(one6G)

Taking communications
to the next level

6G VERTICAL USE CASES

DESCRIPTIONS AND ANALYSIS

WHITE PAPER

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Introduction

The 5G wireless system is designed to provide high-speed data transmission in the order of several Gbps, low latency in the order of a few milliseconds, and high reliability (up to 99.9999%). With prominent features such as network slicing and an evolved core network towards a service-based architecture, it is possible to customize 5G to realize diverse use case categories falling into one of the three categories: enhanced Mobile BroadBand (eMBB), Ultra-Reliable Low Latency Communication (URLLC) and massive Machine Type Communication (mMTC). With these features, along with its focus on vertical sectors, 5G has attracted a lot of attention from various industries, e.g., manufacturing, agriculture, healthcare, logistics, construction, entertainment.

While industries are considering how to make use of 5G in their domains, several technical challenges and potential further improvements of 5G have been identified, e.g., coverage in a non-line-of-sight (NLOS) environment and uplink performance. Such challenges along with other aspects such as "solving social problems", "enhanced communication between humans and things", "expansion of communication environment" and "sophistication of cyber-physical fusion" are driving many researches to start thinking about visions and considerations for 6G [31][40][41][42]. To realize such a future world in 2030, when 6G is anticipated to be introduced, it is expected that novel use cases and applications from certain vertical domains/industries will demand extreme requirements in several performance indicators that cannot be supported by 5G, either by exceeding the capacity of 5G or by having conflicting requirements that cannot be met jointly. Typical 6G use cases and scenarios are depicted in Figure 1-1 [43].

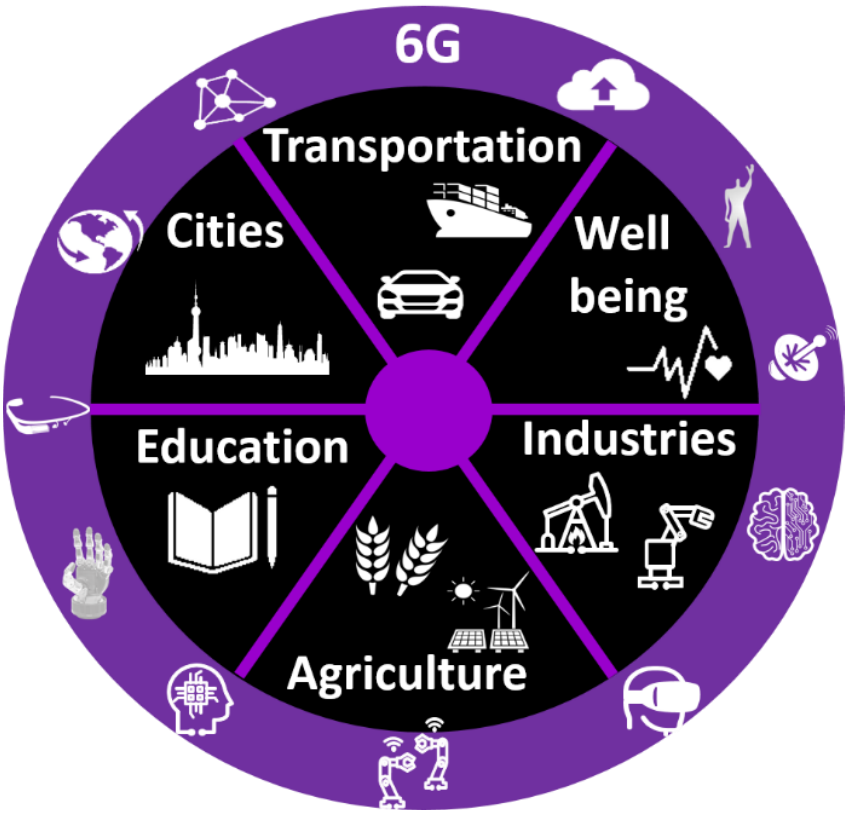


Figure 1-1: Typical 6G use cases and scenarios. [43]

Given the simultaneous technology evolution and technology adoption in different vertical industries, we first try to capture use cases from both technology and vertical industry perspective. Although this white paper does not include an exhaustive list of use cases, it aims to trigger use case driven technology development. The reason to place emphasis on use cases is to primarily identify the specific requirements that need to be addressed. Understanding the requirements is fundamental to developing and proposing technologies. Furthermore, use cases are not only a starting point to identify requirements and technology enablers, but also potential business opportunities and go-to-market strategies. Driven by this motivation, we compile several use cases with relatively elaborate descriptions. The use case descriptions in this white paper comprises of: background to understand the vertical industry setting, the specific requirement that needs to be addressed, the potential technology gaps to meet the requirement, a high-level overview of how the use case can be implemented in practice. With the above details from multiple vertical industry use cases, we can start getting a glimpse of different requirements pertaining to verticals and hence develop holistic solutions, both technical and business.

Focusing specifically on use cases descriptions, this white paper is organized as follows. Various use cases are described in detail in the corresponding section. Then, there is a section where all use cases are grouped as per vertical domains for a better understanding on what are the open issues in the current communication system to support the identified use case and what are expected to be supported for further development of future generation of mobile communication (e.g., 6G). Finally, we have summarized an overview of potential requirements from each vertical domains and what are examples of technology enablers that could fulfill the identified requirements.

Abbreviations

AIaaS AI as a Service
AGV Automated Guided Vehicle
AMR Autonomous Mobile Robot
AR Augmented Reality
CAPEX Capital Expenditure
CME Coronal Mass Ejection
eMBB enhanced Mobile BroadBand
GIC Geomagnetically Induced Currents
GNSS Global Navigation Satellite Systems
IoE Internet of Everything
IoT Internet of Things
ISAC Integrated Sensing And Communication
mMTC massive Machine Type Communication
MNO Mobile Network Operator
NTN Non-Terrestrial Network
OEM Original Equipment Manufacturer
OPEX Operating Expenditure
OWC Optical Wireless Communication
PLMN Public Land Mobile Network
ToD Tele-Operated driving
TSN Time Synchronized Network
UAV Unmanned Aerial Vehicle
URLLC Ultra-Reliable Low Latency Communication
V2V Vehicle to Vehicle
V2X Vehicle to Everything
VR Virtual Reality

Use Cases

In this section use cases contributed from several One6G partners, coming from different vertical industries, are described. The verticals include: manufacture, automotive, telecom, health, etc. All the use case descriptions follow a common template. The template comprises of the following sections:

- Introduction: Describe the motivation of the use case including why the use case needs 6G and why it cannot be fulfilled by 5G
- Actors: Describe the actor(s) (e.g., communication service provider, entity involved) of the use case
- Pre-condition: Describe what are the condition(s) that need to be fulfilled for the use case to be enabled.
- Description/Service Flows: Describe step by step on the use case with the involved actor(s)
- Post condition: Describe what happens after the use case has happened.
- Potential service requirements: Describe what are the service requirements needed to support the use case to make it happen.

Use case#1

Remote software update for vehicles in underserved areas

1. Introduction

Over the last years, the number of software-based components in vehicles has been steadily increasing. In order to easily and conveniently update the software, several car manufacturers have been implementing remote software update. This allows the latest versions of the software, for example to support new features or offer more support to existing ones, to be downloaded while driving or being parked. Thus, reducing the need to visit the service station for such purposes. This is typically enabled via a SIM card installed in the vehicles, and relying on mobile network coverage. However, as mobile network planning is predominantly based on population demographics, all road networks may not necessarily have the desired mobile network coverage or capacity to enable remote software update. For vehicles in areas such as villages, areas out-of-base-station coverage (OOC areas), enabling software update at the desired time interval may not be always possible. The reasons for this could be, vehicles predominantly moving only in the village or OOC area. The goal of this use case is to enable software update to vehicles in underserved areas. An underserved area refers to an area with limited mobile network coverage or capacity to support software update.

2. Actor

Vehicle, Satellite operator, Application server, Mobile network operators

3. Pre-condition

- Vehicle capable of communicating with an application server
- Application server capable of communicating with a vehicle or multiple vehicles
- Application server (e.g., belong to vehicle OEM) publishes a software update
- A vehicle requests for a software update

4. Description/Service Flows

- Either an application server publishes a software update for one or more vehicles, or a vehicle or group of vehicles have a software update request in a certain underserved area. Such requests/updated include unlocking a certain set of available features in the vehicle (e.g., battery range), or bug fixes in vehicle software after sale.
- When vehicles are not under the coverage of mobile network operators, they are served via a secondary communication link that is established, for example, via satellite communication offered by a satellite operator, with the application server.

5. Post-condition

Successful software update at all times when vehicles are located in underserved areas.

Software update to a fleet of vehicles in a certain geographical area such as district, city, state, country.

6. Potential service requirements

It shall be possible to successfully and securely update the vehicle software in areas with limited mobile network coverage without impacting safety functionality of the vehicle. This is particularly critical when the software update is performed while driving the vehicle. Some critical KPI that might need to be fulfilled for the satellite link include: Latency, Throughput, Reliability, Service availability

Use case#2

Tele-operated driving in the presence of mobile network coverage gaps

1. Introduction

Tele-operated driving (ToD) refers to a remote driver taking control of the vehicle (human driven or automated) and driving it efficiently and safely from the current location to the destination [43]. Being able to remotely drive a vehicle requires the availability of wireless links between the vehicle and the ToD server. Apart from availability of the wireless networks, the networks might need to further fulfil certain Quality-of-Service (QoS) metrics on the available wireless links. Since a request to take control or assist a vehicle to drive can originate at time and from anywhere, availability of continuous wireless network coverage along the trajectory of the tele-operated vehicle is crucial. With the current deployment of mobile communication networks, there exists coverage and capacity gaps, for reasons such as, due to low demand. Such gaps and unknown availability of mobile networks can hinder the operation of ToD. Examples of scenarios where a vehicle could encounter mobile network coverage gaps include, among others, travelling from coverage of one base station to another, travelling from coverage of one PLMN to another, while crossing national boarder, traveling from urban to rural areas.

2. Actor

Vehicle, Satellite operator, ToD server

3. Pre-condition

- Vehicle capable of communicating with ToD server
  - The vehicle capable of sharing information about the perceived environment with the ToD server
- ToD server capable of communicating with a vehicle
- The vehicle capable of executing instructions from the ToD server

4. Description/Service Flows

- A vehicle (human driven or automated), Alice, is currently connected to a mobile network.
- Alice requests a remote driver (ToD Server) to take control or assist in driving for a certain length of journey.
- The ToD server acknowledges to serve Alice's request.
- The ToD server based on the information received from Alice or other sources infers a potential discontinuity in the mobile network coverage.
- The ToD server informs and requests Alice about switching to other alternate link, for example, satellite link based remote driving for a certain length of the journey.

- Alice acknowledges the request and seamlessly switches to satellite link based remote driving.

5. Post-condition

Alice is remotely driven until the desired location in a safe and efficient manner without service discontinuity, while seamless switching among the different wireless links depending on their availability.

6. Potential service requirements

The wireless networks shall allow service continuity despite mobility of the vehicles. The wireless networks and the vehicle shall be capable of switching their communication links to the application provider to ensure service availability. From KPI perspective, the wireless links, via mobile network operators or satellite operators need to fulfil certain metrics such as: Latency, Throughput, Reliability, Service availability.

Use case#3

Simplified mobile network for indoor mobile traffic

1. Introduction

5G is designed to provide high data rate, high capacity, low latency and massive connectivity such as Internet of Things (IoT) devices for end customers. 5G Core Network (5GC) has been leveraged with the Service based architecture and network slicing to enable mobile network operator to customize their network to fulfill specific needs or requirements of different verticals. However, the majority of future mobile traffic will continue to be video traffic (76% share of mobile capacity by 2025 [1]), for which many video applications will be based on the "best effort" network and work well with changing of IP, if any. In addition, forecast results show that the majority of mobile traffic generated via indoor e.g., 80% of the mobile traffic are supposed to come from a nomadic behavior of mobile subscribers [2]. In this regard, a mobile network operator can introduce a simplified core network for a large fraction of best effort mobile traffic that does not depend on mobility support (IP address preservation) and reduces CAPEX and OPEX including power consumption.

2. Actor

Mobile subscribers, Mobile Network Operator (MNO), 3rd party service provider

3. Pre-condition

A MNO has a trust relationship with a business partner (3rd party service provider).
A mobile subscriber has a basic tariff for his/her subscription for connectivity service with a MNO.
A mobile subscriber has a subscription with the 3rd party service provider for the best effort service without support for mobility (i.e., IP address preservation).

4. Description/Service Flows

A 3rd party service providers wants to provide a mobile multimedia communication service to its subscriber (mobile subscriber) via a dedicated network slice, which provides a connectionless best effort service without specific QoS treatment and without support for mobility, e.g., without User Plane Function (UPF).

The 3rd party service provider requests the MNO to provide the network slice.
After the mobile subscriber registers to the network of MNO, the mobile subscriber enjoys a mobile multimedia communication via the dedicated network slice.

5. Post-condition

A mobile subscriber enjoys his/her multimedia communication via his/her mobile terminal via the dedicated network slice provided by the 3rd party service provider.

MNO can reduce its CAPEX/OPEX including power consumption for this simplified network slice.

6. Potential service requirements

It shall be possible that a MNO provide a simplified network slice that provide a connectionless best effort service with relaxed QoS treatment and without support for mobility.

KPI needed for such simplified network slice is, for example, high bandwidth to support video traffic, no mobility support and low/less energy consumption.

Use case#4

Secure delegation of trust for mobile connectivity

1. Introduction

The digital economy is at the heart of modern civilization which underpinned by mobile communication systems. We are entering a new era of massive connectivity and the rise of the Internet of Everything (IoE) paradigm. The future 6G network will have to cope with personal IoT networks such as connected wearable or implantable devices (e.g., temperature/blood pressure sensor for health monitoring), and IoT devices resided in the office or factory (e.g., AMR/AGV robots, arm robots)., however, the conceptual trust model has remained the same over the decades. For instance, the subscriber builds a trust relationship in the form of a contract, in return, the mobile network operator (MNOs) provides the cryptographic chip (i.e., physical card or embedded Universal Subscriber Identity Module (USIM)) with a preconfigured credential for the subscriber device. Therefore, as connected devices (including personal devices, vehicles, machines, …) is continuously increasing, the identity management becomes a major challenge, and it will also be a cumbersome and cost-prohibitive process to provide a pre-configured cryptographic chip (i.e., physical card or embedded SIM) for each device. In this regard, a new trust model can be introduced so that an authorized subscriber securely delegates the trust to other devices so that other devices can claim legitimacy to connect to the mobile network without the essence of cryptographic chip. An authorized subscriber can define different conditions in the trust delegation to other devices, for example, the delegation can be for a certain period of time (e.g., 10mins, 1day, 1 month, etc.).

2. Actor

Mobile subscribers, Mobile Network Operator (MNO), 3rd party service provider

3. Pre-condition

A subscriber device is capable of performing cryptographic operation for secure delegation of trust to other devices.

An MNO provides a platform to establish trust relationship between a subscriber's device and other trusted devices, and to delegate trusts among them in the form of digital contracts.

An MNO's network is capable of getting the required information for trust delegation, determining the legitimacy, and securely providing credentials to the delegated devices.

4. Description/Service Flows

A 3rd party service providers or smartphone subscriber establishes the new trust relationship with the MNO. In return, MNO's network trust relationship identification to the subscriber or 3rd party provider.

The subscriber or 3rd party provider determine to delegate the trust to other devices (e.g., based on other device request, the subscriber device or subscriber or 3rd party provider establish a secure connection and share a delegation information. Therefore, the device uses the delegation information and request for the mobile connectivity to the MNO's network and the network determine the legitimacy of the delegation and provide connectivity service to the device.

Furthermore, depending on the configuration or policy set by either the MNO or the subscriber (3rd party provider), the chain of trust can be maintained even if the trust delegated devices go offline or are powered off.

5. Post-condition

A mobile subscriber enjoys mobility connectivity service based on the delegation trust information without establishing the new relationship.

6. Potential service requirements

It shall be possible that an MNO provide a connectivity without trust relationship and cryptographic chip.

Use case#5

Integrated sensing and communication for V2X in ultra-dense networks

1. Introduction

The goal of this use case is to enable efficient operation of ultra-dense networks whose coverage area comprises of dynamically varying environment. Specifically, the base stations are enabled to proactively adapt (e.g., beam alignment, resource management) based on the dynamicity in its coverage. The dynamicity can result from either active or passive elements in the environment. Active elements are those that have established an active connection with the network. Passive elements are those that have not/cannot establish an active connection with the network, but influence the performance of the network. In the context of V2X networks, active elements include, among others, vehicles that are connected to the network. Likewise, passive elements can include, among others, pedestrians without using an active device or foliage. In today's networks, network management and adaptation decisions are largely dependent on active elements. The detection of passive objects can further enable efficient proactive mechanisms in order to meet the demanding requirements of future use cases.

2. Actor

Base stations, vehicles, passive elements

3. Pre-condition

- Base stations capable of detecting active and passive elements in its coverage
- Base stations capable of receiving information about active and passive elements in its coverage or elements approaching its coverage
- Vehicle capable of communicating with appropriate application server
- Application server capable of communicating with a vehicle

4. Description/Service Flows

- Alice, an automated robot taxi, starts travelling towards the city centre. Alice relies on one or more connected vehicle service such as, HD map collection and sharing, remote driving, etc. Alice is initially connected to a base station of a certain mobile network operator.
- Due to the short radio coverage of the base stations in the city due to ultra-dense network deployment, Alice is frequently moving from the coverage area of one base station to another.
- While Alice is travelling, the base stations are able to *detect, either directly or indirectly* (based on other sensing devices in the vicinity)_the presence of Alice, the environment around Alice, and the environment under their coverage. Generally, the environment can comprise of, among others, buildings, foliage, other connected vehicles, pedestrians.

- The environment, even if mostly comprising of passive elements, such as, for example, parked vehicles, road work related activities, can have a significant influence on the radio environment and hence affect the wireless network performance for Alice.
- The base stations, by detecting the dynamicity in the environment due to passive and active elements, can initiate/trigger adaptation mechanisms such as beam alignment to support the stringent requirements of Alice's use cases.

5. Post-condition

- The base stations is aware of active and passive elements in its coverage area.
- Base stations is able to perform adaptations based on the presence of active and passive objects in its coverage area

6. Potential service requirements

From service point of view, the requirements are as follows:

- It should be possible for sensing capable devices to exchange sensing information with each other

From performance metrics point of view, the requirements are as follows:

- Communication requirements:
  - Latency
  - Throughput
  - Reliability
- Sensing requirements:
  - Range resolution: If range resolution is 'x' (m), this means that the sensing system should distinguish between elements that are 'x' (m) apart.
  - Velocity resolution: If velocity resolution is 'x' (m/s), this means that the sensing system should distinguish between elements with velocity difference of 'x' (m/s).
  - Maximum range: Maximum detection range (or distance) of the sensing system.
  - Maximum and minimum velocity: The sensing system needs to be able to detect elements moving with a certain maximum and minimum velocity.

Use case#6

Integrated sensing and communication for V2V communication

1. Introduction

The goal of this use case is to enable an automated vehicle to maintain a direct communication link with a desired vehicle in its vicinity. Since vehicular networks are inherently dynamic in nature, maintaining such a direct communication link requires up-to-date knowledge of the surrounding environment at all times. The surrounding environment may comprise of different kinds of objects such as other vehicles, pedestrians, building, etc. Each of these objects may have different communication capabilities. The capabilities of the objects could range from being able to communicate with the automated vehicle using the same technology, to not being able to communicate at all. Today's vehicular networks largely rely on periodic broadcasts of awareness messages from other vehicles in order to perceive the environment. Additionally, certain vehicle manufacturers offer proprietary services to share sensor information with other vehicles provided they belong to the same manufacturer. Considering that the vehicular environment comprises of objects with diverse communication capabilities and possibly uncertain network coverage, being aware of surrounding objects at all times may not be possible by purely relying on message exchanges. Sensing the environment and detecting different kinds of objects in the vicinity, despite the diverse vehicular communication scenarios, may enable an automated vehicle to become aware of its environment. Based on such environment perception, an automated vehicle could efficiently adapt in order to maintain the direct communication link with the desired vehicle by triggering appropriate mechanisms (such as transmit power control and beam alignment).

2. Actor

An automated vehicle, a desired vehicle to establish direct communication link in the vicinity of automated vehicle, other objects in the vicinity

3. Pre-condition

- An automated vehicle capable of detecting objects in its vicinity
- An automated vehicle capable of establishing a direct communication link with a desired vehicle

4. Description/Service Flows

The following description/service flow is based on considering a sensor sharing use case as an example.

- Alice, an automated robot taxi, starts its journey on a highway.
- Alice wishes to receive sensor information from another vehicle driving ahead of it in a different lane.
- Alice establishes a direct communication link with this desired vehicle.

- After sharing sensor information for a certain duration, Alice detects a van approaching which could potentially block the direct communication link it has established.
- Alice has not established any communication link with the approaching van.
- Based on the detected vehicle, Alice proactively initiates to change its communication mode (communication via network) to avoid the impact of blocked direct communication link.

5. Post-condition

- Alice has managed to continue to share the sensor information despite dynamicity in the environment.
- Alice was able to precisely detect the vehicles (e.g., position, speed, direction, etc) without an active connection.
- The communication link between Alice and the desired vehicle could fulfill the necessary communication requirements for sharing sensor information.

6. Potential service requirements

From service point of view, the requirements are as follows:

- It should be possible for vehicles to precisely detect other vehicles in the vicinity.
- It should be possible for vehicles to instantaneously communicate and coordinate their behaviour based on changes in the environment.

From performance metrics point of view, the requirements are as follows:

- Communication requirements:
  - Latency
  - Throughput
  - Reliability
- Detection/Sensing requirements:
  - Range resolution: If range resolution is ‘x’ (m), this means that the sensing system should distinguish between elements that are ‘x’ (m) apart.
  - Velocity resolution: If velocity resolution is ‘x’ (m/s), this means that the sensing system should distinguish between elements with velocity difference of ‘x’ (m/s).
  - Maximum range: Maximum detection range (or distance) of the sensing system.
  - Maximum and minimum velocity: The sensing system needs to be able to detect elements moving with a certain maximum and minimum velocity.

Use case#7

Ultra-high reliability support with tighter integration between mobile communication network and application layer

1. Introduction

Mobile networks have experienced a constant evolution and an enormous transformation from analog voice calls to modern high-speed broadband services to support millions of applications. 5G set the foundation to realize a variety of use cases based on enhanced mobile broadband (eMBB), ultra-reliable low latency communication (URLLC), and massive machine type communication (mMTC). The URLLC is one of the key pillars of the 5G system and it will continue to influence the future 6G network.

But the current 5G reliability mechanisms are largely influenced by previous generation technologies such as 4G, inheriting some limitations such as failures of the application layer are supposed to be handled by the application layer, as anything outside the mobile network domain is considered as out of the scope of the 5G system. Therefore, 5G is not well prepared for the rapid development of emerging technologies e.g., cyber-physical fusion, eHealth and haptic communication with human sense, where application-network interaction is critical for providing ultra-high reliability. To meet the reliability requirements from emerging services, it relies on redundant paths as possible with Multi-path TCP or IEEE Frame Replication and Elimination, but the communication session will be dropped if the application server fails, e.g., due to power outages. In this case, the reliability mechanism defined by 5G is also not helpful in maintaining the sessions if the application server fails. In general, if the application server fails, the communication session will be re-established with the redundant application server. But even with this approach, it is still not sufficient, because the ongoing session has to be dropped first and then a new session is to be established with a redundant application server. Therefore, a robust reliability mechanism is required for handling with the application server failure with much more coordination between the network and the application. For example, cellular network must have application-level knowledge and seamlessly route traffic to the redundant application servers if the active application server fails.

2. Actor

Mobile subscribers, Mobile Network Operator (MNO), 3rd party service provider

3. Pre-condition

An MNO network exposes an API for the application coordination information, e.g., for detecting the failure of application server, for exchange of reliability information, etc.

A mobile subscriber has a subscription for connectivity service with a MNO.

A mobile subscriber has a subscription with the 3rd party service provider for the service which requires ultra-high reliability (e.g., remote healthcare service provider with AR/VR eyeglass).

4. Description/Service Flows

The 3rd party service provider requests the MNO to ensure ultra-high reliability connectivity between the mobile subscriber and the application server owned by the 3rd party service provider. The 3rd party service provider has several application servers to provide the same service to the mobile subscriber. The MNO is aware of those redundant application servers.

When the mobile subscriber starts using the service provided by the 3rd party service provider, MNO provides a connectivity service to the mobile subscriber communicating with the application server owned by the 3rd party service provider based on the agreed ultra-reliability requirements with the 3rd party service provider.

Due to an unexpected event or power outage, the application server that the subscriber has a connection with is down. Due to ultra-high reliability requirement, the network of the MNO is able to detect that the application server is down. Instead of tearing down the existing connectivity session and then establishing a new connectivity session with another application server providing the same service, the network immediately and seamlessly routes traffic to its redundant application server in a different location.

5. Post-condition

A mobile subscriber enjoys the service with higher reliability and increase the URLLC QoE.

6. Potential service requirements

It shall be possible that an MNO provide ultra-high reliability mechanism based on the application server availability.

Use case#8
Integrated sensing and communication (ISAC) for motion control in dynamic factory environments

1. Introduction

A motion control system consists of a motion controller that periodically sends information to one or more actuators which act on one or more processes (e.g., movement or rotation of a certain component). At the same time, sensors determine the current state of the processes (e.g., current position and/or rotation of one or multiple components) and return it back to the motion controller [3]. In the literature it is called control-to-device [4]. In general, the use case described below is also applicable for control-to-control if the mobile robot or AGV runs an own local control unit.

In dynamic factory scenarios (e.g., with autonomous/automated devices), the information sent to the actuators need to take in to account the current environment with respective to all objects/devices/components in proximity in order to ensure safe and efficient operation. In today's factories the critical machines are encapsulated, and robots are placed within cages in order to guarantee that no human is in danger even if the control of machines fails. Other technologies for human-machine cooperation (Cobot) use sensitive robot skins to stop operation if robot touches humans [5] or robot controls are given/taken back by humans for better operation in certain scenarios such as to meet some urgent unexpected demands. Both such mechanisms require high effort and limits flexibility to be added to the industrial solution. This information is more enhanced when compared to the current state of the processes.

Motion control systems require deterministic low-latency secure and high reliable cyclic communication of data with packet size of 50 bytes to enable fast and precise movements of components. Integration of the sensing function with the communication solution enables new cost-efficient solution to increase flexibility and easy cooperation of humans and robots.

2. Actor

Motion controllers, actuators, processes

3. Pre-condition

- Motion controller equipped with ISAC capability
  - Motion controller capable of sending information to the actuators
  - Motion controller capable of sensing the environment e.g., proximity of obstacles or humans or objects of interest
- Actuator capable of decoding ISAC signal

4. Description/Service Flows

The motion controller triggers the communication system to sends an ISAC signal to actuator(s) over the wireless link. The ISAC signal contains the necessary information to the connected devices like actuators or sensors and triggers updates of the processes (e.g., movement/rotation of a certain component). At the same time, the echoes of ISAC signal can be decoded by the ISAC subsystem integrated in the motion controller(s) to sense the environment to determine the next set of actions.

5. Post-condition

Cyclic communication service with the desired cycle time is established between motion controller and processes in dynamic environments.

6. Potential service requirements

Communication requirements: Latency and Throughput for communication and sensing data, Reliability for each service, sensing and communication bandwidth, waveform, antenna specification (size, beam characteristics), beamforming performance,

Sensing requirements: precise location of the objects, time for full scan, response time, identification of the shape of the objects, accuracy of the scanning, data processing capability for sensing processing, local or remote or distributed processing of sensing data in the 6G network.

Use case#9

Integrated sensing and communication for cooperative carrying of unknown objects by mobile robots

1. Introduction

Cooperative carrying refers to a set of mobile robots cooperating with another to transfer objects e.g. metal frames, parcels, from one place to another in factories as described also in [3]. Depending on the object characteristics, e.g., fragility, texture, etc., and number of mobile robots, the *level of cooperation* may vary. The *level of cooperation* indicates the requirements in terms of coordination between the mobile robots. For example, a rigid, fragile, and heavy object requires more precise coordination among the mobile robots compared to a soft elastic object. Additionally, factories comprise of several different kinds of objects with varying characteristics that needs to be appropriately identified in order to determine the *level of cooperation*. Depending on the material of the object ISAC enables also to detect what is inside and can further adopt the details of cooperation.

2. Actor

Motion robots

3. Pre-condition

- Pre-determine the number of mobile robots and capabilities involved in cooperative carrying
- Mobile robots equipped with ISAC capability
  - Mobile robots capable of transmitting information via ISAC signal to other mobile robots
  - Mobile robots capable of decoding ISAC signal
  - Mobile robots capable of sensing the environment based on ISAC signals
  - Mobile robots capable to exchange sensing and control data with remote processing units

4. Description/Service Flows

The mobile robots start by first identifying the characteristics of the objects. This is based on relying on sensing capability of ISAC system. Based on the identified characteristics, the mobile robots establish a communication with other robots in their proximity. Each step of a communication involves each mobile robot transmitting an ISAC signal to share coordination information and at the same time "sensing" the status of the ongoing task e.g., stability, orientation of the object and the environment to enable efficient coordination. Sensing of the environment will also enable faster transportation even if humans are crossing the path. The speed for transportation depends also on the response time for identifying objects and humans.

The sensing capability of the robot may reduce the need for expensive sensors at the gripper. THz sensing will extend it further to analyse the type of the materials carried by the robot by non-destructive sensing. Type not only in terms of shape and size of the objects, but also characteristics such as fragility, texture, etc. Thus, sensing capability could be applied at multiple levels (i.e., detecting objects types that are being carried, and status of ongoing carrying task) of robots based cooperative carrying operation.

5. Post-condition

Successful (damage-free) transportation of objects within factories.

6. Potential service requirements

Communication requirements: Latency and Throughput for communication and sensing data, Reliability for each service, sensing and communication bandwidth, waveform, antenna specification (size, beam characteristics), beamforming performance,

Sensing requirements: accuracy, update frequency, imaging quality, precise location of the objects, time for full scan, response time, identification of the shape of the objects, accuracy of the scanning, data processing capability for sensing processing, local or remote or distributed processing of sensing data in the 6G network.

Use case#10

Mobile network resilience against solar superstorms

1. Introduction

Solar superstorms or Coronal Mass Ejection (CME) with Geomagnetically Induced Currents (GIC) are natural phenomena that historically have disrupted telecom, power network grids and railroad infrastructures on the Earth. A recent paper is addressing the topic related to the Internet [6]. It is arguing that solar superstorms can potentially cause large-scale Internet outages covering the entire globe and lasting several months. Is mobile network resilience and especially 6G resilience against solar superstorms a relevant topic to address by One6G? The topic has been raised by the managing editor of 6GWorld [7].

The most powerful CME/GIC known from history was on September 1-2, 1859 and is called the Carrington Event [8]. It knocked out telegraph networks all over Europe and North America. On May 13-15, 1921, the most powerful CME/GIC in the 20th century – also known as the New York Railroad Storm [9] – had global impacts on radio propagation and large geoelectric fields (~10 V/km) knocked out and caused fire in telegraph and telephone networks in Europe and North America [10]. On Mars 13, 1989 the power grid in Quebec, Canada, was knocked out for 12 hours [11], and related systems in Northern America were seriously impacted by a solar storm that was magnitude less powerful than the former ones. In July 2012 a solar storm at the magnitude of the Carrington Event missed the Earth by 9 days [12]. Solar superstorms with severe impact on the Earth are rare but will eventually occur again [13].

National authorities are considering solar super storms as risks related to electric power grids, aviation and any business relying on positioning and timing by global navigation satellite systems (GNSS) [14]. Satellite systems might be severe disrupted, which may have immediate impact on financial transactions, ICT systems and telecommunication networks that rely on GNSS time synchronization. The Norwegian National Security Board considers solar storms as medium risks, but with high uncertainties with respect to impacts [15].

There has not been any solar superstorm after the Internet and mobile networks became vital for the entire economy and social life. These networks are mission critical for all kinds of social and economic interactions. All kinds of data, including money, personal information, and legal contracts are virtualized, processed and stored in network connected computer systems. Coming networks will rely on virtualized infrastructures and new customer services will be enabled by mobile edge computing. What will happen to these computer systems, services, and data when the next CME and GIC occurs?

2. Actor

Mobile subscribers, Mobile Network Operator (MNO), 3rd party service provider, and the entire civil society may be affected by solar superstorms.

3. Pre-condition

Mobile network resilience against solar storms will require

- Understanding of potential impact on mobile networks and services
- Ability to monitor solar wind activities and forecast events of CMEs and GICs

- Ability to disconnect electro-magnetic network components from power-grids
- Ability to deploy infrastructure in environments that are not affected of geomagnetic induced currents
- Deployment of technologies that are resilient against massive geomagnetic induced currents, e.g. optical technologies as substitute of electro-magnetic technologies
- Secured storage of data
- Secured storage of network spare parts

4. Description/Service Flows

- All inhabitants and mobile network subscribers should be educated in risks of and procedures to mitigate severe impact of service outage due to CME/GICs
- MNOs should offer a solar activity forecasting service – e.g., something similar to the Northern Light Forecasting App Aurora Alerts [14].
- MNOs need to store and secure all network data, customer data and application data on GIC protected storage medium and locations.
- Spare part inventories of network equipment (RAN, VNFI, etc.) may be required to mitigate impacts of CME/GICs.

5. Post-condition

The mobile network should be in fully operation 1 hour after a massive solar storm (CME/GIC).

6. Potential service requirements

- Risk analyses of mobile network infrastructure (e.g., solar storm emulation tool and digital twin of mobile network to see the effect and help mitigating against it.)
- Revision of technologies with objective to obtain CME/GIC resilience
- Procedures to mitigate severe impacts

Use case#11

Geographical positioning and location sensing as mobile network service

1. Introduction

Everything happens and all things and organisms are located somewhere [16]. Hence, geographical positioning and location-based information on literally everything is of great value. Precise position is required for stationary as well as moving objects that are connected to networks, but also for objects and processes that are NOT connected to any network.

State of the art positioning techniques are based on fundamental localization principles. A radio receiver computes signal measurements with respect to a single or multiple reference transmitters with fixed and precisely known locations in a coordinate reference frame and calculates the position with a certain algorithm [17]. The receiver can be a wireless device with embedded software, or at network-based server.

Location Based Services (LBS) and positioning have been discussed as use cases for telecom in 5G [18, 19], and customers have expectations that mobile network operators in the future will enable precise geographical positioning services – for instance applied for autonomous vehicles. However, mobile networks are not fully utilized for precise positioning services. Mobile networks are applied for positioning of connected objects by deployment of network-based localization servers and calculation of signaling between base stations and the connected object. Such services are applied for localization of phones in emergency calls and for tracking of objects, but level of accuracy is low with hundreds of meters error margins.

Global Navigation Satellite Systems (GNSS) provide more precise positioning solutions than mobile networks. However, GNSS require complementary geodesy systems and networks for magnitude accuracy of geographical position below 10 meters. By connecting GNSS devices to terrestrial base stations with fixed positions, it is possible to calibrate exact position of devices down to centimeters. Standards for such terrestrial reference networks are defined by IAG – the International Association of Geodesy [20]. In Europe the standards are defined and managed by EUREF [21]. Terrestrial reference databases and networks are partly operated by national Mapping authorities, space centers and other public organizations, partly by private companies.

GNSS require special devices for geographical positioning and navigation. So called rover devices are required to obtain accuracy at centimeter level by correlation of data from complementary geodesy networks. Rovers are extensively used for planning, operation and maintenance of constructions and infrastructures. Rovers are applied for positioning of existing physical as well as virtual objects that are not connected to any networks.

Radar and Lidar are sensor systems used for positioning of objects that are not connected to networks. These are for instance used in vehicles for positioning of other objects and obstacles, but also for automatic mapping of surroundings – information that may be uploaded to and shared with network centric location servers. Together with other embedded sensor systems, connected vehicles may for instance share information of local road conditions like icy roads, fog etc. with other road-users.

Various indoor positioning (IPS) and location technologies can enable positioning accuracy with margins of error less from than 1 mm to several meters [22]. Computer assisted and image supported IPS are e.g. used for robot-assisted surgery where ultra-reliable navigation is required and augmented reality are applied for support. Such applications are enabled by Da Vinci Robotic systems from Intuitive [23] and navigation systems from Brainlab [24] and applied by St.Olavs Hospital/NorMIT in Norway [25] .

Mobile networks may eventually enable more precise positioning and localization services by

- Assisted and differential GNSS (DGNSS) which require implementation and operation of calibration and localization servers closer to the users in the mobile infrastructure. 3GPP LTE Release 15 and 16 do feature mobile network support to DGNSS positioning that may enable centimeter accuracy level by using the LTE Positioning Protocol (LPP) [26, 27].
- Utilizing mobile base stations as distributed MIMO radar systems - enabled by cooperative passive coherent location (CPCL) as suggested by Thomä et al 2019 [28].
- Capturing, processing, and sharing of location-based information from CPCL and assisted and differential GNSS with numerous stakeholders.

2. Actor

The supply chain of positioning services are National mapping authorities, operators of Global Navigation Satellite Systems (GNSS), Providers of GNSS devices, Vendors of navigation services, and mobile network operators.

On the demand side precise positioning is required by consumers, primary industries, construction and transport industries, service providers, operators of infrastructures, as well as an increasing amount of manufacturing industries offering products with embedded tracking and remote operation features.

3. Pre-condition

The idea is to develop and monetize 6G as shared infrastructure for telecom, positioning and location-based-services, and radar-based applications. New opportunities may be enabled by so called Cooperative Passive Coherent Location as discussed in the paper by Reiner S. Thomä et al 2019 [28]. This may enable use of radio frequencies, radio signals and telecom infrastructure beyond traditional mobile telecommunication services.

4. Description/Service Flows

The basic idea is to develop 6G for more accurate as well as brand new positioning and location-based services for connected objects, but also for objects and processes that are not connected to any network. Precise positioning is enabled by

- Mobile devices with embedded positioning software for calculation and presentation of positions of the actual object itself, or
- Mobile base stations with distributed MIMO antennas used as radar systems
- Network servers that are calculating positions of remote objects based on radio signals, reference coordinators and specific algorithms

Location-based information are captured from devices and radar systems, and hosted, processed, and shared via location-servers.

5. Post-condition

By combining sensing, positioning and GNSS, 6G will enable high-quality positioning services with cm-accuracy (longitude, latitude, altitude) both for objects connected to networks and objects and processes that are not connected to any network. In local areas 6G should enable accuracy of positioning below 1 cm. Ideally 6G should also provide a back-up solution for high quality GNSS based positioning services with cm accuracy.

6. Potential service requirements

- 6G networks should have native high accuracy (< 1 cm) positioning capabilities for indoor as well as outdoor environments
- Accuracy should ideally be obtained without usage of GNSS.
- 6G based positioning should be combined with remote sensing services.
- Especially for moving objects 6G should improve accuracy, reliability and efficiency of positioning, navigation and location-based services by improvements or substitutes of assisted and differential GNSS.
- Precise positioning and location-based services for moving objects and dynamic processes require ultra-reliable, low latency communications (URLLC) beyond what may be enabled by 5G. Radar and lidar type of positioning and location services require distributed data processing/edge computing and artificial intelligence (AI) capabilities beyond what may be enabled by massive Machine Type Communications (mMTC) in 5G.
- Distributed and local MIMO antennas supporting additional frequency bands will be required for sensing and more accurate positioning.

Use case#12

RF or Optical Wireless Communication Enhanced by Optical Sensing

1. Introduction

The Optical Wireless Communication (OWC) is an alternative to the widely used Radio Frequency (RF) based wireless communication. It utilize the infrared, visible light or ultraviolet range of the spectrum, which is normally categorized into the following types:

- Wireless access network primarily using light-emitting diodes (LEDs), which is often called LiFi
- Free-Space Optical (FSO) point-to-point LOS communication which is normally based on laser, super luminescent diode (SLD) or LED
- Image Sensor Communication (ISC), also known as Optical Camera Communication (OCC) which relies on the widely spreaded image sensors, LED lights and screens for achieving communication with low or moderate data rate
- The FSO or LiFi technologies using the visible light is often referred as Visible Light Communication

In comparison with the RF communication, the OWC offer the following major advantages:

- Almost unlimited (in the scale of hundreds of Terahertz) spectrum which is worldwide available
- There is no Electro-Magnetic Interference (EMI) to existing RF communication network and to EMI-sensitive applications
- Robust to jamming or eavesdropping attack due to easy signal isolation
- Can be easily integrated into the lighting system of buildings, streets, and vehicles, etc.
- High sensing and imaging resolution thanks to its wide bandwidth and sub-micrometer wavelength

There exists also the disadvantages of OWC comparing with RF communication:

- Difficult to mitigate non-line-of-sight (NLOS) condition
- The transmitting power is limited by eye protection, especially in the visible light band
- The commonly used intensity modulation with direct detection (IM/DD) in OWC has normally poorer performance as the coherent-detection commonly used in RF communication.
- Suffering from the Interference from natural or man-made light sources, e.g. the sun, lights, infrared radiation etc.

The OWC is particularly attractive to the application scenarios which are sensitive to EMI, for example:

- In the hospitals equipped with EMI-sensitive devices such as magnetic resonance imaging (MRI), Electrocardiogram (ECG), electroencephalogram (EEG), electromyography (EMG) and electro-oculogram (EOG)

- Aircrafts in which the avionics should be protected from EMI
- Industrial environment which needs explosion-proof protection, such as oil refinery, chemical plants and nuclear plants
- Any scenario in which information security is highly critical

In this use case, it is proposed to make use of the high resolution sensing capability of the optical image sensor for enhancing the RF (Terahertz, mmWave, etc.) and optical high throughput wireless communication network. In this way, the precision and speed of beam search and tracking can be significantly improved, which can further enhance the reliability, capacity, and mobility of the wireless communication network.

2. Actor

- User Terminal (UT) which is hand-held or vehicular and can transmit optical signal carrying its ID and other assistance information. The UT is served with high throughput wireless connectivity via optical signal and/or RF signal in Terahertz or mmWave range.
- OW Sensor which can locate UT and detect the assistance information including its ID transmitted by UT.
- Access Point (AP) which server UT with high throughput wireless connectivity via optical and/or RF signals relying on beamforming for increasing channel gain and channel spatial reuse.
- Intelligent Reflection Surface (IRS) which is a fixed installed passive device which can improve the channel gain especially in NLOS condition by steering the reflected RF or OW wave into a desired direction.
- Access Network Central Unit (AN-CU) which controls the OW sensors, APs and IRSs and distributes the sensed information from OW sensor to the other two types of entities.
- Location Management Function (LMF) which manage the location information of UTs and share it to the relevant entities. The LMF could be in a core network connected to the AN-CU, or located in the AN-CU.

3. Pre-condition

A mobile network which is formed by AN-CU, OW sensors, APs, a core network and optionally IRSs is deployed to serve multiple mobile UTs. The AN-CU controls APs, OW Sensors and IRSs. The OW sensor could be an integrated part of AP or a separated device. An AP and an IRS demand the angular information of an UT to generate a beam to server that UT. The location and reference direction of AP and IRS should be known by LMF and AN-CU.

4. Description/Service Flows

- The UT transmits the assistance information including it's ID using an OW Tx (e.g. LED).
- The assistance information is detected by one or more OW sensors. Additionally, an OW sensor can detect the location information of the UT by using the techniques such as stereo/multi-view 3D imaging and/or AI.

- The assistance information and the location information of UT detected by OW sensor are forwarded to LMF by AN-CU, which can be fusioned to obtain more accurate estimation of UT's location.
- Based on the UT's location information as well as the locations and reference directions of APs and IRSs, the LMF calculate the angular information of the UT referring to a certain AP or IRS.
- The angular information is send by LMF to AN-CU which instruct the beam steering towards the UT.
- The location information of UTs can be also send by LMF to a user application.

5. Post-condition

- Based on the location information of UT obtained via OW sensing, the AP can steer its beam towards a UT precisely and adapting to its movement. In this way, the reliable and high throughput data connectivity between AP and UT can be established.
- The locations of UTs are obtained by user application.

6. Potential service requirements

- Distance precision of OW sensor
- Angular precision of OW sensor
- Beamwidth of the RF or OW AP

Use case#13

Intelligent, deterministic and time synchronization network for haptic and future factories

1. Introduction

Goal 3 of UN SDGs is “Ensure healthy lives and promote well-being for all at all ages”. Well-being will be improved, when people are surrounded by an environment that evokes a positive feeling. Therefore, it is expected to enable the societal development with new trends towards the 2030s, which may lead to strict mobile communication requirements such as data rate in the order of terabits per second, a latency of hundreds of microseconds, and ultra-high end-to-end reliability, may exceed even the capabilities of the 5G systems [29]. Following use case scenarios can highlights the 6G requirements:

- *Immersive Virtual Reality (IVR)*: it is related to the human interacting with virtual entities in a remote environment such as VR Video, VR Gaming, education, health care. For instance, a human subject interacts with a remote IVR System by using tactile devices, sensors/actuators controlled by the IVR System and audio/video devices that reproduce synchronized audio/video streams transmitted by the IVR System and expected requirements are a latency 10-100µs, which is superior to 5G (i.e., 1ms) and seven-9 reliability [29,30].
- Deterministic and time sensitive communication: 5G System supports time sensitive communication among devices in a local network. Basic support of IP-based time synchronization was introduced by the 3GPP 5G core Rel-17, but time synchronization among devices widely scattered with no distance limitation may still be an issue. Furthermore, 5G System does not support (up to Rel-17) wide range deterministic communication and IP-based deterministic networking. Therefore, supporting these capabilities are important to enable the creation of new services involving traffic scheduling and synchronization in a wide area [31].

In summary, the network needs to be intelligent to cope with the different needs of the use cases as described above and to support the distributed network connectivity to supporting low latency, wide area synchronization and deterministic communication in the 6G network to guarantee the service requirements to enable societal development by the 2030s.

2. Actor

Mobile subscribers, Mobile Network Operator (MNO), 3rd party service provider

3. Pre-condition

A subscriber device is capable of performing IVR communication with other devices and/or application server.

An MNO deploys distributed network computing (e.g., gateway functions) at different locations based on the third-party service providers and different classes of traffic requirements. The MNO's network should be able to differentiate and allocate the required network computing.

An MNO has a trust relationship with a business partner (3rd party service provider).

4. Description/Service Flows

A 3rd party service providers wants to provide a IVR communication services to its subscriber (mobile subscriber). The 3rd party service provider (such as application function) exposed the service requirements to the MNO, which further translate into the network KPIs such as latency, reliability. After the mobile subscriber registers to the network of MNO, the MNO's network dynamically determine service considering different network conditions such as available computing resource, location, etc., the mobile subscriber enjoys a IVR communication.

5. Post-condition

A mobile subscriber enjoys IVR communication via MNO network provided by the 3rd party service provider.

6. Potential service requirements

It shall be possible that an MNO provide an ultra-low latency and high reliable with time synchronization and deterministic communication.

Use case#14

Advanced and sustainable massive MIMO wireless transmission technologies for ultra-high data rate applications

1. Introduction

Multi-antenna communication technique, known as Massive MIMO, is one of key enabling technologies in the 5G and Beyond 5G wireless transmission technologies for coverage extension, high throughput, high reliability, high energy efficiency, low latency and supporting high dense number of devices in the coverage area regardless whether the service consumer is mobile or stationary. To increase a capacity of wireless networks, theoretically, one can simply add more and more antennas, both co-located on the same antenna panel and geographically distributed over the service area. However, in practice, it results to many new challenges, e.g., increase energy consumption on both the transmitter side and the receiver side due to an increase number of circuit components. Hence, energy efficient deployment of massive MIMO system in 6G is important aspect to be considered for a sustainable society.

With diverse bandwidth-hungry applications such as holographic communication (e.g., a raw hologram without any compression would require more than 1 Tbps for communication [32]), digital twins, the available bandwidth in the sub-6 GHz and the millimeter-wave bands may not be adequate to meet such high data rate demands of users with such applications, but to consider the Terahertz bands instead. However, THz band communication has disadvantage that it has high path loss, and hence, only suitable for short-range applications. Future wireless transmission technology is expected to overcome such shortcoming of THz band communication, e.g., applying massive MIMO in THz band communication.

2. Actor

Mobile subscribers (Alice and Bob), Mobile Network Operator (MNO)

3. Pre-condition

Alice and Bob have a device that is capable of performing holographic communication.
MNO deploys access points mounted on the street lampposts to provide ultra-high data rate communication to pedestrians (mobile subscribers) walking along the street.

4. Description/Service Flows

Alice is walking on the street, while Bob is at home. Alice wants to use her device to communicate with Bob. Alice set up a holographic communication with Bob by setting a wireless communication between Alice's device and the access point installed at the lamp post. While Alice is walking on the street, her holographic communication with Bob is seamlessly handed over from one access point located at a lamp post to another access point located at another lamp post.

5. Post-condition

Alice enjoys holographic communication with Bob by receiving ultra-high data rate wireless connectivity provided by the MNO.

6. Potential service requirements

It shall be possible that an MNO provides an ultra-high data rate while a subscriber is either stationary or mobile. Wireless transmission for ultra-high data rate between subscriber's device and the access point shall be energy efficient.

Use case#15

AI-as-a-service for V2X: Environmental perception

1. Introduction

AI-as-a-service (AIaaS) is a usage scenario where network can offer services to customers to enable them to access, implement and manage AI based capabilities (such as model and data management, learning and inference) for their applications, and additionally allow their scaling in an efficient, cost-effective and secure manner.

AI based capabilities are largely dependent on data. Hence tools correspond to offering services that can enable, among others, data collection, data preprocessing, data storage, model training, inference, model development, model deployment, and model management.

These diverse services can be classified into multiple categories such as: *AI Software Services, AI Developer Services, and AI Infrastructure Services*, as discussed in [33]. Envisioning the wide-spread deployment of wireless networks with computing capabilities (edge and cloud computing), these infrastructure elements apart from providing the conventional wireless communication services can be providers of *AI services*. Using wireless networks as a platform to offer *AI services* can offer certain distinct features such as:

- Flexible deployment of *AI services* – allowing *AI services* to be closer to the applications due to distributed wireless network architectures. This could impact, for example, time-critical applications.
- Potentially robust *AI Services* – due to availability of multiple computing resources for a certain service.
- Secure communication among different infrastructure elements – to provide security and privacy protection during collection/storage/processing/transmission of sensitive data.

These features offer flexible deployment and management of AI services by leveraging on the inherently distributed wireless network architecture. Furthermore, it can enable distributed and federated learning AI algorithms by bringing computation capabilities closer to data and limiting data sharing.

AIaaS provided via wireless networks can support application in the automotive sector. Specifically, we consider *environment perception* use case to discuss the details.

Environment perception refers to a vehicle being made aware or being able to identify objects and understand the surrounding situation (which can lie within a few hundred meters radius of the vehicle). This relies on collecting data from multiple sensors, such as those in the vehicles, road infrastructure, and wireless networks, and deploying object detection and environment awareness models. Considering the dynamicity in vehicular networks, the wide variety of static and dynamic objects and scenarios that could be detectable on roads, and the critically of V2X services, accurate *environmental perception* information is crucial.

Examples of the three specific AI services for *environmental perception* use case can include:

- *Inference service,* built on *AI Software Services* which provide object detection and environment awareness based on the input of sensor data.
- *Data fusion service,* built on *AI Infrastructure Services* which provide capability to collect, store, process, and communicate data from/to different vehicles and network entities.

- *Online learning service,* built on *AI Software Services* which provide capability to develop and update the object detection and environment awareness models (model implementation and management services).

2. Actor

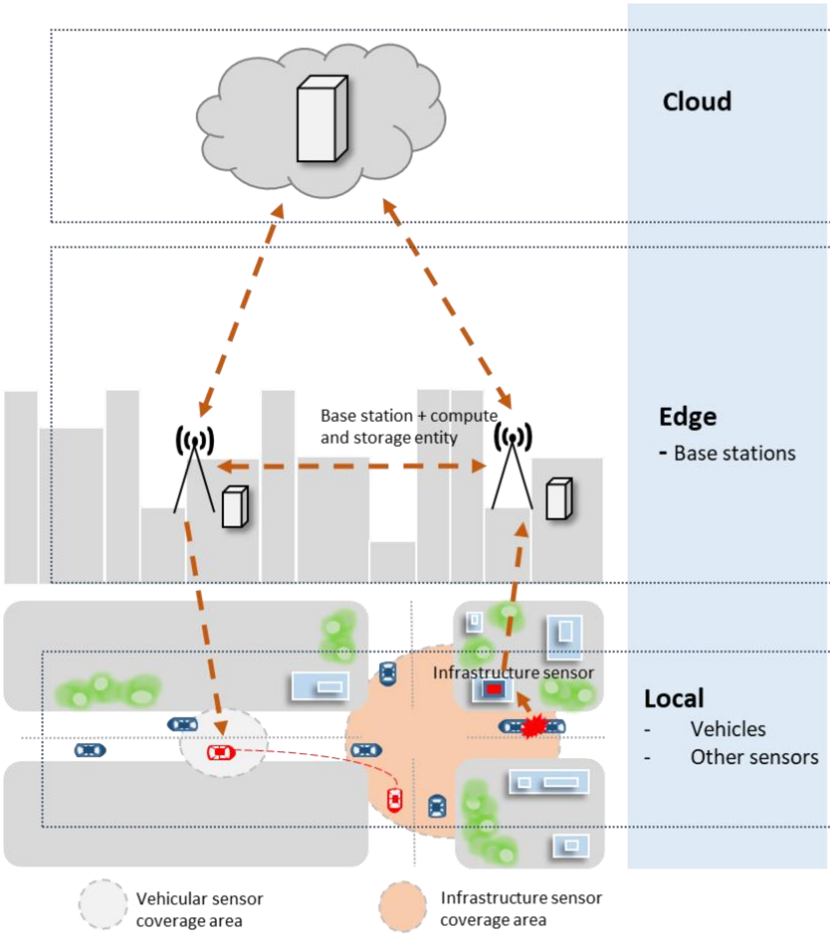
- Vehicles equipped with sensors
- Network providers (e.g., MNOs, who offer communication, compute, and storage capabilities)
- Application service providers (e.g., vehicle OEMs)
- Infrastructure entities installed on the roads to perceive the environment – e.g., roadside units (RSUs)

3. Pre-condition

- Vehicle capable of sensing the environment
- Vehicle capable of communicating with other communication, compute, and storage entities
- *Other sensors* capable of sensing the environment
- *Other sensors* capable of communicating with communication, compute, and storage entities
- Different communication, compute, and storage entities capable of communicating with one another.

4. Description/Service Flows

The service flow is described based on the following *environmental perception* use case illustration.



- The "red" automated vehicle, *Alice*, is travelling towards an intersection.
- As *Alice* travels, it continuously perceives its environment using on-board devices and models which are made available (object detection model, environment awareness model) via *online learning service* from the network.
- Similarly, the other vehicles, e.g., *Bob*, are also using models made available via *online learning* to perceive their environment.
- Alternatively, Alice and Bob can upload the sensor data to the network and perceive the environment via *Inference service* from the network (in order to reduce the demand of on-board computing).
- *AI online learning service* offers vehicles with the most updated and relevant models (e.g., road segment specific, intersection section, highway section specific, etc.) to enable accurate and robust environment perception. *AI online learning service* could rely on mechanisms such as federated learning, distributed learning, or purely centralized learning, among others.
- As Alice is travelling towards the intersection, on the other side of the intersection, Bob and infrastructure entities are detecting a change in the environment, for example, an accident.
- The newly detected information in the above step is communicated to relevant infrastructure entities (e.g., edge computing platforms) that have the capability to store the data, process the data (such as, combine data from different entities, analyze the data to identify the change in the environment). Additionally, the relevant entities can initiate update of environment awareness models. These are enabled via *Data fusion services*.

- Depending on the real-time model update feasibility, either updated models or information about change in the environment is communicated to Alice when in the vicinity of the infrastructure.
- Alice approaches the coverage area of the infrastructure.
- Alice is informed about recently discovered accident scenario.
- Alice takes a suitable action such as choosing an alternate path to the destination. Such decision-making capability could also be enabled via *Inference services*.

5. Post-condition

- The vehicles have accurate perception of their environment.

6. Potential service requirements

Reliability, security, privacy, data storage, data processing, data analysis, communication links with certain QoS.

Use case#16

Factory Automation and Predictive Maintenance by Remote Control of Cyber Physical Systems in Future Factories

1. Introduction

5G systems that are being currently deployed have significant advances beyond LTE but may be unable to meet the connectivity demands of the future digital society [29]. More than 125 billion devices worldwide are expected to be connected by 2030. 6G will connect all personal devices, vehicles and sensors. That is why 6G should support the extended use cases that are already defined for 5G to bring increased throughput, lower latency and increased reliability with high accuracy localization and greater scalability. With the help of 6G use cases, enhanced mobile broadband (eMBB), ultra-reliable low latency communications (URLLC), and massive machine-type communications (mMTC) will be offered at an extended level. Additionally, mixed usage scenarios will be supported, i.e., combined machine type communication with ultra-reliability or a mobile broad band communication with ultra-low latency.

One of the most important 6G radio access use cases that requires connectivity of large amounts of devices is the remote control of cyber physical systems in fully automated future factories, also referred as Industry 4.0 recently. These factories will be the digital transformation of manufacturing through cyber physical systems and IoT services. There will be massive amount of data coming in a periodic, quasi-periodic, or sporadic fashion from many IoT devices, sensors, machines, robots flowing simultaneously in a closed loop factory. Both mMTC and URLLC type of traffic should be supported in this use case. The remote control of robots would require ultra-low latency communication. They would be used as a promising alternative to fully autonomous robots while allowing smooth movements in harsh environments and delivering visual and haptic feedback. Besides that, in critical situations (e.g., possible collisions, actuator damages or human injuries) support of low latency between the robots and the controller becomes crucial. High data rates are needed for video transmission whereas command and sensory data should be sent with ultra-reliable low latency communication, as both might occur in the uplink and the downlink. Allocation of resources in a flexible manner is important since the periodicity of control data and the traffic pattern may differ in time.

In this use case, one important aspect is transferring a physical system into a digital replica, i.e., creating a digital twin or a new version of it whereas another important point is to satisfy the automation requirements itself. 3GPP recently defined the survival time as the maximum time a cyber-physical control system may continue its operation without receiving an anticipated message. Age of Information (AoI) will be an important metric, defined for systems transmitting updates, where the newest update immediately replaces previous ones [3]. The network must support different mechanisms to increase the efficiency of communication for this use case. Automation comes with a certain set of requirements in terms of reliable and synchronous communication to overcome the boundaries between the real factory and the cyber computational space. Internet-based diagnostics, predictive maintenance, operation, and direct machine communications in a cost-effective, flexible and efficient way should be achieved. With the help of 6G, high accuracy positioning will be crucial for Future Factories since the tracking of mobile devices as well as mobile assets become more and more important in improving processes and increasing flexibility in industrial environments [3]. Extended reliability (higher than seven nines), high accuracy localization and ultra-low latency (lower than 0.5 ms) will be needed for a fully automated factory process to survive without human intervention, which cannot be guaranteed by 5G architecture nowadays [39].

In summary, the network needs to be intelligent, providing ubiquitous broadband Internet access anywhere to anyone. Intelligence would imply 6G radio to be able to adapt to changing environment real time, achieving higher autonomy levels. Besides, handling large amounts of data and making predictions based on system needs will play an important role for the efficiency of the resources. Interactivity will provide people with a real immersive experience while trying out different cyber physical systems. Connectivity is the main feature which will enable these 6G usage scenarios. The emphasis of the vertical domains has already gained a crucial role with 5G. It will even be more important at the next generation since the connectivity needs and digitalization of physical space will be main components supported by 6G radio access. In the Factories of the Future, static sequential production systems will be more and more replaced by novel modular production systems offering a high flexibility and versatility. This involves many increasingly mobile production assets, for which powerful wireless communication and localization services are required.

2. Actors

Mobile Network Operator (MNO), mobile subscribers (employee), any connected device, sensors, machines, robots inside the factory (device), factory control system.

3. Pre-condition

Devices located in the factories are capable of transmitting and receiving messages in harmony with other devices also located in the factories.
Factory control system is capable of processing huge amounts of data, making predictions to enhance the efficiency of a process line using the data coming from devices. In contrast to a typical closed-loop control system in factory automation, factory control system achieves conditional monitoring and predictive maintenance based on sensor data, but also big data analytics for optimizing future parameter sets of a certain process. Eventually it notifies employees whenever necessary.

MNO deploys the required infrastructure to provide ultra-reliable, high data rate communication with high accuracy positioning and ultra-low latency.

The MNO's network should be able to differentiate the different types of services and allocate the resources to achieve a mixture of extended 5G features simultaneously (extended mobile broadband, high reliability, low latency, high accuracy localization, extended machine type communication etc.). For example, it is not latency critical for factory control system to make future predictions over a process line, but ultra-reliability is important even for sensor data provided by vision systems. On the other hand, a surveillance footage from a critical part of the system requires a transmission with high data rate and ultra-reliability within seconds. Surveillance video streams can be triggered by different types of events with different types of priorities or in a periodic manner and requires robust resource management of all traffic types and QoS requirements.

4. Description/Service Flows

Via the factory control system, employees are able to see the status of all connected devices.
Sensory and command data come in a periodic manner. At some prioritized parts where surveillance is required, devices on the shopfloor transmit video with high data rates, which is again monitored from the factory control system.

Based on the sensor data received all the time, factory control system makes an estimation and sends notifications to the employees in advance if a maintenance might be needed soon. As the process continues, employees responsible for that part of the system, takes the input from factory control system and uses the digital replica of that subsystem to implement and try out the recommended maintenance.

5. Post-condition

Factory automation achieves the automated control, monitoring and optimization of processes and workflows within a factory, which is a key enabler for industrial mass production with high quality and cost-efficiency.

Using the prediction capabilities of factory control system, the maintenance is taken care of in advance and no unplanned interruption occurs in the process. The remote control of cyberspace by using the digital replica of the real space, i.e. digital twin, or even another digital expression, will ease the maintenance process of any subsystem in the future factories.

6. Potential service requirements

MNOs and Service Providers should provide an ultra-low latency communication (lower than 0.5 ms), e.g. robotics communication, high accuracy localization, ultra-reliability (higher than seven nines), and high data rates. Mixed usage scenarios such as combined machine type communication with ultra-reliability or a mobile broadband communication with ultra-low latency with time synchronization and deterministic communication will be crucial at 6G radio access. Furthermore, the massive usage of wireless sensors and vision systems and the flexible deployment and reorganization of the shopfloor and intra-logistic requires new efficient solutions beyond of the capabilities of 5G. A central intelligent mechanism is needed to process all data coming from devices and employees in the loop so that every single change is monitored, and estimations are made based on the processed data.

Use case#17

Mixed tactile and VR content in robotic control

1. Introduction

The goal of this use case is to enable intuitive, transparent control of robots in remote environments through eXtended Reality (XR) over mobile networks [33]. In the use case, a human operator wears a Head-Mounted Display (HMD) and haptic gloves equipped with electromyography (EMG) and motion capture sensors, controlling the robot through natural motion. Although prototypes of similar setups have been built, their large-scale use over mobile networks is limited by the difficulty in managing connection impairments: if the delay between the operator's motion and the resulting feedback is too large, or the haptic and visual feedback get desynchronized, the user will experience cybersickness [34], feeling vertigo and nausea and significantly decreasing the control performance. Naturally, this is unacceptable for industrial scenarios in which expensive machinery is involved but is also relevant for non-critical applications and commercial applications, to the point that cybersickness makes gaming unviable [35].

In this context, provisioning resources to the XR application is crucial to maintain an acceptable latency [36] and reduce jitter: the concept of motion-to-photon latency [37] has been applied as a performance metric, including all aspects of XR rendering and streaming. Furthermore, the multiple sensory feedback channels need to be synchronized: a mismatch between senses is another cause of cybersickness [38], and the different flows need to be received in time to allow the operator rig to convey the feedback to the user at the correct time.

The data flows can be mostly on the downlink in the case of Virtual Reality (VR), in which only tactile data is sent from the operator to the robot, or both uplink and downlink for Augmented Reality (AR), in which the video from the HMD camera needs to be transmitted on the uplink as well for processing. In both cases, the coordination of multiple data streams, which include the HMD position tracking packets as well as other feedback packets for the flow and the audio and video streams, with inter-related objectives and Key Performance Indices (KPIs) that span multiple flows over the end-to-end loop, is beyond the capabilities of 5G. Even meaningfully expressing these requirements is an interesting challenge and accommodating these requirements in a network slicing setup is a challenge for 6G.

2. Actor

The supply chain of the overall system involves companies making HMDs and haptic sensors and feedback devices, as well as mobile network operators that need to support this kind of application.

On the demand side, this application might involve any remote precision control: there are obvious industrial applications, in which operators can control a robot in a manufacturing environment that would be dangerous or inaccessible to human workers, as well as healthcare applications, such as remote surgery. A less critical application would be to commercial gaming over VR, involving motion capture and mixed tactile and visual feedback for a more immersive experience.

3. Pre-condition

A remote-control setup is needed, in which a human operator can be fitted with an HMD and haptic gloves, using motion capture and EMG sensing technology to control the robot in a remote environment.

Without network support, the operator cannot control the robot, as latency and jitter affect both the video and tactile signals, causing loss of synchronization between sensory inputs and between actions and feedback. The operators suffer cybersickness and loss of control precision.

4. Description/Service Flows

The remote-control setup is activated, and the robot is connected to the operator through the mobile network.

- The operator makes movements that are captured by the haptic/EMG control rig
- The command signals are relayed through the uplink in a timely fashion
- The robot interprets and executes the command in the remote environment
- Visual and tactile feedback are sensed by the robot and transmitted over the downlink
- The haptic feedback system and HMD convey the feedback signals to the operator without loss of synchronization

The role of the 6G network in this service flow is to maintain synchronization between different flows in both directions without violating the service constraints.

5. Post-conditions

The operator is able to control the robot without any unease or loss of performance, and the operation feels both transparent (i.e., as if the operator were performing the action directly) and natural.

6. Potential service requirements

The cellular network must guarantee:

- Low latency service to high-throughput VR content (4K video at 120FPS)
- Extremely low jitter (below the 20 ms requirement)
- Full synchronization between video and tactile input
- Simultaneous URLLC uplink service
- Coordination between uplink and downlink flows with application-level closed-loop and end-to-end latency requirement
- In the AR case, video must be transmitted over the uplink, with the same overall requirements on the connection.

Use case#18

Monitoring of cross level passages in railroads

1. Introduction

Railroad operators currently use cable-based communications for their cross levels. Here, sensors placed in the railroad tracks a few kilometers away from the cross level need to communicate with actuators therein, activating alarm lights and lowering or raising the barrier that prevents cars and people from crossing the railroad when a train approaches. Additionally, railroad operators are interested in receiving data about the wellbeing of the sensors and actuators, or even video surveillance existing at the cross-level passage. This mix of traffic with different requirement, along with the geographical dispersion of available assets, make mobile communications an attractive paradigm since the deployment of cable-based communications is very expensive. 5G networks have started to be explored for these cases. However, the required security, isolation and reliability required in such cases places extreme requirements over network slicing mechanisms (particularly the certification in communications involved in this sector, due to the impact in equipment and human lives in case anything goes wrong), so further network slicing needs to be researched. Additionally, assets can be under the coverage of different network operators, and it is common for verticals to establish deals with a single specific operator, who becomes in charge of providing full connectivity services to the vertical. In fact, there are large countries where there is no full country-wide coverage by a single operator, or where certain areas (i.e., rural areas) have low-quality service, even in important roads. Sometimes, the relief of the terrain also contributes for the poor coverage by a sub-set of operators available in the area. Additionally, to this, it is also very common for railways to have assets in less populated areas, which fall into these low-quality covered areas, where it is possible to obtain better service from (i.e.) regional operators or are even only just reachable by obtaining connectivity via other operators. In this way, for the vertical to have access to the assets belonging to other operators, the contracted operator will act as a mediator in establishing the link between the vertical and other operator's covered assets. This mediation, as it is a service, will incur costs to the vertical, in addition to the costs in accessing the assets in the other operator's domains. Having additional resources allocated would help the mediator to fulfill the SLA for the vertical (railroad operator). Finally, the network slicing establishment process is currently realized over isolated domains (as the network resources are managed by the infrastructure's own management and orchestration. At most, federation agreements can be established, but are still under research, and involve the previous interaction between involved operators (i.e., both business as well as infrastructural preparation), which negate true multi-domain dynamic service establishment and prevent the verticals from enacting true autonomy regarding their network slice/services establishment.

2. Actor

Verticals with assets whose coverage is provided via different network operators.

3. Pre-condition

Each mobile operator provides interfaces allowing the verticals to request network services/slices. Verticals need to have abstracted means to access such interfaces. Verticals need to have the standardized ability to inter-stitch the network services/slices belonging to different network operators.

4. Description/Service Flows

- The vertical interacts with Network Operator #1 and Network Operator #2, requesting the instantiation of a network service/ slice
- Each operator verifies the necessary credentials, resource availability, and reserves resources as the necessary network elements, replying to the vertical on their availability and readiness
- The vertical further indicates to each service/slice the inter-connectivity points towards itself (i.e., assuming that the different operators might have tertiary networks between themselves, it is important that each established network slice component is configured with the ID of an inter-connectivity point – such as an IP address – which will allow the orchestration process within each network operator to identify the equivalent counterpart in other operator(s) and enact the necessary connectivity configurations – such as a tunnel – in order to stitch the different slices) and the other operator, allowing for the inter-stitching of a true end-to-end inter-domain network service/slice continuum
- Each operator returns the necessary elements towards the vertical, which can now interact with the different assets, transparently, as if it was a single network service/slice.

5. Post-condition

The vertical has access to its different wide geographically dispersed actives under coverage from different mobile operators, in a process that was controlled by the vertical itself, supported by interfaces made available by the operators.

6. Potential service requirements

There is the need for mobile operators to support interfaces allowing verticals to request network services/slices, along with inter-stitching capabilities towards network slices/services existing in other operators. The vertical needs to have the knowledge, or access to such interfaces in a abstracted way, and the ability to take decisions on how/which network services/slices need to be inter-stitched.

Use case#19

Livestock Health and Behavior Monitoring

1. Introduction

In agribusiness, improving animals' health and life conditions are important factors for guaranteeing quality and production. Open field grazing is one of the strategies employed in several countries to attain such an end. The challenge, in this case, is to keep track of the health and social behavior of all animals---reaching the order of tens of thousands in some properties---while preventing fast-spreading diseases (foot-and-mouth disease) that, in the event of an outbreak, may substantially impact the economy of an entire country. Sensors capable of measuring biological data, i.e., temperature, motion, and position, can be used to monitor vital information of every animal while assuring higher productivity. These sensors must have low energy consumption, which hinders the transmission over very long distances. Self-sustainable data collector gateways can provide communication between sensors and the server. Based on the animal's health condition (high temperatures) and social behavior (laying down longer than expected or not visiting drinking areas), alarms can be triggered to allow a fast and adequate treatment. Moreover, the sensors can also be employed as a security system by setting up alarms whenever a sensor is removed, or an animal leaves a predefined area.

The implementation of this use case will demand a long-range communication system (reaching at least 50 km) or a satellite-integrated network. Although 5G is still under deployment, most rural and remote areas will not benefit of its features, essentially due to the lack of terrestrial coverage. 5G's infrastructure is expensive and its deployment will require a huge investment that is not cost-effective for either the MNOs or the rural producers. Then, it is imperative that cheaper systems employing long-range frequency bands should be developed for the next generation to effectively expand the network coverage. The use of non-terrestrial networks (NTNs) might as well be a viable alternative. However, the integration of this technology to the 5G's main architecture is still under standardization, which hampers its applicability on this use case. Hence, with 6G, connectivity and coverage will fully be consolidated worldwide allowing the use of monitoring devices for extensive livestock farming.

2. Actor

Biological and motion sensors, gateways

3. Pre-condition

- Biological and motion sensors with low power consumption (lifespan of more than one year) capable of harvesting vital data from the animal (temperature, heart rate, rumination rate, stress level, and position) to provide minutely basis updates. The sensors are capable of transmitting data with rates reaching hundreds of kbps to a relatively short distance. Energy harvesting is an interesting feature of this device to expand battery lifespan.
- Self-sustainable gateways capable collecting data from the sensors and transferring the information for the mobile network infrastructure through a satellite or long-range link.

4. Description/Service Flows

- Each animal receives a biological and motion sensor.
- Self-sustainable gateways, i.e., powered by solar or wind energy, receive the data from the sensors.
- The collected data is forwarded from one gateway to the following using for instance a self-organized mesh network.
- The gateway connected to the mobile network infrastructure delivers the data to be sent to the application server.
- Based on the collected data, algorithms running in the server can trigger alarms based on the animal's health or behavior. Security alarms can also be triggered if the sensor is removed, or one animal leaves the designated area.

5. Post-condition

Information about the health conditions and behavior of the animals is available. Alarms allow fast response to avoid the spread of disease or robbery.

6. Potential service requirements

- Long-range or satellite communication
- High number of connected devices

Use case#20

UAV Remote Controlling for Precise Agriculture

1. Introduction

Higher efficiency in agribusiness activities is mandatory to improve productivity and reduce environmental impact. Conventional methods for applying pesticides and fertilizers use airplanes, tractors, or even people equipped with backpack pumps to spray these chemicals over a given area. This procedure is quite inefficient and contributes to high levels of water and ground contamination. The effectiveness of such a procedure can be improved by employing Unmanned Aerial Vehicles (UAVs), reducing contamination levels and waste of resources. The UAVs equipped with multispectral cameras can collect real-time ultra-high definition (UHD) images of crops to identify, with the aid of an artificial intelligence (AI) services, infested areas or stressed plants due to lack of nutrients. Pulverization UAVs can be deployed to spray the necessary chemicals only in areas in need.

The UAVs can be remotely controlled by either a human or an AI agent. For such, the network must provide high throughput for the real-time UHD video broadcast (around 60 Mbps) and stability and low latency for piloting the UAVs (less than 20 ms). Furthermore, both types of UAVs should be capable of mapping, positioning, and sensing to increase accuracy and guarantee safe flights. Since these UAVs cannot operate in underserved or unserved areas, long-range communication systems (reaching at least 50 km) and NTNs are needed especially when deployed in rural and remote areas. Even with 5G, these areas will not be served by a fast and stable network, mainly due to the low cost-effectiveness of implementing such an infrastructure to benefit a small portion of users. Moreover, 5G has been designed to reduce cell coverage and increase the number of base stations, which are unfeasible for small rural communities. In this case, one possible solution is the development of new accessible long-range technology exploring lower frequency bands, such as the one provided by TV white spaces, while guaranteeing high throughput and low latency. At this expense, 6G assure coverage and the use of UAVs in rural and remote areas.

2. Actor

UAVs

3. Pre-condition

- UAV equipped with a multispectral camera and remotely controlled by an AI or a human operator.
- UAV equipped with a pulverization system capable of spraying chemicals in a precise area. This device can be embedded with radar and other localization sensors to improve precision and safety. The UAV can be autonomously controlled or remotely controlled by a human operator.
- AI services capable of processing real-time images to detect infestations and plant stress and provide the exact pulverization areas.

4. Description/Service Flows

- UAV for image acquisition is automatically or manually deployed.
- UAV transmit real-time georeferenced images captured by a multispectral camera.
- AI services process the images to detect the presence of infestation or stressed plants in different areas.
- A pulverization UAV loaded with the proper chemicals is automatically or manually deployed to apply the supply in the targeted areas.

5. Post-condition

- Areas affected by insects or stressed plants are precisely pulverized, reducing the chemicals used in the procedure and minimizing the environmental impact.

6. Potential service requirements

- Long-range network coverage or satellite network
- High throughput capability
- Low latency capability

Use case#21

Agricultural Machinery Remote Monitoring and Controlling

1. Introduction

Agricultural machinery has been extensively used in most crops, improving efficiency and production. However, employing these machines requires investment and constant maintenance, which, in the event of a mechanical failure, can increase costs and even jeopardize the whole production. Thus, remote controlling and monitoring of these machines has emerged as a possible solution to lower expenses and increase efficiency. For the controlling part, the machines can be deployed autonomously or remotely by a human agent. For such, the machines will be equipped with high resolution cameras and radar sensors to continuously map and sense the crops to maximize its performance and provide its position. The data gathered can be shared with other machines to avoid collision and route overlap. For the monitoring part, sensors embedded in every agricultural machinery will continuously collect relevant information, such as temperature, engine rotation, and oil level, and will transmit them to the artificial intelligence (AI) service. For its turn, the AI service will process the data and estimate when to perform the next maintenance. The maintenance schedule is established according to the machine's best cost-effective performance.

For a successful implementation of this use case, it is imperative that the mobile network extends its coverage to rural and remote areas while ensuring high throughput and low latency. Unfortunately, 5G will not solve this issue since it is mostly focused in higher frequency bands and short range cells. To this end, long-range systems employing lower frequency bands should be developed to enable mobile network access to these regions.

2. Actor

Agriculture machines

3. Pre-condition

- Agriculture machines embedded with high-definition cameras and sensors capable of continuously transmitting a huge amount of real-time data of the machine's conditions and the surrounding environment. The machines can share data with each other to avoid collision and route overlap. The machines are either autonomous or remotely controlled by a human agent.
- AI service capable of processing real-time data, establishing cost-effective performance profiles, and scheduling predictive maintenance for every machine in the farm.

4. Description/Service Flows

- Agriculture machine is deployed in the crops autonomously or remotely by a human agent.
- Agriculture machine scans continuously its surrounding for obstacles and shares its mapping data with other machines deployed in the field.

- Sensors embedded in the agriculture machines transmit real-time data, such as temperature, engine rotation, and oil level.
- AI service receive and process the engine's real-time data.
- AI service establish cost-effective performance profiles and predict best maintenance schedule.

5. Post-condition

- The machines execute their function efficiently and possible maintenance is scheduled and executed only according to their cost-effective performance profile.

6. Potential service requirements

- Long-range network coverage or satellite network
- High throughput capability
- Low latency

Use case#22

AI-as-a-service for industrial robots: Learning to be collaborative

1. Introduction

Robots are becoming prevalent in factories, warehouses, hospitals, and many other fields. These robots are equipped with sensors (cameras, LiDAR, Radar) and actors (fingers, arms, legs) to perform different tasks, e.g., detection, perception, motion planning, decision making. Being together, a group of robots could perform production activities, e.g., welding, painting, soldering, etc., which are done normally by factory workers. Such collaborative activities require communicating and interacting among the robots, which could be based on either robot-to-robot communications or coordination by base stations.

In nowadays, conventional collaborative robots are based on pre-programed actions. Therefore, they can only be used for specific tasks and the respective industrial controllers are pre-programmed for specific environment and actions. They cannot handle unknown situations as well as random factors in the production process.

Advanced features like sensing and AI could innovate how collaborative robots work. For instance, sensing can help the robots to observe the states of other robots and surrounding environment.AI/ML methods can be applied to enhance capabilities of robots, e.g., image recognition, collision avoidance, path planning, etc. With AI/ML method, particularly reinforced learning, the robots can learn how to operate, so that they can perform many tasks and adapt to new environment. The data observed by the robots can be collected for training or retuning AI/ML models, and shared with other robots. Then, AI/ML models can be applied to perform tasks of classification, prediction, or accomplish goals. The robotics can apply reinforcement learning to maximize total or long-term reward in an environment, by adapting actions according to the received reward from the environment. For the case of collaborative mobile robots, multi-agent distributed learning can be applied for multiple robots in a common environment, with interactions between each other. In this way, multi-agent distributed learning could generalize specific tasks, based on which, robots could be more flexible to handle diversified tasks, and more secure and safe to handle potential risks.

If the AI/ML methods are applied by robots, the data volume and the model size would be limited, so that the performance is not fully optimized. The computation complexity of model training is usually intensive, robots may not complete model training in time. As the network usually have higher capabilities in terms of storage and computation power, thus it can offer AI services to the robots. For example, the network can collect the data from multiple robots, apply model training for multi-agent distributed learning, and distribute the trained AI/ML models to robots for real-time inference. As the data collection is from multiple robots, more data can be applied for model training so that the performance can be further improved. The collected data and model parameters from multiple robots are usually correlated, and joint communication and computing can be applied to improve the efficiency of data collection and model distribution procedure. This differs from the classical paradigm of computation followed by communication for AI/ML services. On the other hand, for the multi-agent distributed learning, network can train multiple AI/ML models without any communication overhead between the robots, so that the convergence speed of model training can be much improved. Each robot will make decisions according to its AI/ML model and real-time input data. As the input data of the robots are coupled, it is necessary to design an efficient way of information sharing to meet the latency requirement, joint communication and computing can also be applied here.

2. Actor

- Robots equipped with sensors (e.g., camera, LiDAR, Radar), actors (e.g., fingers, arms, legs), and capabilities of communication, data storage, and model inference
- AI/ML server with capabilities of communication, data storage, and model training

3. Pre-condition

- The robots run an application providing the capability of AI/ML model inference for performing specific tasks
- The robots are capable to collect the observed data, which include sensing data, acting data, communication data, channel state information, etc., and transmit to AI/ML server via uplink transmissions
- AI/ML server can select a set of robots for collaboration and determine training configuration, e.g., training algorithm, learning rate, batch size, number of iterations, etc.
- AI/ML server is capable to collect the observed data from multiple robots, training AI/ML models, and distribute AI/ML models to the robots via downlink transmissions
- The robots can be capable of exchanging information via robot-to-robot communication

4. Description/Service Flows

- AI/ML server select a set of robots for collaboration in performing specific task, and distribute initial AI/ML models to the set of robots
- Each robot applies the AI/ML models for inference, collect the observed data during performing the task, and report the data to AI/ML server
- AI/ML server receive the observed data from multiple robots, re-train the AI/ML models with the data, and distribute new models to the robots
- Until the AI/ML model reaches saturated performance enhancement, the process runs repeatedly from step 1

5. Post-condition

- The robots can collaboratively perform the tasks

6. Potential service requirements

- Synchronized transmissions from different robots
- Uplink transmissions for data collection for AI/ML model training – data rate and latency requirement
- Downlink transmission for AI/ML model distribution – data rate and latency requirement
- Robot-to-robot communication for information exchange - data rate and latency requirement

Use case#23

AI-as-a-service for industrial robots: Collaborative to learn

1. Introduction

Internet of things, in general has seen tremendous growth in the past decades and the use of these IoT devices in industries has given birth to a new specialized field of study commonly referred to Industrial Internet of Things (IIoT). This includes smart manufacturing, autonomous vehicles, smart grids, smart agriculture etc. Smart manufacturing refers to the integration of intelligent services into manufacturing processes and factories where AI techniques play important roles in learning big data generated from industrial machines for process modeling, monitoring, prediction, and control in production stages. As many different organizations utilize similar machines and process, FL could enable collaboration between these different organizations, without the need of sharing their sensitive data. For instance, industrial processes used by different organizations, often utilize machines and robots from the same manufacturer. That is, two companies may acquire a component, for example a robotic arm, from the same supplier. As such, if the supplier wants to use ML for performance monitoring or fault detection, there requires a way of establishing collaboration consent and criteria, as to which company would be interested in collaborating with which other company. Furthermore, the FL server needs to have a directory of the asset models of the machines, that is, their digital representations which describe their data-schemes. This data describing the assets builds the basis for multi-organization collaboration and as such, warrants the need for meta-data publishing and management.

The advantages of such federated learning based collaborative production are two-fold:

- First, by leveraging federated learning method, the learning capability of an individual robot could be extended to a wide range of networked robots and the learning capability of a single plant could be extended at global scale. Such solution will make production more efficient and sustainable.
- Second, this will also bring down the overall requirements and cost on individual robot. For instance, learning could be done based on a group of more sophisticated robots with high computing and intelligent capabilities. On the other hand, knowledge could be shared to those robots with low complexity and low cost.

The AL/ML capabilities offered by current mobile communication systems via the NWDAF largely focuses on improving the internal operation and performance of the wireless networks. However, the overall capabilities of mobile networks can be leveraged to further support the AI/ML demands of vertical industries. This means, the wireless networks are not only viewed as providers of communication links between the devices and AI/ML servers, in this case, FL server, but instead additionally as enablers of AI/ML service improvement in terms of aspects such as performance, data management, and privacy. The inherent design of wireless networks such as low latency links, distributed compute and storage capabilities can offer such capabilities. Specifically with respect to the collaborative use case discussed in this section, the availability of low latency links can enable and trigger fast model training and model parameter exchange between the different devices and the central server. Furthermore, AI/ML model aggregation at FL server and wireless links can be jointly designed so that the bandwidth efficiency and latency can be further improved.

2. Actor

- Robots equipped with sensors (e.g., camera, LiDAR, Radar), actors (e.g., fingers, arms, legs), and capabilities of communication, data storage, and model training
- AI/ML server with capabilities of communication, data storage, and model aggregation

3. Pre-condition

- The robots are capable to collect data, and run an application locally for local model training when perform specific tasks
- The robots are capable to report local model to AI/ML server
- AI/ML server can select a set of robots for local training and determine training configuration
- AI/ML server is capable to collect local models from multiple robots, and distribute global models to the robots

4. Description/Service Flows

- Let Alice be a robot in Factory A. Let Bob be a robot in Factory B. Alice and Bob are performing the same functions but in different factories.
- Both Alice and Bob, either periodically or triggered by certain event, are updating their local models, for example based on the dynamicity in the factory environment. The model update needs to happen in a timely manner to be appropriate for the operating scenario of the robots.
- As time evolves, based on the preference from the manufacturer, the robots sharing the local models with the AI/ML server may change. This can be due to some robots not having an active communication link due to undergoing maintenance or for being out-of-order.
- The AI/ML server incorporates the new updates received from the selected factory robots to develop an updated globally trained model.
- AL/ML server distributes the globally updated model to the desired factory robots.
- Different factory robots are now able to perform better and efficiently operate in their respective factories.

5. Post-condition

- The robots could collaboratively train the AI/ML model despite being distributed.
- The robots are trained to operate in scenarios that was not necessarily known to them.

6. Potential service requirements

- Availability of communication link requirements for FL model training and update to enable timely update of the FL models.
- Exposure of communication link performance to FL server to trigger model update and robot selection.
- Privacy preserving data sharing mechanisms.

Use case#24
Scalable resource control for high demand localized services

1. Introduction

Scalable resource control refers to dynamic adaptation of resources owned by, say, network operators or third-party service providers in order to support increased capacity demands or better enable services (either existing or new). These resources include physical devices (e.g., switched or routers) owned by the operator, or virtual (e.g., virtual machines) hosted by a local or even a global cloud provider. Such resource adaptation can apply to inclusion and exclusion of resources for both control and data plane operations.

In order to meet the dynamic and diverse requirements of future networks, resource adaptation cannot come as a conventional, management activity that requires manual configuration or the added resources. It has to be dynamic, control-oriented, with each added resource being available to use almost instantaneously after it gets connected to at least one other resource already owned by the operator.

5G and previous generations of mobile networks are designed as overlay networks over the (whatever underlying) transport and compute infrastructure, i.e., any interventions in the underlying infrastructure, e.g., scaling up or out, are indeed perceived as following different procedures and management loops. This hinders extreme instantaneous scalability we are targeting in 6G. To fix the problem, we need a holistic design of the mobile system, including consideration of underlying physical infrastructure from the outset, in the 6G architecture. Bringing these two together, the underlying resources and the 6G related functionalities, is therefore the goal.

2. Actor

Mobile network operators (MNOs), third party service providers, mobile subscribers.

3. Pre-condition

- Capability for MNOs to expand their set of available resources to meet the capacity demands. Expansion of the available resources refers to inclusion of resources available from third party service providers, or mobile subscribers.
- Capability within third party service providers and mobile subscribers to be flexibly included and excluded their resources for services offered by MNOs.

4. Description/Service Flows

We describe the service flow by considering a music concert scenario.

- Alice has subscribed to a MNO for wireless network services.
- Alice is at a crowded music concert with hundreds of other people.

- During the concert, vast majority of the crowd, including Alice, are frequently taking multiple photos, recording multiple videos, processing, and sharing them.
- Organizing music concerts at the venue are rare events. Hence the MNOs in the area have not permanently deployed large capacities.
- With the music concert, there is a sudden spike in capacity and resource requirement in the area.
- In order to meet the high localized demand for a relatively brief period for fans like Alice, the MNOs initiate expansion of their resources at the edge/access of the network by collaborating by other third party services providers in the vicinity and mobile subscribers.
- Expansion of MNO's resource set enables faster handling and servicing of the requests.

5. Post-condition

Despite Alice being in a large localized crowd with high data traffic demands, Alice's requests from the network were successfully fulfilled.

6. Potential service requirements

Resilient, dynamic, and instantaneous interconnection and coordination of all the resources.

Use case#25

THz communication enabled data kiosks

1. Introduction

THz communications have been identified as one promising candidate for the physical layer in 6G. The availability of large spectrum chunks has the potential to enable high data rates, in the order of Tbps. Furthermore, the abundance of frequency resources can allow high data rate transmissions at lower latencies. These characteristics make them THz communications a potential candidate to provide limited range hotspots. Referring to these hotspots as data kiosks henceforth, these can be installed in specific indoor and/or outdoor environment, such as airports, metros, factories, vehicle service stations, among others, to offer customers high download data rates over wireless link within a short time interval. THz communication bands could be used to offload traffic demands of high data rate applications from conventional communication bands in scenarios such as congestion or inability to support required data rates requirements.

We describe this use case considering a factory environment where the software of multi-purpose autonomous robots needs to be quickly updated/reloaded. The motivation for this being, a multi-purpose robot within a factory could be customized to operate in multiple areas in a factory from time-to-time such as in an assembly line or in carrying objects around. This software could include, for example, for automated control supported by intelligence.

2. Actor

Mobile network operators (MNOs) network/private network, autonomous factory robots, third party service provider, factory operator.

3. Pre-condition

- MNO has installed THz data kiosks in factory.
- Capability of autonomous robots to navigate to the data kiosks and trigger software download.
- Capability of autonomous robots to communicate over the wireless links (non-THz) with third party service provider.
- Factory operator capable of communicating with a third-party service provider.

4. Description/Service Flows

- A factory operator triggers a third-party service provider to update the software of a robot.
- The third-party service provider initiates communications with MNO/private network to enable the software update of the robot.
- Alice, an autonomous robot is notified via a MNO/private network of a new software update.
- Alice awaits to be notified via a MNO/private network to proceed towards a data kiosk to get the software update.

- Alice receives a notification via a MNO/private network to proceed towards a data kiosk within the factory.
- Alice proceeds towards the kiosk to update/reload the software update.

5. Post-condition

Alice has successfully managed to get a software update/reload.

6. Potential service requirements

Availability of reliable high-rate data links to enable fast data transfer services, such as, update/reload of robot software.

Use Case Families and Analysis

The 25 use cases collected in the previous section can be mapped into 6 different vertical domains as following:

- **Manufacture:** 7
- **Automotive**: 5
- **Health**: 5
- **Telecom** (MBB / Resiliency): 4
- **Agriculture**: 3
- **Transportation** (railway): 1

In the following tables (Table 4-1 to Table 4-6), we describe for each identified use case per vertical domain: 1) what are the open issues in current mobile communication system to support the use case, 2) what is needed for 6G to support the use case.

Table 4-1: Analysis of manufacture related use cases

UC#	What is the use case?	What are open issues to support use case by current mobile communication system?	What is needed in 6G to support use case?
8	ISAC for motion control in dynamic environment	No sensing capability integrated with wireless communication and hence resulting to a high effort and limit flexibility in a factory environment	Offer a cost-efficient solution to increase flexibility and easy co-operation between humans and robots by, for example, integrating sensing and communication functionality.
9	ISAC for cooperative carrying of unknown objects by mobile robots	No radio with sensing capability available for robot	Better robot cooperation with sensing capability when carrying objects
13	Intelligent, deterministic and time synchronization network for haptic and future factories	Only support TSN among devices in local network but not in a wide area	Wide area synchronization and deterministic comm.
16	Factory Automation and Predictive Maintenance by Remote Control of Cyber Physical Systems in Future Factories	Not possible to offer higher reliability than five nines, lower latency than 1ms	Enhanced 6G radio access to support extended reliability (higher than seven nines) and higher accuracy localization and ultra-low latency for lower than 0.5ms

UC#	What is the use case?	What are open issues to support use case by current mobile communication system?	What is needed in 6G to support use case?
22	AIaaS for industrial robots: Learning to be collaborative	Not possible to provide AIaaS to robots	Offer AI service to robots, e.g., collecting data from robots and apply model training for multi-agent leaning and distribute the trained AI/ML models to robots. Support offloading of computation and storage to the network infrastructure.
23	AIaaS for industrial robots: Collaborative to learn	Current 5G focuses on improving internal operation and performance of the wireless networks and not to support AI/ML demands of vertical industries. Not possible to provide AIaaS to Industrial IoT.	Availability of low latency links to enable and trigger fast model training and model parameter exchange between the different devices/robots and the central server. Hence resulting to wide range of networked robots and global scale of the single plant
24	THz communication enabled data kiosks	Not possible to provide extreme data rate like Tbps.	To provide Tbps data rate in a limited range hotspots as data kiosk in any indoor or outdoor environment (e.g., in factory for dynamic software updates for general purpose autonomous robots)

Table 4-2: Analysis of automotive related use cases

UC#	What is the use case?	What are open issues to support use case by current mobile communication system?	What is needed in 6G to support use case?
1	Remote software update in underserved area	Mobile coverage not available over all road networks (due to, for example, limited infrastructure or capacity)	Expand coverage beyond base station to provide service availability in underserved area by using NTN such as satellite
2	Tele-operated driving in underserved area	Unknown variations in mobile coverage, due to coverage or capacity gaps, hinders service availability at all times.	Expand coverage beyond base station to provide service availability in underserved area by using NTN such as satellite

UC#	What is the use case?	What are open issues to support use case by current mobile communication system?	What is needed in 6G to support use case?
5	ISAC for V2X in ultra-dense networks	Network resource management and adaptation is only possible with active element having active connection with network but not for passive element (parked vehicles/road work/pedestrians)	Considering both passive and active elements for managing and adapting radio resources in base station's vicinity
6	ISAC for V2V comm.	Perceiving environment is only possible via periodical broadcast info from other vehicles, but not possible to sense all surrounding objects at all time	Sensing surrounding environment and detecting different kinds of objects in its vicinity would result to a better automated vehicle to maintain direct link with desired vehicle
15	AIaaS for V2X: Environmental perception	Not possible to provide AIaaS to vehicles and hence would require high-end vehicles with high computation and storage	Offer AI online learning service to vehicles with most updated/relevant models to enable accurate and robust environment perception. Offloading all/some computation to AI provided by the network infrastructure

Table 4-3: Analysis of healthcare related use cases

UC#	What is the use case?	What are open issues to support use case by current mobile communication system?	What is needed in 6G to support use case?
4	Secure delegation of trust for mobile connectivity	All IoT devices needs direct subscription with MNO, hence, causing higher cost in service provisioning	New trust model, i.e., trust delegation to other devices to allow them to have connectivity service without having direct subscription with MNO
7	Ultra-high reliability support with tighter integration between mobile communication network and application layer	Not possible to cope with application server failure (power outage), require to drop ongoing session and the establish a new session	More robust reliability mechanism to handle with application server failure by having more coordination between network and application, e.g., application failure aware within the network
11	Geographical positioning and location sensing as mobile network service	Mobile networks are not fully utilized for precise position services	Integrating sensing and positioning tech like GNSS/Lidar/Indoor Positioning (IPS) to mobile network for a more precise positioning solution in < 1cm or even mm range

UC#	What is the use case?	What are open issues to support use case by current mobile communication system?	What is needed in 6G to support use case?
12	Optical Wireless Communication Enhanced by Optical Sensing	5G radio is sometime not appropriate in some environments like in hospital, where some equipment is EMI sensitive or in oil refinery/chemical plants where explosion proof protection is needed	Using OWC as an alternative to radio frequency
17	Mixed tactile and VR content in robotic control	Not coordination between uplink and downlink flows for robotic control and hence causing cybersickness	Synchronization of uplink and downlink flows for XR rendering and streaming (video and tactile input) with extreme low jitter <20ms and low latency

Table 4-4: Analysis of telecom related use cases

UC#	What is the use case?	What are open issues to support use case by current mobile communication system?	What is needed in 6G to support use case?
3	Simplified network for best effort mobile traffic	Current mobile network is still too complex for such best effort mobile traffic due to a high number of NFs	More simplified network with less NFs/services to reduce CAPEX and energy consumption, and hence able to provide cheaper service to end users
10	Mobile network resilience against solar superstorms	Mobile network is not durable/resilient against solar superstorm	Revision of technologies with objective to obtain solar superstorm resilience and mechanism to mitigate severe impact from it
14	Advanced and sustainable massive MIMO wireless transmission technologies for ultra-high data rate applications	Not possible to provide ultra-high bandwidth for holographic comm.	Next generation of MIMO wireless transmission
25	Scalable resource control for high demand localized services	Not possible to provide ultra-fast scalability of network resource in a very short period due to the procedure and management loops required for network resources scaling	Holistic design allowing network resources to be scale instantaneously in a short period of time due to the event that requires resources to meet the demand (e.g., in a concert)

Table 4-5: Analysis of agriculture related use cases

UC#	What is the use case?	What are open issues to support use caseby current mobile communication system?	What is needed in 6G to support use case?
19	Livestock Health and Behavior Monitoring	Unknown variations in mobile coverage, due to coverage or capacity gaps, hinders service availability in rural or remote areas. 5G infrastructure is too expensive and not profitable to deploy in such rural area for monitoring livestock health and behavior.	- Reducing the cost for deployment in rural area with high number of connected devices. - Extending the range of network coverage by incorporating new terrestrial network radio designs and NTN solutions.
20	UAV Remote Controlling for Precise Agriculture	Unknown variations in mobile coverage, due to coverage or capacity gaps, hinders service availability in rural or remote areas. 5G infrastructure is too expensive and not profitable to deploy in such rural area for remote UAV control and monitoring crops and plants and spraying necessary chemicals.	- Reducing the cost for deployment in rural area for UAV control that require high throughput (60Mbps) and low latency capability (<20ms) - Extending the range of network coverage by incorporating new terrestrial network radio designs and NTN solutions.
21	Agricultural Machinery Remote Monitoring and Controlling	Unknown variations in mobile coverage, due to coverage or capacity gaps, hinders service availability in rural or remote areas. 5G infrastructure is too expensive and not profitable to deploy in such rural area for remote monitoring and control of agricultural machinery	- Reducing deployment cost in rural area for remote monitoring and control of agricultural machinery - Extending the range of network coverage by incorporating new terrestrial network radio designs and NTN solutions.

Table 4-6: Analysis of transportation related use cases

UC#	What is the use case?	What are open issues to support use caseby current mobile communication system?	What is needed in 6G to support use case?
18	Monitoring of cross level passages in railroads	Not possible to combine assets from different MNOs for service provisioning in an underserved area	Allow verticals to request network slice that along with inter-stitching capabilities towards network slices existing in other operators.

Conclusions

In this white paper, we have described various use cases (in total of 25) provided by different one6G partners. From these 25 use cases, we have grouped them into different vertical domains and provided analysis on what is the issue why current mobile communication system cannot fulfil the identified use case and what future mobile communication system such as 6G should be enhanced to support the use cases. Based on the analysis, we can further draw a conclusion on what are the major requirements for 6G for each vertical domain and what are potential technology enablers to fulfil the identified requirements as discussed in Table 5-1. It shall be noted that some requirements are still to be further investigated on which technology could support the identified requirements.

Table 5-1: Major requirements and potential technology enabler(s) for 6G to support use cases in different vertical domain

Vertical	Major requirements derived from use cases	Example(s) of potential technology enabler
Manufacture	Better and more flexible cooperation among robots or between robots and human	ISAC, wide area TSN, AIaaS
	Ultra-high reliability communication (seven nines)	Advance 6G radio access
	Ultra-low latency < 1ms for digital twins/cyber physical systems	Advance 6G radio access
	Ultra-high data rate transmission for quick software updates	THz comm.
Automotive	Extending network coverage in underserved area	Tighter integration of NTN into cellular networks
	Better sensing capability for surrounding environment	ISAC, AIaaS
Transportation (railway)	Allowing vertical to provide service from assets belonging to different MNOs	Flexible Programmable Infrastructure (FPI)
Healthcare	Ultra-high reliability communication (seven nines)	Tighter integration between mobile network and application layer
	Better and more precise location service provisioning	Tighter integration of various positioning technologies (e.g., GNSS/Lidar/IPS) into mobile networks
	High data rate transmission in hazardous/EMI sensitive area	OWC
	Synchronization of UL/DL data flows for haptic robotic control	[Still to be investigated]
	Secure and sustainable wireless connectivity service provisioning	Trust delegation for service subscription

Vertical	Major requirements derived from use cases	Example(s) of potential technology enabler
Agriculture	Extended network coverage in underserved area	Tighter integration of NTN into cellular networks
	Simplified and cost-efficient mobile network deployment in rural area	New radio designs (e.g., using software-defined radio systems)
Telecom	Simplified network for best-effort traffic and economic viability	[Still to be investigated]
	Mobile network resilience to natural disaster (e.g., solar superstorm)	[Still to be investigated]
	Ultra-high data rate transmission for advance multimedia comm. (hologram)	NextGen MIMO, THz, OWC
	Instantaneous network resources scaling for unexpected event	Flexible Programmable Infrastructure (FPI)

References

[1] "Ericsson Mobility Report", June 2020, https://www.ericsson.com/49da93/assets/local/reports-papers/mobility-report/documents/2020/june2020-ericsson-mobility-report.pdf

[2] "Indoor 5G Scenario Oriented White Paper", Version 3.0, October 2019, https://www.huawei.com/en/news/2019/10/huawei-hkt-gsa-indoor-5g-scenario-oriented-whitepaper

[3] 3GPP SA1, "3GPP TS22.104 V18 - Service requirements for cyber-physical control applications in vertical domains," v18.3.0, December 2021.

[4] I. o. I. E. N. w. 5. N. 5G-ACIA, "Integration of Industrial Ethernet Networks with 5G Networks," 5G-ACIA, 2019.

[5] "Bosch-Rexroth APAS smart skin," Bosch-Rexroth, 2018. [Online]. Available: https://apps.boschrexroth.com/microsites/apas/downloads/Download_20170324_web_apas_broschure_EN.pdf [Accessed 2018].

[6] S. A. Jyothi, "Solar Superstorms: Planning for an Internet Apocalypse," in SIGCOMM'21, August 23–27, Virtual Event, USA, 2021.

[7] A. Lawrence, "Could a Sunspot Wreck 6G?," 6GWorld, 1 September 2021. [Online]. Available: https://www.6gworld.com/exclusives/could-a-sunspot-wreck-6g/

[8] Wikipedia, "Carrington Event," [Online]. Available: https://en.wikipedia.org/wiki/Carrington_Event [Accessed 2 November 2021].

[9] T. Phillips, "The Great Geomagnetic Storm of May 1921," https://spaceweatherarchive.com/, 12 May 2020. [Online]. Available: https://spaceweatherarchive.com/2020/05/12/the-great-geomagnetic-storm-of-may-1921/.

[10] M. Hapgood, "The Great Storm of May 1921: An Exemplar of a Dangerous Space Weather Event," *Space Weather,* vol. 17, no. 7, pp. 950-975, July 2019.

[11] S. Odenwald, "The Day the Sun Brought Darkness," 13 Mars 2009. [Online]. Available: https://www.nasa.gov/topics/earth/features/sun_darkness.html

[12] C. Gebhardt, "Carrington Event still provides warning of Sun's potential 161 years later," 28 August 2020. [Online]. Available: https://www.nasaspaceflight.com/2020/08/carrington-event-warning/

[13] E. Siegel, "Ask Ethan: How Prepared Are We For The Next Giant Solar Flare. Forbes," 26 February 2021. [Online]. Available: https://www.forbes.com/sites/startswithabang/2021/02/26/ask-ethan-how-prepared-are-we-for-the-next-giant-solar-flare/?sh=2dde9bf7196e

[14] National Research Council, "Severe Space Weather Events–Understanding Societal and Economic Impacts. Workshop Report," The National Academies Press, Washington, DC, 2009.

[15] DSB, "Analyser av krise scenarier 2019," Direktoratet for Samfunnsikkerhet og Beredskap, Oslo.

[16] Norwegian Government. Ministry of Local Government and Modernisation, "Everything happens somewhere - National geospatial strategy towards 2025," 18 November 2018. [Online]. Available: https://www.regjeringen.no/contentassets/6e470654c95d411e8b1925849ec4918d/en-gb/pdfs/en_nasjonal_geodatastrategi.pdf.

[17] D. Dardari, E. Falletti and F. Sottile, "Introduction," in *Satellite and Terrestrial Radio Positioning Techniques. A signal processing perspective*, Academic Press, Elsevier Ltd., 2012, pp. 1-23.

[18] R. Keating, M. Säily, J. Hulkkonen and J. Karjalainen, "Overview of Positioning in 5G New Radio," in *16th International Symposium on Wireless Communication Systems (ISWCS)*, 2019.

[19] S. Dwivedi, R. Shreevastav, F. Munier, J. Nygren, I. Siomina, Y. Lyazidi, D. Shrestha, G. Lindmark, P. Ernström, E. Stare, S. M. Razavi, S. Muruganathan, G. Masini, Å. Busin and F. Gunnarsson, "Positioning in 5G networks," 5 February 2021. [Online]. Available: https://arxiv.org/pdf/2102.03361.pdf [Accessed 3 November 2021].

[20] International Association of Geodesy (IAG), "IAG Statutes," 2021. [Online]. Available: https://www.iag-aig.org/statutes-and-by-laws/32 [Accessed 3 November 2021].

[21] EUREF, "EUREF Permanent GNSS Network," [Online]. Available: https://www.epncb.oma.be/ [Accessed 3 November 2021].

[22] G. M. Mendoza-Silva, J. Torres-Sospedra and J. Huerta, "A Meta-Review of Indoor Positioning Systems," *Sensors,* vol. 19 (20) , no. 4507, 17 October 2019.

[23] Intuitive, "Advancing what's possible in minimally invasive care," [Online]. Available: https://www.intuitive.com/en-us [Accessed 3 November 2021].

[24] Brainlab, "Is navigation really necessary?," [Online]. Available: https://www.brainlab.com/surgery-products/overview-spinal-trauma-products/spinal-navigation/ [Accessed 3 November 2021].

[25] NorMIT, "Tomorrow's surgery starts here," [Online]. Available: http://normit.no/en/ [Accessed 3 November 2021].

[26] 3gpp, "TS 37.355 – LTE Positioning Protocol (LPP) v16.6.0," 27 September 2021. [Online]. Available: https://www.3gpp.org/ftp/Specs/archive/37_series/37.355/37355-g60.zip [Accessed 3 November 2021].

[27] F. Gunnarsson and S. M. Razavi, "LTE Positioning and RTK: Precision down to the centimeter," 19 November 2018. [Online]. Available: https://www.ericsson.com/en/blog/2018/11/lte-positioning-and-rtk-precision-down-to-the-centimeter.

[28] R. S. Thomä, C. Andrich, G. D. Galdo, M. Döbereiner, M. A. Hein, M. Käske, G. Schäfer, S. Schieler, C. Schneider, A. Schwind and P. Wendland, "Cooperative Passive Coherent Location - A Promising 5G Service to Support Road Safety," *IEEE Communications Magazine,* vol. Vol. 57, no. No. 9, pp. 86-92, 2019.

[29] M. Giordani, M. Polese, M. Mezzavilla, S. Rangan and M. Zorzi, "Toward 6G Networks: Use Cases and Technologies," in IEEE Communications Magazine, vol. 58, no. 3, pp. 55-61, March 2020.

[30] Z. Zhang et al., "6G Wireless Networks: Vision, Requirements, Architecture, and Key Technologies," in IEEE Vehicular Technology Magazine, vol. 14, no. 3, pp. 28-41, Sept. 2019.

[31] NTT DOCOMO, "5G Evolution and 6G", White Paper, Jan 2022, https://www.nttdocomo.co.jp/english/binary/pdf/corporate/technology/whitepaper_6g/DOCOMO_6G_White_PaperEN_v4.0.pdf.

[32] X. Xu, Y. Pan, P. P. M. Y. Lwin, and X. Liang, "3D holographic display and its data transmission requirement," in International Conference on Information Photonics and Optical Communications, Oct. 2011, pp. 1–4.

[33] Lins, Sebastian, Pandl, Konstantin D., Teigeler, Heiner, Thiebes, Scott, Bayer, Calvin and Sunyaev, Ali, (2021), Artificial Intelligence as a Service, Business & Information Systems Engineering: The International Journal of WIRTSCHAFTSINFORMATIK, 63, issue 4, p. 441-456.

[33] Huawei Technologies Co., "Empowering consumer-focused immersive VR and AR experiences with mobile broadband," Huawei Technologies Co., White Paper, 2016. [Online]. Available: https://www.huawei.com/en/industry-insights/outlook/mobile-broadband/insights-reports/vr-and-ar

[34] H. G. Kim, W. J. Baddar, H.-t. Lim, H. Jeong, and Y. M. Ro, "Measurement of exceptional motion in VR video contents for VR sickness assessment using deep convolutional autoencoder," in ACM Symposium on Virtual Reality Software and Technology (VRST), Gothenburg, Sweden, Nov. 2017.

[35] O. S. Peñaherrera-Pulla, C. Baena, S. Fortes, E. Baena, and R. Barco, "Measuring Key Quality Indicators in Cloud Gaming: Framework and Assessment Over Wireless Networks," Sensors, vol. 21, no. 4, Feb. 2021

[36] M. Lecci, F. Chiariotti, M. Drago, A. Zanella, and M. Zorzi, "Temporal Characterization of XR Traffic with Application to Predictive Network Slicing," arXiv preprint arXiv:2201.07043, Jan. 2022

[37] J.P. Stauffert, F. Niebling, and M.E. Latoschik, "Simultaneous run-time measurement of motion-to-photon latency and latency jitter," in IEEE Conference on Virtual Reality and 3D User Interfaces (VR), Atlanta (GA), USA, Mar. 2020 (pp. 636-644)

[38] Q. Zeng, Y. Ishibashi, N. Fukushima, S. Sugawara, and K.E. Psannis, "Influences of inter-stream synchronization errors among haptic media, sound, and video on quality of experience in networked ensemble," in IEEE 2nd Global Conference on Consumer Electronics (GCCE), Tokyo, Japan, Oct. 2013 (pp. 466-470)

[39] Shimaa A. Abdel Hakeem, Hanan H. Hussein, HyungWon Kim, "Vision and research directions of 6G technologies and applications," Journal of King Saud University - Computer and Information Sciences, 2022, ISSN 1319-1578, doi: 10.1016/j.jksuci.2022.03.019.

[40] 5G Infrastructure Association (5GIA), "European vision for the 6G network ecosystem," June 2021.

[41] Networld2020, Strategic Research and Innovation Agenda 2021-27 (SRIA), "Smart networks in the context of NGI," Sept. 2020.

[42] W. Tong and P. Zhu (Eds), 6G: The Next Horizon: From Connected People and Things to Connected Intelligence, Cambridge University Press, 2021.

[43] one6G Taking communications to the next level, position paper, Nov, 2021, https://one6g.org/download/1350

[44] 5GAA, white paper, "C-V2X Use Cases Volume 2: Examples and Service Level Requirements", 20 Oct. 2020. https://5gaa.org/wp-content/uploads/2020/10/5GAA_White-Paper_C-V2X-Use-Cases-Volume-II.pdf

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