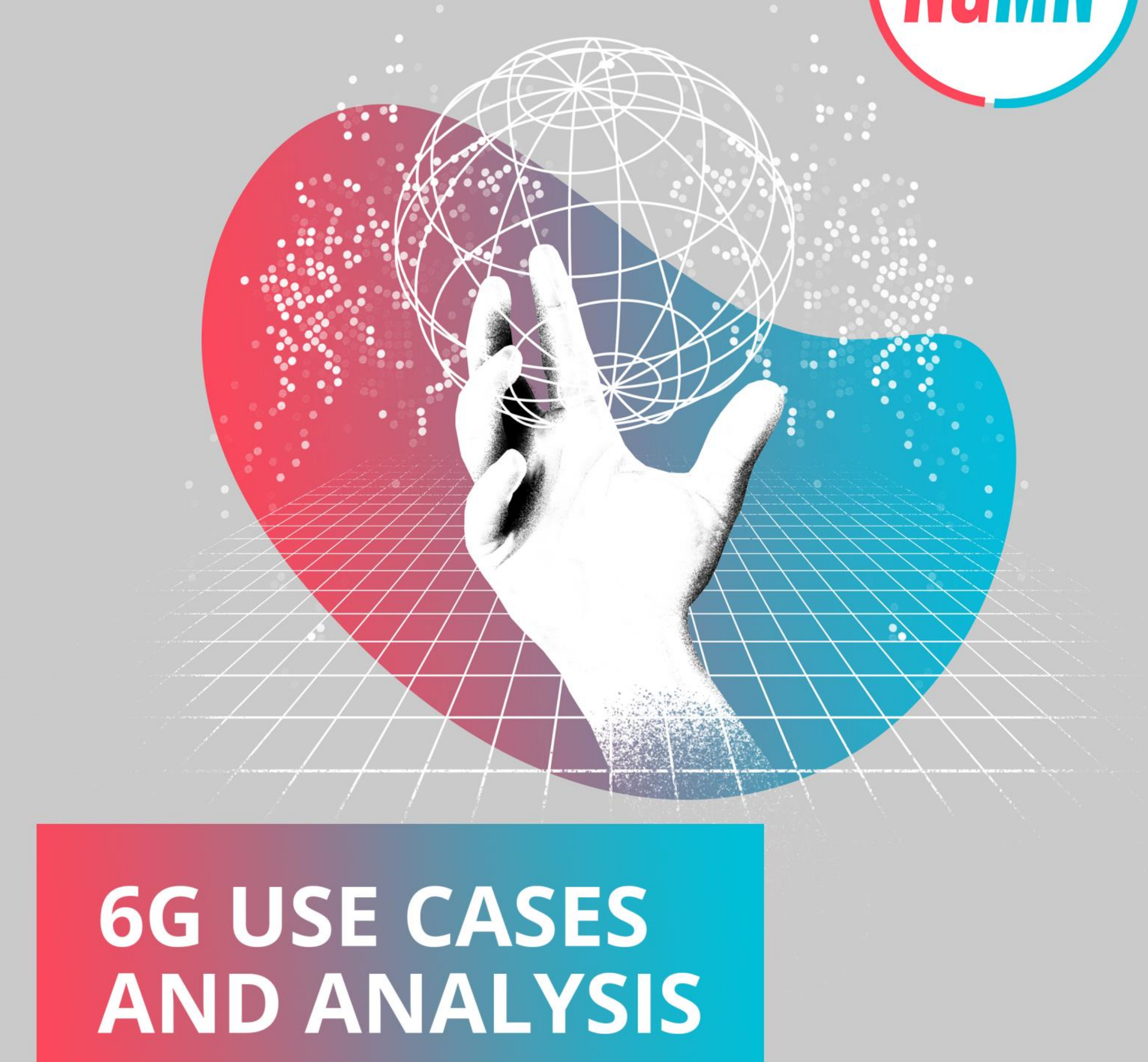

6G USE CASES AND ANALYSIS

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6G USE CASES AND ANALYSIS

by NGMN Alliance

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EXECUTIVE SUMMARY

The journey to 6G continues with the identification of use cases that attempt to predict major trends in usage scenarios helping to steer the needs and requirements for future generational change. These predictions on demand will feed into the ITU-R IMT Vision for 2030 and beyond that specify future connectivity requirements, followed by standards development organisations who develop and standardise appropriate technologies.

A similar approach was used for 5G, leading to the introduction of capabilities that fulfil the forecast need of industry and users. For example, 5G introduced new capabilities in both the radio access and core network. Firstly, the 5G radio access network was designed to be forward-looking and flexible to support new frequency bands, able to support many different new applications demanding more critical KPIs. Secondly, the 5G core network, was designed with service-based architecture, access-independent and as a converged framework to support a wide range of services.

The increasingly intelligent cloud-native design of 5G allows it to play out beyond this decade. In this context, it is important to consider the drivers and demands when we identify differentiated opportunities for future 6G capabilities. It is with this background that NGMN invited its membership (operators, technology suppliers and academic advisors), to contribute towards their views on which demands and use cases they predict will emerge in the future decade.

The approach taken includes multiple steps: methodology design, use case collection, high-level classification, generic use case abstraction, and use case analysis. A total of 50 use cases were contributed, which were categorised into 4 classes, then mapped into 14 generic use cases. At this stage, these use cases are considered provisional to be further explored and prioritised. At first glance, some of these use cases appear to be in the context of 5G and 5G-advanced. Due to the limitation of time and depth, the project has made a preliminary analysis on 5G differentiation.

Whilst a variety of usage scenarios have been forecasted (in the 6G time-horizon), many could also be served over advanced 5G networks. It is challenging to identify those use cases that will be addressed specifically after 2030 and aligned with 6G. Therefore, the use cases presented here are provisional.

Enhanced Human Communication includes use cases that have the potential to enrich human communications, such as immersive experience, telepresence & multimodal interaction.

Enhanced Machine Communication reflects the growth in the use of collaborative robotics, and autonomous machines, the requirement for sensing the surrounding environment and the need for robots to communicate among themselves and with humans.

Enabling Services include use cases that require additional features such as high accuracy location, mapping, environmental, or body sensing data.

Network Evolution describes aspects related to the evolution of core technologies including AI as a service, energy efficiency, and delivering ubiquitous coverage.

High-level analyses and assessments of use cases were conducted at early stage in several areas, including potential technology components, feasibility, impacts on deployed 5G networks, and 5G differentiation.

Societal needs, differentiated market demands, and operational necessities are key drivers to prioritise the use cases to guide the 6G system design. An important imperative in 6G drivers is environmental sustainability, both in terms of 6G eco-design as well as its enabling impact to reduce the environmental carbon footprint of industries and human activities. Aspects such as security, trust and privacy are also central in considering future technologies. NGMN will further focus on these imperatives in future phases of work on 6G, particularly with respect to analysis of alignment with demands and drivers. We expect new use cases to emerge, in support of digitisation, as we continue to update the work to be inclusive of the innovation beyond the imagination of today.

CONTENTS

1 INTRODUCTION

The scope of this document is to collect and assess proposed use cases for 6G, explore their implications for 6G R&D activities, and enlighten the way forward. It is the second deliverable in the NGMN Alliance 6G Project and follows from its publication of '6G Drivers and Vision' [1] in April 2021.

1.1 Context

Activity on 6G research commenced in 2019 with interest emerging about the same time around the world. In the years that have followed, billions of dollars have already been pledged by nations and regions across the world to support research and innovations.

Consequently, research institutions are devoting significant resource to study future communication needs and technologies. Many vision papers [2]-[15] have been published containing dozens of use cases; and the ITU has commenced its journey towards defining a vision, timeline, and subsequent set of requirements for a communication system for IMT for 2030 and beyond.

Whilst activities are well established in research institutions around the world, a view from the global community that represents mobile network operators and communication service providers, working together with their partners, becomes essential. This contribution from the NGMN Alliance builds on its earlier '6G Drivers and Vision' document. It delivers industry guidance considering the proposed use cases, the technical challenge, and the expected considerations that the introduction of a new generation entails.

1.2 Document Structure

Section 2 of the document introduces the motivation for deriving, grouping, and analysing use cases, and the methodology and approach conducted.

Section 3 describes the Use Case Classes and Generic Use Cases, along with the methodology used by the NGMN Alliance to collect industry views and develop a framework and a set of potential Generic Use Cases for 6G.

Section 4 summarises all the analyses applied on the use cases, such as applicability, technical components, 5G differentiation and alignment with NGMN 6G drivers.

Section 5 depicts the NGMN 6G project's plan for 6G requirements and provides guidance on how adopted use cases will influence 6G technology development and industry adoption.

2 MOTIVATION AND METHODOLOGY

2.1 Use Cases Motivation

The terminology of 'Generations' is well-established in the context of wide-area mobile communication networks, with new generations such as 2G, 3G, 4G, and 5G being introduced over successive 10-year cycles. To date, this approach has served the industry and consumers well: the framework of continuous innovation has led to substantially improved spectrum efficiency and utilisation of network resources to deliver the remarkable capabilities that are increasingly available over 5G.

In each transition from one generation to the next, collective views from across the industry attempt to predict the future customer demand, identify shortfalls in capability on the existing generation, and identify or promote new possibilities enabled by new ideas, new technologies or new paradigms. 3G was preceded with predictions on the need to support much greater voice capacity and a demand for video-calls, 4G addressed the forecast growth in mobile broadband demand, and 5G is set to respond to the demand for new 'vertical' applications. The predictions are often derived from use cases describing forecasted customer behaviour and demand, and whilst the predictions have not always or entirely materialized in the expected timeline, they have helped to provide focus to the design of successive technology capabilities.

These predictions on demand feed into the ITU-R IMT Vision that specify future connectivity requirements, followed by standards development organisations (SDOs) who develop and standardise appropriate technologies.

A similar approach was used for 5G, leading to the introduction of capabilities that fulfil the forecast need of industry and users. For example, 5G introduced new capabilities in both the radio access and core network.

Firstly, the radio access was improved to support forward compatibility and new frequency bands, as well as very high data rates, low latency, and high reliability. This means that the radio has a forward-looking capability to support theoretical data rates over wide areas that exceed what can be delivered practically when considering affordability and physical constraints related to radiated power, spectrum bandwidth, and site density. The flexibility that the radio access offers enables it to address applications that have the most demanding characteristics associated with reliability and delay, or massive machine type communications, for bespoke applications, such as manufacturing, in local areas.

Secondly, the core network was designed around a service-based architecture using modern IT approaches that are cloud-native, and its design is access-independent meaning that it can natively support fixed and mobile services. The deployment of the 5G core network will play out over this decade and potentially beyond, providing the framework for convergence and support for a wide range of services.

Taken together, this future ready approach of the 5G network results in a connectivity framework suitable for further evolution. In this context, it is important to consider what customer demand is forecasted that diverges from the underlying connectivity platform provided by 5G, and to identify opportunities for future capabilities.

It is with this background that NGMN have invited its operator members, technology suppliers and academic advisors to contribute towards their view on what customer demand, and use cases, they predict will emerge and be relevant to 6G.

2.2 Methodology and Approach

The NGMN Partners were invited to contribute on 6G use cases. To guide contributors on the format sought for a use case description, a template was provided to seek a consistent approach to characterisations. An inclusive approach to collect use cases has been followed. Contributions were provided from the 41 members that participated in this project leading to 50 proposed use cases that were then grouped into 4 classes, relating to Enhanced Human Communication, Enhanced Machine Communication, Enabling Services, and Network Evolution. Then within each of the class the original use cases were further dismantled and regrouped into a few generic use cases based on similarity, and total 14 generic use cases were defined. Finally, for each generic use case, an analysis was applied on multiple dimension and areas, including Applicability, Feasibility and 6G implications.

Figure 1: Methodology and Approach

3 USE CASE CLASSES AND POTENTIAL GENERIC USE CASES

Tens of use cases were presented and discussed. The template and the list of proposed use cases are shown in Appendix A and Appendix B.

Expectedly, there has been a general similarity among the use cases identified and proposed in global research and the ecosystem related to the 6G.

A high-level grouping of use cases into four classes was done based on their key common characteristics and potential technology needs. These classes are labelled as:

- **Enhanced Human Communication** – such as immersive experience, telepresence and multimodal interaction
- **Enhanced Machine Communication** – such as robotic communication and interaction
- **Enabling Services** – such as positioning, mapping, automatic protection, smart health, and manufacturing
- **Network Evolution** – such as Native Artificial Intelligence (AI) exposed as a service, energy efficiency, and coverage

Given similarities and/or complementary nature of the use cases, a number of potential generic use cases were derived and developed. At this stage, these use cases are considered provisional to be further explored and prioritised. These are shown in the figure below.

ENHANCED HUMAN COMMUNICATION	ENHANCED MACHINE COMMUNICATION	ENABLING SERVICES	NETWORK EVOLUTION
XR immersive holographic telepresence communication	Robot Network Fabric	3D hyper-accurate positioning localization, and tracking	Trusted Native AI – AIaaS
Multi-model communication for Teleoperation	Interacting Cobots	Interactive mapping, digital twins & virtual worlds	Coverage expansion
Intelligent interaction: sharing of sensation, skills & thoughts		Automatic detection protection & inspection	Energy Efficiency
		Digital healthcare	
		Smart Industry	
		Trusted composition of services	

Figure 2: Use Case Classes and Potential Generic Use Cases

It is obviously expected that a generic use case may go beyond the proposed use cases and may not be confined to one particular class, possessing characteristics represented by others. Furthermore, there exists some overlaps and inter-dependencies among generic use cases.

This chapter outlines descriptions and expected attributes of proposed generic use cases.

3.1 Enhanced Human Communication

A few generic use cases belonging to this high-level class are proposed below.

3.1.1 XR Immersive Holographic Telepresence Communication

Human centric extended immersive and 3D reality (encompassing VR, MR and AR) and holographic telepresence may eventually become the norm for both work and social interaction. It will be possible to make it appear as though one is in a certain location while really being in a different location – for example, appearing to be in the office while actually being in the car. We will have systems that combine current facial expressions with a virtual self within the digital representation of the physical world.

Merged reality telepresence experience and use case will be enabled by wearable devices, such as smart contact lenses or glasses and those embedded in our clothing; skin patches and bio-implants may not be so uncommon. We will have multiple wearables that we carry with us and they will work seamlessly with each other, providing natural, intuitive interfaces. Touchscreen typing will likely become outdated and be replaced with more intuitive interfaces such as gesturing, talking, and eye tracing. The devices we use will be fully context-aware, and the network will become increasingly sophisticated at predicting our needs. This context awareness combined with new human–machine interfaces will make our telepresence interaction much more intuitive and efficient.

Another variation of this use case class is mixed reality co-design that allows remote human centric collaboration and "experience before prototyping". This may, for example, apply to a factory scenario where two people are designing interactively using both physical objects and virtual objects. MR reality co-design system will allow designers to cooperatively design innovative virtual products in the world of virtual-real fusion. Context awareness as integral part of the MR co-design process will allow designers to focus on the design itself and its relationship with the external environment. MR co-design will link into new forms of human-machine interaction e.g. by capturing designer’s head or eye movement, emotional state, facial expressions, and body parameters such as heart rate or blood pressure. Such approach can be subsumed under the term “spatial computing”. Moreover, the co-design context can be captured by spatial mapping and imaging technology. It is expected that in the near future, designers' behaviour and vital characteristics could be included in the co-design process. With the leverage of machine learning and AI, MR co-design use case will be greatly enhanced. Similar to the immersive reality, advances in user equipment in conjunction with wearables will greatly impact the MR, and together transform the next generation of Industrial IoT.

3.1.2 Multimodal Communication for Teleoperation

Human Multimodality Information such as audio (hearing) and visual (sight) or a combination thereof (audio-visual) are transferred over communication networks. Yet interacting sense of touch (haptic) and particularly the kinaesthetic (muscular movement) component has much stricter end-to-end latency communication requirements for Human-In-The-Loop (HITL) interactions for teleoperation. Enabling bi-directional haptic teleoperation is one of the key drivers behind 6G technology aiming to benefit from combining inputs from more than one sources and/or output to more than one destination for the multi-modal communication services to be perceived closer to reality.

Human Multimodality Information (i.e., audio, video, taste, odour, haptic and emotion) captures information from wearable terminals as well as inferential knowledge gained from ambient sensors and social sensory insights can provide complementary methods to enhance remote HITL communication and control. The sensing part of this technology is rooted in industrial sensor technology. The communication side of it comes from the evolution (and convergence) of wireless sensor networks and cellular communications technology, to complete this convergence because of its combination of extreme high availability, reliability, and ultra-low latency. With 6G, multimodal sensing and communication fusion will realise the transmission of synchronised multimodal information varying requirements for different modalities (e.g., bitrate, latency, reliability, security) across groups of distributed devices. This enhances delivering customised services that will enrich the user experience, using new sensors and new data modalities to support multimodal interaction and operation.

3.1.3 Intelligent Interaction & Sharing of Sensation, Skills & Thoughts

People may be able to interact with devices or control machines via brain-machine interfaces. With 6G, Brain-Computer Interfaces (BCIs) may realise the sharing of sensations and thoughts between human and machine, human and human, crossing a long distance and in real-time. People would feel to have sort of telekinesis, with their thoughts immediately realised without legacy human interaction in between. With 6G a new term seems to come into play which will be called Internet of Behaviour (IoB), where humans will include their individual characteristics into the information flow.

With more and more systems being driven by AI technologies, the machine no longer passively waits for users to input. This brings fundamental changes to the Human-Computer Interface. Machines may sense what humans “do” and reason what humans “want”. For example, self-driving cars and personalized healthcare robots are emulating human behaviours. Machines are more focused on understanding and replicating the human mind and brain. Those machines are trying to perceive, recognize and think like humans, and human-machine interactions will evolve to equal human-like interactions with emotions and mutual understanding.

BCI systems are providing an alternative method of interaction between humans and the world. In the past, most BCIs focused on helping people with severe movement disability by replacing or restoring lost movements. Today, more and more BCIs are aiming as consumer products for all users. Certain functions of the human body can be replaced with machines manipulated by mind.

3.2 Enhanced Machine Communication

A few generic use cases belonging to this high-level class are proposed below.

3.2.1 Robot Network Fabric

The cities in 2030 are expected to be traversed by a high number of autonomous mobile robots, drones, automatic guided vehicles (AGV) for packet delivery and personal traffic. Key objectives will be to keep this traffic safe for people, collision-free, and efficient. Here, 6G networks can play a crucial role by enabling traffic management of connected robot vehicles in a central coordination of robot trajectories, taking into account an aggregated set of data containing other robots and unconnected objects. Negotiation of paths through stated intentions from robots can ensure collision avoidance. By collecting, processing, and distributing sensor data from all connected nodes in the network (robots, base stations, etc.) and dynamically mapping in high-precision in 3D, the robots can effectively see around corners and predict the future path, and do not need to carry so many onboard sensors but can rely on the larger network. This allows for smaller, less expensive, and lighter robots that can be used for new types of autonomous transport. Traffic can be made easy and safe for connected robots and humans navigating through the busy connected city.

3.2.2 Interacting Cobots

A much closer interaction is expected to develop between humans and robots, through the form of collaborative robots, cobots. These connected cobots should be able to reliably read and interpret human actions and intents and react in a trustworthy way, and thereby assist humans in an efficient and safe way. They should be able to work as colleagues on precise and challenging tasks in industries, with the help of digital twins to do the job of robots more efficient, or as care assistants in the homes of elders or disabled, doing the heavy work of humans. A cobot could be a separate machine taking commands or adapting to the situation presented, or closer to humans as an exoskeleton or adaptive wheelchair. Cobots could also form teams amongst each other, solving tasks together and collaborating with humans on group level. To unleash the highest potential and efficiency it should be possible for sets of cobots to jointly define the way they collaborate and even communicate, naturally under the control of the network.

3.3 Enabling Services

A few generic use cases belonging to this high-level class are proposed below.

3.3.1 3D Hyper-Accurate Positioning, Localisation, and Tracking

High-accuracy 3D localisation and improved tracking capabilities at centimetre or better level, particularly in indoor environment, will open many new opportunities in future smart factories, warehouses, hospitals, and libraries to enable full automation especially for autonomously moving collaborative robots. For instance, the capabilities of future assistant robots will approach that of human in daily work and life. To adapt to human's living and working environment, high precision at centimetre level is needed such as to find and rotate door handle, pick up the right box/book from the shelf, and capture the right tool from the drawer. Another example in future libraries, where all books with positioned sticker (wireless module) can be randomly placed in shelves without sorting. Their positions will be automatically collected, and a 3D digital twin model can be established which contains precise locations of each book. A robotic librarian can fetch a book for a patron using positioning information.

High precision relative localisation is also much desired for autonomous systems that are becoming pervasive in smart manufacturing when two or more robots operate in collaboration. For instance, a drone may need to land on a moving carrier vehicle to get charged; a delivery robot may need to refill liquid or solid substance to a smart container (bin/tank) when it is detected as empty, etc. In such proximity use cases, centimetre-level relative localisation accuracy is required to perform the task.

3.3.2 Interactive Mapping

Digital twins are means to get an accurate and updated view of situations in a machine or a house. They form the basis of smart cities and digitalised factories. In the 2030s they have the potential to become ubiquitous tools and knowledge platforms in many sectors of society for learning, steering, analysis, and more purposes. By connecting a large set of digital twins of separate parts of a city a real-time representation of physical assets can form a continuous interactive map, i.e. a virtualised model of the physical world. This would enable efficient large-scale system management, for instance a municipality governing transport, heating, water, waste etc. Further it can enable real-time representation of the environment for surveillance, navigation, and other purposes. Large numbers of wireless sensors and actuators give accurate map information and perform actions when the map is updated. It becomes possible to plan future activity, and even to simulate future map status based on past events on which analysis can be made. The processing and analysis powers can be provided as a network service together with the links to the physical world which is constantly synchronized with the digital map.

3.3.3 Digital Healthcare

Health care will be substantially transformed into what we call digital healthcare, with 24/7 monitoring of vital parameters for both the healthy and the sick through numerous wearable devices. Health monitoring and medical research will also include in-body devices that communicate with on-body devices outside, which in turn can transport the data to the internet where a digital body double is analysed: 6G telemedical paradigm will be enabled by body sensing and analytics in conjunction with wide area connectivity. This will enable options of daily life support and supervision with special relevance of inclusion of for example the elderly. XR tooling in conjunction with haptic information, including surface, touch, actuation, motion, vibration and force, along with audio/visual information will allow medical staff an immersive experience while leveraging digital twin insight.

Therefore, body networks with connected medical sensors and actuators can contribute to help fix shortcomings of today's healthcare system as regards closed-loop interactive remote monitoring and predictive therapy, i.e., enabling a paradigm of actuation, such as medicine dispensers and pacemakers. State-of-the-art consumer-grade wearables of today are IoT based. They provide basic personal health monitoring and reporting (temperature, pulse, glucose level, blood pressure). In the 2030s, not only will these sensors be more accurate and reliable for diagnostic purposes, but they will typically be part of sub-networks with the option of updates from and interaction with distributed cloud repositories.

There is a need for privacy preserving technologies to be used end to end and for device data off-load in particular.

3.3.4 Automatic Detection, Recognition and Inspection

Supported by the communication systems of the future, the 6G network may sense the environment. Advanced techniques will be used in security-screening procedures to eliminate security lines at airports, for instance. A combination of various sensing modalities may be used to screen people as they move through crowded areas rather than only at entrances. For example, it could be programmed to detect metallic objects of certain kinds that people may be carrying in a crowded controlled area automatically. The network can sense and identify potential threats.

In a smart hospital in the foreseeable future, device-free gesture and activity recognition enabled by 6G networked sensing and machine learning will enable functionalities such as gesture recognition, heartbeat detection, fall detection, respiration detection, sneeze sensing, intrusion detection, etc., providing automatic protection to the patients during their daily routines. For instance, the medical rehabilitation system could provide automatic supervision of patients during their physiotherapy exercises. Prompt alerts will be sent upon incorrect movements or gestures in an automatic way, thus significantly improving the capacity of medical rehabilitation.

In future intelligent factories, 6G will enable ultra-high resolution imaging monitory systems and remote operation platform systems. Intelligent factories will leverage these superior sensing solutions to implement contactless ultra-high precision detection, tracking, and quality control. It enables applications such as detection of slits or leakage on products or equipment using 6G communication networks and devices without the need to install extra infrastructures.

A variety of application scenarios may include eliminating security lines at airports, intelligent health care of gesture recognition, heartbeat detection, fall detection, respiration detection, sneeze sensing, intrusion detection, intelligent factories of contactless ultra-high precision detection, tracking, and quality control.

3.3.5 Smart Industry

The “Smart industry” takes care, not only of the production process but also, of the whole business process, while paying attention to the carbon footprint reduction, the resource circularity, and a recent trend on reduction of employees’ daily commute and of physical transportation that an environmental consciousness and concerns with COVID-19 set recently.

For manufacturing, the business practice consists of production process research, product research, product design, prototyping, production, shipping, warehousing, and delivery. The "Smart industry" that the mobile communication offers supports all those steps, where the entire process constitutes an overall closed loop, while each step forms its own closed loop, between the physical and the digital worlds. It is this end-to-end smart loop, among others, that further evolves, and has potential opportunity for differentiated opportunities in 6G usage scenarios, including some highlighted in other sections. This is to be further explored.

Production process research and product research: The interactive mapping, introduced earlier, is the enabler of the big, closed loop and allows analysis of real-time dynamics for industrial production, storage and sales. The interactive mapping gives feedback to the research process so that it can develop new scenarios for future products and even a new business process. This then decreases time-to-market, increases cost efficiency, and effectively protects the maximum benefit of production.

Product design and prototyping: Mixed reality co-design and the advanced manufacturing concept is the enabler to design, create, test and build equipment in a virtual environment or in a virtual-real fusion of worlds. Only when that equipment performs to exact specifications in such environment, will the physical manufacturing be allowed to start. This then allows remote collaboration. Production intelligent robots with recognition capability and backed by a trusted data platform becomes the main force of agile manufacturing, leading to more self-driven, intelligent manufacturing. Such robots complete even difficult, dangerous tasks.

Motion control is the core logic of automation process, and responsible for controlling, moving, and/or rotating the machine's parts in a well-defined manner. It is supported by the integrated sensing and communication with hyper-high accuracy synchronization and scheduling, hyper-low latency, and hyper-high reliability both in communication and node processing. These then enable a higher-quality product and a highly efficient production process at any time and place.

Shipping, warehousing, and delivery: Products are equipped with biodegradable tiny tags, enabling identification and positioning by the cellular system. Tagged items are posted in a map. The use of tags can help to enable resource circularity and reduce material consumption. Cargo-carrying drones, AGVs, and intelligent robots increase efficiency.

3.3.6 Trusted Composition of Services

Enhanced human and machine communication will more and more require convergent networks which will allow for a trusted composition of services to support the various, increasingly dynamic and complex use cases of the future.

A tourist exploring a foreign country may serve as an example. This person may carry along a set of wearables and mobile devices which have been paired in advance and provide a personal network context with a set of services such as exposure of topics of personal interest, health indicators, payment interfaces, etc. The tourist should be able to dynamically access the services provided by other network contexts for example when approaching a sightseeing location. Based on the personal preferences, establishing network connectivity should not only allow for transmission of data packets but also for the discovery and pairing of the services hosted in the different networks. This is expected to support more complex scenarios such as customized guided VR augmented tours with optimised downlink bandwidth which will take into account the topics of interest and personal health conditions and allow for simple payment of the consumed services.

These types of scenarios are typically difficult to implement and will require a trustworthy relationship between the various services in order to prevent that data is exposed or utilised in an unintended way. 6G will provide a framework for a simplified and trusted composition of services by establishing a federated control-plane between different networks (mobile and fixed access, Bluetooth, Wi-Fi, …). The control plane manages the needed service endpoints for service registration, discovery and pairing of user-plane functions. It will allow humans to define policies of how the user-plane services may interact and make use of personal data.

3.4 Network Evolution

A few generic use cases belonging to this high-level class are proposed below.

3.4.1 Native Trusted AI (AIaaS)

AI can be a tool to optimize performance, but it can also be a general service provided by the mobile network to enable new applications. This is referred to as "AI as a Service (AIaaS)", in which the network with an AI plane/layer will be able to expose and serve distributed AI learning and inference as native AI services where needed.

AIaaS could be utilised by the mobile communication network itself for operation and management (OAM) purpose in order to realise the vision of zero-touch autonomous networks. For instance, network configuration, function implementation, etc. can be implemented, operated, managed by the network system itself through the continuous learning capabilities offered by AIaaS service through the network. The training of the AI models as well as the reference through the AI models for these automation tasks would need the communication, sensing, and computing functions integrated in the 6G networks as a whole, especially when large scale training and inference models are incorporated on distributed edge nodes. Such distributed nature is the key to make the whole computation and resource management scalable towards more complex tasks and larger areas of intelligence.

Similarly, AIaaS would be an integrated service of the 6G network to enable other use cases for operators' own operational necessities such as dynamic traffic and resource management, as well as the energy saving mechanisms trying to follow those dynamics. Data management is another example of applications that would benefit from AIaaS. Obtaining vast amounts of data does not mean that the data is either high-quality or usable. As such, AIaaS is necessary to support efficient data processing to select high-quality data while reducing computation complexity and energy consumption.

Besides serving the requirements from the operator's network itself, an important aspect of AIaaS is to create new values by providing distributed AI solutions through the mobile network to external (third party) user applications, including those driven by deep neural networks. The capability to provide highly efficient and fast convergence training as well as low latency inference would be the key to realise intelligence-of-everything for future human-centric social services as well as advanced smart vertical industries. Examples of the enabled third-party user applications may include but not limited to vision (image and video) recognition, activity recognition, as well as automatic security inspection in smart factories and health monitoring in smart hospital.

3.4.2 Coverage Expansion

Traditionally mobile operators have enabled communication between people in populated areas. Recently they are trying to also cover people in unconnected remote areas or on maritime ships. 6G envisages to extend the coverage to areas that have not been reached out so far due to technical or economic reasons. According to the spirit of UN Sustainable Development Goals (SDGs), the communication needs to be affordable to anyone anywhere. Economic communication means bridges digital divide that manifests itself during COVID-19.

With the seamless multi-access service continuity of terrestrial and non-terrestrial networks, 6G may provide global 3D coverage, eliminating coverage gaps. The 3D coverage extends from land-surface to sea, sky, and space, following ever-expanding sphere of people's activity. The non-terrestrial network can serve as relay link for the local terrestrial base station. The direct connection between non-terrestrial networks and mobile devices is also an attractive prospect. The integrated mobile devices ensure seamless switchover between different access services.

Several use cases are considered. (i) Broadband connection for people on the move and outside urban areas is an important scenario. Integrated 6G system should provide scenario specific optimal MBB coverage for people in cars, trains, aircraft and ships. (ii) Environmental issues that UN SDGs plans to address require sensors to be widely deployed. A certain part of coverage needs to be bound to a communication method suitable for efficient data gathering (e.g. by satellite or high altitude platform station). (iii) Decent work and economic growth that UN SDGs targets potentially get benefit from unattended operation of e.g. mining and farming in a remote site under harsh conditions. Such sites require high-reliability low-latency in a limited duration although it's in a remote area. (iv) In some cases, natural disasters may disrupt terrestrial networks. With the integration of terrestrial and non-terrestrial networks, 6G may ensure non-stop services which is critical for disaster management.

3.4.3 Autonomous System for Energy Efficiency

The optimisation of energy consumption in the network and devices can be realised through an intelligent allocation of networking, computing, and storage resources, by harnessing autonomous system capabilities that engage native AI/ML models. These AI/ML models are flexible, adaptable, and tuneable to suit a variety of deployment arrangements, while optimising the corresponding energy utilisation, and while satisfying the demand that is just sufficient to preserve an attractive user experience.

Among a variety of usage scenarios to optimise energy consumption, a cognitive management of the dormant, inactive, and active states of a network element or a device, and the associated state durations could be modulated elastically. This uses an autonomous system, which utilises closed-loop feedback AI/ML learning models for a realisation of state-of-the art self-CHOP (Configuration, Healing, Optimising, and Protecting) behaviours in the E2E network sliced system.

Along these directions, the on/off states of system resources could be modulated through the use of native AI/ML models to closely follow demand, while simultaneously sustaining the desired behaviour, performance, system availability and service experience. Hence, the corresponding energy consumption levels associated with networking, computing, or storage network elements, may be reduced, or turned off, without adversely affecting the associated service experience.

Both ambient energy (e.g., solar, wind, geothermal etc.) and dedicated energy (e.g., electro-magnetic coupling, piezoelectric conversion, capacitive or inductive coupling etc.) harvesting techniques could be leveraged for a realisation of Green AI/ML models, amenable to reduced training time for minimizing energy consumption, while optimising Energy Efficiency.

4 USE CASE ANALYSIS

4.1 Summary of Generic Use Case Analysis

In addition to anticipating potential 6G use cases, the project team evaluated those use cases in several aspects, in alignment with NGMN drivers, such as environmental impact and energy consumption, feasibility, industry growth opportunities, and impact on deployed 5G networks.

Sustainability is an important driver for 6G, both from the perspective of 6G as an enabler to reduce the environmental footprint of industries and more generally human activities, and from the perspective of 6G being itself designed to minimize its own environmental footprint. The use cases analysis in terms of sustainability is however not straightforward as most use cases can have positive effects, and on the other hand will have an environmental impact by themselves. The net benefit of each use case in terms of overall sustainability, in particular CO2 emission reduction, will depend on the actual service and application scenario, whose identification is beyond the scope of this document. Identifying services leveraging these generic use cases in order to provide sustainability value will be an important effort to be performed in the future steps of 6G development together with representatives of future users.

The key drivers to prioritise the use cases to guide the 6G system design are as follows,

- Societal Goals: The need to address societal objectives at large, as also expressed in the UN SDG.
- Market Expectations: The need to satisfy customer requirements by offering new services and capabilities, supported by evolving technologies in a cost-effective manner.
- Operational Necessities: The need to make the planning, deployment, operations, management, and performance of the mobile operator's networks increasingly more efficient.

For all the contributed use cases and the defined generic use cases, a preliminary assessment has been applied to ensure the use cases are aligned with one or more drivers.

Interaction with future users, including citizens, industries and governments will be key in the coming months and years in order for our industry to build confidence on the future market demand for the various generic use cases. NGMN will further focus on these imperatives in future phases of work on 6G, particularly with respect to an analysis of the alignment with demands and drivers.

As introduced in the previous chapter, use cases have been grouped into four classes of Generic Use Cases:

- Enhanced **Human** Communication
- Enhanced **Machine** Communication
- Enabling **Services**
- **Network** evolution

In the following, we review the generic use cases in order to identify how 5G features can be expanded and consider the implications with regards to future network evolution and 6G.

The project has applied high-level assessment and analysis focusing on the following areas:

- Applicability: Broadness, Mobility & Wide-area, Network/Device/App
- Feasibility: Enabling technologies / spectrum; Extreme requirements, complexities
- 6G Implications: 5G Differentiation & impacts; alignment with Drivers

In order to provide timely guidance to the industry, we deferred detailed technical requirements and KPIs for future work. This should be viewed as more of a high-level analysis from a technical perspective. The results of these preliminary analyses are included in the appendix for reference, which forms a good basis for our next phase of work. A summary table of the generic use cases with a high-level analysis including an early assessment on the differentiation to 5G and proposed technology components to support the use cases is contained in Appendix C and Appendix D.

4.2 Discussion

4.2.1 Technology Component Summary

From the large set of the original 50 use cases a variety of proposed technology components were identified as being necessary to support their delivery. This includes components that are additional or complementary to the communication technology such as new devices, form factors, and novel human-machine-interfaces. Various use cases also assume the availability of increased environmental awareness obtained through joint sensing and communications, particularly using higher frequency bands where finer spatial resolution can be obtained. A set of use cases also assume the availability of 3D, hyper-accurate positioning.

Services that require much higher data rates will necessitate the use of new frequency bands. This may include new allocations for mid or high-band spectrum, and novel bands for XR immersive telepresence.

Many of the proposed use cases assume AI services, enabled through a distributed edge architecture with integrated communication and computing capabilities, agnostic to licenced or unlicenced spectrum. Data management and potentially new network interfaces will be required to support privacy protected and scalable AIaaS through the whole network on a large scale. Network sensing and various IoT input may serve as data source for the AI services through low latency and massive capacity uplink access. It is expected serving AI as a native service in the network would have clear competitiveness in real time applications, which also make it different from the currently API exposure based mobile edge computing. Clearly AI will also be facilitated outside of an Operators network, so rich APIs to the enhanced 6G capabilities should be baked into the Standards.

4.2.2 Initial Analysis

The generic use case classes are further discussed below.

Enhanced Human Communication describes a collection of use cases that have the potential to enrich human communications. A subset of technology components will be necessary depending on each use case, and therefore it is likely that components will be introduced over time as market demand for these capabilities become better understood.

Several of the individual use cases are non-mobile (fixed or nomadic) as they require to collect sensory or ambient information from the surrounding environment, or will likely be available in localised areas due to need for extremely high data rates. Therefore, it is expected that these use cases will be realised over converged networks, possibly using short range communications to a wireless access point that has access to fibre to transport the highest data rates. It can also be anticipated that the appropriate access technology will be determined not just by the speeds provided, but also by the ability to deliver the connectivity with significant energy and cost efficiencies.

Extended reality type applications have, to date, been motivated for gaming and entertainment, training, and business applications such as virtual conferencing. The adoption of the more future looking type of applications will be dependent on various external factors including developments in user equipment, the human-machine-interface and broad social acceptance, whilst maintaining essential aspects such as privacy and security.

Enhanced Machine Communication reflects the growth in the use of robotics and autonomous machines within industry, the requirement for sensing the surrounding environment and the need for robots to communicate among themselves and with humans. Many of these scenarios will be within an industrial setting where requirements are often specific and bespoke. For example, robots may be required to support high-resolution imaging, force-sensing, acoustic-sensing, proximity awareness, or air quality sampling, depending on their application. In other scenarios, fleets of mobile robots in a logistics plant may require to be centrally coordinated to optimise the flow of goods, yet robots also need to communicate with each other for collision avoidance and to manage fault conditions.

This variety and complexity within industrial settings demands different communication requirements, in addition to interoperability and high reliability. In some cases, very high uplink throughput is required, whilst in other situations time synchronisation or latency may be more important. The variety of use cases indicate that protocols must be adaptive and flexible including peer-to-peer and centralised communications.

Several use cases proposed require new capabilities for **Enabling Services** that provide additional information such as high accuracy location, environmental, or body sensing data. How this data is collected is application specific and may include a variety of sources such as personal-area-networks, networks of trusted sub-networks, or data gathered from the network edge. The underlying need is for data to be collated, processed, and information to be derived such that actions or decisions can be made. Trustworthiness of data becomes critical, whilst privacy and security must also be maintained.

Network Evolution will continue to address essential requirements such as energy efficiency, intelligent operational efficiency, and coverage. Artificial intelligence is anticipated to become intrinsic for certain parts of network operation and management, including radio management and control and network compute resource allocation. Compute resources are also likely to become distributed throughout networks supporting artificial intelligence features extending the broad capabilities of communication networks to provide intelligent connectivity services.

Common to many use cases is the requirement to process new, complex, and diversified data collected from multiple sources therefore requiring computing resources distributed across networks to support artificial intelligence.

4.2.3 Differentiation Relative to 5G

The previous chapters have identified and grouped a set of potential use cases. At first glance, some of these use cases appear to be in the context of 5G and 5G-advanced. Due to the limitation of time and depth, the project has made a preliminary analysis on 5G differentiation, while further in-depth discussions and research are needed.

An important observation since the launch of 5G is that the growth in data across mobile and fixed networks has been enormous, driven primarily by the increasing use of video streaming across all media platforms. As high-capacity networks have become widely available, growth in the use of consumer smartphone apps that use video as the primary means of engagement has followed. Further, the COVID pandemic has dramatically driven data growth, with work-from-home and remote-learning driving the wide-scale adoption of video conference platforms, unimaginable just a few years earlier. Together, these changes in services and consumption have influenced network developments in way that were unforeseen when 5G use cases were proposed.

Use cases should therefore be recognised as being speculative in nature. At least as important is the ability for mobile and fixed networks to continue to scale, in a flexible way, that is sustainable, energy efficient and cost-effective in order to address the inevitable growth in demand in future decades whilst minimising the impact on the environment.

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5 NEXT STEPS

Next, the NGMN 6G project will start the 3rd phase study on 6G requirements. With greater details and specifics identified, we will continue to update and refine this 6G use cases document.

Many of the use cases identified in this document are reflected in research and other global initiatives and imply an opportunity for value add as new features and capabilities are added over time. The analysis by NGMN members indicates that several prospective use cases may be specific, bespoke, or localised in nature, potentially requiring an evolutionary approach from 5G and service ubiquity over converged networks.

The consideration, research, evaluation, and the development of future ecosystems, including any of these potential use cases, should prioritise the key imperatives and challenges:

- Address societal and environmental needs, including well-being, prosperity, sustainability, trust, safety, affordability, and inclusion

- Advance enablement of digital transformation and automated industries to address future market needs, with expanded and differentiated opportunities, operational efficiency and complexity management, productivity, sustainable business, and return on investment

- Ensure interoperability, environmental and economic sustainability, and global harmony supporting value creation and delivery

- Be supported by market research or evidence of stakeholder pull that demonstrates customer demand

Further details on imperatives, along with examples of attributes and (horizontal) considerations, which are necessary for characterization and prioritisation towards feasibility, deliverability, and effective role of these use cases, are outlined in NGMN 6G Drivers & Vision white paper, published in April 2021. Furthermore, future NGMN work is expected to provide insight and guidance on use case and design requirements, in synergy with organisational partners and the global ecosystem as market demand becomes clearer.

We expect the significant and the forward-looking prospects of 5G to evolve, in support of digital transformation and automated industries, as we define the framework for the end to end anticipated, as well as the unimagined needs, use cases, and the potential systems of the future decades.

LIST OF ABBREVIATIONS

3D	Three-dimensional
3GPP	3rd Generation Partnership Project
AGV	Automatic Guided Vehicles
AI	Artificial Intelligence
AIaaS	AI as a Service
API	Application Programming Interface
AR	Augmented Reality
BIC	Brain-Computer Interface
CHOP	Configuration, Healing, Optimising, and Protecting
CO2	Carbon Dioxide
COVID	Coronavirus Disease
E2E	End-to-End
HITL	Human-In-The-Loop
IMT	International Mobile Telecommunications
IoB	Internet of Behaviour
ITU	International Telecommunication Union
KPI	Key Performance Indicator
MBB	Mobile Broadband
ML	Machine Learning
MR	Mixed Reality
R&D	Research and Development
SDG	Sustainable Development Goal
SDO	Standards Development Organisation
THz	Terahertz
UN	United Nations
VR	Virtual Reality
XR	Extended Reality

REFERENCES

[1] NGMN, 6G Drivers and Vision, April 2021, https://www.ngmn.org/wp-content/uploads/NGMN-6G-Drivers-and-Vision-V1.0_final.pdf

[2] Finnish 6G Flagship, White Paper on 6G Drivers and the UN SDGs, April 2020

[3] W. Saad, M. Bennis, and M. Chen, A Vision of 6G Wireless Systems: Applications, Trends, Technologies, and Open Research Problems, IEEE Network, May/June 2020

[4] Samsung, The Next Hyper Connected Experience for All, July 2020

[5] G. Liu et al., Vision and requirements of mobile network beyond 2030, China Communications, September 2020

[6] Ericsson, Ever-present intelligent communication, November 2020

[7] University of Surrey, 6G Wireless: A New Strategic Vision, November 2020

[8] 5G Forum, 6G Vision Ver. 1.0, November 2020

[9] Hexa-X, 6G Vision, Use Cases and Key Societal Values, February 2021

[10] Wen Tong and Peiying Zhu (Eds.), 6G: The Next Horizon: From Connected People and Things to Connected Intelligence, Cambridge University Press, June 2021

[11] IMT-2030 (6G) Promotion Group, 6G Vision and Candidate Technologies, June 2021

[12] 6G IA, European Vision for the 6G Network Ecosystem, June 2021

[13] D. Soldani, 6G Fundamentals: Vision and Enabling Technologies, Journal of Telecommunications and the Digital Economy, September 2021

[14] KDDI, Beyond 5G/6G Ver. 2.0, October 2021

[15] NTT DoCoMo, 5G Evolution and 6G Ver. 4.0, January 2022

APPENDIX A

The following table shows the template for use case contribution.

CHARACTERIZATION	DESCRIPTION FOR GUIDANCE
Synopsis	Provides a name, overview of the use case, and purpose.
Alignment with NGMN Drivers	In the NGMN 6G Drivers & Vision (April 2021) the motivation and drivers for 6G is defined. The use case will be described in terms of its alignment with drivers.
High level requirements and Spectrum	This should introduce the broad requirements, whether it will be delivered over mobile networks or fixed, and whether new spectrum bands would be needed. Formal KPI's are not sought at this stage.
Environmental impact including energy consumption	At this early research stage detailed breakdown is not sought, but consideration should be given to key issues such as expectations related to energy consumption, embedded energy, visual impact, and life-cycle management. Use cases that lead to reduction in projected energy consumption to be described.
Technology needs relative to 5G	5G deployments and business cases will mature and evolve through this decade with further enhancements in subsequent 3GPP releases and by other organisations. If a use case identifies a new technology capability that is not supported in the envisaged release cycle then this should be highlighted.
Impact on deployed 5G networks	This should describe what changes are proposed to 5G networks that are deployed towards the end of the decade. Will the use case be supported with expected evolution of 5G, and if not what is the likely impact on the wide area mobile networks?
Feasibility	It is possible that a use case will not be relevant over wide-area mobile networks because it would be either unaffordable to deliver or constrained by resource such as radiated power and spectrum bandwidth. The use case should identify such constraints such that its opportunity and positioning is identified.
Industry growth opportunity	Guidance is sought on whether opportunity is wide-ranging across all stakeholders or if it is relatively niche.
Disruptive impact	Guidance is sought on whether it would lead to a step-change in technology such as that from 3G to 4G or whether it is more iterative and builds upon 5G networks.

APPENDIX B

The following table shows the contributed use cases, and their mappings to class (Enhanced **H**uman Communications, Enhanced **M**achine Type Communications; Enabling **S**ervice Communications; **N**etwork Evolution) as well as the generic use cases.

CONTRIBUTED USE CASE	CLASS	GENERIC USE CASE
Enhanced human-centric communication	H	
360 degree full-view extremely immersive XR	H	
Glass-free 3D and holographic display integrated with XR	H	
Immersive Society – Native Volumetric Capturing and Holographic/AR Projection in 6G	H	
Immersive XR & Holographic Interaction	H	XR immersive holographic telepresence communication
Merged Reality Telepresence	H	
Massive multisensory merged reality	H	
Interactive haptic & multi-sensory comm. for teleoperation	H	
Mixed reality co-design	H	
Internet of Skills – Native Support of 6G, AI and Robotics	H	
Human well-being – Sharing of sensation, emotion, & mood	H	Multimodal communication for teleoperation
6Senses- Elite athletes training	H	
6Senses- Personal Exclusion Zone	H	
Human well-being – Transcendence of time and space	H	Intelligent interaction: Sharing of sensations, skills & thoughts
Intelligent Interaction	H	
Interacting/navigating robots	M	Robot network fabric
Unmanned Aircraft System Traffic Management	M	
COBOT / Collaborative Robots	M	Interacting cobots
Machine-Driven Micro-Services Enabling Service Provisioning to Non-Human End-Users	M	

CONTRIBUTED USE CASE	CLASS	GENERIC USE CASE
3D Hyper Accurate Positioning	S	3D hyper accurate positioning, localisation, and tracking
Ultra-high accuracy positioning, localisation, and tracking	S	
Simult. imaging, mapping, localisation, & creation of 4D map	S	Interactive mapping
Gesture and activity recognition	S	
Interactive 4D map	S	
High resolution mapping: digital twins and virtual worlds	S	
Trusted sub-networks and In-X: In-body networks	S	Digital healthcare
Precision healthcare	S	
Augmented human sense	S	
Human Digital Twin	S	
Gesture & activity recognition, augmented human sense	S	Automatic security, protection, and inspection
Automatic security	S	
Sub-ms level Motion Control	S	Smart industry (to be further outlined including teleoperation)
Smart Industry	S	
Wide area deterministic communication	S	
Plug & Play compute resource (for media/ broadcasting)	S	
Physical internet of tags	S	
Traveller's Help – Instant Translation	S	
Transportation support	S	
Supper Transportation	S	
Trusted Composition of Services	S	Trusted Composition of Services
Network for AI / AI as a Service	N	AI as a service for learning and management
AI as a service for distributed learning and inferencing	N	

CONTRIBUTED USE CASE	CLASS	GENERIC USE CASE
AI communication	N	
AI as a Service for network OAM	N	
AI as a Service for data management	N	
Dynamic Edge Computing Scaling	N	
Coverage expansion	N	Coverage expansion
Mobile broadband for trips on aero planes or ships	N	
Autonomous system for energy optimization	N	Energy Efficiency

APPENDIX C

The following table is a list of generic use case analysis.

CLASS	USE CASE	CONTEXT	6G IMPLICATION	
			DELIVERABILITY	DIFFERENTIATION TO 5G
H	XR Telepresence	Services are aligned with new devices/HMI technology, and sensing technologies.	Early XR capabilities can be delivered over 5G and fixed networks. The more demanding applications foresee new HMI, devices, sensing, and compute capabilities.	The highest data rates would require the bandwidth associated with higher frequency bands, and a new air interface, for localised coverage and short-range communications.
	Multimodal Teleoperation	Aligned with the ability to deliver information related to human senses, necessitating intelligent transfer and prediction of sensory and/or ambient information. Extensions include operation of machines or robots at a distance.	Dependent on the ability to capture sensory information. Industrial and mobile private networks may be necessary to support dedicated industrial use cases.	New requirements may emerge related service delivery to multiple devices and need for to synchronized multi-modal communication and control.

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	Sensory Interaction	Extension of multimodal tele-operation but extended to include brain-machine interfaces and deep ML/AI.	Dependent on breakthrough technologies and social acceptance.	Fundamental changes in how networks are perceived. Transition from a communication media towards networks that predict, anticipate, and support human activity.
M	Robot Network Fabric	Enables robots to coordinate mobility by using sensing and mapping data, improve traffic flow for vehicles.	Peer-to-peer communication and protocols required for vehicles, possibly extending V2X type capabilities.	Enabled by joint sensing and communications that improves resolution and high-speed communications.
	Interactive Cobots	Close coupling between humans and machines.	Peer-to-peer communications with extensions enabling robots to generate their own collaboration service.	Enabled by the use of volatile services, initiated and managed by robots through on-demand service.
S	3D Positioning localisation and tracking	Accurate 3D positioning, localisation and tracking for logistics or drone control	High accuracy positioning requires visibility to multiple radio link (beacons) in the local environment, otherwise integration of satellite based GNSS services with accuracy enhancements is used. Radio sensing is being explored for localisation and tracking.	Integration of radio beacons that support localised high accuracy positioning, possibly as part of communication infrastructure. Combined sensing and communications is a new concept relative to 5G.

Interactive Mapping	Combine sensing from network assets and terminals, to support real time mapping.	High frequency (THz) bands required for resolution but range is limited. Terminal sensing requires very accurate positioning in order to combine data from different sources.	Combined Sensing and Communications is a new concept relative to 5G.
Health	Integration of body-sensor to provide enriched health information.	Body-area-networks must be very low power, and interwork with a gateway to transport information to health centre.	Advances in body sensors and short range radio interfaces to transfer information.
Control & Protection	Use of environmental sensing to support safety and industrial processes.	Dependent on high frequency (THz) bands required for resolution, supported by dedicated terminal.	Combined Sensing & Communications is a new concept relative to 5G
Smart Industry	Combination of features such as real-time mapping, mixed reality co-design, image recognition, and asset tracking.	Includes additional technology features for bespoke applications.	Extend and expand 5G capabilities beyond production process.
AIaaS	Network with AI plane/layer to expose and serve distributed AI learning and inference, to provide native AI services where needed.	Integration of sensing, communication, learning, and computing.	Change from session-oriented communication to AI task- oriented communication is potentially a new concept.

N	Coverage	Extending coverage, including HAPS and satellite.	Integration of non-terrestrial platforms, and convergence of different connectivity platforms.	Integration of non-terrestrial platforms, and convergence of different connectivity platforms.
	Energy Efficiency	Usage of AI/ML to optimise utilisation of network elements.	Extension of O&M functionality to incorporate learning.	Extension of O&M functionality to incorporate learning.

APPENDIX D

The following table is a list of proposed technology components, structured by Network, Device, or Service for each of the Generic Use Case Groups.

ENHANCED HUMAN COMMUNICATION	ENHANCED MACHINE COMMUNICATION	ENABLING SERVICES	NETWORK EVOLUTION
Network	**Network**	**Network**	**Network**
Mix of low, mid and high frequency bands	Mix of low, mid and high frequency bands	High frequency bands such as mmWave and higher spectrum up to Terahertz band for high accuracy and high-resolution RF sensing, localisation and imaging	Combination of low/mid/high frequency bands for both large coverage of distributed learning/inference, and large data/model/parameters/decision exchange in real-time
Spectrum efficiency improvement low and mid band	High bands for local coverage and sensing	Native and trustworthy AI	Agnostic to licensed or unlicensed spectrum
THz for local coverage	Multi-path connectivity and data channels	Integrated sensing and communication	Distributed machine learning, e.g. federated learning, split learning
Enhanced sidelink	Wide-area network sensing	Collaborative sensing	Data management
Densification and small cells	Ultra-reliable and ultra-precise	Joint passive and active localisation	Semantic communication
Specialized and local networks	E2E latency	New waveform, new hardware architecture	Deep edge architecture
Synchronised multimodal comm. & control			

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ENHANCED HUMAN COMMUNICATION	ENHANCED MACHINE COMMUNICATION	ENABLING SERVICES	NETWORK EVOLUTION
Bidirectional extreme low latency and extreme high reliability needed		Joint signal processing algorithms Dynamic edge computing Wide-area service availability and resilience Multi-path connectivity and data channels Wide-area network sensing Privacy preserving technologies (such as homomorphic encryption, confidential compute, data self-governance, multi-party compute and federated learning) Native network security Visible light communication	Convergence of computing and communication Joint resource distribution and management Network sensing as data source Low latency and massive capacity uplink access Low latency inference Low overhead learning Energy efficient large-scale AI Fast convergence of learning Low training loss Consistency/Reliability/in AI generalisation Scalability in architecture

ENHANCED HUMAN COMMUNICATION	ENHANCED MACHINE COMMUNICATION	ENABLING SERVICES	NETWORK EVOLUTION
			Agnostic to licensed or unlicensed spectrum Distributed machine learning, e.g. federated learning, split learning Data management
Device Novel HMI New devices and form factors Network and device as a sensor Volumetric codecs, RT rendering	**Device** Sensor data sharing Mapping service Management of robot trajectories	**Device** Low cost, maintenance free devices/stickers Embedded zero-energy devices	
Service Spatial mapping and geofencing Stream & service-based architecture	**Service** Trustworthy AI Intent interpretation	**Service** Digital twin Mapping service	

ENHANCED HUMAN COMMUNICATION	ENHANCED MACHINE COMMUNICATION	ENABLING SERVICES	NETWORK EVOLUTION
Local compute Intelligent interaction, sensing and prediction co-design E2e scaling of resource incl transport AI/ML-based services for sensing, communication, and feedback accessible at network edge AI/ML-based services including UE, 5GC, RAN & AF for sensing, communication, and feedback accessible at network edge	Robot-defined communication services Sensing surroundings Application-network interaction Flexible service definition with dynamic requirements	Intelligent real-time analysis Mixed reality co-design system and haptic communication Cobot/robot/avatar backed by trusted data platform and AI Advanced people/device traffic flow management Holistic support to the entire business process in a closed loop	