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5G E2E TECHNOLOGY TO SUPPORT VERTICALS URLLC REQUIREMENTS

Verticals URLLC Use Cases and Requirements

by NGMN Alliance

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Abstract: Short introduction and purpose of document

This document summarizes URLLC use cases that have been developed in various SDO's and industrial consortia, identifies some of those use cases that are more likely to be focus of the eco-system initially. It intends to provide guidance to SDO's in developing technology to support URLLC and further work on "E2E technical solution for URLLC" in the NGMN project "Verticals URLLC requirements".

Document History

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2/26/2019	V.2.3.2	Ana Galindo-Serrano, Georg Wannemacher, Xinli Hou	Update to Section 6.3.2, 6.4 & 6.5 by Ana; 6.5.2 (now 6.5) by Georg, worked out comments on Ch. 3, editorial update on Ch. 5 by Xinli;
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5/10/2019	V.2.3.9	Billy Liu/HKT, Javan/Bell, Xinli Hou, Wang Dong, Wang Rui/China Mobile	Update with comments from HKT/Billy Liu (6.2.2), Javan's input to Sec.6.7, update of Ch. 7 from Wang Rui, A new use case "remote control of RMG Crane" provided by Wang Dong/China Mobile, and other editorial changes throughout the document.
5/27/2019	v.2.4	Ana Galindo-Serrano, Xinli Hou, Javan Erfanian	Updated based on comments from Orange, Javan and comments from the project meetings on May 3 & May 13.
5/31/219	v.2.5	Xinli Hou	Updated based on comments from project meeting on May 28.
6/6/2019	v.2.5.1	Dhruvin	Dhruvin/Ericsson's update on definition of survival time.
6/20/2019	V2.5.2	Lei Cao	Updated based on comments from project meeting on June 14.
7/25/2019	V2.5.3	Lei Cao	Updated Table 5 and Table 6 in Page 41 based on comments from Kevin Holley of BT.
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1 INTRODUCTION

Among the three types of 5G use cases, enhanced mobile broadband (eMBB), as the name suggests, aims at improving the use experience of mobile broadband services. With mobile broadband services provided by Long Term Evolution (LTE), people are truly connected anytime anywhere. Being connected is an essential part of life, at least in a large part of the world. Proliferation of mobile broadband services such as mobile video & music streaming, mobile payment, mobile navigation, mobile sports has led to an explosive growth of mobile broadband traffic. Initial 5G launch will meet the demand of traffic growth more cost efficiently with higher capacity, faster data rate by providing enhanced MBB services. Compared with MBB services provided by earlier generations of mobile networks, eMBB is faster, more energy and cost efficient. That said, eMBB reassembles some characteristics of mobile broadband services: it aims at the same market segments (i.e., mass consumer markets); and it will likely follow the similar business model as in LTE although price and tariff plan may change.

Likewise, mass Machine Type Communications (mMTC) can find its precedents in services provided by narrow-band Internet of Things (NB-IoT) such as telemetering, which is experiencing a fast growth in recent years.

What makes 5G totally different is its capability to support vertical use cases that requires ultra reliable low latency communications (URLLC). Such mission critical use cases can be found in industry automation, real-time control, augmented reality/virtual reality (AR/VR)-based applications, as well as consumer-oriented services such as gaming.

To a large extent, the industry has a good understanding of eMBB and mMTC use cases, technically and business-wise. URLLC use cases are new that differentiate 5G from earlier generations of mobile communication systems, although a lot of studies and proof of concepts projects have been carried out to understand where URLLC is needed and what are the requirements on communications systems, how 5G can be the best solution to meet those requirements.

To facilitate the technology specification in standard organizations and support operator business development, as well as to foster the eco-system, a holistic view of URLLC use cases and their requirements on 5G is needed.

To this end, this document starts with a survey of use cases that have been developed in various standard development organizations (SDO’s) and industrial consortia. Furthermore, to provide guidance to SDO’s in developing technology to support URLLC and further work on “End to end (E2E) technical solution for URLLC”, some of these use cases and their requirements are identified as prioritized use cases based on different criteria, particularly on the significant operator’s added value. Note that automotive use cases are thoroughly studied in other industrial forums, e.g., 5G Automotive Association (5GAA), and they are out of scope of this work. Finally, a categorization of service level requirement is introduced to guide the study on E2E technical solutions as well as network deployment to support URLLC use cases. The document is concluded with a summary of key findings.

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[3] Interview with Huawei, 5G gaming and VR will boost personal data use 'by 15-fold in seven years' (available here)

[4] 3GPP TR 22.804, "Study on Communication for Automation in Vertical Domains (Release 16)".

[5] 3GPP TS 22.104, "Service requirements for cyber-physical control applications in vertical domains; Stage 1 (Release 16)".

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3 REFERENCE FRAMEWORK AND DEFINITIONS

3.1 Reference framework

In the following Open System Interconnection (OSI) seven layer model is used to set up a context for the terms used in this document.

As illustrated in Fig. 1, for devices (e.g., sensors and actuators) in verticals to communicate with application systems (where e.g., control applications or data analytics applications reside) via 5G, devices are equipped with user equipment, that is a 5G User Equipment (UE) module, and higher layer protocol stack as needed; the application systems are connected to a network via Network Interface Card (NIC) where the network is connected to 5G core network directly or via one or more networks based on 3GPP or non-3GPP technology.

In case of device-to-device communications, both devices are connected to 5G radio access network by user equipment.

The entity in a device, e.g., a process in a sensor, or the applications in the application systems which invokes communication services, is called an **endpoint device**. The interface at which a protocol layer service is invoked is called a **service access point**.

In a light weight implementation, some or all of the higher layer protocol stacks, from application layer down to network layer, can be empty. The endpoint device invokes network services provided by the 5G UE or NIC for communications.

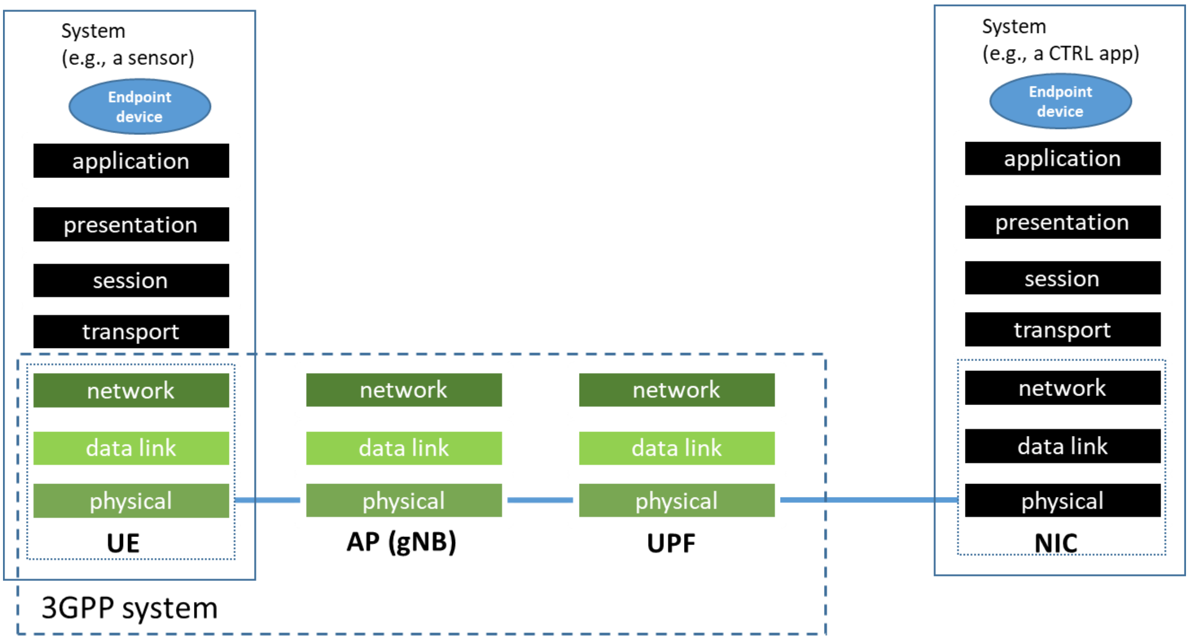


Fig. 1 Reference framework of communication systems in vertical applications

3.2 Latency and jitter

With the above described framework in mind, **end-to-end latency** is defined as the time that takes to transfer a given piece of information from a source endpoint device to a destination endpoint device, measured at the application service access points, from the moment it is transmitted by the source endpoint device to the moment it is successfully received at the destination endpoint device. In Fig. 2, t_7-t_1 and t_{14}-t_8 are end-to-end latency.

Latency at air-interface is defined as t_4-t_3 for uplink and t_{12}-t_{11} for down link.

Please note that there are other definitions of end to end latency. For example, in NGMN "Extreme Requirements" project, end to end latency is defined as the time that takes to transfer application-layer data of a given size from a source to a destination, from the moment it is transmitted by the source to the moment it is successfully received at the destination (one-way latency). In other words, the E2E latency is measured from the L7/6 interface on the end system side to the L7/6 interface on the AS side, or vice versa. For the purpose of that project, it might be appropriate to exclude application protocol handling time from the end to end latency. We take the approach to consider the complete communication protocol stack, although some layers can be empty in some specific implementations.

In some use cases, **round trip delay** is an important performance parameter, which is defined as the time that takes to transfer a given piece of information from a source end point device to a destination endpoint device, for the information being processed at the destination endpoint device and a response being transmitted back to the source endpoint device. In Fig. 2, t_{14}-t_1 is the round trip time.

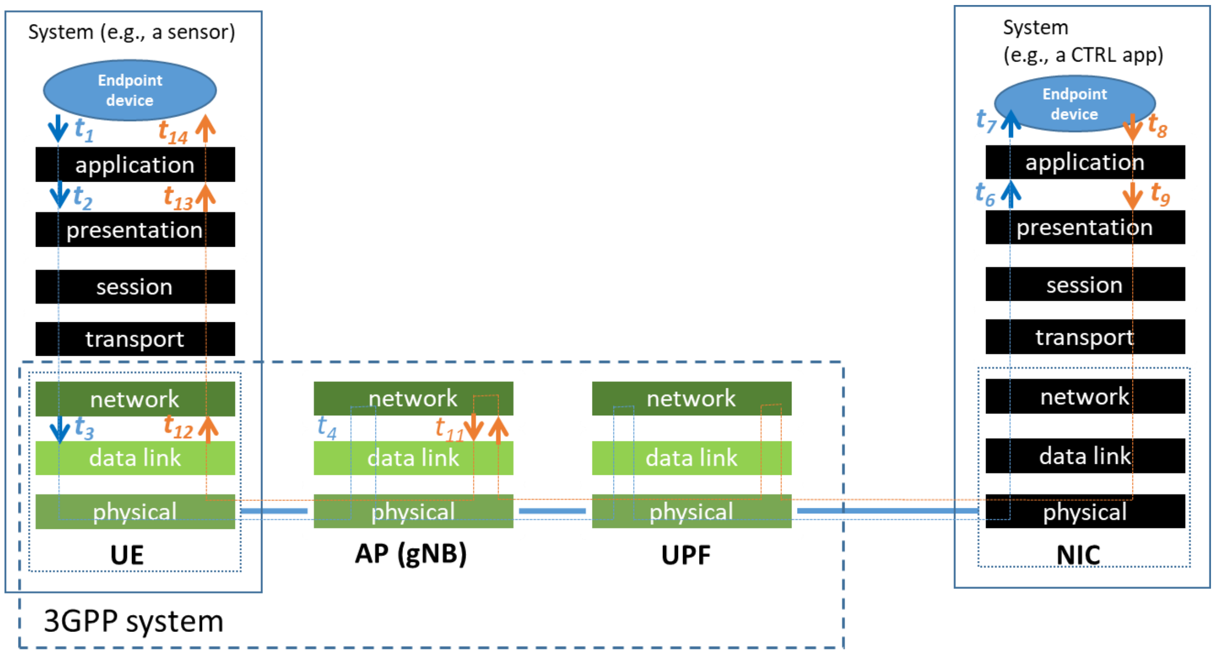


Fig. 2 Reference points of latency definition

The **jitter** is the variation of a (characteristic) time parameter. An example is the variation of the end-to-end latency. If not stated otherwise, jitter specifies the symmetric value range around the target value (target value ± jitter/2). If the actual time value is outside this interval, the transmission was not successful.

3.3 Reliability

Reliability is defined as percentage value of the amount of sent packets/messages successfully delivered to a given node within the time constraint required by the targeted service, divided by the total number of sent packets/messages. Depending on the protocol layer the packets are referred to, two variances are defined:

1. **End-to-end reliability** is defined as percentage value of the amount of sent application layer packets successfully delivered to a given node within the time constraint required by the targeted service, divided by the total number of sent application layer packets.

2. **Network reliability** is defined as percentage value of the amount of sent network layer packets successfully delivered to a given node within the time constraint required by the targeted service, divided by the total number of sent network layer packets. This is the definition of reliability in 3GPP TS 22.261 [6].

The reliability definition adopted in this document is in line with that commonly used in telecom industry but different from the **communication service reliability** defined in 3GPP TS 22.104 [5] which is inherited from IEC 61907 [8].

In TS 22.104, **communication service reliability** is defined as ability of the communication service to perform as required for a given time interval, under given conditions, where given conditions would include aspects that affect communication service reliability, such as: mode of operation, stress levels, and environmental conditions. Communication service reliability may be quantified using appropriate measures such as meantime to failure, or the probability of no failure within a specified period of time.

3.4 Throughput

When data rate is measured at application layer service access point, it is called **user experienced throughput**; at network service access point, it is called **network throughput**; and at the data link layer service access point of the UE, called **air interface throughput**.

3.5 Availability

The following definition in 3GPP TS 22.261 [6] is adopted:
Communication service availability: percentage value of the amount of time the end-to-end communication service is delivered according to an agreed Quality of Service (QoS), divided by the amount of time the system is expected to deliver the end-to-end service according to the specification in a specific area.

NOTE 1: The end point in "end-to-end" is assumed to be the communication service interface.

NOTE 2: The communication service is considered unavailable if it does not meet the pertinent QoS requirements. If availability is one of these requirements, the following rule applies: the system is considered unavailable in case an expected message is not received within a specified time, which, at minimum, is the sum of end-to-end latency, jitter, and survival time.

When communication service availability is referred throughout this document, the communication service interface in the above NOTE 1 is assumed to be application layer service access point. In case the communication service interface in NOTE 1 refers to network layer service access point, the term **network availability** is used.

3.6 Other important definitions

Survival time: the time that an application consuming a communication service may continue without an anticipated message. This definition was taken from clause 3.1 in [6]. It is influence quantity, which is not essential for the performance of an item but affecting its performance [5]. The survival time is an application-specific characteristic.

Time synchronous accuracy: the difference in the latency between transmission and receiving paths. Time synchronous accuracy is a concern in some use cases, for example, electricity distribution automation. This parameter is important because devices such as distribution termination units (DTUs) rely on it to deduce the clock information in cases where Global Positioning System (GPS) is not available. Time synchronization is critical in these measurement units to ensure correct decision making.

4 URLLC CHALLENGES AND TRADE-OFFS

Enabling ultra low latency and/or ultra reliability, required by such use cases as industrial automation, tactile internet, augmented and virtual realities, or autonomous automotive applications, has shown to involve important challenges. A flurry of activities has been ongoing in research, industry initiatives and standardization to analyze and address these challenges towards enablement of these use cases, and transformation of relevant industries. Given the distinct and central role of the operators to enable these use cases and to provide significant value, NGMN has given considerable and fundamental attention to this. The 5G White Paper, and the specific initiatives, 5G Verticals Requirements, 5G Extreme Requirements, and the current work, Verticals URLLC Requirements, have focused and continue focusing on this, in addition to the ongoing project of 5G End to End Architectural considerations.

The URLLC challenge is not merely limited to enabling a low-latency or an ultra-reliable link. It is also about the end-to-end implications and tradeoffs, in providing an available, efficient and sustainable service. Our collective efforts, across research, industry and standardization, and specifically our end-to-end requirement study, should consider both: the achievement at a protocol or layer level (e.g., physical layer enhancements) and at end to end architectural, deployment, and business (model) levels (e.g., design scenarios and tradeoffs).

Flexibility (e.g., in numerology) and efficiency (e.g., in coding/modulation and messaging overhead) developed in 5G radio specifications and ongoing enhancements (3GPP Rel. 16), along with a growing amount of research work have been addressing these challenges. At the lower layers, the efficiency of scheduling, time to transmit, propagate, and process, and the potential re-transmissions, among others, have been considered. The size of a packet has a role. On the one hand, a short packet may pose less latency, and on the other hand, its overhead makes it less efficient.

The 5G service-based architecture, network slicing, and evolving telco cloud provide exposure of granular microservices, and policy-based orchestration of necessary functions, for different service scenarios, including URLLC use cases. The separation of planes, allows moving the user plane flows flexibly as needed. In other words, the increasingly distributed intelligence and the ability to create edge clouds and cloudlets can be leveraged in the design for URLLC use cases. The modular and composable service-based architecture (SBA) provide a great deal of flexibility in placement of dynamic and scalable microservices. With such capabilities, intelligent and automated network slicing will be able to orchestrate the particular resourcing, chaining and interactions needed for each service (type) in general, and for URLLC use cases, in particular. The 3GPP Rel. 16 also has study items on enhancements to SBA, URLLC support in 5G Core, and network slicing, among others being studied in TS 23.501.

As indicated, when it comes to deployments, a major concern is the tradeoffs between different targets. If we step back and revisit our definitions, we note an inter-play between the latency, the reliability and the load, before we even consider efficiency and coverage. Simply put, our QoS consists on delivering a number of packets, at a certain success rate, within a latency budget. The targets for these parameters alone can be in conflict and may need to be optimized in design. Targeting higher reliability, say through re-transmissions, or transmitting a larger number of packets, can be at expense of latency. Then, looking at the broader picture, a solution that requires more bandwidth, more resources (as typically required for reliability), and/or higher number of nodes and lower inter-site distance, challenges cost and energy efficiency.

In the NGMN White Paper on 5G Extreme Requirements [9], published in 2018, there is a detailed analysis highlighting tradeoffs such as latency, packet size, load, and efficiency. It also distinctly validates the existing challenge of providing a high coverage for URLLC. However, a number of use cases and user scenarios will require availability in wide area. New technology enablers and paradigms, design principles, specifications, and deployment and business models must address this. These include, for example, edge cloud models, slice models, cooperative/diversity and multiplexing models, low-error “first” (one-shot) transmission, prioritized “instant” channel access and resource allocation, new protocols, etc. The increasing densification may further accommodate providing distributed edge, resourcing, and cooperative/multiplexing models. After all, realizing the potential value provided by 5G (operators) towards the transformations expected in the next decade requires enabling ultra-low latency and/or ultra-reliability as a service, where and when needed, with quality, availability, and (cost/energy) efficiency.

The following section further outlines these use cases along with the relevant industry activities.

5 SURVEY OF URLLC USE CASES AND RELEVANT INDUSTRY ACTIVITIES

Vertical use cases have been extensively studied by SDOs and industry forums in order to drive the development of relevant (communication) technology such as 5G. In the following, organizations and their activities relevant to URLLC use cases are introduced, followed by a survey of vertical use cases that may have URLLC requirements on end-to-end solutions.

A lot of automotive use cases require URLLC. Industrial organizations such as 5GAA and AECC are dedicated to study automotive use cases and technologies required to support them. These organizations and use cases are not covered in this document.

Industrial organizations focusing on technologies supporting vertical use cases but not able to support URLLC requirements are not considered either.

5.1 Organization and work related to URLLC use cases and requirements

5.1.1 3GPP

Of the 3GPP work on URLLC use cases and requirements, TR 22.804 “Study on Communication for Automation in Vertical Domains” [4] is of special interests. The document provides a comprehensive list of 5G use cases for automation in the following vertical domains:

- Rail-bound mass transit;
- Building automation;
- Factories of the future;
- eHealth;
- Smart city;
- Electrical power distribution;
- Central power generation;
- Programme making and special events (PMSE) comprising all production, event and conference technologies;
- Smart farming.

These vertical use cases identify detailed potential 5G service requirements from verticals perspective, which often necessitate low latency and high reliability[1]. The potential requirements are derived from different sources:

- Existing work on dependable communication as used in vertical domains; see, for instance, IEC 61907 [8];
- Use cases describing network operation in vertical domains with, for instance, common usage of the network (multi-tenancy) and network monitoring for assurance of service level agreements;
- Security mechanisms already used in vertical domains; supporting the specific security requirements of vertical domains;
- New (additional to already existing 3GPP stage-1 work), representative use cases in different vertical domains based on input from relevant vertical interest organisations and other stakeholders.

3GPP TR 22.804 also provides an overview of automation concepts and how communication for automation is modelled in the vertical domains. Additionally, it provides an overview on security needs for communication in vertical domains, illustrates existing security mechanisms in these domains, and identifies potential related 5G security requirements.

[1] Definition of the term “reliability” used in telecom industry is different from vertical industries. See Section 3.3 for more information.

For the purpose to describe the service and operational requirements for a 5G system (including a UE, NG-RAN, and 5G Core network), 3GPP TS22.261 v 16.x.y “Service requirements for the 5G system; Stage 1 (Release 16)” includes two informative annexes:

- Annex A (informative): Latency needs to support example use cases from vertical industries.
  This annex summarize the latency values required to support the potential opportunities in the use cases on vertical industries based on the NGMN white paper on vertical industries [1]. Latency in this annex refers to the end-to-end latency at the application layer as defined in Chapter 3.
- Annex D (informative): Critical-communication use cases.
  It describes use cases and service requirements (including security) in discrete automation, process automation, electricity distribution and intelligent transport systems.

3GPP TS 22.104, “Service requirements for cyber-physical control applications in vertical domains; Stage 1 (Release 16)” [5], provides Stage 1 normative service requirements for 5G systems, in particular service requirements for cyber-physical control applications in vertical domains, where communication services need to be ultra-reliable and, in some cases, the end-to-end latency must be very low. Communication for cyber-physical control applications supports operation in various vertical domains, use cases in industrial automation and energy automation are given in Annex A for information.

For Rel. 17 timeframe that started in February 2019, 3GPP SA1 started a new Study Item on further service requirements for cyber-physical control applications in vertical domains.

The objective of this study item is to identify further potential 5G service requirements for cyber-physical control applications in vertical domains, which often require URLLC. Specific use cases will be provided to motivate the additional service requirements. Relative to the Rel.16 baseline, there are more specific requirements or additional requirements for closely-related additional Rel.17 functionality in order to improve the applicability of 5G systems to vertical domains.

The aspects addressed for studying further cyberCAV potential service requirements in this study item will be restricted to:

- Industrial Ethernet integration, which includes time synchronization, different time domains, integration scenarios, and support for time-sensitive networking (TSN);
- Non-public networks, non-public networks as private slices, and further implications on security for non-public networks;
- Network operation and Maintenance in 5G non-public networks for cyber-physical control applications in vertical domains; Enhanced QoS monitoring, communication service and networks diagnostics; Communication service interface between application and 5G systems, e.g. information to network for setting up communication services for cyber-physical control applications and corresponding monitoring;
- Network performance requirements for cyber-physical control applications in vertical domains;
- Positioning with focus on vertical dimension for Industrial IoT;
- Device-to-device/ProSe communication for cyber-physical applications in vertical domains;

5.1.2 5G-ACIA (5G Alliance for Connected Industry and Automation)

5G-ACIA (https://www.5g-acia.org/) has been established to serve as a global forum for addressing, discussing, and evaluating relevant technical, regulatory, and business aspects with respect to 5G for the industrial domain. It aims at ensuring the Information and Communication Technology (ICT) needs of the automation industry are considered when developing 5G standard. It will foster developing a 5G technology that addresses industrial requirements, and ultimately building an adequate business model.

5G-ACIA consists of players of ICT and Operation Technology (OT) industries with the following working structure.

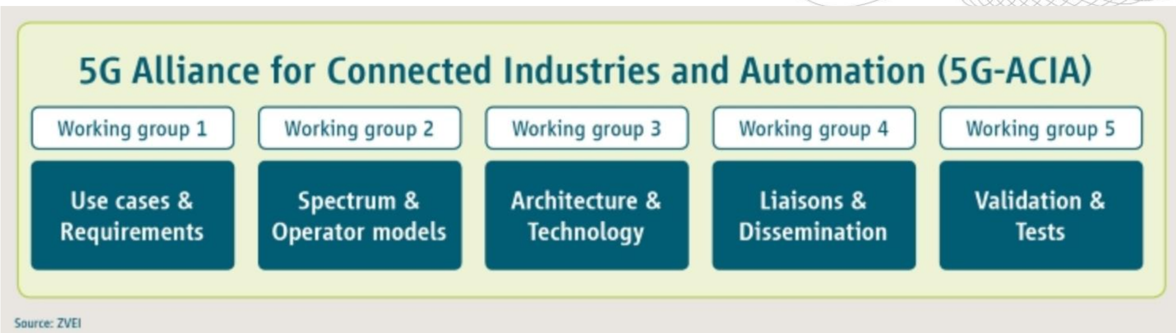


Fig. 3 5G-ACIA Organization structure

With a focus on connected industry and automation, 5G-ACIA is working on use cases and requirements from OT industry perspective, actively making contributions to 3GPP and other SDO's.

In its white paper "5G Alliance for Connected Industries and Automation: Designing 5G for Industrial Use", 5G-ACIA provides an overview of 5G's basic potential for manufacturing industry, and outlines relevant use cases and requirements. Not being complete, the example use cases demonstrate that QoS requirements can be very divergent ranging from process control with a cycle time of >50ms and availability of >99.99% to motion control demanding for availability of more than six 9's and cycle time can be as low as <0.5ms. Worth noting that 5G must also meet operational and functional requirements of the industry, such as dependability, functional safety, security, cost efficiency and process flexibility.

Furthermore, the white paper introduces some of the main building blocks of 5G and certain major challenges that yet to be resolved. It also includes an introduction to 5G-ACIA as an important initiative in the merging point of 5G and vertical industries.

Other publications of 5G-ACIA include "5G for Automation in Industry" describing how the 3GPP-defined 5G architecture will impact industry especially process and discrete manufacturing; and "5G Non-Public Networks for Industrial Scenarios" describing Industrial Internet of Things (IIoT) deployment scenarios for 3GPP-defined 5G non-public networks.

For the latest information about 5G-ACIA publications, please visit their web site.

5.1.3 IIC (Industrial Internet Consortium)

The Industrial Internet Consortium (IIC, https://www.iiconsortium.org/), now incorporating OpenFog, has the mission to deliver a trustworthy IIoT in which systems and devices are securely connected and controlled to deliver transformational outcomes. Through its Working Groups IIC coordinates and establishes the priorities and enabling technologies of the industrial internet in order to accelerate market adoption and drive down the barriers to entry. They have 270 members, from large and small industry, entrepreneurs, academics and government organizations with an interest in helping to shape and grow the Industrial Internet. There are currently 19 Working Groups and teams, broken into the following broad areas:

- Business Strategy and Solution Lifecycle
- Liaison
- Marketing
- Security
- Technology
- Testbeds

IIC aims at establishing IIoT solutions best practices; creating new use cases; influencing global standards processes; facilitate ecosystem engagements; and demonstrating best practices via test-beds. Verticals that are covered by IIC include energy, healthcare, manufacturing, mining, retail, smart cities, and transportation.

IIC publishes a lot of technical papers, industry white papers as well as test-beds in smart grid, smart city, healthcare etc. Some of those test-beds address use cases requiring URLLC. IIC works in a broad scope of work related to industrial Internet. For example, one security case study is about how to mitigate rogue insider and Advanced Persistent Threats to sensitive Intellectual Property through network technology. IIC is currently working on a technical report titled "Industrial Internet of Things Networking Framework" that targets guidance on how to select relevant networking technologies for diverse IIoT application and deployment needs.

5.1.4 AII (Alliance of Industrial Internet)

The Alliance of Industrial Internet (AII, http://en.aii-alliance.org/) was jointly initiated by manufacturing industry, communications industry, Internet and other enterprises, aiming to study and promote industrial Internet standards, results of industrial internet testing and demonstration, as well as products and application innovation. Although most of its results are published in Chinese, its work is worth of reference.

AII consists of eleven working groups working on requirements, technology and standards, safety, test platform, industrial development, spectrum, network connectivity and so on. The following two working groups are of special interests for those who want to learn URLLC use cases and solutions.

Requirements Working Group analyze various industrial Internet use cases and draw common requirements; collect best practices and build a data base; define detailed business requirements, technical requirements, categorize and classify these requirements and output them to other working groups of the alliance. 5G is one of several networking technologies considered here. In 2018, it mainly studied the following topic and published results in white papers:

- Wireless use cases for:
  - Intelligent manufacturing.
  - 3C fields.
- Use cases for medium and small enterprises.

The 1st edition of wireless use cases in automobile manufacturing was published in 2018 [2]. It analyzed seventeen wireless use cases in automobile manufacturing and summarized three classes of use cases:

- 1st class: the low latency use cases such as motion control (robot and robot coordinated control, assembly workshop tighten wireless), mobile robots (material transmission among the working procedures in welding workshop, sheet metal parts transmission in stamping workshop, assembly parts, visualization in remote adjustment of welding assembly), closed loop process control (wireless interaction of technology information).
- 2nd class: large bandwidth application of image detection, monitoring and scanning. For example, video monitoring application in welding process, wireless machine vision application in vehicle quality inspection, wireless handheld 3D scanner application in industrial design stage, and wireless AR application in production troubleshooting.
- 3rd class: applications for equipment monitoring, such as plant asset management (equipment based on (Radio Frequency Identification (RFID), the wireless scan code in the process of tracking, vehicle assembly, vehicle wireless scan code in the process of quality supervision, inspection, three-dimensional garage in wireless handheld RFID), equipment condition monitoring and remote asset management application (remote maintenance robot, welding group control station data back, wireless intelligent instrument and quality inspection devices, online environment monitoring, monitoring of energy consumption, etc.).

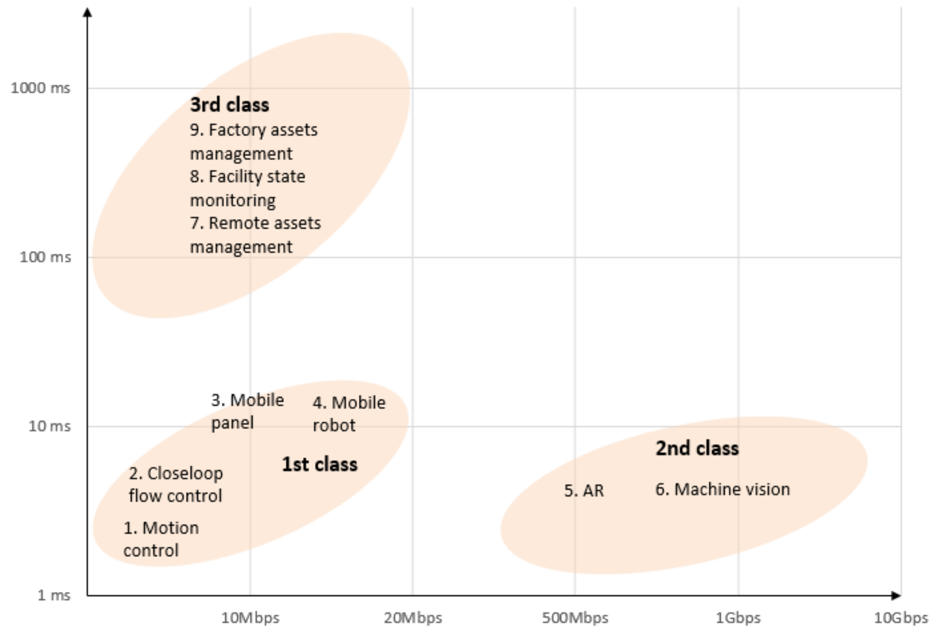


Fig. 4 Classification of wireless communication use cases in automobile manufacturing

Network Connectivity Working Group established the industrial wireless ad hoc group in September 2018. It plans to study industrial wireless communication requirements, technical solutions and promote industrial wireless applications. Its scope of work includes:

- Developing wireless network requirement standard per industry per use case and per application, in collaboration with Requirement Working Group.
- Enhancing 5G and other industrial wireless technology based on application requirements.
- Establishing a series of standards for enhanced industrial Internet.
- Drive 5G-based innovative application trial and promotion.

5.1.5 IEC

International Electrotechnical Commission (IEC) is a leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies. IEC has an extensive work range including smart city, smart grid, cyber security, smart electrification and so on. To promote international co-operation in the electrical and electronic fields, IEC publishes many standards, reports and specifications. Some of these publications such as 61850, 61907 and 62657 series of standards present the requirements of industrial automation on wireless communication.

IEC 62657 series introduce the communication requirements on wireless communication system application in industrial automation. The communication system can be applied in process automation and factory automation with different requirements on latency and bandwidth. Process automation, which is applied mainly in control, monitoring and diagnostics, requires the sampling period of 100ms bit rate of hundreds of bit per second and the bandwidth of 34MHz. Factory automation contains wireless devices on digital I/O points. It requires operation cycle time of 10ms, bit rate of 1 Mbps and 42MHz bandwidth.

IEC 62657-1 provides some wireless communication use cases in industrial automation:

- Safety of worker around transporting machines.
- Level monitoring and alarming in a tank farm.
- Field worker support with wireless equipment.

- Vibration monitoring and analysis of rotating machines.
- Oil wellhead monitoring and control.
- Applications for factory automation with a large number of nodes.

These use cases have different requirements on transmission time, reliability, coverage, power consumption and so on.

IEC 61850 series presents the communication requirements of Power Utility Automation Systems. The communication performance requirements include message performance requirements, requirements for data and communication quality, which may be related to URLLC application. The communication performance of transmitted messages is mainly measured with time, including event time, transfer time and time synchronization, and communication quality. The event time illustrates the time tag of transmitted events/values and the transfer time means the end-to-end transmission time including processing time and network transfer time.

According to different transfer time and time synchronization classes, the message types include:

- Fast message (for protection).
- Medium speed message (for automatics).
- Low speed message (for operator).
- Raw data message (for samples).
- File transfer functions.
- Command messages and file transfer with access control.

The protection related message and raw data message transmission requires low latency (e.g., less than 10ms). As for the communication quality, the focus is on data integrity, reliability and availability. The reliability consists of security (i.e., security against "unwanted commands") and dependability (i.e., dependability against "missing commands"). There are two security classes in which inter-tripping schemes belong to high security class and require the probability of unwanted commands down to 10^{-8}. There are four dependability classes with probability of missing commands of 10^{-2} (e.g. inter-tripping schemes), 10^{-3}, 10^{-4} (e.g., permissive under-reach schemes) and 10^{-5}. The maximum actual transmission time should be less than 10ms for first three classes and can be more than 10ms for the last one.

5.2 Summary of URLLC use cases

Vertical industry use cases have been studied by various SDO and industry consortia. 3GPP has classified 5G use cases into three categories: eMBB, mMTC and URLLC. However there is no clear cut to which category a use case belongs to. There are use cases, for example, requiring both eMBB and URLLC.

In vertical use cases, endpoint devices or user equipment are connected for the purpose of:

- Monitoring or surveillance

  One or more endpoint devices transmit sensory information to the other endpoint device as necessary in order for the other endpoint device to deduce the health of a tool, product, or system. Systems diagnostic solutions may "close-the-loop" around the diagnostic information to implement control capabilities such as equipment shutdown or continuous process improvement; however, the performance requirements of the system are primarily driven by the data collection, and actuation is usually event based (i.e., not time dependent).

  While most of diagnostic use cases may require high reliability, they often do not demand for very restrictive latency requirements.

- Close-loop control or interact

One or more endpoint devices transmit the necessary sensory information to the other endpoint device. Based on collected information, control applications residing in the other endpoint device decide if and what actions are to be taken by which devices, and transmit actuation information to the corresponding endpoints, which can be different from the endpoint devices from which the sensory information was originally collected.

In vertical industry applications, the control interaction is often time-critical and demand for high reliability where networks must guarantee a certain level of response time determinism to be effective. Otherwise, it may lead to a potentially huge financial damage.

- Open-loop control or interact
  In some applications, open loop control capability is required. For example, as a safety measure in industrial applications one endpoint device must be able to send actuation information to one or multiple endpoint devices to handle emergency situation. These use cases often require low latency and high reliability.

Note that latency and reliability requirements can sometimes be traded off with each other as discussed in the previous section. Use cases are considered URLLC use cases only if their requirements on low latency or high reliability targets or both that cannot be compromised by one another.

With this in mind, monitoring use cases are not likely URLLC use cases. Not all control/interactive use cases demand for ultra high reliability and low latency. That said, URLLC use cases are mostly, if not always, control or interactive use cases. Table 1 summarizes use cases, without any indication of priority order, that are likely have ultra-high reliability and low latency requirements on the underlying communication systems that are better be implemented with 5G.

Table 1: Use cases potentially with URLLC requirements[2]

Use Case Groups	**Use case examples**	**References**
AR/VR	Cloud AR/VR	Sec. 5.3.10, TR 22.804
	Augmented worker	Sec. 6.2 of this document
Tactile Interaction	Gaming	Sec. 6.2.3 of this document
	Remote control of RMG Crane	Sec. 6.3 of this document
	Mobile control panel with safety functions	Sec. 5.3.6, TR 22.804
Intelligent transport	Virtually coupled trains	Sec. 5.1.9, TR 22.804
Factory of the Future	Motion control	Sec. 5.3.2, TR 22.804
	Mobile robots	Sec. 5.3.7, TR 22.804
	Process automation – closed loop control	Sec. 5.3.11, TR 22.804
Smart Energy	Primary frequency control	Sec.5.6.2, TR 22 804
	Power distribution grid fault management	Sec. 5.6.4, TR 22.804
	Synchronicity between the entities	Sec. 5.6.5, TR 22.804
	Differential protection	Sec. 5.6.6, TR 22.804
	Wind power park control traffic	Sec. 5.7.5, TR 22.804
UAV (Drones)	UAV traffic control	Sec. 6.6 of this document
Positioning	Precise GNSS positioning	Sec. 6.7 of this document

[2] As mentioned earlier, automotive use cases are out scope of this document.

6 PRIORITIZED URLLC USE CASES AND THEIR REQUIREMENTS

6.1 Introduction

As can be seen from the previous chapter, there is a broad range of use cases from different vertical industries that may potentially have URLLC requirements. This chapter will highlight some of the use cases (summarized in Table 2) that are of primary interests of operators and the requirements and concerns that need to be addressed by 5G.Note that the order of use cases in the table does not represent nor indicate any order of priority. All use cases are equally identified as ones that are believed to be focused on by the ecosystem first when developing 5G applications.

Table 2. Summary of prioritized use cases

Use case group	Use case example	e2e latency	jitter	round trip time	e2e reliability	network reliability	user experienced througput	network throughput	availability	time synchronous accuracy	device/connection density
AR/VR	Augmented worker	10ms			99.9999%						
	VR view broadcast			<20ms	99.999%		40 - 700Mbps				3000/km^2
Tactile interction	Cloud Gaming	<7ms (uplink)			99.999%		1 Gbps				3000/km^2
Energy	Differential protection	<15ms	<160us		99.999%		2.4Mbps			10us	10-100/km^2
	FISR	<25ms					10 Mbps				10/km^2
	Fault location identification	140ms	2ms		99.9999%		100 Mbps			5 us	10/km^2
	fault mngmnt in distr. Power generation	<30ms				99.999%	1Mbps		99.999%		<2000/km^2
Factory of the future	Advanced industrial robotics	<2ms		<30ms task planner; <1-5ms robot ctrl	99.9999% to 99.999999 %						
	AGV control	5ms			99.999%		100 kbps (downlink) 3-8Mbps uplink				
	Robot tooling	1ms robotic motion ctrl; 1-10ms machine ctrl	<50%		99.9999%						
UAV	UTM connectivity				99.999%		< 128 bps				
	Cmnd & Ctrl	<100ms			99.999%						
	Payload	application dependent									
Position measure-ment deleivery	for AR in smart factory	<15ms							99.9%		
	for inbound logistics in manufacturing	<10ms							99.9%		

6.2 AR/VR

6.2.1 Augmented worker

Augmented worker allows assistance for tasks such as equipment repair where the operator must intervene but the access is difficult (for example, in a nuclear power plant) or the expert is at a remote place and cannot

carry out the task himself (intervention in a factory). In this case the (human) operator/expert will intervene remotely with the help of a special software and equipment (goggles, gloves, etc.), called as “Augmented Worker”, which is a remote controlled operation to carry out remote intervention tasks.
Augmented Worker use case will be possible thanks to 5G networks that will provide ultra-low latency enabling an accurate remote operation. The (human) operator/expert is aware in real time of the ongoing process inside the factory. The (human) operator/expert is in the center of data exchanges for protection of the systems and its own protection.
The (human) operator/expert must be able to perceive a failure scenario and take back manual control of the automated processes. Optimization of both human actions and automated processes to improve productivity is required.

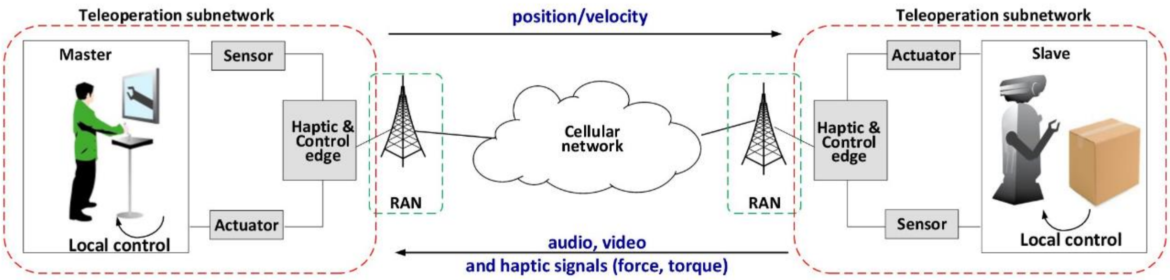


Fig. 5 Augmented Worker

In order to support augmented worker, the requirements on communications services are as follows:

- End to end latency: 10ms.
- End to end reliability: 99.9999%
- Positioning: indoor positioning service with horizontal positioning accuracy better than 1 m, 99% availability, heading < 10 degrees and latency for positioning estimation < 15 ms for a moving UE with speed up to 10 km/h.
- Other requirements including: Application-level requirements:
    - The AR (Augmented Reality) application should have easy access to different context information (e.g., information about the environment, production machinery, the current link state, etc.).
    - The (bi-directional) video stream between the AR device and the image processing server shall be encrypted and authenticated by the 5G system.
    - Need for real time data processing.
    - Need for real time data processing.
- 5G network architecture requirements:
    - No need for dynamic scalability.
    - Mobility at standard values.
    - Frequent connectivity.
    - Introduction of edge computing (desirable).
    - Accurate security mechanism (required).
    - A specific network slice may be required.

6.2.2 360 panoramic VR view video broadcasting

Today video broadcasting is only on limited Field of View. 360 panoramic VR will be the next generation of technology to enable 360-degree surrounding experience in real time just like being in the stadium watching in any direction, thanks to goggles used by the spectators. In additional, 360-degree cameras can be installed at designated locations to provide view from different angles at the same time. In particular, "first person view", for example, installed at the driver helmet or mounted on Formula E car to let the audience has the same eye level halo view.

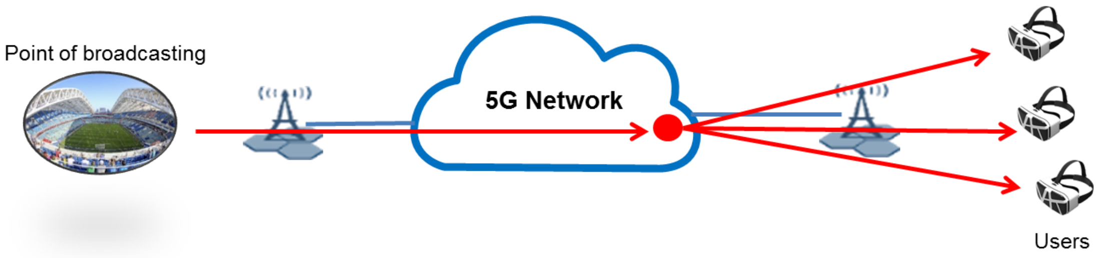


Fig. 6 Illustration of VR view of video broadcasting

One of the key requirements in this application is to match with the motion-to-photon (MTP) requirement of human, which is 20ms. Or else, the audience may fall into situation of cyber sickness. In this case, the end-to-end round trip delay needs to be within 20ms as shown in the following diagram.

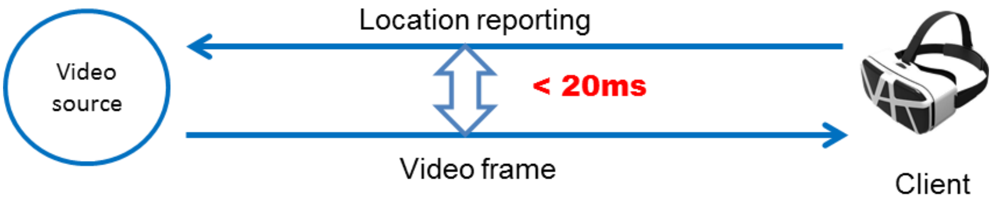


Fig. 7 End-to-end round trip delay in VR

On the other hand, the application also request for high bandwidth as well.

In order to support 360 panoramic VR view video broadcasting, the requirements on communications services are as follows:

- Round trip time: < 20ms[3]
- End to end reliability: 99.999%
- User experienced throughput[4]: 40Mps (4K video) to 5Gbps (12K video which equivalent to 4K in TV)
- Other requirements including:
  - Indoor coverage is essential as the audience may stay at indoor site.
  - Need to support multiple devices within an area : 3000/km2
  - Supporting at least 3 degrees of freedom (3DoF) with 60 frames per second and 6 degrees of freedom (6DoF) with 75 fps.

6.2.3 AR and MR cloud gaming

AR and Mixed Reality (MR) are becoming mainstream technology that can be applied in daily use. Gaming such as next generation of Pokemon Go is one of the major areas of AR/MR application [3].

[3] 20ms should include the time displaying image to the user which, in other words, depends on the technologies of end devices as well.
[4] The bandwidth requirement is client dependent. The figure quoted is taken from reference [10].

Fig. 8 An example of AR/MR based gaming applications

One of the barriers on this application is the size of the VR gear as the application is compute demanding. The industrial trend is to offload the compute intensive work to Edge Cloud. This will put a low latency and high bandwidth requirement on the transport network. Especially, the gear needs to send the captured video to the Edge side.

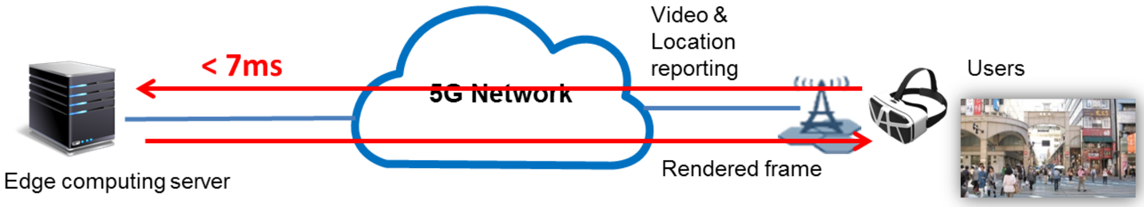


Fig. 9 Cloud gaming with edge computing

In order to support AR and MR Cloud gaming, some of the requirements on communications services are as follows:

- Uplink end to end latency < 7ms.
- End to end reliability: 99.999%.
- User experienced throughput: 1Gbps (uplink & downlink).
- Need to support multiple devices within an area: 3000/km^2.

6.3 Remote control of automated Rail-Mounted Gantry (RMG) crane

In a port, the automated Rail-Mounted Gantry (RMG) Crane is used to perform container stacking and lifting operations in container yards. For the safety of RMG Crane operators, there is a desire to operate RMG cranes remotely form the port control center, where the operator controls the RMG loading and unloading operations based on the real-time video backhauled from the terminal field. Remote RMG control provides not only a safe and comfortable working environment for the operator, but also enables one-to-many operations, i.e., remotely support equipment operations in multiple locations.

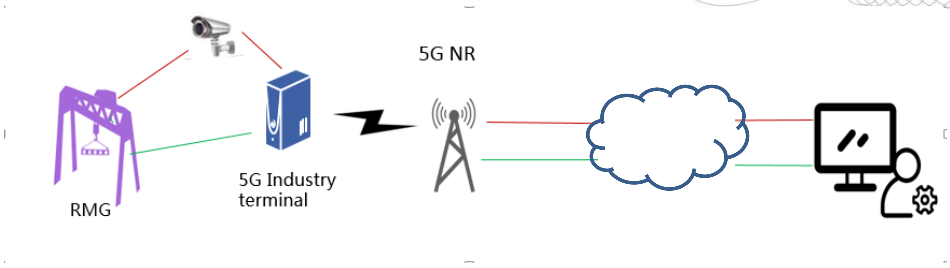


Fig. 10 Remote control of RMG Cranes.

In this case, 5G network is required to provide sufficiently high uplink data throughput and transmission reliability, sufficiently low transmission latency. From the perspective of network deployment, it can be a mix of indoor/outdoor. This case requires video real-time backhaul and remote control applications. Specific considerations in terms of handover delay and cell capacity are needed.

The network architecture requirements:

- Mobility at standard values.
- High-frequency connectivity.
- Moderated number of connected devices per venue.
- Introduction of edge computing would be desirable.
- Special attention to security/privacy of concerned data.

In order to support this case, the requirements on communications services are as follows:

- End to end latency: 20 ms.
- High reliability for remote control information: 99,999%.
- Remote control bit rate (down link): 100 kbps
- Real time video (1080P) for human control: 40Mbps in UL for one RMG crane, 120Mbps in UL for a cell.
- Need for real time data processing.

6.4 Energy

6.4.1 Smart distributed power distribution automation

Smart distributed power distribution automation terminal mainly realizes protection and control over the power distribution grid, detects the power distribution grid line or equipment state information, rapidly implements fault diagnosis and accurate positioning, rapidly isolates the fault section or failure equipment and consequently resumes normal area power supply.

6.4.1.1 Development trends of smart grid

Traditional distribution grid protection largely adopted simple over-current and over-voltage logic without relying on communication. It cannot realize segmental isolation, leading to an extended outage range. To realize precise fault isolation, operation information of adjacent elements should be obtained. Centralized or distributed structure can be adopted for information transmission.

Centralized structure:

Central logic unit mainly takes charge of protecting logic operation and sending protection instruction. Local logic units are responsible for local information acquisition and processing, executing local protection instructions, and transmitting processed local information to the central logic unit. Communication is needed between central logic unit and each local logic unit. Centralized identification of fault location could be realised in a centralized structure, see Fig. 11Fig. 11.

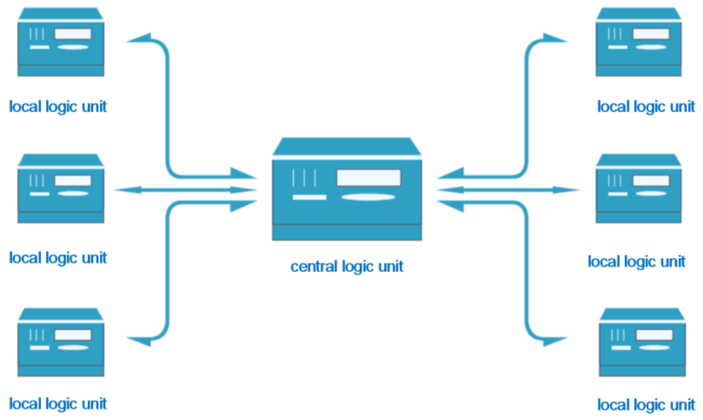


Fig. 11 Centralized structure of distribution network protection

<u>Distributed structure:</u>

Terminals are divided into groups according to the grid structure; each terminal in a group can play the role of a central logic unit and locally execute protection operation. Local information processed by terminals is transmitted to the O&M centre. Communication is needed between local logic unit and the adjacent local logic units, and is also needed between O&M centre and each local logic unit. Differential protection (DP) and FISR of Medium Voltage Ring could be realised in a distributed structure, see Fig. 12.

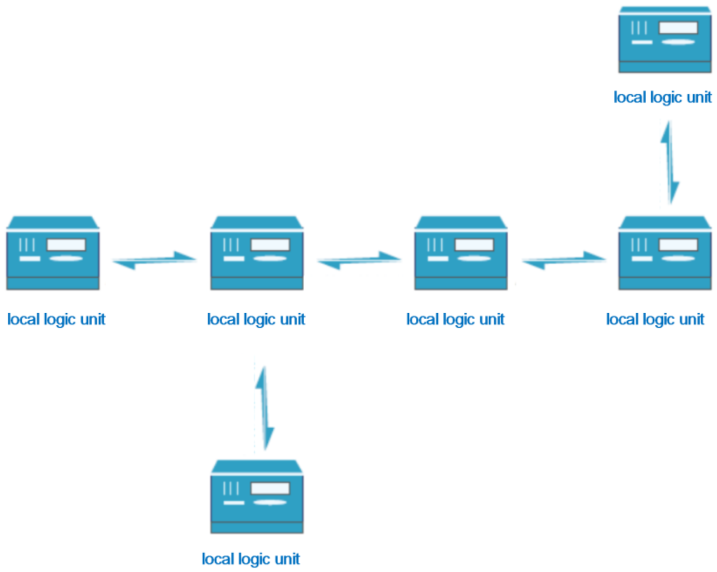


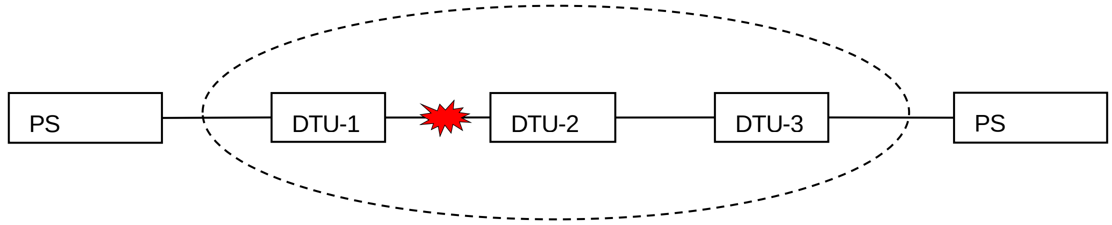
Fig. 12 Distributed structure of distribution network protection

Nowadays, smart distributed power distribution automation can be implemented based on cable/fibre transmission with high O&M load and high deployment cost. Considering the large number of existing stations in power distribution network, the cost will increase dramatically if smart distributed power distribution automation is implemented based on fibre. 5G will be a cost efficient alternative solution to optical fibre to carry power grid services. In particular, in the situation of overhead line, fibre cable installation is prohibitively expensive. The electrical power companies consider 5G can be potentially applied to meet URLLC requirements at least in differential protection and FISR system. More specifically, fault location, isolation & service restoration is an area demanding for a communication channel with very low latency and high reliability.

6.4.1.2 Differential protection requirements

Differential Protection (DP) can realize precise localization and fast isolation of fault in power distribution grid. Furthermore DP could shorten the power supply recovery time from hour-level to minute-level, significantly reduce scope impacted by power failure and improve power quality.

As illustrated in Fig. 13, several distribution termination units (DTUs) compose a protection zone of DP. All DTUs exchange their current value information with their neighbours in a strict cyclic pattern. A timestamp is associated with each current value and indicates when the current value is sampled. If there is no fault or fault occurs out of the protection zone, differential current among all DTUs is almost zero. If fault occurs inside of the protection zone, differential current will exceed a threshold, and then the circuit breaker cuts off the circuit. So the fault is isolated.



PS: Power Station
DTU: Distribution Terminating Unit

Fig. 13 DP implementation in a Distribution Network of Smart Grid

Considering AC value changes periodically, synchronisation among DTUs is very important to make sure all DTUs sample at the same time.

The current of the DTU is sampled 24 times within 20 ms, that means message is generated every 0.833ms. The message, containing sampled current value, voltage value and so on, is transmitted from one DTU to its neighbouring DTUs with an end-to-end latency of less than 15 ms. The message size is approximately 250 bytes according to IEC 61850[5], therefore the user experienced throughput is 250*8bit/0.833ms = 2.4Mbit/s.

In order to support differential protection, the requirements on communications services are as follows:

- End to end latency: less than 15ms (DTU-to-DTU)
- Jitter: less than 160us
- End to end reliability: 99.999%
- User experienced throughput: 2.4Mbps (for both downlink and uplink)
- Time synchronous accuracy: less than 10us
- Other requirements including:
    - Connection quantity: 10~100/km2 (both out-of-door & in-door)
    - Throughput density: 24~240 Mbps/km2
    - Typical end-to-end communication range: 10km

.

[5] IEC 61850 is a series of international standards that define communication protocols for intelligent electronic devices at electrical substations.

Notes

- End-to-End latency is a DTU-to-DTU one way latency including uplink downlink air interface latency between 5G terminals and gNodeB, core network latency between gNode Bs and high-layer protocol processing latency. Please also refer to Section 3.2.
- Time synchronous accuracy refers to the difference in latency between transmission and receiving path. This is a critical factor considered by power companies in adopting 5G for this application. If the time synchronous accuracy requirements cannot be met, the application won't work. 10µs is a reference value but it can vary depending on the final agreement made with power companies.
- A jitter in latency in DP may cause a series of data packets arriving at the destination out-of-order, and further cause a wrong decision in the destination DTU. Therefore, in Section 5.6.6.6 of TR22.804, a jitter is required to be less than 50% cycle time (i.e., 0.833ms). However, re-ordering mechanism or time-stamp could be used to solve out-of-order issue. Therefore, jitter is an important consideration in this case.

6.4.1.3 FISR of medium voltage ring

Fault isolation and system restoration (FISR) in a medium-voltage ring is for automation of fault management in the distribution grid. Fault management includes localization of the fault, isolation of the fault, and service restoration. It can help to reduce the outage time in the grid and reduce the workload of maintenance team via automation.

The following diagram shows a typical Medium Voltage Ring.

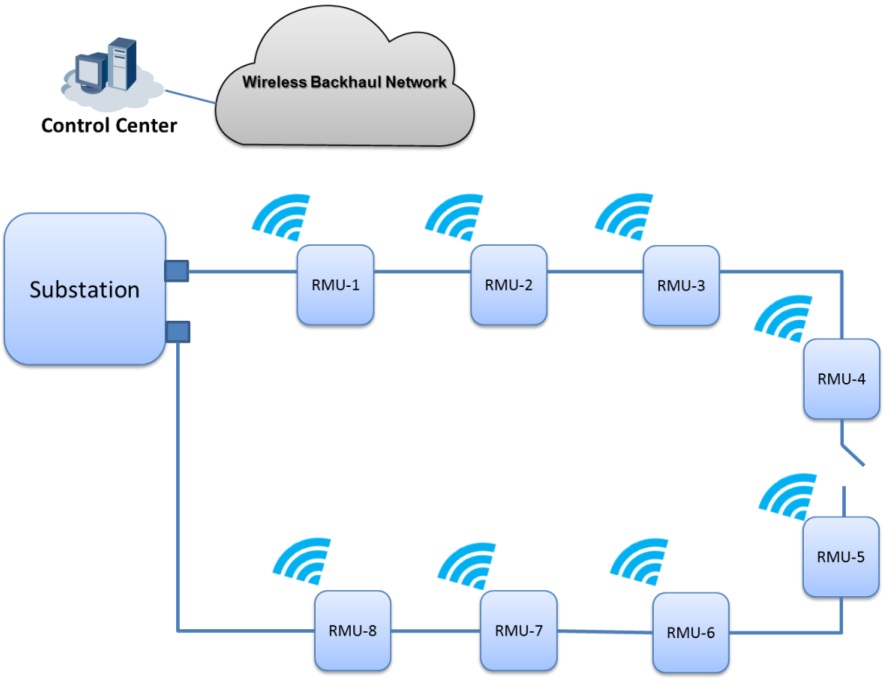


Fig. 14 Medium Voltage Ring

Ring Main Unit (RMU) is the key actor to detect, isolate, recover and report the faults in the ring. It keeps sending the states (e.g., "emergency closer idle") and actions taken (e.g., "activating closer") to the Control Centre via the wireless backhaul as well.

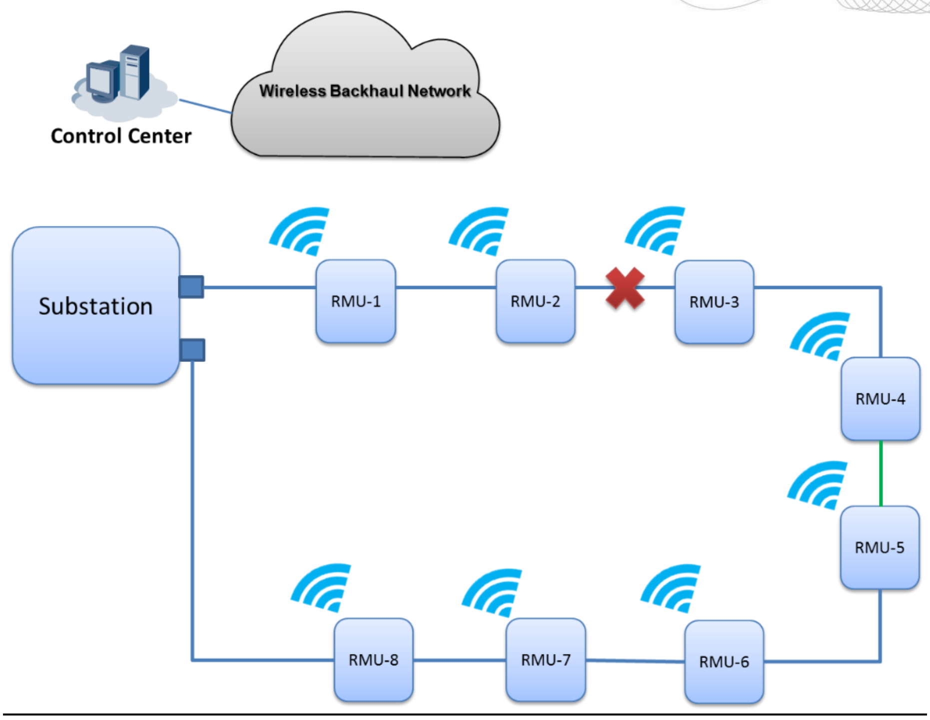


Fig. 15 Flow of fault Isolation and service restoration

The flow of FISR Procedure is as follows (see also Fig. 15)

1. Supposing the cable between two RMU (2 and 3 in this example) is broken, the corresponding RMUs will detect the fault and report it to the control center.
2. RMU-4 will then open the load switches to ensure the distribution network can still operate and in the meantime, report the action taken to the control center.

With the events reported, the Control Center can further take network wide operation if necessary. In terms of FISR, this is a part of the multiple-tier FISR architecture normally adopted by power companies.

The requirements on communication services to support FISR is as follows,

- User experienced throughput: 10Mbps.
- End-to-End Latency: less than 25ms.
- Connection quantity: 10/km2 (in urban area).
- Typical end-to-end communication range: Up to 100km.
- Follow the communication requirements specified in IEC 61850-90-4 and IEC 61850-90-12.

6.4.1.4 Identification of fault location

In distribution electricity, the Phasor Measurement Unit (PMU) is deployed along the electricity line and used for real-time measurement and monitoring of frequency/voltage/power to reflect the state of the system, as illustrated in Fig. 16. When fault happens in the network, there will be change of the frequency/voltage/power in the distribution electricity. All PMUs will record the time of the change and send the information (the change of the frequency/voltage/power and the corresponding time) to the server. Based on the information from PMUs the server performs analysis and identifies the location of the fault. In this case, time information among the PMU's must be accurately synchronized, which put a high demand on the time synchronous accuracy, see Section 5.6.5 of 3GPP TR 22.804 [4] for more information.

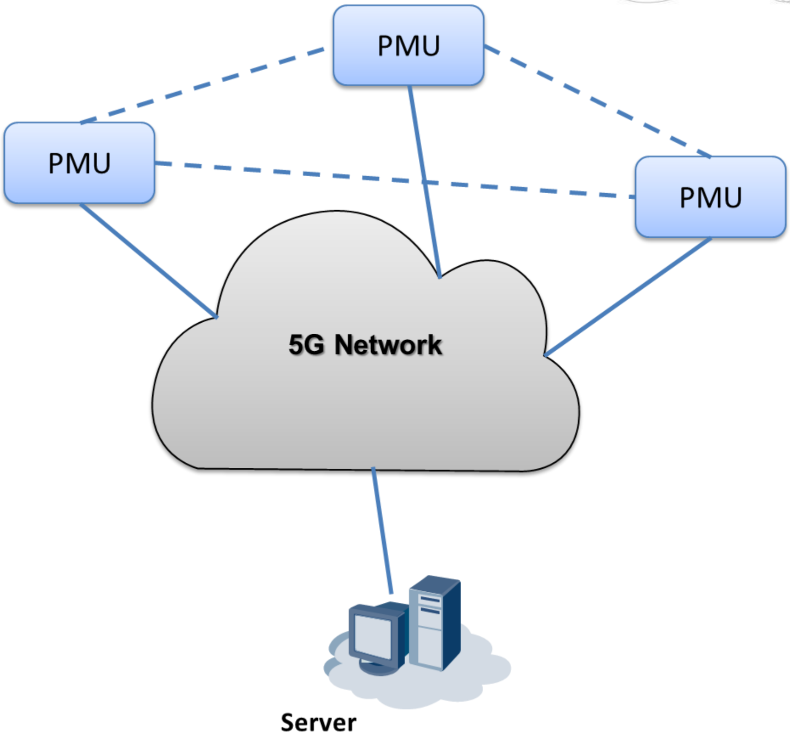


Fig. 16 Architecture of fault location identification system.

To support the fault location identification service, the following requirements need to be fulfilled.

- User experienced throughput: 100Mpbs.
- End-to-End Latency: 140ms.
- End to end reliability: 99.9999%.
- Connection quantity: $10/km^2$.
- Time synchronous accuracy: 5µs.
- Jitter: 2ms.
- Typical end-to-end communication range: 2km (from PMU to server).

6.4.2 Fault management for distributed electricity generation in smart grids

This use case consists of remote decoupling protections for Distributed Generation (DG) in electric grid and considers two electric feeders in a primary substation and all the DGs connected to these feeders. Fig. 17 presents the schema of the existing solution for protection of distributed electricity generation in smart grids [13].

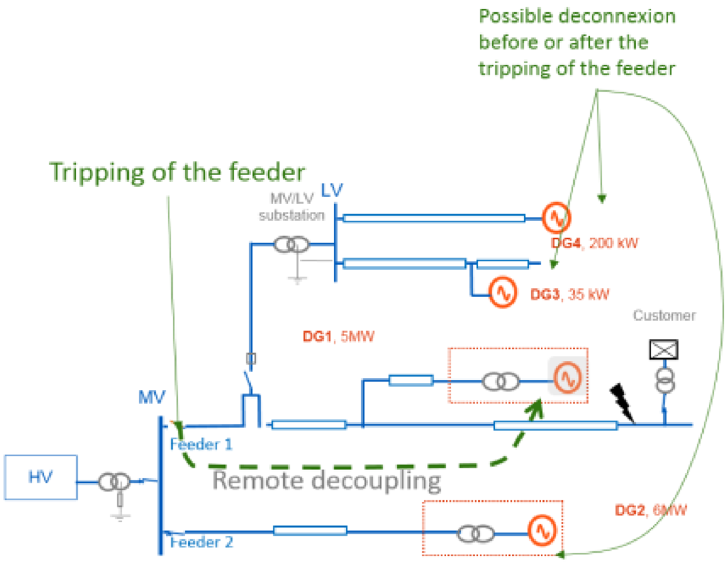


Fig. 17 FDP implementation in Distribution Network of Smart Grid.

The use case comprises the following elements, which represent the high-level architecture demands.

- A schema network of distributed energy sources can be PV panels or wind generation equipped with their protections.
- A schema of a two feeder's primary substation equipped with protections.
- The schema of a distribution network, connecting sources and primary substation.

The use case comprises the following steps/phases, representing different conditions in the network:

- At the beginning, there exists a specific configuration (NORMAL phase).
- A fault situation occurs (PRIMARY FEEDER 1 OPEN phase).
- The information is immediately relayed to the DG1, DG3 & DG4 of the grid (DGs FEEDER 1 OFF phase).

The problems that the use case targets to solve relate to:

- More robust electric grid due to hierarchical coordinated protection;
- Worst case latency, thus delivering a single message within its guaranteed delivery time;
- Ongoing evolution of the power grid into a grid supporting a much greater amount of distributed generation without any risk of unwanted islanding.

In order to support fault management for distributed electricity generation in smart grids, the requirements on communications services are as follows:

- End to end latency for fault detection: guaranteed worst case, <30 ms.
- End to end reliability: 99.999%.
- User experienced throughput: 1Mbps.
- Network availability: 99.999%.
- Other requirements including:
    - Power efficiency – Battery lifetime in all equipment at least 10-15 years, if possible 20 years.
    - Ubiquitous coverage and better penetration.
    - Low device unit cost – radio modules at few euros.
    - Strong security – 100% secure.
    - Number of connections < 2000 devices/km^2.

In case of the latency cannot be obtained, a notification should be issued to switch to the deployment of a fall-back configuration of the DGs protections.

Finally, the following integration needs are identified at first instance:

- Infrastructure elements integration and configuration.
- 5G network availability.
- URLL slice.
- Provision of radio equipment/module to be integrated at device level.

6.5 Factory of the future

6.5.1 Advanced industrial robotics

The main motivation with advancement of industrial robotics for manufacturing factories is to enable product customization and further optimization of the production lines to remain competitive in an innovation driven economy [11][12]. Reducing cabling and centralization of control nodes will reduce infrastructure cost and will provide higher flexibility, which are the main traits of the factories of future. High speed wireless infrastructure such as 5G networks and cloud computing can support such transition with minimal impact. Virtualizing robot controllers and centralized such controlling nodes in a local data center enables flexible reconfiguration of the automation cell and production control, while at the same time enabling advanced computing in the (local) cloud reducing investment cost.

Industrial robotic cells have a local computer, a Programmable Logic Controller (PLC), that costs money, takes space and creates heat that requires cooling. Individual, isolated robot controllers also have limitations on coordination. Moving control into a cloud environment allows the footprint of the robot to be reduced, facilitating a higher density production. It also allows reducing the robot cost as a control computer is not required for each robot. To achieve this goal, robots shall be connected with their controllers via a high bandwidth, low latency, and reliable wireless communication network. An on-site cloud computing environment is realized alongside with the legacy system. Control functions (e.g. AGV coordination functions, line PLC, station PLC) which control the overall automation cell (including robots and conveyor belts) are placed on such a local cloud platform, which is connected with sensors and actuators (on AGV, Valves, I/O modules, on robot) as shown in Fig. 18.

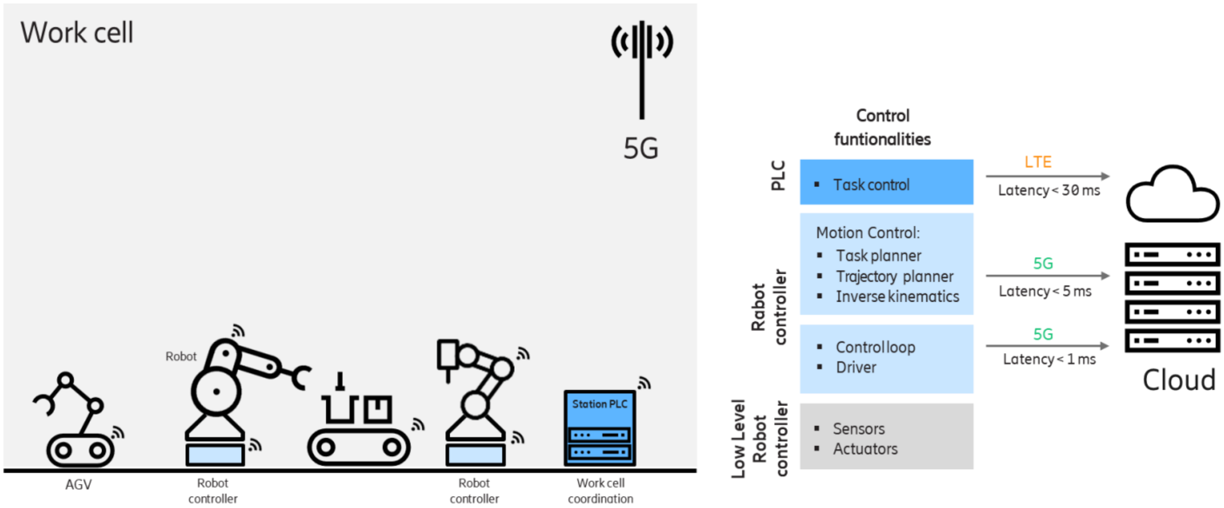


Fig. 18 Cloud robotics enabled by 5G latency requirements (Source: Ericsson).

The 5G network must fulfill the following requirements:

- Ultra-reliable and low latency communication with latency bounds according to Fig. 18,

- On-premise cloud capability with local breakout of user traffic,
- Highly reliable virtualization platform,
- Reliable network infrastructure, e.g. with redundancy,
- Relevant security and authentication mechanism.

The 5G network requirements, for this use case, depend on which control functions are moved into a cloud execution. Moving more control functions into the cloud increases the flexibility for the robotics solution, but also imposes more stringent performance requirements on the communication network. This trade-off is illustrated in Fig. 18. For example, with round trip latencies below 30 ms the task control can be moved to the cloud. If also robot motion control is to be moved to the cloud, the round-trip latency may not exceed 5 ms. If also the isochronous real-time control of the drives should be moved away from the robot, a round trip latency of less than 1ms would be required.

6.5.2 Control the journey of automated guided vehicles

In the factories of the future there will be coexistence between Automated Guided Vehicles (AGV) and humans. The introduction of AGV will allow the transportation of products, pieces of products, tools and raw materials across the factory according to logistic needs between storage areas and production lines. To execute these complex tasks AGVs are to be mobile robots with the capacity to follow information flows on inventory and others, capacity for handling materials, monitoring and control, image processing, recognition, etc.

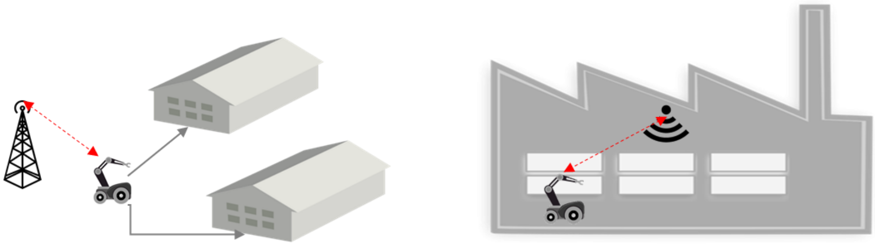
Unmanned intervention on industrial sites will be possible thanks to 5G which fulfils the low latency, high reliability, network availability and high precision location required for the remote control of unmanned vehicles. AGV will also have an important level of autonomy and perception ability thanks to the use of sensors to sense and react with their environment, see Section 5.3.7 of 3GPP TR22.804 [4].

In this use case there are two options for control i.e., a) AGVs controlled by a centralized automatic controller or b) AGV controlled by a human, as presented in Fig. 19.

In the centralized automatic controlled case, AGVs are automatically steered to move materials efficiently in a restricted facility, see Section 5.3.7 of 3GPP TR 22.804 [4]. It requires live monitoring and remote control applications. For the human controlled case it requires additionally augmented reality application.

Fig. 19 AGVs controlled by (a) a centralized automatic controller or (b) a human controller.

From the network deployment point of view it can be a mix of indoor/outdoor or purely indoor, as presented in Fig. 20. This will imply specific considerations in terms of frequency band, penetration loses, handover processes and intra-band interference.



a) b)

Fig. 20 AGVs network deployment in a) indoor/outdoor or b) indoor environments.

The network architecture in this use case will have the following characteristics:

- No need for dynamic scalability.
- Mobility at standard values.
- Frequent connectivity.
- Moderated number of connected devices per venue.
- Introduction of edge computing would be desirable.
- Special attention to security/privacy of concerned data. Slicing could be a good solution for this.

The following requirements on communication services should be accomplished to achieve this use case:

- End to end latency of 5 ms.
- High reliability: 99,999%.
- Remote control bit rate: 100 kbps.
- Real time video for human control (case b) in Fig. 19): 3 to 8 Mbps in UL for 1080p.
- Need for accurate location.
- Need for real time data processing.

Another particularity of this use case is that it requires a high level of safety to enable automated vehicle in shared human/moving machines areas. Emergency stop procedures are to be introduced which can be triggered by the AGV itself as well as by the central control unit.

6.5.3 Production line enhancement – robot tooling in the factory

In the factories of the future there will be different types of communications:

- between machines (a machine can be a robot)
- between human and machine (also called cobotics)

in order to enhance production in the future factory.

Production Line and robot tooling in the factory will be enhanced thanks to new features provided by the 5G network. The reliability of the transmissions has to be very high: the measurements need to be received successfully and any commands sent to the actuator must also be received successfully, all within tight latency bounds. In the Factories of the Future, static sequential production systems will be more and more replaced by novel modular production systems offering a high flexibility and versatility. This involves a large number of increasingly mobile production assets, for which powerful wireless communication and localisation services are required.

The 5G architecture must fulfill following characteristics for production line:

- No need for dynamic scalability
- Mobility at standard values
- Frequent connectivity

- High security mechanism will be requested

The following requirements will be needed for this use case:

- End to end reliability: up to 99,9999%
- Ultra-low end to end latency for a cyclic data communication service, characterised by at least the following parameters:
  Cycle time of:
  - 1 ms for precise cooperative robotic motion control
  - 1 ms to 10 ms for machine control
- Need for real time data processing
- Jitter < 50% of cycle time

6.6 Unmanned Aerial Vehicle (UAV) traffic control

UAVs are already considered for a magnitude of use cases and applications. Use Cases and related requirements on the technology are quite divers. Nevertheless a basic set of features can be identified and analysed with regard to the demand towards technical implementations:

- A coordination of manned and unmanned air traffic contributes to entire air traffic safety. Current rules for flying in visual range do not provide sufficient guarantee, in particular since due to speed and size of objects human capabilities are not sufficient to control all actions while flying an aircraft or even a UAV in full control with all surrounding objects.
- For professional and efficient use of UAVs an automated operation is required. By precise planning of a mission the UAV can perform all required activities. By sending the telemetry-data from UAV to pilot and any commands from pilot to UAV the other way round, the pilot remains in control and can step in if necessary.
- To cover all Use Cases the connectivity of UAVs should be independent from range of current remote controls mainly operated with WiFi.
- Beyond Command & Control for controlled flight an additional Payload-Communication shall be established. The transmission of these payload data can be an essential part for certain use cases with UAVs. While in some use cases storage of sensor- and video-data may be sufficient which are captured and analyzed after return and landing of the UAV other use cases may depend on the just-in-time transmission of the payload-data to explore full potential of the UAV mission.

In fact, three different transmission needs have to be handled in parallel (see Fig. 21):

- A channel for the interaction with air traffic management for safe integration of the UAV in the air space. This is called the UTM (UAV-Traffic Management) channel.
- A Command & Control channel between UAV and its pilot.
- A payload channel which depends on the kind of mission and the specific demands on this transmission.

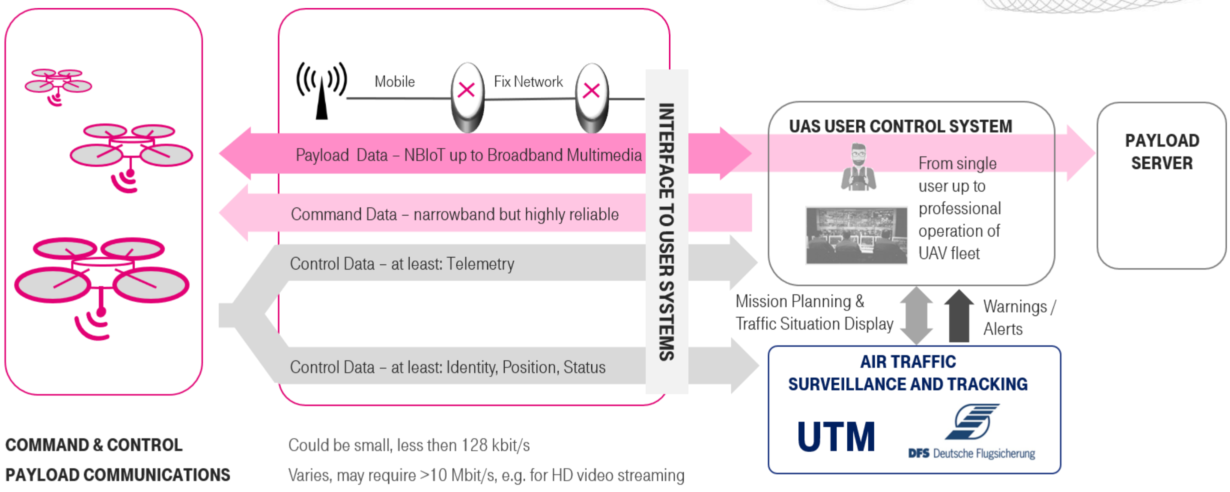


Fig. 21 UAV Communication traffic overview.

In fact, a lot of communication is needed with specific demands regarding availability of the data link, throughput, latency, area coverage. Although each single transport stream may have specific technical solutions, overall the mobile communication network must be able to cover all of these demands with respective quality, efficiency and economics in parallel.

Specific requirements for communication are:
UTM connectivity:

- Narrow band communication (expected 128bit/s or less).
- High availability (>99.999%).
- Large coverage area (99%).

Command & Control connectivity

- Mainly Narrow band communication (expected more than for UTM connectivity depending of the amount of telemetry data the UAV is providing).
- High availability (>99.999%).
- Large coverage area (99%).
- Low end to end latency, i.e., fast transmission in particular for commands from pilot to UAV: < 100ms.

Payload connectivity

- Very flexible and powerful: no or low throughput up to broadband coms.
- Low Latency – if required by a specific use case.

Overall

- Optimized connectivity for UAVs while reduction of interference effects (maybe by beam-forming).
- Priority for UTM connectivity and Command & Control-connectivity against payload traffic to increase air safety since in case of reduced bandwidth the essential traffic for air safety are kept as long as possible for the sake of payload.

The above features would support a multitude of use cases like UAV operations in logistics, infrastructure inspection, measurement and photography, security and surveying, agriculture, rescue and safety, even Drone taxi with relatively homogenous demands in command & control while payload and style of mission can vary a lot.

6.7 Positioning services

Positioning can be understood as a base-line service that enables a large variety of use cases making use of geo location. Use cases can be found in the fields of:

- IoT.
- Digitalization of (industrial) production facilities and campus areas.
- Autonomous vehicles.

Positioning services provide the localization information with the relevant high availability/reliability to the use case processing units. The latency requirements are E2E latencies from the triggering of the position measurement till the reliable delivery of the positioning data to the use case entity. Table 3 provides the detailed requirements on availability/reliability and latency for the positioning services related to the respective use cases.

Use cases may not be limited to these fields exclusively. Despite the focus has been in the past on the consumer segment, the main driver for positioning services from mobile networks of today is more introduced by business and business-to-consumer use cases. As such a key capability of mobile networks will be to provide appropriate positioning services to serve the positioning demand from various use cases.

Fig. 22 describes key positioning services of mobile networks and the types of use cases that can be served by them. It shows three main service areas:

- Precise Positioning.
- Cellular Positioning.
- 5G NR Positioning.

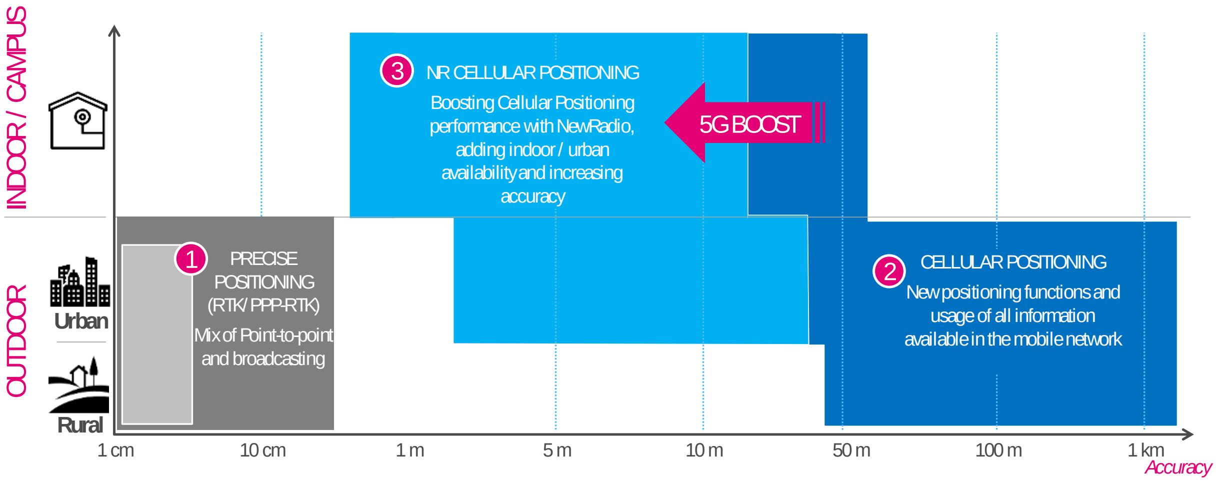


Fig. 22 Mobile positioning services and requirements.

These areas provide a “toolbox” of mobile network positioning service elements. There is no one approach that fits to all requirements. Typically, the requirements on the positioning service are determined by use cases, such as:

- Accuracy of the position information.
- Environment: e.g., outdoor, campus, indoor.
- Power consumption of the applied solution.
- Periodicity of positioning requests and information, respectively.
- Response time (latency) on a positioning request.

In the following sections these service areas and the related use cases are summarized.

6.7.1 Precise positioning

Precise Positioning delivers **meter-level down to centimetre-level positioning accuracy** to outdoor receivers by using GNSS (Global Navigation Satellite Systems) correction data via mobile data or mobile broadcast.

Currently the GNSS device market is getting a technology push with the introduction of **low cost multi-frequency chipsets** and components. These multi-frequency GNSS devices are building the foundation for precise positing applications.
Compared to the previous generation of single frequency GNSS devices with single frequency L1 technology the upcoming generation will support at least two frequencies (L1/L5 or L1/L2). These high precision GNSS devices will push the potential accuracy of the GNSS solution from the **meter to the centimetre**.

To fully leverage this potential accuracy following components are required (see Fig. 23):

1. Multi-frequency GNSS receiver and GNSS antenna
2. Correction data from a multi-frequency correction service
3. Positioning engine that calculate the coordinates of the precise position

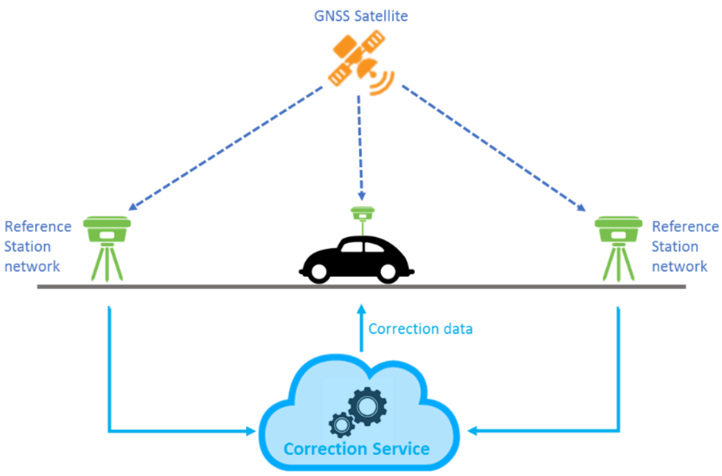


Fig. 23 System overview for precise GNSS positioning.

Today this technology with its components is professionally used with highely-priced systems in agriculture, machine control and surveying. The application can utilize accurate coordinates that are delivered out of a GNSS positioning engine. The results are also usually combined with other positing systems like Inertial Measurement Units (IMU) to compensate for poor line-of-sight from the GNSS Antenna to the satellites (e.g. under trees or bridges).

The market introduction of low cost GNSS devices enriches various applications with precise positions for example Advanced Driver Assistance Systems (ADAS), Internet of Things (IoT), Mapping or Logistics. The technology has the capability to provide a position of 1-2 centimetres accuracy within seconds. The position is an absolute position that can be located precisely on a HD-Map in a global coordinate system.

The GNSS devices on the road need to be connected to correction service to calculate its position. If the number of users is increasing a correction service with broadcast capabilities is required.

However, current terrestrial correction services are mainly provided via cellular internet applying unicast technology serving each user individually. These terrestrial unicast correction services have following properties

- It enables a position accuracy of 1-2 cm in less than 30 seconds

- Each GNSS device requires its own connection to the correction service backend
- Mobile internet connectivity is required to receive correction (usually TCP/IP)

This type of services is well established for the highly-specialized professional users that can afford higher cost of GNSS devices and service subscriptions. Mass market use cases demand a scalable approach that is offered at low cost while ensuring the service quality.

A new scalable solution for the mass market requires a new type of connectivity for the GNSS devices that can serve massive number of clients in a broadcast mode and avoids individual user connections into the backend of the correction service. This will maximize the scalability of the solution.

To achieve this, the broadcast capability of modern cellular networks can be used to distribute the data of the correction service to GNSS devices efficiently, see Fig. 24. Thereby, the broadcast service takes advantage of the cellular structure of the mobile network where correction data is distributed locally per radio cell to all users covered and subscribed to the service. An integrated connectivity as well as correction service management will take care that a superior service level can be provided.

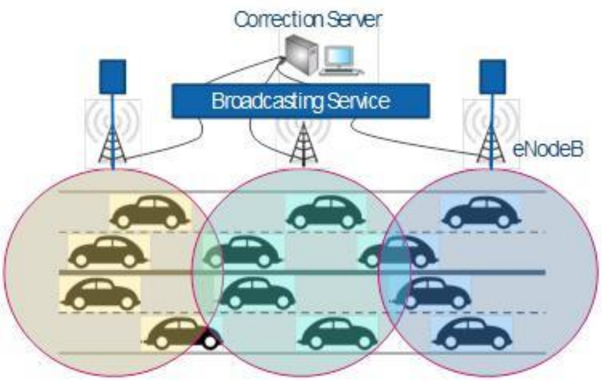


Fig. 24 Broadcast service via cellular network

This broadcast capability has been standardized at 3GPP in Rel-15. This service will be ensured in both integrated service fields, connectivity service and correction service.

Typical applications and use cases for Precise Positioning service are

- Autonomous vehicles
- Driverless trains and boats
- Precision farming
- Freight hubs (rail, truck, maritime)
- Ground robots / autonomous delivery
- Commercial drones

6.7.2 Cellular positioning

Cellular Positioning will deliver a **verified, indoor and outdoor tracking/navigation** at very low cost and suitable for **low cost devices** by using positioning data derived from mobile network functions.

The basic functionality is already standardized since 3GPP Rel-9. It was mainly driven by the U.S. FCC E911 mandate to ensure localization of calls in emergency events.

Nowadays use cases from various industries demand positioning service from mobile networks, such as:

- Asset and shipment tracking
- Local content provisioning
- Personal trackers
- Proximity marketing
- Physical access control (verified location)
- Digital freight paper

For many of these use cases legacy GNSS positioning is currently the only practical option. However, it has some downsides limiting the applicability of use cases:

- Only operating outdoors
- Relatively high power consumption, thereby limiting operation time
- Introducing additional equipment costs

Network based positioning services for broadband and narrow band access networks will be able to close the gap for many use cases. These services make use of network functions of the mobile network, see Fig. 25 below:

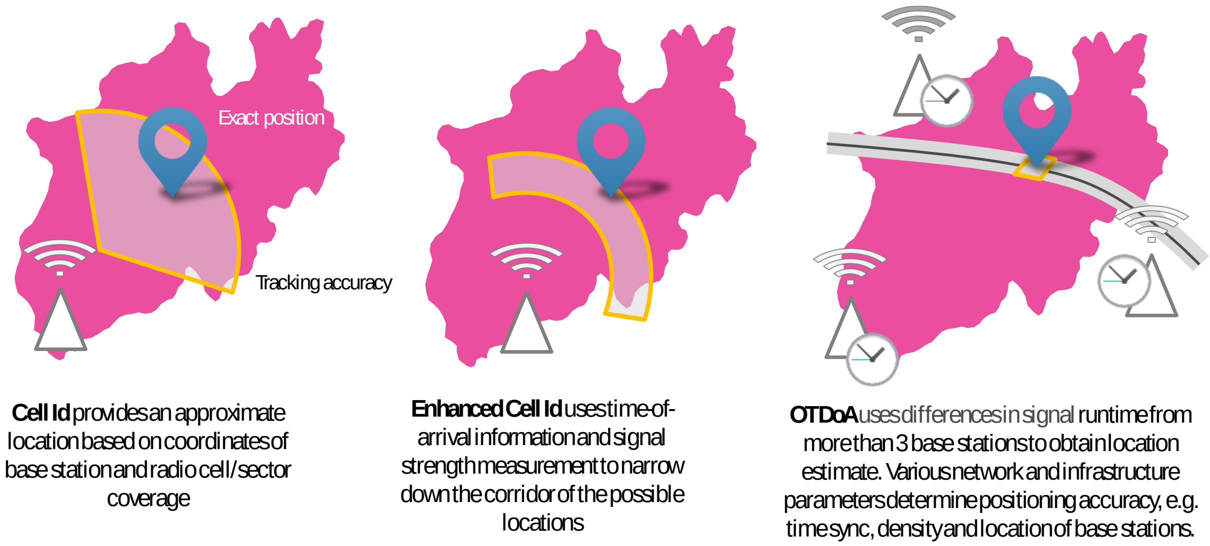


Fig. 25 Mechanisms applying positioning services in mobile network

These network services are mainly limited in their positioning accuracy, up to some 10 meters, for LTE, Cat-M and NB-IoT. Hence, legacy positioning services in mobile networks can only serve the demand of specific use case.

6.7.3 5G NR positioning

5G NR has the potential to open up network-based positioning for new use cases in the factory of the future or smart factories:

- Autonomous vehicles, such as
    - Autonomous vehicles deliver parts and tools inside the factory to the designated assembly line
    - Dynamic routing and change of destination
    - Self-driving fork lifts
- Asset management
    - Localization of tools and equipment at factory buildings (i.e. on campus)
    - Optimized handling and provisioning of assets
    - Optimized refill/maintenance/exchange processes for mobile assets like waste containers, compressors, tanks

- Warehouse management
    - 3D positioning allows optimization and automation of storage processes
    - Goods can be loaded and unloaded automatically by autonomous robots

3GPP SA1 provided a list of requirements on 5G NR for these types of uses cases (see Table 3 below) and 3GPP RAN started to work on a dedicated Study Item in Rel-16, with first focus on a reduced requirement set.

Table 3. Overview of use cases and their positioning requirements

Scenario	Horizontal accuracy	Availability	Heading	Latency for position estimation of UE	UE Mobility
Mobile control panels with safety functions (non-danger zones)	< 5 m	90%-	N/A	< 5 s-	N/A
Process automation – plant asset management	< 1 m	90%	N/A	< 2 s	< 30 km/h
Augmented reality in smart factories	< 1 m	99%	< 0,17 rad	< 15 ms	< 10 km/h
Mobile control panels with safety functions in smart factories (within factory danger zones)	< 1 m	99.9%	< 0,54 rad	< 1 s	N/A
Flexible, modular assembly area in smart factories (for tracking of tools at the work-place location)	< 1m (relative positioning)	99%	N/A	1 s	< 30km/h
Flexible, modular assembly area in smart factories (for autonomous vehicles (only for monitoring proposes))	< 50 cm	99%	N/A	1 s	< 30 km/h
Inbound logistics for manufacturing (for driving trajectories (if supported by further sensors like camera, GNSS, IMU) of autonomous driving systems))	< 30 cm (if supported by further sensors like camera, GNSS, IMU)	99.9%	N/A	10 ms	< 30 km/h
Inbound logistics for manufacturing (for storage of goods)	< 20 cm	99%	N/A	< 1 s	< 30 km/h

6.8 End to end analysis

This chapter has provided a sample of several prioritized use cases, particularly related to a few AR/VR scenarios, and automated factories, energy and control systems. As indicated earlier, this document does not cover automotive use cases, covered by NGMN partner, 5GAA.

Each vertical has a number of potential use cases, with variety of requirements. It is neither possible to identify all relevant scenarios, nor to accurately specify their requirements. However, the analysis is an effort to provide considerations for architectural design requirements, standardization, and deployment.

It is obvious that the performance envelope needs to advance, in terms of ultra-low latency and ultra-high reliability (in addition to high throughput, etc.), to meet the extreme requirements. At the same time, there is an increasingly need for flexibility and efficiency to make this possible and feasible. The system must be able to adjust to the requirements dynamically, with dedicated slices, as well as cross-slice management as required by the use case. This will also allow the possibility of horizontal synergy, and energy efficiency.

The other relevant work items, such as End-to-End Architecture and Service-Based Architecture, are affected, given the role of slice management, micro-service flexibility of function exposure, distributed intelligence, edge clouds, and automation. It also further motivates the standardization work (in RAN and SA) for URLLC enhancements, potentially continued beyond Rel 16. The challenges and trade-offs identified in Chapter 4 must be considered to enable these, and also make the operation feasible and sustainable.

7 CATEGORIZATION OF SERVICE LEVEL REQUIREMENTS

In this section, category of core requirements for URLLC service will be provided. There are various URLLC services, among which some may need low latency and some may need high reliability, it is difficult to list and classify all cases with corresponding performance requirements. In the meantime, the operators should evaluate the matching degree of network ability and service requirement to offer good user experience. Therefore, it is proposed to define categories of service level requirement for key performance parameters such as end-to-end latency, reliability, user experienced throughput etc. With the service level categorization, it will be simpler to describe use case requirements, matching that to the network capabilities and provided QoS at different levels, and facilitate network design and planning.

E2E latency, reliability and user experienced throughput are three essential performance requirements, which are classified in table 4/5/6.

Table 4: Category of E2E latency

category	End-to-end latency
1	<1 ms
2	1 ~ 10 ms
3	10 ~ 20 ms
4	20 ~ 50 ms
5	> 50ms

Table 5: Category of E2E Reliability

category	Reliability
1	>99.9999%
2	99.9999%
3	99.999%
4	99.99%
5	99.9%

Table 6: Category of User Experienced Throughput

category	User Experienced Throughput
1	>100Mbps
2	10Mbps
3	1Mbps
4	100kbps
5	<1kbps

Meanwhile, some specific requirements, such as positioning, time synchronous accuracy, and jitter are not applicable for all use cases. Table 7/8/9/10 show the category of these parameters.

Table 7: Category of Positioning Precision

Category	Positioning Precision
1	<50cm
2	<1m
3	<10m
4	<50m
5	<100m

Table 8: Category of Time Synchronous Accuracy

category	**Time Synchronous Accuracy**
1	<5us
2	<10us
3	<20us
4	<50us
5	<100us

Table 9: Category of Jitter

category	**Jitter**
1	<160us
2	<2ms
3	<20ms
4	<50ms
5	50ms <jitter<50% cycle time

Table 10: Power Efficiency

category	**Jitter**
1	>20 years
2	15~20 years
3	10~15 years
4	5~10 years
5	<5 years

Every URLLC cases listed in Section 6 can be identified by a combination of the above category of parameters. Take AR/VR, differential protection and Fault management for distributed electricity generation for example:

AR/VR augmented worker:

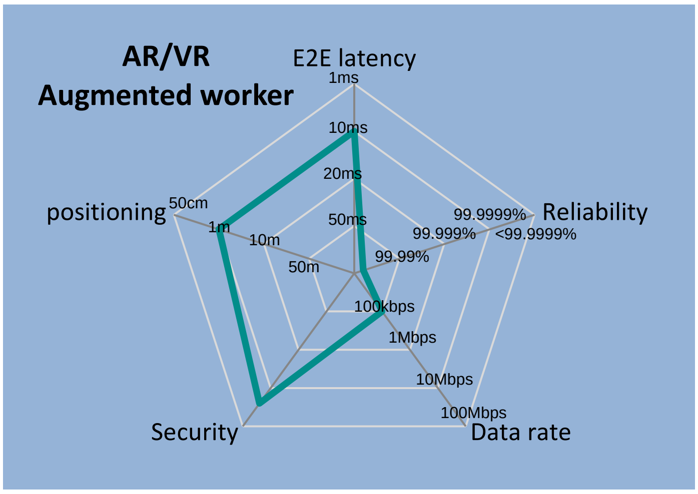


Fig. 26 Key requirements for AR/VR augmented worker

Differential protection:

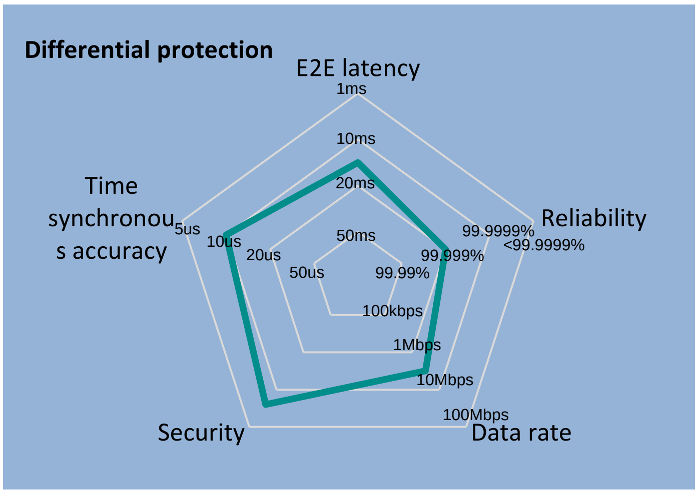


Fig. 27 Key requirements for differential protection

Fault management for distributed electricity generation:

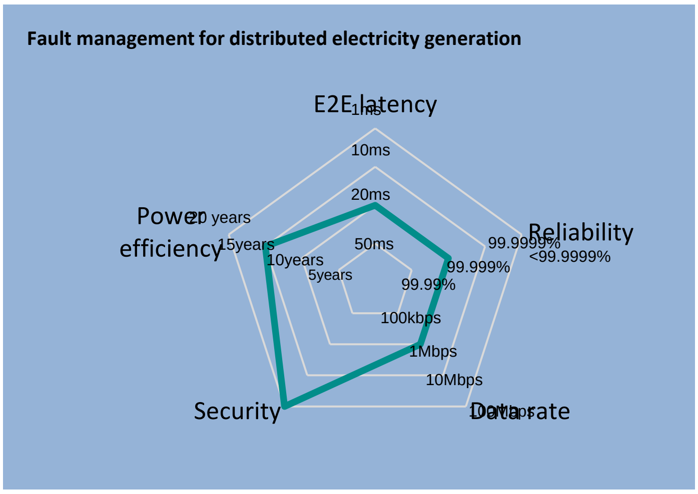


Fig. 28 Key requirements for Fault management for distributed electricity generation

Note1: Security is very important for vertical industry. However, due to the complexity of communication systems, security classification needs further study.

8 SUMMARY

Use cases that require URLLC are extensively studied. 3GPP developed 5G technology clearly stands out as the best candidate to meet the requirements of these use cases on communication systems with QoS assurance, flexibility, agility as well as cost and energy efficiency. This document tried to provide a survey of the relevant work performed in some of the SDOs and industry forums. This survey is by no means exhaustive. Instead it aims at providing a holistic view of the URLLC landscape.

Some of the use cases are identified as prioritized use cases based on the potential value a mobile network operator may provide in supporting such use cases. These include AR/VR based services for consumers (e.g., gaming) and industries (such as augmented worker for remote operations and remote support); automated fault detection and isolation in electricity distribution networks; control of AGV in factories and of drones.

Having a deeper look into the requirements of these use cases on communication services, we see a wide span of performance targets, for example, the latency ranges from 1ms in robot tooling to the order of 100ms in fault location identification in smart energy; reliability ranges from 99.9% to 99.9999%; and use experienced throughput from less than 128bps in command & control of drones to hundreds of Mbps or more in AR/VR-based applications. Indeed, there is no clear definition of ultra reliable low latency use cases. What is even more important to realize is that when driven solutions for URLLC use cases, an evolutionary approach can be taken, to start addressing use cases with a more relaxed requirements, and gradually evolving the technology and network deployment to address use cases with more aggressive targets.

The other observation is that some of the use cases may have stringent requirements on all three performance characteristics including latency, reliability and user experienced throughput, making these use cases a combined URLLC and eMBB use cases.

Given the wide varying range of performance requirements, a categorization of service level requirements was proposed in order to facilitate 5G technology development, network design and planning as well as 5G service provisioning.

The work presented in this document will hopefully provide an entry guide to those who want to learn URLLC use cases and requirements. The prioritized use cases are contributed by a few operators. Depending on the markets, operators' maturity in addressing vertical segments and their business strategy, aditional use cases can be considered as prioritized.

Some very important vertical use case requirements are not discussed. For example, security and dependability of communication systems are often a very important requirement of vertical use cases. For the identified prioritized use cases, some of the requirements are yet to be quantified.

Operators must collaborate with vertical industries and ecosystem partners to close these open loops to succeed in a connected society.

9 LIST OF ABBREVIATIONS

5GAA	5G Automotive Association
AGV	Automated Guided Vehicle
AP	Access Point
AR	Augmented Reality
CyberCAV	Cyber Control Application in Vertical domains
DG	Distributed Generation
DP	Differential Protection
DTU	Distribution Termination Unit
E2E	End to End
eMBB	Enhanced Mobile Broadband
FISR	Fault Isolation and Service Restoration
GPS	Global Positioning System
ICT	Information Communications Technology
IIoT	Industrial Internet of Things
LTE	Long Term Evolution
mMTC	Mass Machine type Communications
MR	Mixed Reality
NB-IoT	Narrow Band – Internet of Things
NG-RAN	Next Generation-Radio Access Network
NIC	Network Interface Card
OSI	Open System Interconnection
OT	Operation Technology
PLC	Programmable Logic Control
PMU	Phasor Measurement Unit
QoS	Quality of Service
RFID	Radio Frequency IDentification
RMU	Ring Main Unit
SBA	Service-based Architecture
SDO	Standard Development Organization
TSN	Time Sensitive Networking
UAV	Unmanned Aerial Vehicle
UE	User Equipment
UPF	User Plane Function
URLLC	Ultra Reliable and Low Latency Communication
UTM	UAV Traffic Management
VR	Virtual Reality