NEXT G ALLIANCE

An ATIS Initiative

EVERYDAY LIVING

EXPERIENCE

CRITICAL ROLES

SOCIETAL GOALS

6G

Next G Alliance Report: **6G Applications and Use Cases**

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1 SCOPE

The Next G Alliance is identifying the drivers of the future applications that have the potential to influence development of next-generation mobile communication technologies. It does this by gathering applicable information, reviewing trends, and assessing the evolution of applications and use cases. Main drivers are classified into the Next G Alliance's four foundational areas of use cases (Everyday Living, Experience, Critical Roles, and Societal Goals), with the goal of better understanding how next-generation technology and its ecosystem can help improve the way humans live and interact.

Complementing the audacious goals, the Next G Alliance has set, the *Next G Alliance Report: 6G Applications and Use Cases* includes four categories of use cases: Network-Enabled Robotics and Autonomous Systems, Multi-sensory Extended Reality, Distributed Sensing and Communications, and Personalized User Experiences. The report also includes high-level functional and performance requirements based on both audacious (new and challenging) and obvious (slightly enhanced) characteristics developed by the Applications Working Group.

By taking a proactive view of 6G applications and their potential, the Next G Alliance is developing the North American perspective on what is required to fuel the success of a host of applications yet to be imagined. The goal is to foster innovation so that emerging applications can help drive evolution of the 6G network.

2 GENERAL

2.1 Industry Trends and Market Expectations

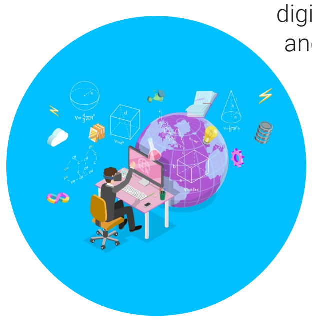
6G applications are expected to expand North American markets and affect virtually all aspects of life, society, and industries, further changing the way people live and work. The new types of applications that will be enabled as a result can be characterized as follows:

> **Everyday Living:** 6G applications will help improve the quality of ordinary daily living. For example, service robots may provide health care, caregiving, indoor/local delivery services, and intelligent travel assistance.

With the enhanced capability of pervasive sensors and intelligent network fabric, humans as end users of 6G services are expected to reap the benefit of improved quality of ordinary living in their residential environments or while they are travelling, through ambient intelligence.

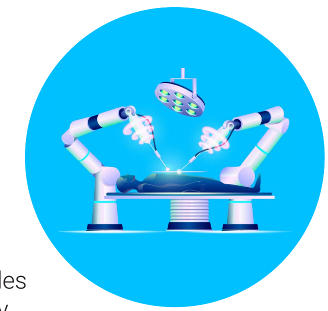
It is envisioned that the workforce necessary to support ordinary daily living in society would grow more prominent in accordance with the global trend of an aging population. According to "World Population Ageing"[1], published by the United Nations, old-age dependency ratios were highest in Europe and North America, with 30 older persons (aged 65 or older) per 100 persons of working age (aged 20 to 64) followed by Australia and New Zealand, with 27 older persons per 100 persons of working age. This ratio is projected to rise considerably, reaching 49 older persons per 100 persons of working age in Europe and North America in 2050. This observation highlights the growing need for intelligent assistance for humans as end users who receive these types of services (e.g., caregiving, delivery assistance, and travel assistance)[2], which is considered a great market potential and business opportunity.

> **Experience:** Customer experiences and interfaces with technology will be improved by dynamic and expanded 6G applications. Enhancements are expected to expand human interaction with devices, from voice assistants to service robots, and systems to provide enriched immersive virtual/augmented/mixed reality (VR/AR/MR) experiences.



Applications here target services in the field of MR entertainment, human-machine interactions, health care (physical and psychological) assistance, real-time interactive gaming with physical interactions, classrooms powered with MR content, and robotics and XR-enriched Simultaneous Localization and Mapping (SLAM)-based applications such as in the transportation field.

> **Critical roles:** 6G technology advances will enable applications to deliver improvements to critical functions within fields such as health care, manufacturing, agriculture, transportation, and public safety.



Applications addressing critical roles are intended to advance the quality of technology in and around health care, manufacturing, agriculture, and public safety with the use of robotics. Autonomous robots, powered by 6G technology, networks, and applications, are envisioned to naturally interact with humans to enhance productivity and maintain essential operations. These applications may use digital twins, where humans interact naturally with robots in the digital space to implement actions or tasks in the physical world. Example applications include remote surgery, therapy, and monitoring.

> **Societal goals:** 6G applications will facilitate the achievement of high-level societal goals and increase public safety. The 2030 Agenda for Sustainable Development lays out 17 goals that the United Nations hopes to accomplish throughout the world by 2030[3]. These goals reach broadly and address dimensions of societal, environmental, and economic issues. In looking at these crucial sustainable development goals, a key value that 6G can offer society and the economy is in the applications and services that can be enabled. For instance, 6G-enabled applications can assist in achieving high-level societal goals such as digital equity (e.g., cost efficiency, affordability, access, and societal sustainability).

Per the National Digital Inclusion Alliance, digital equity is a condition in which all individuals and communities have the information technology capacity needed for full participation in our society, democracy, and economy. Digital equity is necessary for civic and cultural participation,

employment, lifelong learning, and access to essential services[4]. While great strides are currently being made to address digital equity and social sustainability, 6G applications are expected to enable greater awareness and collaboration while extending services to remote areas or digitally isolated members of the population.

Societal sustainability is a fundamental objective for 6G and will be considered in network design to reduce CO_2 emissions and improve energy efficiency. Elements like ultra-long-life batteries, zero data-zero energy devices, and self-powered sensors are a few examples of technologies that will help achieve some of the sustainability objectives.

2.2 Support of Existing Applications, Services, and Capabilities

As North America transitions from 5G to 6G networks, it is expected that many, if not all, existing 5G customer-facing applications, services, and capabilities will be supported. These include voice, messaging, and multimedia services. Some may require backward compatibility or interoperability. Some may require modifications or expansions of existing capabilities. Others may be able to be delivered via completely new technical solutions.

One lesson learned from previous generations is that these transitions must be identified and planned during the development of the "next" generation to ensure that technical solutions are well integrated and can be realized at the launch of the new networks.

It is imperative that all national and regional regulatory requirements be supported at the launch of the next generation of mobile networks.

Requirements
The following is a list of initial requirements to support existing applications, services, and capabilities.

> **Native voice services shall be available at the launch of 6G networks.** Voice communication is still used in 5G, and it is reasonable to expect that this will continue in 6G. Voice is a basic form of human interaction because it can communicate emotions and personality in addition to data and information. Emergency services (e.g., 911 and E911 calling) still require support for voice communications. Mobile voice services are by nature real-time critical services. Voice services are unlike other mobile services that use caching or buffering to mask delays. The slightest delay or interruptions will be noticed and will cause annoyance. Enabling seamless and high-quality voice calls across multiple generations of radio access technologies requires intricate network design and must be part of 6G fundamental requirements.

> **Interworking/handoff with 5G voice services shall be supported.** 6G networks will co-exist with 5G networks for a long time. Interworking and seamless integration with 5G systems provide continuity and a smooth transition to 6G.

> **Messaging service(s) shall be available at the launch of 6G networks.** Messaging services have become integral to everyday life, from social interactions to business applications. While the technical implementation of messaging service(s) is irrelevant to the consumer, support for interoperable message services is needed. Mobile operators are leveraging new technologies to transform the voice and messaging business to become relevant in the enterprise market. It is imperative that this trend continues with 6G.

> **All national/regional regulatory requirements shall be met at the launch of 6G networks.** As 5G services evolve to 6G, and with the introduction of new 6G services, diligence is required to ensure national and regional regulatory requirements can be satisfied. During 5G's launch, it was discovered that aviation navigation systems are susceptible to interference from 5G in adjacent spectrum, which caused delays in deployment of 5G networks near airports. For example, if robots or in-body networks are used for health care, privacy and laws addressing the protection of health information must be addressed. National security and customer/public safety should be addressed at the launch of 6G.

> **Customer security and privacy shall be designed into all applications, services, and capabilities.** One of the audacious goals identified by the Next G Alliance is "Trust, Security, and Resilience." This requirement emphasizes how security by design is a foundation to 6G and not an afterthought.

2.3 Overview

The rest of this report is organized as follows. Sections 3 through 6 propose four key categories of use cases.

Section 3, "Network Enabled Robotics and Autonomous Systems," addresses aspects including how network-enabled robotics and autonomous systems might influence the quality of living and working, such as in assisted-living and health care environments. Examples include online cooperative operation among a group of service robots, and field robots for hazardous environments.

Section 4 "Multi-Sensory Extended Reality," addresses how multi-sensory extended reality might influence the quality of experience in truly immersive and highly interactive operating environments for on-line sports and gaming, coordination of remote team operations and interactive classrooms. Examples include ultra-realistic interactive sport, immersive gaming/entertainment, MR co-design, MR telepresence, immersive education, and high-speed wireless connection in aerial vehicles for entertainment and service.

Section 5, “Distributed Sensing and Communications,” addresses how terrestrial and non-terrestrial connectivity services might facilitate the future state of the world with ubiquitous connectivity in various markets such as health care, agricultural, environmental, and public safety markets. Examples include remote data collection, untethered wearables and implants, eliminating the North American digital divide, public safety applications, synchronous data channels, and in-body networks for health care.

Section 6, “Personalized User Experiences,” addresses how personalized user experiences might influence the quality of living that especially requires an improved level of user identities, preferences, and situational context. Exemplary use cases include personalized leisure and travel experiences, personalized shopping experiences, personalized learning, and education experiences.

Section 7 proposes the initial set of characteristics that are considered relevant to develop detailed functional and performance requirements, as well as technology enablers aligned with the audacious goals that Next G Alliance has published.

3 NETWORKED-ENABLED ROBOTIC AND AUTONOMOUS SYSTEMS

These systems can perceive their surroundings using sensors such as GPS, light detection and ranging, sonar, radar, camera, and odometry. These capabilities enable robotic and autonomous systems to interact with humans in natural ways and to make decisions necessary to assist or support a set of tasks utilizing communication services.

3.1 Use Case – Online Cooperative Operation among a Group of Service Robots

Recent advancement of wireless communication technology, and potentially newer capabilities of aerial 3D networks, specifically for robotic applications, may greatly enhance industrial automation and vastly improve everyday life. 5G communication technology (e.g., TSN and NPN) has built up a basic foundation for the evolution in industry automation. However, everyday living could be enhanced by robotic applications, so-called service robots with ambient intelligence, for humans in unstructured settings.

3.1.1 Description

In a group-operation model, multiple service robots work together for certain tasks, often referred to as a multi-agent scenario/model. There are two modes of operations:

1. **Competitive Mode:** Each service robot in the group should go for a game-theoretic decision-making process (typically zero-sum game) when some service robots cannot share the necessary information in time and must operate with limited information. This happens when the communication condition is not good enough.
2. **Cooperative Mode:** When the communication channel/link condition is good enough (not only at a certain epoch but continuously during their operation), the group of service group robots can share necessary information fully. As a result, they could better coordinate strategy planning and be more productive or efficient than the competitive mode of operation.

This use case presents a few examples of certain types of collaboration among multiple service robots (SOBOTs), with the focus on what is required and what can be further studied.

3.1.2 Business Opportunity and Mapping to 6G Audacious Goals

Over the past several years, studying networked robotics has grown in both popularity and importance due to its various services using connectivity, remote or local, and to and from robots. Networked robotics is critically important for Industry 4.0 and beyond, providing an additional layer of benefits for enterprises and related industry. It also is necessary for some critical factors that our daily living environments have already begun to face. The following is a list of societal implications of networked robotics.

- **Productivity of manufacturing and logistics:** Industrial robots in manufacturing and logistics environments are getting more intelligent and more capable of tasks that require a higher level of efficiency and performance. Examples include clock synchronization, ultra-low latency, communication service availability, positioning accuracy, and high data rates.

> **Imbalance of resource allocations:** Many resources, including human workforces and network resources, are scarce at times, although one can perform the optimal scheduling for a given decision-making problem. Health care delivery is one of the most common examples that has critical issues regarding the imbalance of resource allocations. Remote or local medical robotics service is a typical example of using networked robots to improve the quality of health care delivery, such as in emergency or urgent cases with limited availability of medical personnel and resources where a patient is located[5].

> **Population aging:** Old-age dependency ratio (OADR) is defined as the population aged 65 years or over divided by the population aged from 20 to 64 years, which is often used as a proxy for the social and economic dependency of the older population[6].

Mapping to 6G Audacious Goals

Goals	Remarks
Trust, Security, and Resilience	Required for Service Robots (SOBOTs) that are used for personal care purposes (e.g., ambient-assisted living, continuing care retirement community), for healthcare purposes (surgeon robots, sensor and actuators for on-body or in-body network scenarios), for critical roles (search and rescue scenario, indoor and local outdoor delivery scenario), and so on.
Digital World Experience	SOBOTs that are equipped with multi-sensory interaction capabilities with humans are expected to provide multi-sensory capability-based experience to the givers (e.g., remote caregivers, remote healthcare provider, rescue robot, travelling family member), the receivers (e.g., patients, rescue officer, in-home family member or pet animal) or both.
AI-Native Network	SOBOTs that stays with or in the proximity of humans are expected to require network resources to play their committed roles efficiently and reliably: intelligent and light-weight efficient optimization for network resource utilization and network path and topology scheduling and maintenance.

3.1.3 Example Service Scenario

Types of network coverage: in-coverage, partial coverage, and out-of-coverage.

Pre-condition: a group of service robots capable of surface sensing has established a group-based operation.

Scenario 1: Uu-based operation. A group of robots perform surface sensing individually, with possible collaboration for request-and-response, in a particular area of interest. Each participating member robot delivers the collected data (raw or processed) to the associated online 3D map builder module (OMM).

NOTE 1: OMM is typically a server in the cloud.

Scenario 2: SL-based operation. A group of robots perform surface sensing individually, but one member robot acts as a leader (say "leader robot") that collects data from other participating member robots, with possible collaboration for request-and-response, and in a particular area of interest.

NOTE 2: OMM is in the leader robot.

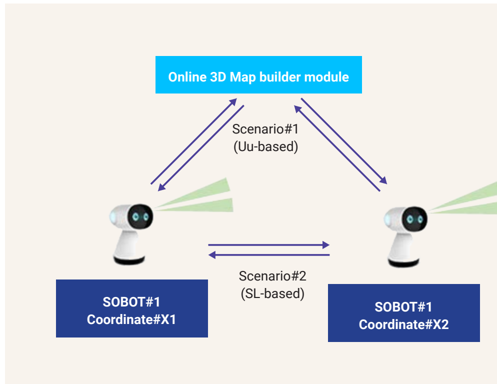


Figure 3.1-1: Online collaborative 3D map building scenarios: Uu-based and SL-based

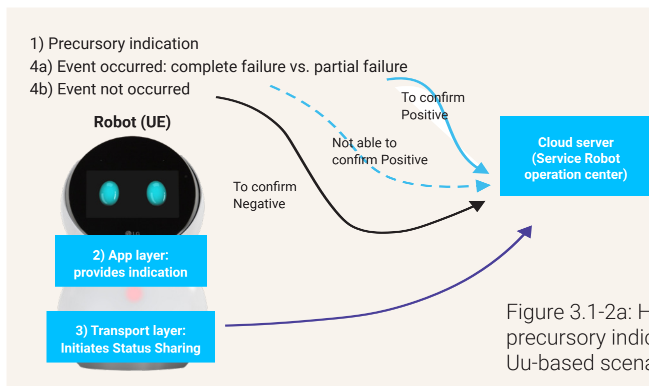


Figure 3.1-2a: Handling of precursory indication in Uu-based scenario

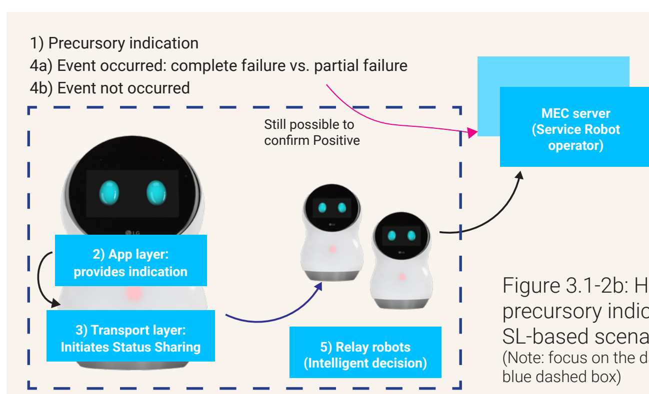


Figure 3.1-2b: Handling of precursory indication in SL-based scenario
(Note: focus on the dark blue dashed box)

3.1.4 Requirements

Online cooperative 3D map building (basic application cases): 6G systems shall be able to provide a means to ensure a very high level of clock synchronization accuracy on application-layer data (e.g., measurement data) that a group of SOBOTs build up collaboratively (e.g., synchronization among SOBOTs within a collaborating group and synchronization among the multiple sources related to the respective SOBOTs) in which the applications layer requires the accuracy level.

6G systems shall be able to provide a means to detect anomaly (e.g., combined with noise factors or compromised by malfunctioning or malicious attacks) on the integrity and validity of clock synchronization source information in a timely manner in which the timeliness is required by the applications layer.

6G systems shall be able to provide a means to share the accuracy level and integrity-related info of clock synchronization with the cloud (in the Uu-based scenario) or with the leader robot (in the SL-based scenario).

6G systems shall be able to provide a means to re-establish the connection when an ongoing connection is disrupted (e.g., due to radio link failure between a robot and the communicating counterpart) within a very short period of time, as required by the applications layer.

General cases: Network exposure function shall be provided to efficiently support application enablement.

A sufficient level of security and privacy protection shall be ensured by the communication system.

3.1.5 Study Areas

Two modes of operations in a group of service robots are competitive versus cooperative.

The system model considered in this document is as follows. In the system, there are multiple SOBOTs (which are UEs) that are looking for a gNB (or an MBSR) to initiate a connection with. This initiation can be the start of a new session or the initiation of a handover request to that targeted gNB. Also, in the system there are multiple gNBs for those UEs to attempt to initiate a session with, as depicted in Figure 3.1-3.

Issue: How to form a stable matching of robots to establish a stable group of robots, and what requirements are expected to be necessary?

- Drawback: (delay and computational burden until an attempt is accepted by a candidate "mate").
  - Despite the simplicity of obtaining the optimal solution for matching problem (or assignment problem), a SOBOT is exposed to the possibility that it has to solve another problem in order to select the next best gNB if the current best gNB cannot accommodate the initiation request from this SOBOT due to some reasons. For example, this gNB is overloaded or this SOBOT is not sufficiently qualified or eligible to use particular radio resources (or network slices) under the given condition at that moment in time.
  - Even in an NPN setting where a SOBOT can see multiple options when selecting a cell, if the cell selection is performed by the cell in a unilateral way, the decision is not necessarily guarantee to be "stable."

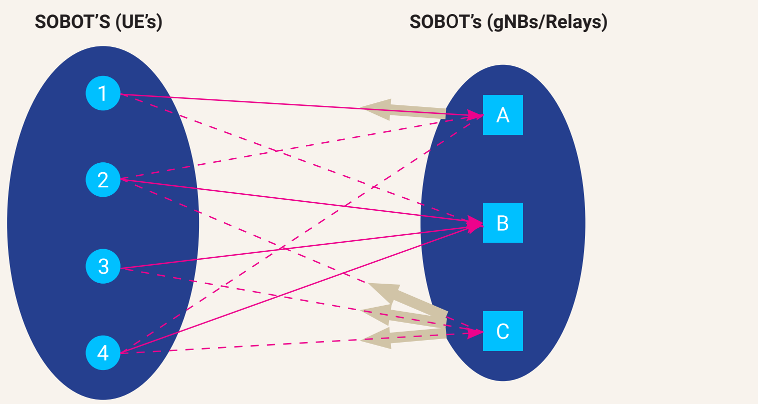


Figure 3.1-3:
A simple example of stable matching

In the stable matching example illustrated in Figure 5.1-3, the arrow from a UE to a RAN node means that this particular UE intends to attempt to access the indicated RAN node (e.g., MBSR, eNB, or gNB). The solid arrow for each UE means the most preferred RAN node by that UE; namely, each UE is most likely to attempt to access that RAN node instead of other RAN nodes that this UE has a dotted arrow(s) to.

3.2 Use Case – Field Robots for Hazardous Environments

3.2.1 Description

Field robots are a revolutionary way to perform inspections or maintenance in remote or hard-to-access locations in a workplace. Furthermore, they can be deployed to perform tasks that are either too dangerous or too laborious for human workers. The field robot accuracy and reliability also make them a top choice to perform mission-critical tasks.

In today's smart factories, inspection and maintenance of critical assets are typically done manually with electronic equipment connected to the network. However, for places like petrochemical plants, where flammable gases or vapors may exist, network and electricity uses are restricted due to plant safety and accident prevention. In such hazardous workplaces, critical assets maintenance would be better done by visual inspections through field robots. The trend is to have humans paired with robots through 5G-powered MR glasses to detect faulty assets by video streaming with 8K resolution.

In 6G, the AI-native communication fabric will have the power to instigate a paradigm shift in this field. 5G allows for real-time haptic feedback (e.g., sense of touch) from the robots and makes it possible to control field robots reliably for tele-operation from greater distances. The stringent monitoring methods on autonomous robotics require 3CLS services (Convergences of Communications, Computing, Control, Localization, and Sensing), with extremely high reliability, low delay and latency, and security control. The performance of tele-operated robots will certainly improve with 6G.

3.2.2 Business Opportunity and Mapping to 6G Audacious Goals

Mobile inspection and maintenance robotics is a fast-growing industrial market. One of the main advantages of mobile robots is that they can reach locations inaccessible by humans because of size constraints, temperature, immersion in liquids, or other safety reasons.

According to a report by Grand View Research[7], the market size of the tele-operated inspection and maintenance robots and other field service robots was valued at USD 12.3 billion in 2019 and are expected to grow from 2020 to 2027 with a CAGR of 41,0%. The increase in recent years is due to compelling growth in the oil and gas industry. It is expected that there will be high demand for inspection robots like remotely operated vehicles (ROVs) to monitor underwater assets such as pipeline, foundations, and water intakes.

Mapping to 6G Audacious Goals

This use case can be mapped into the 6G audacious goals as shown in the following table:

Goals	Remarks
AI-Native Network	Orchestrate communications-computing-control-localization-sensing resources to achieve a reliable and responsive control system, specifically, on: (i) Network compute fabrics (ii) Internet of senses and (iii) Precise localization.
Trust, Security, and Resilience	Utilize acquired AI outcomes to enhance the decision-making process to build trust among users.

3.2.3 Example Services Scenario

The tele-operated field robots will be operated in various environments, typically in harsh, toxic, hard-to-reach, underwater, or afar locations. Some examples can be found in:

- **Oil and gas industry**: Hazardous locations such as those with pressurized combustible material, enclosed spaces, or exposing people to high or low temperatures.
- **Electric power grid**: Inspection of high-voltage equipment.
- **Offshore wind turbines**: Inspection and repair of turbine blades.
- **Manufacturing facility offshore or faraway**: To support the offshore drilling rig inspection and maintenance workers who spend weeks away from home.
- **Nuclear decommissioning**: Handle radiation and contamination hazards.
- **Environmental exploration**: Deep base metal mines or underground tunnel exploration. Also, cave exploration for search and rescue.

There are many ways to equip the field robots, but the camera and the means to monitor the operational environment are crucial to support the field robots.

Cameras	360-degree, pan-tilt-zoom (PTZ), stereo, RGB-D, infrared illumination, depth
Environmental monitoring	Sensors for temperature, humidity, gas leakage such as methane, vibration, and sound (microphone).

Table 3.2-1: Supportive application-specific sensors for field robots

In order to act responsibly by taking timely actions and maintain reliable operation for remote-control field robots in hazardous workplaces, three features need to be incorporated in the control loop of the tele-operated field robots:

1. Real-time edge AI/ML computer vision.
2. Real-time field robots' calibration to restore perception accuracy.
3. Real-time field robots logging analysis to trace and track unsafe issues.

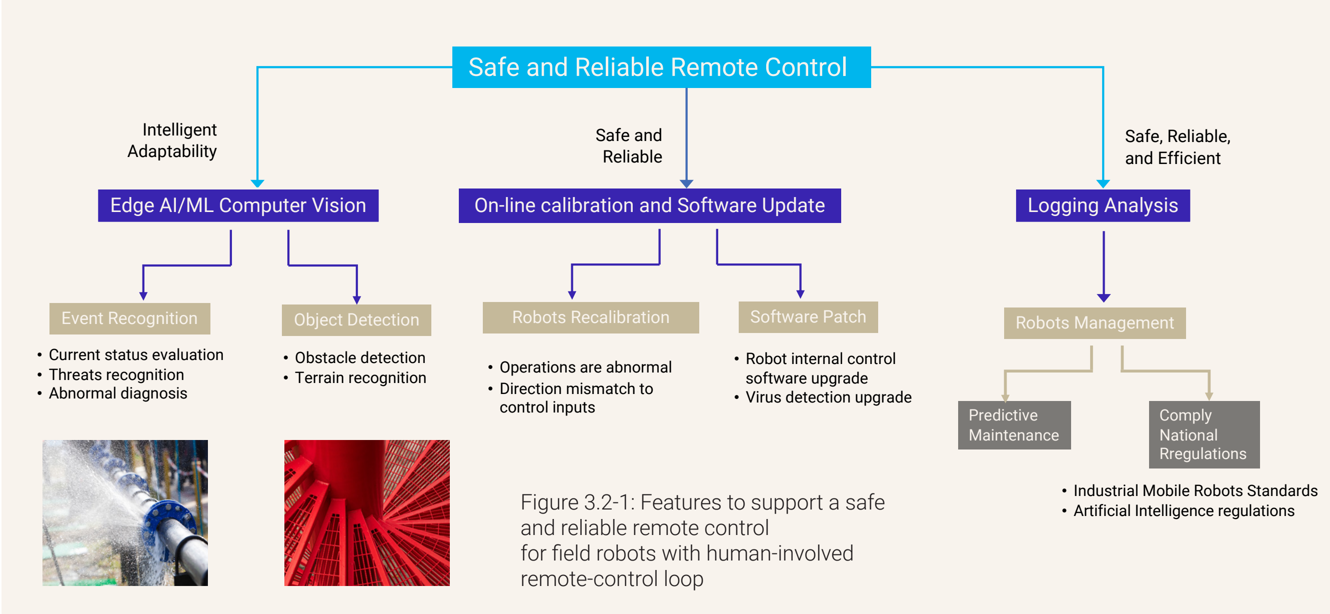


Figure 3.2-1: Features to support a safe and reliable remote control for field robots with human-involved remote-control loop

As shown in Figure 3.2-1, these features and the functions supporting them form the core to enable a safe and reliable control system for tele-operated robots.

From a tele-operations' perspective, there are three scenarios that need to be addressed and the requirements can be assessed according to these scenarios:

1. Real-time operation with single robot paired with an operator.
2. Real-time operation with multiple robots teamed with an operator.
3. Autonomous robots including in disaster relief conditions (public safety).

3.2.4 Requirements

The key requirement characteristics for this use case are latency, communication service availability of 6G network with adequate support for live images transmission, and high positioning accuracy. Access security is also an important requirement to ensure that only authorized parties can control tele-operation.

> **Latency**: 6G systems shall provide ultra-low latency that is suitable to support reliable tele-operation of robots. Very-low E2E packet latency enables the remote operator to interact in real time with fast-moving objects, allowing the robot to be controlled appropriately and intuitively.

> **Communication Service Availability**: One of the key challenges to tele-operate field robots is maintaining a safe and reliable control operation, which requires a very high communication service availability. Dynamic connectivity for a versatile network will be needed to overcome environment changes (e.g., smoke, fire, electrical sparks, water, collapsed metal).

> **Data Rate**: Support of transmission of high-definition pictures or films (refresh rate may vary).

> **Position Accuracy and Object-Sensing Accuracy**: Projected to reach centimeter levels with robotic online calibration capability. Furthermore, terrain navigation and position update assisted by the "network sensing in the network" capabilities.

> **Coordination Among Robots**: In scenario 2, a secure and trusted network is required to share information such as distributed decision-making logic and the data gathering among robot sensing devices. Another application is the semi-autonomous control that manages different robots to undertake coordinated activities.

> **Autonomous of Robots**: The autonomous robotic system without human remote control requires extremely high levels of localization and mapping, AI-assisted decision-making, and robotic functional capabilities. The 6G network with intelligent resource management capabilities from contextual awareness offers optimized processing, transmission, and storage resources based on the necessity of AI vision, OTA software upgradability, and self-calibration should be considered.

3.2.5 Study Areas

The recommended related study areas to enhance the field robotics are:

> Digital twins
> Mobile robots
> Tactile internet; 6G and beyond 5G
> Intelligent resource management
> Simultaneous localization and mapping (SLAM)
> Robot sensing systems; sensing in network
> Human computer interaction
> Edge and cloud-based operations
> Intelligent systems

4 MULTI-SENSORY EXTENDED REALITY

Multi-sensory XR is the umbrella term for the collection of immersive technologies that include AR and VR.

4.1 Use Case – Ultra-Realistic Interactive Sport – Drone Racing

4.1.1 Description

Ever since the first World Drone Prix held in Dubai in 2016, drone racing has established its position in the global interactive sport world. Drone racing, using the 5G wireless system as the carrier today, creates an interactive racing experience for the players. In 6G, the cyber-real racing environment will provide more than 2x16K resolution images through a 360-degree spherical display. The Motion to Photon (MTP) latency will be less than 20 ms to satisfy the human body's natural somatosensory and smooth cognition requirement. All of this will create a multi-person, ultra-realistic, interactive sport experience.

The essence of drone racing is the image quality, both the resolution and the latency, which depends heavily on the network capability. The pilot is flying the drones visually, so the use case relies on the network to provide adequate live images in a timely manner. It started by streaming the video through a point-to-point analogue radio or through 4G/Wi-Fi networks. The limited transfer data rate and jitter/latency in these networks could limit the video-refresh rates and, as a result, the pilots have to race at a lower speed and sometimes fly "in the dark." The industry gets a boost with 5G's eMBB and uRLLC capabilities to provide better images and allow agile controls. The improved field display equipment also has greatly improved performance and enhanced the user experience. 6G systems will have peak data rates in the Tera-bps range, much lower latency, and offer new network compute fabrics. They are expected to boost the industry by enabling a full 3D imaging transmission with the throughputs at multi-Giga-bps range. The result will be a superior end user experience in space maneuvering and enable an exciting ultra-realistic interactive drone racing scenario.

Figure 4.1-1: The Drone Racing Sport Show

4.1.2 Business Opportunity and Mapping to 6g Audacious Goals

Uncrewed aerial vehicles (UAVs) or drones started in the 4G era mainly for providing aerial photography. Later on, assisted with GPS and other positioning technologies, special-purpose drones gained popularity and can be seen in many agricultural, transportation, and even public safety applications. Racing drones are getting more attention with the promotions of global racing leagues. The interactive sport will get more popular with the excitements brought by the agile maneuverability and the immersive reality experience powered by 5G and 6G networks.

According to a report by POLARIS Market Research[8], the global racing drone market size was valued at USD 411.8 million in 2019 and is anticipated to grow to USD 2.1 billion in 2026 with a CAGR of 22.1%. Special drones, such as "high-speed drones" or "first person-view (FPV) drones," are used in drone racing events. It is rapidly becoming a popular sport throughout the world. This new type of interactive sport lets pilots fly their drones at high speed in an arena with a physical racetrack and injected digital bonus rewards. They also can participate in "air-combat" types of duels with a referee server under a more complex sport environment. The growth of the ultra-realistic interactive drone racing sport looks promising and will bring in new economic activities with the merchandise, telecasting rights, and other revenue streams through franchising.

Mapping to 6G Audacious Goals:

Goals	Remarks
Digital World Experience	Accomplish ultra-realistic interactive experience to people via drone (racing). 2x16K (360-degree spherical content, Head 6 degrees of freedom (DoF)), MTP moderate latency drone max speed equivalent to vehicular speed, maker-less (people may not need to wear goggles in some specific operation scenario).

Figure 4.1-2: The way players currently operate the racing drone

4.1.3 Example Service Scenario

The example service scenario is a duel where the two players fly drones through a racetrack and grab digital injected objects for bonus points. The time and the bonus points are then calculated to determine the winner. The scenario is shown in the video provided on the Next G Alliance Applications Working Group webpage.

In 2021, most AR/VR/MR commercial products focus on a single user experience. Some of the popular products are, for example, the HTC VIVE Pro 2 (monocular resolution 2448x2448, 120 degree field of view, 120 fps)[9], Oculus QUEST 2 (1832x1920 resolution)[10], and Microsoft HoloLens 2 (2K resolution)[11].

Currently, in Taiwan's 5G network environment, a drone flying at vehicular speed requires moderate uplink transmission rate and experiences high E2E latency. The video image is decoded, and the presence of the injected digital objects is calculated and combined by the personal goggle, or they can be directly connected to a high-performance computer host beside the user. 5G networks today can provide good FPV images, but they cannot support a 360-degree high-resolution image transmission, nor the short delay. There is still room for improvement in the image quality, fidelity, and MTP latency of adding virtual objects to support a real-time realistic interactive experience.

In the 6G era, the ultra-realistic interactive drone racing will be able to support multiplayers to immerse themselves in the real world and the virtual objects. The player can control the real UAV to interact with the virtual objects in real-time. Real-time image calculation for combining physical and virtual objects will be performed in the cloud, allowing interactions in different spaces. As to the screen resolution, the target is to provide a resolution of 2x16K or better, 360-degree spherical content, and have less than 20 ms MTP latency to achieve a multiplayer, ultra-realistic, interactive sport experience.

4.1.4 Requirements

The key network technology requirements for the drone racing scenario depicted in Figure 4.1-3 are latency, throughput, and mobility. These are the requirements from the use case's perspective and may need to be further translated into adequate network or communication requirements.

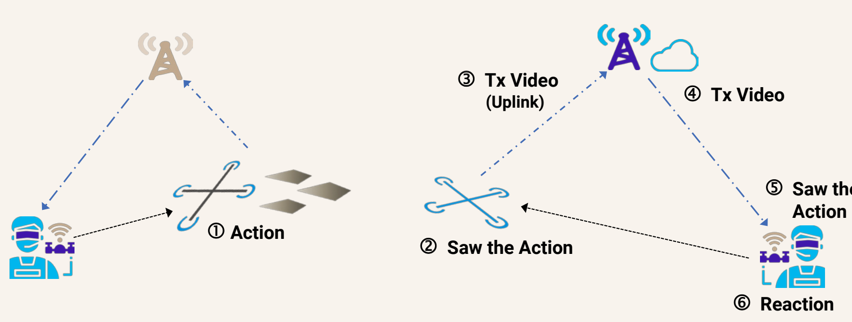


Figure 4.1-3: Ultra-Realistic Interactive Drone Scenario

> **Latency (both video and MTP): Moderate**

Low latency is the most important part for people to feel the immersion. It is also the most fundamental factor to avoid dizziness for players. According to research[12 13 14], most people will be aware of incoherence when MTP delays are longer than moderate latency of 20 ms.

> **Throughput: Ultra-High Data Rate**

The transmission data rate required for the AR process to provide million-pixel information in an 8K screen is about 60 Mbps or higher[15 16]. Although the required data rate is about 0.5 Gbps today, in the 6G era, the estimated display data rate for transmitting a 16K video, which is expected to be the mainstream image quality, will require a bandwidth of 2 Gbps (after using a data compression level of 1/200). In the design of a single drone operation scenario, the front and rear 16K resolution screens will be used to achieve 360-degree spherical content and 6 DoF presentation of objects. This 2x16K resolution will require an estimated uplink data rate of 4 Gbps (2x2 Gbps) to achieve the immersive ultra-realistic function of a single drone.

> **Mobility: Vehicular Speed**

When the drone is flying at vehicular speed, the 6G system should still be able to meet the data rate and delay requirements for real-time video streaming. It should still maintain good service continuity during the handover process between base stations.

4.1.5 Study Areas

The work on the following topics should be continued to help enhance the drone racing performance:

> **Ultra-reliable connection:** Support normal throughputs up to the Gbps level and above, and for situations with special requirements for ultra-low latency transmission capabilities less than 100 microseconds.

> **AI inside:** The 6G network system itself will have AI capable of self-management and adjustment of network resources, ensuring the network capabilities of the server to adapt to complex and diverse application scenarios.

> **Distributed computing network:** The 6G network system has distributed collaborative computing capabilities. Built-in AI will ensure data security, dynamically provide data collaborative computing, and effectively allocate network transmission resources to improve the overall system performance.

4.2
Use Case – Immersive Gaming/Entertainment

4.2.1 Description

Studies show immersive gaming is a transformative experience that is the trend of future gaming. Finding themselves *in* the game, immersive gamers are keen to seek more XR entertainment, and are willing to invest in equipment and pay higher premiums for superior quality of experience. 6G is necessary to make this trend happen.

Although 5G provides high speed, low latency, and better connectivity for immersive experiences such as gaming, it may not be able to simultaneously support large numbers of immersive gamers. With 6G, geographically separated players can seamlessly engage with a higher level of synchrony, low latency, and exceed the limitations of human senses.

In addition to ubiquitous connectivity, superior bandwidth, and congestion control, reliability is key to XR gaming, especially in the immersive gambling world (wherever virtual gambling is legal). Higher levels of built-in reliability in 6G are expected to bring higher consistency to the user experience. In the U.S. alone, the commercial gambling industry has made over USD 44 billion in 2021, surpassing the 2019, pre-pandemic record[17]. Only 6G characteristics and services can enhance the user experience to create the ambience that makes players feel as if they are in the same room, reading each other's expressions, touching the cards, etc. In addition to reliability, quality of experience (QoE) is imperative to cloud and XR gaming. QoE is shaped by several factors, including user, context, and network aspects. User factors relate to the user's personality, interests, age, culture, and gender. The context revolves around the user's activity, location, and economic capability. Finally, the network aspect for QoE is an umbrella that covers aspects of connectivity such as jitter, low latency, required bandwidth, frame rate, congestion control, etc., to provide high-precision networking and near-immediate interactions. 6G can provide real-time feedback between application, device, edge server, and network to provide the highest levels of QoE.

4.2.2 Business Opportunity and Mapping to 6G Audacious Goals

In 2019, pre-pandemic, the XR market grew in manufacturing, education, entertainment, and business applications. The ongoing COVID-19 pandemic accelerated that growth. The need for human interactions to spark innovation and higher levels of productivity inspired a new paradigm in communication and ignited XR conferencing and holographic communication.

Several sources of market research project[18] that the XR market will have a CAGR between 24% and 48% through 2030. It is expected that the global XR market will surpass the USD 1.1 trillion mark by the end of 2030. It is also expected that the gaming category will witness the fastest growth between 2020 and 2030. The support for tactile and noninvasive brain-computer interfaces provides the next generation of gaming interactions without the need for handheld controls. Among the U.S. population of 328 million, there are 215 million gamers, with the average age between 18 and 35. Females make up 46% of that demographic.

In an independent study[19], 95% of gamers would pay a higher premium for next-gen-enabled gaming services, and 60% of those would pay 50% more than what they pay today (approximately USD 126 per month compared to current monthly average USD 84). Most studies from wireless providers and gaming companies recognize there is one factor gamers will not tolerate: poor QoE. The resolution, field of view, optical calibration, low latency, and high refresh rate are some of the factors that play a huge role in the performance of the immersion device. Latency means lost revenue. The study shows that 79% of gamers would consider replacing their home broadband and mobile connectivity for a better gaming experience, if a competitor offered it.

Most revenue is currently generated in the single-user category. To accelerate the ubiquity of the 6G immersive edge platforms, service providers (telcos) and gaming agents need to market more popular services to help raise the capital for this and other 6G investments. The next generation of HMDs and lightweight glasses need to reach consumer price levels to enable mass participation in immersive experiences. Telcos can play a key role in fast-tracking price reductions. In Japan, next-generation, lightweight glasses are around USD 670, while the price is closer to USD 295 in Korea, where the glasses are subsidized by wireless carriers. With additional investments, the quality of the gamer experience increases, and their willingness to pay rises.

However, without experiencing the immersion that XR brings, end users are not likely to invest in next generation headsets. Service providers, gaming platforms, and headset manufacturers may consider a realistic, hands-on marketing approach by collaborating to showcase the experience in their stores (e.g., wireless provider stores). Consequently, users would be motivated to invest in lightweight glasses that offer higher QoE. Lighter XR glasses would enjoy longer hours of gaming, with less bulk or fatigue.

Figure 4.2-1: The XR Market[20]

Mapping to 6G Audacious Goals:

Goals	Remarks
Digital World Experience	Further details discussed in the next sub-section.

4.2.3 Example Service Scenario

Scenario 1: Interactive Special Events

The immersive environment (coordination and image processing) will vary based on the complexity and level of interaction with the game objects. The interaction with holiday characters could be customized with children's names and based on information parents share in advance to create the interaction, potentially utilizing AI to manage the experience. With special glasses, children can finally interact with special characters.

Figure 4.2-2: Special Event Example

Scenario 2: Immersive Gambling and Esports

The current global online gambling market is valued at almost USD 59 billion and is projected to reach almost USD 93 billion in 2023[21]. While most of the current revenues are from internet betting, the traditional gambling casino operators are eyeing truly immersive experiences for their customers to feel like they are in the brick-and-mortar casino. The experiences would build on better haptic feedback, ultra-clear graphics, realistic surroundings, and allowing players to immerse themselves in their respective games (e.g., blackjack or poker) without pressing buttons on a phone or a game controller.

In this gambling scenario, lag must be undetectable to human senses. Even milliseconds of latency risk unfavorable impacts on casino games, especially with high-stakes games. These KPIs are necessary to provide the player with the AR of the actual physical casino, guaranteeing faster reactions to the slightest movement of the player's fingers, head, and body.

With the legalization of virtual gambling in many states, and with the impacts of the COVID-19 pandemic, gamblers welcome the convenience of playing from home, especially if they can enjoy the same interactive experience with other players and live entertainment.

Esport events are a fast-growing segment of the XR entertainment market. They are reaching a level that might be considered in the Olympics. Today, stadiums are packed for esports tournaments with professional and amateur players competing against each other. It requires lightweight glasses, as well as low latency, real-time broadcasting, replay, and best-seat capability, which is a feature in the XR domain where users can pay to have a sideline view of the game.

According to Statista, the esport market was valued at USD 1.08 billion in 2021 and is forecast to grow to USD 1.62 billion in 2024[22]. Currently, sponsorship and advertising comprise a large share of that revenue. The following shows the progression of change in sports from analog to Techno sports (blending esports and physical sports through AR). An example of this can be seen in this ©HADO Techno Sports Clip[23].

Figure 4.2-3: ©HADO

Mapping to 6G Audacious Goals (with respect to each scenario):

Goals	Remarks for Scenario 1	Remarks for Scenario 2
Digital World Experience	Enabling multi-sensory entertainment, creating economic value. Moderate latency 16K video throughput.	Enabling multi-sensory entertainment, creating economic value. Low latency 16K video throughput.

4.2.4 Requirements

Scenario 1: This experience requires balancing latency and throughput. To deliver a realistic experience, long delays will not be tolerated, and moderate to low latency is desired. The lower the latency, the more realistic the experience is and the easier it is for users to believe that they are interacting with a real character, not a game.

However, the quality of the images also contributes to the realistic experience. Bandwidth required for 8K video per eye (total 16K) would be necessary. Service providers and game platforms are expected to engineer the edge resources, such as image servers to meet the expected service levels.

Scenario 2: The latency needed for this experience would be bounded low end-to-end latency in application level. Immersive gambling involving haptics or holographic communication would require very low latency[24]. Latency is critical when the betting case is time sensitive. Otherwise, latency could potentially place some players at a disadvantage, which will not be acceptable.

XR esports will require sensors and advanced headsets that help convey the slightest movements to the players. Bandwidth in the gigabit capacity is needed to deliver the full immersive experience and the visual processing levels needed to recreate the active sport environment.

4.2.5 Study Areas

More market research should be conducted to determine the required QoE, willingness to pay, and the value of renting equipment as part of the service offering.

Lab testing should be done on the most demanding video gambling experiences and esports to gain insights into engineering the necessary edge computing resources.

Conducting more research to determine how QoE can be:

> Monitored and assessed in real time.

> Improved with a feedback mechanism from user to edge server and to the network to take specific actions based on the level of service. Actions could range from adjusting encoder frame rate, bitrate, and resolution rate to establishing a dedicated slice for higher QoE.

> First-person perspective, 6 DoF, multi-player games, and players in multiple geographical locations will expose the next level of challenges.

4.3 Use Case – Mixed Reality Co-Design

4.3.1 Description

MR co-design is defined as remote or co-located collaboration and "experience before prototyping," a concept where MR merges the real and virtual worlds.

MR co-design systems will allow designers to create innovative products and combine them in a virtual-real environment. Context-awareness is an integral part of the MR co-design process and will allow designers to focus on the actual design and its relationship with the external environment. MR reality co-design will capture movement, emotions, and facial expressions. By using new forms of man-machine interactions, more vital measurements of the human body will be captured by MR co-design.

Such an approach can be subsumed under the term "spatial computing." The MR co-design process obtains additional context captured by spatial mapping and imaging technology. By 2030, the MR reality co-design process will include various designers' behaviors and vital parameters.

With the leverage of AI/ML, enhancements for MR co-design use cases will be great. The decomposed and advanced user equipment in conjunction with wearables will transform the next generation of industrial IoT.

Figure 4.3-1: The Remote Collaboration and Experience

4.3.2 Business Opportunity and Mapping to 6G Audacious Goals

MR co-design is an emerging use case. It is particularly attractive for collaboration, co-creation, and co-design for creative designers and practitioners who require real-time, shared platforms to work on projects simultaneously. Many enterprises, not limited to manufacturing, are experimenting with this. While the benefits of MR co-design can vary by project and vertical, early indications are that the benefits can be substantial. In one such example of applying collaborative VR for ideation or concepts to develop a character for a Netflix show, the overall time required was reduced by 75% (from 32 hours to 8 hours)[25].

While this is just one case and cannot be generalized, it is clear that productivity gains during the design/development will be the primary driver of MR co-design adoption. One can consider this as the next step in the evolution of computer-aided design tools. If the 28%-32% productivity gains that companies realized in the design process when they shifted from 2D CAD to 3D CAD is any indication, one can expect similar or even more gains when MR co-design is adopted.

The overall total AR/MR market is expected to grow from about USD 9 billion in 2020 to about USD 220 billion in 2027[26]. It can potentially reach USD 350 billion by 2030, for a total 10-year opportunity of about USD 1.6 trillion.

The majority of enterprise AR/MR spending will be on use inspection, assembly, training, and data logging applications. For example, the manufacturing vertical accounts for about 13% of the total USD 1.6 trillion in AR/MR spending between 2021 and 2030, with about 78% on inspection, assembly, training, data logging and other use cases, while 22% will be for use cases leveraging remote expertise of which MR co-design is likely to be a major component.

3D-CAD spending is projected to have a 6.4% CAGR and reach about USD 16 billion in 2028[27]. As MR technology matures and the overall ecosystem develops, adoption by different industries, particularly manufacturing that involves product design and development, will result in a gradual shift in spend from 3D-CAD to MR co-design.

Mapping to 6G Audacious Goals:

Goals	Remarks
Digital World Experience	MR co-design is a remote or co-located collaboration, a concept where MR merges the real and virtual world. Designed to capture movement, emotions, and facial expressions, MR will enable new human collaboration, human-machine communications, and man-machine interactions. In MR co-design, spatial computing is one component that may be utilized to capture vital measurements of the human body.

4.3.3 Example Service Scenario

MR enables the team of designers to see 3D virtual design models superimposed over a real environment. The team could be from different disciplines and co-located or dispersed geographically.

Scenario 1: Onsite MR co-design-based community, city, or building planning (e.g., planning a city park, designing a skyscraper, interior design). This would require local devices and applications to monitor and react to the local environment to properly position the virtual objects in relation to real objects.

Scenario 2: MR-based multiple dispersed user cooperative design (e.g., co-creating a digital prototype with haptic feedback by remote or not co-located users).

4.3.4 Requirements

Imagine a factory scenario where two engineers in different locations are designing a product together and assembling some real and virtual objects in a 10x10x10m space. Such a scenario may require higher data rates and, in all probability, require a new frequency band specifically allocated for 6G. This concept shall need low E2E latency in application level, high reliability, and synchronization support. It also requires precise localization, spatial computing, HMI, and imaging technologies:

- A remote reality prototype requires a very high data rate for a one-way immersive experience for a collaborative space.
    - Photo-realistic/truly immersive MR for a 100x100x100 cm workspace digitized at ~1,000 pixels per cubic cm.
    - 10^9 pixels x 16 bits/pixel.
    - 160 Gbps raw data rate compressed at 300:1 = ~500 Mbps uplink and downlink.

4.3.5 Study Areas

Further study areas in relation to this use case would be to identify how 6G networks will support the following:

- Spatial computing as it interacts with virtual and physical domains, including people, things, and environment.
- Spatial mapping, an ability to create a 3D mapping environment imaging technology.

4.4
Use Case – Mixed Reality Telepresence

4.4.1 Description

MR and 3D functionality will be the norm for work and social interactions, making it possible to appear as though one is in a certain location while being in a different location (e.g., appearing to be in the office while in the car).

The MR telepresence experience enables a combination of wearable devices, (e.g., earbuds and devices embedded in our clothing). The goal is for each person to have multiple wearables that work seamlessly with one another and with natural, intuitive interfaces. Touchscreen typing will most likely become outdated, while gesturing and speaking to devices we use to get things done will become the norm.

The devices we use will be fully context aware, and the network will become increasingly sophisticated at predicting our needs. Context awareness is a style of computing where situational and environmental data regarding people, places, and things are taken into consideration to respond to an immediate need. This context awareness combined with new human-machine interfaces will make our telepresence interaction much more intuitive and efficient.

4.4.2 Business Opportunity and Mapping to 6G Audacious Goals

MR telepresence has multiple applications and has the potential to revolutionize how we communicate, collaborate, play, and work.

On the communication and collaboration front, the COVID-19 pandemic has changed the way people work and has accelerated the use of collaboration tools and videoconferencing as in-person meetings gave way to online meetings. The expectation is that even after the pandemic ends, remote working will be more prevalent than it was prior to the pandemic. In addition, as industries continue their digital transformation, a class of "new-collar" jobs — handled by workers that blend human and machine skills and deliver a higher cognitive and physical performance — will emerge and will account for close to 70% of the workforce by 2030[28]. This will fuel the market demand for videoconferencing, which is expected to grow at an 11.5% CAGR from 2021 and reach USD 9.95 billion in 2028[29]. A subset of this videoconference sector will be the 3D telepresence market, which is expected to reach USD 6.2 billion in 2027, with a CAGR of 19.6% from 2020[30]. As cost points continue to decline and MR technology matures, one can expect about 60% of a videoconference will be done through 3D/MR telepresence by 2030.

Through telepresence or exoskeleton technology, assistive robotics — where the robot component is an extension of what the human worker can do — will become more prevalent. This class of robots will allow people to safely work in hard-to-reach areas, perform dangerous work or operate heavy or awkward equipment. While other industries may benefit, this is deployed most widely in health care settings for surgical procedures. As a result, surgical robots, whose capability will be further enhanced with developments in telepresence and haptic technologies, is a substantial market that is expected to reach USD 22 billion by 2028[31].

Mapping to 6G Audacious Goals:

Goals	Remarks
Digital World Experience	XR and haptics, hands-free and touchless interfaces, hologram XR, and multi-modal XR (haptics + audio + visual communications with tight synchronization). A style of computing where situational and environmental data regarding people, places, and things is taken into consideration to respond to an immediate need, combined with new human-machine interfaces, will make telepresence interaction more intuitive and efficient.

4.4.3 Example Service Scenario

Scenario 1: Multisensory telepresence communication (e.g., meetings on the go and from anywhere). Meeting participants are the primary actors.

Scenario 2: Gestural control of an industrial robotic arm in manufacturing.

Scenario 3: Health care telesurgery such as immersive remote surgery. Doctors, hospitals, and patients are the primary actors.

Most scenarios are indoors, although there are a few outdoor scenarios, such as when the actor is on the road.

4.4.4 Requirements

Holographic and 3D telepresence:

> Extremely high data rate and volume, extremely low E2E latency and jitter, multiple streams with high synchronicity, spatial computing (digitizes and optimizes data based on human interaction), and high localization precision.

> Ultra-high data rates (for 19.1 Gigapixel), and very low E2E latency at the application level and low power consumption.

> Synchronization time (managing five streams for different senses needs high synchronicity) and cm-level localization precision.

4.4.5 Study Areas

Further study areas in relation to this use case would be to identify how 6G networks support the following:

> High synchronicity between different streams such as audio, video, and environment sensory inputs.

> Ultra-reliable network connectivity.

4.5 Use Case – Immersive Education with 6G

4.5.1 Description

Education is one of the most important drivers of societal development. Hence, high-quality education should be widely and equally available for everybody around the world. Accessibility and quality of education is, however, facing challenges such as lack of infrastructure, high costs, logistic challenges, outdated and restrictive tools, and means. For instance, remote schooling during the COVID-19 pandemic faced challenges such as lack of student-student and student-teacher interaction, difficulty in using traditional tools of education remotely, lack of a suitable learning environment, and low-quality internet connections.

In conjunction with novel technologies such as multi-sensory extended reality and AI/ML, 6G can help generate a fully immersive education experience. In an immersive classroom, a group of students equipped with devices such as XR headsets, motion sensors, etc. participate in an educational session in a cyber-physical space. The immersive nature of the classroom will enable real-time, human-controlled avatars even though they may be physically distant from each other. Students can participate in group activities that go beyond traditional applications such as voice and video. Using digital twin technologies, sensors can replace physical tools such as lab equipment, music instruments, etc. for enhanced safety and reduced cost. Sensors can also be used to improve the classroom experience by capturing hand gestures and body movements. Digital content such as volumetric and holographic video could replace traditional teaching methods, thereby enhancing the learning experience and student engagement.

Universally accessible high-quality wireless networks with continuous service enable participation from any location, even in the most distant locations and even while in motion. Support for mobility will also enable a wider range of educational material, for instance, enhancing the learning quality of a field trip to a museum. Remote immersive education can also be used to provide students with physical and/or learning disabilities with high-quality and accessible education.

4.5.2 Business Opportunity and Mapping to 6G Audacious Goals

There are vast business opportunities for immersive education. Enhancing education access and experience are of major interest for both the private and public sector worldwide. It is estimated that virtual reality in education will reach a market size of USD 32.94 billion in 2026 with a compound annual growth rate of 39.7%[32]. In addition to that, immersive education could reduce the overall infrastructure and operation costs for educational facilities, thereby reducing the overall cost of providing universal education.

Mapping to 6G Audacious Goals:

Goals	Remarks
Digital World Experience	Provide interaction and collaboration between potentially distant instructors and students in the immersive space. Enhance education quality by enabling digital representations of real-world experiences that would not be possible otherwise.

Figure 4.5-1: In-class immersive education

4.5.3 Example Service Scenario

Fully remote education: Given the necessary network infrastructure, an education session can be moved entirely to a remote setting where students and instructors equipped with necessary devices will be able to participate in the immersive classroom. In this scenario, no school infrastructure is required, but all students need a high-speed network connection to satisfy the application's high QoS demands.

In-class immersive education: An in-class education session can use the immersive space for consuming immersive multimedia content such as virtual field trip, or a virtual lab session to work with material that is either not accessible or dangerous in the real world.

4.5.4 Requirements

Universal Network Access and Extreme Performance

- Extremely high downlink and uplink data rates.
- Low E2E latency.
- Very high availability through interworking and seamless mobility between terrestrial and NTN networks.
- Full-service continuity through support for cooperative technologies such as sidelink, mesh, and multi-connectivity.

Integration of sensing, computation, and communication:

Integration of sensing capability into the network.

- High accuracy localization and high-resolution positioning services.
- Low-latency, real-time sensing through coordination and integration of sensing capabilities with communication protocols.
- Support for edge computing for compute offloading in case of low-power devices.

Very high sensitivity for user data privacy and network security.

4.5.5 Study Areas

- Terrestrial and NTN networks' interconnectivity and seamless mobility.
- Multi-access operations should be enhanced to seamlessly leverage cellular and non-cellular communications.
- Accurate coordination and inclusion of sensing capabilities with communication protocols is required.
- Adaptable network architecture with flat data/control plane design.
- Integrating AI/ML functionality in the network architecture for seamless and efficient use.
- Ensuring user data privacy, especially for applications that operate with AI/ML functionality.

4.6
Use Case – High-Speed Wireless Connection in Aerial Vehicle for Entertainment Service

4.6.1 Description

This use case presents a few examples of high-speed wireless connection for and within an aerial vehicle for entertainment and service. The objective of the scenarios described in this use case are meant to ensure the communication stability to enhance the end user experience in a harsh environment such as airborne, high altitude, or high-mobility scenarios when in-flight entertainment services such as high-quality video streaming or internet gaming services are supported.

Wireless connectivity is an internal part of our daily life, from work to personal life. Most of our activities or information are shared via wireless. The increasing dependency on wireless prompted air transportation companies to rethink how they can offer connectivity during flight. Since 2012[33], Delta Airlines has been successful in offering in-flight Wi-Fi services.

On the ground, many services use 5G or 5G advanced. However, wireless connectivity in an airplane may not be enough to support the same services as on ground. Although NTN or NTN evolution fills some 5G holes, it is still insufficient to support high-quality video streaming or internet gaming services in the airplane.

A high-quality wireless connection lets users enjoy most services without interruption during the flight, such as a videoconference or multi-player game. During the flight, children can use educational materials. In the event of an in-flight medical emergency, a high level of wireless connectivity could enable remote diagnostics by a doctor on the ground who could then describe the appropriate treatment.

4.6.2 Business Opportunity and Mapping to 6G Audacious Goals

In-flight wireless access is currently made through Wi-Fi. Existing in-flight Wi-Fi is very slow and very expensive. As an example[34], an airline's in-flight internet connection speed is approximately 500-600 Kbps for download for an individual user and approximately 300 Kbps for upload. That is significantly slower than 4G and 5G.

Based on a survey[35], 67% of passengers would rebook with an airline if high-quality wireless access were available in flight. In other words, the higher quality wireless connection makes for better customer satisfaction and loyalty. The in-flight wireless connectivity market is forecast to be worth USD 130 billion by 2035[36].

5G and 5G advanced have supported NTN to serve remote areas including airspace, sea, and land not covered by a TN. 5G/5G advanced NTN may enhance backhaul links for in-flight wireless connections, but further improvement may be needed. For example, interworking between TN and NTN satellites or between NTN satellites can be supported in 6G. Caching or prefetching may be considered to reduce inherently large propagation delay in NTN.

Based on this improvement, the flight travel time can be connected and thus not boring because passengers can use entertainment, games, education, and business services.

Mapping to 6G Audacious Goals:
This use case is to ensure the stability of the communication link to enhance the end user experience in an in-flight environment when high-quality services are supported.

Goals	Remarks
Digital World Experience	Providing necessary connectivity means to support high-definition real-time interactive activities for in-flight scenario.

4.6.3 Example Service Scenario

Scenario 1: In-flight video (e.g., over-the-top (OTT) media services) streaming and internet gaming services.

Airline passengers can use wireless to watch high-quality streaming video on their own device. Scenarios of having a videoconference in-flight may be considered. For example, an avatar appears in a videoconference to convey the user's intent, and AI/ML technologies may be used to support sematic information delivery. Internet gaming or interactive shopping services can also be supported. This scenario may require high data rates and/or low latency, but inherently NTN may have a large propagation delay and/or a poor path loss. Interworking between TN and NTN or between NTN satellites may be supported to enhance data rates or compensate for poor wireless channel conditions. A backhaul link from the NTN may be a bottleneck to support high-speed wireless connections in flight. To support high-quality services in flight, caching or prefetching may be considered. For example, an edge node in the airplane may have cache memory to store user data and deliver it if there is another user's request. For this, sidelink connectivity between airplanes may be supported. As another example, to reduce latency, a data network on ground may prefetch data to users before they request it.

Scenario 2: In-flight local wireless networking.

So far, in order to use one's own device in the airplane, Wi-Fi has been used. In an airplane, various services can be supported through high-speed local wireless networking between passengers or between passengers and cabin crew. For example, gaming services among passengers using their own devices (e.g., laptop or smart devices) can be provided. Passengers can play highly interactive, first person-view VR games between one another. They also can request a specific service by simply sending a text message to a cabin crew when requesting service, or they can send a video directly to the cabin crew in an emergency to request a quick response.

4.6.4 Requirements

> DL/UL E2E latency is low or moderate.

> DL/UL experience data rate is medium or high.

> > NOTE: The above two requirements are intended to support caching or prefetching between devices, edge, and relay.

> E2E packet jitter is sensitive.

> Availability is high.

> E2E DL/UL packet reliability is high.

> NTN connectivity through aircraft-mounted relay to UEs is supported.

4.6.5 Study Areas

The suggested research topics related to this use case are:

> Data rate enhancement technologies (e.g., coordination mechanisms between airplanes, satellites, and ground towers, relaying, AI/ML native air interface, semantic/goal-oriented communication, and sidelink connections).

> Latency reduction technologies (e.g., caching, prefetching, enhanced channel access mechanisms, AI/ML native air interface, semantic/goal-oriented communication, and sidelink connections).

> Roaming, PLMN, service provider switching mechanisms such as when ground towers are involved in aerial vehicle communication.

> Coexistence mechanisms with aviation devices and sensors.

5 DISTRIBUTED SENSING AND COMMUNICATIONS

Distributed Sensing and Communications use cases and categorization include sensors tightly integrated with communications to support autonomous systems.

Use cases within the Distributed Sensing and Communications category describe a future state of the world with ubiquitous connectivity facilitated by TN and NTN connectivity services that unlock massive, creative, and value-driving sensor and data collection opportunities. These use cases address markets such as health care, agriculture, and environmental/public safety markets with ideas such as implantable sensors, fully remote sensors, and ultrawideband video collection systems. Summarizing greatly, requirements of this future state include wide-area coverage with options such as massive throughput and ultra-low power operating modes from network providers and device manufacturers. These use cases look toward consumers to support industry with demand and government to empower industry through proper regulation.

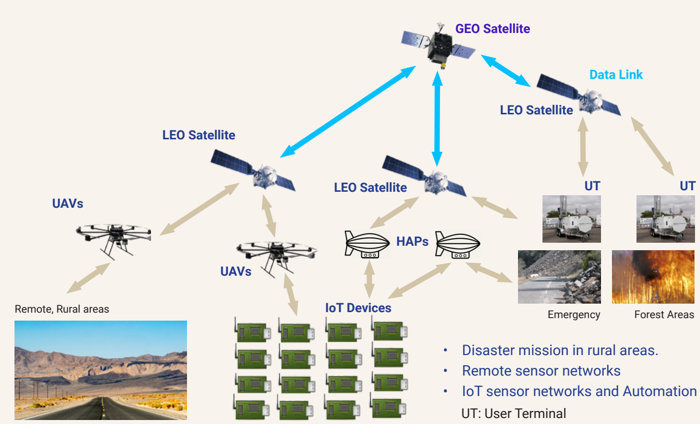
5.1 Use Case – Remote Data Collection

5.1.1 Description

The recent launch of LEO satellites in pursuit of ubiquitous internet coverage rekindled interests in the IoT in rural areas. LEO satellite networks are expected to provide the fast connections, global coverage, and other services that the current TN networks cannot adequately provide for rural IoT services.

NTN is an umbrella term for any network with base stations on non-terrestrial flying objects such as HAPs (e.g., balloons), UAVs, and satellites. To support IoT coverage in rural areas, NTNs are comprised of diverse connectivity links and can supplement inadequate rural coverage with TN infrastructure as shown in Figure 5.1-1.

Figure 5.1-1: Synergetic multi-connectivity system for remote area network coverage



This use case leverages interworked satellite-6G networks to provide global, ubiquitous mobile internet coverage for all kinds of devices. To better interwork with the terrestrial 6G network, the satellite segment needs to address and support the same functional aspects supported by the 6G system (e.g., interfaces, QoS, security)[37].

5.1.2 Business Opportunity and Mapping to 6G Audacious Goals

The economic stake of IoT in the future world remains very high as these technologies find new application areas in health care, smart manufacturing, education, and, in particular, logistic tracking systems. With that said, business opportunities for remote-area data collection primarily reside in two realms: IoT communication using control systems based on LEO solutions and edge AI software targeted to enrich the IoT services.

The 2016 Market Watch[38] valued the IoT devices market at USD 32 billion and forecasts that it will reach USD 158 billion in 2024. The global IoT devices market is expected to have a CAGR of 23% between 2017 and 2024. In addition, Northern Sky Research (NSR)[39] expects the satellite IoT (S-IoT) market will include more than 5.3 million terminals by 2024 and have USD 495 million in revenue by 2024. Notably, increased adoption of cloud platforms across developing regions drives growth of the IoT devices market. Although cloud platforms provide advanced analytics and monitoring for IoT services, expensive cloud solutions create support challenges in remote areas. This presents growth opportunities for LEO adoption in IoT with edge computing as a cost-effective alternative.

Similar to other 6G use cases, the edge AI software development business is booming and has formed a sizable market. Edge AI provides faster, more reliable, more economical, and easier access to critical operations data, particularly at remote complex sites such as natural disaster areas. Satellite densification brings new problems and calls for complex solutions for on-the-fly AI/ML optimization approaches. The challenges include interference management, resource allocation, path selection, and adaptivity at different layers of the protocol stack[40]. For instance, in a complex mega-LEO system such as Starlink, characterized by a mesh network of inter-satellite links (ISLs) in space, an AI/ML scheme could be adopted to adjust routing paths using ISLs based on the link status. The routing in a 3D system with multiple layers (also involving UAVs/HAPs) would be even more complex. Moreover, AI/ML can help maximize the number of users served under certain co-channel interference, mobility conditions, energy consumption levels, and link dynamics. AI/ML predictions can optimize handover decisions within layers and among layers of the 3D NTN architecture.

Mapping to 6G Audacious Goals:

Goals	Remarks
Cost Efficient Solutions	*Extreme low cost* - Utilize AI and LEO infrastructure to provide low cost, especially for remote areas.
Distributed Cloud and Communications Systems	*Extreme massive connectivity* - Support for high density of IoT sensor networks covering special services such as logistics.
Sustainability	*Extreme coverage* - Orchestrate communications-computing-control localization among NTN resources to achieve extreme coverage.

5.1.3 Example Service Scenario

The remote data collection will operate in various environments requiring remote data gathering or tele-operations such as:

- Disaster relief mission in rural areas. This includes disaster prevention (e.g., forest fire prevention monitoring) and long-term monitoring of the land (e.g., debris flow monitoring).
- Remote exploration using sensor networks and Internet of Senses. In particular, logistics tracking in a remote area.
- Smart infrastructure such as IoT sensor networks and automation.

From a remote data gathering perspective, to act responsibly by taking timely actions and maintaining reliable operation for remote area data collection, two features need to be incorporated in LEO networks:

- **Radio resource management (RRM) support**: efficient RRM support of different traffic such as multimedia traffic (with eMBB) and IoT traffic (through mMTC).
- **Routing support**: perform routing at the nearest gateway in NTN systems, where the TN is used to connect to the destination.

In this scenario, multiple sensors produce large volumes of data, which are accumulated by entities in the NTN, to perform prescriptive and predictive analytics for real-time logistics tracking in remote areas as shown in Figure 5.1-2. In a LEO communication network, identification and sensing technologies enable integrated logistics such as a study in the harbor environment provides an overview for the operator to take action in a timely manner. The IoT network passes the information gathered to the data operator's data center and also communicates through the overlayed LEO network. This requires coordinated action, especially in remote areas with extreme MTC connectivity and coverage challenges.

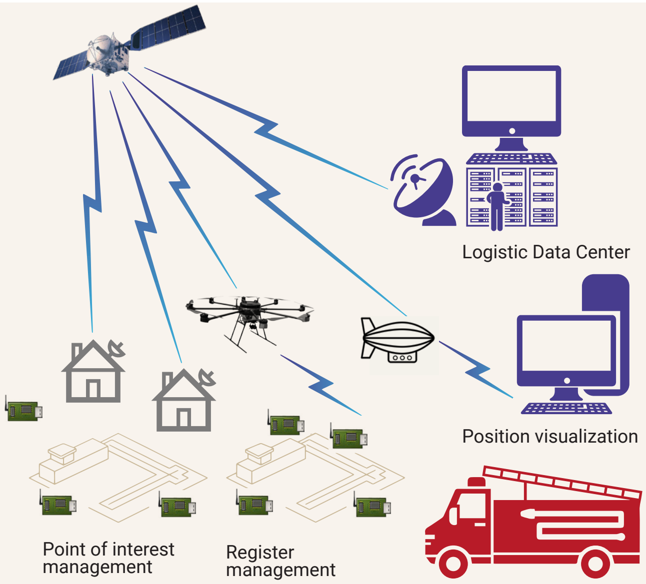


Figure 5.1-2: Logistic Tracking within the Remote Sensor Network over NTN

5.1.4 Requirements

Three requirements are derived from this use case:

- **Extreme Massive Machine-Type Communications (mMTC) support**: extreme massive use of sensors is considered for IoT applications (e.g., monitoring remote areas).
- **Enhanced Mobile Broadband (eMBB)**: users in remote areas or disaster areas.
- **Extreme Coverage**: users in remote areas should have coverage.

5.1.5 Study Areas

The following topics can be studied to help improve the use case:

- Digital World Experience.
- IoT networks; tactile internet.
- Intelligent resource management.
- LEO, HAPs, UAVs.
- Agile/lean protocol stack; edge and cloud for intelligent systems.

5.2 Use Case – Untethered Wearables and Implants

5.2.1 Description

This use case presents the concept of truly independent untethered wearables and implants with native 6G cellular connectivity. Advances in low-power 6G communications and chipsets shall enable cellular-based, low-power sensor systems and disrupt alternative, non-6G connectivity technologies such as Bluetooth, LoRa, Wi-Fi, or similar. Increased device connection density will further expand network demands and require additional network features such as energy harvesting and wireless charging[41 42].

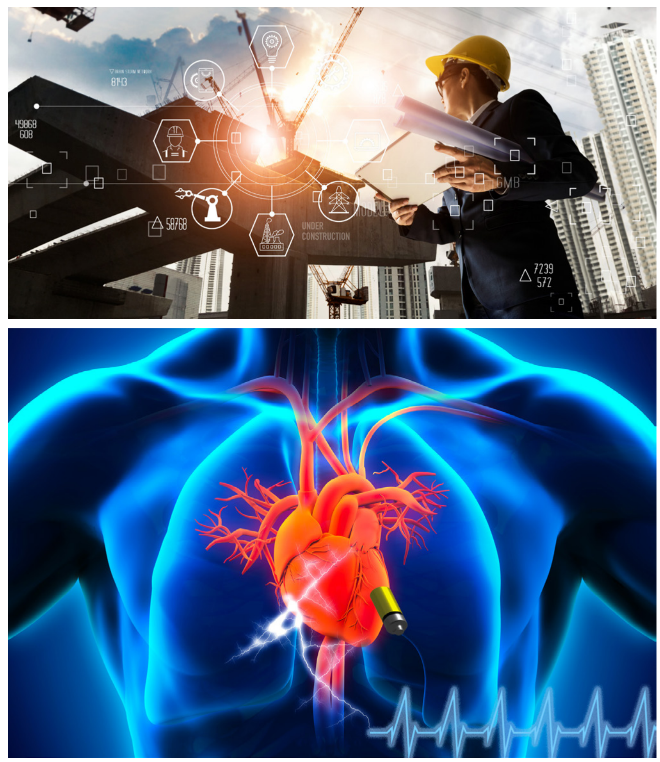


Figure 5.2-1: Untethered Application Areas

5.2.2 Business Opportunity and Mapping to 6G Audacious Goals

The number of cellular-connected devices will continue to grow exponentially as population increases, life expectancy lengthens, and cellular services advance. In 2018, there were an estimated 8 billion IoT connected devices in the world. In 2025, that number is expected to reach 31 billion or over 200% growth[43]. During that same period, the population grew from approximately 7.5 billion to approximately 8.2 billion, meaning that device-based service growth significantly outpaces human growth. In 2018, there were roughly three IoT devices per human, whereas in 2025, four are expected. The networks connected to these services simply need to keep up with that demand.

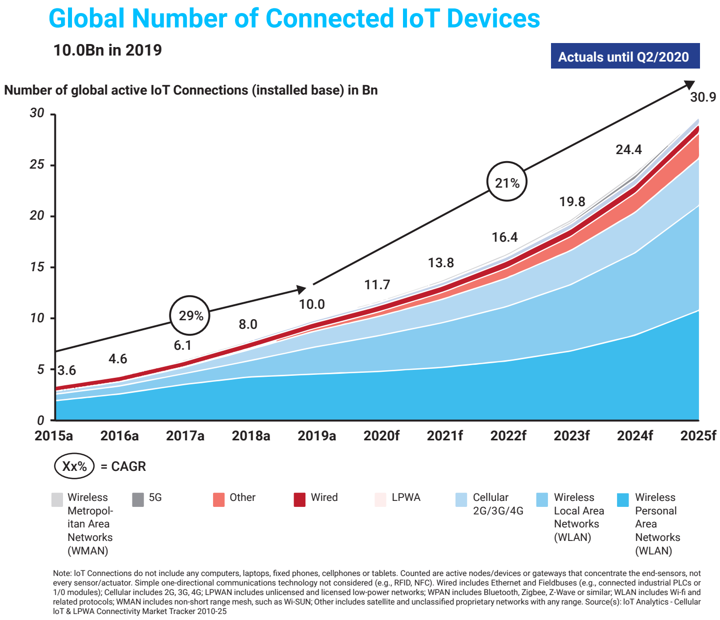


Figure 5.2-2: Number of Connected Devices Globally

In the future, cellular device connectivity will benefit from the same advances that other connectivity technologies enable. Bluetooth, LoRa, Wi-Fi, and similar technologies capture a large share of the IoT device market because of their low-power characteristics. But devices designed with these types of technology lack native cloud connectivity, which ultimately shifts the total cost of ownership from the sensing device to an accompanying radio or similar connectivity function. For network providers, the return on investment largely depends on the industry's ability to reduce the size, weight, and power of cellular connectivity. Specifically, new low-power chipsets and low-power features within communications protocols built upon NB-IoT and CAT-M1 are required to enable cellular users to truly cut the cord from local cloud connectivity devices.

Attaining this future requires cellular devices and connectivity to improve baseline SWaP performance. In 2022, the two most widely used technologies are Wi-Fi (5.5 billion) and Bluetooth/Zigbee/similar (5.3 billion)[44], and each far surpass cellular on power performance. Notwithstanding, with cellular as a minority technology in a much broader market presents a unique opportunity to increase market share in the upcoming years.

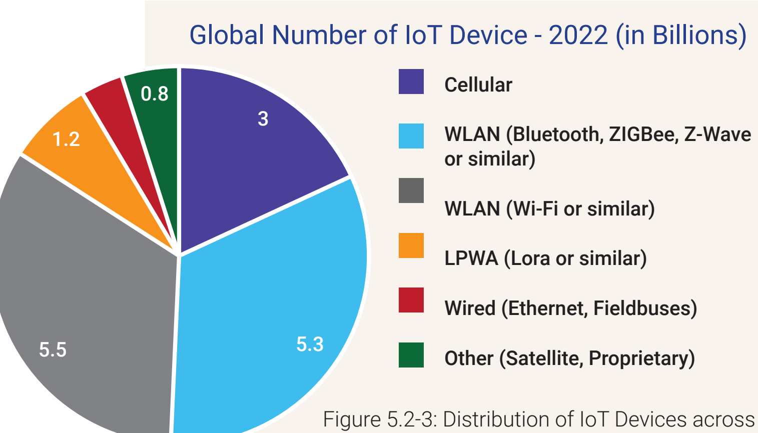


Figure 5.2-3: Distribution of IoT Devices across Connectivity Type

Mapping the use case to audacious goals characterizes this use case's applicability to Digital World Experience, Distributed Cloud and Communications Systems, and Sustainability.

Mapping to 6G Audacious Goals:

Goals	Remarks
Digital World Experience	Enables remote sensor systems potential installed in very hard-to-reach places including human implants or building foundations.
Distributed Cloud and Communications Systems	Demands of the network include requests for ubiquitous connectivity.
Sustainability	The ability to leverage edge sensors for longer durations.

5.2.3 Example Service Scenario

Business opportunities include enabling new services based on unmanaged remote sensing systems. Examples include:

> Remote health care (cellular pacemaker).

> Personal fitness (cellular 9DOF/GPS reporting systems).

> Building and infrastructure monitoring (e.g., embedding sensors in walls, foundations, beams, pillars).

> Livestock monitoring (e.g., farm animals).

> Remote environmental and climate monitoring.

5.2.4 Requirements

6G system requirements include:

> The capability to securely connect large numbers of untethered wearable and implantable cellular devices.

> Support untethered wearable and implantable cellular devices with wireless charging capability.

> Enable implantable devices to reside in living tissue and safely and reliably transmit and receive over the 6G network.

> Support devices in ultra-low-power deep-sleep modes with periodic reconnect.

5.2.5 Study Areas

The following topics can be studied to help improve this use case:

> Current and future power-draw levels of cellular devices when compared to competing technologies.

> Connectivity limitations in service areas.

> Deep understanding of competitive low-power/low-bandwidth interfaces to ensure feature parity with future offerings within this class.

> Study into RF, wireless charging, and energy harvesting.

5.3 Use Case – Eliminating the North American Digital Divide

5.3.1 Description

The term "digital divide" describes the gap between those benefiting from adequate broadband internet access and those suffering without it. The quality (e.g., speed) of the access accounts for the largest "gap" in broadband internet access. The FCC's current speed benchmark is 25 Mbps download and 3 Mbps upload, which defines "advanced telecommunications capability." Another contributing factor to this gap is availability of the access (e.g., percentages of urban, rural, and tribal areas with (fixed terrestrial) access to advanced telecommunications capability). The metric used to characterize the gap is if there are multiple providers offering competition and consumer choice. Lastly, "adoption" refers to the extent to which an individual uses fixed broadband[45]. While several programs target mobile broadband demands, the basic definition and scoping of the "digital divide" has longer roots in fixed and TNs.

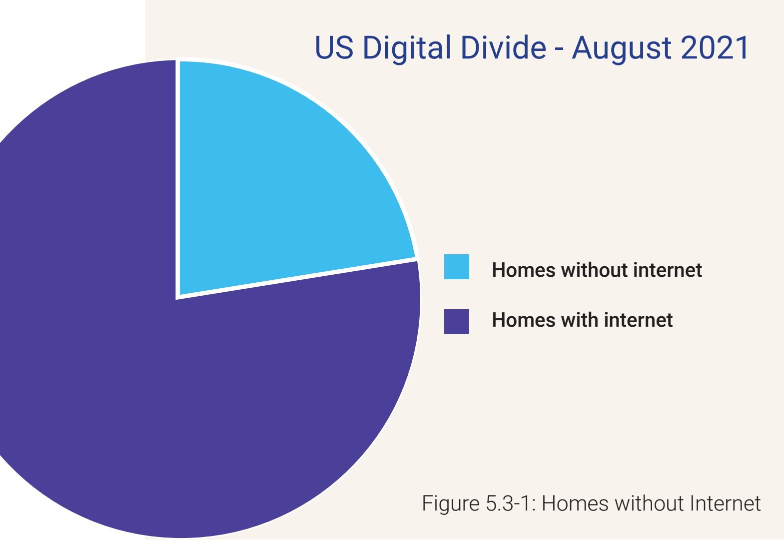


Figure 5.3-1: Homes without Internet

Percentage of Americans with Access to Fixed Terrestrial Broadband at Speeds of 25 Mbps/3 Mbps

	2014	2015	2016	2017	2018	2019
All of US	89.4%	89.9%	91.9%	93.5%	94.4%	95.6%
Urban	96.4%	96.7%	97.7%	98.3%	98.5%	98.8%
Rural	60.4%	61.5%	67.8%	73.6%	77.7%	92.7%
Total	57.2%	57.8%	63.1%	67.9%	72.3%	79.1%

Table 5.3-2: Percentage of Americans with Access to Adequate Internet[46]

Obvious digital inequality exists in several ways, including communities living in urban areas and those living in rural settlements, varying socioeconomic groups, varying economically developed countries, and varying education levels. Individuals with access to a broadband connection are also digitally split due to low-performance computers, limited broadband speeds, and limited access to subscription-based content[47].

Unfortunately, the term "adequate" fails to properly mandate a measure of success. This description does not require coverage in every household or at public facilities (e.g., schools and libraries). The Congressional report acknowledges that differing technologies vary in their ability to meet the benchmark metrics of their advanced telecommunications capability. Technical aspects of "adequate…access" include, but are not limited to, quality and capacity of existing infrastructure, broadband deployments, and capacity to support massive numbers of devices.

This use case focuses on an under-represented portion of the population: people living with physical disabilities who need hardware and software tools/aids for their independent access and use of the internet. These individuals may face additional technical challenges to access and use the internet due to the affordability of devices/tools/aids needed. This submission uses the term "universal access" to mean access to all consumers, regardless of physical abilities.

There are also non-technical aspects such as digital literacy and the development of digital skills to consider. Aspects may have both technical and non-technical components such as building trust and overcoming apprehension for digital economies (e.g., e-commerce, online banking, or telehealth). Affordability for devices and access also contributes to the digital divide. Non-subsidized costs for mainstream (e.g., smartphones) may be onerous to those individuals with limited income. The cost of specialized devices for those with disabilities is not a mainstream discussion point of this issue.

5.3.2 Business Opportunity and Mapping to 6G Audacious Goals

Network equipment and integration providers will grow top-line revenue by expanding offers to underserved communities. This unaddressed portion of the connectivity TAM enables basic services for those in need while also expanding the footprint of high-speed coverage to enable new applications discussed in this report. Specifically, with a properly installed communication backbone, other data producers will leverage those channels and serve these communities with secondary gains. For example, the figure below shows the percentage of U.S. adults currently underserved but within the addressable market.

Percentage of U.S. Adults Who Did Not Use the Internet in 2019

U.S. Adults	10%
Men	10%
Women	9%
White	8%
Black	15%
Hispanic	14%
18-29 age	0%
30-49	3%
50-64	12%
65+	27%
Less than $30K income	18%
$30K-$50K	7%
$50K-$75K	3%
$75K+	2%

Figure 5.3-4: Percentage of US Adults Who Did Not Use the Internet in 2019[48]

Providers shall expect additional revenue opportunities from these market segments in a post-pandemic world. Remote and hybrid work, education, and socialization are here to stay. But network providers cannot capture that market segment without offering ubiquitous coverage. The pandemic brought forward new ways to work, live, and play, yet customers remain underserved in many areas of the world. Specifically, some use cases presented in this report have been flagged as subject to the digital divide as shown in the table below.

Use Case	
Network Enabled Robotic and Autonomous Systems	
Online Cooperative Operation among a Group of Service Robots	Applicability for SOBOTs to assist disabled individuals. SOBOTs need to be affordable, and networks must be available for all.
Multi-Sensory Extended Reality	
Ultra-Realistic Interactive Sport – Drone Racing	Access is needed for all to enjoy esports and online entertainment.
Immersive Gaming/ Entertainment	
MR telepresence	Applicability to remote physical “obstacles” for disabled individuals.
Immersive Education	Overcomes inaccessibility (for whatever reason) to quality education and educational experiences.
Distributed Sensing and Communications	
Remote Data Collection	(Medical) Sensors supporting isolated individuals would benefit by this capability.
Untethered Wearables and Implants	Those without Internet will be unable to utilize telemedicine and leverage advanced medical wearables/implants. This could be leveraged for Alzheimer’s patients who “wander”.
Public Safety Applications	Capability that can provide remote specialized support and assistance for first responders to interact with disabled citizens.
Healthcare – In-body Networks	Those without Internet will be unable to utilize telemedicine and leverage advanced medical wearables/implants.
Personalized User Experience	
Personalized Hotel Experience	Personalized experiences could be expanded and leveraged to address needs of disabled individuals.
Personalized Shopping Experience	

Table 5.3-5: Summary of New Applications Working Group Use Cases

Finally, as public/private partnerships emerge as a method for private companies to finance public entities, each and every public school, library, and service center should have "brought to you by" network connectivity to empower those in need and potentially capture loyalty coupled to purchased services. Summarizing greatly, the total population of schools and libraries in U.S. and Canada represents this total addressable market segment.

Public Entity	Number
Number of (K-12) schools in US (2020)[49]	130,930
Number of public libraries in the U.S.[50]	9,057
Number of public schools in Canada[51]	14,600
Number of libraries in Canada[52]	1,015

Table 5.3-6: Public School and Library Count in U.S. and Canada

Note that in a future state with ubiquitous coverage, there will still be a portion of the U.S. population that will struggle with basic internet access due to physical limitations. With great advances in AI/ML, only high-speed, low-latency telecommunications channels manage services to ease internet access. Channels' uses include inferencing, command and control, and management upgrades.

Mapping to 6G Audacious Goals:

Goals	Remarks
Trust, Security, and Resilience	New users within new coverage areas may hesitate to adopt the technology.
Digital World Experience	New first time online experiences.
Distributed Cloud and Communications Systems	Urban and rural connectivity and coupled sensor-based services.
Sustainability	Close the digital divide without reopening it.

5.3.3 Example Service Scenario

Business opportunities and services needed to close the digital divide:

> Ubiquitous coverage throughout North America.

> PPP-based coverage within schools, libraries, and public service centers.

> Over the network sensor applications (e.g., health monitoring) addressing the underserved leveraging newly installed backbones.

5.3.4 Requirements

Some requirements for this use case include:

> **Speed**: near 100% of the population with download/upload speeds at or above 5G levels.

> **Availability**: increase availability to near 100% in all areas (e.g., urban/rural/tribal areas).

> **Affordability**: provide services at cost levels that enable subsidized communication options.

> **Adoption**: interfaces to new/existing technology shall reduce the learning curve and adoption of access and use (subjective).

5.3.5 Study Areas

The following topics can be studied to help improve the use case:

> Current and future 5G coverage levels, coverage map.

> Typical 5G connectivity speeds (up and down).

> Percentage of underserved citizens and public entities.

> Typical applications lacking in underserved communities (e.g., digital pay services).

5.4 Use Case – Public Safety Applications

5.4.1 Description

Public safety services include establishing rules and regulations for the benefit of functioning communities, security, and policy enforcement to ensure compliance, and enabling access to information to understand and address challenges existing within. This use case presents advances to public safety applications for high-resolution video.

5.4.2 Business Opportunity and Mapping to 6G Audacious Goals

Cities are like any other business. They compete with one another for residents by providing the best possible services to attract business. In exchange, cities receive taxpayer dollars to finance operations and improvements when servicing their communities. Public safety application providers need 6G to enable new services in and around ultra-high-definition video that will enable better service from public safety entities. Potentially, such video resolution will even enable multiple services on top of one video stream.

Such advances would greatly improve a city's bottom line by removing duplicate single-service sensors, specifically video.

Even in a 5G world, there are challenges around the cost effectiveness of 24x7 streaming. 1080p 60 fps with 60% motion creates more than 1TB of data a month. With 5G, network providers shy away from such heavy loads. As security operators transition from 1080p to 4K, 8K, or higher and from single imager to multi-imager, fusion, and volumetric data capture, the network load will only increase. In the 6G world, network providers shall offer massive symmetrical bandwidth to service customers wanting bi-directional video and immersive experiences.

Mapping to 6G Audacious Goals:

Goals	Remarks
Trust, Security, and Resilience	Security monitoring within the smart city.
Cost Efficient Solutions	Provide ultra-high throughput at reasonable prices.
Digital World Experience	Creating digital content from remote locations.
Distributed Cloud and Communications Systems	Video and non-video sensors within the 6G network.

5.4.3 Example Service Scenario

Business opportunities and services:

> Enhanced multimedia communication support for first responders.

> Wide-area monitoring, including urban and rural areas.

> Infrastructure monitoring.

> Natural resource monitoring.

> Parking, traffic, and public safety services.

5.4.4 Requirements

Public safety use cases require the following:

> The ability to stream ultra-high resolution and frame-rate video from urban and rural areas at acceptable costs.

> Course-change detection for potentially immobile assets (e.g., bridges).

> Detection and reporting of adverse weather conditions (e.g., tornado, fire, storms).

> Support for customized use cases required by providers of the smart city.

5.4.5 Study Areas

This paper would benefit from additional research into the following:

> Expected bandwidth requirements for 8K, 12K, 16K, and higher sensor resolution with frame rates up to 800 fps (assuming 60% motion).

> Requirements for new technologies like LIDAR and point cloud streaming.

> Potential network advances to breakdown silos within the public sector.

> Understanding privacy concerns and proper technology to facilitate secure collaboration between entities.

5.5 Use Case – Synchronous Data Channels

5.5.1 Description

With the introduction of massive numbers of IoT sensors, data collection will continue to grow exponentially. Accurate data is critical for powering 6G applications and services, as well as timing and synchronization of data challenges with accuracy. It is expected that the massive amounts of data generated by increased sensors, AL/ML, and the metaverse will require accurate transport to deliver this data on time with full synchronization.

In 3GPP 5G Release 16[53], network providers introduce capabilities to ensure synchronicity of cloud disseminated instruction for edge devices. This is particularly applicable to Industry 4.0, but drivers of other use cases demand time-sensitive sensor devices. For example, the introduction of massive amounts of AI-enabled sensors, such as computer-vision-enabled cameras or NLP-enabled acoustic devices, create edge-based data insights. However, visualization of metadata concurrently with video or audio channels remains the implementer's responsibility. It's time for the network to facilitate a guaranteed time of arrival for all data producers, as shown in Figure 5.5-1. By specifying channels providing tightly synchronized data, edge and cloud applications shall focus on value driving applications including:

> Collaborative content manipulation.

> Lower power game play.

> Fully synchronous metaverse.

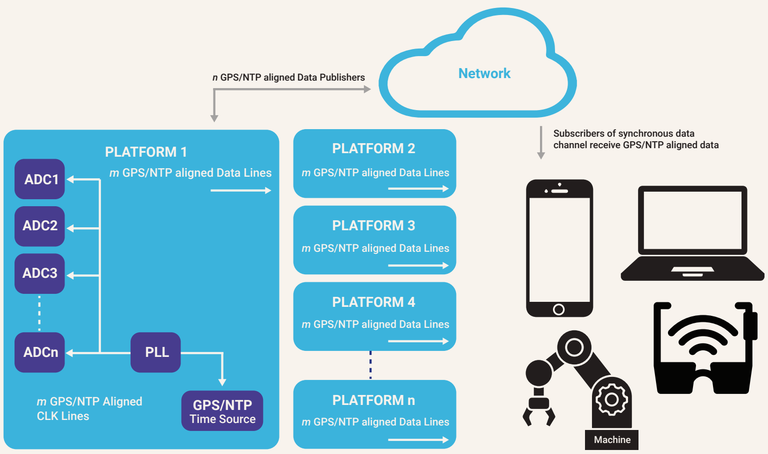


Figure 5.5-1: Subscribers of the Synchronous Data Channel

Additionally, mandating well quantified jitter and synchronicity requirements will remove synchronizing steps taken on nearly every computing platform. Many methods and tools exist within software frameworks like Matlab, MathWorks, Octave, and embedded frameworks like Python, C/C++ to compensate for errors in poorly delivered data series. In consideration of these methods and the near 20 billion IoT devices around the world, the expectation of energy savings in data centers, remotely power devices, and grid connected equipment is very high.

The high-level requirements establish capabilities for communications sessions enabling data publishing aligned to GPS/NTP time synchronization (e.g., 1PPS or similarly aligned subsample) to service data fusion algorithms and systems with extreme time sensitivity. A channel can be fully synchronous (e.g., hardware timed alignment via PLL) or synchronous emulation (e.g., edge resampled) to enable legacy hardware and deficient platforms to emulate compliance to the new requirement, as shown in Figure 5.5-2. Recipients of data on this channel receive data with a guaranteed epoch alignment without using error checking or correction mechanisms. The figure below shows a hardware pseudo-diagram for this use case.

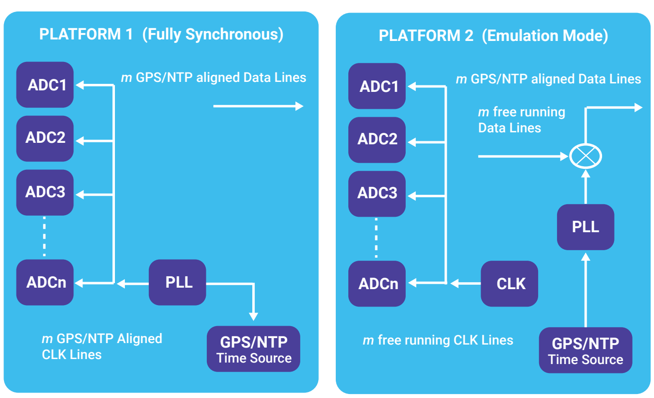


Figure 5.5-2: Fully Synchronous vs. Emulation Mode

5.5.2 Business Opportunity and Mapping to 6G Audacious Goals

Network and service providers offering the lowest jitter and highest synchronicity will capture more of the sensor data collection market by establishing a competitive advantage over other providers. Creators and implementers of the metaverse, AI/ML applications, and other sensor fusion applications want data as fast, but also as accurately, as possible. When selecting between components of a system, designers understand opportunity costs associated with network stacks providing varying data quality levels.

Mapping to 6G Audacious Goals:

Goals	Remarks
Trust, Security, and Resilience	Use of synchronicity and preserving time of creation in support of authenticity.
Cost Efficient Solutions	Saving energy through improving data quality.
Digital World Experience	Digitizing the world, powering the metaverse.
AI-Native Network	Empowering computer scientists with the highest quality data.
Distributed Cloud and Communications Systems	Remote sensors.

5.5.3 Example Service Scenario

Business opportunities and services needed:

> Automobiles, including autonomous vehicles.

> Human body sensors (wearables and CV-deduced synchronization).

> ML, data fusion, data insights.

5.5.4 Requirements

Suggested requirements for synchronous data channels include:

> Establish capabilities for communications sessions

enabling data publishing aligned to GPS/NTP time synchronization (e.g., 1PPS or similarly aligned subsample) to service data fusion algorithms and systems with extreme time sensitivity.

- Channel can be fully synchronous (e.g., hardware timed alignment via PLL) or synchronous emulation (e.g., edge resampled) to enable legacy hardware and deficient platforms to emulate compliance to the new requirement.
- Recipients on this channel receive data with guaranteed epoch aligned without using error checking or correction mechanisms.

5.5.5 Study Areas

This use would benefit from additional research into the following:

- Total energy lost estimate per year based on 20 billion IoT data streams using resampling methods described.
- Complementing the existing 5G 3GPP's TSN specification in search of enabling bidirectional functionality and, specifically, features for edge-aligned publishing.
- Further study on synchronization between different streams in a multi-modality communication session.

5.6 Use Case – Health Care – In-Body Networks

5.6.1 Description

Health care continues to be transformed by the development and continued improvement of wearable devices. Today, vital parameters may require 24/7 monitoring for both the healthy and the sick; such monitoring occurs through numerous wearable devices. In addition, real-time health monitoring may include devices either on the surface (e.g., wearable skin patches, sensors for temperature, and blood pressure) or in implants (e.g., pacemaker, insulin pump, and muscle controllers) communicating with access points (AP), which transport data (e.g., health parameters) to the internet so prompt actions can be taken. Thus, the paradigm for 6G telemedicine will be enabled by in-body sensing and analytics in conjunction with wide-area connectivity options.

Furthermore, the in-body networks can assist in fixing shortcomings of today's health care system regarding closed-loop interactive remote monitoring and predictive therapy. Providing basic personal health monitoring and reporting (e.g., temperature, pulse, glucose level, and blood pressure), wearables today are state-of-the-art, consumer-grade, IoT-based devices. By the 2030s, these sensors will be precise and reliable for diagnostic purposes. Such sensors, included as in-body sub-networks, provide updates, and interact with distributed cloud repositories.

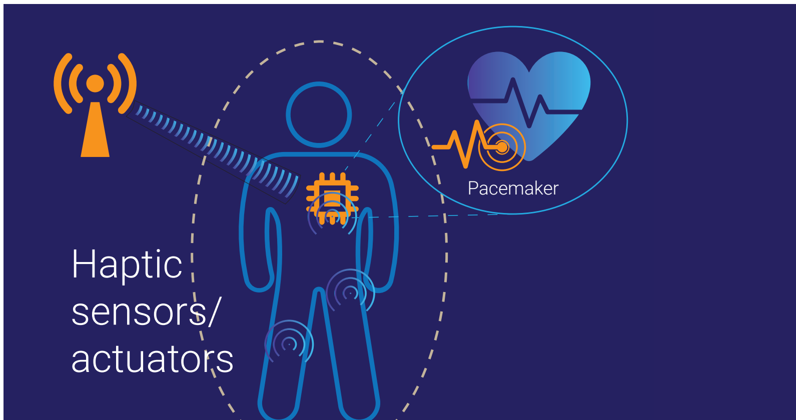


Figure 5.6.1: In-Body Use Case Scenario

5.6.2 Business Opportunity and Mapping to 6G Audacious Goals

Patients and health care providers are the primary actors in this use case which would have high-to-medium economic viability.

Smart wearables, implants, ingestible electronics, and remote physiological monitoring can profoundly impact overall patient well-being and how health care is delivered. It can boost patient engagement and satisfaction by allowing them to spend more time in the comfort of their home and interacting with their care centers whenever needed. A significant driver for this market is the proliferation of smartphones and the increasing penetration of connected devices in health care. In addition, the COVID-19 pandemic has accelerated the demand for remote patient monitoring and telehealth.

The global Body Area Network (BAN) market size was valued at approximately USD 10 billion in 2020 and is projected to reach about USD 30 billion by 2030, registering a CAGR of 11.6% from 2021 to 2030[54]. This market comprises three major segments: health care, sports, and fitness. The sports and fitness segment dominates today's market, but this is expected to shift by 2030, with health care accounting for a higher share.

Mapping to 6G Audacious Goals:

Goals	Remarks
Digital World Experience	Will typically be included as part of sub-networks with the option of updates and interaction with distributed cloud repositories.
Trust, Security, and Resilience	Health care through in-body networks must include security and trusted devices. The design should not compromise the doctor/patient data and anonymity. To ensure privacy, 6G features may include some level of AI/ML.

5.6.3 Example Service Scenario

Scenario A: Monitor health conditions such as heart rate or blood pressure for diagnostic purposes. In addition, the elderly population is increasing globally, and this population will drive the growth of AR in the health care system. Furthermore, the use of AR in the health care field allows doctors to utilize clinical instruments and determine how new drugs interact with the patient's body.

Scenario B: Enable the treatments using in-body sensors and actuators (e.g., a wireless pacemaker controlling heartbeat, or a wireless insulin pump) that ensure the right glucose level in diabetic patients, and a muscle controller that can enable movements in patients with motor disabilities.

In addition to health care, local highly specialized subnetworks with limited coverage may be installed in locations with high-performance requirements, such as production modules, vehicles, or aircraft in different verticals.

5.6.4 Requirements

The performance requirements of in-body subnetworks may not be extreme in terms of either data rate or latency. In this case, a subnetwork is considered to consist of several devices with possibly one or more access points, which connect to an overlay network. In-body applications are life-critical, and it is, fundamentally, important that the required service level is ensured to the patients when necessary and as mandated by the healthcare provider. In addition, operations are battery-driven, with expected battery life in the order of years; thus, leading to major energy consumption constraints.

In order to support in-body networks comprised of micro-sized implants and ingestible devices, this technology needs to support extreme connectivity for conciseness, consistency, and improved efficiency; cost and energy consumption reduction are expected.

5.6.5 Study Areas

Working Groups impacted by this use case are 6G vision-enabling technology and spectrum dependency.

Additional items to consider are:

> Interference management across sensors, actuators, and access points.

> Federation of personal, enterprise, and operators' networks with flexible ownership and business models.

> Security and privacy architecture with distributed authority and zero-trust models.

6 PERSONALIZED USER EXPERIENCES

Personalized user experiences are real-time, fully automated, and secure personalization of devices, networks, products, and services based on a user's personal profile and context information (e.g., user's preferences, trends, and biometrics). context. Exemplary use cases that demonstrate the value of personalized user experiences include personalized leisure and travel experiences, personalized shopping experiences, personalized learning, and education experiences.

6.1 Summary and Overview

Existing 5G systems lack sufficient awareness of user identities, preferences (e.g., device, service, and application), and situational context (e.g., user's activity, biometrics, mood, etc.). This limitation prevents 5G systems from personalizing network resources, services, and applications and providing users with an enriched QoE.

6G use cases envisioned in this category demonstrate the value of automating in real/pseudo-real time the secure personalization of devices, networks, services, and applications based on a user's profile and current situational

6.2 Business Opportunity and Audacious Goal Alignment

Technology continues to play an ever-increasing role in daily lives. As humans go about their daily routines within their homes, at their workplaces, in stores, at restaurants, and while traveling, they encounter technologies such as interactive smart displays and digital assistants to assist and enrich their experiences. These technologies typically involve network-connected devices that enable users to connect the activities they perform in their physical world with information flowing to and from their digital world.

These technologies are starting to enable new and enhanced business opportunities. Businesses are incorporating these technologies into their products and services to gain a competitive edge. They seek improved ways to connect and provide their customers with more personalized types of service in hopes of establishing long-term relationships with their customers.

Traditionally, personalized service has required human-to-human interaction because technology and machines have lacked the intelligence and interpersonal relationship skills necessary to provide personalized service to humans. However, with recent technology advancements such as AI, smart bots, and a growing number of connected IoT devices, businesses are realizing the possibilities for new forms of personalization between users and machines. For example, technology that enables devices and services with awareness of different users and their preferences are starting to be deployed. This trend of technology personalization is expected to be a major focus and differentiator for businesses in the 6G timeframe.

Mapping to 6G Audacious Goals:

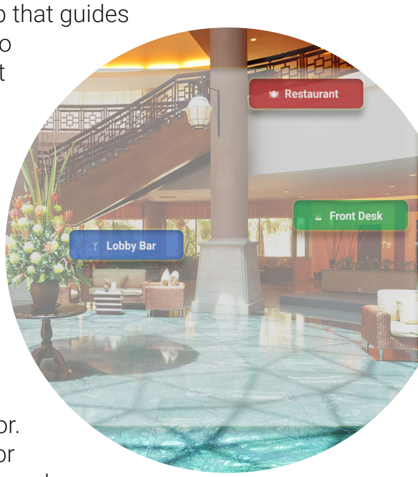
Goals	Remarks
Trust, Security, and Resilience	Personalization of the 6G system (devices, network resources, services, and applications) for individual users will require collecting, storing, and applying a user's personal profile and situational context information. Hence personalization will introduce new and challenging security threats, as well as privacy and trustworthiness implications that the 6G system must address.
Digital World Experience	Personalization of the 6G system will enable customized, multi-sensory experiences that provide transformative forms of human-to-human and human-to-machine interactions based on the personal preferences, routines, habits, and social relationships of users.
Distributed Cloud and Communication Systems	Personalization of the 6G system will enable on-demand and customized distributed cloud and communication systems for different individual users, as well as categories of users. This will enable communications and unified computing services to work together and scale across devices, network computing resources, and data centers in a manner that meets users' personalized requirements and needs.
AI-Native Network	6G AI-native systems will have the intelligence to learn how users engage and interact with devices, network resources, services, and applications. Based on this knowledge, the 6G system will be equipped to personalize itself by making dynamic adjustments to its resources to align with each user's needs and preferences and their context of use.

6.3
Use Case – Personalized Hotel Experience

Scenario 1: Personalized real-time automated guest check-in

While in transit, a guest's location and estimated arrival time at the hotel may be tracked to enable customized preparation of their room and so other hotel services (e.g., dinner reservations, room service) can be ready and to their liking upon arrival.

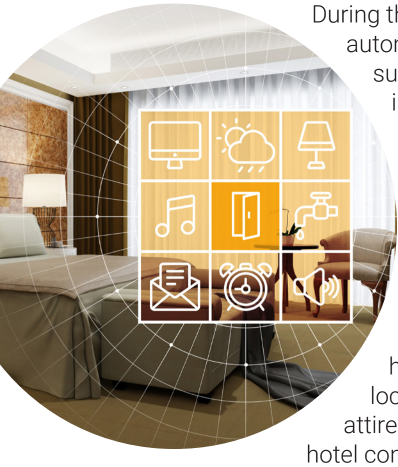
As the guest enters a hotel lobby, multiple hotel sensors perform an automated and secure multi-factor guest check-in process in a matter of seconds. Intelligent sensors perform facial recognition of the guest and detect the guest's personal device (e.g., smartphone, watch, and glasses). A notification is pushed to the guest's personal device with confirmation they have been automatically checked in along with their room number and an AR-based map that guides them to the elevators to take them to their room floor. Sensors also detect the presence of the guest's family members traveling with them and their personal devices. After receiving authorization from the guest's device, notifications are also pushed to each of the family member's personal devices, as well.



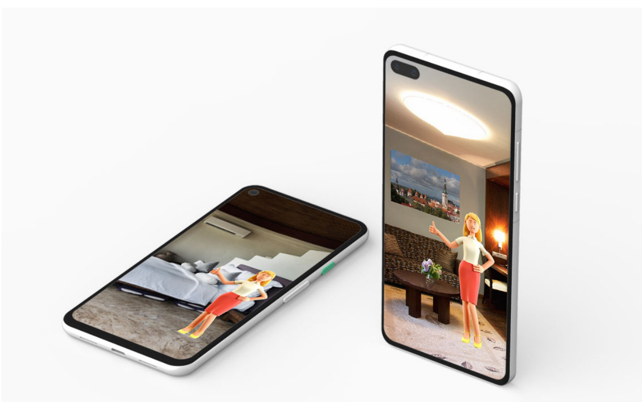
Upon entry into the elevator, the elevator detects the guest and automatically selects their room floor. Once on their floor, an AR-based floor map is displayed on the guest's personal device directing them to their room. Sensors on their door perform an automated and secure unlock procedure using multi-factor facial recognition and device detection.

Upon entry into the room, personalization of various smart devices in the room is automatically performed (e.g., thermostat, lights, blinds, bed firmness or softness, TV and streaming services, personalized digital pictures or artwork, virtual assistants, and concierges). This personalization is done by taking into account user profiles and real-time situational context of the guest and family members present in the room (e.g., their mood or actions, time of day). This information is securely gathered and aggregated from the guest's or family member's personal device(s) and/or from network resources (e.g., user profiles stored and managed by a service hosted in the cloud) and used to configure the devices in the room to provide the guests with a more personalized and satisfying stay in their hotel room.

Scenario 2: Personalized virtual hotel concierge and automated room service



During their stay, guests interact with several automated, personalized services. One such service is their own personal interactive virtual concierge, that answers their questions and provides recommendations for amenities and local attractions in and around the hotel. This concierge service is personalized based on preferences, interests, and situational context of the guest and family members staying in the hotel. For example, based on the location of the guests in the hotel, their attire, time of day, weather, etc., the virtual hotel concierge can make recommendations. The virtual hotel concierge can, over time, learn the preferences, activities of interests, and past activities of the guests such that it can form a relationship with the guests and further personalize its recommendations.



During their stay, guests also interact with automated, personalized service robots, which provide food service in their rooms or in hotel restaurants, deliver amenities such as towels and soap, and remove trash. The robots can be configured to track the guest's favorite meal and beverage selections. They can interact with guests to collect feedback regarding the services they provide (e.g., coffee was not hot enough) and adapt their service accordingly.

Scenario 3: Automated hotel check out and privacy assurance

During their stay and especially when checking out, any personalized devices, network resources, services, or applications that the user interacts with are wiped clean of any personal information once the user is no longer interacting with these resources. Supporting increased levels of personalization of 6G devices, network resources, services, and applications residing in public settings such as hotels, creates additional security threats and personal privacy concerns. These forms of personalization typically require the use and possible exchange of user information with resources that are not owned and operated by the user. Users typically interact with these resources for short opportunistic periods of time (e.g., hotel stays), after which new users come along and interact with the same resources. For this reason, special care must be taken to ensure secure methods are used when establishing trust between these resources and users, configuring the resources with personalized information during periods of user interaction to ensure no personal information is leaked and misused, and making sure that the resources are wiped clean of any personal information once a user completes interacting with the resources.

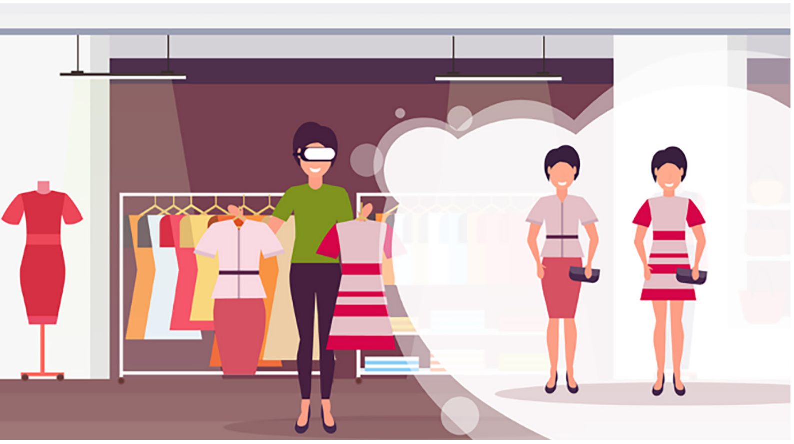
6.4 Use Case – Personalized Shopping Experience

Scenario 1: Interactive and virtual stores

Virtual shopping centers can be available as an immersive virtual environment providing real-time shopping experiences that will enable customers to immerse themselves in and be present in virtual stores, including interaction with products before actual purchase. In addition, customers could meet with friends in this virtual world and shop together in real time.

The virtual shopping experience will be personalized. Depending on the customer, different environments can provide a different level of immersion for the customer with varying degrees of realism. For example, as a customer enters a virtual clothing store, predictive impact analytics can automate the store mood by personalizing sounds and scents. In addition, the customer sees digital mannequins that are wearing styles based on their preferences and the clothes they may be browsing. Retailers will have a deep knowledge of every customer, informed by multiple data points, including an understanding of emotive cues used to personalize the retail space, even understanding whether a consumer likes or dislikes a product determined by a facial expression.

Scenario 2: Personalized customer service



A customer enters a virtual store and may be approached by avatars playing the role of sales consultants, navigating customers through the environment, advising them on certain goods, providing additional information, or answering questions. Through analytics, the retailer can personalize what the virtual sales consultants know about the customer to help them find the right product more quickly. For example, if a customer has been searching for a pair of jeans, an avatar consultant can advise on the jeans' best fit and style and suggest shirts to match.

Scenario 3: Immersive product demos

The virtual store environment will provide immersive experiences to help users engage with the product, touch, and feel it, and get to know it. A customer will be able to interact with products just like they would in the real world through immersive product experiences such as 3D visualizations, virtual try-ons, and other product demos. In addition, with 360-degree product views, customers can look at products from every angle, better understand the product's scale and proportions, and rely less on product descriptions and user manuals.

Scenario 4: Gamification of retail experiences

Retailers can integrate next-generation gaming experiences into the virtual store environment based on a user's profile. When a customer enters a virtual store, they are presented with the option of playing a game and are instantly offered promotions and discounts based on their personalized shopping preferences and achievement of milestones in the branded games. By engaging users with these branded game experiences, a retailer can encourage users to spend more time in the virtual store, particularly when personalized rewards are involved.

6.4.1 High Level Requirements

Based on a user's current situational context (e.g., location, activity, biometrics, mood), the 6G system will require the capability to perform the following in real time/pseudo real time:

> Securely monitor and collect information regarding user preferences and the interactions that users have with 6G devices, network resources, services and applications in a manner that does not jeopardize user privacy.

> Learn patterns and preferences involving how, when, where, and which types of interaction users have with 6G devices, network resources, services, and applications.

> In real/pseudo-real time detect trigger conditions based on the situational context of the user and securely perform actions on 6G devices, network resources, services, and applications to reconfigure/adapt their settings, data/content, operations, and performance to the align with user preferences and provide users with personalized experiences (e.g., hotel and shopping experiences).

6.4.2 Study Areas

> How can information regarding the preferences and interactions that users have with 6G devices, network resources, services, and applications in their proximal surroundings be securely monitored and collected within the 6G system without jeopardizing user privacy?

> How can patterns and preferences involving how, when, where, and which interaction users have with 6G devices, network resources, services, and applications in their proximal surroundings be learned within the 6G system?

> How can the 6G system detect trigger conditions based on the situational context of the user (e.g., user's presence, change in location, change in activity, change in emotional state) and securely perform actions on 6G devices, network resources, services, and applications to adapt their settings, data/content, operations, and performance to align with user preferences and provide personalized experiences (e.g., hotel and shopping experiences)?

7 RECOMMENDATIONS

6G applications are expected to foster North American market growth and improve the quality of life for consumers. Enhancements are expected to expand human interaction with devices, from voice assistants to service robots, and systems to provide enriched immersive VR/AR/MR experiences. It is expected that more than 60% of current smartphone users will have lightweight XR glasses by the time 6G is commercially deployed. These lightweight devices will be capable of generating a massive amount of traffic and will require low latency. It is expected that the use of robots will drastically expand from manufacturing to health care, logistics, elderly care, and social companions. These robots will have mobility and natural language capabilities. They will require accurate localization and mapping for seamless mobility, as well as access to data centers for natural language processing. The support of XR devices at scale and robotics at scale must be a fundamental part of the 6G design and architecture.

6G applications are also expected to improve productivity, quality, time-to-market, and cost-effectiveness for enterprises. The Applications Working Group has classified the 6G use cases into the following four categories:

> Network-Enabled Robotics and Autonomous Systems

> Multi-Sensory XR

> Distributed Sensing and Communications

> Personalized User Experiences

Although every use case can be different, each category of use cases has its own general set of characteristics. The 6G characteristics have been categorized in the following manner:

> Performance

> Localization and Sensing

> Connectivity

> Communication

> Services

> Terminal/Device

The following Next G Alliance Working Groups can benefit from this report:

> Technology Working Group

> 6G National Roadmap Working Group

> Societal and Economic Needs Working Group

> Green G Working Group

> Spectrum Working Group

The following external organizations can benefit from this report:

> Research Organizations

> Communications Service Providers

> Hyperscale Cloud Providers

> Enterprises

7.1 Characteristics – Performance

> DL User Experience Data Rate: The minimum data rate required to achieve a sufficient quality experience for an application to function correctly, with the exception of the scenario for broadcast-like services, where the given value is the maximum that is needed. "Data rate" refers to the data volume V that is transmitted within a given duration T. With V measured in bits and T in seconds the data rate D = V/T is a quantity measured in bits per second.

Per 3GPP, GBR: The minimum guaranteed bit rate per EPS bearer in downlink; MBR: The maximum guaranteed bit rate per EPS bearer in downlink. Best effort.

> > **Proposed range of values:** Very Low: < 100kbps, Low: < 10 Mbps, Medium: 10 – 50 Mbps, High: 51 Mbps – 100 Mbps, Very high data rate: 101 - 1000 Mbps, Ultra high data rate: > 1000 Mbps

> UL User Experience Data Rate: The minimum data rate required to achieve a sufficient quality experience in other words for an application to function correctly, with the exception of scenario for broadcast-like services where the given value is the maximum that is needed. Data rate refers to the data volume V that is

transmitted within a given duration T. With V measured in bits and T in seconds the data rate D = V/T is a quantity measured in bits per second.

Per 3GPP, GBR: The minimum guaranteed bit rate per EPS bearer in downlink. MBR: The maximum guaranteed bit rate per EPS bearer in downlink.

> **Proposed range of values:** Very Low: < 100kbps, Low: < 10 Mbps, Medium: 10 – 50 Mbps, High: 51 Mbps – 100 Mbps, Very high data rate: 101 - 1000 Mbps, Ultra high data rate: > 1000 Mbps

> Synchronization precision: Maximum allowed time offset within a synchronization domain between the sync primary device and any sync secondary device. This is also known as clock synchronicity.

> **Proposed range of values:** Low: > 1ms, Moderate: > 100us, High: > 10us, Very High: > 1us, Ultra High: < 1us, N/A: Not Applicable

> Service Continuity: Seamless service continuity is supported in scenarios where the UEs are mobile and handover (intra-/inter-technology) occurs, achieving continuous connectivity and data-centric services as the UE moves in-between cells, access technologies, and/or edge data networks.

> **Proposed range of values:** Not Required, Required

> Mobility (type/speed): Maximum relative speed under which the specified reliability should be achieved.

> **Proposed range of values:** Fixed (including nomadic), Pedestrian: > 0 km/h to 10 km/h, Vehicular: 10 to 120 km/h, High speed vehicular: 120 to 350 km/h, Very high speed: 350 to 500 km/h, Ultra high speed: > 500 km/h

> DL E2E Packet Latency: The time taken for a piece of data to be transmitted E2E across a network from a source to a destination endpoint (e.g., between a web client and server) in DL direction.

> **Proposed range of values:** Very low: < 1ms, Low: < 10ms, Moderate: < 50ms, High: < 100ms, Very High: < 500ms, Best effort

> UL E2E Packet Latency: The time taken for a piece of data to be transmitted E2E across a network from a source to a destination endpoint (e.g., between a web client and server) in UL direction.

> **Proposed range of values:** Very low: < 1ms, Low: < 10ms, Moderate: 10ms-100ms, High: 100ms-500ms, Not: Best effort

> E2E Packet Jitter: The variation in latency within a flow of packets transmitted E2E across a network from a source to a destination endpoint (e.g., between a web client and server).

> **Proposed range of values:** High: Very Sensitive (Microseconds), Moderate: Sensitive (millisecond), Not Sensitive

> Availability: Probability that a system will be operational when a demand is made for service. Measured as Uptime/(Uptime + Downtime).

> **Proposed range of values: Low:** < 90%, Medium: 90% – 95%, Medium High 95 - 99.9%, High: > 99.9%, Very high: > 99.999%, Extremely high: > 99.99999%, Best Effort

> DL E2E Packet Reliability: The loss rate of packets transmitted E2E across a network in the downlink direction (e.g., from a web server to a client).

> **Proposed range of values:** Very low: < 10%, Low: < 1%, Moderate: < 10E-3, High: < 10E-6, Very high: < 10E-8, Best effort

> UL E2E Packet Reliability: The loss rate of packets transmitted E2E across a network in the uplink direction (e.g., from a web client to a web server).

> **Proposed range of values:** Very low: < 10%, Low: < 1%, Moderate: < 10E-3, High: < 10E-6, Very high: < 10E-8, Best effort

7.2 Characteristics – Localization and Sensing

> Position Accuracy: Describes the closeness of the measured position of the UE to its true position value. The accuracy can describe the accuracy either of an absolute position or a relative position. It can be further derived into a horizontal position accuracy — referring to the position error in a 2D reference or horizontal plane — and into a vertical position accuracy referring to the position error on the vertical axis or altitude.

> **Proposed range of values:** Fixed: (no Localization needed), Relaxed: (3 m – 30 m), Moderate: (1 m - 3m), Stringent: (0.1 m – 1 m), Very stringent: (1 mm - 10 cm)

> Range resolution: The range resolution of a sensor is defined as the minimum separation (in range) of two targets of the equal cross-section that can be resolved as separate targets. Equivalent to delay resolution.

> **Proposed range of values:** Relaxed: (50m -200 m), Moderate: (10 -50 m), Stringent: (0.1m -10 m), Very stringent: (1 mm - 10 cm)

- Object-Sensing Accuracy: Measure sensing accuracy based on missed detection (MD), the probability of false alarms (FA), and parameter estimation errors.
    - **Proposed range of values:** Relaxed: < 10%, Stringent: < 1%

7.3 Characteristics – Connectivity

- Survival time: The time that an application consuming a communication service may continue without an anticipated message.
    - **Proposed range of values:** Very low: < 0.1ms, Low: 0.1 - 1ms, Moderate: 1 – 50ms, High: 50-100ms, Very High: > 100ms
- Connectivity Type (BAN/PAN/WAN/LAN)
    - Body Area Network (BAN) - short-range – includes in-body networks with devices such as implants and body sensors.
    - Personal Area Network (PAN) - short-range, where distances can be measured in meters, such as a wearable fitness tracker device that communicates with an app on a cell phone over BLE. This shall include short-range, low power 6G '"in" subnetworks (X is an entity such as a production module, a robot, a vehicle, a house).
    - Local Area Network (LAN) - short - to medium-range, where distances can be up to hundreds of meters, such as home automation or sensors installed within a factory production line that communicate over Wi-Fi with a gateway device is installed within the same building.
    - Wide Area Network (WAN) - long-range, where distances can be measured in kilometers.
    - **Proposed range of values:** BAN, PAN, LAN, WAN, Multiple
- Sidelink connectivity: Refers to the need or ability of the device to use sidelink connectivity (e.g., UE-to-UE, V2V, UE-to-wearable).
    - **Proposed range of values:** Required, Can be beneficial, Not applicable
- Criticality: Refers to the need of the device to provide services in situations when failure is not an option.
    - Mission critical - failure by the device can jeopardize enterprise operation and cause significant loss in business and assets
    - Safety critical - execution failure or faulty execution by the device could result in injury or loss of human life
    - **Proposed range of values:** Non-critical, Safety critical, Mission critical
- Priority Services (NS/EP): Public safety/Critical Communications Priority Services. Various priority services exist today to support key personnel in their critical communications during a National Security and Emergency Preparedness (NS/EP) condition. These services include priority voice, video, and data. Priority signaling/control and priority IP packet transport capabilities have been defined in standards to provide preferential treatment on communication by a service user (authorized by the Office of Emergency Communications (OEC)) for NS/EP.
    - **Proposed range of values:** Yes, No
- Connection density: Number of devices per km²
    - **Proposed range of values:** Low: < 1000, Medium 1000-10000, High: ≥ 10000, Very High: ≥ 1M, Ultra-High: ≥ 10M, Variable

7.4 Characteristics – Communication

- Communication direction
    - One-way - Simple Devices make one-way service requests while monitoring themselves. Examples include home appliances, propane tanks, commercial vending machines, porta-potties, and garbage cans. Data flows only outward, with "Help me!" messages like "I need to be filled," "I need to be emptied," or "I need to be serviced because of the following diagnostics code." No message is sent when no servicing is needed (unless a periodic ping of existence is required). NOTE: While communication is primarily one-way, the device may have the ability to download config changes and updates to firmware, but this is done less frequently.
    - Two-way - Interactive devices with bidirectional communication of data. For example, a connected smoke detector must deliver a smoke alarm with absolute certainty. Need network to provide acknowledgments of a received message to enable better fault management and the required level of reliability.
    - **Proposed range of values:** One-way, Two-way
- Common Communication mode

- Common Communication mode - excludes Operational maintenance communication such as firmware updates and configuration changes.
- Unicast - “one-to-one” communication that passes from a single source to a single receiver or destination.
- Multicast - “one-to-many” technique that sends information from a single source to multiple destinations that express an interest in receiving it.
- Broadcast - “one-to-all” communication technique that ensures that all the nodes on a network receive the same information.
- **Proposed range of values:** Unicast, Multicast, Broadcast

- Data reporting mode
  - Time Driven - where machines periodically turn on their sensors and transmitters to transmit the collected data
  - Query Driven - where devices reply to certain instructions from application servers by transmitting data
  - Event Driven - where devices react to certain critical query or event
- Continuous-based - where devices send their data continuously to the remote server at a pre-specified rate.
  - Hybrid-driven - combination of the aforementioned types
  - **Proposed range of values:** Time Driven, Query Driven, Event Driven, Hybrid-driven

7.5 Characteristics – Services

- Edge Computing Service: Edge computing enables applications to be localized and brings them closer to end-users to improve network transit latency, save transport costs, and localize data for security and privacy reasons. If the use case needs this service, then it could delve deep into detailed needs such as computing, storage, networking, application services, proximity, and resource management.
  - **Proposed range of values:** Required, Not Applicable
  - AI/ML Service: Ability to use the AI/ML capabilities provided at the edge or telco cloud in the system. If the use case needs the AI/ML service, then it could delve deep into detailed needs such as personalization, training data security, privacy, trust, service location, ownership, traceability, accountability, and incentivized/distributed/collaborative AI/ML.
  - **Proposed range of values:** Required, Not Applicable
- Adaptability – APIs: Requires ecosystem support of network- and device-based APIs.
  - **Proposed range of values:** Network-based, Device-based, Both, API not needed

7.6 Characteristics – Terminal/Device

- Device Lifespan: Some standalone consumer products may have a relatively short lifespan (2-4 years) whereas infrastructure, automotive, and domestic appliance applications need to have stable support for more than a decade (or even longer). This will drive support requirements on the network.
  - **Proposed range of values:** Short: 2-4 years, Medium: 4-8 years, Long: More than 8 years
- Device Power Constraints: Devices that are power constrained use battery technologies or they can use some techniques for taking (harvesting) power from their environment using other devices and/or thermal dissipation limits of the form factor.
  - **Proposed range of values:** Unlimited, Constrained: < 2W, Limited: < 500mW, Very Limited: < 50mW
- Number of subscriptions supported by the device: Number of SIM slots or number of profile spaces available in eSIM.
  - **Proposed range of values:** 1, > 1
- Device Configuration and Customization: Ability to update (e.g., personalize or upgrade) specific settings and services of a device before or after deployment.
  - **Proposed range of values:** Not Required, Required Pre-deployment, Required Post-deployment

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9 ABBREVIATIONS

6G	6^{th} Generation
AI	Artificial Intelligence
AR	Augmented Reality
CAD	Computer-Aided Drafting Design
CAGR	Compound Annual Growth Rate
CV	Computer Vision
DoF	Degrees of Freedom
E2E	End-to-End
FPV	First-Person View
GPS	Global Positioning System
HAP	High-Altitude Platforms
HMI	Human-Machine Interface
IIoT	Industrial Internet of Things
IoT	Internet of Things
LEO	Low-Earth Orbit
MBSR	Mobile Base Station Relay
ML	Machine Learning
MR	Mixed Reality
NPN	Non-Public Network
NTN	Non-Terrestrial Networks
NTP	Network Time Protocol
PLL	Phase Lock Loop
TSN	Time-Sensitive Network
RAN	Radio Access Network
ROV	Remotely Operated Vehicle
SLAM	Simultaneous Localization and Mapping
SOBOT	Service Robot
UAV	Uncrewed Aerial Vehicle
VR	Virtual Reality
XR	eXtended Reality