SWG Specific Applications

WORKING DOCUMENT TOWARDS A PRELIMINARY DRAFT NEW REPORT ITU-R M.[IMT.APPLICATIONS]

Applications of IMT for specific societal, industrial and enterprise usages

(Question ITU-R 262/5)

(202X)

Source: Annex 3.5 to Document 5D/886; Annex 3.2 to Document 5D/1361; Document 5D/896; Document 5D/904; Document 5D/918; Document 5D/923; Document 5D/992; Document 5D/1000; Document 5D/1004; Document 5D/1047; Document 5D/1064; Document 5D/1161; Document 5D/1169; Document 5D/1202; Document 5D/1327; Document 5D/1340; Document 5D/1352;Annex 4 of Annex 17 to Document 5A/491; Document 5D/1379; Document 5D/1388; Document 5D/1437; Document 5D/1502; Document 5D/1509

[Editor's Note : Replace technology (e.g. 4G, 5G, etc.) with generic terminology (IMT-2000, IMT-Advanced or IMT-2020)]

[Editor's note: Table of Contents to be updated after document is stable.]

Table of contents

Page

1 Scope

This Report addresses the usage, technical and operational aspects and capabilities of IMT for meeting specific needs of societal, industrial and enterprise usages.

2 Introduction

Report ITU-R M.2441, published in 2018, provided an initial compilation of usage of IMT in specific applications. Further, it introduces potential new emerging applications of IMT in areas beyond traditional voice, data and entertainment type communications as envisaged in the vision for IMT-2020. PPDR is one of the specific applications of IMT is addressed in Report ITU-R M.2291.

This report has been developed in response to Question ITU-R 262/5 which calls upon ITU-R to study specific industrial and enterprise applications, their emerging usages, and their functionalities, that may be supported by IMT.

APT recently developed a report[1] on new/emerging critical applications and use cases of IMT for industrial, societal and enterprise usages, addresses the capabilities of IMT and its use cases, to meet the needs of private mobile broadband networks.

Today's industrial automation is powered by ICT technology and this trend will increase manifold with advent of new broadband mobile technologies such as IMT-2020 technologies, leading to increased business efficiencies, improved safety, and enhanced market agility. Industry 4.0 enables industries to fuse physical with digital processes by connecting all sensors and actuators, machines and workers in the most flexible way available. Tethering them to a wired network infrastructure is expensive and, ultimately, it will limit the possible applications of Industry 4.0 and Industry 5.0 in the future. Industrial grade private wireless will unleash its real potential by providing the most flexible and cost-effective way to implement a wide range of industry applications. Current IT based automation solutions are well adapted for day-to-day business communications, but are limited in reliability, security, predictable performance, multiuser capacity and mobility, all features which are required for operational applications that are business or mission critical. Similarly, applications in mines, port terminals or airports require large coverage area, low latency and challenging environments, which so far only two-way mission critical radios could meet. In both mining and port terminals, remotely operated, autonomous vehicles, such as trucks, cranes and straddle carriers are used requiring highly reliable mission critical mobile communications.

Taking manufacturing, with thousands of factories with thousands of employees, as an example, typical business cases revolve around controlling the production process, improving material management, improving safety, and introducing new tools. Fortunately, IMT-2020 technologies are available in configurations perfectly suited to building industrial-strength private wireless networks to support Industry 4.0. IMT-2020 technologies bring the best features of wireless connectivity and have proven their capabilities both in large consumer mobile networks area and in many industrial segments. The time is ripe for many industries to leverage private networks using IMT-2020 technologies to increase efficiencies and automation. In simple terms –

i) A private network is a dedicated network of the enterprise involving connections of the people, systems and processes of the enterprise.

ii) A private network is a dedicated network by the enterprise setup internally in the enterprise by internal IT teams or outsourced.

[1] APT Report No. APT/AWG/REP-126 - Emerging critical applications and use cases of IMT for industrial, societal and enterprise usages.

iii) A private network is a dedicated network for the enterprise to enable communication infrastructure for the systems and people associated with the enterprise.

iv) A private network is tailored to meet the requirements and the use case(s) of the enterprise.

For certain critical applications, a dedicated network, for example, could be a closed/private wireless communication network of the enterprise, that is not connected to a public communication network and is intended solely for ensuring the production activities of enterprises, or control technological processes in production.

The emergence of IMT-2020 technologies provides manufacturers with the much-needed reliable connectivity solutions, enabling critical communications for wireless control of machines and manufacturing robots, and IoT sensor solutions, which will unlock the full potential of Industry 4.0.

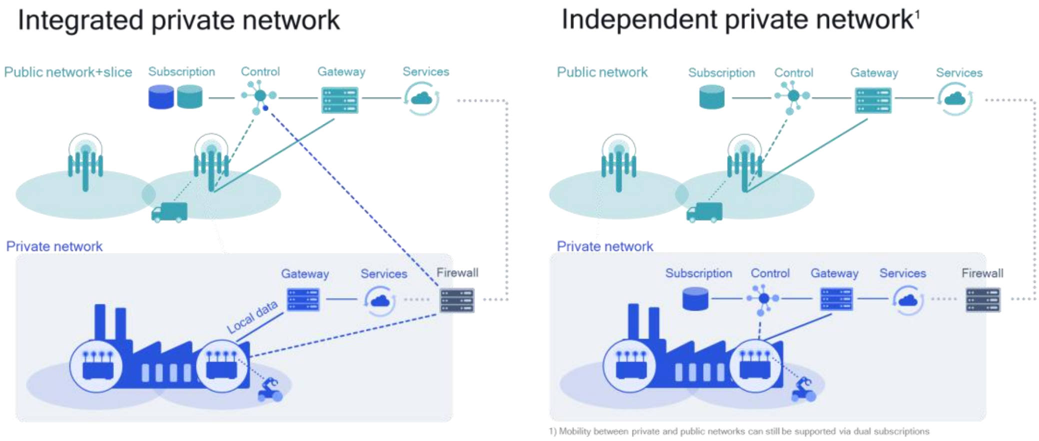
Apart from manufacturing, many other industries are also looking at IMT-2020 technologies as the backbone for their equivalent of the Fourth Industrial Revolution. The opportunity to address industrial connectivity needs of a range of industries includes diverse segments with diverse needs, such as those in the mining, port, energy and utilities, automotive and transport, public safety, media and entertainment, healthcare, agriculture and education industries, among others.

Some recent trial of IMT-2020 technologies in port operations demonstrated the “3GPP 5G” capabilities for critical communications enablers such as ultra-reliable low-latency communication (URLLC), enhanced mobile broadband (eMBB) to support traffic control, AR/VR headsets and IoT sensors mounted on mobile barges and provided countless possibilities to improve efficiency and sustainability in the complex and changing industrial environments, e.g. ports and mining. Some ports are increasing/accelerating their adoption of digital processes, automation and other technologies to enhance efficiency and resiliency to crises such as a global COVID-19 pandemic.

Similarly, in mining exploration sites, the drilling productivity could be substantially increased through automation of its drills and other technologies. Additional savings from improved efficiency and sustainability could also lead to lower capital expenditures for mines (CapEx) as well as a better safety and working environments for their personnel.

FIGURE 2.1

Examples of private network architectures



An example of an application in health care that need critical communications supported by the capabilities of IMT-2020 is remote robotic surgery. A latency of one millisecond is critical in providing haptic feedback to a surgeon that is connected through a mobile connection to a surgical robot. A high data rate is needed to transfer high-definition image streams. As an ongoing surgery cannot be interrupted an ultra-reliable communication is needed to keep connection down-time and packet loss very low.

A new generation of private networks using IMT technologies is aimed to address critical wireless communication requirements in public safety, manufacturing industries, and critical infrastructure. These private networks using IMT technologies are physical or virtual systems that have been deployed for private use by a government, company or group of companies. .

3 Related ITU-R documents

[1] Question ITU-R 262/5 – *Usage of the terrestrial component of IMT systems for specific applications*. (Copy reproduced in Attachment 2.)

[2] Recommendation ITU-R M.2083 – *Framework and overall objectives of the future development of IMT for 2020 and beyond*.

[3] Report ITU-R M.2440 – *The use of the terrestrial component of International Mobile Telecommunications (IMT) for Narrowband and Broadband Machine-Type Communications*.

[4] Report ITU-R M.2441 – *Emerging usage of the terrestrial component of International Mobile Telecommunication (IMT)*.

[5] Report ITU-R SM.2404 – *Regulatory tools to support enhanced shared use of the spectrum*.

[6] Report ITU-R SM.2405 – *Spectrum management principles, challenges and issues related to dynamic access to frequency bands by means of radio systems employing cognitive capabilities*.

[7] [Draft new] Report ITU-R M.[UTILITIES] – *Utility Radiocommunications Systems*

4 Acronyms and abbreviations

[Editor's note: This list may be updated once the document is developed further.]

A/V: Audio / Video

ADS: Automated Drilling solutions

AED: Automated External Defibrillators

AGV: Automated Guided Vehicles

AHS: Automated Haulage Solutions

AR: Augmented Reality

CBRS: Citizens Broadband Radio Service

COVID-19: Coronavirus

CSP: Contracted Service Provider

DAS: Distributed Antenna Systems

DER: Distributed Energy Resources

DiGA: Dynamic in-Game Advertising

DL: Downlink

DRAN: Distributed Radio Access Networks

DS-TT: Device-Side TSN Translator (DS-TT)

E2E: End-to-End

ECG: Electrocardiogram

eMBB: enhanced Mobile Broadband

ER: Emergency Room

EV: Electric Vehicles

FRMCS: Future Railway Mobile Communication System

GaaS: Gaming as a Service

GPS: Global Positioning System

IMT: International Mobile Telecommunications

IoT: Internet of Things

ISM Band: Industrial, Scientific, and Medical radio Band

LIDAR: Light Detection and Ranging

MCX: Mission-Critical Services

MDT: Mobile Data Terminal

MEC: Mobile Edge Compute

MMO: Massively Multi-player Online

mMTC: Massive Machine Type Communications

MOCN: Multi-Operator Core Network

MORAN: Multi-Operator Radio Access Network

MR: Mixed Reality

N.A.: Not applicable

NPN: Non-Public Network

NSA: Non-Standalone

OTA: Over the Air

PLMN: Public Land Mobile Network

PMSE: Programme Making and Special Events

PoC: Proof of Concept

QoS: Quality of Service

RAN: Radio Access Network

REC: Railway Emergency Communication

RFID: Radio Frequency ID

SA: Standalone

SMS: Short Messaging Service

TBD: To be determined

TSN: Time Sensitive Networking

UHD: Ultra-High Definition

UL: Uplink

URLLC: Ultra-Reliable Low Latency Communications

UTC: Universal Time Coordinated

V2X: Vehicle to Everything

VPP: Virtual Power Plant

VR: Virtual Reality

5 Industrial and enterprise usages and applications supported by IMT

Enterprises can generally expect reliable and secure network services with LTE for fixed and mobile broadband applications across a wide coverage area. Furthermore, 5G promises higher capacity, lower latency, and massive machine-type communications services. While there are subtle differences across different industrial sectors, IMT applications over LTE and 5G networks typically involve the following: video surveillance, remote control, autonomous vehicles and robots, automation, and immersive experiences.

This document defines a private LTE/5G network as a cellular network intended for enterprise and industrial applications.

5.1 IMT applications in mining sector

Mining is a key industrial sector of the global economy. Annual mining production has almost doubled to 20 billion metric tons over the past 35 years, according to World Mining Data 2021. The demand for rare minerals and other raw materials is increasing as many industries undergo transformative shifts, e.g., electrification in the automotive sector. With growing demand, the Mining sector has been investing in new technologies to help improve operational efficiency and meet regulatory requirements to protect workers. The mining vertical is one of the early adopters of private IMT. For decades, private wireless networks have been vital aspects of mining operations in remote surface and underground mines. However, the old methods of voice dispatching and SCADA systems to transmit terminal data back to centralized servers in a hub are no longer viable in today’s advanced mines, which require a real-time response for full autonomy, i.e., remote operation of minefields. Communication in remote mining venues, need for automation and worker safety in isolated and dangerous terrain, as well as lack of reliable carrier based cellular coverage has promoted mine operators to build and operate their own IMT networks.

The development of mining is a gradual development process from mechanization to automation, digitalization and intelligence. With the rapid advancement of industry digitization, the uplink demands of the mining have gradually increased. Based on the IMT system, the digital transforming of the mining can be better carried out and the mining use cases will be fully developed. Top mining companies are moving towards full autonomy, leveraging private wireless networks to connect, monitor, and automate dispersed minefield operations. Going forward, modernization and digitization of the mining vertical is putting additional demands on these early IMT networks and promoting them to expand and evolve to accommodate additional functionality. For any mine operator primary goals of deploying a communication solution can be summarized in the following:

– Prevent failures/breakdowns/unplanned downtime
– Enhance worker safety
– Improve efficiency
– Reduce energy consumption
– Meet environmental requirements.

Mining Venues and Use Cases

Mining sites are usually located in isolated geographic areas where spectrum coverage by cellular providers is limited or non-existent. Sites can include massive areas of undulating terrain that may be constantly changing due to excavation and rock removal activities. Venues can be over ground or underground. Underground mine shafts can be extensive and deep with unusual environmental characteristics that may cause wireless spectrum to behave differently. Communication services using RLAN mesh or IMT platforms have been in use in mining sites for many years. These are usually simple standalone platforms that enable basic services for connectivity, worker safety, automation of haulage or drilling equipment, and monitoring of site and activities for security purposes.

Demand for more and better wireless has increased by orders of magnitude with the evolution of the mining industry. The main use cases in mining[2,3] are as follows, and for a more complete analysis of the mining vertical use cases, there are several additional resources available online at Cisco[4], Baker Hughes[5], World Economic Forum[6], and Enterprise IoT Insights[7].

Intellectual mining production

Intellectual mining production supported by IMT system in mining and production provides real-time transmission and interaction of data such as high-definition video surveillance, working conditions of devices, operating parameters and scheduling commands, various environmental indicators etc. And through the data analysis and devices control of intelligent centralized control platform, the remote monitoring and control of working devices in mining production has been realized. And the intellectual mining production could reduce staff in mining and even realize unmanned mining, and improve the production efficiency and the safety production level.

Innovative worker wearables and tools, beyond existing Push to Talk (PTT), to enable more intelligent monitoring and hands-free richer interactions of workers remotely. Wearables may be sensors located on hard hats, body cams, and remote expert goggles. These devices need to be ruggedized and functional in hard-to-reach places such as mine shafts.

---

2 NDRC, NEA, CCAC, and MIIT. Implementation plan for 5G applications in energy sector, 2021, https://www.gov.cn/zhengce/zhengceku/2021-06/12/5617357/files/dee249852d5541b59d9c69aaf7b7743b.pdf.

3 CNCA, CCS, CIIA, *et al.*, White Paper: 5G+ Intelligent mining, 2021, http://www.coalchina.org.cn/uploadfile/2021/1124/20211124095946555.pdf.

4 https://www.cisco.com/c/en/us/td/docs/solutions/Verticals/Industrial_Automation/IA_Verticals/Mining/IA-Mining-DG/IA-Mining-DG.html.

5 https://info.bakerhughesds.com/rs/400-ZOJ-998/images/BakerHughes_BN_Mining_WP-040821.pdf.

6 https://www.weforum.org/agenda/2019/03/seven-trends-shaping-the-future-of-the-mining-and-metals-sector/.

7 https://enterpriseiotinsights.com/20210413/enterprise/in-mining-vertical-new-tech-means-new-risk-everyone-wants-to-be-second-ambra-ceo-says.

For instance, major mining companies see the high uplink bandwidth of 5G networks as key to backhauling large amounts of video traffic data for remote monitoring. In addition to video, real-time monitoring of environmental sensors, such as ventilation systems in underground mines, is a critical infrastructure for worker safety.

Intelligent inspection in mine

Supported by IMT system and high accuracy positioning technology in mining, to meet the needs of intelligent inspection, the real-time interaction of positioning and information of personnel and devices in mine could be realized , for example, the intelligent robots and AR devices could be used for intelligent inspection.

For the intelligent inspection based on robots, the real-time transmission of sensing data, video surveillance and control data in intelligent robots in mine has been realized. The intelligent robots in mine with video cameras and multi-parameter sensors, etc. provides the real-time collection, storage and transmission of images, sound, temperature, smoke, methane and other data. And with the help of corresponding inspection analysis system, the intelligent analysis and the processing of inspection data can be realised. Furthermore, the intelligent inspection based on robots in mine could replace the inspector in mine and improve the quality and efficiency of inspection.

And for the intelligent inspection based on AR, the existing inspection contents such as text, picture, video and 3D animation could be edited and sorted to form a standardized inspection process, and transformed into visual and iterative inspection data in time. By using of the IMT system, the AR device for intelligent inspection could receive the relevant inspection data, and then guide the inspection personnel to complete the inspection work in accordance with the standards and specifications in real time.

Automated vehicles in open-pit mine

Supported by IMT system and based on the V2X technology, remote driving and autonomous operating in open-pit mine is realised, which is combined with the sensing information of various sensor and the decision planning based on the vehicle positioning and map information. It also could predict the operation status of the system by building virtual environment model with the sensing information base on the vehicle infrastructure cooperative system. Therefore, this use cases could avoid transportation accidents effectively which is caused by human error operation, fatigue driving, unprofessional operation, etc.

In addition, there are fleet management solutions (FMS) for task scheduling and routing of haulage vehicles. These systems are human controlled but need connectivity, in the order of kilobytes, to a central site to communicate route and order details to the drivers of haulage vehicles.

Environmental monitoring and safety protection

Supported by IMT system, the visual communication, real-time high-definition video transmission, and environmental monitoring data collection could be realised to meet the massive high-definition video data transmission requirements of environmental monitoring and safety protection, and provide intelligent safety warnings for the entire mine and the entire process. In particularly, this use case provides full range of high-definition video surveillance for mining by use of characteristics of IMT system such as broadband and low latency, and realises the automatic identification of key information such as in the process of belt transportation, water detection and release, staff activities, etc. And through the analysis of the video, it could detect the abnormal situations in time, such as on-site disasters of water penetration, fire, thick smoke, large dust, roof fall, etc. And based on the real-time video analysis results of edge computing server, it also provides intelligent safety early warning for safe production in mining, and the protection of mine personnel and property safety.

Extensive use of environmental sensors to ensure early detection of dangerous chemicals for both safety reasons as well as conformance to emerging environmental protection requirements. These sensors can encompass a very large network needing low throughput and low power connections. Data collected from these sensors will need to be accumulated and analyzed to derive trends for intelligent decision making.

Massive live video and Light Detection and Ranging (LIDAR) surveillance via either static or using drones, combined with other venue surveillance for security and safety purposes is top of mind in mining, as well.

Intelligent operation and maintenance based on AR

Supported by IMT system, the AR intelligent operation and maintenance systems have the functions of real-time data collection, real-time positioning, multimedia interaction with voice and video, proximity detection and tele-diagnosis, etc. The devices failure in mining could be located quickly with the help of AR equipment when the equipment is abnormal. And the on-site situation could be handled base on the tele-diagnosis and guidance of remote expert system when the on-site maintenance personnel encounter problems which cannot be solved independently.

Automated Haulage Solutions (AHS), Automated Drilling solutions (ADS)

Increased automation is the ongoing trend for all heavy vehicles, such as dozers, excavators, and loaders. Currently, most haulage or drilling vehicles can only arrive to level 3-4 of autonomy, meaning while they can control a lot of their activities independently, they still need a human controller who can control this equipment remotely while sitting at their workstation in a central NoC. The amount of bandwidth required for control of this equipment is not very large, around one megabyte. However, for each piece of equipment, there is also a massive amount of data that is being collected, through video or other sensors, some of which needs to be used in real time to fine tune the activity of the equipment. These additional data paths can increase bandwidth demand for each equipment to 15-20 Mbyte uplink traffic. For example, automated drilling bits can be monitored closely to see what type of rock formation is being exposed, which can then be used to increase or decrease the power of the bit.

General connectivity in changing terrains (e.g., mine shafts, mine pits)

Most mines are in constant churn and topological change. Wireless set ups need to be able to change and adapt to these topographical changes.

Moreover, full autonomy requires remote control of drilling rigs and autonomous vehicles, such as unmanned hauling trucks. Here, the 5G channels supporting latency of 10’s of milliseconds are essential. A fully autonomous operation may also include unmanned drones and video-equipped robots to inspect mines. Besides these advanced autonomous applications, mining companies can simplify communication platforms for personal voice calls and emergency communication systems with a private LTE/5G network instead of various disparate networks.

The mining industry’s early investments in automation technologies, including private LTE networks in minefields, have paid dividends during COVID as remote operation using automation technology solutions has kept the mining operations running. With proven safety records and operational efficiency gains, investment in “smart” mining operations leveraging automation technologies and private 5G networks will be vital in meeting the increased demand for mining production.

IMT Considerations for Use in Mining

In addition to the benefits, there are also certain considerations regarding the use of IMT networks in mines, which can include:

– **Spectrum sources for mines have been either private or leased carrier spectrum**. Availability of CBRS and ISM bands as shared spectrum sources are intriguing developments for mines, however, effective deployment of these spectral bands are yet to be seen. Additionally, major concerns for use of shared spectrum or carrier's licensed spectrum in mining venues is lack of complete reliability and availability. Any outage at the mine can result in massive revenue loss or decreased worker safety. As such mine operators prefer to have full control of their spectrum and radio sources to prevent outage.

Other spectral considerations can relate to how spectrum behaves in different mine locations, such as a mine shaft where higher frequency spectrum does not propagate very well due to weaker reflection capability. For all use cases, a complete RF analysis of mine site and venues is necessary to assess effective spectrum performance and outcomes. Ongoing RF analysis and expertise may need to be applied due to the changing terrain of a mine site.

– **Mining venues will tend to cost optimize for all needs,** as with other legacy venues such as oil and gas. Any IMT equipment and solution will have to prove its value for enabling overall cost saving. Existing RLAN mesh and IMT solutions are just being deployed and put to trial. It is not clear how much cost saving IMT will bring.

– **The choice of a privately operated network versus a managed service** through a carrier operated network is a question, as with other verticals. So far, large complex mining operators have chosen expert IT and network operations firms who are very familiar with nuances of the mining vertical to set up and operate private networks for the mines while smaller and simpler mining sites have used carrier services.

– **Lack of approved hardened IMT hardware for mining venues**. IMT adapters or industrial routers with IMT adapters will need to be ruggedized and integrated into AHS and ADS, and these systems will then need to be tested for performance and reliability in specific mine venues.

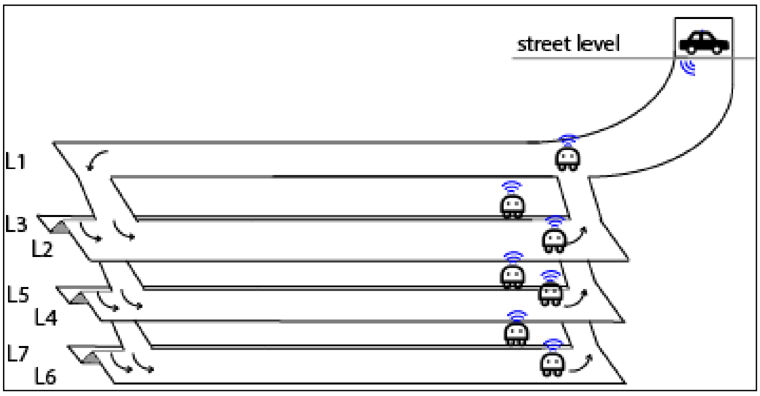
– **Coverage Extension in Mines**

For indoor scenarios like underground mines, beyond the point where outdoor wireless coverage penetrates, a possibility to provide 5G coverage is to make use of fixed or vehicle relays, i.e. base stations with wireless backhaul, to create a transient wireless connectivity[8]. An example is shown in Fig. 5.1.1.

[8] 3GPP TR 22.839: *Study on vehicle mounted relays.*

FIGURE 5.1.1

Transient coverage extension



The following can be available for this scenario:

- 5G macro cellular coverage to the *exterior* of the mine into which transient coverage is required, e.g. to connect users, sensors or other IoT devices in the mine. In Figure x, this is the vehicle parked across the entrance;
- a set of vehicles equipped with relays, configured to work together to provide a network topology. These vehicles could proceed autonomously, controlled remotely or be driven by personnel.
- a topography consisting of areas that are accessible to vehicles, portions of which need coverage, even if temporarily or ad hoc coverage.

The mobile relays topology may change depending on dynamic coverage demand, e.g the vehicle relays can move or reconfigure to provide access to different areas or moving users, when and where indoor coverage is required.

Sensors and other IoT devices in the facility (for example air quality meters in the parking garage), as well as users who need only periodic connectivity (e.g. to upload and download data opportunistically), will receive connectivity from the transient coverage extension. This will enable data collection from a range of otherwise isolated devices and other communication on a periodic basis, or as needed (e.g. during a disaster response).

Other relay connectivity options, to extend coverage in remote areas such as mines, are also supported by IMT2020[9].

5.2 IMT applications in oil and gas sector

Like other critical infrastructure industries such as Mining, the Oil and Gas industry is undergoing a digital transformation journey to improve operational efficiency and worker safety. In addition, the industry is under immense pressure to reduce its carbon footprint. As the industry migrates toward renewable energy like wind and solar, oil and gas will remain significant energy sources for the world for many years to come. However, the transition will be gradual. Digitalization will play a key role in empowering energy companies to extract and process this vital commodity more efficiently. The industry has rebounded strongly from COVID, and the high oil prices support increased capital expenditure on various digital transformation and clean energy projects.

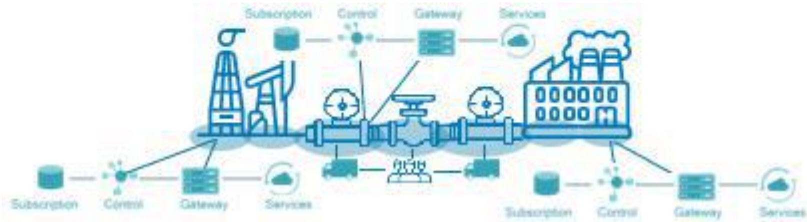
9 3GPP TS 22.261: *Service requirements for next generation new services and markets.*

Fuel resources, such as oil and gas, provide energy to industry and almost all spheres of human activity. The oil and gas sector covers all processes of extraction, processing, storage and transportation of fuel. The scale and level of development of the sector has an impact on the activities of the economy and the increase in labor productivity. A significant territorial gap between the areas of fuel production and consumption contributes to the development of many types of transport, one of which is the infrastructure in the form of pipelines, consisting of areal and linear objects, forming a single pipeline system. Such systems are very long (more than 100 thousand km), are located and take place in remote and hard-to-reach geographical places, including those with special climatic conditions.

Closed wireless communication networks of industrial class (technological communication networks) are an integral part of the oil and gas sector enterprises operating hazardous production facilities (see Figure 5.2.1).

FIGURE 5.2.1

Closed wireless communication network of industrial class (technological communication network)



The characteristic features of the use of broadband mobile IMT technologies at oil and gas sector enterprises operating hazardous production facilities include the following:

– for areal and linear objects of the enterprise it may be necessary to use different radio frequency ranges for the purposes of ensuring production processes;

– the organization of interaction of wireless communication networks of linear and areal objects of the enterprise is possible only on the basis of the use of dedicated communication lines;

– wireless communication networks of linear and area facilities of the enterprise are isolated from the public network and from the Internet;

– wireless communication networks of linear and area facilities of the enterprise provide switching functions and all other functions only for a group of customers and are not available to the general public;

– wireless communication networks of linear and area facilities of the enterprise are limited by geographical size;

– wireless communication networks of linear and area facilities of the enterprise have restrictions on the number of internal subscribers and do not have access points to other networks;

– mutual communication is allowed only between terminals connected to wireless communication networks of linear and area facilities of the enterprise.

The goals of digital transformation projects are improving operational efficiency and keeping workers safe. Workers in this industry work in harsh environments. Providing a voice and data communication system for workers in remote locations is essential for worker safety and retention. In addition, providing communication links to family members is vital for worker retention, who often spend months offshore or in remote sites. Moreover, mission-critical push-to-talk (MCPTT) or push-to-video (MCPTx) services can empower workers and improve productivity through group calls, video sharing, geo-location, and other advanced services. Video monitoring is another critical application. Intelligent video surveillance systems can be used to control security access. Also, remote monitoring of environmental sensors for gas leakage detection can prevent potentially fatal accidents. Alert information from the sensors can be integrated with actuators to stop leakage for accident prevention. Some existing systems currently use RLAN-based meshing networking over small areas. 5G can expand the coverage areas over longer distances and handle more machine-type communications. Another practical application is asset tracking. Geo-location of assets dispersed across remote oil rigs can provide the centralized operations center visibility of critical assets. Visibility and predictive maintenance of critical equipment can reduce unplanned downtime.

The digital transformation of the oil and gas sector using the existing and planned IMT technologies, including in a closed wireless communication network of industrial class (technological communication networks), opens up new ways and opportunities for real-time decision-making, effective interaction and work in close coordination of people among themselves and with resources.

The following IMT applications have attractive opportunities for oil and gas sector enterprises:

– combining multiple sensors and devices into a system capable of interacting without human intervention can increase efficiency and reduce maintenance costs.;

– augmented and mixed reality will make information and consultations available directly at the place of work. This is of great importance for remote and hard-to-reach places;

– monitoring the health status of people performing work with increased danger (for example, working at height, working in a confined and confined space, working with the use of open fire) or involved in particularly responsible processes, in combination with their precise positioning, will improve labor protection conditions;

– combining various systems, such as telephone communication, mobile radio communication (individual, group, between terminals), data transmission, real-time video transmission, audio and video conferencing, dispatch communication will reduce complexity and reduce costs by increasing efficiency.

In addition to the immediate IMT applications mentioned above, some leading oil & gas companies are exploring advanced applications such as a ‘digital twin’, i.e., a digital replica of physical assets, to optimize process flows at processing plants. Other applications include industrial robots handling repetitive tasks in hazardous environments, such as drones equipped with video and other environmental sensors to monitor plant facilities for quality control and inspection.

5.3 IMT applications in distribution and logistics

The world is embracing e-commerce. According to United Nations, e-commerce grew 3% year-over-year to 19% of all retail sales in 2020, and it grew even more during COVID. Warehousing and logistics are in demand as the sector has become a critical aspect of the e-commerce supply chain. Efficient flow management of warehouse and logistics can be a competitive differentiator for an e-commerce retailer, and logistics companies are grappling with reducing delivery time. Moreover, retailers are demanding transparency in the supply chain. The industry is employing digitization and automation to expedite the flow of goods within warehouses to meet these growing demands. One of the critical IMT applications over a private 5G network is automated flow management employing video surveillance cameras for security access, material handling, and inventory management. For example, video surveillance outside the docking area can alert the logistics system to get ready for unloading goods from an incoming truck. In addition, autonomous guided vehicles within the warehouse can transport goods from the unloading dock to the warehouse for inventory control and management. Additionally, the 5G advanced indoor positioning features, along with sensors attached to packages and machines, can enable the logistics company to track the locations of assets. Also, geofencing can be applied to determine when a tagged device enters or leaves a particular area to track key assets.

Pallet Tracking[10]

Reusable pallets (plastic or other material) can be commonly used in logistics, providing a cost-effective solution and long-term return on investment by avoiding packaging waste. Such pallets can be used for providing goods between a warehouse and several distribution sites and stores, e.g. for the transport of accessory and spare parts to the assembling line of a manufacturer for example.

Some of the main challenges associated to the use of such pallets are the retention on site as well as the loss (or theft) of these pallets. Therefore, tracking of pallets is important for the productivity while providing better inventory control and improved quality and the objective of pallet tracking application is to improve/optimize flow by reducing retention on site and loss or theft and to maximize the duration of use of such pallet.

Regarding how 5G can be used and applied for such application, one can assume that each pallet is equipped with a small size 5G IoT device including a 5G communication module with a very small battery. The battery-powered IoT UE should be able to operate for the entire lifetime of the reusable pallet (e.g. few years) without large capacity battery packs and without being replaced during this period of time. The 5G system can also be interfaced to an application server (e.g. Pallet Tracking Management System) which can track the overall flows of all pallets it is managing.

In one specific example, automotive spare parts and accessories may need to be delivered from the supplier to an assembly line of an automotive manufacturer with reusable plastic pallets. When in movement, each pallet is capturing often its location position. It is not necessary needed to send its location position all the time but it may be needed to store it on a regular basis (to be set up in function of the owner requirements - for example every 5 minutes) then to send on a less regular basis (every hour for example) a status update which include its position or all positions captured regularly since the previous status update as well as its battery status. The status update can be based as well on event (arrival on the distribution site or assembling line for example). When the pallet is on the distribution site, it will continue to send regular update communicating its status and position enabling to inform when a pallet is staying longer than needed on this site or when moving outside of the zone allowed for the pallet. In this case, an alert is sent. When they are empty (and not used), the pallets are piled up on each other. The pallets may still communicate their status update even when piled up in order for the Pallet Tracking Management System to have an accurate inventory.

5.4 IMT applications in enterprises and retail sector

This use case contributes to daily business operation of retailers and shopping malls by providing them with detailed information on the potential customers visiting their physical storefronts. These scenarios apply to a big supermarket with dozens of staff, retail stores strategically controlling inventory for selling “today’s” goods, and convenience stores dealing with fresh foods and lunch boxes with one-day consumption limit.

The enterprise and retail sector can be a difficult market for LTE and 5G as RLAN is already quite prevalent. RLAN offers a cost-effective networking solution for many data applications in local areas. For example, RLAN is a general wireless broadband network to the Internet in many enterprise locations and handles point-of-sale transactions in some retail settings. However, in large congested spaces, such as malls, the RLAN network services can be challenging. Private LTE/5G offers superior

[10] *3GPP TR 22.836: Study on Asset Tracking*

coverage with fewer access points and better handle mobility scenarios than RLAN. Moreover, proven SIM authentication offers a higher security framework.

Video remains the core IMT application in the enterprise and retail sector. For security, connecting video surveillance cameras inside and outside enterprise buildings is commonplace in enterprise and retail locations. Wirelessly connecting video cameras is more cost-efficient than trenching cables in a large campus environment.

Cameras on the street or inside a shopping mall capture the crowd image, count the number of people in the image, classify them into customer personas such as a parent interested in children's goods, an elderly interested in a hobby, and so on, predict their near-future traffic patterns, and identify potential customers visiting each individual shop. Based on the area-specific potential customers, the retailers can optimize their operations: increasing, decreasing, or reallocating selling staff, adjusting the selling goods or restaurant menus, and discounting products to avoid being wasted. A 4-D map that shows the area-wise distribution of people with their demographic attributes, e.g., sex and age, will facilitate short-term predictions about potential customers and their product/service demands (Figure 5.4.1). Cameras are connected to a network either wirelessly or wired. Mobile network connected cameras are preferable as they provide greater convenience because they are not restricted to locations where installation, network coverage, security, and power supply can be a problem. Mobile cameras also provide flexibility for a special event and reconfigured monitoring areas. Technical challenges with mobile cameras are that they need high airlink capacity, particularly in uplink direction, which is atypical for cellular mobile network.

Assuming a full-HD image resolution and Motion JPEG compression, the data rate from one camera would be about 45-60 Mbit/s. A typical area such as a medium-size building with about 100-150 tenants would require 600-800 cameras. This means that the total image traffic would be in the region of 27-48 Gbit/s.

In addition, AI/ML may be applied to make intelligent decisions and quick responses by the area owners.

FIGURE 5.4.1

Heat Map Inside Supermarket

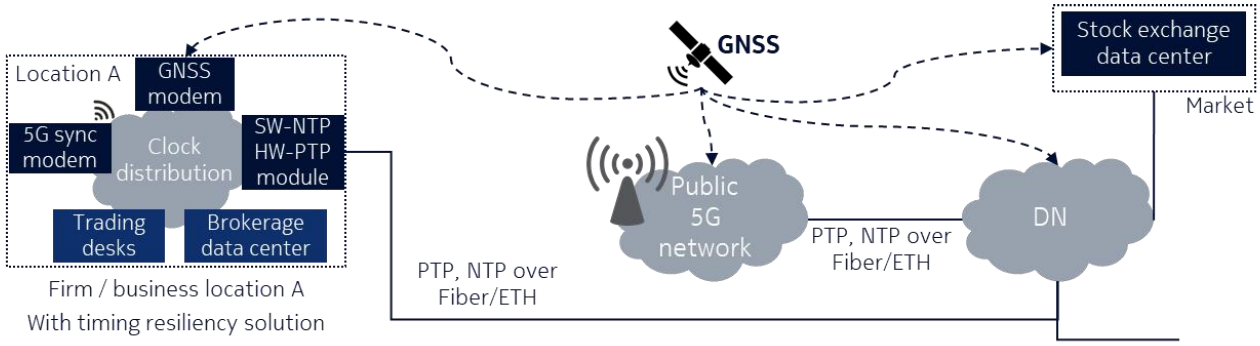
Another private LTE and 5G application involve building automation for intelligent energy management to reduce carbon footprint. For example, a building management system with remote IoT monitors to turn on/off lighting, and air conditioning/heating smartly can yield energy savings. Another IMT application with LTE/5G is push-to-talk (PTT) to improve mobile voice and data communication services. The online shopping experience may be enhanced with AR/VR for retail. For example, a customer may be able to digitally project a piece of furniture at home or "try" on a new pair of eyeglasses or clothes using a smartphone. While many AR/VR applications can be enabled on RLAN, these AR/VR applications can be enhanced in large outdoor and mobile settings with 5G.

Time resiliency for financial enterprises

Financial markets require precise and verifiable timing on trades to meet regulatory oversight, maintain precise records and prevent fraud. A timing resiliency service can support these time constraints by synced time stamps and traceability to UTC. The 5G system could provide efficient time resiliency, and this can work as either a replacement or backup for other time services such as GNSS or fiber[11]. Figure 5.4.2 illustrates an example scenario.

FIGURE 5.4.2

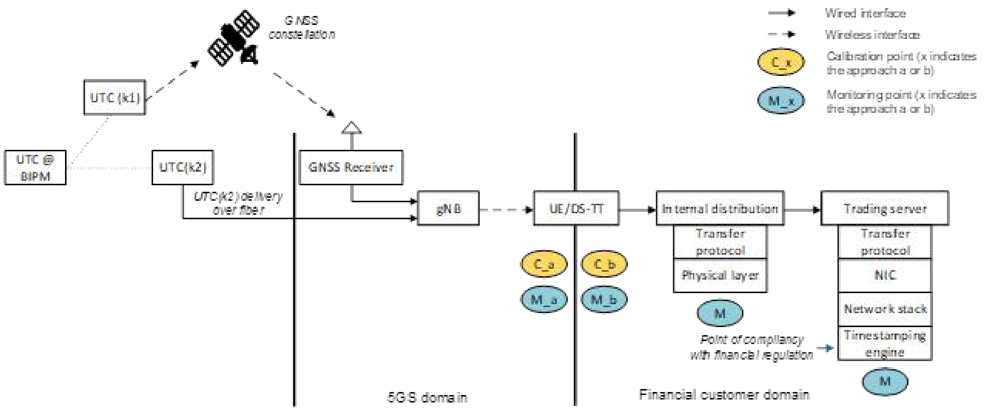
Example of time resilience use case for financial markets.



In one approach (see Fig 5.4.3), the 5G system can provide traceability to UTC up to the DS-TT. In such case, the 5G system needs to continuously monitor and audit each link within the time distribution chain within the 5G system domain. The UTC traceability is certified up to the provision point at the DS-TT. Therefore, monitoring, calibration, and certification functionalities are required at the DS-TT.

FIGURE 5.4.3

UTC time distribution with 5G system indicating the traceability chain



Enhanced user experience in shopping/entertainment venues

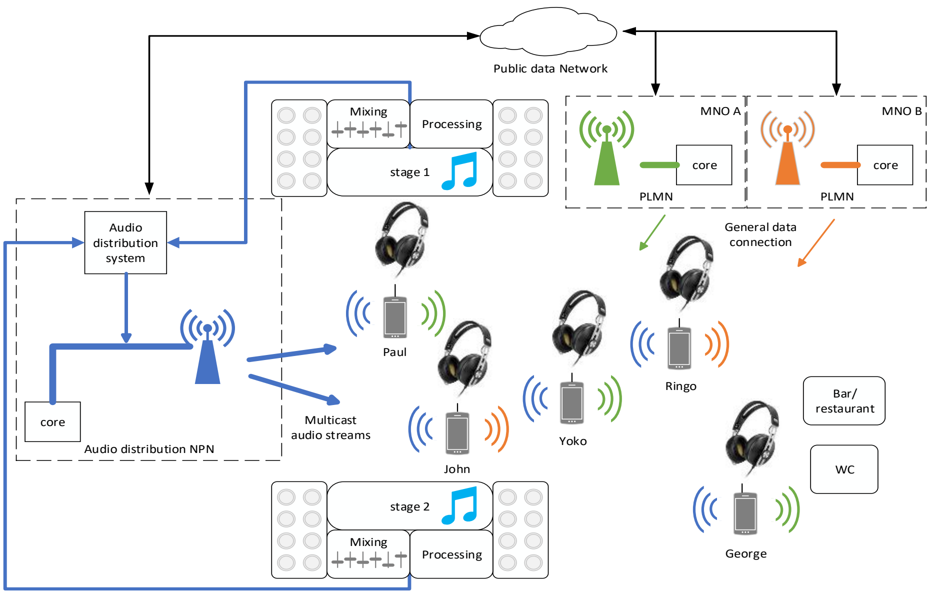
A concert venue can deploy IMT applications to support a better audience experience, including live streaming as well as integrated services for audience participation. As individuals in the audience move around the venue, they can enjoy optimal visual and audio experiences via their smartphone or other devices. By selecting from a suite of offered audio and video channels, the user

[11] 3GPP TR 22.878: *Study on 5G Timing Resiliency System.*

has access to audio and video from stage 1 while enjoying lunch at the bar. Meanwhile, a friend at stage 2 sends a video clip of a great drum solo, which the user can access on the same device (Figure 5.4.4).

FIGURE 5.4.4

Example scenario for live production with integrated audience services[12]



An alternate perspective is illustrated by daily operation of retailers and shopping malls enhanced with IMT applications providing information on the potential customers visiting their physical storefronts.

By making use of various sensors, e.g., motion detectors, cameras, and collecting positioning and ranging data, shopping malls can detect and categorize shoppers into customer personas such as a parent interested in children's goods, an elderly interested in a hobby, and so on, predict their near-future traffic patterns, and identify potential customers visiting each individual shop[13][14][15]. Based on the area-specific potential customers, the retailers can optimize their operations: increasing, decreasing, or reallocating staff, adjusting the selling goods or restaurant menus, and sending coupons to passers-by for items they are likely to want.

5.5 IMT applications in healthcare

The healthcare vertical can benefit greatly from IMT. It is a broad category that can include anything from enhanced telemedicine and remote home monitoring systems to improved responsiveness with connected ambulances using high-throughput computational processing and application of analytics. IMT can improve operations within a healthcare facility with AR/VR assisted education and training, asset tracking and interconnectivity for real-time patient data, as

[12] 3GPP TR 22.827: *Study on Audio-Visual Service Production.*

[13] 3GPP TR 22.891: *Study on New Services and Markets Technology Enablers.*

[14] 3GPP TR 22.872: *Study on positioning use cases.*

[15] 3GPP TR 22.855: *Study on Ranging-based Services.*

well as even innovative emerging use cases such as remote surgery in unique venues which today are limited to military health support on frontline soldiers.

Covid-19 caught the world off guard. To ensure such pandemics never surprise us again, innovative technologies that utilize enormous sensor data, communication, and computing power shall help us predict disease outbreaks and give the public an early warning. The advancement of sensor technologies and improved ML/AI capabilities will extend human sensibilities and detectability of environmental change.

In this use case, data is collected from multiple sources. With enriched big data, an advanced ML algorithm is able to detect abnormal patterns, which assists health experts and authorities in determining if a pandemic is imminent.

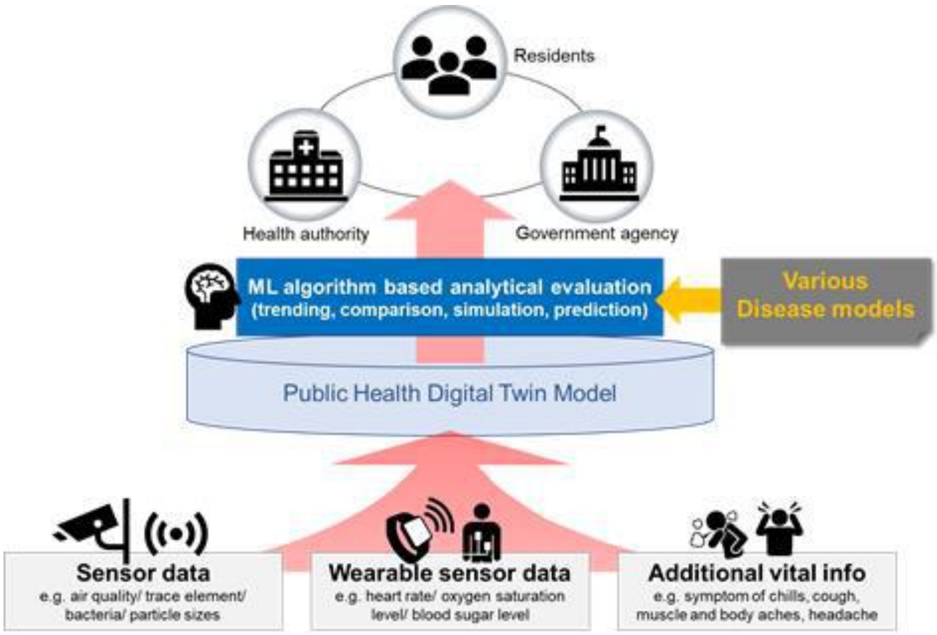
Even though many wearable devices are synchronized to a mobile user, many wearable devices may still have their own wireless modules to connect to mobile network directly. A user can easily have 5 wearable devices which will increase mobile usage and as well as device density dramatically. As density of device increases, data rate demand will also increase. Assuming each wearable device generates 0.1-1 MB data every 1 to 10 seconds and each user has average 5 data-generating wearable devices, each user can add the minimum 127 GB per month, which will increase the traffic on the mobile network significantly. It is also worth to note that some applications, such as person-fall-notification are latency and location sensitive.

Frequent synchronizations among mobile devices shorten battery life. Wearable devices need to have a long battery life, preferably longer than a week to avoid inconvenience to end user.

It is well known that there are strong dependency data format on wearable devices which prevents interoperability between devices. Further works are needed to work on data standardization to ensure all data are synchronized and coordinated.

FIGURE 5.5.1

Disease Outbreak Prediction Workflow



Critical medical applications

5G can have an important impact on healthcare through wirelessly and continuously collecting patient's monitoring data for processing and centralized storage. Also, 5G enables shifting care location from hospitals to homes and others remote facilities which translates into additional savings. Other cost savings can be achieved for hospitals where wireless transmission of low latency data streams improves operating room planning, enable streamlining equipment usage and simplifies operating theater implementation.

Various use cases can be considered, possibly categorized as follows[16] :

– Use cases covering the delivery of critical local care in the context of a hospital or a medical facility where the medical team and the patients are collocated. In these use cases, devices and people can consume indoor communication services delivered by non-public networks.

– Use cases of remote care, where medical specialists and patients are located at different places. This, in particular, covers medical services delivered by first rescuers. In this context, devices and people consume communication services delivered by PLMNs where a mobile network operator can use network slicing as a means to provide a virtual private network, or private slice.

Two examples are described below.

Local Operating Room (OR) - Duplicating Video on additional monitors

In the context of image guided surgery, two operators are directly contributing to the procedure:

– A surgeon performing the operation itself, using relevant instruments;

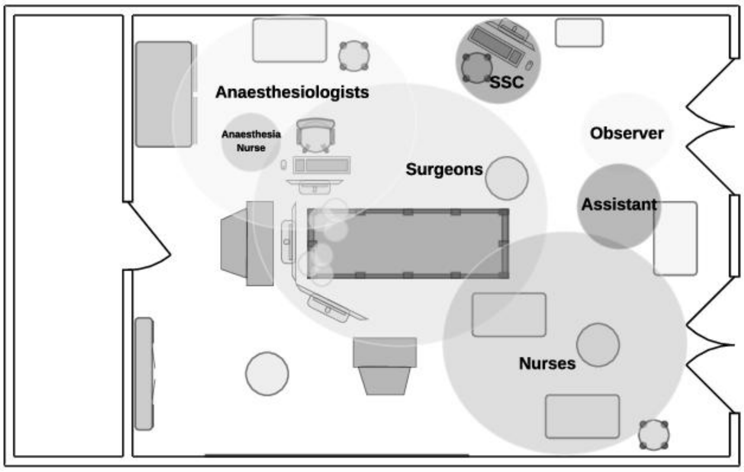
– An assistant controlling the imaging system (e.g., laparoscope).

In some situations, both operators prefer not to stand at the same side of the patient. And because the control image has to be in front of each operator, two monitors are required, a primary one, directly connected to the imaging system, and the second one being on the other side. The picture below gives an example of work zones inside an operating room for reference:

[16] 3GPP TR 22.826 "Study on Communication Services for Critical Medical Applications".

FIGURE 5.5.2

Example of operating work zones



As shown on **Error! Reference source not found.**Figure 5.5.2, additional operators (e.g., surgery nurse) may also have to see what is happening in order to anticipate actions (e.g., providing instrument).

The live video image has to be transferred on additional monitors with a minimal latency, without modifying the image itself . The latency between the monitors should be compatible with collaborative activity on surgery where the surgeon is for example operating based on the second monitor and the assistant is controlling the endoscope based on the primary monitor. All equipment is synchronized thanks to the Grand Master common clock.

Telesurgery

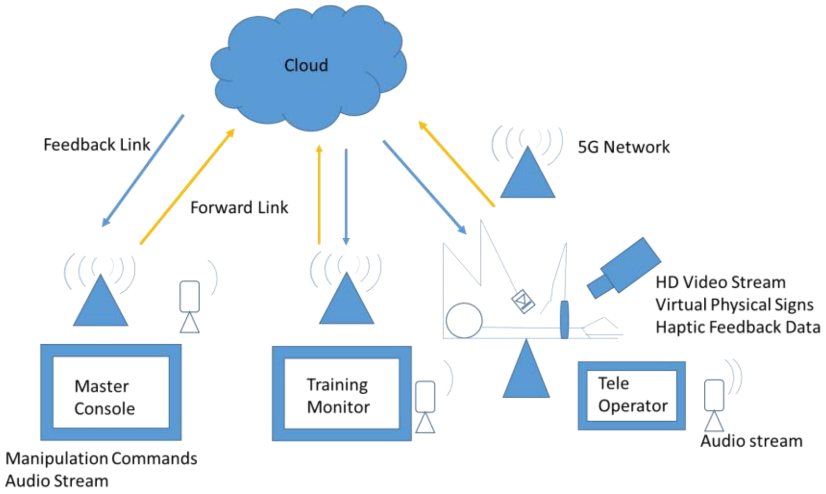
Remote surgery (also known as telesurgery) is the ability for a doctor to perform surgery on a patient even though they are not physically in the same location. It is a form of telepresence. A robot surgical system generally consists of one or more arms (controlled by the surgeon), a master controller (console), and a sensory system giving feedback to the user.

In a specific example, an injured patient may need a very delicate surgery to clear a heart vessel. The level of expertise needed is not available at his local hospital but the hospital has managed to find a specialist in another hospital within the same country (he/her cannot physically be present for the operation).

The set up for the telesurgery is shown in the diagram below(Figure 5.5.3). The patient lies on the operating table connected to the Robotic machine which is connected to the 5G network. This system has a video monitor, audio stream, robotic arm. The system is operated by a teleoperator. A training monitor is also connected to the same cloud network using the 5G network, for other observes to view the procedure.

FIGURE 5.5.3

Typical robotic system setup for teleoperations



The Master Console system is located at the remote location of the surgeon who is able to control the robotic arm that does the surgery and issues audio commands for the doctors and nurses assisting them in the operation at the hospital. The forward link transports real time commands to control motion and rotate the robotic arm of the teleoperator along with voice stream of the surgeon.

The feedback from the teleoperator at the local hospital to the surgeon at a remote location is transporting real time multi modal sensing which includes: 3D stream, force feedback e.g. pressure, tactile feedback e.g. tissue mechanical properties and patient's physiological data such as blood pressure, heart rate along with voice stream from assistant nurses, anaesthetists and other collaborating surgeons by the patient's side.

The performance of the telesurgery may impose stringent communication requirements on 5G, e.g. latency, jitter and packet loss.

The global COVID-19 pandemic has been a catalyst for rapidly adopting innovation in healthcare. Technology was called upon to enable connectivity with patients, while protecting them and frontline workers and other personnel. The pandemic created a great urgency to set up field clinics to address patient surge and later for vaccinations. Visits and patient exposure were reduced with tele-medicine and remote patient monitoring at home and hospitals, highlighting benefits of improved wireless connectivity that is easy to use and set up. It is expected that the innovation trends that started with the pandemic will continue to drive adoption of new technologies such as IMT and private cellular.

Use cases and deployment venues

Wireless use cases for the healthcare vertical generally fall into two large categories based on location: use cases inside of healthcare facilities and those outside of them.

Use-cases inside healthcare facilities

Within healthcare facilities, key use-cases for IMT include:

– location of equipment (asset tracking)

– connectivity of devices for data entry (e.g., tablets, laptops)

– automated collection of biometric health data for patients (IoT)

– remote surgery (long term objectives, which create precedents in AR/VR 'assisted surgery').

Use-cases outside of healthcare facilities

Outside of healthcare facilities, the following use-cases enable better and less costly extended care:

– telemedicine/tele-visits

– remote patient monitoring.

Chronic patients can be released from a hospital while maintaining necessary monitoring, freeing up valuable hospital space without compromising care. HIPAA concerns here have largely been solved as solutions already exist using a patient's own home RLAN. The use of public macro network IMT could expand reliability and coverage for patients, while maintaining confidentiality through the cellular network's inherent privacy features versus relying on patients configuring equipment to work on their home networks.

This can be especially valuable for older patients who are less mobile–IMT could give them access to diagnostics that they normally would not have. Mobile diagnostics (which is a subset of telemedicine) requires more bandwidth than is available today and this helps healthcare organizations reduce their risks and improve patient care by diagnosing early in the process. These bandwidth-heavy diagnostics also apply in ambulance and clinics on wheels or temporary clinics.

Benefits of Deploying IMT in Healthcare

IMT can help address the growing need for connectivity within hospitals. While RLAN is already deployed in most healthcare facilities, challenges arise from growing demand from administration and operations (e.g., connecting and tracking an increasing number of mobile assets/sensors per bed) as well as from a patients and visitors with multiple devices such as phones, tablets, laptops, and wearables. A complementary IMT network can free up capacity on the existing RLAN system and enable new high capacity, low latency applications.

In addition, new requirements for temporary healthcare facilities have emerged because of the COVID-19 pandemic, including temporary outdoor care facilities, quarantine centers, alternate temporary indoor testing locations, and mobile vaccination sites. A IMT wireless system is better suited to support these highly mobile requirements[17].

This increasing adoption will likely remain even as the pandemic subsides as there are clear efficiencies for both doctors and patients. Improved technologies will enable a wider range of telemedicine to be covered, such as with higher resolution cameras and real-time connected biometric sensors. In the case of tele-visits, unanticipated needs not provisioned by the healthcare system may depend on an individual patient's own devices and bandwidth. Here, the rapid public adoption of new mobile broadband devices makes this use-case available to more consumers.[18]

---

[17] Outside of permanent and temporary healthcare facilities, tele-visits have proven their worth through 2020 and 2021 during the COVID-19 pandemic. According to McKinsey, only 11% of US consumers used telehealth in 2019, but this rose to 46% by mid-2020. Congress loosened rules to allow telehealth under Medicare to enable vulnerable patients to get care. A survey by Juniper Research has projected that telemedicine will save the global healthcare industry $21B in costs by 2025 (from $11B in 2021, a YoY grown of > 80%).

[18] Telemedicine and tele-visits have large benefits: over 20% of all ER visits could be avoided via virtual urgent care, 24% of office visits and outpatient care could be virtual, and 35% of home health attendant services could be virtualized. The net effect could be 20% of all office, outpatient, and home health spend could be shifted to telemedicine. This shift improves outcomes by increasing access to care and efficiency.

Challenges for Deploying IMT in Healthcare

There are two major unknowns to work through when deciding on which path to take for IMT connectivity:

– **How predictable is the IMT connectivity?** While the general perception of IMT is that all IMT is "much faster," there is a lack of awareness of how to predict, design, and achieve the needed coverage and capacity for current and future use-cases.

– **What will it cost?** It is difficult to determine and compare the costs of the various options to address the tangible and intangible benefits and ROI (return on investment).

For use-cases outside of healthcare facilities, working with CSPs is the obvious choice. Temporary healthcare facilities can make use of IMT gateway routers to connect the entire facility. The challenge could be in migrating to IMT use-case inside healthcare facilities, where a new IMT network coverage needs to be built, and the device ecosystem needs to be established.

Due to concerns over liabilities, the more extreme use-cases taking advantage of the many attributes of IMT, such as dedicated network slices with guaranteed throughput, ultra-high speeds and low latency, will take time to emerge. These promise to enable revolutionary services such as remote surgeries.

However, it will be simpler to initially focus on the simpler use-cases that provide proven value:

– **Remote Patient Monitoring.** IMT-connected devices can be used for patients that need to be tracked and monitored 24x7 both inside and outside of healthcare facilities. By partnering with the CSP and an IoT healthcare service provider, a hospital can get a dedicated network slice and edge storage, as well as processing and AI capabilities to analyze patients' vital signs in real time.

– **Telehealth.** It proved its value during the COVID-19 pandemic. Live video consultations and other services bring quality care directly to those who need it, regardless of location. As a result, healthcare organizations have begun equipping their doctors and care providers with cellular broadband solutions to ensure secure, compliant, and reliable telehealth services can be dispensed from anywhere.

In the mid to longer term, increasing adoption of IMT-enabled IoT devices and applications can expand services to the above-listed use cases. Doctors and patients no longer need be in the same place to gain access to real-time data from connected diagnostic and medical devices such as stethoscopes, otoscopes, vital sign monitors, ultrasound devices, blood glucose monitors and ECG machines. In addition, IMT could further improve remote healthcare. For example, in the future a doctor can use specially designed haptic gloves and VR equipment to perform procedures remotely through robotic machinery.

The use of emergency vehicles is evolving too. In some countries, ambulances are already equipped with cellular in-vehicle networks to support computer-aided dispatch, mobile data terminals (MDTs), automated external defibrillators (AEDs), live video streaming and connected medical devices. These technologies enable the communication of critical patient information between the field and the hospital and help save lives. Many of these ambulatory capabilities are being deployed over 4G today. However, the low latency, high bandwidth, and enhanced security of IMT are essential for mainstream adoption.

Annex (Case study on Healthcare) contains additional information on remote mobile medical care using mobile medical care vehicles operated in cooperation with clinics in regional medical care, as well as the remote pregnant women's medical examinations conducted by mobile medical car touring various areas as examples of specific usage scenarios of 5G mobile medical care vehicles in Japan, which were obtained as results of a survey.

5.6 IMT applications in utilities

Major electrical, water, and gas utilities are at the cusp of grid modernization projects. Utilities are representative of public sector verticals, which reflect a huge group of organizations interested in deploying their own private LTE and eventually private IMT networks. As critical infrastructure providers, utilities prefer to own and operate a fully private network and amortize the upfront capital expenditure over 20+ years. Utilities are beholden to very stringent disaster recovery requirements for their communication networks. For instance, if the power goes off during a natural disaster, the utility wide area network (WAN) is expected to remain operational for days – not a few hours. Hence, utilities don't want to be "tied down" to an operator's network, which typically has less stringent requirements. Home metering via a public operator network may be okay, but managing a grid network via the public network is something they will most likely avoid. In addition, they are in urgent need of secure, flexible, reliable, broadband wireless connectivity to fully realize the potential of their grid modernization and digital transformation initiatives.

Legacy utility communication networks are built on narrowband technologies put in place many decades ago. Today, it isn't easy to find suppliers for this aging infrastructure. One of the drivers of WAN modernization based on private LTE and 5G is to tap into the broad cellular ecosystem and consolidate legacy wireless systems. In addition, with distributed renewable energy sources from solar panels on rooftops to neighborhood solar farms coming online, modern grid systems must adapt to how and where energy is sourced and distributed. Some utilities see this moment to invest in next-generation grid networks that can consolidate multiple disparate wireless technologies and support smart metering and other revenue-generating opportunities like smart city applications, such as smart lighting and municipal smart lighting. Moreover, many of these initiatives involve deploying new applications that enable the utility to collect and use data from a wide variety of grid assets, including smart meters, gas sensors, voltage regulators, distributed energy resources (DERs), and drones. Other initiatives involve the rollout of new or enhanced workforce management, safety, or other applications that connect to vehicles and field workers. In both cases, utilities are depending on these initiatives to help them to realize important organizational objectives, including lower operating costs, improved grid safety and reliability, better customer engagement, and more renewable energy generation. For these initiatives to succeed, connectivity with strong cyber security is essential. As the grid becomes automated, the cyber-attack surface increases because there are more devices, applications, and support staff with full access to these new systems.

A key application of modern utility communication networks is for additional intelligent instrumentation of the distribution assets at substations to improve the reliability of power delivery from generation to the distribution grid and ultimately to customer locations. Smart metering is one example of remote monitoring and control applications to make the distribution grid more intelligent. More innovative remote monitoring can measure electricity consumption and provide granular data on the status of the distribution grid, e.g., outage detection, in near real-time. Perhaps, the game-changer among 5G utility applications is high voltage transformer protection. With sub-10 millisecond latency, a high-voltage transformer protection application may be possible using a private 5G network.

While the 5G low-latency capability may be a game-changer for the utility sector, private LTE may offer immediate benefits to utilities in the near term. LTE is a mature and proven technology with a robust infrastructure and device ecosystem. Some forward-thinking utilities are realizing the cyber security benefits of a private LTE network. LTE, the global standard, is very secure on its own. A private LTE network allows utilities to install additional cyber protection systems such as identity and access controls, heuristic based monitoring systems and others. With private networks, organizations can completely isolate this communications control network from the Internet, often called "air gap" deployments, if they choose to do so. When you own the network, you make those decisions. When you subscribe to someone else's network, they make those decisions. More information regarding how utilities are embracing private LTE networks can be found at Anterix[19]. Therefore, utilities can deploy private LTE networks with a "5G-ready" path cost-effectively until the 5G technology matures further, especially the lower network latency capabilities that will expand the practical applications further into the transmission grid beyond the automation of the distribution grid.

IMT will contribute to realizing a carbon-neutral society by accurately predicting and controlling the rapid and dynamic changes in energy supply and demand associated with the introduction of renewable energy. It will achieve this goal through its enormous computing capacity and ultra-high-speed networks and by realizing low-cost and stable power generation and transmission facilities. Because electricity is hard to store in large volumes efficiently, it is critically important to match the supply to the dynamically changing demand, which is currently carefully controlled by transmission and distribution operators. If there is a significant discrepancy between the actual demand and supply, it will seriously impact blackouts.

However, there might be problems with supply reliability and social costs in the near future. As for supply reliability, the difficulty in adjusting supply and demand will be increased due to instability associated with the shift to renewable energy. Although there are several technologies for power balancing, such as the inertia force of thermal power generation and the pumped-storage hydroelectricity, they are not sufficient for resolving the expected instability when renewable energy dominates the majority of power generation. In that model, the range of power fluctuations becomes unpredictable and very large.

Today, on the supply side, thermal power plants, which have a built-in physical frequency adjustment mechanism, are mainly used. However, if it remains a core component of the grid system in the era of renewable energy, then, from the viewpoint of social cost, we have the following issues:

– need to maintain thermal power generation facilities even though its usage ratio is low to meet peak demand

– need to continuously operate the thermal power generation facilities, at a certain ratio to renewable energy

– need to apply restrictions to the demand-side economic activities, including Commercial and Industrial, when there is a gap between supply and demand that exceeds the acceptance of the Grid System.

Thus, such a traditional framework of centralized grid management is approaching its limits due to increased social costs and burdens on both commerce and industry. We should advance to a new type of grid operation that integrates demand-side resources such as distributed power sources. Another problem for the future is the response speed when the frequency deviates rapidly from a stable frequency like 50 Hz due to a failure. Current technology involves direct control of a massive battery but with extra costs. When controlling a large number of small batteries through a third-party service provider, the service provider takes a long time to calibrate and cannot respond within the required response time.

The overview of this use case is shown in Figure 5.6.1. There are many prosumers as resources, such as EVs (Electric Vehicles), PVs (Photovoltaics), and stores. When the power grid gets in trouble and decreases the frequency, the VPP (Virtual Power Plant) aggregator requests adjusting the electricity supply and demand. The VPP aggregator then immediately simulates which resources

[19] https://anterix.com/why-are-utilities-embracing-private-lte-networks-a-qa-with-mike-brozek-of-anterix-2/.

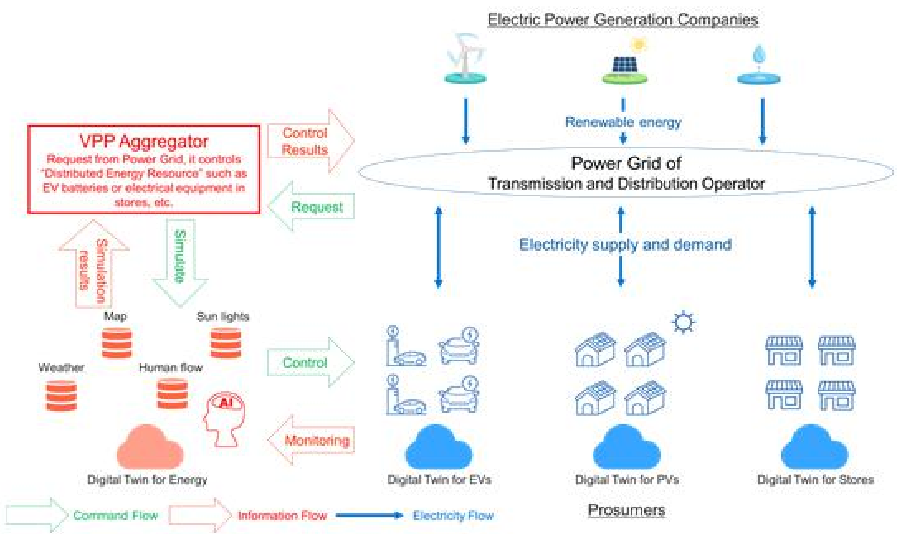
can be used and how much based on various data from the digital twin for energy and consumer data from each digital twin. Based on the result, the VPP aggregator controls electricity supply and demand using prosumers equipment such as EV batteries in EV stations, PVs, and air conditioners/refrigerators in the stores. Thus, the cycle can make the power grid stable even if renewable energy will increase.

As mentioned earlier, we have to solve social challenges with new technologies such as high accuracy forecasting of power generation and demand by digital twin computing and real-time procurement of supply and adjustment power from many demand-side resources (EVs and consumer devices) using large-scale, high-speed communications.

For example, when the VPP aggregator wants to know how much energy it can gather from EVs, it has to determine which EV battery can be taken, based on the simulation from various data such as route information of each EV, the status of the battery, map, weather, etc. Each EV will rely on mobile network to update its battery status, routing information, and availability constantly. Also, the required time to respond to the adjustment request from the power generation company should be within 250 ms in ERCOT, Texas. When the aggregator responds, it should continue to provide stable power for 10 minutes. In this case, private PVs and EVs aren't used, but commerce and industry batteries are used usually because of the response time.

FIGURE 5.6.1

Overview of Renewable Energy Flow Optimization



Utilities venues and use cases

Utilities facilities consist of expansive territories, stretching across hundreds and thousands of square miles. Many areas are not served by major carriers, while many millions of devices may need to be connected, monitored, maintained, and managed. All potential IMT network activities may impact power generation and delivery to consumers, with a sharp focus on outage prevention and/or fast outage recovery. These can be summarized as:

– **Electric power distribution with renewable energy sources**[20]

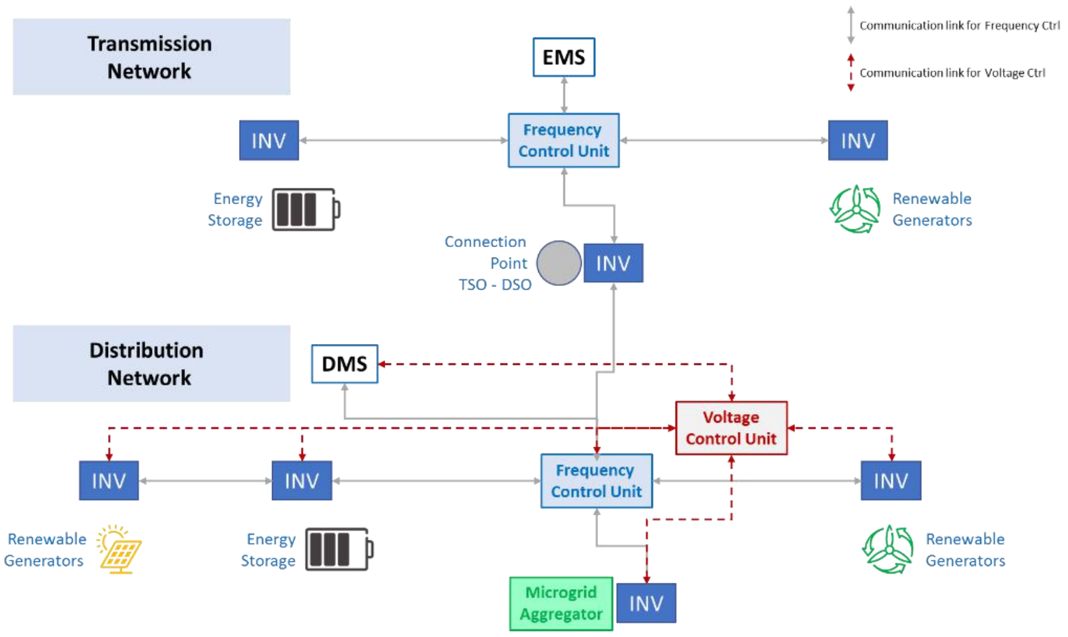
[20] *3GPP TR 22.804, "Study on Communication for Automation in Vertical Domains "*

The main goals of future electric-power distribution includes—among others—the reduction of CO_2 emissions by relying on renewable energy sources (RES), decentralisation of energy production, continuous matching of injected and outgoing energy levels, resource efficiency, cost efficiency, maximum security, and reliable provisioning of services to consumers.

These improvements are important for addressing the needs of increasingly volatile and decentralised markets. A major enabler for all this are inter-connected communication systems and computing infrastructure, which interconnects control centres, substation automation units, energy storage systems, and power plants of all sizes in a flexible, secure and consistent manner. 5G may significantly contribute to revolutionising the way how electric energy is monitored, stored, and controlled for the entire industry sector.

FIGURE 5.6.2

Communication Links in Future Energy Networks with up to 100% RES



Application areas that could be applied to communication in scenarios depicted in Figure 5.6.2 are:

Primary frequency control: The focus of this application area is on the instant monitoring and control of the frequency in the grid. In frequency control, the grid can be a long-distance transmission network covering countries or large parts there-of, or short-distance distribution networks connecting local consumers and distributed producers of energy. Typically, primary frequency control uses decentralised or distributed control architectures allowing taking corrective actions swiftly on a local level.

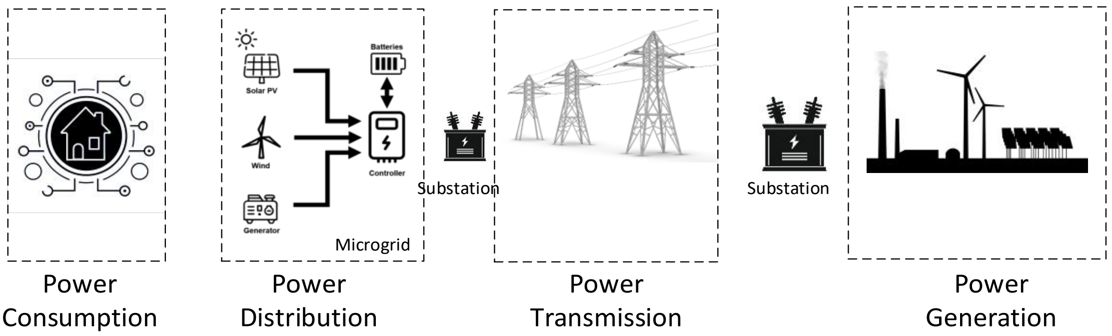
Secondary frequency control: The focus of this application area is the second, less time-critical correction of the frequency in the grid. Typically, secondary frequency control uses centralised control architectures, allowing frequency control units to take corrective actions across all parts of the controlled power network.

Distributed voltage control: The focus of this application area is monitoring and control of the voltage levels in distribution networks. Sensors located close to the electric inverters in the local grid measure the impedance on the grid and forward these values to a voltage control unit co-located with a secondary substation automation unit. The correction action is a target impedance value that is sent to the electric inverters so that additional energy can be injected into the grid, or electric inverters may throttle the energy added by power plants or storage systems.

Other application areas are differential protection, fault location, isolation, and service restauration.

– **Smart Grid**[21] – is the digital technology that allows for two-way communication between the utility and its customers, and the sensing along the transmission lines is what makes the grid smart. Like the Internet, the Smart Grid will consist of controls, computers, automation, and new technologies and equipment working together, but in this case, these technologies will work with the electrical grid to respond digitally to our quickly changing electric demand. A typical smart grid architecture would include the following segments as shown in the figure 5.6.3 below:

FIGURE-5.6.3



The different elements would have both the flow of energy and the information. The power generation may include multiple sources that include conventional and renewable (e.g., coal, oil, natural gas, nuclear, wind, hydro, solar). A typical architecture for the communication elements in a smart grid is shown in the figure 5.6.4 below.

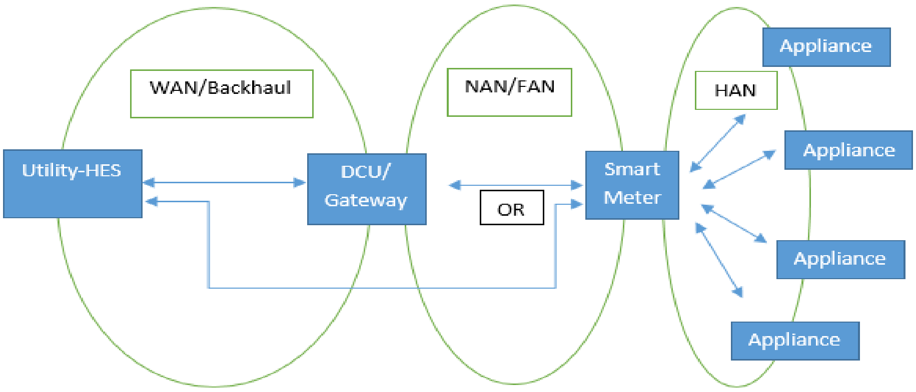
FIGURE-5.6.4

M2M Enablement in Power Sector (Source: TEC Technical Report[22])

---

[21] https://www.smartgrid.gov/the_smart_grid/smart_grid.html.

[22] TEC Technical Report on M2M Enablement in Power Sector, https://www.tec.gov.in/pdf/M2M/M2M%20Enablement%20in%20Power%20Sector.pdf



The AMI Data Management system would acquire data from the field devices and report it. This sub-system would also perform validation, editing and estimation of the various measurements within the system.

The Connectivity between the concentrator and the utility (including the feeder / distribution system) is typically utilizing high-bandwidth communications links. These links are usually capable of handling highly reliable data with high capacity.

The communication between the user's smart meter and the utility is provided by a neighbourhood area network which is capable of providing good coverage, better non line of sight communication and the ability to scale and provide communicate method to multiple meters.

The smart meter is responsible for recording the energy utilization, communicating the energy consumed in addition to other parameters like Power Factor, Voltage, Frequency, etc. at regular intervals.

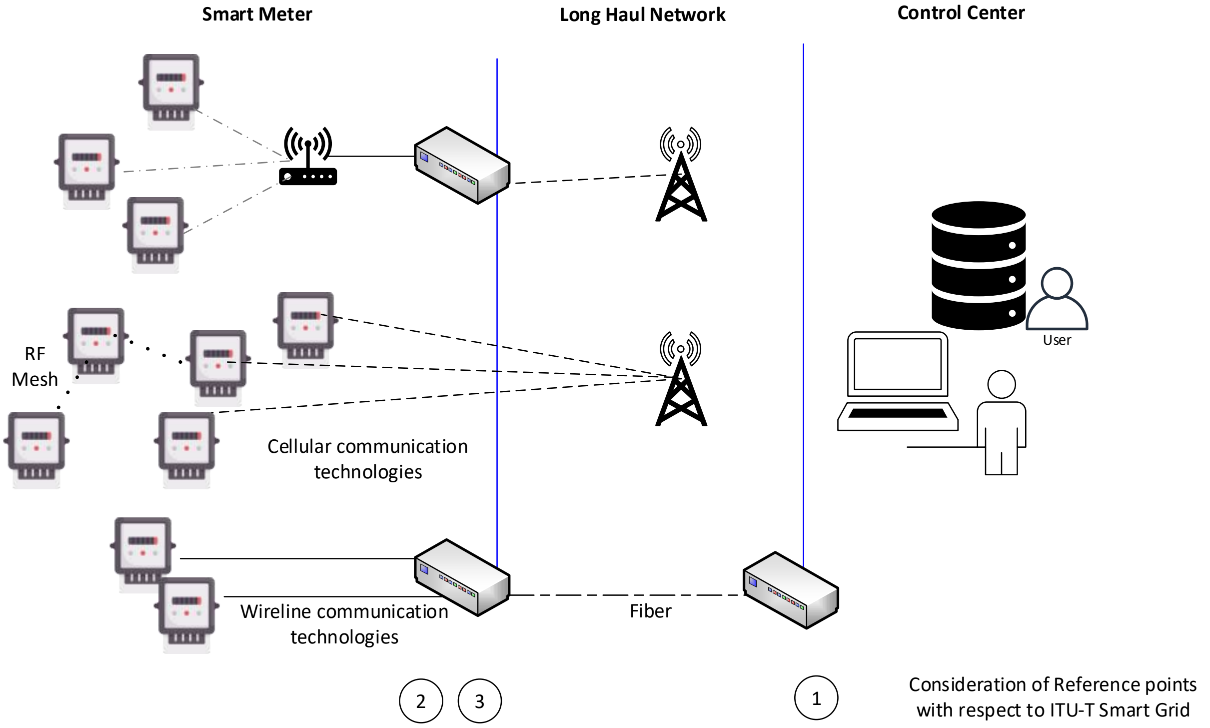
The power consumption itself may include a smart home or a smart building that utilizes communication between the building / home interior devices and the smart meter.

Smart Grid related use cases can be summarized as below:

- **Distribution Automation (Volt/Var Optimization and Circuit Reconfiguration)** refers to digitized management of the electricity distribution network components. Activities include monitoring and measuring of specific metrics on grid devices and taking necessary actions to ensure quality and compliance to regulations.
- **AMI and substation backhaul** refers to collection of usage metrics from customer meters, aggregation of these data points and processing at substations as well as further up in the network. These backhaul networks complement a low throughput metering network. The network connectivity interfaces in a typical AMI system are shown in the Figure 5.6.5 below:

FIGURE 5.6.5

Network Connectivity Interfaces in a typical AMI system and corresponding reference points as per ITU-T Smart Grid report



- **Emerging modes of energy production** through renewables such as solar and wind, either regulated or non-regulated, are causing increased scale, introduction of enterprise and residential class generators and need for new electricity flow and control devices which have to be incorporated into the modern grid and managed. Effective management of these new modes of production requires a level of monitoring and applied intelligence that needs to rely on increasingly more and better wireless.
- **Independent Power Producer interconnection and Microgrids** are emerging entities that need to be enabled and incorporated into existing grid infrastructure. Ramifications of these new developments is increased need for flexibility and change in a traditionally static grid infrastructure.
- **Line current differential protection in power distribution grid**[23]

This is one of several smart grid distributed control use cases supported by IMT-2020.

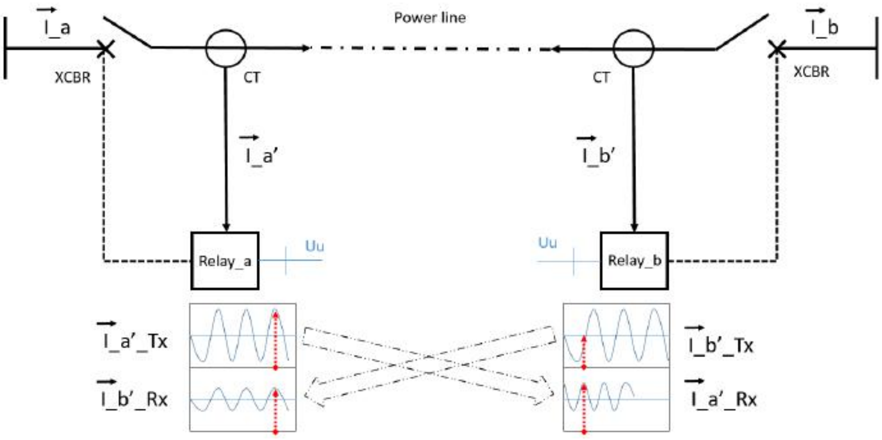
Line current differential protection has been widely used in electrical transmission systems to protect High-Voltage (HV) transmission lines. As a proven protection mechanism, it is also deployed for power distribution networks to protect (Medium-Voltage) MV distribution lines where applicable. The popularity of line current differential protection comes from the fast protection mechanism, reliability and the absolute selectivity of protected zones. Therefore, for Low-Voltage (LV) and MV power lines (both underground and overhead), current differential protection could be deployed easily with cellular

[23] *3GPP TR 22.867 "Study on 5G Smart Energy and Infrastructure"*

technology without having to lay dedicated communication cables, either in refurbishment or new distribution substation construction projects.

FIGURE 5.6.6

Line Current Differential Protection by two protection relays (Relay_a) and Relay_b), deployed in two substations



In terms of sampling, a protection relay needs to sample the local current periodically, and transfers sampled data within a pre-defined time period T. Secondly, once the buffered samples pertinent to the same instant in time are available, the relay must align them in time (Figure 5.6.6). As a relay needs to perform correct alignment of local and received data before calculating the differential current, the relay needs to know well enough when the remote relay transmits a specific data packet. Current clock synchronization is realized by relays attaching timestamps to measurement samples before transmission.

– **Remote Worker** – reliable connectivity for office and field workers enabling rich media collaboration at close to real time speeds. All emerging collaboration applications can apply to the utility's personnel, such as enhanced Push to Talk, mobile video conferencing, remote expert, hands free connectivity, etc.

– **Robotics** – Drones have started to be used for observation and maintenance, and these use cases are expanding as robotics technologies mature.

– **Cyber-security** – is a critical requirement and consists of strong access control for personnel and devices, and active monitoring of all networking activities to prevent and protect against malware. Increased automation of grid networks, as well as dependence of large user communities and critical infrastructure on electricity has huge implications on cyber-security requirements of smart grids.

– **Situational awareness –** includes detecting and correcting outages in the most optimal way possible. Early detection of location and cause of outage requires intelligent connectivity of devices as well as extensive telemetry and analytics. Increase in scale and complexity of the smart grid imposes additional requirements on these traditionally manual event detection and correction.

Detailed set of use cases and requirements can be found at Cisco[24].

[24] https://www.cisco.com/c/m/en_us/solutions/industries/portfolio-explorer/portfolio-explorer-for-utilities.html

Different communication technologies may be utilized for the transfer for data in these reference points / interfaces. These have been listed in the table (Table 5.6.1) below:

Table 5.6.1 : Communication Technologies

Sl. no. / Scenario	Communication Network	Related technologies
Devices / Smart meters connected directly to Head end system.	Smart meters connected on wide area network technologies to PSTN / PLMN.	GSM 2G, 3G, LTE, CDMA, EC-GSM, NB-LTE/NB-IOT, LTE Cat-M1, 5G mMTC Devices as well as Network should have IPv6 or dual stack (IPv4 and IPv6) capability.
Devices / Smart meters connected through Gateway/DCU to Head end system.	Smart meters connected on short range communication technology to Gateway in Field area network (FAN) / Neighbourhood area network (NAN)	• RF mesh network: 6LoWPAN, ZigBee etc. • (PLC): Prime PLC, G3-PLC etc.RF star network: LPWAN non-cellular technologies - LoRa, Sigfox etc.
	Gateway/DCU connected to Head end system on Wide Area Network (WAN) Technologies	GSM 2G, 3G, LTE; 5G, RLAN, CDMA, Fixed line broadband, Ethernet, . Gateway as well as Network should have IPv6 or dual stack (IPv4 and IPv6) capability.

All the communication technologies in the home area network may not have the capability of IPv4/IPv6. However, it is required that all the devices / Gateways (to be connected directly to PSTN / PLMN) have IPv6 or dual stack (IPv4 and IPv6) capability.

In view of Internet Architecture Board (IAB) statement on IPv6 released recently, IPv4 support may not be available in future developments, therefore transition to IPv6 only in PSTN/ PLMN networks and Gateways / devices to be connected directly to these networks will be required[25].

Given high reliability and stringent latency requirements on the grid to network interface, typically fiber optic and/or 5G could be the best suited. The smart meter / customer domain to the network may utilize a communication network capable of meeting highly scalable device density requirements that may generate small volume of data, but at frequent intervals, communication technologies utilized could be a mix of 4G/5G/PLC/RF-Mesh among others to ensure high penetration and reliable transfer of the measurement of data in a secure manner. In order to make sure that the network coverage, capacity and reliability is of primary importance, a 4G/5G technology needs to be considered as the first preference, and then RF-Mesh complements by providing a coverage extension.

[25] ITU-T Recommandation Y Suppl. 53 on IoT Use cases – (Use case on AMI)

IMT Considerations for Utilities

As smart grid designs evolve, it is still not clear how much wireless demand, and of what form and function, would be required in a fully modernized grid. What we do know is that the scale of devices supporting modernization is expected to be at least six times greater than today's quantities of devices being deployed. To give a sense of scale, there are currently 150 million smart meters deployed in households across US, that number is expected to increase by at least six-fold as the electric grid modernizes - and this does not include the actual meters. If meters also use LTE, then the scale of new devices increases by another order of magnitude. Furthermore, performance of future devices is expected to be 10x faster and they need to be more reliable than today's devices.

This massive increase in scale will have to be provided in new and future proofed deployment profiles that can last decades without need to change. As such, there is no surprise that IMT technologies are being considered for next generation utilities designs. IMT proposed enhancements that can benefit utilities include Massive Machine Type Communications (mMTC) to address the projected high density of IOT-based devices, Ultra Reliable Low Latency Communications (URLLC) to address the performance and reliability requirements for connectivity of mission critical components and Enhanced Mobile Broadband (eMBB) to improve communications to mobile users (fleet and mobile workers).

Some unanswered questions remain regarding IMT deployment by utilities, which are more focused on deployment logistics, cost, and ownership. These specifically include:

– **Private cellular versus managed service** – Utilities are considering both privately owned cellular networks that can be owned and operated by themselves, as well as managed services offers from carriers. Both deployment scenarios are considered viable and beneficial. The privately owned scenario enables a utility company to have total control over their assets which is preferred by all utilities, but it also incurs higher operational cost for maintenance of radios and packet core. The managed service offer enables utility companies to take advantage of the expansive footprint of carriers, and to offload complexity of radio and packet core management to the carriers.

– **Availability of suitable spectrum** – Many utility companies have acquired spectrum and/or are considering using shared spectrum (CBRS in the US and ISM bands in other parts of the globe) for their immediate uses. Managed service offers by carriers will enable utilities to take advantage of the larger spectrum holdings of carriers as well. What remains to be seen is cost structure of these offers, can carrier owned spectrum be cost effective or not. Or should the FCC (or similar authorities in other countries) dedicate spectrum bands for use by utilities?

– **Resilience and high availability** – All deployment scenarios being considered must be able to ensure a high level of resilience and availability. Utility companies can design and build these reliability requirements into their private networks through redundant design and comprehensive monitoring and assurance. When using a managed service, they will need similar assurances from the service provider. To satisfy the utilities requirements carriers may need to dedicate spectrum, radios, packet core instances, and edge computing to utility customers. These dedicated resources can be enabled through the IMT slicing feature set.

  Nevertheless, it is not clear how the cost structure of a dedicated slice for utilities will compare with privately owned networks. Also operationally speaking, any slice that gets offered to utilities may be part of a shared resource which may be subject to congestion. Carriers will need to prove their ability to prioritize grid traffic from their commercial cellular traffic in all shared slice platforms. These are challenges that are yet to be solved in practical and business acceptable terms although IMT technology does provide a technical blueprint.

– **Edge compute** – massive scale needed by utilities is going to force processing to the network edge to optimize network traffic flows. IMT's virtualized form factors of packet processing, as well as support for Multi-Access Edge Compute, can enable highly distributed designs at the edge. More renewables will force the need for control of the grid in real time, increasing low latency requirements which also drives the need for more capable edge computing to support required latencies.

– **Cyber security** remains a top of mind for all smart grid systems. Beyond technical requirements to ensure cyber security it is also expected that government regulations will play a role as Grid safety becomes a more pronounced requirement for national security.

Additional information regarding the impact of IMT networks on utilities can be found at Smart-Energy.com[26] and Edison[27] [28].

The future of smart grids from an IMT perspective

IMT-2020 brings entirely new ways of using mobile technology for the benefit of cities and rural communities[29]. Much as IMT-Advanced's speed and capacity propelled users into the app economy and expanded the use of mobile video, IMT-2020 will be a platform for entirely new innovations. Imagine what can be done with a 100x increase in traffic capacity and network efficiency, a 10x decrease in end-to-end latency, and speeds that are over 600 times faster than the typical IMT-Advanced speeds on today's mobile phones. IMT-2020's faster, ultra-reliable, low-latency and higher-capacity wireless connectivity, combined with other emerging technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), and Quantum Computing, will enable a whole new world of possibilities.

Smart grid technologies are considered an important enabler for dealing with the increasing demand for electricity, especially given the complexity of the electricity infrastructure. IMT technologies will be able to unlock further efficiencies in smart grids by supporting large numbers of low-cost, low-power sensors that extend monitoring for many of the grids' unconnected areas. The densified coverage of IMT-2020-enabled sensors will allow unprecedented visibility for demand-side management that helps better forecast energy requirements, reduce electricity peaks, promote the consumption of renewable energy and ultimately reduce costs. In addition, the data collected can be integrated into consumer-facing systems to allow better visibility into residential energy use, enabling households to take more proactive roles in managing consumption. Densifying smart grids with IMT-2020 sensors will also enable the self-healing capabilities of future smart grids that can diagnose maintenance issues in real time, and automatically react to avoid outages. It has been estimated that IMT-2020-connected smart grids can enable a wide range of applications that can help reduce

[26] https://www.smart-energy.com/industry-sectors/iot/the-new-source-of-capacity-5g-in-utilities-in-2020-and-beyond/.

[27] https://www.edison.com/home/our-perspective/pathway-2045.html.

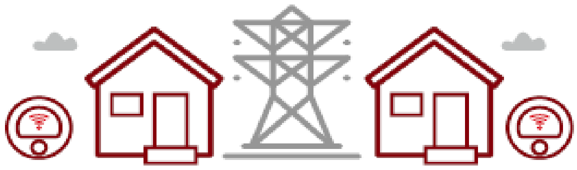
[28] https://www.edison.com/home/our-perspective/pathway-2045.html.

[29] Accenture Strategy and CWTA, Accelerating 5G in Canada – Benefits for Cities and Rural Communities. *Available (retrieved 2020-05-29):* https://www.cwta.ca/wp-content/uploads/2019/11/Accelerating-5G-in-Canada-V11-Web.pdf.

household energy consumption by up to 12% (Figure 5.6.7)[30]. Government investments, such as the Smart Grid Program in Canada[31], will further encourage a shift to smart grids and cleaner energy production.

FIGURE 5.6.7

IMT-2020-enabled smart grids can reduce household energy consumption by up to 12%



Cities can also utilize IMT networks in the deployment of smart street lighting, especially as more vendors start to integrate IMT-2020 and advanced sensors into new lighting poles. Smart lighting systems consume 50% to 60% less energy than traditional lamps, due to the use of LED and the increased capability to adjust brightness. Connectivity also unlocks further cost savings of up to 80% by providing more visibility into maintenance operations[32]. For example, an increasing number of Canadian cities are building public-private partnerships focusing on smart city applications for energy management[33]. The cities may see significant annual cost reduction benefits from smart street lighting alone. In addition to annual cost savings, cities can see additional benefits from automatic adjustment of smart street lighting, which can reduce light pollution and increase the visibility of the night sky[34]. This is illustrated in Figure 5.6.8.

FIGURE 5.6.8

IMT-2020 networks in the deployment of smart street lighting

[30] *Ibid.*

[31] *Cf.* https://www.nrcan.gc.ca/climate-change/green-infrastructure-programs/smart-grids/19793 and https://energyrates.ca/the-main-electricity-sources-in-canada-by-province/.

[32] Mark Halper, "Toronto Town Settles on Smart Lights for Now", LEDs Magazine, 11 April 2018. *Available (retrieved 2020-06-08):* https://www.ledsmagazine.com/articles/2018/04/toronto-town-settles-on-smart-lights-for-now.html.

[33] CISION, 7 February 2018 – "Bell and City of Kingston Partner for Smart City Program" *Available (retrieved 2020-06-08):* https://www.newswire.ca/news-releases/bell-and-city-of-kingston-partner-for-smart-city-program-673114793.html.

[34] Infrastructure Canada, Smart Cities Challenge – City of Yellowknife. *Available (retrieved 2020-06-08):* https://www.infrastructure.gc.ca/cities-villes/videos/yellowknife-eng.html.

Smart Street Lighting Systems can lead to significant annual cost savings.

Issues to be taken into account[35]

With the increasingly pervasive need for communication, the focus is now switching to machines and sensing, commonly referred to as the "Internet of Things (IoT). This potentially expands the market to cover every conceivable device on the planet, and every imaginable parameter. In this environment, utilities are one of the prime targets for 5G applications as the energy sector has increasing requirements for monitoring and control driven by regulatory and commercial pressures given that the ways in which energy is generated and consumed are changing rapidly.

As with any new technology/evolution, much is promised but there is little evidence against which to judge these claims. The big issues for utilities are cost, reliability and confidence in the supply chain. It is important to note that the availability and resilience of a communications system is more a feature of network design, operation and maintenance than it is of the technology employed. There is nothing inherent in 5G to make it more reliable and resilient than previous generations of technology; on the contrary, there is the potential that the extra infrastructure – located closer to the end service points - needed to provide 5G promises will increase the cost of enhancing reliability. Since all modern communications networks are software controlled, this must also be recognized as a common-mode failure point, especially with the increasing complexity of modern software systems.

Another major issue is security. Any wireless network is open to monitoring over the air, interception and/or tampering. However, provided the security system is designed with this vulnerability in mind, the network could potentially be better secured than legacy systems.

We also have to look at 5G applications and markets, suggesting where utilities might fit into these ecosystems. Cognizance is taken of the international situation with different constraints on spectrum availability in different geographic regions and markedly different starting positions and customer densities.

Utilities will also wish to participate in the 5G world by acquiring spectrum in order to have the option to construct their own private 5G networks and integrate them into a 5G world. These private 5G networks will take a variety of forms but will need to be able to integrate and interwork with commercial 5G infrastructure operated by telecommunications providers. Reasons that utilities might want to operate private 5G networks might include the need to have:

– Networks able to operate for extended periods in the absence of primary power.
– Greater security than offered by commercial networks.
– Deterministic low latency services.
– Coverage into areas not served by commercial operators being either remote rural areas, industrial sites with poor coverage, underground locations, tunnels, etc.
– Redundant telecommunications provision.

5.7 IMT applications community and education sector

Community

As many cities have launched the concept of a "smart city," advanced area management is one of the key investment areas for many nations, cities, and any person or business related to real estate development. Fostering this evolution are advanced sensing technologies.

---

[35] Cutting Through the Hype: 5G and Its Potential Impacts on Electric Utilities - https://eutc.org/wp-content/uploads/2019/04/Cutting_through_the_Hype_Utilities_5G-2.pdf.

Sensor devices capturing information beyond the capabilities of human beings are already a reality. Image sensor performance exceeding 1,000-fps is one of the examples already seen in the market today. Together with neuromorphic or AI integrated sensors, event-driven and adaptive-data type sensors requiring different levels of QoS will soon be available to handle applications of various types.

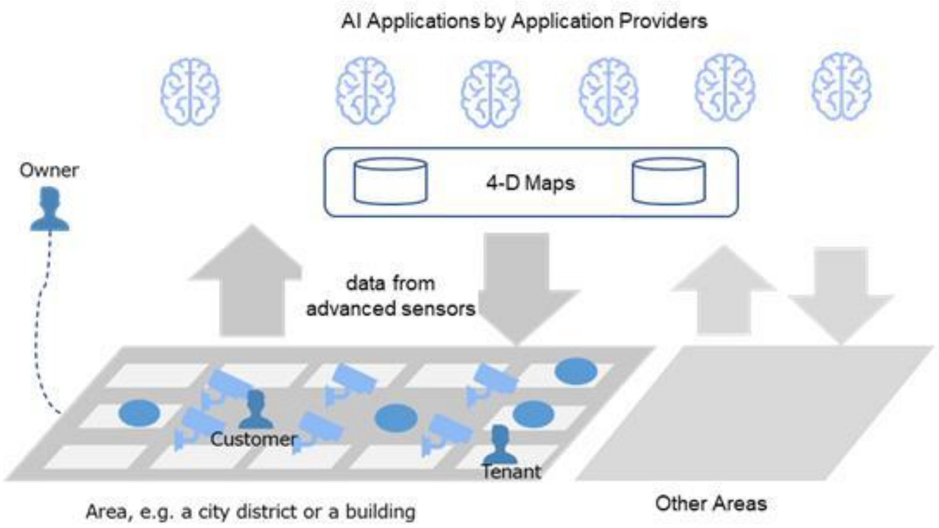
Advanced sensing is not limited to image capturing. LiDAR will capture the precise position of objects. Fiber sensing will capture the condition of a wide geographic area in which fiber is installed. Thus, a communication network consisting of wireless and wired network can deliver services beyond traditional communication. In turn, the sensing use cases expands performance dimensions to mobile network, such as detection probability, sensing resolution and accuracy in range, velocity, and angles, depending on applications. Furthermore, leveraging signals from various networks for sensing, wireless network communication, particularly in challenging RF condition, can be improved with less overhead, delivering more efficient energy and resource utilizations.

Live 4D map can be built by collecting various sensing data and matching the four-dimensional "latitude, longitude, altitude, and time" information. The 4D maps will facilitate the development of various valuable applications. Some may detect incidents and automatically initiate the incident response operation. In contrast, others, which are referred to as digital twin applications, may make short-term predictions and generate some proactive actions.

Sensor devices will need to be connected to a centralized data center via mobile network as they will be placed widely, unsuitable for wired connection from deployment and cost perspectives. 4D maps enabling applications such as autonomous vehicle will need precise location with resolution to cm level and simultaneous synchronization (Figure 5.7.1). IMT-2020 and future mobile networks promise technologies to achieve such a high resolution.

FIGURE 5.7.1

Area Management with Advanced Sensors and 4D Map



Education

The education vertical is a broad topic and can range in scope from a small metropolitan grade school to a large, rural university campus. Education vertical use cases include:

– Remote learning

– Enhanced mobile broadband for large campuses
– Immersive lessons through AR and VR
– Smart classrooms and campuses
– High-capacity video downloading and streaming.

As in healthcare, COVID-19 pandemic has impacted education in numerous ways, catalyzing remote learning in more ways than we could have imagined. Remote learning is severely hindered when broadband access is not available or is not sufficiently capable of providing rich connectivity to emulate classroom situations for younger students who need active supervision to carry on their learning. IMT can close this gap either through a CSP service plan or through a private IMT network. Multiple examples[36] of private IMT networks for remote learning have popped up throughout in some countries in the past year and the trend continues.

Key pain points for this vertical include:

– Operational budget
– Better wireless indoor (capacity) and outdoor (coverage)
– Full broadband access for remote learning
– Security, need to own and control the communication network
– Commercial Service Provider coverage
– Need to future proof to keep up with the latest complex technologies.

One of the main barriers to IMT adoption in the education vertical is available capital and operational budget. There may be the perception that a large, top-ranked, private university has plenty of budget through grants, tuition, or endowments to implement the latest technologies, but direct feedback through multiple interviews advise that is simply not the case. Most of that money is earmarked for specific projects or for specific departments.

Other than remote learning, some of the more popular potential use cases for the education vertical includes high-speed outdoor connectivity on large campuses, immersive lessons through AR and VR, smart classrooms and campuses, and fast video downloading and streaming. It is interesting to imagine students going to school, putting on VR glasses, and taking a tour inside a historical monument (e.g. Saint Peter’s Cathedral), flying through the solar system, or witnessing a march in a large city (e.g. Washington) as if they were there. The high throughput and low latency capabilities of IMT can make this a reality.

College campuses all have existing RLAN solutions that likely provide excellent indoor coverage today, but many college administrators or IT personnel explain it is a constant game of catch up. There is a seemingly insatiable appetite for broadband service. New devices are constantly coming to the market, and it is an inevitability that some will find a corner where the coverage is poor or inadequate.

Additionally, there may be large areas of outdoor space where coverage might be insufficient. University architects and land planning groups are averse to visible access points or antennas, so it can be challenging to build the infrastructure necessary to complete an outdoor RLAN system. A new IMT wireless system would better support the outdoor requirements and can be used to complement the indoor RLAN system. An outdoor IMT system could also facilitate the evolution to a smart campus environment providing the medium to support wireless security cameras, digital

[36] https://www.rcrwireless.com/20210609/spectrum/intel-aws-to-deploy-private-cbrs-network-in-california-school-district

information kiosks, and many other devices and sensors. Once established, the IMT system can easily migrate indoors to offload the RLAN system, which could be dedicated to specific use cases.

Lack of commercial wireless coverage indoors is a common complaint for various verticals including college campuses. A private IMT solution could not only complement the RLAN system by supporting secure and staff dedicated applications, but it could also serve as a carrier grade, neutral host system bringing CSP services indoors. As mentioned previously, there are multiple ways to implement a neutral host IMT solution.

On the public network side, an active distributed antenna system (DAS) solution could be installed and shared among all CSPs, but the price tag can be high for both the university and the CSPs and performance can be difficult to optimize. As an alternative, a Distributed Radio Access Network (DRAN) could be deployed, but this would be dedicated to each CSP, so it could be highly intrusive from the vantage of the university.

On the private network side, a neutral host network could be setup to support roaming agreements with the CSPs, where their customers roam onto the University's private IMT network. While the end user would see the university's network identifier on their phone or device, they would still be able to access their CSPs voice and data services. One disadvantage could be that the end user may not have all their subscription services available to them from their home network.

Alternatively, a private/neutral host network can also be configured as a shared Radio Access Network (RAN) solution. The Multi-Operator Radio Access Network (MORAN) option, allows sharing of the RAN equipment, enables each CSP to use their own frequencies and connects the system back to their own core. However, there are limited equipment options that support this type of deployment. In a Multi-Operator Core Network (MOCN) configuration, both the RAN equipment and the frequency spectrum are shared. The MOCN based network connects to the CSP core through a MOCN gateway in a fashion transparent to the end user. End users will see their home network identifiers on their devices and access all services they have subscribed to from their CSP. While there are no major technical roadblocks to implementing either a MORAN or a MOCN solution, it may be difficult to come to commercial terms with the CSPs. That is where partnering with a large MSP may be beneficial, as commercial terms may have already been agreed upon and connection processes formalized.

Professional live conference / presentation events

In various on-site live audio presentation scenarios, one or several persons (presenters) are holding a talk in front of an interested audience, which can interact with the presenter/s, for instance by posing questions. Other scenarios include the moderation of corporate events, panel discussions or conferences.

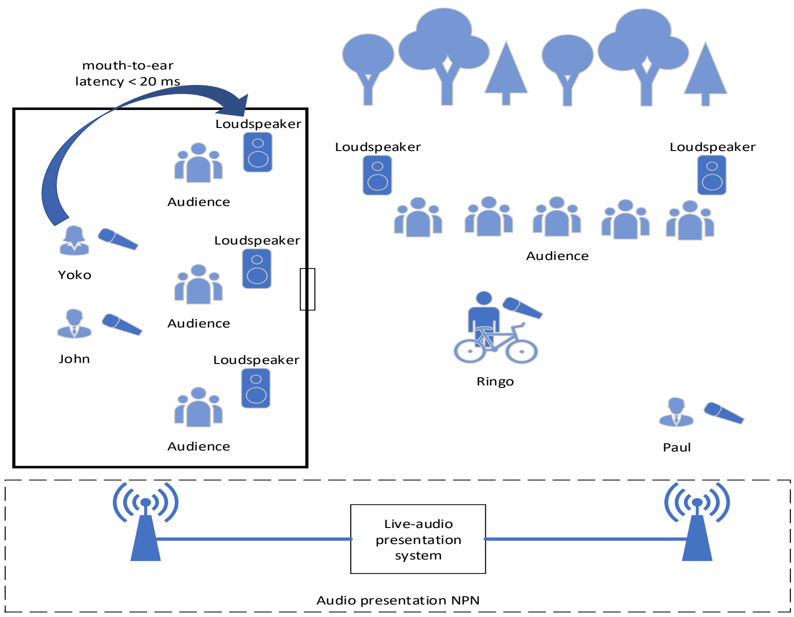
On-site live audio presentation scenarios are typically confined to a local area, e.g. conference rooms, lecture halls, press centres and trade fairs. They can be located indoors or outdoors. Typical operation has a defined duration known in advance. Characteristic for this use case is that all production equipment is available at the location, the wireless communication service is limited to the local area and all audio processing such as audio mixing is done in real time. The wireless network covering the venue/location may be provided by a PLMN or a local non-public network (NPN).

Wireless microphones are used for capturing audio from presenters within the local service area. A large number of simultaneously active wireless microphones can be expected. These wireless microphones can be scattered into different rooms, stages or spaces within the same complex. The captured audio signals are transmitted to a central audio mixing console. The audio mixing console creates the new desired audio streams. These streams delivered to downstream equipment and applications, such as amplifiers and loudspeakers of a public-address system, streaming services for hearing impaired participants, translation services, recordings, etc.

An example scenario is shown in Fig. 5.7.2, including both indoor and outdoor audience.

FIGURE 5.7.2

On site Live audio presentation network



Audio & Video streaming in professional live events

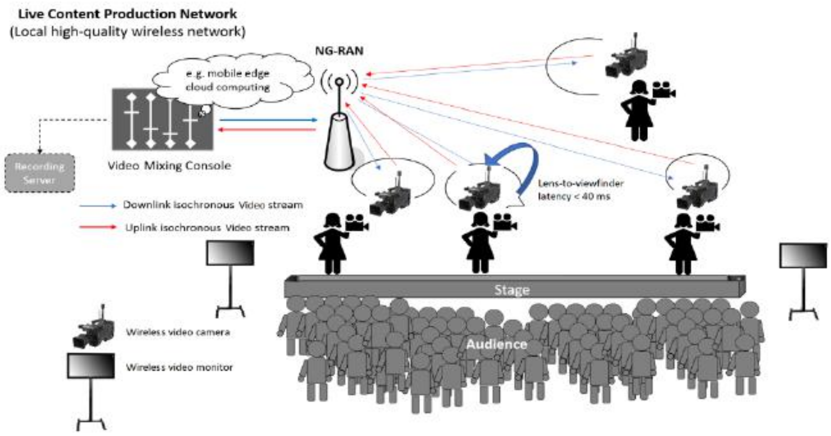
Using wireless technologies for producing and capturing a live event (e.g. a concert), i.e. for further exploitation of its cultural and creative content, maybe quite challenging. For instance, during a concert, artists on stage use wireless microphones to capture their voices or instruments' sound while hearing themselves via a wireless in-ear monitoring system. Cameramen operate their wireless cameras capturing the performance. The technical crew, the production team and the security staff are usually connected to each other via an intercom system. Lighting, video and sound effects are remotely controlled over stage control systems. The term PMSE equipment is used to sum up all wireless audio and video equipment involved in professional A/V productions.
See an example futuristic scenario in Figure 5.7.3[37]. Each wireless camera signal is streamed to a central video mixing console and each camera receives a control and video return signal. The video mixing console does the mixing and combining of the different video streams. Most cameramen rely on receiving a personalized video mix of the event streamed back to his camera viewfinder. In this context, personalized means that each cameraman can receive a different video mix (i.e. point to point downlink transmission) fully adapted to his/her needs and preferences. Sometimes a group of cameramen in the production may want to receive the same video-mix. For this latter case, a point to multipoint downlink transmission could be chosen. The video mixing console produces further outgoing streams for the stage video monitoring device, playout and recording.

---

[37] 3GPP TR 22.827: *Study on Audio-Visual Service Production.*

FIGURE 5.7.3

Live content production network



From a 5G deployment point of view, one example could assume a temporary infrastructure using a 5G local non-public network (NPN) is setup on site, together with all PMSE equipment required to produce the event. Multiple cameras will connect via this local non-public 5G network to the studio or outside broadcast van. All audio & video data is sent via the local non-public 5G network for communication, camera control, GPS data, AR sensor data, and return video.

5.8 IMT applications in manufacturing

Given the combined trends of the Fourth Industrial Revolution (or Industry 4.0) and the recent spread of the COVID-19 virus, there is a growing need for remote and real-time monitoring of people, goods, machinery, equipment operation, etc., throughout the modern factory. The objectives of such monitoring include early detection of abnormal situations and rapid implementation of required measures (dynamic adjustment of machine parameters, emergency stop on the production line, evacuations, etc.) because these contribute to improve yield ratio and keep workers safe.

For example, suppose an anomaly is detected at a chemical plant. In that case, there is increasing demand to let experienced engineers check real-time on-site conditions through video captured with high-definition (4K/8K) cameras to accurately grasp the situation and quickly analyze the anomaly's cause. In this way, these experienced personnel would be able to issue instructions on how to adjust the current operating state before a major production failure or accident occurs and how to return the production status to normal at an early stage.

At present, however, no service can reliably transmit such large volumes of data whenever and wherever needed in real-time at a reasonable cost. The current situation is that the cause of a detected anomaly is inferred based on limited and incomplete information and assigned engineers' experience and intuition, resulting in the longer time, larger labor, and higher cost in handling the problem on-site.

As a result, many companies faced with stagnant productivity, labor shortages, and increased accidents look forward to a solution that can transmit large volumes of data as in high-definition live video inexpensively and safely.

Even though high-speed, large-capacity wireless communication services exist today, bandwidth-guaranteed network services are expensive due to scarcity of spectrum, and their use as necessary insurance against abnormal times is not worth the cost.

IMT-2020 networks promise spectrum efficiencies of between 0.12 - 30 bits/s/Hz, up to 5X of that of IMT-Advanced. In addition, IMT-2020 and future generation network will be able to support much higher number of IoT devices, approximately 100X and 1000X of 4G, respectively. Network latency will also be improved by 10X from IMT-Advanced to IMT-2020. All these advantages make a wireless network suitable and affordable to support 4th industrial revolution.

In addition, services for managing and automatically optimizing communications traffic loads directly through from a high-definition camera to LAN, gateway, edge computer, access circuit, communications building, relay circuit, Internet, and global cloud, for example, are insufficient. Furthermore, high-definition video from the field often includes sensitive information involving personal privacy and corporate secrets. Still, it is not unusual for the work of on-site management, remote monitoring, and implementing measures to minimize damage, restore operations, etc., to be handled by different companies. As a result, appropriately protecting such confidential information based on inter-company contracts requires complicated security management operations that tend to drive up business costs. This problem, in turn, makes remote maintenance operations of factories, plants, buildings, and urban spaces difficult. As a result, it has been necessary to deploy personnel in the field to visually inspect on-site facilities and manage safety by human wave tactics (i.e., by sheer force of numbers). This is considered one reason why productivity has not risen in industrial sectors such as manufacturing, distribution, and transportation.

With IMT-2020 network slicing, which enables the multiplexing of virtualized and independent logical networks on the same physical network infrastructure, an enterprise can create a scalable network slice entailing its specific service level requirements implemented on top of a common network infrastructure. Such a network slice is an isolated end-to-end network tailored to private usage, leading to much tighter security control.

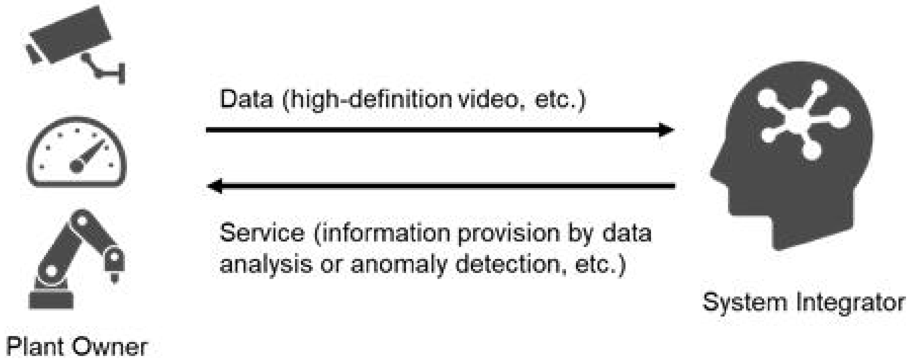
In cooperation with domestic and overseas communications operators, hardware vendors, software vendors, users, universities, research institutions, the national government and municipalities, community groups, etc., we seek to achieve a secure and high-efficiency data distribution service that can appropriately protect, transmit, and share large volumes of data such as high-definition live video used for safety monitoring of manufacturing sites, urban spaces, etc. based on laws, regulations, and ethics.

This use case also includes the following situations: Factory managers watch high-definition video data from cameras in factories and plants from a remote headquarters office of the same company while on a business trip or working from home. Factory managers connect the manager's office and the machine manufacturer's office and share the same video data to both offices simultaneously while consulting with the maintenance staff of the machine used in the factory to recover from the trouble (Figure 5.8.1). In such cases, there is a problem IMT-2020 cannot solve yet in interconnecting multiple private networks and public networks operated by each location or company to minimize latency and synchronize the transmission of high-definition video data.

To address this issue and accelerate the Fourth Industrial Revolution initiative, the development of new technology which can transmit a large volume of data continuously, reliably, and inexpensively is desired.

FIGURE 5.8.1

Overview of Factory Remote Operation



Manufacturing

Manufacturing is perhaps the most noted vertical to be benefiting from IMT, mostly due to Industry 4.0 transition that is set to drive next wave of modernization in manufacturing. Born in Germany and launched in 2011, Industry 4.0 (I4.0) refers to the introduction of a fourth Industrial Revolution through the fusion of the cyber and physical worlds to drive value and competitiveness in a global marketplace. Foundations of I4.0 are broad and consist of several design principles and technology pillars which are more broadly described in detail in the following paper.[38]

While IMT can be instrumental for many I4.0 enhancements, IMT alone is not sufficient to realize I4.0. There are many other aspects of manufacturing processes that need to evolve in parallel to enable IMT features to be usable and effective, which is a point that sometimes gets undermined in our enthusiasm to deploy IMT. The following Digital Transformation Assessment[39] summarizes current challenges faced by manufacturing sector and is a good summary of where IMT fits in the larger set of manufacturing top of mind and demands.

Manufacturing wireless use cases

Manufacturing is a broad practice that can involve many activities, anywhere from supply chain interactions, warehousing of goods, production processes and assembly lines, shipment of goods, and many more other steps. Primary concerns in all manufacturing venues include:

– **Need for greater operational efficiency and resilience** - Preventing interruptions in production lines, improving quality of production, and decreasing cost of production are everyday concerns in all manufacturing contexts. Interruptions are very costly and can have many root causes from failures of an outdated tool, to lack of sufficient network bandwidth causing poor connectivity of critical tools, or even outdated processes requiring a complete modernized redesign of the factory.

– **Delivering on existing commitments** – Maintaining production commitments while identifying meaningful cost savings in procurement, manufacturing methodology, logistics and service are a top priority for all manufacturing sectors. In all cases operational managers tend take the most immediately available and cost-effective solution to their production problems. Introduction of new tools or redesign of factory floor and network has to take into account existing tools and enable continuity of operation as much as possible. New factory designs in a greenfield context are being

[38] https://www.cisco.com/c/dam/en_us/solutions/industries/manufacturing/white-paper-c11-742529.pdf.

[39] https://www.ibm.com/downloads/cas/MPQGMEN9.

considered but even timing and cost of new factory launches will dictate choice of solution.

– **Cyber vulnerabilities** remain a huge concern. Control of access and protection of data in compliance with enterprise policy as well as industry and regional regulations are extremely important and can dictate choices of technology.

Auto manufacturing is one of the most complex practices and one vertical where companies have been considering IMT for process enhancements. Almost all auto manufacturing plants world-wide have either already started a PoC (proof of concept) and trial for IMT or are considering it. Here is a list of typical requirements being considered:

– **Robotics and automation -** Production robots are usually not mobile due to large power requirements, however, there are many aspects of a large robotic arm operation that can benefit from low latency wireless sensor capabilities. In most cases similar features can be implemented with wired, industrial ethernet. Nevertheless, new cases are continuously being identified as factory design evolves. Automated Guided Vehicles are a moving robot which can benefit from rich wireless connectivity with low latency. Modern AGVs are sophisticated machines that can do very many activities if provided enough intelligence, which increasingly requires rich, low latency, secure, and resilient wireless connectivity that can be provided with IMT. Introduction of AGVs into existing factory floors needs to be considered with care as there are many safety compliance requirements. While AGVs are not a priority for auto manufacturers, once proven effective and safe, they can become a very powerful addition to factory floors.

– **Tracking and monitoring** of various aspects of production through video and sensor surveillance with application of analytics to study production patterns and optimize processes. Many of these activities can be done with existing RLAN based cameras and IoT sensors, but IMT can provide enhancements, particularly in outdoors venues.

– **Life Cycle Management** of auto inside and outside of factory, this may include download of massive amounts of data Over The Air (OTA) in the form of firmware or software to enable troubleshooting, testing, and upgrading car components in various stages of production, shipment, and eventual use. These massive data and control exchanges need to be enabled inside the factory during production as well as outside the factory in remote shipyards or dealer shops, as well as when the car is put in use at the mechanic shops or even owner’s home. Data download requirements can be very large for factory floors where large numbers of units may need to be handled in parallel for production.

– **Small wireless tools** such as scanners or radio frequency identification (RFID) readers are pervasive and usually supported with RLAN, but here IMT can also provide enhancements, particularly in outdoors venues.

– **Smart factories of the future**: whether these flexible assembly stations can be almost totally cord-less except for power, is a vision that is being designed and evaluated. These smart factories will use massive amounts of wireless connectivity which translates into not just IMT usage, but many other wireless modalities, as well. These designs are in ideation stages and their full realization will take a few years. Nevertheless, new factories are considering enabling all forms of wireless to be ready for new tooling and processes that may emerge.

– **Wireless connectivity** on factory campus to prevent pulling cables.

– **Augmented and virtual reality** applied to various venues to enhance operator experience.

The Manufacturing sector is diverse, spanning multiple industries from consumer electronics to heavy machinery to automobiles. Each domain has specific workflows and operational requirements to keep the factory humming. Gaining a few percentage points in operational efficiency for high-value, high-volume goods, such as automobiles and steelmaking, can yield $ billions in cost savings and productivity gains. As a result, there has been a keen focus and interest among car manufacturers and heavy industries to trial private 5G networking. Today, manufacturers rely on a diverse mix of wired and wireless network technologies for factory automation. Manufacturers are excited about leveraging the Ultra-Reliable Low Latency Communications (URLLC) and Time-Sensitive Networking (TSN) capability in 5G to address the deterministic transfer of data in industrial use cases in a cable-free environment. In highly automated manufacturing environments, a single millisecond latency will likely be needed to maintain ultra-reliability, up to 99.9999% for advanced manufacturing. A dedicated licensed or local spectrum will be essential in meeting the high URLLC performance expectations.

While 5G promises high bandwidth capacity, lower latency, and massive IoT connections, the deterministic link capability is the most exciting part. Keeping uptimes high is crucial in any manufacturing process. If the underlying network performance is erratic, it is difficult for manufacturers to hold the line running smoothly. For example, remote control of connected manufacturing robots, autonomous guided vehicles (AGV), and other sensor monitors requires a reliable network to make wide-scale operations run smoothly. In addition to factory automation, 4k video and machine vision for quality control are key aspects of 5G applications on factory floors. Here, a robust uplink bandwidth to stream large video traffic up to edge computing servers is required. Another video-centric application to increase worker productivity is augmented reality (AR) goggles. Technicians can pull up datasheets on AR goggles for remote diagnostics and inspection. Also, they can use AR/VR to tap “expert” resources in an immersive setting during troubleshooting.

The possibility of consolidating multiple industrial networks like RLAN, Bluetooth, DECT, Fieldbus, and industrial Ethernet onto a “universal” 5G network is one of the motivators for manufacturers. While a complex manufacturing environment will likely require multiple networks, the appeal of 5G use for reconfigurable manufacturing workflows is a big draw for manufacturers. They desire granular instrumentation of manufacturing lines across many fixed and mobile devices and IoT sensors. In addition, they need real-time data flows from those devices and sensors to optimize the manufacturing process – ultimately to increase yield and prevent downtimes.

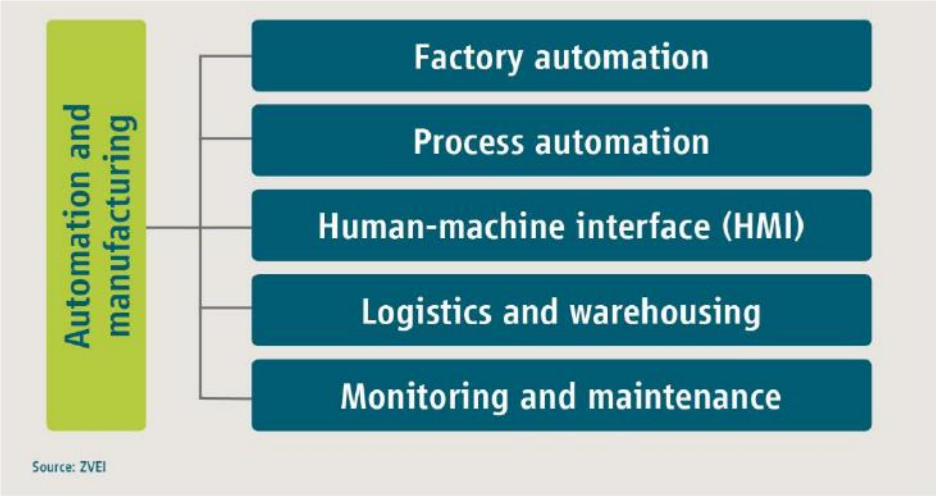
Connecting \Smart factories of the future: With the recent changes and digital evolution of the manufacturing industry and factories of the future, often referred to as "Industry 4.0", 5G wireless connectivity plays a key role in supporting several industrial applications, especially with respect to end-to-end latency, communication service availability, jitter, and determinism. Smart factories will use wireless connectivity which translates into not just IMT usage, but many other wireless modalities, as well. These designs are at different stages and their full realization will take a few years. Nevertheless, new factories are considering enabling all forms of wireless to be ready for new tooling and processes that may emerge.

Manufacturing is diverse and heterogeneous and is characterized by a large number of automation use cases. These can be divided into five distinct areas of application[40], as depicted in Figure .

[40] 5G-ACIA, “5G for Automation in Industry”, Whitepaper, March 2019

FIGURE 5.8.2

Automation areas in manufacturing[41]



Factory automation comprises the automated control, monitoring and optimization of processes and workflows within a factory. This includes closed-loop control applications (e.g., based on programmable logic or motion controllers), robotics, and aspects of computer-integrated manufacturing. Communication services for factory automation need to fulfill stringent requirements, especially in terms of latency, communication service availability and determinism. Operation is limited to a relatively small service area, and typically no interaction is required with the public network (e.g., for service continuity, roaming, etc.).

Process automation refers to the control of production and handling of substances such as chemicals, foodstuffs and beverages, etc. The aim of automation is to streamline production processes, lower energy consumption and improve safety. Sensors measuring process parameters, such as pressures or temperatures, operate in a closed loop by means of central and/or local controllers in conjunction with actuators, e.g., valves, pumps, heaters, etc. A process-automated manufacturing facility may range in size from a few 100 m^2 to several km^2, or may be geographically dispersed within a specific region. Communication services for process automation need to meet stringent requirements. For instance, low latency and determinism are crucial for closed-loop control. Interaction may be required with the public network (e.g., for service continuity, roaming, etc.).

Human-machine interfaces (HMIs) include many diverse devices for interaction between people and production systems. These can be panels mounted to a machine or production line, as well as standard IT devices, such as laptops, tablet PCs, smartphones, etc. In addition, augmented and virtual reality (AR/VR) systems are expected to play an increasingly important role in the future. Production IT encompasses IT-based applications, such as manufacturing execution systems (MES) and enterprise resource planning (ERP) systems. The primary goal of an MES is to monitor and document how raw materials and/or basic components are converted into finished goods. An ERP system generally provides an integrated and continuously updated view of business processes. Both systems depend on the timely availability of large volumes of data from the production process. Communication services for HMIs and production IT need to meet stringent requirements. For example, very low latency is imperative for some use cases. Most HMI and production IT use cases

[41] 5G-ACIA, “5G for Automation in Industry”, Whitepaper, March 2019

are limited to a local service area, and typically no interaction is required with the public network (e.g., for service continuity, roaming, etc.).

Logistics and warehousing refer to the organization and control of the flow and storage of materials and goods in the context of industrial production. Intralogistics is logistics on a defined premises, for example to ensure the uninterrupted supply of raw materials to the factory floor by means of automated guided vehicles (AGVs), forklift trucks, etc. Warehousing refers to the storage of materials and goods, for example employing conveyors, cranes, and automated storage and retrieval systems. For practically all logistics use cases, the positioning, tracking and monitoring of assets are of high importance. Communication services for logistics and warehousing need to meet very stringent requirements in terms of latency, communication service availability and determinism, and are limited to a local service area (both indoor and outdoor). Interaction is required with the public network (e.g., for service continuity, roaming, etc.).

Monitoring and predictive maintenance refers to the monitoring of certain processes and/or assets, but without immediately impacting the processes themselves (in contrast to a typical closed-loop control system in factory automation, for example). This includes condition monitoring and predictive maintenance based on sensor data, massive wireless sensor networks, and remote access and maintenance. Communication services for monitoring and predictive maintenance are limited to a local service area (both indoor and outdoor). Interaction is required with the public network (e.g., for service continuity, roaming, etc.).

The primary manufacturing-domain use cases can be grouped into ten categories. Typical manufacturing application areas, and example use cases can be summarized as shown in Table 5.8.1[42].

TABLE 5.8.1

Manufacturing applications (rows) and example use cases (columns)

	Motion control	**Control-to-control**	**Mobile control panels with safety**	**Mobile robots**	**Massive wireless sensor networks**	**Remote access and maintenance**	**Augmented reality**	**Closed-loop process control**	**Process monitoring**	**Plant asset management**
Factory automation	X	X		X	X					
Process automation				X	X			X	X	X
HMIs and Production IT			X				X			
Logistics and warehousing		X		X						
Monitoring and maintenance					X	X				

The industrial domain is diverse and heterogeneous and is characterized by a large number of different use cases and applications, with sometimes very diverse requirements. Major areas, such as factory automation, may differ substantially from others, such as the process industry. This holds true with respect not only to quality-of-service requirements, but also to typical deployment scenarios and operational and functional requirements. In general, however, common to all relevant areas of application is that a new generation of industrial connectivity solutions may lead to substantial improvements and optimizations[43].

---

[42] 3GPP TR 22.804: *Study on Communication for Automation in Vertical Domains*.

[43] 3GPP TR 22.832, "Study on enhancements for cyber-physical control applications in vertical domains; Stage 1", v17.4.0, March 2021

Among the important aspects of different use cases that need to be considered are quality of service, security and safety, reliability and availability, brownfield support, backward and forward compatibility, cost-efficiency, and maintainability and manageability of the solutions by domain-specific personnel. An exhaustive discussion of a large number of different use cases and associated requirements can be found in respective literature such as 5G-ACIA whitepapers[44,45,46] and 3GPP SA1 documents[47,48,49,50].

5G has the potential to provide (wireless) connectivity for a wide range of different use cases and applications in industry. Interestingly, 5G is likely to support various Industrial Ethernet and TSN features, thereby enabling it to be integrated easily into the existing (wired) infrastructure, and in turn enabling applications to exploit the full potential of 5G with ease.

Certain more concrete use cases for the "Factory of the Future" have already been defined and analysed by 3GPP, with considerable support from a number of vertical industry players, in technical reports TR 22.804[51] . In this respect, wireless communication and in particular 5G may support achievement of the fundamental goals of Industry 4.0, namely, to improve the flexibility, versatility and productivity of future smart factories. An illustrative overview of some use cases is shown in Figure , in which the individual use cases are arranged according to their major performance requirements, classified according to the basic 5G service types eMBB, mMTC and URLLC. As can be seen, industrial use cases, such as motion control or mobile robotics, may have very stringent requirements in terms of reliability and latency, whereas others, such as wireless sensor networks, require more mMTC-based services. However, use cases and applications also exist that require very high data rates as offered by eMBB, such as augmented or virtual reality.

---

[44] 5G-ACIA, "Key 5G Use Cases and Requirements", Whitepaper, May 2020

[45] 5G-ACIA, "5G for Automation in Industry", Whitepaper, March 2019

[46] 5G-ACIA, "5G for Connected Industries and Automation", Whitepaper, 2nd edition, February 2019

[47] 3GPP TR 22.804, "Study on Communication for Automation in Vertical Domains", v16.3.0, July 2020

[48] 3GPP TR 22.832, "Study on enhancements for cyber-physical control applications in vertical domains; Stage 1", v17.4.0, March 2021

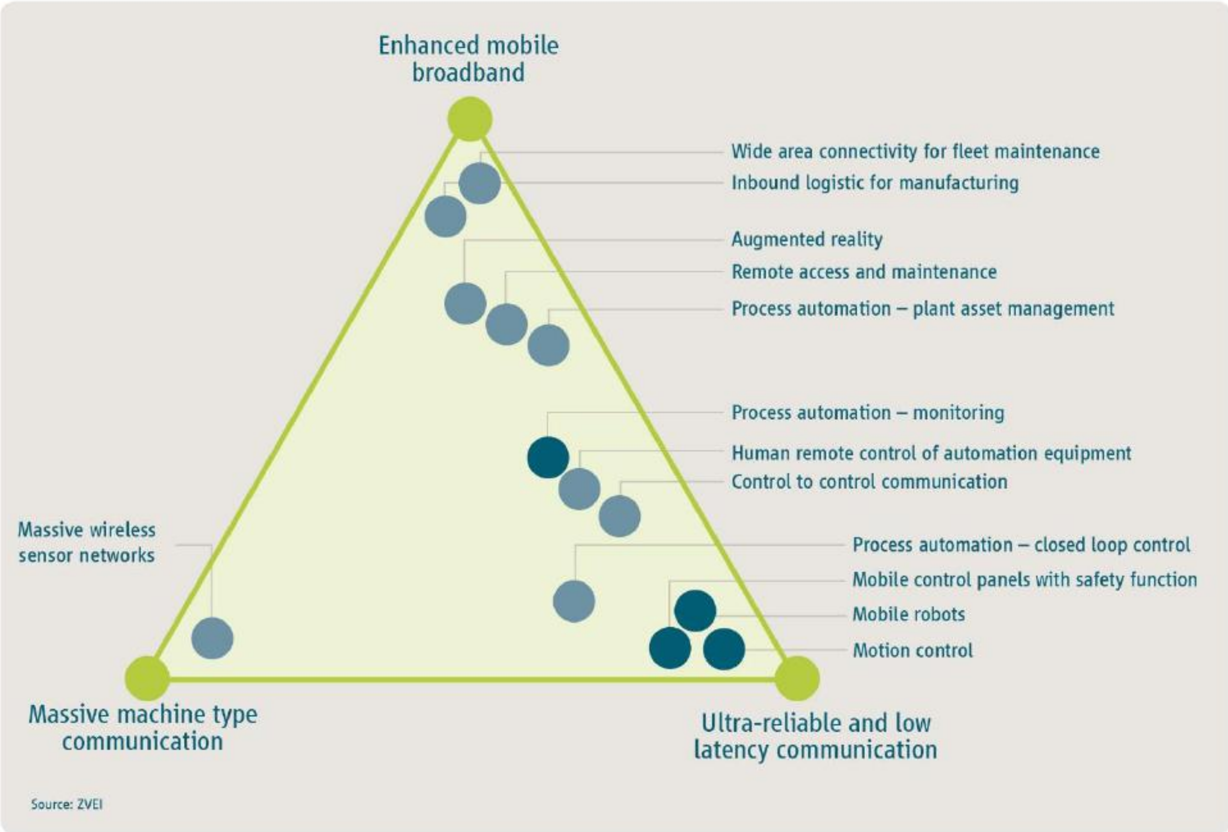
[49] 3GPP TS 22.104, "Service requirements for cyber-physical control applications in vertical domains; Stage 1"

[50] 3GPP TS 22.261, "Service requirements for the 5G system; Stage 1"

[51] 3GPP TR 22.804, "Study on Communication for Automation in Vertical Domains", v16.3.0, July 2020

FIGURE 5.8.3

Overview of selected industrial use cases and arrangement according to their basic service requirements[52]



Among all listed use cases, motion control appears the most challenging and demanding. A motion control system is responsible for controlling moving and/or rotating parts of machines in a well-defined manner. Such a use case has very stringent requirements in terms of ultra-low latency, reliability, and determinism. By contrast, augmented reality (AR) requires quite high data rates for transmitting (high definition) video streams from and to an AR device. Process automation lies somewhere between the two, and focuses on monitoring and controlling chemical, biological or other processes in a plant, typically extended, involving both a wide range of different sensors (e.g., for measuring temperatures, pressures, flows, etc.) and actuators (e.g., valves or heaters).

Several of the industrial automation requirements will not be addressed in the first release of 5G, which mainly focuses on eMBB. Instead, these requirements have been addressed in future releases, in particular Release 16 and Release 17. Only 3GPP 5G Rel-16 provides major enablers and important functionality for Industrial 5G to be deployed in factories. Release 17 will bring further enhancements. At the time of writing (May 2022) there have been no devices and networks for 5G Rel-16 available. Therefore, potential users of industrial 5G have not had yet the opportunity to deploy, test, and evaluate 5G with industrial features. Practical use of industrial 5G in real industrial environments and under everyday operational conditions will finally show the achievable performance of 5G. Industrial use cases typically also present operational and functional requirements. Examples of operational requirements include the demands for simple system configuration, operation, management, SLA assurance mechanisms (e.g., monitoring, fault

52 5G-ACIA, "5G for Connected Industries and Automation", Whitepaper, 2nd edition, February 2019

management, etc.), standalone and private networks (non-public networks), network capability exposure and interfaces, and the like. Examples of functional requirements include aspects such as security, functional safety, authentication, identity management, etc.

A critical operational requirement is for a production line to operate smoothly and faultlessly; this implies that every station and component as well as the communication services should work as intended. This requirement can be subsumed as the dependability (of an item) and as dependable communication. Dependability can be broken down into five properties: reliability, availability, maintainability, safety, and integrity[53,54]. Many industrial use cases have quite high requirements on dependability, especially compared to traditional use cases in the consumer domain.

Functional safety is one of the most crucial aspects in the operation of industrial sites. Accidents can potentially harm people and the environment. Safety measures must be applied in order to reduce risks to an acceptable level, particularly if the severity and likelihood of hazards are high. Like an industrial control system, the safety system also conveys specific information from and to the equipment under control. Some industrial network technologies are able to transport both industrial control information and safety-critical information. A 5G system applied in industrial automation should also support functional safety. It is important for the safety design to determine the target safety level, including the range of applications in hazardous settings. In accordance with this level, safety measures can be developed for and used by 5G based on proven methods.

Security: Previous industrial real-time communication systems – generally wired, and often isolated from the Internet – were not normally exposed to remote attacks. This changes with increasing (wireless) connectivity as required for Industry 4.0 and offered by 5G. The use of wireless technologies requires that consideration be given to a wide range of types of attack: local versus remote, and logical versus physical. These attacks threaten the areas referred to above of reliability, dependability, availability and safety, resulting in risks to health, the environment and efficiency. Specifically, logical attacks exploit weaknesses in the implementation or interfaces (wired and wireless) by performing side channel analyses. Physical attacks focus on hacking of/tampering with devices by exploiting physical characteristics (and ultimately breaking a critical parameter, for example a key). The 5G industrial solutions must be protected against local and remote attacks (both logical and physical), as these can be automated and then carried out by anyone against a large number of devices (for example, bots performing distributed denial-of-service attacks). Local and isolated management of devices is therefore to be made possible in order to assist in the prevention of remote attacks.

In addition, device authentication, and message confidentiality and integrity are crucial for industrial communication systems. While data confidentiality is very important in order to protect company IP and prevent industrial espionage, data integrity becomes of paramount concern for industrial applications. This particularly applies to machine-to-machine communication in which data is used to either feed the control loop or control actuators. This can lead for instance to machine failure or quality issues if not detected.

Finally, the security architecture must support the deterministic nature of communication, scalability, energy efficiency, and low latency requirements for industrial applications. Looking into the industrial domain, no matter if process or factory automation, 5G always has to be integrated into an existing brownfield situation with legacy communication infrastructure. Therefore, coexistence and integrability is imminent. In addition to the afore mentioned service requirements, the requirements to the hardware and devices also play a crucial role for the successful application

---

[53] 3GPP TS 22.104, "Service requirements for cyber-physical control applications in vertical domains; Stage 1"

[54] 3GPP TS 22.261, "Service requirements for the 5G system; Stage 1"

of 5G to industrial domain, e.g., reliability in harsh environments regarding vibrations, temperature, dirt, or humidity.

There are several documents that provide a good overview of use cases and requirements on 5G for use in manufacturing, provided with considerable support of industrial vertical players. 5G-ACIA published several whitepapers focusing on and containing potential 5G use cases and requirements in manufacturing[55,56,57]. 3GPP SA1 conducted several studies and work items on vertical use cases and requirements, manufacturing contributed to studies[58,59] and work items related to communication for automation in vertical domains (CAV). This resulted in normative 5G requirements in corresponding 3GPP specifications[60,61]. These documents had been written at an early stage of the path towards industrial 5G. The described use case can potentially be implemented with 5G. The specifications and first tests with 5G devices in industrial settings look promising. Nevertheless, only practical use of industrial 5G in real industrial environments and under everyday operational conditions will finally show the achievable performance of 5G. Especially, since only 3GPP 5G Rel-16/17 will provide major enablers and important functionality for Industrial 5G to be deployed in factories. (Devices for 5G Rel-16 have been not available yet at the time of writing (May 2022)).

Several 5G use cases in manufacturing are restricted to a local area. Often, such local use cases require a non-public network[62] . Especially standalone non-public 5G networks are important in industrial communication for local use cases. A flexible integration of such SNPNs into existing OT environments and with existing industrial communication networks is necessary.

5G-ACIA is also working on Industrial 5G Edge computing use cases, requirements and deployment options. Industrial applications and some 5G network functions can run on the factory premise or on service provider's edge very close to the factory premises adding efficiency to the latency, bandwidth and complex computation requirements.

Several key 5G use cases of industrial operational technology providers, for instance, in manufacturing, are provided in[63] :

– **Connectivity for the factory floor**

Many fixed-position or mobile devices such as drives, robots, machines, sensors, actuators, screen terminals, and other systems, that interact on the factory floor, require fast and reliable connectivity. 5G-based wireless transmission offers new opportunities and greater flexibility. Typical closed-loop control applications will run over the 5G network. On-site service engineers will be able to access the 5G network for monitoring and maintenance. Safety is a key issue on the factory floor. If safety-relevant

---

[55] 5G-ACIA, "5G for Automation in Industry", Whitepaper, March 2019

[56] 5G-ACIA, "5G for Connected Industries and Automation", Whitepaper, 2nd edition, February 2019

[57] 5G-ACIA, "Key 5G Use Cases and Requirements", Whitepaper, May 2020

[58] 3GPP TR 22.804, "Study on Communication for Automation in Vertical Domains", v16.3.0, July 2020

[59] 3GPP TR 22.832, "Study on enhancements for cyber-physical control applications in vertical domains; Stage 1", v17.4.0, March 2021

[60] 3GPP TS 22.104, "Service requirements for cyber-physical control applications in vertical domains; Stage 1"

[61] 3GPP TS 22.261, "Service requirements for the 5G system; Stage 1"

[62] 5G-ACIA, "5G Non-Public Networks for Industrial Scenarios", White Paper, 2019

[63] 5G-ACIA, "Key 5G Use Cases and Requirements", Whitepaper, May 2020

components communicate wirelessly, ultra-high reliability and availability is absolutely essential and response time is an extremely important parameter. An example is a safety light curtain. If one of the light beams is interrupted by an object, the light curtain generates a signal in order to prevent injuries. The required response time for a light curtain is generally based on the specific industrial use case, e.g., the proximity of the nearest worker to a potential danger, the walking speed of the worker, and the total reaction time that is needed to place the machine in a safe state. Typically, a light curtain system will periodically poll safety equipment in order to elicit a response within a specified time, i.e., confirming the safety equipment is operational. Certain safety functions may require a response time of a maximum of 1 ms. If the response is delayed or not received, the machine is placed in a safe state and tools are deactivated. The costs for such an interruption increase drastically when not just a single machine, but interlinked machines are impacted.

– **Seamless integration of wired and wireless components for motion control**

Not all devices in a motion control system will be connected wirelessly. As a result, motion control systems need to integrate wired industrial communication network components with wireless 5G components. This seamless integration has to support the demanding performance requirements of motion control applications such as cycle times/transfer intervals and microsecond latency.
An example is the process of joining the chassis and the car body in automobile manufacturing. It requires communication between the conveyor carrying the chassis and the conveyor carrying the body. The chassis and the body are moved closer to each other to allow them to be bolted together. These movements must be precisely controlled, as any collision will result in damage to valuable car components.

– **Local control-to-control communication**

Control-to-control communication is needed when devices with separate controllers interact to perform a shared task. There is a local aspect to this scenario if the devices are positioned close to one another in a single environment, e.g., they are components of a larger machine or they are multiple machines within a single production building. Examples are shuttles in a packaging machine and collaborative handling of large components.

– **Remote control-to-control communication**

Remote control-to-control communication is required for devices that normally interact autonomously with their local controller and only need remote communication occasionally (e.g., when there are changes to tasks) or for servicing/maintenance.
An example is a remotely controlled PCB assembly line.
Printed circuit board assembly lines typically operate entirely autonomously but can be remotely controlled to implement product changes or to capture in-process data. Communication is required between the multiple controllers for the various components/devices on the assembly line and the central control unit.

– **Mobile robots and AGVs**

Mobile robots and autonomous guided vehicles (AGVs) add greater flexibility to industrial environments and are being deployed ever more frequently. Wireless communication is essential for any mobile device, as wired data transmission is not an option. Common use cases for mobile robots include material handling (picking/put-away) in warehouses and at production plants. Picking robots retrieve items from various storage positions and convey them to a predetermined destination, such as a packing station or container. At production plants, mobile robots are used to retrieve products and to move them from one production step to the next. Extremely large AGVs are often deployed in chemical plants. They are typically remotely controlled by an operator in a control room. The operator observes images captured by cameras mounted on the AGV. The camera signals are transmitted wirelessly. The operator immediately stops the AGV if they recognize an obstacle in the AGV's path or any other malfunction. Any failure of or delay in the transmission of camera signals can potentially lead to serious accidents or, at the very least, unnecessary interruptions to the operation of the AGV.

– **Closed-loop control for process automation**

The various interacting components within a control loop, such as sensors, actuators and control units, require fast and reliable communication. In process automation, these components are generally located in environments of greater area. An example are controlled conditions in a chemical reactor. The growing need for production efficiency and product quality calls for the precise control of manufacturing processes. Pumps, valves, heaters, coolers, stirrers and other components are monitored continuously by sensors measuring flowrates, temperature, and pressure in order to keep conditions in the reactor within tight thresholds. Long-term dependability of all components, including availability, reliability, security and confidentiality of communications, are crucial for this use case.

– **Remote monitoring for process automation**

Remote monitoring for process automation requires communication for observation, diagnosis and monitoring. Certain sub-processes (process steps) may require their own dedicated non-public networks. As an example, in the oil and gas industry, items of equipment are distributed over a significant geographical area, e.g., an oil field. Data on the efficiency and operational status of wells, assets and devices are captured by corresponding sensors for remote monitoring. Availability, reliability, and communication security are important aspects for the entire communication chain. In addition, consideration must be given to battery operation in some cases due to a lack of on-site power supply.

Major general challenges and particularities of the Factories of the Future include the following aspects:

1) Industrial-grade quality of service is required for many applications, with stringent requirements in terms of end-to-end latency, communication service availability, jitter, and determinism.

2) There is not only a single class of use cases, but there are many different use cases with a wide variety of different requirements, thus resulting in the need for a high adaptability and scalability of the 5G system.

3) Many applications have stringent requirements on safety, security (esp. availability, data integrity, and confidentiality), and privacy.

4) The 5G system can support a seamless integration into the existing (primarily wire-bound) connectivity infrastructure. For example, the 5G shall allow to flexibly combine the 5G system with other (wire-bound) technologies in the same machine or production line.

5) Production facilities usually have a rather long lifetime, which may be 20 years or even longer. Therefore, long-term availability of 5G communication services and components are essential.

6) 5G systems support non-public network operation within a factory or plant, which can have standalone operation (i.e. a non-public network can operate without dependency on a PLMN) or can be integrated within a PLMN.

7) The radio propagation environment in a factory or plant can be quite different from the situation in other application areas of the 5G system. It is typically characterised by very rich multipath, caused by a large number of—often metallic—objects in the immediate surroundings of transmitter and receiver, as well as potentially high interference caused by electric machines, arc welding, and the like.

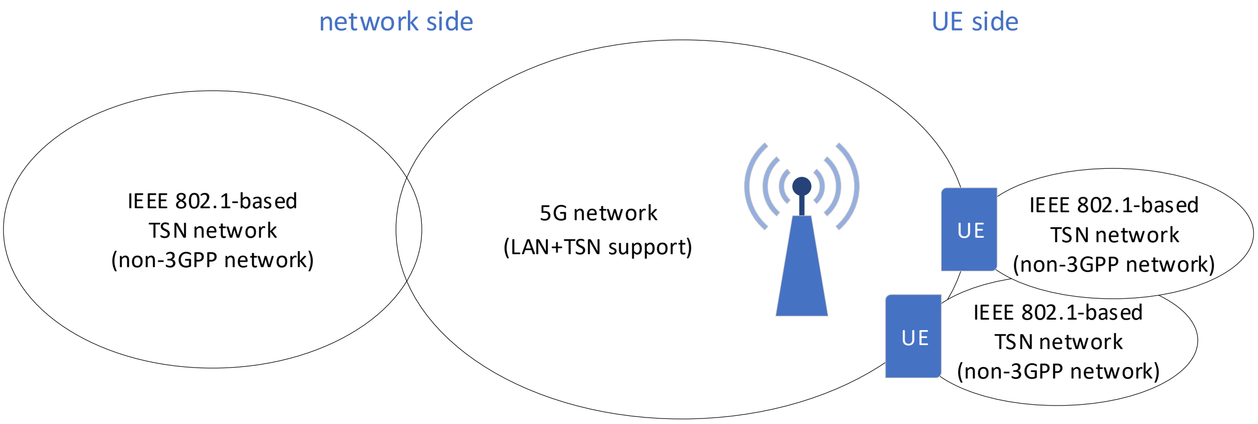
8) The 5G system is able to support continuous monitoring of the current network state in real-time, to take quick and automated actions in case of problems and to do efficient root-cause analyses in order to avoid any undesired interruption of the production processes, which may incur huge financial damage. Particularly if a third-party network operator is involved, accurate SLA monitoring is needed as the basis for possible liability disputes in case of SLA violations.

Integration of 5G networks with industrial communication networks

Industrial 5G networks need to be integrated in existing industrial communication networks. In order to support this, a 5G LAN interface is necessary, that supports Virtual LANs and Ethernet. Furthermore, support of Time-Sensitive Networking (TSN) and integration of 5G in industrial TSN networks is of importance. Time-Sensitive Networking (TSN) is an important functionality of IEEE 802.1-based industrial communication networks in order to provide deterministic, reliable, real-time communication, and the integration of 5G networks and IEEE 802.1-based TSN networks is very beneficial[64].

FIGURE 5.8.4

Integration of IEEE 802.1-based TSN networks with 5G networks (network side, UE side)[65]



The integration between the IEEE 802.1-based networks and the 5G networks can be through the 5G LAN service of the 5G network on the network side and/or on the UE side (see Figure 5.8.4). The integration on the UE side is used, for instance, in use cases where machinery, AGVs, or robots with their own internal network (wired, TSN) are connected to the backhaul part of the industrial communication network through a 5G wireless link in order to enable mobility or tether less

64 *3GPP TR 22.832: Study on enhancements for cyber-physical control applications in vertical domains*

65 3GPP TR 22.832, "Study on enhancements for cyber-physical control applications in vertical domains; Stage 1", v17.4.0, March 2021

movements. IEEE 802.1AS-based time synchronization is an important functionality in such industrial TSN communication networks. The accuracy of the time synchronization between the time transmitter (sync master) and any time receiver (sync device) needs to be in the range of 1 µs[66] . The clock synchronization accuracy of the 5G system needs to be smaller than this value, since the 5G network is only a part in this integrated industrial network.
Depending on the actual physical process, the actual cyber-physical control application, the design of the machinery, AGVs, and robots, and the design of the integrated industrial communication network, different mappings of TSN/time synchronization functionalities to 5G network elements are possible.

In general, the different functionalities for the time/clock synchronization are completely unrelated to the industrial communication network except that they need the communication network for distributing the time/clock synchronization messages. Time/clock synchronization is done within time domains or synchronization domains. There is usually one global time domain, that covers the whole industrial communication network, and multiple working clock domains, that are local and restricted to the devices that work together.

The functionalities of sync master and sync device can be associated with any network device in the industrial communication network. A device may be sync master for one domain and sync device for another domain concurrently.

In general, the sync master can be located on any device that is performant enough to provide the sync master functionality. For the global time domain, the sync master is usually located in the backhaul part or central part of the industrial communication network (non-5G network). For the working clock domains, the location of the sync master depends on the layout of the integrated 5G network / TSN network and the design of the machinery and production cell (the scope of the working clock domain).

Regarding sync devices, they can be any device that is performant enough to handle the sync device functionality. Usually, all end devices with time/clock synchronization will be sync devices. The location of a sync device depends on the layout of the integrated 5G network / TSN network and the design of the machinery and production cell (the scope of a working clock domain).

Two specific deployments of time transmitter/sync master and time receivers/sync devices are of specific interest to industrial communication:

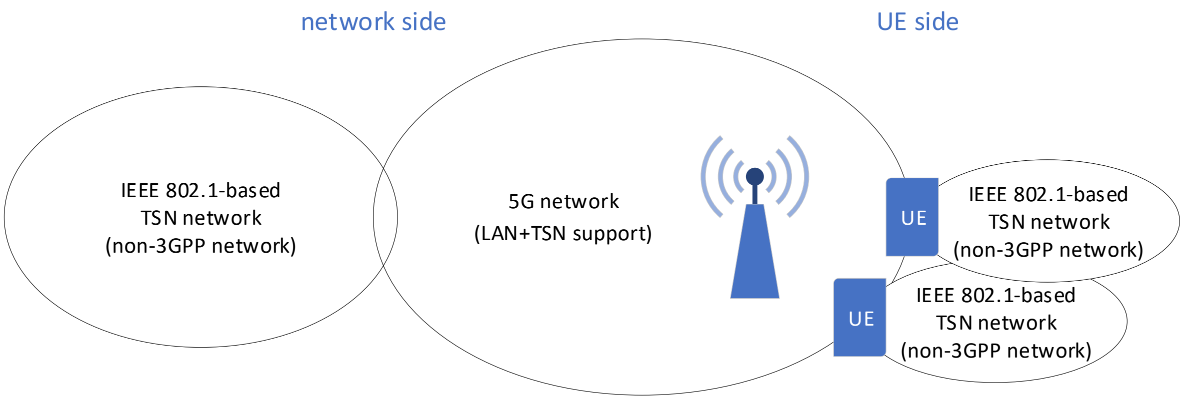
– Time transmitter/sync master is located on the network side of the 5G network. Time receivers/sync devices are located on the UE side, behind a wireless connection (cf. Figure 5.8.5). This is introduced in 5G Rel-16 specifications.

FIGURE 5.8.5

Integration of IEEE 802.1-based TSN networks with 5G networks (network side, UE side)[67]

[66] 5G-ACIA, “Key 5G Use Cases and Requirements”, Whitepaper, May 2020

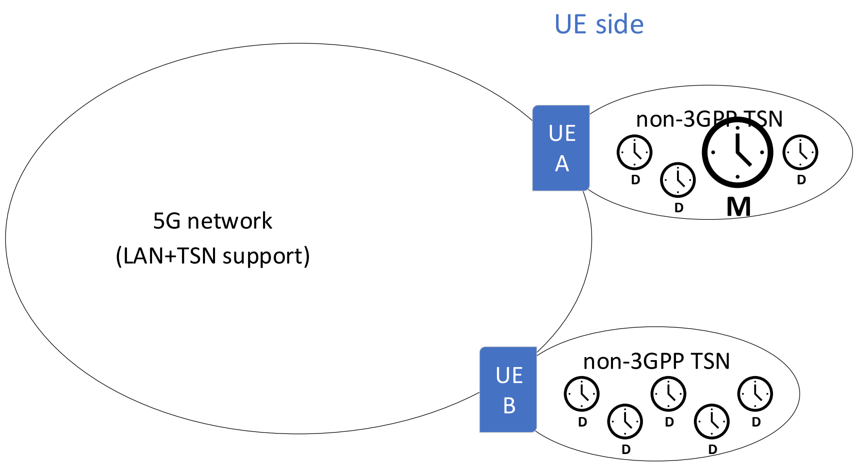
[67] 3GPP TR 22.832, “Study on enhancements for cyber-physical control applications in vertical domains; Stage 1”, v17.4.0, March 2021



– Time transmitter/sync master is also located on the UE side, behind a wireless connection. Time receivers/sync devices are located on the UE side, behind a wireless connection. The path of the time synchronization messages passes through two wireless 5G links (cf. Figure 5.8.5, see Figure 5.8.6 for this specific deployment). This is introduced in 5G Rel-17 specifications.

FIGURE 5.8.6

5G network on path of synchronization messages with two wireless links (both, UL and DL)[68]



How well the so-called 5G Time-Sensitive Communication (TSC) can support IEEE 802.1AS-based time synchronization and IEEE 802.1/5G-integrated industrial TSN networks can only be seen when relevant Rel-16 and Rel-17 functionality is available in industrial 5G devices and networks.

The following figures show three examples of anticipated Industrial 5G use cases. Figure 5.8.7 shows the anticipated Industrial 5G use case of a flexible modular assembly area[69,70], where 5G is used for the communication of mobile assets such as AGVs, mobile robots, etc.

---

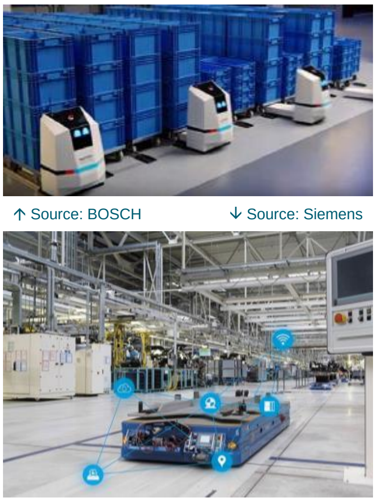
[68] 3GPP TR 22.832, “Study on enhancements for cyber-physical control applications in vertical domains; Stage 1”, v17.4.0, March 2021

[69] 5G-ACIA, “Industrial Use Cases & Requirements”, Web Seminar, July 2020

[70] 3GPP TR 22.804, “Study on Communication for Automation in Vertical Domains”, v16.3.0, July 2020

FIGURE 5.8.7

Anticipated Industrial 5G Use Case – Flexible Modular Assembly Area[71]



- Communication of **mobile assets** such as **AGVs, mobile robots**, etc.
- 5G for industrial-grade **coverage & reliability**
- 5G positioning might support **tracking & navigation**
- URLLC for **interaction** between and to **mobile machines** closing the control-loop over-the-air
- 5G for **connecting sensors on board** (cameras, etc.) with QoS

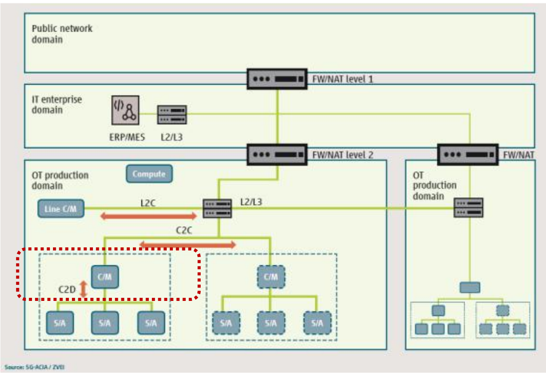
	Characteristic parameters	Max # devices[1]
shuttle, shuttle	• Transfer interval 10..100 ms • message size 256/512 byte	2 / 50
AGV, AGV Root train	• Transfer interval 40..500 ms • message size ≤ 256/512 byte • User-experienced data rate for aperiodic traffic ~15 kbit/s	4 / 450
	• During movement: transfer interval 40..500 ms, message size ≤ 256/512 byte • During operation: transfer interval 1..10/50ms (interaction with active/passive assets); message size ≤ 256/512 byte • User-experienced data rate for aperiodic traffic ~15 kbit/s	4 / 100
	• Tool localization: time to first fix < 1 s; update time of position 100 ms; position accuracy < 1 m	4 / 500

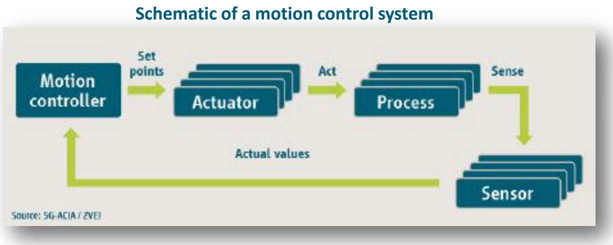
[1]Maximum # devices per 10 m x 10 m / LOS space

Figure 5.8.8 shows the anticipated Industrial 5G use case of motion control[72,73], where 5G is used for wireless communication between the motion controller and its sensors and actuators requiring very low latency of ~1 ms and below, but also requiring high communication service availability (CSA) and Communication Service Reliability (CSR).

FIGURE 5.8.8

Anticipated Industrial 5G Use Case – Motion Control[74]





- Line controller-to-controller (L2C) and controller-to-controller (C2C) communication
- Controller-to-device (C2D) communication

CSA: Communication service availability
CSR: Communication service reliability
MTBF: Mean time between failures

Use case (high level)		CSA (%)	CSR (MTBF)	Transfer interval	Survival time	Message size (byte)	# of devices	Typical service area
Motion Control	Printing machine	>=99.9999	~ 10 years	< 2 ms	2 ms	20 bytes	>100	50 m x 10 m x 10 m
	Machine tool	>=99.9999	~ 10 years	< 0.5 ms	0.5 ms	50 bytes	~20	50 m x 10 m x 10 m
	Packaging machine	>=99.9999	~ 10 years	< 1 ms	1 ms	40 bytes	~50	50 m x 10 m x 10 m

[71] 5G-ACIA, "Industrial Use Cases & Requirements", Web Seminar, July 2020

[72] 5G-ACIA, "Industrial Use Cases & Requirements", Web Seminar, July 2020

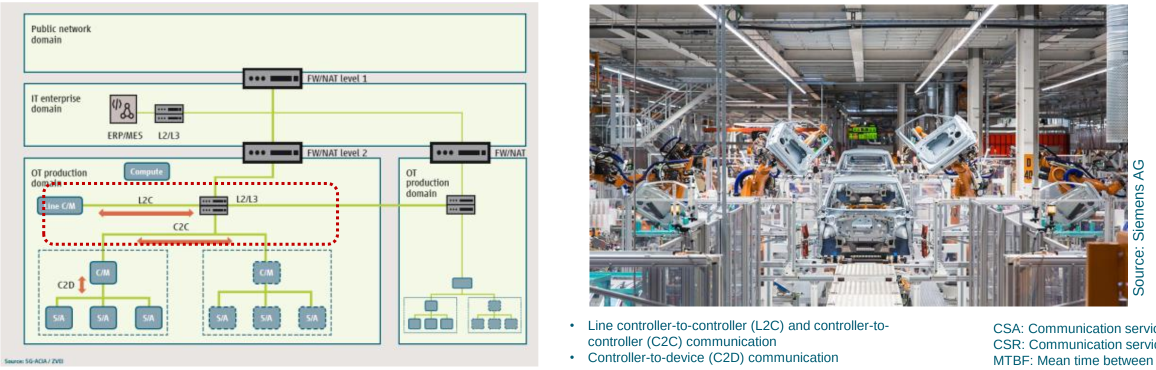
[73] 3GPP TS 22.104, "Service requirements for cyber-physical control applications in vertical domains; Stage 1"

[74] 5G-ACIA, "Industrial Use Cases & Requirements", Web Seminar, July 2020

Figure 5.8.9 shows the anticipated Industrial 5G use case of control-to-control communication[75] , where 5G is used for communication between controllers, for instance, in order to coordinate interaction between the different controlled devices.

FIGURE 5.8.9

Anticipated Industrial 5G use case – Control to Control



- Line controller-to-controller (L2C) and controller-to-controller (C2C) communication
- Controller-to-device (C2D) communication

CSA: Communication service availability
CSR: Communication service reliability
MTBF: Mean time between failures

Use case (high level)		CSA (%)	CSR (MTBF)	Transfer interval	Survival time	Message size (byte)	# of devices	Typical service area
Control to Control	Large Printing machine	≥ 99.9999	~ 10 years	≤ 10 ms	10 ms	1 k	5 to 10	100 m x 30 m x 10 m
	Machines in an assembly line	≥ 99.9999	~ 10 years	≤ 50 ms	50 ms	1 k	5 to 10	1000 m x 30 m x 10 m

21 July 2020 5G Alliance for Connected Industries and Automation 8

Besides the different key performance parameters (KPIs) such as high communication service availability (CSA), low latency, and periodic-deterministic traffic, industrial use cases have also several functional and operational requirements such as:

– Non-public network operation, standalone non-public networks
– Time synchronization
– Support of Time-Sensitive Networking
– Flexible integration with existing industrial communication networks
– Communication service interface/API/network exposure function for operations and management by vertical
– QoS monitoring, network diagnosis
– Positioning.

Several of these functionalities for industrial 5G have been only specified in 3GPP 5G Rel-16 or Rel-17. At the time of writing (May 2022), however, devices for 5G Rel-16/17 with the specific functionalities for industrial 5G have been not available yet. Only when such devices will be available and can be tested in industrial environments und daily operational conditions, it can be seen to what extend 5G can fulfill the requirements of industrial use cases such as presented in the above figures.

[75] 5G-ACIA, "Industrial Use Cases & Requirements", Web Seminar, July 2020

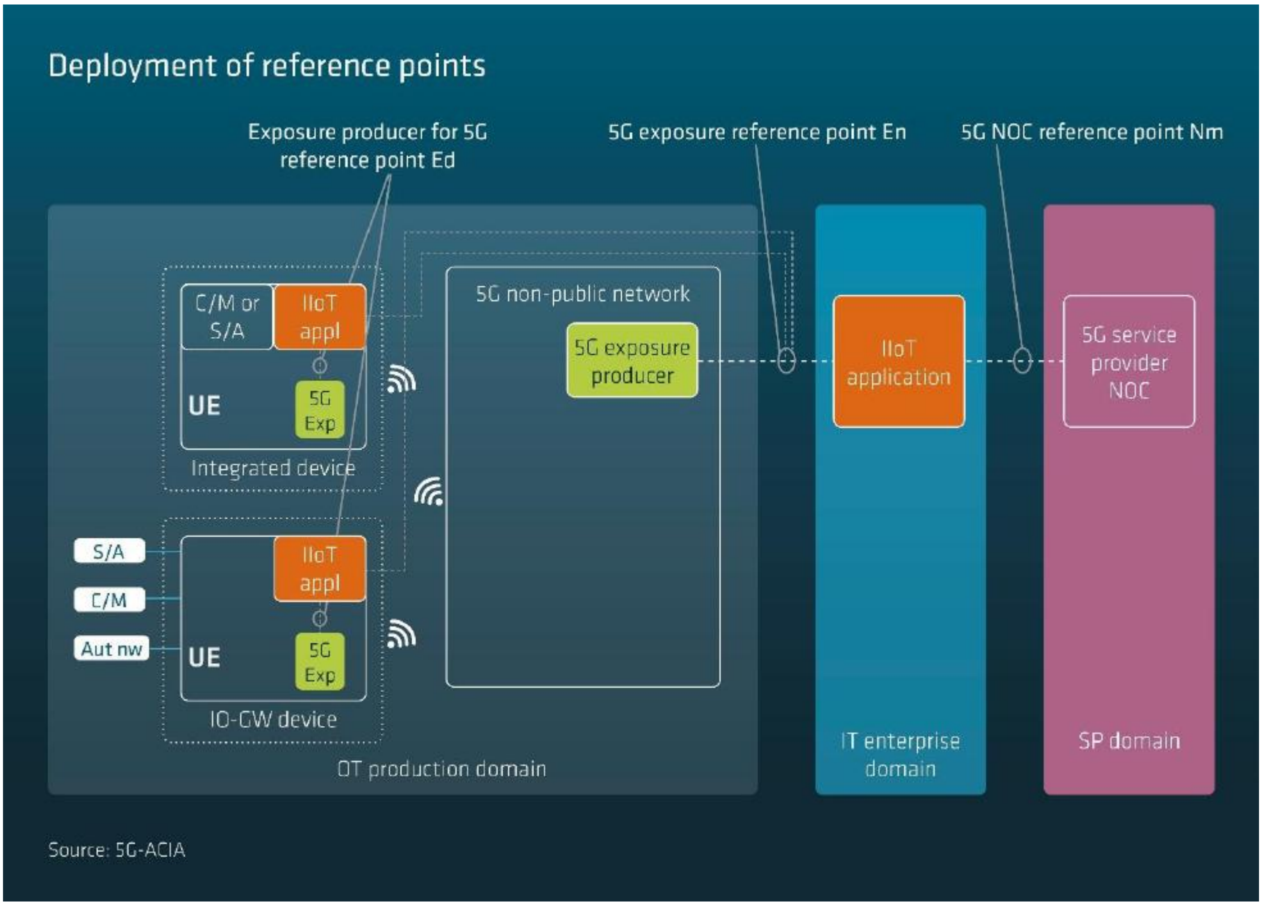
Exposure of 5G network capabilities

The primary role of exposure interfaces is to manage the user plane of a 5G Non-Public Network[76] . The user plane supports the transmission of application data at layers two and/or three of the OSI networking model. IIoT/industrial applications are software entities that consume the services of the 5G exposure interfaces.

The exposed 5G services are integrated with the IIoT applications via industry-compliant reference points. The 5G exposure services are available via two reference points, Ed and En. These reference points are situated between the IIoT application and the 5G system. Ed is the reference point between a UE and an IIoT application, and En is the reference point between the 5G NPN and an IIoT application. The 5G NPN user plane is managed (e.g., connections established, monitored, changed, terminated, etc.) by the services exposed via the reference points.

FIGURE 5.8.10

Deployment of reference points[77]



It should be noted that a 5G NPN can connect to non-3GPP networks, for instance TSN networks; this option is not explicitly shown in Figure 5.8.10.

---

[76] 5G-ACIA, “Exposure of 5G Capabilities for Connected Industries and Automation Applications”, White Paper, February 2021

[77] 5G-ACIA, “Exposure of 5G Capabilities for Connected Industries and Automation Applications”, White Paper, February 2021

The capabilities that a 5G non-public network (5G NPN) must expose towards IIoT applications to enable a range of operational use cases are divided into device management and network management. Exposure of 5G network capabilities allows factory operators to perform frequent (daily) tasks without the need to involve the network operator. These tasks are, for instance, onboarding of devices to the 5G NPN, managing and monitoring device connectivity and monitoring of 5G NPN performance and operational state[78] .

5.9 IMT applications in airports and ports

Major transportation hubs like airports and shipping ports are like small cities with different types of communication needs and use cases. For instance, multiple wireless networks are used in airports – RLAN for consumer and retail data communications, distributed antenna systems (DAS) for in-building cellular services, separate Land Mobile Radio (LMR) systems for public safety communications, etc. Operating multiple networks in a shared environment like airports and ports can be costly for port operators to maintain. Therefore, operators seek a new system to simplify and offer reliable and secure wireless networking services to handle mission-critical operations. While IMT applications in airports and ports share similar goals to improve operational efficiency with more robust cyber security, subtle differences exist.

A key metric in airport operations is aircraft turnaround time at terminals. Airlines effectively rent gates at airports. Hence, quicker turnaround times at terminals equate to higher utilization for the airlines. Moreover, consumers prefer airlines that keep on-time departures and arrivals, so there is a consumer experience benefit also. Multiple operational aspects can impact aircraft turnaround times at terminals, including baggage handling, de-icing, aircraft flight diagnostic download, real-time updates to ground crews, ticketing agents, security personnel, etc. Having reliable and secure networks to support the numerous operational use cases can improve the overall operations at the airport, from air traffic controllers on towers to airline ground crews and security agents. From a consumer perspective, seamless ticketing and baggage handling to a smooth security check-In process enabled on a reliable and secure private network are beneficial.

Automation and worker safety and retention are the key motivation for IMT applications at shipping ports. The world’s largest shipping ports operate 24 (hours) × 7 (days). In this dynamic environment, worker safety is a major concern. Another pain point for port operators is worker retention due to poor working conditions. For example, crane operators work in tight spaces, high above the ground, for an extended period. Remote control of crane operations, container trucks, and other heavy machinery in ports can alleviate these pain points. For instance, with real-time video streaming and analytics, a crane operator may be able to operate multiple lifts and cranes situated at an operations center. As a result, remote operations can increase productivity, save labor costs, and improve worker safety.

Real-time video is critical for port security and remote control operations. Video surveillance is essential to maintaining port security. Real-time video surveillance with computer vision can be used to maintain security control and access. In addition to infrastructure security, real-time video is vital for handling heavy machineries, such as cranes and unmanned container trucks, in remote command and control operations. Private 5G networks promise superior coverage, low latency, and massive machine-type communications with fewer radios than existing RLAN-based meshing

[78] 5G-ACIA, “Exposure of 5G Capabilities for Connected Industries and Automation Applications”, White Paper, February 2021

networks. While existing RLAN and meshing solutions are fine for fixed wireless applications, they are not reliable in dynamically changing mobile environments such as ports.

Drone inspection of port operations is another interesting IMT application found in shipping ports. In addition to drones, video-mounted cranes and containers tagged with sensors are used to track containers to help locate goods (within containers) in ports. Port operators are increasingly called upon to provide visibility of the supply chain to logistics and trucking companies and end customers in an increasingly connected world. As a result, port operators increasingly seek new technology solutions, such as private 5G and video analytics, to gain additional operational efficiency and compete against other port operators worldwide.

Maritime industry and communications

The maritime industry has specific use cases and communication requirements that may not apply to other industries. IMT 5G support can be used to address such specific needs, for example[79]:

- secure mechanisms to associate a UE identity with a vessel identity.
- long communication range
- determining accurate position, heading and speed of UEs, e.g. for maritime emergency requests or assisting other UEs with safety information.
- mechanisms of distributing a maritime emergency requests received from a UE to other UEs on a vessel.

Some use cases are described below[80].

Pilotage service in ports

The use case on pilotage service is to provide shipboard users such as a pilot or a shipmaster and shore-based users such as pilot authorities, pilot organization or bridge personnel the exact information necessary to manoeuvre vessels over IMT systems through pilotage areas such as dangerous or congested waters and harbours or to anchor vessels in a harbour in order to safeguard traffic at sea and protect the environment.

Tug service in ports

A tug is a boat or ship that manoeuvres vessels by pushing or towing them. Tugs move vessels that either should not move by themselves (e.g. vessels passing in a narrow canal, berthing and unberthing operations) or those that cannot move by themselves (e.g. barges, disabled ships, oil platforms). The use case of tug service is described for ship assistance (e.g. mooring), towage (in harbour/ocean), or escort operations to safeguard traffic at sea and protect the environment by IMT systems.

5.10 IMT applications in the agriculture sector

With a global population of almost 8 billion, there is a greater demand for food. In the current environment where agricultural land use per capita is decreasing, the future of farming is “precision agriculture” – i.e., producing more with less. It is all about making farming smart. Amidst the growing strain on natural resources, empowering farmers with smart tools to maximize food production while minimizing the land and water usage is critical. To achieve this goal, farming equipment, such as tractors and IoT sensors for irrigation systems and others, needs to be connected and work in unison for situational awareness of the entire farming and livestock operations.

---

[79] *3GPP TS 22.119 Maritime Communication Services over 3GPP system; Stage 1*

[80] *3GPP TR 22.819 Feasibility Study on Maritime Communication Services over 3GPP system.*

For example, remote monitoring of IoT sensors to check water quality, soil conditions, weather, and other environmental conditions will be critical to determine when to plant, water, and harvest. Another IMT application is to support autonomous farming vehicles, such as connected tractors and trucks, for planting and transporting crops. For example, with improved 5G positioning, autonomous tractors can plant seeds with better precision for higher crop yields. Moreover, video-equipped drones can be employed to monitor the vast farmland and livestock remotely. In addition to connecting connected farm equipment and IoT sensors, wide-area private cellular networks in rural farms can enable voice and data communication among farmworkers in the field and distribution partners.

Smart farming

Smart farming is about the application of data gathering (edge intelligence), data processing, data analysis and automation technologies within the overall agriculture value chain. One of the newest trends in agriculture is using the advancement in IoT technology to make smarter decisions which may lead to reduce farming costs, and boost production.

This Smart farming is something that is already happening, as corporations and farm offices collect vast amounts of information from crop yields, soil-mapping, fertiliser applications, weather data, machinery, and animal health (e.g., animal health data collected from sensors are used for monitoring and early detection of events and health disorders in animals can be prevented).

Two examples are described below[81].

Automated irrigation

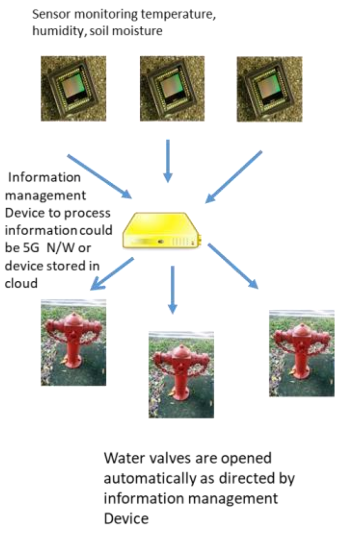
This use case describes a typical example of using 5G networks for supporting smart farming when it comes to data collection and processing of information. Automated irrigation systems contain valves and sensors deployed around the farmland, which is centrally controlled and managed by an information management system.

The information management system, which can be a 5G device or 5G network services, stores and processes the data collected from the sensors. When the soil needs to be irrigated, e.g. the moisture level is low and humidity is also low compared to what was pre-defined. the information management system detects the low soil moisture level and low air humidity from the data collected from the sensor then a trigger is automatically activated to send control messages to open the water valve(s) and allow water to irrigate the soil and increase the level of soil moisture (Figure 5.10.1). At the same time an alert is sent to the farmer to report that the action that has taken place. When the pre-defined level of soil moisture is reached, the sensor(s) report(s) this to the information centre and a trigger is activated to automatically close the water flow. The management information systems will notify the farmer valve has closed.

[81] 3GPP TR 22.804: *Study on Communication for Automation in Vertical Domains*.

FIGURE 5.10.1

Automated irrigation system



Protection against animal poaching

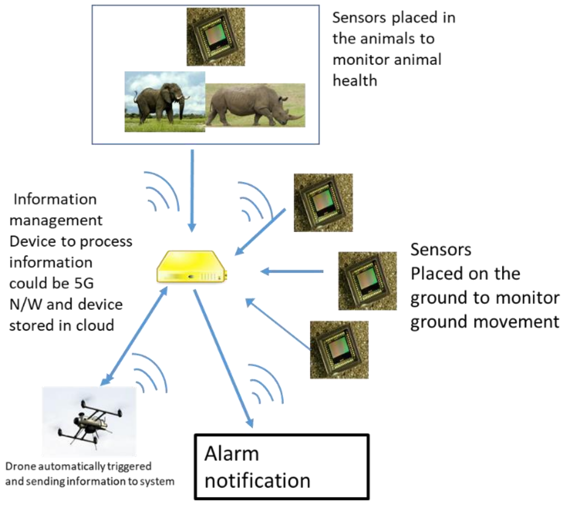
Animal poaching can be a challenging issue in many farming environments. Although armed personnel are deployed to stop poaching, they need to be quick to reach the animals that are being poached and this, in some cases, can be very challenging. With the use of a 5G and automated sensor monitoring, it is possible to quickly detect animals that are being hunted. This will give the rangers a better opportunity to be proactive rather than reactive.

Consider a reserve that has all animals tagged or injected with sensors as shown in the picture below (Figure 5.10.2). These sensors send data to a processing centre, i.e. an information management centre, which can either be deployed in a 3GPP network or a 3GPP device. On a regular basis, sensor data is sent from the animals and from the sensors in the environment to the information management centre. If an animal happens to be in distress, the temperature sensor on animal may indicate an increase in temperature, and sensor pulse data also indicates an increase in pulse rate.

The sensor data from the environment is also collected, and a combination of all the information is processed so that a decision can be made whether to send a drone-based sensor and to take pictures. The data is processed together with the sound that is being picked up in the neighbouring ground sensor to detect if it is another animal that is chasing the distressed animal or it is being chased or chasing another animal. If this sound indicates that it there is an external threat then the sensor automatically initiates a drone or ranger to go view the area. Captured pictures are sent to the information management centre for processing.

FIGURE 5.10.2

5G to support protection against animal poaching



5.11 IMT applications in Gaming

Gaming is a unique vertical that drives innovative usage models, which may not have been previously imaginable and are changing the way wireless services are offered and consumed. Much in the same way that texting services replaced basic SMS and paging services in the early days of IMT, gaming has grown in leaps and bounds in ways unimaginable 20 years ago. Similar sets of innovations may be driven through new usage methods and emerging technologies surrounding gaming.

Democratization of the gaming experience and availability of games for any smartphone user is already making the appealing gaming vertical even more potentially lucrative to the IMT-enabled telco industry. The combination of improvements to network infrastructure, as well as the evolution of the gaming industry ecosystem towards better catering to mobile users, will have the most significant impact for the future of mobile gaming. IMT network improvements will unlock better speeds, throughput, and most importantly, low latency for better mobile gaming. However, what matters more than these network characteristics is the consistency of delivery for ideal gaming experiences.

To appeal to the valuable IMT gaming segment, the industry ecosystem will likely evolve as follows:

– Expanded cloud gaming offering - continuation of gaming on any screen

– Advancements in mobile wearables i.e., VR and augmented and mixed reality (AR/MR)

– High fidelity immersive environments (better graphics, shapes, textures, sound etc.)

– Game creation specifically for IMT mobile device access

– Greater industry collaboration, partnerships, and sponsorship

– IMT gaming focused value bundling, gaming-as-a-service (GaaS) and innovative new business models.

Together, these improvements will create a more dramatic shift to cloud gaming, smoother gameplay, more immersive (VR and AR/MR) and social experiences, as well as refined go-to-market approaches to incentivize IMT gaming.

IMT Technology Considerations for the Gaming Vertical

– **IMT New Radio (NR) architecture**: Gaming performance and experience will improve as telecommunications providers shift from IMT NSA (non-standalone) to IMT SA (standalone) networks. Additionally, there will be enhanced coverage densification provided by mid-band spectrum, and both enhanced speed and coverage from high-band and mmWave spectrum. More specifically, IMT SA's enhanced mobile broadband (eMBB) and Ultra-Reliable and Low Latency Communications (URLLC), will dramatically improve and guarantee speed (reliability of more than 99.999%), throughput and very low latency allowing for next level IMT gaming experience. When it comes to mobile gaming, these advancements could feel like going from the original PlayStation game console to PlayStation 5, leap frogging generations of innovation and creating IMT-enabled high fidelity experiences.

– **Speed:** It can be expected that speed requirements will grow over time, but it will not just be speed itself that matters. Other factors determining the likely minimum speed thresholds may depend on cloud provider, game genre type, resolution requirement, accessories used – as well as impact consistency requirements to enable smooth gameplay. While uploading has traditionally not been as important, the growing popularity of sharing video clips on YouTube™ is starting to change this. Today, games and associated services may require 10-20 Mbit/s, but this could climb to 20-40 Mbit/s or more in the future.

Additionally, the lower the volatility of speeds, the better the end user experience. For example, 10-15 Mbit/s is often better than 10-50 Mbit/s, if data throughput remains stable. Of course, in general, higher and more consistent speeds are ultimately more desirable (e.g., 40-50 Mbit/s is better than 10-15 Mbit/s). Today, game streaming is currently capped at 4K (Google Stadia) but tomorrow this could shift to 8K.

– **Latency**: Network features such as multi-access edge computing, regional cloud, network slicing and QoS will assist in bringing users closer to telco networks, as well as prioritizing gaming traffic for improved latency to better support immersive multiplayer and cloud gaming. Improved latency of less than 20 ms also enables VR/AR gaming experiences.

– **Edge computing**: will be a critical feature for supporting the ultra-low latency and throughput required by IMT gaming as well as VR/AR, especially since most cloud gaming providers have centralized architecture. Paired together, IMT and edge computing will help reduce workload and battery drain on mobile devices and enable a better overall user experience through reduced frame loss and motion-to-photon latency.

As consumer IMT network technical knowledge and understanding grows, expectations will likely shift from simply understanding latency, to knowing how consistently it is delivered (guaranteed), which will make metrics like 'jitter' more important and more commonly understood.

For IMT gamers, pings above 100 ms can impact a player's ability to compete in fast-paced games. While IMT with edge computing should help improve this, high motion-to-photon latency (or simply "lag"), can create a side effect of nausea among some gamers. In a recent experiment with Google Stadia, a tester evaluated the cloud gaming experience on different game genres and determined:

– 1-25 ms no perceived lag, feels native

– 25-100 ms some perceived lag

– 100+ ms noticeable lag.

Given the ‘on the go’ benefit of IMT gaming, coverage will also be a growing consideration for gaming consumers. In particular, ‘availably rate’[82] is a helpful metric that some third-party sources use to measure the proportion of time IMT users spend connected to an active IMT signal.

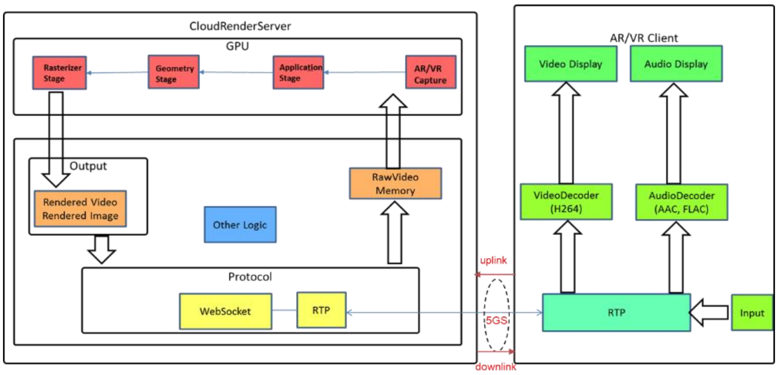
Cloud/Edge/Split Rendering for Gaming

The use of mobile devices for gaming is becoming more and more popular, can be a normal smart phone or AR/VR devices. When playing the game, the sensors within the devices produce some data which is needed to perform rendering computing. Different rendering scenarios exist[83], e.g., rendering may be done exclusively on the device or, all or part of the rendering can be done in the network/cloud.

For cloud rending use case, the user device doesn’t perform rendering computing, but it sends the sensor data in uplink direction to the cloud side in a real time manner. When the cloud side receives the sensor data, it performs rendering computing and produces the multimedia data and then sends back to the user devices for display. The following Figure (Figure 5.11.1) shows the general idea.

FIGURE 5.11.1

Cloud rendering for games



In order to reduce the latency, edge computing can be enabled for the cloud side.

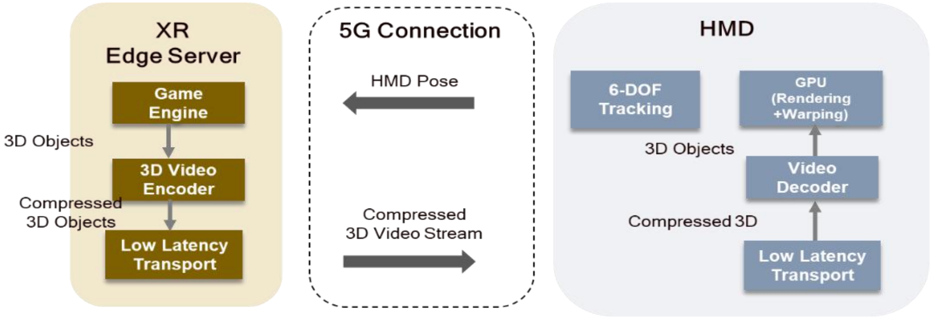
Compared with existing gaming services, cloud gaming is extremely delay and bandwidth sensitive because there is no buffer for the video frame and any non-real time delivery or packet loss will cause discontinuous frame or bad gaming experience. To address some of these challenges, so-called “split” rendering architectures are also possible, where the device is able to do local/partial rendering. One example is shown in Figure 5.11.2.

[82] https://www.opensignal.com/reports/2021/01/usa/mobile-network-experience - Availability rate, as per the OpenSignal US report from January 2021, noted that T-Mobile moved from 22.5% to 30.1%, Verizon moved from 0.4% to 9.5% and AT&T moved from 10.3% to 18.8%.

[83] *3GPP TR 22.842: Study on Network Controlled Interactive Services*

FIGURE 5.11.2

Split Rendering (video streaming case)



The general gaming service flow can be summarized as follows:

1) The game player turns on the 5G device and starts to play the game. The gaming app performs hand-shake with the server side so that end-to-end transportation path of the game related data is established.

2) The cloud rendering server may request 5G network to steer the traffics towards local cloud rendering server in local data network.

3) The sensor data are produced within the user device and these data are sent to the cloud render server via 5G in uplink direction.

4) The cloud rendering server perform rendering and produce multimedia or pre-rendered graphics data.

5) Multimedia or pre-rendered graphics data are sent to the use device in downlink direction.

6) The end use device performs multimedia decoding and potentially post-rendering and then displays the audio-visual viewport.

Transportation of uplink sensor data and downlink multimedia/pre-rendered data has very stringent requirements on packet delay and bandwidth.

Multi-modal haptic gaming

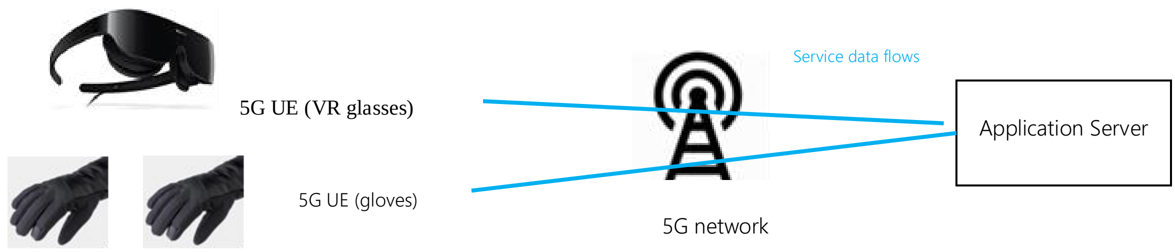
Immersive multi-modal gaming applications may include multiple types of devices such as VR glass, gloves and other potential devices that support haptic and/or kinaesthetic interaction. These devices can be 5G UEs connected to the immersive multi-modal VR application server via the 5G network, see Figure 5.11.3[84].

Based on the service agreement between MNO and immersive multi-modal VR application operator, the application operator may in advance provide the 5G network with the application information including the application traffic characteristics and the service requirement for network connection.

FIGURE 5.11.3

Immersive multi-modal gaming

[84] 3GPP TR 22.847: Study on supporting tactile and multi-modality communication services



In a typical example, the application user utilizes the devices to experience immersive multi-modal VR application. The user powers on the devices to connect to the application server, then the user starts the gaming application. During the gaming running period, the devices periodically send the sensing information to the application server, including haptic and/or kinesthetic feedback signal information, which is generated by haptic device, and the sensing information such as positioning and view information, which is generated by the VR glasses. According to the uplink data from the devices, the application server performs necessary process operations on immersive game reality including rendering and coding the video, the audio and haptic model data, then application server periodically sends the downlink data to the devices, with different time periods respectively, via 5G network. The devices, respectively, receive the data from the application server and present the related sensing including video, audio and haptic to the user.

Gaming Industry Ecosystem

– **Cloud Gaming providers** – IMT network experience improvements will encourage the shift from console / PC gaming to cloud gaming. This trend may lead to greater collaboration between cloud computing and telco providers to enable a better network gaming experience through different technologies like edge computing, as well as increased marketing partnerships[85].

– **Game Developers and Publishers** – The industry is anticipating the development of ‘IMT original’ high fidelity games, which are adapted to the unique requirements of specific mobile devices, such as leveraging the camera, GPS, sensors, as well as the medium itself. It is expected the overall accelerated shift to mobile will change the perception that mobile gaming compromises quality. A comparable example of this change is like how HD and modern special effects have impacted the Hollywood film industry in terms of production quality. Examples of this popularity include “Call of Duty” and “Mario Kart Tour”, which are both major gaming franchises now available on mobile. In addition, the popularity of free-to-play gaming models like the one used in “Candy Crush” are demonstrating the benefit of the mass adoption of mobile play leading to new, profit-driven business models via advertising and in-game purchases.

– **Wearables** – Over the next few years, there will likely be a dramatic progression in wearables, given the substantial improvements in latency. VR will shift to mobile with higher graphic resolution. AR/MR will create immersive gaming experiences through expanded field of view, as well as enable real-time shareable / viewable AR content to facility team experiences. Wearables will essentially create a new 'hardware’ category not unlike the first-generation game consoles of the 1980’s. One example is the Microsoft HoloLens 2, which demonstrates benefits including an increased ability to see

[85] An example of such a partnership is the recent three-year deal Verizon signed for the official IMT network service partnership with Riot Games for League of Legends and Valorant e-sports

more holograms at once through increased field of view, as well as a more refined ergonomic, instinctual, and untethered experience.

– **AR/VR technologies** will be used in gaming applications to immerse players into the heart of a game storyline and provide enticing virtual objects. Due to the more entertaining environment, AR/VR technologies could potentially lead to renewed momentum for outdated games. AR/VR developers can use improved user experience to attract and appeal to gamers in new ways. It is likely that this category will see access to IMT provide an avenue for lower-cost, lighter weight, more comfortable peripherals with better batteries. Better battery life could take the form of improved batteries overall and more efficient devices.

New peripherals will also make it easier to play games on a smartphone, including third-party controllers, VR headsets, and battery packs. Furthermore, through the Internet of Senses, features such as haptics (visceral), spatial (immersive) audio, and smell could eventually make it to the forefront of VR and AR gaming titles. Ultimately, mass adoption of VR/AR will likely be dependent on the quality of the released content, as well as how successful it will be used in other vertical use cases, such as stadium-based entertainment viewing[86].

– **E-Sports** – This rapidly growing sector of the gaming industry will be heavily affected by IMT gaming. Many telcos are partnering with game developers to demonstrate the benefits of their IMT networks through mobile e-sports tournaments. For players, lower latency can result in more wins. When applied to a competitive setting, network characteristics will have to be on a fair playing field like equitable rules/equipment for any other professional sport.

Audiences can also expect better streaming and more immersive experiences provided by VR/AR (with expanded field of views). It is likely that competitive VR/AR multi-player games could grow in popularity for competitive esports, as well. With enhanced fan experiences, increased advertising and sponsorship dollars are likely to follow[87].

– **Gaming Genres** – Existing gaming genres will continue such as: shooting games, sports games, action/adventure games, casual single player & multiplayer games. However, there will likely be developments such as the rise of Massively Multiplayer Online (MMO) games and emergence of new story telling capabilities and new genres like interactive real-world games, given network advancements and improvements in AR. Pokémon Go, a free-to-play, location-based augmented reality game developed by Niantic, has gained growing popularity driven by multi-player and AR features.

– **Advertising** – IMT gaming should in principle be the catalyst for more targeted and relevant in-game advertising. Dynamic in-game advertising (DiGA) will allow brands to create dynamic in-game events more easily and efficiently. In addition, geo-targeted advertising will be more impactful as more customers take gaming on the go. From fast food geo-targeted ads to a branded experience side-missions, there will be greater potential ad revenue from the shift towards cloud-based IMT gaming.

[86] One example of an innovative VR/AR game title was the November 2019 release of Half-Life: Alyx, which ended up being the highest profile VR game, causing sales to soar for all other VR devices, including Facebook's Oculus

[87] Recently, Verizon formed a partnership with Dignitas allowing gamers to train in a state-of-the-art IMT e-sports facility in Los Angeles, CA as part of their IMT Lab.

Emerging Business Models in IMT Gaming

The growth of IMT gaming will foster the growth of Gaming as a Service (GaaS). GaaS allows users to access a game or content (via on-demand streaming) from any device through a recurring revenue model. It offers ways to monetize video games either after their initial sale, or through a free-to-play model. There are a variety of GaaS examples ranging from Massively Multiplayer Online Games (MMOs) which use a monthly subscription, game subscription services like Xbox Game Pass which provide access to a large digital library, cloud gaming like PlayStation Now which allow subscribers to play via remote servers on local devices, microtransactions which profit off low-cost purchases and season passes, which provide large content updates over the course of a season or year.

With the ability to target the desirable IMT gaming segment, there will likely be curated IMT gaming specific packages from telco providers to incentivize purchases. These could take the form of the following:

– Premium packages with abundant data

– Discounted / bundled[88] cloud games with IMT contract

– Bundled wireless and wireline offering.

There will likely be continued growth in marketing partnerships and sponsorships with cloud gaming providers varying from promotion of edge computing and QoS service features, customer loyalty program benefits, branding with game developers, and co-marketing. Many telcos are seeing the advantages of these partnerships for promoting new IMT offerings to the gaming community[89].

5.12 IMT applications in Rail Sector

Over the last 20 years, the ground-to-train communication system has become a core part of railway operations, enabling significant harmonisation and improvement of previously heterogeneous railway services and applications under legacy analogue systems.

The evolution of such system, and its integration with IMT networks, is expected to revolutionize numerous aspects of digitalisation in the Rail sector. Future Railway Mobile Communication System (FRMCS), standardized by 3GPP (in cooperation with UIC and other rail sector stakeholders and authorities), targets to be the future worldwide telecommunication system relying on 5G and Mission-Critical Services (MCX) to support critical communications for rail networks.

One example of those critical communication applications is the Railway Emergency Communication (REC). REC serves two main purposes in railway operation:

[88] Recently, US-based wireless companies have started to aggregate content through discounted digital bundling to differentiate offers, reduce churn, promote IMT usage, and gain consumption data. Verizon offered 12 months of PlayStation Plus and PlayStation Now, starting in late 2020 for IMT customers with select unlimited plans.

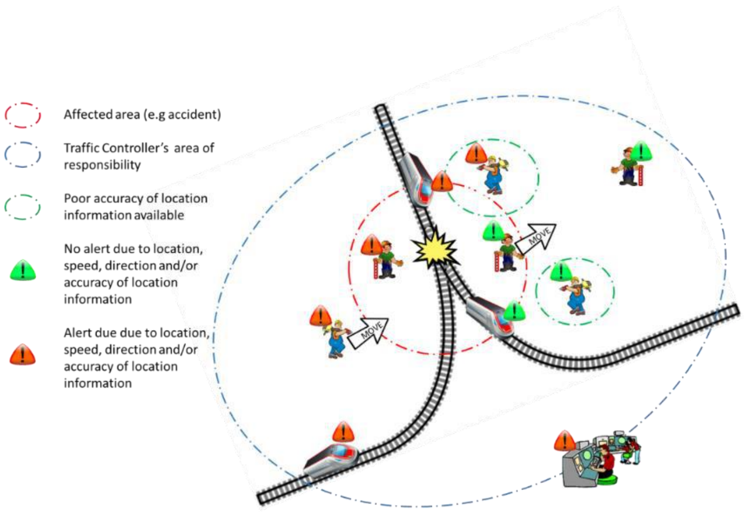
[89] South Korea Telecom (SKT) partnered to provide ‘SKT IMTX Cloud Game’ powered by Microsoft Xbox Game Pass Ultimate in South Korea. The offering included access to more than 100 games in the Xbox Game Pass catalog for approximately US $14.40 per month, which is viewed as both a revenue generator from an existing base, as well as an acquisition tool for gaining new customers. In January 2020, a South Korean cellular carrier also launched a cloud gaming service GeForce NOW (January 2020) in partnership with Nvidia and made accessible on the LG Plus smartphone. As a retention play, it was offered free of charge to customers who had subscribed to its IMT service.

Elsewhere, Verizon’s three-year official IMT network service partnership with Riot Games for League of Legends and Valorant e-sports is expected to provide customers with discounts on League of Legends in-game purchases through the Verizon Up program. In addition, AT&T has worked with ESL to launch ESL Mobile Open an all-year e-sports league.

- Alert Drivers or other railway staff about an emergency. Receiving such alert will result in immediate actions to be taken by the recipients. These actions are defined by operational rules, e.g., a driver will slow down train speed to 40km/h, drive on sight, and
- based on operational rules, additional information about the emergency can be exchanged using voice and/or data communication.

FIGURE 5.12.1

Illustration of FRMCS Users in a railway emergency alert area



Other FRMCS use cases include automated train operation and, in future, fully self-driving trains, which cannot exist without a high-performance, secure telecommunications network. Equally, sophisticated train monitoring systems will not be possible without a high-quality mobile network. Not to mention the remote operation/information or the inevitable use of video support which will be a necessary part of modern rail applications.

Different applications and related use cases are described e.g., in *3GPP TR 22.989*[90] for on-network mode, and *3GPP TR 22.990*[91] for off-network mode. The corresponding requirements are available in e.g., *3GPP TS 22.289*[92] and *3GPP TS 22.280*[93] .

6 Required capabilities of Industrial and Enterprise usages supported by IMT

This section includes the required capabilities for different industrial and enterprise usages. The actual deployments within any specific industrial and enterprise usages may require a combination of eMBB, mMTC and URLLC capabilities. The IMT technologies serve a variety of use cases, often with different service requirements, managed by the system by dynamically allocating the network resources depending on the use case. In the context of the industrial and enterprise usages,

---

[90] 3GPP TR 22.989: *Study on Future Railway Mobile Communication System.*

[91] 3GPP TR 22.990: *Study on Off-Network for Rail.*

[92] 3GPP TS 22.289: *Mobile Communication System for Railway, Stage-1.*

[93] 3GPP TS 22.280: *Mission Critical Services Common Requirements.*

a technical report from India on emerging communication technologies and use cases in IoT Domain[94] discusses the capabilities of IMT.

The rest of this section provides required capabilities as provided by the relevant organizations studying the application of IMT to different usage scenarios. The below table (Table 6) provides a summary of the different usage scenarios :

TABLE 6 : Summary of Tables of this Chapter

Usage Category	**Industrial and Enterprise usage**	**Table**
Community, education (A/V applications)	Low-latency periodic deterministic audio	Table 6-1.1
	Low-latency periodic deterministic audio - presentation use cases	Table 6-1.2
	Low latency video	Table 6-1.3
Factory / Manufacturing	Periodic deterministic communication in factories - performance requirements	Table 6-2.1
	Communication service performance requirements for industrial wireless sensors	Table 6-2.2
	Clock synchronization service performance requirements for factories using for IMT-2020 (5G System)	Table 6-2.3
Gaming	AR/VR rendering and gaming – KPIs	Table 6-3.1
	Multi-modal gaming - service performance requirements	Table 6-3.2
Healthcare	Low latency ultra-reliable imaging/video traffic for medical applications	Table 6-4
Industrial Automation	Use-cases in industrial automation	Table 6-5
Industrial Mining	Required capabilities of use cases in industrial mining	Table 6-6
Rail Communications	Performance requirements for rail scenarios – main line	Table 6-7
Retail	Timing resiliency performance requirements for IMT-2020 (5G System)	Table 6-8.1
	Timing resiliency accuracy KPIs for members or participants of a trading venue	Table 6-8.2
	Performance requirements for Horizontal and Vertical positioning service levels	Table 6-8.3
Utilities	Service performance requirements for Electrical Distribution and Smart Grid	Table 6-9

[94] Emerging Communication Technologies & Use Cases in IoT Domain, Release 2.0, Nov 2021, https://tec.gov.in/pdf/M2M/Emerging%20Communication%20Technologies%20&%20Use%20Cases%20in%20IoT%20domain.pdf.

Community, education (A/V applications)

TABLE 6-1.1

Low-latency periodic deterministic audio[95]

Profile	# of active UEs	UE Speed	Service Area	E2E latency	Transfer interval	Packet error rate	Data rate UL	Data rate DL
Music Festival	200	10 km/h	500 m x 500 m	750 µs	250 µs	10^{-6}	500 kbit/s	-
	100	10 km/h	500 m x 500 m	750 µs	250 µs	10^{-6}	-	1 Mbit/s
Musical	30	50 km/h	50 m x 50 m	750 µs	250 µs	10^{-6}	500 kbit/s	-
	20	50 km/h	50 m x 50 m	750 µs	250 µs	10^{-6}	-	1 Mbit/s
	10	-	50 m x 50 m	750 µs	250 µs	10^{-6}	-	500 kbit/s
Semi-professional	10	5 km/h	5 m x 5 m	750 µs	250 µs	10^{-6}	100 kbit/s	-
	10	5 km/h	5 m x 5 m	750 µs	250 µs	10^{-6}	-	200 kbit/s
	2	-	5 m x 5 m	750 µs	250 µs	10^{-6}	-	100 kbit/s
AV production	20	5 km/h	30 m x 30 m	750 µs	250 µs	10^{-6}	1.5 Mbit/s	-
	10	5 km/h	30 m x 30 m	750 µs	250 µs	10^{-6}	-	3 Mbit/s
Audio Studio	30	-	10 m x 10 m	750 µs	250 µs	10^{-6}	5 Mbit/s	-
	10	5 km/h	10 m x 10 m	750 µs	250 µs	10^{-6}	-	1 Mbit/s

TABLE 6-1.2

Low-latency periodic deterministic audio - presentation use cases [96]

Profile	# of active Ues	UE Speed	Service Area	E2E latency	Transfer interval	Packet error rate	Data rate UL	Data rate DL
Ad hoc	20	5 km/h	300 m x 300 m	4 ms	1 ms	10^{-5}	200 kbit/s	-
	8	stationary	300 m x 300 m	4 ms	1 ms	10^{-5}	-	200 kbit/s
Campus	1000	5 km/h	2 km x 2 km	4 ms	1 ms	10^{-5}	200 kbit/s	-

[95] *TS 22.263: Service requirements for video, imaging and audio for professional applications (VIAPA).*

[96] *TS 22.263: Service requirements for video, imaging and audio for professional applications (VIAPA)*

Profile	# of active Ues	UE Speed	Service Area	E2E latency	Transfer interval	Packet error rate	Data rate UL	Data rate DL
Conference	10	5 km/h	100 m x 100 m	4 ms	1 ms	10^{-5}	1.5 Mbit/s	-
	4	stationary	100 m x 100 m	4 ms	1 ms	10^{-5}	-	1.5 Mbit/s
Lecture room	4	5 km/h	10 m x 10 m	4 ms	1 ms	10^{-5}	50 kbit/s	-
	2	stationary	10 m x 10 m	4 ms	1 ms	10^{-5}	-	50 kbit/s

TABLE 6-1.3

Low latency video[97]

Profile	# of active Ues	UE Speed	Service Area	E2E latency	Packet error rate	Data rate UL	Data rate DL
Uncompressed UHD video	1	0 km/h	1 km^2	400 ms	10^{-10} UL 10^{-7} DL	12 Gbit/s	20 Mbit/s
Uncompressed HD video	1	0 km/h	1 km^2	400 ms	10^{-9} UL 10^{-7} DL	3 .2 Gbit/s	20 Mbit/s
Mezzanine compression UHD video	5	0 km/h	1000 m^2	1 s	10^{-9} UL 10^{-7} DL	3 Gbit/s	20 Mbit/s
Mezzanine compression HD video	5	0 km/h	1000 m^2	1 s	10^{-9} UL 10^{-7} DL	1 Gbit/s	20 Mbit/s
Tier one events UHD	5	0 km/h	1000 m^2	1 s	10^{-9} UL 10^{-7} DL	500 Mbit/s	20 Mbit/s
Tier one events HD	5	0 km/h	1000 m^2	1 s	10^{-8} UL 10^{-7} DL	200 Mbit/s	20 Mbit/s
Tier two events UHD	5	7 km/h	1000 m^2	1 s	10^{-8} UL 10^{-7} DL	100 Mbit/s	20 Mbit/s
Tier two events HD	5	7 km/h	1000 m^2	1 s	10^{-8} UL 10^{-7} DL	80 Mbit/s	20 Mbit/s
Tier three events UHD	5	200 km/h	1000 m^2	1 s	10^{-7} UL 10^{-7} DL	20 Mbit/s	10 Mbit/s
Tier three events HD	5	200 km/h	1000 m^2	1 s	10^{-7} UL 10^{-7} DL	10 Mbit/s	10 Mbit/s
Remote OB	5	7 km/h	1000 m^2	6 ms	10^{-8} UL 10^{-7} DL	200 Mbit/s	20 Mbit/s

[97] *TS 22.263: Service requirements for video, imaging and audio for professional applications (VIAPA)*

Factory/Manufacturing

TABLE 6-2.1

Periodic deterministic communication in factories - performance requirements [98]

Characteristic parameter			**Influence quantity**						
Communication service availability	**reliability: mean time between failures**	**End-to-end latency**	**Msg size [byte]**	**Transfer interval:**	**Survival time**	**UE speed)**	**# of Ues**	**Service area**	**Remarks**
99.999 % to 99.999 99 %	~ 10 years	< transf. interval	50	500 µs	500 µs	≤ 75 km/h	≤ 20	50 x 10 x 10 m	Motion control
99.999 9 % to 99.999 999 %	~ 10 years	< transf. interval	1 k	≤ 10 ms	10 ms	-	5 to 10	100 m x 30 m x 10 m	Control-to-control in motion control
99.999 9 % to 99.999 999 %	~ 10 years	< transf. interval	1 k	≤ 50 ms	50 ms	-	5 to 10	1 kmx30 m x 10 m	Control-to-control in motion control
> 99.999 9 %	~ 10 years	< transf. interval	40 to 250	<50 ms	Transf interval	≤ 50 km/h	≤ 2,000	≤ 1 km^2	Mobile robots
99.999 9 % to 99.999 999 %	~ 1 month	< transf. interval	40 to 250	4 to 8 ms	Transf interval	< 8 km/h)	TBD	50 x 10 x 4 m	Mobile control panels
99.999 9 % to 99.999 999 %	≥ 1 year	< transfer interval value	20	≥ 10 ms	0	typically stationary	typically 10 to 20	≤ 100 m x 100 m x 50 m	Process automation
99.999 %	TBD	~ 50 ms	~ 100	~ 50 ms	TBD	stationary	≤ 100,000	up to 100,000 km^2	Primary frequency control
> 99.999 9 %	~ 1 year	< transfer interval value	15 k to 250 k	10 to 100 ms	transfer interval value	≤ 50 km/h	≤ 2,000	≤ 1 km^2	Mobile robots – video-operated
> 99.999 9 %	~ 1 year	< transfer interval value	40 to 250	40 to 500 ms	transfer interval value	≤ 50 km/h	≤ 2,000	≤ 1 km^2	Mobile robots
99.99 %	≥ 1 week	< transfer interval value	20 to 255	< 60 s	≥ 3 x transfer interval	typically stationary	≤ 10,000 to 100,000	≤ 10 km x 10 km x 50 m	Plant asset management

98 *TS 22.104: Service requirements for cyber-physical control applications in vertical domains*

TABLE 6-2.2

Communication service performance requirements for industrial wireless sensors [99]

Characteristic parameter						Influence quantity					
Communica-tion service availability: target value	**reliability: mean time between failure**	**End-to-end latency**	**Transf interval**	**Service bit rate: user experienced data rate**	**Battery lifetime [year]**	**Message Size [byte]**	**Survival time**	**UE speed**	**UE density [UE / m²]**	**Range [m]**	**Remarks**
99.99 %	≥ 1 week	< 100 ms	100 ms to 60 s	≤ 1 Mbit/s	≥ 5	20	3 x transfer interval	Stationary	Up to 1	< 500	Process monitoring, e.g. temperature sensor (A.2.3.2)
99.99 %	≥ 1 week	< 100 ms	≤ 1 s	≤ 200 kbit/s	≥ 5	25 k	3 x transfer interval	Stationary	Up to 0.05	< 500	Asset monitoring, e.g. vibration sensor (A.2.3.2)
99.99 %	≥ 1 week	< 100 ms	≤ 1 s	≤ 2 Mbit/s	≥ 5	250 k	3 x transfer interval	Stationary	Up to 0.05	< 500	Asset monitoring, e.g. thermal camera (A.2.3.2)

TABLE 6-2.3

Clock synchronization service performance requirements for factories using IMT-2020 (5G)[100]

User-specific clock synchronicity accuracy level	Number of devices in one communication group for clock synchronisation	5GS synchronicity budget requirement	Service area	Scenario
1	up to 300 UEs	≤ 900 ns	≤ 100 m x 100 m	Motion control Control-to-control communication for industrial controller
2	up to 300 UEs	≤ 900 ns	≤ 1,000 m x 100 m	Control-to-control communication for industrial controller

[99] *TS 22.104: Service requirements for cyber-physical control applications in vertical domains*

[100] *TS 22.104: Service requirements for cyber-physical control applications in vertical domains*

Gaming

TABLE 6-3.1

AR/VR rendering and gaming – KPIs [101]

Use Cases	Characteristic parameter (KPI)			Influence quantity		
	Max allowed end-to-end latency	**Service bit rate: user-experienced data rate**	**Reliability**	**# of UEs**	**UE Speed**	**Service Area**
Cloud/Edge/Split Rendering	**5 ms (i.e. UL+DL between UE and the interface to data network)**	0,1 to 1 Gbit/s supporting visual content (e.g. VR based or high definition video) with 4K, 8K resolution and up to120 frames per second content.	**99,99 % in uplink and 99,9 % in downlink**	**-**	Stationary or Pedestrian	Countrywide
Gaming or Interactive Data Exchanging	**10ms**	0,1 to 1 Gbit/s supporting visual content (e.g. VR based or high definition video) with 4K, 8K resolution and up to120 frames per second content.	**99,99 %**	**≤ 10**	Stationary or Pedestrian	20 m x 10 m; in one vehicle (up to 120 km/h) and in one train (up to 500 km/h)

101 *TS 22.261: Service requirements for next generation new services and markets*

TABLE 6-3.2

Multi-modal gaming – service performance requirements[102]

Use Cases	**Characteristic parameter (KPI)**			**Influence quantity**			**Remarks**
	Max allowed end-to-end latency	**Service bit rate: user-experienced data rate**	**Reliability**	**Message size (byte)**	**UE Speed**	**Service Area**	
Immersive multi-modal VR (UL: device → application sever)	5 ms	16 kbit/s -2 Mbit/s (without haptic compression encoding); 0.8 - 200 kbit/s (with haptic compression encoding)	99.9% (without haptic compression encoding) 99.999% (with haptic compression encoding)	1 DoF: 2-8 3 DoFs: 6-24 6 DoFs: 12-48	Stationary or Pedestrian	typically < 100 km^2	Haptic feedback
	5 ms	< 1Mbit/s	99.99%	1500	Stationary or Pedestrian	typically < 100 km^2	Sensing information e.g. position and view by VR glasses
Immersive multi-modal VR (DL: application sever → device)	10 ms	1-100 Mbit/s	99.9%	1500	Stationary or Pedestrian	typically < 100 km^2	Video
	10 ms	5-512 kbit/s	99.9%	50	Stationary or Pedestrian	typically < 100 km^2	Audio
	5 ms	16 kbit/s -2 Mbit/s (without haptic compression encoding); 0.8 - 200 kbit/s (with haptic compression encoding)	99.9% (without haptic compression encoding) 99.999% (with haptic compression encoding)	1 DoF: 2-8 3 DoFs: 6-24 6 DoFs: 12-48	Stationary or Pedestrian	typically < 100 km^2	Haptic feedback

102 *TS 22.261: Service requirements for next generation new services and markets*

Healthcare

TABLE 6-4

Low latency ultra-reliable imaging/video traffic for medical applications[103]

Profile	Characteristic parameter					Influence quantity				
	availability: target value in %	**reliability: Mean Time bw Failure**	**End-to-end latency**	**Bit rate**	**Direction**	**Message Size [byte]**	**Survival time**	**UE speed (km/h)**	**# of active UEs Connection**	**Service Area**
UHD medical video over NPNs	>99.99999	>1 year	<1 ms	< 50 Gbit/s	UL; DL	~1500 - ~9000	~8ms	stationary	1	100 m2
Ultrasound images over NPNs	>99.9999	>1 year	<10ms	500 Mbit/s - 4 Gbit/s	UL; DL	~1500	20-100 ms	stationary	1	100 m2
UHD video telesurgery over PLMNs	>99.9999	>1 year	< 20 ms	< 6 Gbit/s	UL; DL	~1500 - ~9000	~16 ms	stationary	<2 per 1000 km^2	<400 km
UHD video for medical exam over PLMNs	>99.99	>1 month	<20 ms	<4 Gbit/s	UL; DL	~1500 - 9000	~16 ms	stationary	<20 per 100 km2	<50 km
Ultrasound images over PLMNs	>99.999	>>1 month (<1 year)	<20 ms	<200 Mbit/s	UL; DL	~1500	~16 ms	stationary	<20 per 100 km2	<50 km
CT/MR real time scan over PLMNs	>99.999	>>1 month (<1 year)	< 100ms	<670 Mbit/s	UL, DL	~1500	<100 ms	<150	<20 per 100 km^2	<50 km

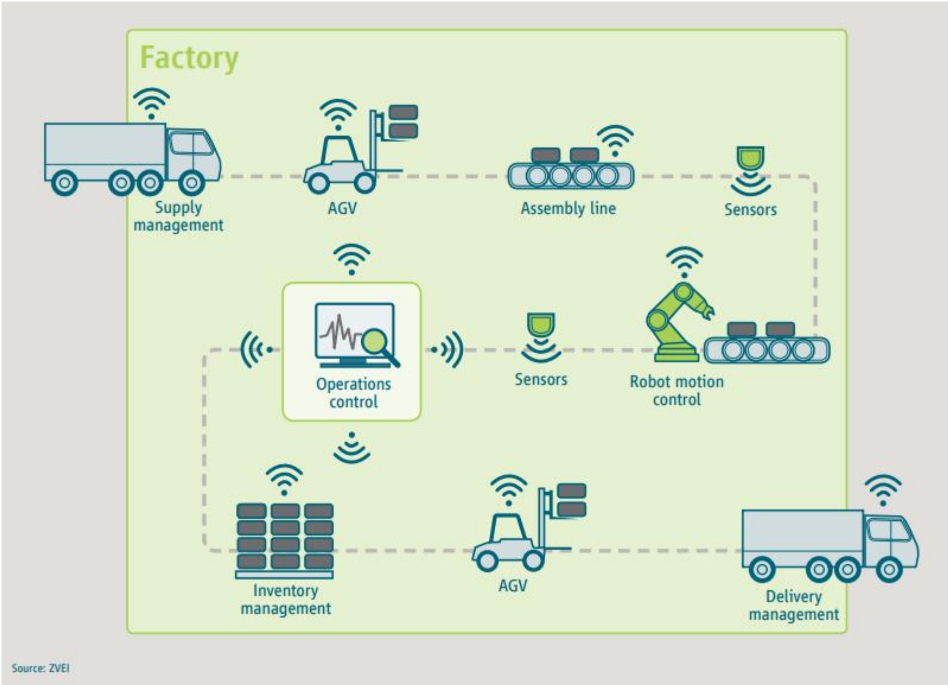
Industrial Automation

As per 5G-ACIA there may be different traffic model categories in a factory floor that address the use-cases. According to 5G-ACIA, there are diverse use cases with varying demands on the communications networks. These have been prioritized and described in 3GPP TS 22.104 Annex 2. The traffic model addresses the use cases encountered in factory and process automation, human-machine interfaces and production IT, logistics and warehousing, and monitoring & maintenance, as shown in figure (Figure 6.1) below.

[103] *TS 22.263: Service requirements for video, imaging and audio for professional applications (VIAPA)*

FIGURE 6.1

Wireless components in the Smart Factory



The Table below depicts a typical industrial automation requirement projected by 5G-ACIA[104].

TABLE 6-4

Use-cases in industrial automation

Use case (high level)		**Availability**	**Cycle Time (Interval time)**	**Typical payload size**	**No. of devices**	**Typical service area**
Motion Control	Printing machine	>99.9999%	< 2 ms	20 bytes	>100	100 m × 100 m × 30 m
	Machine tool	>99.9999%	< 0.5 ms	50 bytes	~ 20	15 m × 15 m × 3 m
	Packing machine	>99.9999%	< 1 ms	40 bytes	~ 50	10 m × 5 m × 3 m
Mobile robots	Cooperative motion control	>99.9999%	1 ms	40 – 250 bytes	100	< 1 km^2
	Video-operated remote control	>99.9999%	10 – 100 ms	15 – 150 kbytes	100	< 1 km^2
Mobile control panels with safety functions	Assembly robots or milling machines	>99.9999%	4 – 8 ms	40 – 250 bytes	4	10 m × 10 m
	Mobile cranes	>99.9999%	12 ms	40 – 250 bytes	2	40 m × 60 m
Process automation (process monitoring)		>99.99%	> 50 ms	Varies	10 000 devices per km^2	

[104] 5G-ACIA white paper. https://www.5g-acia.org/fileadmin/5G-ACIA/Publikationen/Whitepaper_5G_for_Connected_Industries_and_Automation/WP_5G_for_Connected_Industries_and_Automation_Download_19.03.19.pdf.

A successful roll-out of an IMT based factory automation will also require performance testing[105] of the wireless connectivity and interfaces in actual deployment environments.

3GPP IMT-2020 (5G) service-level performance requirements

Different IMT-2020 (5G) capabilities and requirements are needed to support specific industrial applications and use cases. A set of performance requirements identified for some of the categories described in sec. 5 are summarized below.

Industrial Mining

The production environment and intelligent transformation requirements of mining provide more stringent required capabilities for IMT system in terms of round-trip time (RTT), number of connected devices, required capabilities of uplink, positioning accuracy, as well as stability, security, etc. Considering safety of communications and the actual mining environment, etc. the required capabilities of use cases in industrial mining are as follows:

TABLE 6-6 [106]

Required capabilities of use cases in industrial mining

Use cases in industrial mining		**RTT(ms)**	**No. of connected devices per cell/typical requirements**	**Required capabilities of uplink**		
				Peak data rate per user/device	**Average capacity of cell**	**Edge data rate per user/device**
Intellectual production and inspection	Remote monitoring and control(e.g. remote centralized control of tunnelling machine and coal cutter)	<100 ms	50 devices	lower		
	Video surveillance (e.g. high-definition video transmission in mining focusing on remote control)	<100 ms	30~40 cameras(4k)，（range: 240m of fully mechanized mining face）	20 Mbit/s	0.8 Gbit/s	10 Mbit/s
Comprehensive sensing	State sensing(e.g. environmental monitoring and safety protection of sensor devices, including the detection of human health, environment, and working devices status)	<1000 ms	>100 devices	Lower		
	Video sensing(e.g. the video sensing of transport transhipment point and transport yard focusing on the fault monitoring)	<100 ms	Several cameras(fixed and mobile) (range: 200 m of tunnel)	10 Mbit/s	0.3 Gbit/s	5 Mbit/s

[105] https://5g-acia.org/wp-content/uploads/2021/04/5G-ACIA_PerformanceTestingOf5GSystemsForIndustrialAutomation-1.pdf.

[106] CMCC, HUAWEI. The value of uplink capability of 5G in industry digitization, 2020, http://www-file.huawei.com/-/media/CORP2020/pdf/download/Values_of_5G_Uplink_Capabilities_in_Industry_Digitalization.pdf

Use cases in industrial mining		RTT(ms)	No. of connected devices per cell/typical requirements	Required capabilities of uplink		
				Peak data rate per user/device	**Average capacity of cell**	**Edge data rate per user/device**
	Location sensing(e.g. the positioning of people, automated vehicles and working devices in mining)	<100 ms	Sub-meter level positioning accuracy	Lower		
Real-time interconnection	Instant communication and tele-diagnosis(e.g. based on the wireless equipment to satisfy the rapid diagnosis of different locations in intelligent operation and maintenance)	<100 ms	Voice: 10 groups Video: 3-5 groups	10 Mbit/s	0.2 Gbit/s	5 Mbit/s

Rail communications

TABLE 6-7

Performance requirements for rail scenarios – main line [107]

Scenario	End-to-end latency	Reliability	Speed limit	User experienced data rate	Payload size	Area traffic density	Service area dimension
Voice Communication for operational purposes	≤100 ms	99,9%	≤500 km/h	100 kbit/s up to 300 kbit/s	Small	Up to 1 Mbit/s/line km	200 km along rail tracks
Critical Video Communication for observation purposes	≤100 ms	99,9%	≤500 km/h	10 Mbit/s	Medium	Up to 1 Gbit/s/km	200 km along rail tracks
Very Critical Video Communication with direct impact on train safety	≤100 ms	99,9%	≤500 km/h	10 Mbit/s up to 20 Mbit/s	Medium	Up to 1 Gbit/s/km	200 km along rail tracks
	≤10 ms	99,9%	≤40 km/h	10 Mbit/s up to 30 Mbit/s	Medium	Up to 1 Gbit/s/km	2 km along rail tracks urban or station
Standard Data Communication	≤500 ms	99,9%	≤500 km/h	1 Mbit/s up to 10 Mbit/s	Small to large	Up to 100 Mbit/s/km	100 km along rail tracks
Critical Data Communication	≤500 ms	99,9999 %	≤500 km/h	10 kbit/s up to 500 kbit/s	Small to medium	Up to 10 Mbit/s/km	100 km along rail tracks

[107] *TS 22.289: Mobile Communication System for Railway, Stage-1*

Scenario	End-to-end latency	Reliability	Speed limit	User experienced data rate	Payload size	Area traffic density	Service area dimension
Very Critical Data Communication	≤100 ms	99,9999 %	≤500 km/h	100 kbit/s up to 1 Mbit/s	Small to Medium	Up to 10 Mbit/s/km	200 km along rail tracks
	≤10 ms	99,9999 %	≤40 km/h	100 kbit/s up to 1 Mbit/s	Small to Medium	Up to 100 Mbit/s/km	2 km along rail tracks
Messaging	-	99.9%	≤500 km/h	100 kbit/s	Small	Up to 1 Mbit/s/km	2 km along rail tracks

Retail

TABLE 6-8.1

Timing resiliency performance requirements for IMT-2020 (5G) System [108]

Use case	Holdover time	Sync target	Sync accuracy	Service area	Mobility	Remarks
Power grid ((IMT-2020 (5G) network)	Up to 24 hour	UTC	<250 ns to1000 ns	< 20 km^2	low	When IMT-2020 (5G) System provides direct PTP Grandmaster capability to sub-stations
Power grid (time synchronization device)	>5 s	UTC	<250 ns to1000 ns	< 20 km^2	low	When IMT-2020 (5G) sync modem is integrated into PTP grandmaster solution (with 24h holdover capability at sub-stations)

TABLE 6-8.2

Timing resiliency accuracy KPIs for members or participants of a trading venue [109]

Type of trading activity	Maximum divergence from UTC	Granularity of the timestamp
Activity using high frequency algorithmic trading technique	100 µs	≤1 µs
Activity on voice trading systems	1 s	≤1 s
Activity on request for quote systems where the response requires human intervention or where the system does not allow algorithmic trading	1 s	≤1 s
Activity of concluding negotiated transactions	1 s	≤1 s

[108] *TS 22.261: Service requirements for next generation new services and markets*

[109] *TS 22.261: Service requirements for next generation new services and markets*

Any other trading activity	1 ms	≤1 ms

TABLE 6-8.3

Performance requirements for Horizontal and Vertical positioning service levels [110]

Positioning service level	Absolute(A) or Relativel positioning	Accuracy (95 % confidence level)		Positioning service availability	Positioning service latency	Coverage, environment of use and UE velocity		
		Horizontal Accuracy	Vertical Accuracy			IMT-2020 (5G) positioning service area	IMT-2020 (5G) enhanced positioning service area	
							Outdoor and tunnels	Indoor
1	A	10 m	3 m	95 %	1 s	Indoor - up to 30 km/h Outdoor (rural and urban) up to 250 km/h	NA	Indoor - up to 30 km/h
2	A	3 m	3 m	99 %	1 s	Outdoor (rural and urban) up to 500 km/h for trains and up to 250 km/h for other vehicles	Outdoor (dense urban) up to 60 km/h Along roads up to 250 km/h and along railways up to 500 km/h	Indoor - up to 30 km/h
3	A	1 m	2 m	99 %	1 s	Outdoor (rural and urban) up to 500 km/h for trains and up to 250 km/h for other vehicles	Outdoor (dense urban) up to 60 km/h Along roads up to 250 km/h and along railways up to 500 km/h	Indoor - up to 30 km/h
4	A	1 m	2 m	99,9 %	15 ms	NA	NA	Indoor - up to 30 km/h
5	A	0,3 m	2 m	99 %	1 s	Outdoor (rural) up to 250 km/h	Outdoor (dense urban) up to 60 km/h Along roads and along railways up to 250 km/h	Indoor - up to 30 km/h
6	A	0,3 m	2 m	99,9 %	10 ms	NA	Outdoor (dense urban) up to 60 km/h	Indoor - up to 30 km/h
7	R	0,2 m	0,2 m	99 %	1 s	Indoor and outdoor (rural, urban, dense urban) up to 30 km/h Relative positioning is between two UEs within 10 m of each other or between one UE and IMT-2020 (5G) positioning nodes within 10 m of each other		

110 TS 22.261: *Service requirements for next generation new services and markets.*

Utilities

TABLE 6-9

Service performance requirements for Electrical Distribution and Smart Grid [111]

Characteristic parameter			**Influence quantity**				
Communication service availability: target value [%]	**Communication service reliability: mean time between failures**	**End-to-end latency: maximum**	**Message size [byte]**	**Transfer interval: target value**	**Survival time**	**# of UEs**	**Service area**
Primary Frequency Control (Centralized and Decentralized Control)							
99.999	TBD	~ 50 ms	~ 100	~ 50 ms	TBD	≤ 100,000	several km^2 up to 100,000 km^2
Distributed Voltage Control							
99.999	TBD	~ 100 ms	~ 100	~ 200 ms	TBD	≤ 100,000	several km^2 up to 100,000 km^2
Distributed automated switching for isolation and service restoration: Typically event-driven, aperiodic deterministic communication service supporting fault detection and isolation.							
> 99.999 %	-	20 ms	-	< 100	-	-	stationary
Intelligent Distributed Feeder Automation							
99.999	–	Normal: 1 s; Fault: 2 ms	-	Normal: 1 s; Fault: 2 ms	–	–	54-78/km^2
High speed current differential protection Automation (stationary UE, Decentralized Control)							
> 99.999	-	5-15 ms	< 245	≤ 1 ms	transfer interval (one frame loss)	≤ 100/km^2	several km^2
Smart grid millisecond-level precise load control							
99.999 9	–	< 50 ms	< 100	n/a	-	10 km^{-2} to 100 km^{-2}	TBD
Distributed Energy Storage (stationary UE)							
> 99.9	-	DL: < 10 ms UL: < 10 ms	UL: 800 kbyte	UL: 10 ms	-	> 10/km2 (urban); > 100/km2 (rural)	several km2
Central Power Generation							
99.999 999 9	~ 10 years	16 ms	-	≤ 1 ms	-	-	Several km^2

Editor's note: The document was reviewed and the edits/updates were accepted up to this point. The meeting will start review of the material of Section 7, 8, 9 and Annexes during 43rd meeting of WP5D.

[111] TS 22.104: *Service requirements for cyber-physical control applications in vertical domains.*

7 Technical and operational aspect of industrial and enterprise usages supported by IMT

The 3GPP NR RIT represents the releases 15 and 16 of NR, which uses either 1) FDD operation and therefore is applicable for operation with paired spectrum or 2) TDD operation and therefore is applicable for operation with unpaired spectrum.

Channel bandwidths up to 400 MHz and Carrier Aggregation over 16 component carriers are supported, yielding peak data rates up to roughly 140 Gbit/s or Gbit/s in the downlink and 65 Gbit/s or Gbit/s in the uplink.

For optimal support of specific verticals, the NR RIT has been designed, or enhanced, with certain key features, to support Ultra-Reliable and Low Latency Communications (URLLC) and Industrial IoT (IIoT).

A short summary of these capabilities is listed below:

– Logical Channel Priority (LCP) restrictions
– Packet duplication with DC or CA
– New QCI table for block error rate 10^{-5}
– Physical layer short transmission time interval (TTI)
– NR PDCP duplication enhancements,
– Prioritization/multiplexing enhancements,
– NR Time Sensitive Communications (TSC) related enhancements, e.g. Ethernet header compression,
– Precise time information delivery, and
– in-band coexistence with NB-IoT and eMTC.

In 3GPP Rel-16, spectral efficiency is increased further for massive-MTC transmissions and reduced energy consumption for massive-MTC devices enabled e.g. uplink transmission using preconfigured resources in idle mode (allowing the device to skip random access procedures) and multi-transport-block scheduling in both the DL and UL transmission directions (reducing the control signalling overhead).

The key capabilities to support industrial applications are summarized below.

7.1 Non-public networks

Non-Public Networks (NPN)[112] refers to a network that is intended for non-public use using 3GPP technology. It could be exclusively used by a private entity such as an industry enterprise and could utilize both virtual and physical elements and be deployed in different type of configurations. A Non-Public Network (NPN) enables deployment of IMT-2020 (5G System) for private use. An NPN may be deployed as:

1 Stand-alone Non-Public Network (SNPN): SNPN is operated by an NPN operator and doesn't rely on the network functions provided by a Public Land Mobile Network (PLMN) owned by mobile network operator (MNO). An NPN operator could be the enterprise itself or a 3rd party. An NPN operator has full control and management capability on the network functions provided by SNPN.

112 3GPP 5G for Industry 4.0, https://www.3gpp.org/news-events/2122-tsn_v_lan.

2 Public network integrated Non-Public Network (PNI-NPN): PNI-NPN is an NPN deployed with the support from a public network. Based on the contract between the MNO and enterprise, the MNO could provide network resources extracted from the public network for the enterprise to use.

Non-Public Networks (NPN)[113] refers to a private network that is intended for non-public use using 3GPP technology. It could be exclusively used by a private entity such as an industry enterprise and could utilize both virtual and physical elements and be deployed in different type of configurations. A Non-Public Network (NPN) enables deployment of IMT-2020 (5G System) for private use. An NPN may be deployed as:

Stand-alone Non-Public Network (SNPN): SNPN is operated by an NPN operator and doesn't rely on the network functions provided by a Public Land Mobile Network (PLMN) owned by mobile network operator (MNO). An NPN operator could be the enterprise itself or a 3rd party[114]. An NPN operator has full control and management capability on the network functions provided by SNPN.

In terms of physical deployment, the term non-public Network refers to networks with radio, core, and transmission resources dedicated to the enterprise and – crucially – under the control of the enterprise. This typically means that at least part of the network equipment will be deployed on the customer premises, regardless of which party manages it day-to-day.

Some options[115] to deploy and operate Non-public Networks are described below :

(1) Standalone non-public network (isolated deployment)

In this option, the NPN is deployed as an independent, standalone network. All network functions are located inside the logical or physical perimeter of the defined premises (e.g., factory) and the NPN is separate from the public network. Standalone NPNs can be deployed in a locally licensed spectrum, unlicensed spectrum or using spectrum licensed by an MNO.

FIGURE 7.1.1

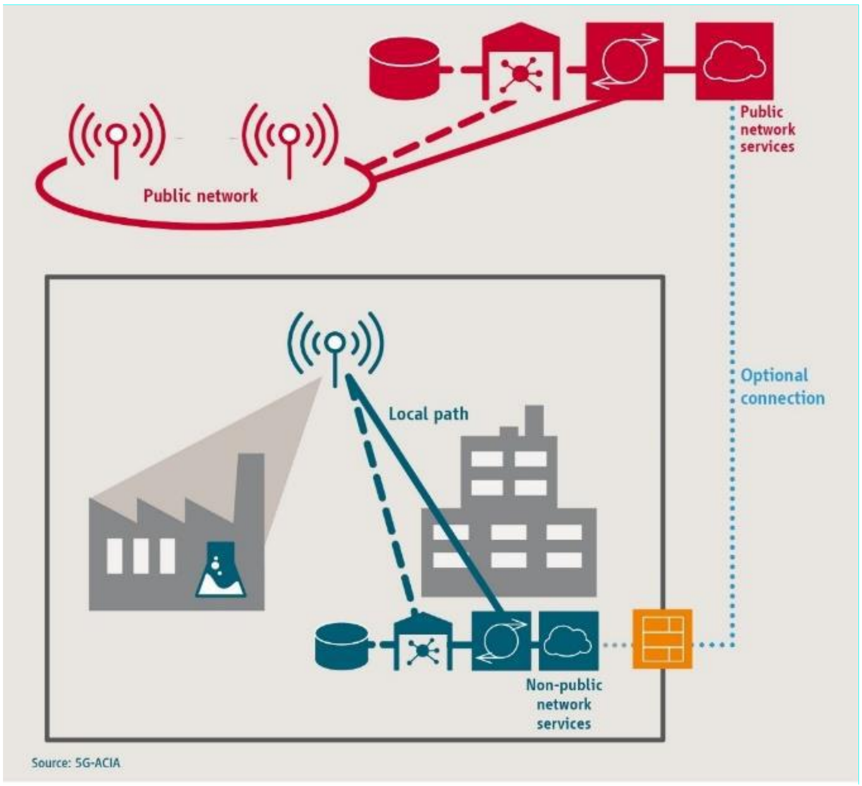
Deployment as standalone non-public network / isolated deployment

[NOTE: The figure (Figure 7.1.1) below shows a standalone non-public network with physically isolated deployment. Optionally, the deployment could also be logically isolated. In addition, as shown in the Figure below, the connection to public communication network is also optional.]

[113] 3GPP 5G for Industry 4.0, https://www.3gpp.org/news-events/2122-tsn_v_lan.

[114] A 3rd party could be any SNPN provider which can work with the SNPN spectrum allocation or offer its own spectrum as per regulatory rules.

[115] https://5g-acia.org/wp-content/uploads/2021/04/WP_5G_NPN_2019_01.pdf

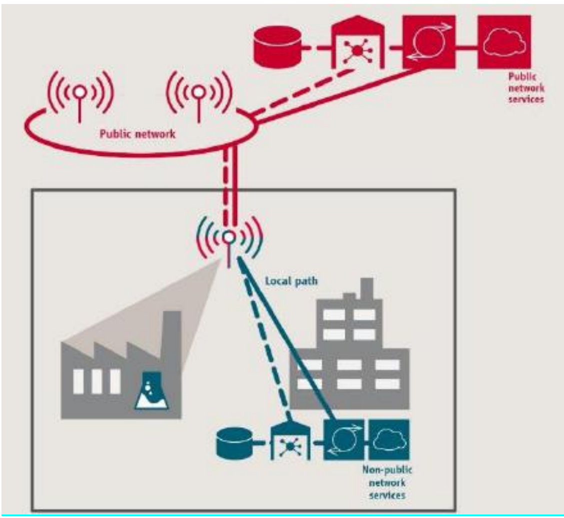


(2) Shared radio access network

In this option, the NPN and the public network share part of the radio access network, while other network functions remain segregated. All data flows related to the NPN traffic portion are within the logical perimeter of the defined premises, e.g., factory, and the public network traffic portion is transferred to the public network. 3GPP specifications include functionality that enables RAN sharing.

FIGURE 7.1.2

Deployment with shared RAN

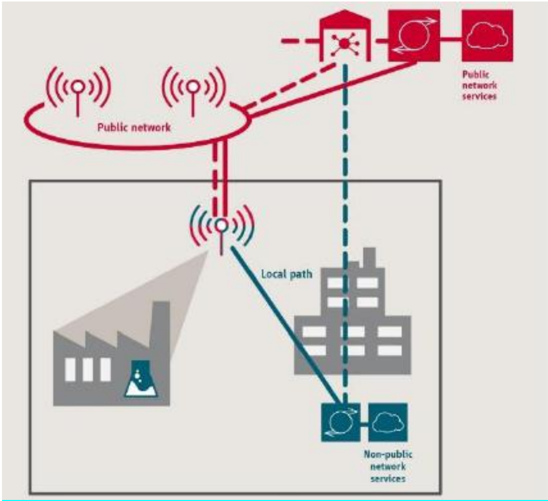


(3) Shared radio access network and control plane

In this option, the NPN and the public network share the radio access network for the defined premises, and network control tasks can be performed in the public network. Nevertheless, all NPN traffic flows remain within the logical perimeter of the defined premises, while the public network traffic portion is transferred to the public network.

FIGURE 7.1.3

Deployment with shared RAN and control plane

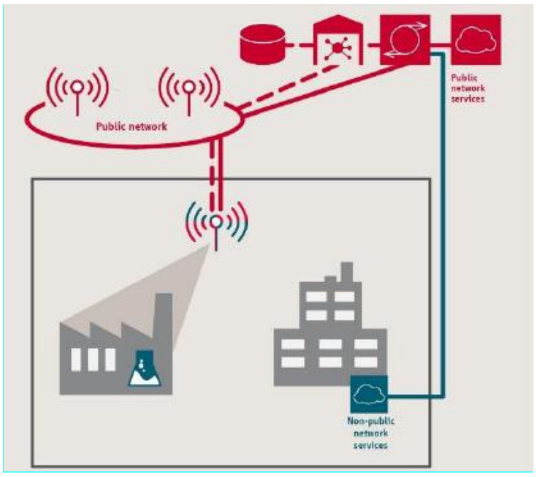


(4) NPN hosted by the public network (e.g., by means of network slicing)

In this scenario, both the public network traffic portion and the NPN traffic portion are external to the defined premises but treated as if they were parts of completely different networks. This is achieved through virtualisation of network functions in a (generic) cloud environment. These functions can then be used for both public and for non-public network purposes. User Plane and parts of the control plane can be deployed in a factory.

FIGURE 7.1.4

NPN deployed in public network



Non-public networks are designed and deployed by enterprises to optimize or enable business processes. Broadly, there are three drivers to deploy an NPN :

– To guarantee coverage: Often in locations with harsh radio frequency (RF) or operating conditions or where public network coverage is limited/non-existent (e.g., remote areas),

– To gain network control: For example, to apply configurations that are not supported in a public network. Security and data privacy are also important. The requirement to retain sensitive operational data on-premises is crucial to high tech industrial companies,

– To meet a performance profile: Specifically, a profile that will support demanding applications. 5G has a clear performance advantage over LTE and RLAN in cyber-physical industrial systems.

Both physical and virtual non-public IMT networks need to operate in frequency bands identified for IMT in order to benefit from the economies of scale of the global IMT ecosystem. A virtual non-public network may be deployed in areas where there is coverage by MNO network(s), whereas a physical non-public network can be deployed anywhere, where locally access to spectrum for non-public networks is available.

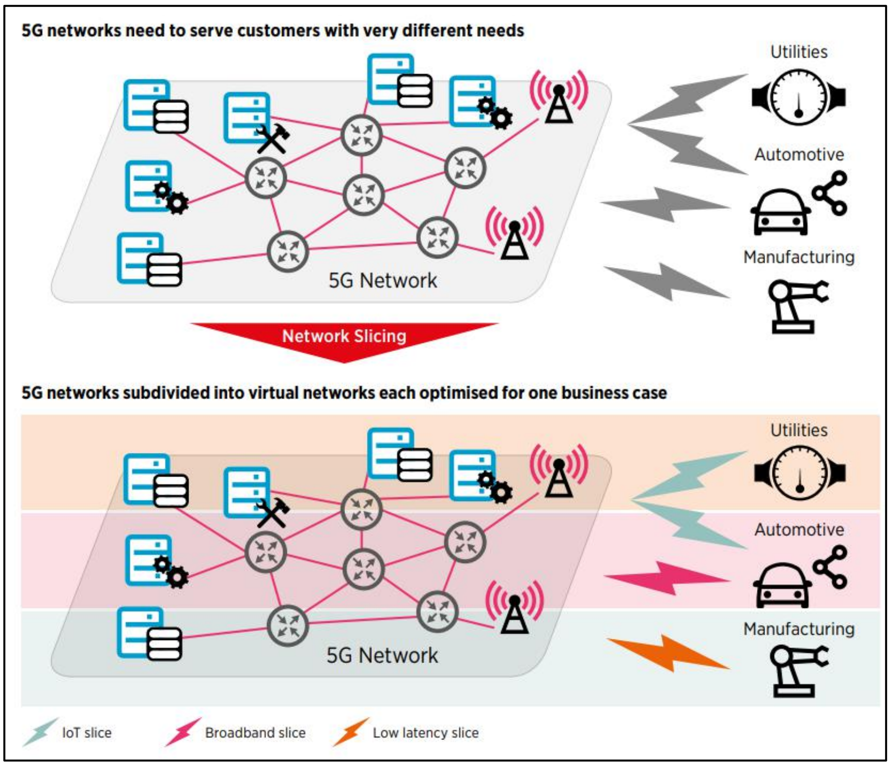
7.2 Network Slicing

From a mobile network operator's point of view, a network slice is an independent end-to-end logical network that runs on a shared physical infrastructure, capable of providing a negotiated quality. The technology enabling network slicing is transparent to business customers. A network slice could span across multiple parts of the network (e.g. terminal, access network, core network and transport network) and could also be deployed across multiple operators. Network slicing makes it possible to create an IMT-2020 (5G) based private network with specific operational characteristics as well as varying degrees of security/isolation, storage, bandwidth allocation, exposure, self-management, and so on.

To provide the best level of isolation, resources assigned to a network slice are ideally dedicated.

FIGURE 7.2

Network Slicing (source: GSMA[116])



Assuming that it is acceptable, some slices may share resources to reduce cost. Distribution and coverage are considered per slice. Some slices are local, while others may be wider in reach. Some slices require local Network Functions (NFs) for latency reasons, while others do not.

The ability to engineer network slices depends on an evolving toolbox of versatile enablers in five areas: cloud infrastructure, RAN, core, transport, and operations support systems/business support systems (OSS/BSS). Depending on the scenario, different combinations of enablers will be required to engineer the appropriate network slice(s). The enablers specified by 3GPP are available in the Technical Review paper on Network Slicing[117].

7.3 TSN (Time Sensitive Network)

To introduce IMT-2020 (5G) for wirelessly connecting the various parts in a factory floor, integration of traffic from TSN traffic is important to co-exist with same guaranteed QoS requirements as the wired TSN applications. In addition, to the low-latency requirements of control and user plane data for IMT-2020 (5G), it was found essential to support integration of TSN into 5G NR.

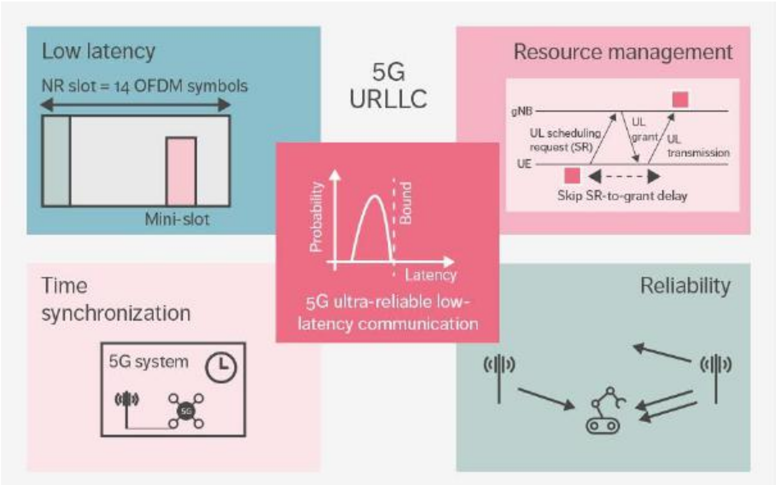
3GPP 5G RAN introduced several features in NR over Release 15 and Release 16 to enable low-latency applications as depicted below (Figure 7.3):

[116] https://www.gsma.com/futurenetworks/resources/an-introduction-to-network-slicing-2/.

[117] Ericsson Technology Review, Applied network slicing scenarios in 5G, https://www.ericsson.com/en/reports-and-papers/ericsson-technology-review/articles/applied-network-slicing-scenarios-in-5g.

FIGURE 7.3

Components of enabling TSN in IMT-2020 (5G). Source (Ericson Technology Review[118])



3GPP NR achieves the URLLC requirements of IMT-2020 using mini-slot transmissions, and UL transmissions without scheduling request (SR). The 5G RAN can reuse the existing time/phase synchronization used in telecom network[119].

TSN is a Layer 2 technology and includes IEEE 802.1Q based bridges and bridged network components. TSN uses Ethernet packets than Internet Protocol. And hence the data flow - forwarding decisions made by the TSN bridges uses the Ethernet header contents and not the IP address. This allows TSN to carry payload of any industrial application without requiring IP based network endpoints. TSN is focused on delivering the payload deterministically in time.

The entire IMT-2020 (5G) System appears as a TSN bridge component and configured to deliver deterministic and timely messages between the end-devices. The IMT-2020 (5G) UE using a TSN Translator (TT) function converts from FRER data to IMT-2020 (5G) PDU and delivers it to the UPF which again translates back to TSN data formats before delivering it to the TSN bridge.

7.4 High precision positioning

Accurate device positioning is a key enabler for many vertical applications, such as public safety and indoor navigation. The benefit of cellular-based positioning, which complements existing GNSS systems, is that it works well outdoors and indoors. 3GPP Release 16 supports multi-/single-cell and device-based positioning, defining a new positioning reference signal (PRS) used by various IMT-2020 (5G) positioning techniques (Figure 7.4) such as roundtrip time (RTT), angle of arrival/departure (AoA/AoD), and time difference of arrival (TDOA). Roundtrip time (RTT) based positioning removes the need of tight network timing synchronization across nodes (as needed in legacy techniques such as TDOA) and offers additional flexibility in network deployment and maintenance.

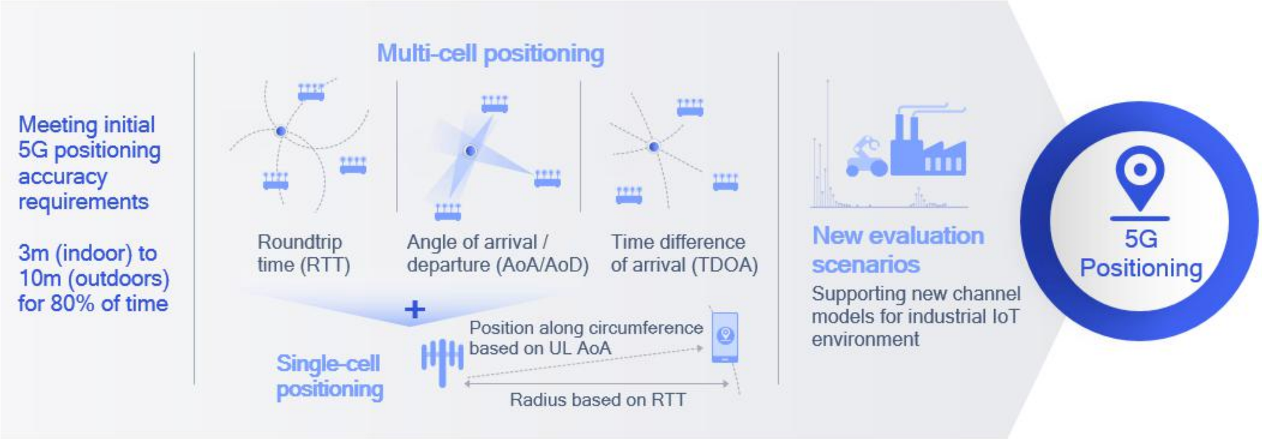
---

[118] 5G-TSN integration meets networking requirements for industrial automation https://www.ericsson.com/en/reports-and-papers/ericsson-technology-review/articles/5g-tsn-integration-for-industrial-automation.

[119] ITU-T G.8275.1 Precision time protocol telecom profile for phase/time synchronization with full timing support from the network.

FIGURE 7.4

3GPP based Positioning techniques. Source [Qualcomm]



7.5 Technical and operational aspect supported by IMT in mining sector

The IMT system in mining has a flexible networking model, which could not only be networked separately, but also could be integrated with wired dispatching telephone, administrative office telephone, RLAN (e.g. Wi-Fi), video surveillance system, IP broadcasting system, etc. to realize the organic integration of multiple systems and construct the integrated communication network for mining. And it also supports the connection with public network mobile communication system and public switched telephone network.

Supported by IMT system in mining, many functions could be realized, such as the real-time transmission of data such as high-definition video surveillance and working conditions of devices, operating parameters and scheduling commands, various environmental indicators ,etc. the integration of collected data, data analysis and devices control of the intelligent centralized control platform. Realize the condition monitoring of devices such as shearer, hydraulic support, scraper conveyor, reversed loader, crusher and other devices, the video surveillance of mining face and the remote control of the fully mechanized mining equipment to improve the production efficiency and the safety production level.

8 Deployment and implementation aspects

[Editor's Note : Title of this Section needs to be reworded to reflect the contents of this section]

Mobile cellular network technology is typically deployed and operated by licensed mobile network operators (MNOs). Non-public Networks (NPN) induce additions to this construct and their implementation can vary depending on which party should design, deploy, operate, manage, and own NPNs.

Unlike MNO networks that need spectrum that is authorized over wide geographical areas on an individual basis, non-public networks can be implemented using local spectrum authorization on a geographically shared basis.

The choice of which geographic areas and frequency band(s) should be used for local–networks is determined at the national level. The method of spectrum assignments used to grant local spectrum access for non-public networks is also a national decision.

A number of administrations took the lead to enable locally licensed or geographically shared IMT spectrum available for enterprise use and have begun to recognize spectrum sharing and localised broadband networks in providing flexibility and meeting the needs of critical communications by vertical industries and enterprises. Some administrations have decided to partition the IMT spectrum between commercial carriers and private broadband and others enabled opportunistic use and dynamic access to IMT spectrum that is licensed to commercial carriers

The local private networks are suitable for different groups of applications, with specific architectures applicable to building various types of networks as discussed above. They can be used by industries to automate manufacturing lines, reduce security risks, protect employees from dangerous environments, monitoring and control of assets, predictive performance and condition-based maintenance, digital assistance, etc. Enterprises use the private network to improve productivity, efficiency, flexibility, quality, security, and competitiveness.

The newer IMT technologies have enabled private networks to go wireless which give them additional benefits such as use of robots, software driven controls, remote location monitoring and control, ease in detection and resolution of issues, lower operational cost etc. Considering the benefits of IMT based private networks, wireless connectivity is increasingly becoming a necessity for business-critical services in industrial processes, such as those related to assembly lines and other modes of production. Wireless networking with these transformations to take place even in the most dynamic, remote, or highly secure environments, while offering the scale benefits of a technology that has already been deployed worldwide.

In cases, where an enterprise wishes to deploy and maintain its own private network, one of the most important inputs is availability of access spectrum in globally harmonized IMT bands. The need for spectrum for private networks can be met in many ways, such as, using shared spectrum, leasing of spectrum by Telecom Service Providers to the private entities and earmarking some dedicated spectrum for private captive networks.

In many cases, the administrations have earmarked some quantum of spectrum in harmonized IMT bands for private captive networks. Such spectrum, assigned to enterprises, is utilized within a limited geographic area; therefore, it is also referred as spectrum for localized or local use. Spectrum assigned for localized private captive networks is used in such a manner that the signals are restricted within its geographic area and do not cause interference to other outside systems. Considering the need for spectrum for private networks, administrations have allocated spectrum specifically for local use.

In the global scenario, most of the administrations have considered spectrum in low-band, mid-band and/or the mmWave spectrum for private network licenses. Some countries have earmarked frequency range for private networks in global IMT frequency bands which are currently being used for other services also and therefore, it is offered on a shared use basis.

9 Summary

TBD

ANNEX

Case studies

Annex I – Case study of IMT applications in mining sector

The mining environment is very challenging for radio signal propagation. Mines are under constant churn and topological changes constantly changing the radio signal condition and the area where connectivity is used. Operating a mine needs similar infrastructure as many other industrial facilities, such as lights, fixed and moving machines and tools condition monitoring, people tracking and so forth. These functions may be offered as a service(s) to the mining company by multiple parties, where each of the services has its own service quality targets.

Connectivity deployment considerations

The diversity of use cases in the mining industry benefitting connectivity is broad ranging from sensor and tools condition and location monitoring to reliable low latency operations. These use cases have from a service point of view very different requirements, where sensor and tool monitoring is a battery-powered operation with long operating times whereas the low latency use is likely with machines with power supply.

There are different deployment strategies for providing connectivity for the mining sector. One example is to use e.g. lighting infrastructure which can provide a device to device connectivity with mesh for the whole area to which other devices may connect. It can be envisioned that lighting is used in most of the mining areas since it is a personnel safety issue, and it is extending the connectivity area and reliability as new lights are installed.

Spectrum for wireless operation in mines would benefit from local licensing. Shared spectrum operation would allow flexible spectrum use and different equipment capabilities for competitive service costs. Direct device to device with e.g. DECT-2020 NR communication improves the signal availability for different services and provides a useful solution to enable reliable process control and monitoring for the mining processes.

Intellectualized tunnel boring and anchor machine in mining supported by IMT-2020

Under the coal mine in Gaoyang, Shanxi Province, China, the core network and base station controller of IMT-2020 were deployed, and the base station and CPE (Customer Premise Equipment) of IMT-2020 were developed at anchor digging machine. High-definition camera, 3D scanning imaging data, sensors and electrical control system in mining are connected to IMT-2020 network through the CPE, and connected with control center in mines, surveillance system of ground control center and service application system based on the core network of IMT-2020. Through related deployment and connection, the real-time data transmission of working condition, 3D imaging, high-definition video and remote control signaling for the tunnel boring and anchor machine in mining could be realized. And the condition of mining face could be displayed in all directions. The control system could control devices remotely and monitor the cutting track in real-time by communicating with the controller of the devices in time.

Annex II – Case study of IMT applications in oil and gas sector

Oil and gas sector enterprises operate hazardous production facilities. Areal objects are characterized by a high density of various devices, sensors, buildings, structures, people focused on a local geographical area. While linear objects are distributed over a large area and need a radio coverage area along their entire length. This imposes specific features of IMT application in closed/private wireless dedicated or technological communication networks, such as ensuring high reliability, high security, high data transfer rate, stable and trouble free connection of wireless sensors with low power consumption, low latency.

Closed/private wireless networks need to have a sufficient and properly protected radio frequency spectrum for the introduction of new and promising IMT technologies.

Combining sections of the radio frequency spectrum in different radio frequency ranges can help meet the needs and increase the efficiency of using the radio frequency spectrum (for example: upper ranges – for area objects, medium ranges - for linear objects) when implementing multi-band closed/private wireless networks.

Annex III – Case study of IMT applications in construction and similar usages

Industry 4.0, industrial IoT and digital twins are concepts that are used in the construction industry and their use is foreseen expanding in future. A specific example of a digital twin in the construction industry would be the Building Information Model, BIM. With the online information access to BIM, the whole construction process is achieving significant savings by improved efficiency. However, for the digital twin and the BIM model to work, reliable connectivity is required which is independent of the location of construction.

Connectivity deployment considerations

The construction industry needs reliable connectivity also outside of built, urban areas to support their operations for BIM. This issue is emphasized e.g. in roadbuilding as well as other infrastructure projects, which may occur in rural, sparsely populated areas. Thus, reliable local connectivity between the machines, measurement and monitoring devices, personnel, and central control, with the local device to device network based on mesh capability can enable savings in time and costs as well as improving sustainability and personnel safety while doing so.

These areas typically are with operator network signal levels, which might not be reliable enough to cover the connectivity for all tools and construction vehicles. With proper network design and planning, oftentimes there will be a possibility to connect to operator networks from a central location of the construction site, for example with the directional high gain antenna pointing to operator networks base station. This point, for example, the control cabin, at the construction site, will provide the “back-end connection” functionality for the local network based on e.g. DECT-2020 NR at the site will provide reliable connectivity for the working equipment and personnel.

Spectrum for wireless operation such construction projects would benefit from local licensing. Shared spectrum operation would allow flexible spectrum use and different equipment capabilities for competitive service costs.

Annex IV – Case study of IMT applications in healthcare

Hospital and institutional healthcare is an industry that is under constant pressure to become more effective and efficient while at the same time offering a high level of service and security to patients. Wireless technologies play an important role in achieving the challenging goals that healthcare institutions are faced with.

On the one hand, the communication between patients and clinical staff as well as between clinical staff members is often of a mission-critical nature. Secondly, there is a trend of medical devices, such as patient monitors, infusion pumps, ventilators etc. to be connected to the in-house IP network through different wireless technologies in order to notify staff of medical alarms or other critical information.

– Another important requirement to increase efficiency and safety is the possibility to keep accurate track of equipment as well as people. Much time is lost by searching for available medical equipment as well as members of staff and patients.

– Finally, there is an increasing demand for personal security as staff members are increasingly confronted with aggressive behaviour.

Many different solutions have been developed to address the above-mentioned requirements. These make use of a number of different wireless technologies. Each of these technologies will typically demand its own wireless infrastructure that needs to be maintained and managed. Some technologies make use of frequency bands that are becoming more and more overcrowded which poses risks in case of mission-critical messages being exchanged. Dependency on external providers of in-house wireless infrastructure is often not preferred by healthcare institutes that want to keep full control of their in-house systems, as well as keep these operational systems separated from systems provided for patients and visitors use.

DECT-2020 NR already today offers solutions to many of the requirements mentioned above, as it allows private networking, connectivity between devices, sensors and alarm equipment for the security of staff and equipment localization. DECT-2020 NR is also envisaged to allow the design of dedicated smart devices for staff which have been around for some time but have not seen a breakthrough yet.

An example is given below on remote mobile medical care using mobile medical care vehicles operated in cooperation with clinics in regional medical care, as well as the remote pregnant women's medical examinations conducted by mobile medical car touring various areas as examples of specific usage scenarios of 5G mobile medical care vehicles in Japan.

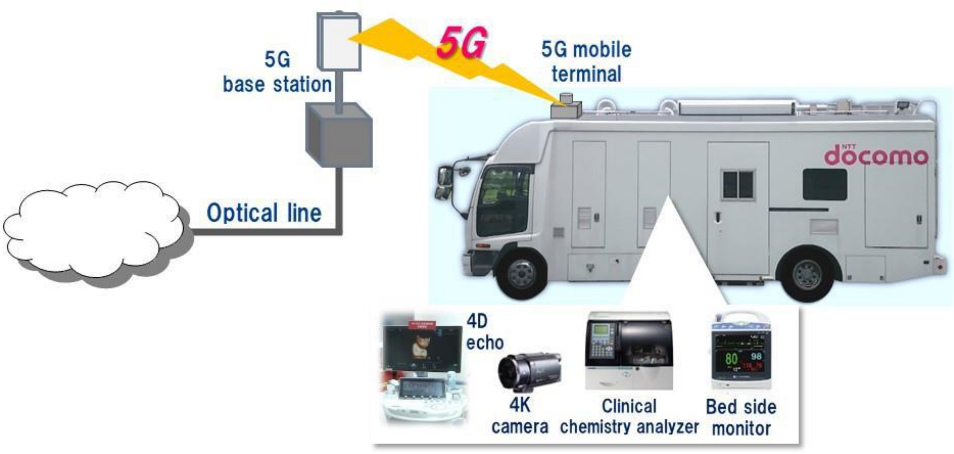
i) The concept of a mobile medical care vehicle that utilizes 5G

Telemedicine service that applies the 5th generation mobile communications system (5G) as a use case in the medical field can make use of its features such as ultra-high-speed communication. Telemedicine consists of a specialist / senior doctor in a remote location who provides support and guidance to medical staff in the same examination room / treatment room as the patient, while referring to various examination / diagnosis information transmitted via the telecommunication network. Therefore, it is important to reproduce the environment as if you were in the same examination room as the patient even in a remote location.

Among the medical equipment used in various clinical departments, especially those that handle visual data (video, photo / still image), the resolution has been significantly increased in recent years, and the video has high definition such as 4K and 8K. If these medical data can be transmitted without deterioration or loss and with low delay, accurate and detailed diagnosis will be possible even in remote areas. In addition to examination / diagnosis information from medical equipment, high-resolution camera images for grasping the patient's condition at a remote location, and video conferencing is also useful for smooth communication between doctors. In order to collectively transmit this large amount of information to remote locations, a higher-speed, larger-capacity telecommunication network is required compared to a conventional system. By utilizing 5G, which is capable of high-speed communication about 10 times faster than 4G, it is possible to provide telemedicine services that meet those requirements. Furthermore, in such a telemedicine system, it is possible to take advantage of the characteristics unique to 5G mobile communication, that is, the ability to freely move within a wide service area and connect to a network at any time from a desired location. A specific example is the 5G mobile medical care vehicle, which is expected to be a new tool that can provide the same level of medical care in a wide range of areas from urban areas to suburbs. A mobile medical care vehicle (Figure 1) equipped with medical equipment that supports general medical examinations and various medical examinations and connected to the network via 5G, can go to workplaces, various facilities, non-medical areas, disaster sites, etc. In those places, various medical examinations and telemedicine can be performed with the support and guidance of specialists.

FIGURE 1

Mobile medical care vehicle connected to the network via 5G[121]



Below, this contribution introduces the remote mobile medical care using mobile medical care vehicles operated in cooperation with clinics in regional medical care, as well as the remote pregnant women's medical examinations conducted by mobile medical car touring various areas. These are examples of specific usage scenarios of 5G mobile medical care vehicles in Japan, which were obtained as results of a survey.

ii) Remote mobile medical care to support regional medical care[122]

In Japan, prior to the start of full-scale commercial service of 5G, the "5G Field Trials" led by the Ministry of Internal Affairs and Communications (MIC) were carried out for three years from 2017. Participants from various fields participated in this, with the aim of creating new markets and new services and applications through the realization of 5G.

As a trial example of a service that utilizes 5G in the medical field, there is a telemedicine service conducted by NTT DOCOMO together with a medical institution.

The trial results for the specific telemedicine service were introduced in ITU-D SG2 by Japan, and among them, a mobile medical care vehicle was additionally introduced for remote medical care at local clinics. A new trial of telemedicine was carried out to realize advanced telemedicine services.

The scene verified in the trial assumes that a doctor dispatched in a mobile medical care vehicle to the area where the clinic is located receives advice and instructions from a specialist in a university hospital, and the mobile medical care vehicle has a high definition and low-delay video conferencing system, a high-performance echo, a small 4K close-up camera, and medical equipment such as a bedside monitor with a 12-lead electrocardiogram function. In addition to images of video conference and real-time medical images from mobile medical care vehicle, past

---

[121] M. Sugita and Y. Okumura, “Remote Medical Examination for Pregnant Woman utilizing 5G Mobile Medical Care Vehicle,” INNERVISION, vol.36, no.1, pp.62-65, Jan. 2021. (in Japanese)

[122] Y. Okumura, et al., “Field Trials of Telemedicine System utilizing 5G,” Magazine of IEICE Communications Society, no.55, pp.186-199, Jan. 2021. (in Japanese)

diagnostic images of patients can be transmitted simultaneously by 5G from clinics to university hospitals.

Two experimental 5G mobile terminals and two 5G base stations were used, and each 5G transmission was performed between the mobile terminal and the base station using the 100 MHz band (200 MHz band in total) at frequencies in the 4.5 to 4.7 GHz band. Transmission is performed between the base station and the university hospital using an optical line (Figure 2). In the actual trial, the two scenes shown in Annex 1 (a) were conducted, and the following opinions and impressions were obtained from the doctors who participated in this trial.

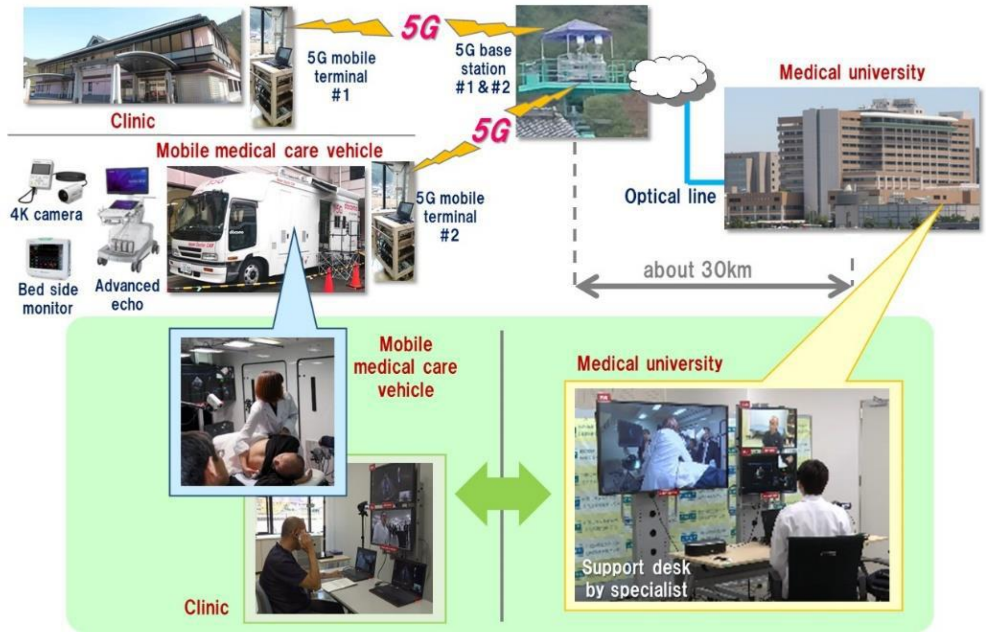
(Specialist at a university hospital) Compared with diagnostic images that are usually seen in clinical practice, the images transmitted from remote locations do not show any deterioration, and the resolution of the diagnostic images is sufficient. In addition, since three types of images, a close-up camera, a bedside monitor, and an echo, can be integrated and viewed at the same time, the patient's condition can be comprehensively grasped. I can examine as if the patient were in the same room.

(Mobile medical care vehicle doctor) Since the specialist doctor provides real-time support from a remote location, medical treatment can be performed without anxiety.

(Observer doctor) Unlike still images such as MRI and X-ray images, echo images are dynamic images, and it is important to maintain quality when transmitting images. In this trial, the image quality was adapted for accurate diagnosis.

FIGURE 2

Remote mobile medical care by linking clinics and mobile medical care vehicles



iii) Remote medical examination to reduce the burden on pregnant women[123]

As another demonstration example of a mobile medical care vehicle equipped with 5G, the following is a trial of remote pregnant women's medical examination that can contribute to solving

[123] M. Sugita and Y. Okumura, "Remote Medical Examination for Pregnant Woman utilizing 5G Mobile Medical Care Vehicle," INNERVISION, vol.36, no.1, pp.62-65, Jan. 2021. (in Japanese)

social issues such as eliminating regional disparities in medical care and responding to large-scale disasters.

Pregnant women are recommended to be examined every 4 weeks at the beginning, every 2 weeks after 22 weeks, and weekly after 36 weeks. In the past, pregnant women's medical examinations only checked the maternal blood pressure, weight, and urinalysis (urine protein / sugar), as well as the uterine floor (uterine size) for the foetation and listened to the heartbeat. Currently, to confirm the well-being of the foetation, ultrasonic diagnostic imaging method has been introduced as a foetal examination, and some obstetrics and gynecology departments also use 4D ultrasound image with time elements added to 3D (three-dimensional) ultrasound image. However, now that the new coronavirus infection is prevalent, there are many voices of pregnant women saying, "I want to check the condition of the foetation frequently by medical examination, but I want to reduce the number of visits to the hospital as much as possible."

Therefore, NTT Medical Center Tokyo and NTT DOCOMO conducted a trial assuming that an obstetrician and gynecologist in a remote location would perform a medical examination of a pregnant woman in a 5G mobile medical care vehicle.

In the first stage of trial, they were conducting a simulated experiment of remote pregnant women's medical examination, and a medical examination environment for pregnant women was reproduced by arranging medical equipment such as a 4D echo, a 4K close-up camera, a dry clinical chemistry analyzer, and a bedside monitor in an indoor space simulating a mobile medical examination vehicle, while constructing remote support desks with examination video monitors and the Picture Archiving and Communication Systems (PACS), which is a medical image management system, in an indoor space simulating a hospital examination room. They also installed a 4K video conferencing system that connects both places (upper part of Figure 3). The inspection video from each medical device and video conference were collectively transmitted via the experimental 5G equipment and optical fibre. At the trial, a scenario was executed consisting of three scenes (see Annex 1 (b)) that could actually occur for pregnant women. The participants' evaluations of the above trial are shown below.

<Hospital doctor> Compared to 4G, 5G transmits a clearer echo examination image and close-up camera image (lower left in Fig. 3) to a specialist, and can accurately confirm the condition of the foetation and the condition of the complexion and skin of the pregnant woman. Furthermore, it is extremely useful because it is possible to have a medical examination while consulting with a hospital specialist in real time through a 4K video conference call.

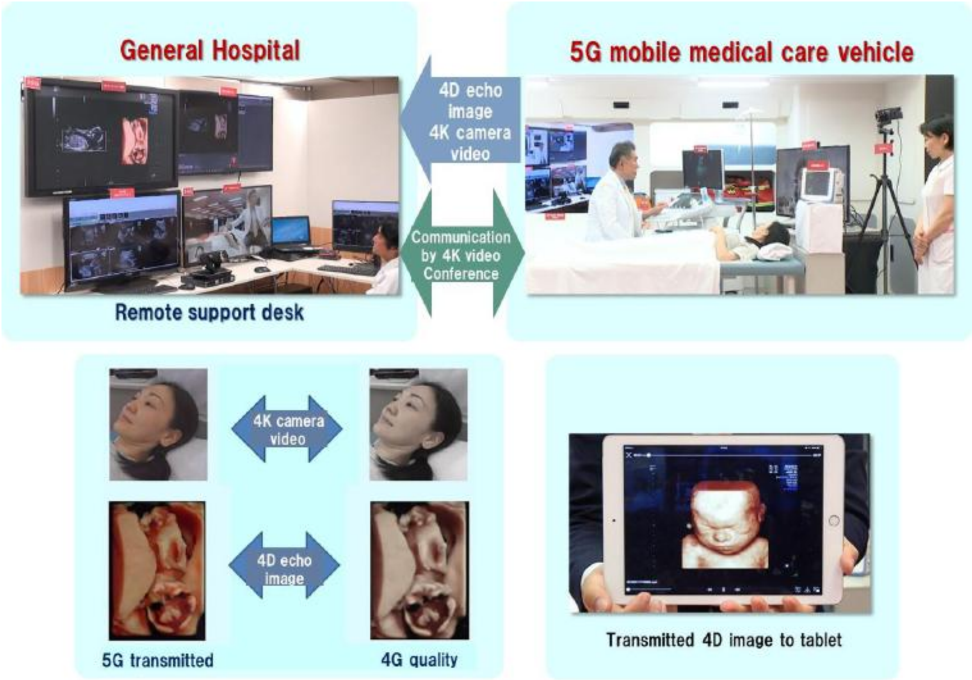
<Nurse> When a midwife cares for a pregnant woman on a remote island or in a depopulated area, access to a specialist is an issue, but with the introduction of a mobile medical care vehicle, it is possible to provide midwives and care for pregnant women at any time while accessing the specialist. 5G mobile medical vehicles are also very useful in the field of midwifery.

<Pregnant women> There are few obstetrics and gynaecology clinics and hospitals in rural areas, and it is a heavy burden for pregnant women to take regular time to visit a distant obstetrics and gynaecology department. Therefore, it would be very helpful if a remote pregnant woman could be easily examined with a mobile medical care vehicle.

In this trial, we also confirmed the effectiveness of the service that transfers and displays the diagnostic video (4D echo output) file sent to the hospital at the time of the medical examination and stored in the PACS to the tablet of the family (lower right of Figure 3).

FIGURE 3

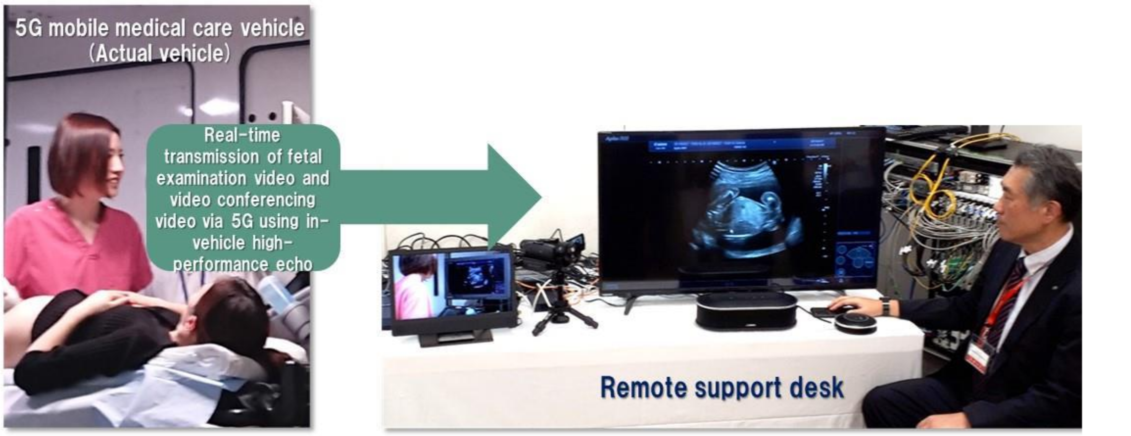
Remote pregnant woman medical examination using 5G mobile medical care vehicle



Following the first-stage trial, a second-stage trial was conducted using an actual vehicle (8-ton truck base) as a mobile medical care vehicle. To carry out verification by obstetricians and gynaecologists and demonstrations for medical personnel, an echo examination image of an actual pregnant woman in a mobile medical car and a 4K camera image showing the state of the pregnant woman were transmitted in real time to a remote support desk via an experimental 5G equipment (Figure 4). In this verification, it was confirmed that a mobile remote pregnant woman medical examination can be performed using an environment in which an ultrasonic examination device, an examination bed, and a 5G mobile terminal are installed in an actual truck vehicle. This showed the possibility of remote pregnant women's medical examinations in a wide range of areas using mobile medical vehicles. In addition, many medical personnel who visited the demonstration expressed their expectations for the realization of maternity medical examinations outside clinics and hospitals. There was opinion that the early introduction of mobile medical vehicles in low populated areas would stop the population decline.

FIGURE 4

Demonstration experiment using an actual vehicle



Contact for technical aspects of this report: Yukihiko Okumura, NTT DOCOMO, INC., okumuray@nttdocomo.com.

Details of each trial introduced in this report

(a) Scenes conducted in the actual trials for remote mobile medical care

Scene 1: A doctor at the clinic was informed by a patient who had been visiting the clinic because of heart disease that he could not move because he had a severe cough and his whole body was sluggish. The clinic doctor immediately connects to a university hospital specialist via a 5G network, and transfers the "high-definition echo information (heart)" taken in the past to the specialist. The clinic doctor also informs the specialist that he is suspected of having myocardial infarction or heart failure. The specialist then decides to dispatch the mobile medical care vehicle to the patient's home area and to carry out telemedicine with the specialist (cardiologist).

Scene 2: After the mobile medical care vehicle that received the dispatch request arrives at the patient's home area and guides the patient into the vehicle, the doctor in the vehicle transmits diagnosis information such as "vital sign", "electrocardiogram", and "high-performance echo image (heart)" to the specialist. The specialist confirms the past echo image and the latest diagnosis information, and shares the diagnosis result and treatment plan with the mobile medical vehicle doctor.

(b) Scenes conducted in the actual trials for remote medical examination

Scene 1: A pregnant woman who complained that "the baby does not move much" arrived at the mobile medical care vehicle, and the vehicle doctor contacted the hospital doctor and started a medical examination. First, the hospital doctor referred to the contents of the Mother and Child Health Handbook (brought by the pregnant woman) transmitted as a camera image, grasped the number of weeks and the weight gain status of the mother, and confirmed the smooth growth of the foetation.

Scene 2: Regarding the current state of the foetal, 4D echo examination images are transmitted in real time from the mobile medical care vehicle to the hospital, and the hospital doctor says that the BiParietal Diameter (BPD), which represents large lateral diameter of the foetal head, is equivalent to desired value of the number of weeks, and the heart is normal. It was confirmed that there was no problem with the foetation by confirming the smooth heartbeat and the smooth growth of the head, arms and legs. Furthermore, it was confirmed that the growth status was favourable even when compared with the inspection images recorded in the PACS during the past pregnancy examinations.

Scene 3; The vehicle doctor reported that the haemoglobin level may indicate anaemia based on the results of a blood sampling test performed by the pregnant woman on a mobile medical car, and transmitted the pregnant woman's complexion to the hospital using live images from a 4K camera. A hospital doctor who confirmed that the pregnant woman was anaemic pointed out that the anaemia may have weakened the foetal movement due to the lack of nutrition in the foetation. In addition, hospital doctors instructed pregnant women to eat separately and get proper nutrition.

Annex V – Case study of IMT applications in utilities

Utilities are providing services that can be considered to represent various public sector services modern society is increasingly requiring. These services may be of monopolistic of nature such as electricity distribution, water and heating systems and various local, city or metropolitan public services.

The energy system is globally in a transition towards distributed and renewable electricity production, which is fundamentally changing the electricity distribution and markets in future from centralized distribution systems to decentralized, local electricity production and consumption as well as maintaining grid stability due to higher electricity production variance of renewable energy. These proceedings create new requirements for communication reliability, availability, and resilience with a fraction of the value of produced or consumed electricity. In many regions, the energy systems are shared between different actors, such as high and mid voltage system operators managing the electricity distribution system and distribution system operators (such as DSOs) who are managing local low voltage energy distribution and consumer services. In some markets, there may be in addition separate companies selling the energy to consumers to limit the monopolistic market.

Utility applications

Utility services may cover large areas which are both densely populated regions as well as a sparse area with long distances.

Smart Grid is the technology that enables information sharing to control the electricity grid. From the resilience point of view, the system is divided into several independent subsystems, which have their own performance requirement and reliability as well as parallel systems to prevent a single point of failure.

Electricity distribution system covers applications which are related to high- and mid-voltage distribution systems.

Smart metering (AMI) and low voltage system: Smart meters are in future the sensors that are providing information on quality parameters of electricity. Also, in future the dynamic load control may be offered via them to manage electricity system stability.

Distributed energy production (DER) through renewables such as solar and wind will require control to be incorporated into the modern grid. This management requires data exchange which scale is demanding better wireless. These DER systems may in the future form microgrids emerging entities that require effective and cost-competitive communication solutions for the local automated electricity market.

Connectivity deployment considerations

In future, it is anticipated that distributed energy production is radically increasing when mankind is reducing CO_2 emissions globally. These systems will be in use in most of the buildings and connected to microgrid or traditional grid and require connectivity to ensure proper electricity system operation.

Smart meters are widely in use globally and many emerging countries will get active as the future energy is produced from renewables and consumed with microgrids. These services assume that the data transfer cost is a fraction of the energy value which is a demanding challenge.

This is a massive increase in scale which requires an order of magnitude denser networks, lower operating costs and a lifetime of few decades.

Utilities can benefit from Massive Machine Type Communications (mMTC) with autonomous mesh communication to address the high density and high reliability of smart meter operation or solar panel use as an example. Ultra-Reliable Low Latency Communications (URLLC) is to address the performance and reliability requirements for connectivity of mission-critical components in e.g in distribution grid power stations.

Utilities would benefit from shared and flexible spectrum use since the future energy systems will be relying on wireless communication which needs to be purpose-built and cost-effective and where multiple utilities may operate.

Annex VI – Case study of IMT applications community and education sector

There are advanced IMT networks on university and college campuses, but most of them are isolated to specific buildings for research purposes. For instance, one IT director at a major university in California explains, "Trying to pull money out of the general fund to put in a campus-wide IMT network means taking money from some department that is trying to construct a lab that may help cure the next cancer or solve the next energy problem or develop the next student who figures that next problem out, whatever that happens to be."

Fortunately, there has been some momentum around government assistance for public and private schools at all levels to close the digital divide. For example, the American Rescue Plan Act of 2021 provides $7.2 billion for the E-rate program that makes it easier to connect homes and libraries to the Internet[124].

Annex VII – Case study of IMT applications in manufacturing

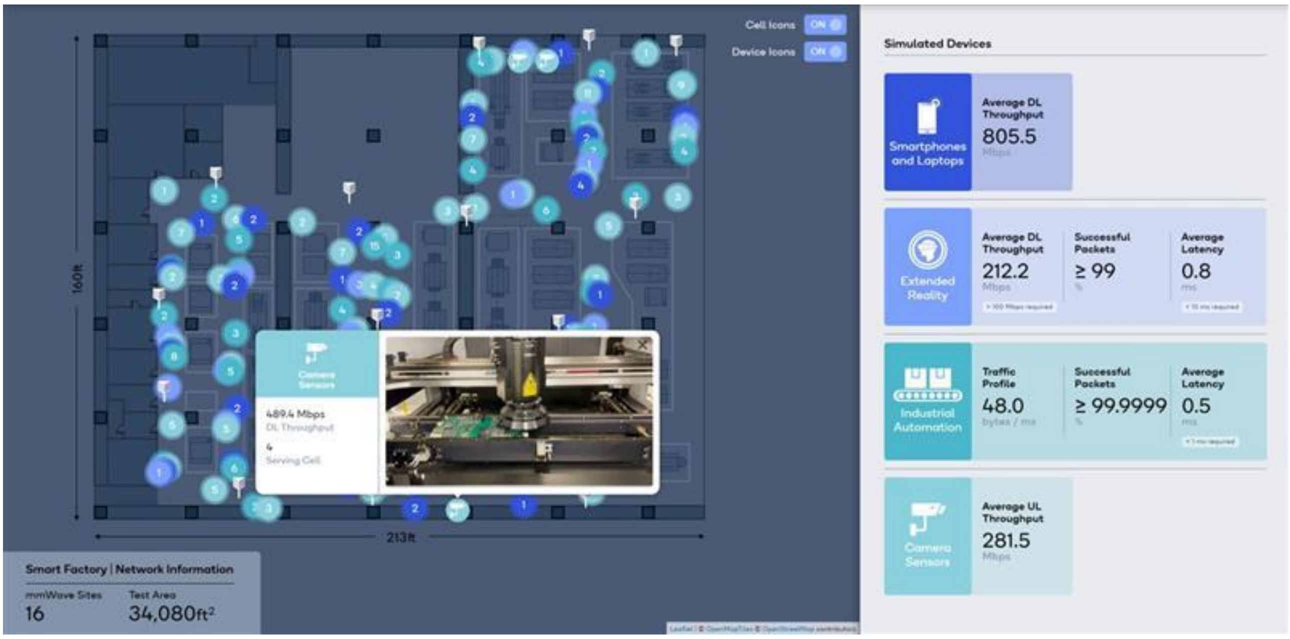
(i) mmWave in Manufacturing

5G mmWave can support diverse connectivity need in new verticals. As an example, a 5G mmWave private network supporting a smart factory use case was simulated in one case. A smart factory floor map of about 34 000 square feet with a 12 feet ceiling height is simulated. This smart factory layout has 16 mmWave base station sites covering the space, including the factory floor and some office spaces. The mmWave network operates utilizes 800 MHz of bandwidth.

FIGURE 5

Smart factory use case

[124] https://www.fcc.gov/consumers/guides/universal-service-program-schools-and-libraries-e-rate



The following kind of devices are part of the smart factory:

Table 1 : **Devices in smart factory**

Devices	Remarks	Throughput	Latency	Reliability
Smartphones and always connected laptops	General purpose connectivity for personnel and other usages	800 Mbit/s download		
Boundless XR	Enabling many emerging Industry 4.0 use cases, such as guided maintenance and task execution. To support immersive augmented reality experiences, heavy processing is done on the edge server while lighter-load compute can be processed on-device.	100 Mbit/s	10 ms latency (Obtained average 0.6 ms latency)	
TSN	To enable cutting the wire for extremely high-performance industrial automation use cases		Milliseconds	Six nines 99.9999%
Low complexity IoT devices (RedCap)	Industrial Camera Sensors (100 MHz Bandwidth)	10 s of Mbit/s		

Utilization of mmWave in the smart manufacturing scenario provides the ability to utilize Flexible UL/DL, scenario, and use-case specific configuration of spectrum utilization by devices and greater control on resource utilization.

The following 3GPP features enable the highly scalable and flexible mmWave based manufacturing deployment:

– Time Sensitive Networking (TSN)

– Coordinated Multipoint (CoMP) / Multi TRP (M-TRP)

– URLLC / eURLLC

– MU MIMO – multi-user MIMO

– Positioning

– mmWave network.

[Note: Further results on the performance obtained may be included in future]

(ii) 5G-ACIA endorsed testbed examples

5G-ACIA testbed Aachen (Germany): 5G-based monitoring of critical machining processes

There are two use cases trialed at the 5G-ACIA endorsed testbed "5G-Industry Campus Europe":

1 5G for wireless acoustic workpiece monitoring,

2 5G versatile multi-sensor platform for digital twin.

In the first use case trialed within the testbed, an acoustic emission (AE) sensor has been developed and integrated into a 5-axis milling machine, to monitor the condition of cutting tools. Acoustic workpiece monitoring is a technology that makes use of AE sensors for collecting relevant data for the monitoring system. AE sensors are widely applied for monitoring cutting processes, in particular for performing the following items in real-time:

– Monitoring of tool wear,

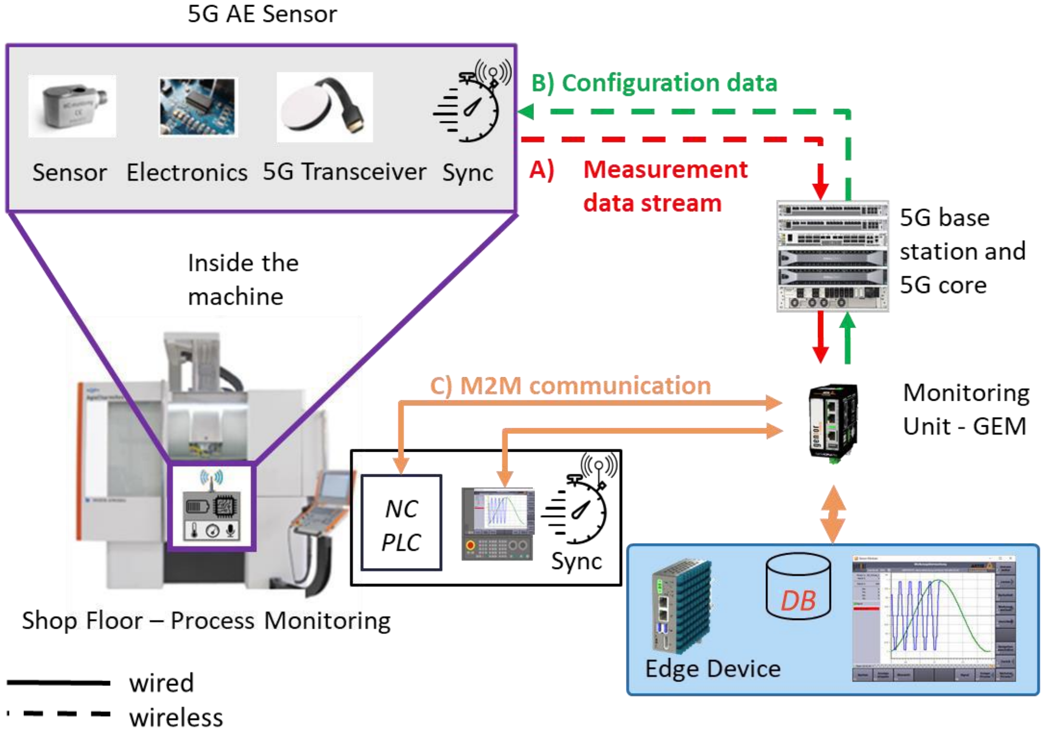
– Detection of tool breakage,

– Detection of collision of the machine spindle,

– Detection of inhomogeneities of the workpiece material.

FIGURE 6

5G wireless acoustic emission sensor system (AE - acoustic emission, GEM - Genior Modular, NC - Numerical Control, PLC - Programmable Logic Controller)

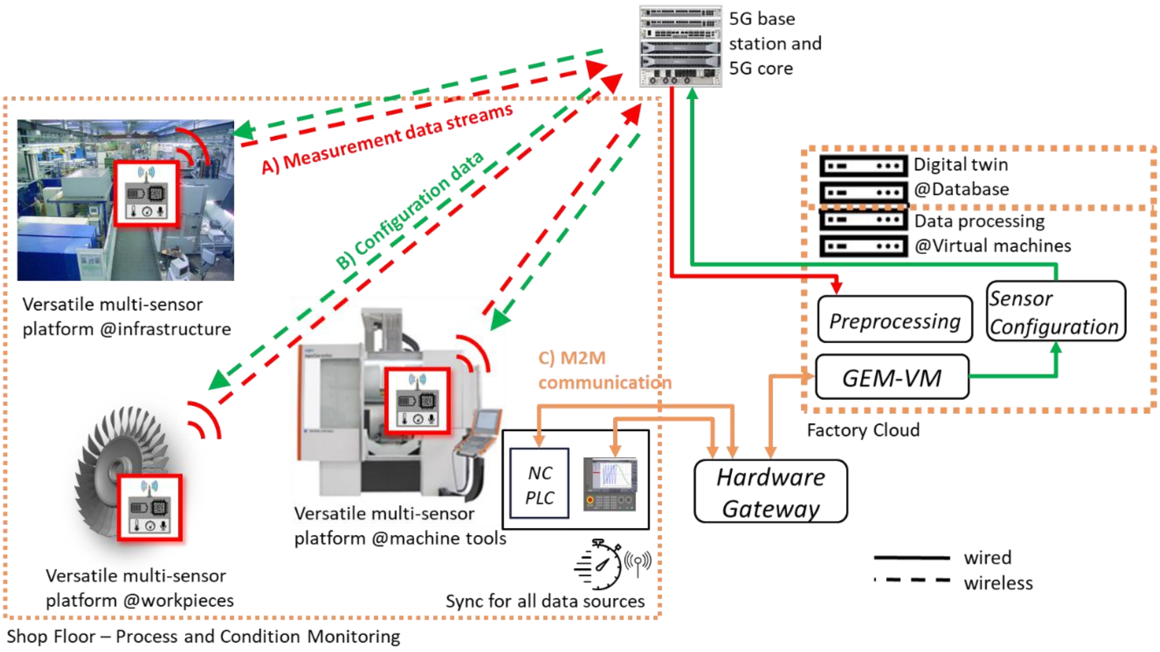


A timely detection of any of the above disturbances is highly desirable as it allows an intervention into the process, to optimize the fabrication process, as well as to reduce the production costs due to decreased failure rates.

A wireless acoustic emission sensor with 1 MHz sampling rate will be integrated with a 5G device. The sensor will be connected to the workpiece during the machining process to provide measurements from the machine to a monitoring unit, e.g., located in an edge cloud. The raw signals are pre-processed on the wireless device using an FPGA and then transmitted via 5G as UDP packets with a data length of 1024 bytes and a frequency of 1 ms. The measurements are analyzed, and the observations are fed to the machine control to steer the machining process. The entire loop of acoustic emission measurements, data collection and analysis in the monitoring unit and adaptively steering the machining process from the machine control needs to take place in real-time.

FIGURE 7

Process and shopfloor monitoring based with 5G multi-sensor platform (GEM-VM - Genior Modular Virtual Machine, NC - Numerical Control, PLC - Programmable Logic Controller)



The wireless 5G versatile multi-sensor platform (MSP) aims to address and solve the limitations of current sensor-systems. We envision a fine-grained system of widespread sensors and transducers, whose heterogeneous data is collected, transferred via 5G and aggregated in a local cloud close to the shopfloor, that we call the Factory Cloud. The general concept can be seen in Figure 7: on the shop floor, multiple machines and workpieces as well as the infrastructure, are equipped with MSPs and are connected via 5G to the Factory Cloud, where measurement data can be processed and stored. Extracted information can then be fed back as process parameter adjustment or control to the machines. Sensors are tuned and orchestrated in form of configuration data.

Many diverse physical quantities can be measured or sensed across a factory, relating to machines, workpieces, and the infrastructure as well. Each of those may have different requirements, especially regarding reliability and latency that can potentially be rather challenging. Critical process parameters in machining are for example accelerations or forces, which are an indicator of unforeseen behavior of the workpiece to be machined. Chatter marks or tool deflection may be the result, leading to insufficient quality of final product. To instantly react on such incidents, a latency less than 10 ms may be required to adopt the machining parameters. This requirement is typically associated with the URLLC (Ultra Reliable and Low Latency Communication) feature of 5G.

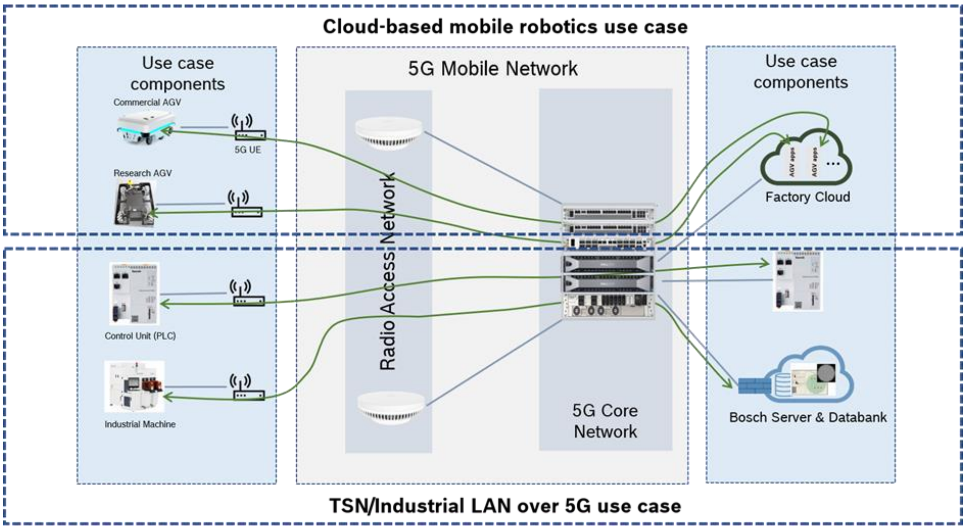
More information about the two sensor systems and the associated use case can be found here.

5G-ACIA testbed Reutlingen (Germany): 5G for enhanced semiconductor factory automation

The main objective of the testbed in the Bosch semiconductor factory is to test and demonstrate in realistic factory scenarios two use cases and validate that the 5G system provides the required performance support. The use cases are cloud-based mobile robotics and Time Sensitive Networking (TSN)/industrial Local Area Network (LAN) over 5G. Figure 8 illustrates the use cases.

FIGURE 8

Cloud-based mobile robotics and TSN/Industrial LAN use case



– **Cloud-based mobile robotics use case**

This use case focuses on the feasibility, flexibility, and performance of wirelessly controlled mobile robots in a manufacturing shop floor equipped with 5G technology. A novelty of this use case is the possibility to decouple the closed-loop control of the robot from the robot's embedded system and place it into an edge cloud execution environment (i.e., a factory cloud) while sustaining the Key Performance Indicators (KPIs), like sufficiently low execution latency and adequate fault-tolerance. Moving the control logic into the cloud benefits from scaling of the workload when changing the tasks for the robots, ease of maintenance of the control software and improved resiliency to software and hardware failures. Furthermore, decoupling the control logic from the AGV enables innovative control solutions such as collaboration between individual AGVs by, e.g., facilitating the creation and sharing of up-to-date common maps. For instance, simultaneous localization and mapping (SLAM) capabilities of an AGV can enhance the route selection for other AGVs in real-time, i.e., one AGV detects an obstacle, the other one reacts by finding another path to the destination.

Moving the control of the robot into the cloud comes with stringent requirements on the communication in form of low-latency and reliable radio connectivity. More details about this use case can be found at D1.1 (5gsmart.eu).

– **TSN/Industrial LAN over 5G use case**

This use case focuses on investigating and validating the applicability of 5G for transporting the traffic of TSN/industrial LAN (I-LAN) applications. Nowadays, due to the stringent requirements of the industrial applications, all operational I-LANs are realized based on fixed (wired) communication networks. Limited flexibility for setting up new production lines or for restructuring an existing production line, as well as complex and costly maintenance, are major drawbacks of the wired I-LAN realizations. In particular, this can be an issue in view of the recent trends for making the industrial environments as flexible as possible, e.g., smart factories of the future in the context of Industry 4.0. Introducing 5G comes with the potential of reducing the cables and connectors wear and tear, for the mobile machines/controllers, resulting in reduced maintenance costs. Additionally, replacing the cables for communications between controllers and machines with 5G communications results in a greater flexibility for implementation and adaptation of the industrial manufacturing infrastructure. Consequently, this can improve the productivity of manufacturing through reducing the time for setting up or customizing a production cell/line and improving the maintenance. Partially replacing fixed interconnections between TSN/I-LAN nodes with 5G mobile communications puts however very stringent requirements in terms of latency and reliability on the communication system. More details about this use case can be found at D1.1 (5gsmart.eu).

5G-ACIA testbed Kista (Sweden): 5G-enhanced industrial robotics

This testbed demonstrates, evaluates and validates 5G capabilities for 5G-enhanced industrial robotics. Robotics is a vital part in modern manufacturing. 5G wireless communication and edge cloud computing are two technical trends that may disrupt the way in which industrial robots are deployed and used in the future. The 5G-enhanced industrial robotics testbed validates novel design of industrial robotics, where part of the robot control is moved from the robot to a central location, e.g., a control room in the factory. This puts stringent requirements on 5G in terms of reliable and low latency communication for connecting the robot to the controller.

The use cases investigated are:

1 5G-connected robots and remotely supported collaborations of connected robots

2 Machine vision assisted real-time human robot interaction over 5G

3 5G-aided visualization of the factory floor

These new use cases bring several advantages: The hardware of industrial robots can be simplified, become cheaper and occupy less space on the shopfloor. This is achieved by moving control functionality into an edge cloud – a local computing infrastructure located e.g., in a control room of the factory, rather than from today’s design where the control is placed in embedded processor on the industry robot or in a dedicated control hardware that is in proximity of the robot and connected to it via cable. By removing cabling, the flexibility of redesigning the shopfloor is improved. Wireless connectivity allows to increase the number of mobile robots on the shopfloor which can take over more tasks in a flexible production process. A key component of the testbed is the vision system that is being used to identify objects as well as support the mobile robot navigation.

An overview of use case setup is illustrated in Figure 9, further details can be found in: D1.1 (5gsmart.eu).

FIGURE 9

Use case setup for 5G-enhanced industrial robotics