrastructure owner, that is, Mobile Network Operator (MNO). The NSP takes the responsibilities of managing and orchestrating corresponding resources that the Network Slicing consists of.

The network slice operators who are capable of understanding adequately the vertical needs are in a strong position to offer the optimal resources – not deviating from the desired performance to increase customer happiness, and at the same time, not exceeding unnecessarily the performance if it is not utilized in any case, in order to dedicate limited resources among the other users balancing with the respective the requirements.

The collection of the vertical needs for network slicing setup has been exercised already by different entities such as GSMA and ATIS. An example of the effort is the attribute and value assessment of the GSMA North Americas Network Slicing Taskforce related to regional key verticals. These activities found out that in order to adequately adjust a set of NSs, it is business-critical for NSP to understand the realistic needs. With such a variety and diversity of the requirements of verticals, network resource utilization must be optimized taking into account wide view of the complete ecosystem. This is a new aspect in the already highly complex optimization tasks of the operators, and automatized methods such as self-organizing network optimization techniques based on Artificial Intelligence (AI) and Machine Learning (ML) models may turn out to be essential to facilitate this task.

In the practical deployment of services and their enablers, such as regionally optimized set of NSs, the GSMA PRD NG.116 presents some of the most logical common slices to ensure fluent user experiences in the interoperable environment, including roaming scenarios that benefit from the uniform user experience offering cross the operator community. It can be assumed that this model for preparedness will continue being utilized also in the future for better coping with the requirements of 6G users.

5.2 Vertical Requirements Interpretation

The GSMA NETSLIC Taskforce researched regional vertical needs of selected use cases in the North America market area during 2019-21. In this effort, the Taskforce designed and applied NS assessment process as depicted in Figure 2 [11]. Based on the designed process, the Taskforce applied the following steps:

(a) **Regional Priority Verticals**: Identify relevant verticals that can benefit from network slicing. Assess the priority of the verticals in terms of relevance of the markets the verticals represent. As an outcome, form a priority list of the verticals.
(b) **Vertical Needs Assessment**: Reach out to the priority verticals in order to understand the practical environment and needs for the communications technologies via their *use cases*, applying systematic information gathering process.
(c) **Use Case Assessment**: On the selected use cases, by understanding typical needs and challenges, form each use case into a list of relevant attributes and their value ranges.
(d) **Network Slice Template Forming**: Finally, map the attributes and their values into network slicing templates. Of the templates, GST (Generic Network Slice Template) lists the relevant attributes related to the use case whereas the NEST (Network Slice Type) presents the values for that GST.

The GST and NEST are essential information elements for the stakeholders that set up and manage network slices technically and commercially. The MNOs wanting to ensure fluent user experience and service level, considering
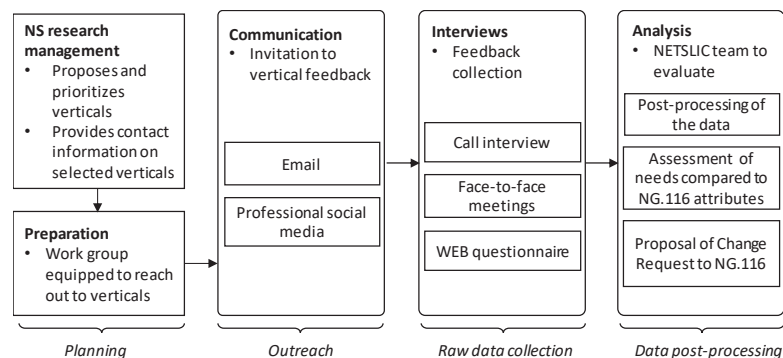

Figure 2 The process for vertical engagement and requirements assessment [11].

the home operator's network and well as the roaming scenarios, can use similar settings within the considered area.

5.3 Use Case Example: Commercial Flight Telematics

Commercial Flight Telematics is an example of vertical that the GSMA NETSLIC Taskforce has studied. The process depicted in Figure 2 was applied in commercial use case study of the transmission of telematics data log transfer that is triggered upon the landing of the plane at the airport. The communications link may be any available one such as Wi-Fi hotspot within the landing area, or cellular communications system of any of the commercially available generations. This use case relies on in-built IoT device of the aircraft that establishes connection autonomously with a ground server upon the landing of the aircraft.

In order to optimize the rather short period the plane stays on the ground, the aircraft starts sending the stored telematics data to the server for further processing immediately after establishing the connection. The IoT device can also receive SW updates and data contents, such as entertainment system's audio and video, as well as flight plan–related information. Being isolated system for the data transmission in uplink and downlink, there is no person-to-person communication channel involved. In this specific use case, it can be assumed that the current solutions are largely based on 4G connectivity although also legacy technologies may be involved, as well as Wi-Fi and satellite communications.

The further assessment of this use case indicated that security is of utmost importance, and that in avionics domain, all the solutions need to be certified, which requires rather long time. Furthermore, along with the potential sun-setting of legacy cellular systems in certain areas, there is a need to consider future-proofed technologies with the focus of at least 15 years in the future. Finally, there are potential issues related to the interferences, outage areas and congestion of the Wi-Fi or cellular networks.

In this specific example, it can be noted that the requirements of the use case map largely with the capabilities of 4G and 5G. Nevertheless, the telematics environment will develop during the next 10 years, so it can be expected that these requirements may largely benefit from 6G performance along with a) overall development of the enabling technologies; b) their adaptation to the commercial flight environment also during the flights.

As a result of this thought process, it may well turn out to be that – upon the global and regional regulation – in addition to mere telematics

Table 4   Commercial Flight Telematics Use Case requirements presented in a form of GSMA NG.116 GST and NEST, complemented by 6G evolution considerations

GST	NEST
3.4.1. Availability	Time for service delivers, divided by amount of time system is expected to deliver service: High (95–99.95%). The maximum value defined now in 5G (99.999 in Release 15, and 99.9999 in Release 16) can further increase in 6G benefiting this use case. It is worth noting the enhanced technical value range as such may not be the significant aspect, but the capability of 6G to optimize the performance further based on the characteristics and needs of use cases, by differentiating the allocated performance figures is an important difference with the current methods to manage 4G and 5G performance characteristics.
3.4.2. Area of service	List of countries and areas the airline is operating in. The list is specific to network slice providers and roaming agreements.
3.4.5 Downlink throughput per network slice	Guaranteed and maximum – Preferred guaranteed: 1 Gb/s (total of the network slice at the airport). While 5G is designed to provide maximum of 20 Gb/s for single user in downlink, 6G will be designed to exceed this value possibly 10-fold.
3.4.9 Isolation level	Physical isolation of the resources of the network slices (highest level). Data may be protected separately at the application level, in which case the highest network slice isolation is not needed.
3.4.24 Session and service continuity	Session and Service Continuity (SSC) mode (1, 2, 3) – SSC 3 for highest assurance (changes to the user plane can be visible to the UE, while the network ensures that the UE suffers no loss of connectivity). 6G may have wider set of SSC modes.
3.4.28 Supported device velocity	Vehicular, i.e., 120 km/h (data transmission starts automatically upon planes taxing and continues when they are parked at the gate). 5G allows maximum of 500 km/h terminal speed. 6G may be able to tolerate faster terminal speeds in an optimized and dynamic way based on the respective use case requirements. As the attributes contributing to the 6G performance are not yet available in specification, the practical management of this attribute in the future 6G networks is an example of the opportunity to evolve technologies beyond 4G and 5G based on foreseen use cases.
3.4.31 Uplink throughput per network slice	Guaranteed (and maximum) – Preferred guaranteed data capacity for the planes transmitting data to ground servers, the whole slice 1 Gb/s. 5G is designed to provide maximum of 10 Gb/s in uplink, and 6G will probably outperform it 10-fold.
3.4.34 User data access	No traffic transferred via public Internet: (1) Termination in the private network, and (2) Local traffic (no internet access).
3.4.35 V2X communication	3: YES – via 5G New Radio (NR) and 4G radio access network (E-UTRA).

use cases during and off-flights, there could be even possibilities for the mobile communications ecosystem to consider highly dynamic, nomadic, and adaptive Ad-Hoc aerial networking that can provide communication services supported by aircraft-mounted base stations. 6G could, in fact, serve as complement terrestrial communications with aircraft-mounted base stations and satellite components and provide voice and data services within the limitations of these environments.

6 Conclusion

The 6G visions are still merely under drafting. Nevertheless, there are concrete indications on the forthcoming need for 6G to tackle the performance requirements of the ecosystem beyond 5G as various industry initiatives involving key telecom stakeholders show. At the same time, ITU SG13 NET-2030 has already identified potential architectural models and use cases that the current 5G era cannot cope with, justifying thus the 6G development.

As has been already a "tradition" with previous mobile generations, the 6G seems to be commercially viable again after a decade from the first deployments of 5G, as of 2030. An important component to create the 6G requirements and respective systems capable of complying with them, the industry will gather and report experiences from the practical 5G deployments throughout 2020s.

There are still rather novel enablers that will evolve further and will serve as feasible platform for 6G, one of the most concrete examples being the Network Slicing concept. Nevertheless, the most fruitful development of 6G will benefit from the deep understanding of realistic vertical requirements and use cases. The adequate assessment of these aspects will be one of the key tasks of the ecosystem in order for standardization bodies to design respective solutions, and for providers of services, devices and technologies to concretize the practical outcomes. Thus, the industry benefits from the related up-to-date methods for the sharing, gathering, and evaluation of requirements as a basis for the development.

Disclaimer

Please note that the contribution of Dr. Penttinen hereby represents his own views in his personal capacity, and they do not necessarily reflect the position of his current or former employers.

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Biography

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