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TECHNICAL REPORT

**Digital Enhanced Cordless Telecommunications (DECT);
Study on URLLC use cases of vertical industries
for DECT evolution and DECT-2020**

Reference

DTR/DECT-URLLC1

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DECT, use case, PMSE, IoT

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Digital Enhanced Cordless Telecommunications (DECT).

The present document presents a study of use cases and vertical scenarios for Ultra-Reliable Low-Latency Communications (URLLC) based on different developments paths evolving DECT technology.

The present document is a preparation of follow-up technical specifications within DECT, DECT ULE, DECT evolution and DECT-2020.

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Introduction

The present document has been produced by ETSI TC Digital Enhanced Cordless Telephony (DECT) Working Group (WG) Ultra-Reliable Low-Latency Communications (URLLC).

1 Scope

The present document presents a study of use cases and vertical scenarios for Ultra-Reliable Low-Latency Communications (URLLC) intended to be used as base requirements for evolving DECT.

The proposed use cases can be classified as belonging to the following three major application areas:

- Home and Building Automation, including Smart Living;
- Industry automation - Factories of the Future, Industry 4.0;
- Media and entertainment industry - Programme Making and Special Events (PMSE).

The identified scenarios are intended to be implementable under 5G technology assumptions and timeframe. However some of them may also be implementable enhancements of current DECT technology.

By 5G technology assumptions, it is meant state of the art radio interfaces based on OFDM with optional use of MIMO.

The present document also describes the methodology and sources used for the identification of use cases, and describes the required DECT standard specifications for the implementation of the different evolution paths.

The present document is a preparation of follow-up technical specifications within DECT, DECT ULE, DECT evolution and DECT-2020.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI EN 300 175-1: "Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 1: Overview".

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[i.3] ETSI EN 300 175-3: "Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 3: Medium Access Control (MAC) layer".

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[i.5] ETSI EN 300 175-5: "Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI); Part 5: Network (NWK) layer".

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[i.12] ETSI EN 301 649: "Digital Enhanced Cordless Telecommunications (DECT); DECT Packet Radio Service (DPRS)".

[i.13] ETSI TS 102 527-1: "Digital Enhanced Cordless Telecommunications (DECT); New Generation DECT; Part 1: Wideband Speech".

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[i.34] 3GPP TSG-SA WG1 Meeting #80 S1-174146: "Use case: Low-latency audio streaming for local conference systems".

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3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the terms and definitions given in ETSI EN 300 175-1 [i.1] and ETSI TR 121 905 [i.27] apply.

3.2 Symbols

For the purposes of the present document, the symbols given in ETSI EN 300 175-1 [i.1] and ETSI TR 121 905 [i.27] apply.

3.3 Abbreviations

For the purposes of the present document, the abbreviations given in ETSI EN 300 175-1 [i.1], in ETSI TR 121 905 [i.27] and the following apply:

AR	Augmented Reality
A/V	Audio/Video
CCI	Culture and Creative Industry
DL	Downlink
IP	Internet Protocol
IEEE	Institute of Electrical and Electronics Engineers
IEM	In-Ear Monitor
PA	Public Address
PER	Packet Error Rate
PLMN	Public Land Mobile Network
PMSE	Programme Making and Special Events
PTP	Precision Time Protocol
SLA	Service Level Agreement
UE	User Equipment
UL	Uplink
VR	Virtual Reality

4 Overview, general concepts and methodology

4.1 Overall intention and initial assumptions

The present document was conceived as part of the initial studies for DECT-2020, a 5G radio technology intended to be the long-term evolution of DECT. DECT-2020 is assumed to be based on a new radio interface, with flexibility to use state of the art concepts and paradigms such as OFDM and MIMO. The only fundamental initial limitations were that:

1) the technology should be for license-exempt operation;

2) should be able to operate over existing DECT bands with minimum disturbance to existing DECT equipment and over additional frequency ranges which might show up in future; and

3) should have a coverage area compatible with the transmission power levels of current DECT.

Although not explicitly stated, it was found convenient targeting the technology to areas not currently served by the existing major developments of cellular and WLAN [i.23] technologies. From the very beginning the area of URLLC (Ultra Reliable Low Latency Communications) was identified as a primary target due to its foreseen importance and the fact that it is not well served by existing wireless technology standards. Although 3GPP is targeting similar area in its 3GPP-5G standardization program, it is also clear that there will be enough scenarios and use cases clearly requiring or preferring solutions based on license-exempt operation of wireless networks deployed and operated by the end user.

Three major application areas have been identified with detailed scenarios and use cases consistent with the expected range of DECT evolution and DECT-2020 radio technologies. These are:

- Home and Building Automation, including Smart Living;
- Industry automation - Factories of the Future, Industry 4.0;
- Media and entertainment industry - Programme Making and Special Events (PMSE).

Especially the first two applications areas have relation with the Internet of Things (IoT), in general an important driver of 5G developments.

It should also be noted that the study done by the present document has been conducted immediately after or in parallel to other studies of the topic conducted by other organizations. As examples: 5G Infrastructure Public Private Partnership (5G-PPP) [i.36], PMSE-xG Project [i.38], ZVEI [i.60], and 3GPP WG SA and SA1. The study conducted by the present document has followed the outcome of other initiatives as much as possible. A special attention has been paid to the 3GPP WG SA and SA1 work, what has been found for the three areas (Home and building Automation, Industry automation, and PMSE) fully consistent with own investigation and also compatible with the expected coverage area of DECT-2020.

Finally, some of the scenarios were found as being implementable not only over DECT-2020, but also over evolutions of current DECT technology with different enhancements. In several cases this would require accepting limitations, but time to market, cost or other considerations will justify the development of this approach. The possible solution using evolutions of current DECT technology, when possible, is named "DECT evolution". DECT-2020 and DECT evolution solutions are not exclusive and will coexist in the market. Therefore, DECT-2020 is not necessarily intended as a replacement of DECT or DECT evolution. The possible implementation approach of both paths into the DECT standard is described in clause 6.

4.2 Sources and methodology for media and entertainment industry use cases

The initial work on Media and entertainment industry use cases was based on direct inputs from TC DECT industry participants. There was direct participation in TC DECT meeting of major players in the area such as Sennheiser and Shure as well as input documents directly submitted to TC DECT [i.31].

The input for the media and entertainment industry use cases was completed with requirements submitted to other standard groups, namely to 3GPP WG SA1 ([i.32], [i.33], [i.34] and [i.35]) These documents, are indeed based on the outcome of PMSE-xG Project [i.38], a project co-funded by the German Ministry of Transportation and Digital Infrastructure. These documents are in general consistent with the input received directly from the industry (Sennheiser and wiseSense) for DECT-2020 and DECT evolution. 3GPP SA consolidated the different inputs in the several drafts of 3GPP TR 22.804 [i.24], [i.25] and [i.26], that were followed up during the preparation of the present document. The final version of 3GPP TR 22.804 (V1.0.0) [i.26], released in mid-December 2017, has been selected as base material for filling the media and entertainment industry sections of the present document. It should be noted that the 3GPP TR is fully consistent with own investigation of the topic based on inputs from TC DECT participants and contains near all the material previously submitted and discussed at TC DECT [i.31].

4.3 Sources and methodology for home automation and industry automation use cases

For the Home Automation and Industry Automation areas, the study conducted by the present document has followed up the contributions submitted to 3GPP SA and SA1 and consolidated in the several drafts of 3GPP TR 22.804 [i.24], [i.25], [i.26], the output of the 5GPPP project [i.36], [i.37], the activity at AIOTI WG3 [i.29] and the internal vision of relevant companies ([i.30], used with permission).

At the end, it was found that the material submitted to 3GPP SA1 as consolidated in the last available draft of 3GPP TR 22.804 (V1.0.0) [i.26] was selected as base text for these clauses.

It should be noted that the contributions submitted to 3GPP as consolidated in [i.26], and used in clauses 5.2 and 5.3 of the present document, are relatively agnostic regarding the underlying radio technology. They contain 3GPP singularities mostly in the use and connectivity to a 3GPP core network, what is considered out of scope and not an issue for the study conducted by the present document (nothing fundamental prevents connecting a DECT-2020 RAN to a 3GPP core network). There are, however, a few exceptions regarding radio coverage that should be further analysed.

4.4 The STF 537 survey on use cases for license-exempt radio in IoT

In addition to all described sources, ETSI STF 537 has designed and implemented an independent mechanism for capturing use cases and for inviting prospective users to envision requirements and use case in the specific scenario of the future DECT-2020 radio interface. This has been implemented as a dedicated survey on use cases for license-exempt radio in IoT. The survey material and are included in the Annex A of the present document.

The survey design was finalized in the 2Q of November 2017 and, was presented at the AIOTI WG3 meeting at Sophia Antipolis on 27 November. It was later distributed to all AIOTI WGs, to ETSI TBs and to some relevant industry associations.

Since the survey will be kept open after the publication of the present document, only the first received responses have been taken into account. Further analysis of survey result is left to further revisions of the present document or to separate technical reports. In principle, the received responses are consistent with the material used in clause 5 and also confirm the preference for license-exempt radio regimen for some of the use cases.

4.5 Classifications of Reliability, Latency and Data-rate

4.5.1 Definitions

According to ITU-R documentation for preparation of submissions of IMT-2020 candidate [i.40] and [i.41], the following definitions are used in the present document.

Latency: The contribution by the radio (network) to the time from when the source sends a packet to when the destination receives it (in ms).

Reliability: Reliability relates to the capability to provide a given service with a very high level of availability.

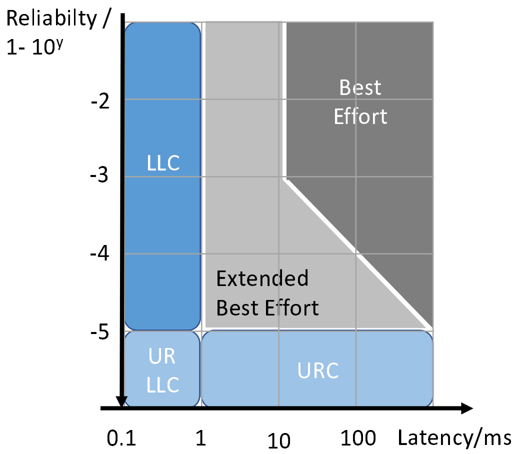


Figure 1: Classification by Reliability and Latency

4.5.2 Classifications

Latency and reliability classes are defined as follows:

- Low Latency Communications (LLC): Latency smaller or equal 1 ms (one direction).
- Ultra-Reliable Communications (URC): Reliability greater or equal than $1\text{-}10^{-5}$ (based on link outage).
- Ultra-Reliable Low Latency Communications (URLLC): Reliability greater or equal than $1\text{-}10^{-5}$ and latency smaller or equal 1 ms (one direction).

4.6 5G visions for the different vertical domains

4.6.1 Overview and 5G PPP vision

A good summary of requirements for the different IoT scenarios can be found in the White Paper from Siemens "5G communication networks: Vertical industry requirements (2016)" [i.30] (used with permission). The summary tables from this paper have also been reused in the AIOTI report "IoT relation and impact on 5G" [i.29]. The White paper summarizes its view on requirements for 5G timeframe based on the verticals Smart City, Smart Mobility, Smart Manufacturing, Smart Energy and Smart Building.

The consolidated view of the requirements is shown in table 1, shown below, column "consolidated view from verticals".

Table 1: 5G promises vs. Vertical requirements (summary)

Category	Requirement	Explicit 5G promises (according to [1], Figure 2)	Consolidated requirements from verticals - Siemens view
Industry-grade Service Quality	Realtime capability – Latency	5 ms (e2e)	1 ms (local) 5 ms (long distance)
	Realtime capability --Jitter	-	1us (local)
	Bandwidth	Peak data 10 Gbps Mobile data volume 10 TB/s/km^2 Number of devices: 1 mio/km^2	kbps ... 10Gbps
	Time period of information loss during failures	-	none (seamless failover)
	Availability/coverage	-	ubiquitous
	Range (distance between communication neighbors)	-	0,1 m ... 200 km
	Reliability (minimum uptime per year [%])	99,999%	99,9999%
	Mobility	500km/h	500km/h
	Outdoor terminal location accuracy	<1m	0,1 m
	Multi-tenant support	yes (Network Slices)	yes
Operation and maintenance	Non-standard operating conditions	Energy consumption reduced by factor 10	• Battery powered devices with >10years lifetime • Harsh environments (weather, vibrations, heat, dust, hazardous gases, etc.)
	Ease of use	-	• Communication services approach • Plug and play device (sensor, actuator, controller) integration
	SLA Tooling	-	Service Level Agreement (SLA) monitoring and management tools for provider and consumer
	Service deployment time (time between service request and service realization)	90 min	hours
	Private 5G infrastructures	-	yes
Non-technical	Scalability: Number of devices per km^2	10^6	10^5
	Globally harmonized definition of Service Qualities	-	yes
	Technology availability	-	>20 years
	Globally simplified certification of ICT components	-	Yes
Assured Guarantees		-	mandatory

The column "5G promises" refers to the view by the 5G Public-Private-Partnership (5G PPP), The 5G-PPP is a Public-Private-Partnership (within the EU Horizon 2020 framework. The vision of 5G-PPP referred in the table as "reference [1]" is the presentation "5G Vision, The 5G Infrastructure Public Private Partnership: the next generation of communication networks and services" (see reference [i.37]). The table of promised 5GPP requirements referred in tables 1 and 2 is the figure 2 of the 5G-PPP brochure.

The detail of the requirements for the different verticals is shown in table 2.

Table 2: 5G promises vs. Vertical requirements (detail)

Category	Requirement	Explicit 5G promises (according to [1], Figure 2)	Siemens demand	Smart City	Smart Mobility	Smart Manufacturing		Smart Energy			Smart Building
						Process	Discrete	Low Voltage	Medium Voltage	High Voltage	
Industry-grade Service Quality	Realtime capability – Latency	5 ms (e2e)	1 ms (local) 5 ms (long distance)	-	1ms (local) 10 ms (long distance)	20ms (local) 1s (long distance)	1ms (local) 20ms (long distance)	-	25ms	5ms (long distance)	100ms
	Realtime capability – Jitter	-	1us (local)	-	-	20ms	1us	-	25ms	1ms	-
	Bandwidth	Peak data 10 Gbps Mobile data volume 10 TB/s/km^2 Number of devices: 1 mio/km^2	kbps ... 10Gbps	kbps (sensors) ... Mbps (video supervision) ... 10 Gbps (data centers)	10 Mbps ... 1 Gbps	100 kbit/s (automaton stream) ... 100 Mbps (remote access, video supervision)	100 kbit/s (automaton stream) ... 100 Mbps (remote access, video supervision)	1 kbps per subscriber	5 Mbps per secondary substation	1Gbps along power lines	100 kbit/s (automaton stream) ... 100 Mbps (remote access, video supervision)
	Time period of information loss during failures	-	none (seamless failover)	1s	100 ms	100 ms	none (seamless failover)	minutes	25ms	none (seamless failover)	100 ms
	Availability/ coverage	-	Ubiquitous	City-level	Ubiquitous	Industrial Plant Areas	Industrial Plant Areas	Ubiquitous	Ubiquitous	Ubiquitous	City-level
	Range (distance between communication neighbors)	-	0,1 m ... 200 km	10 km	1 km (cars) ... 10 km (trains)	0,1m ... 10 km	0,1 m ... 100 m	10 km	20 km	200 km	100m
	Reliability (minimum uptime per year [%])	99,999%	100%	99,9%	100%	100%	100%	98%	99,9%	100%	99,9%
	Mobility	500km/h	500km/h	100km/h	500km/h	50km/h	50km/h	5km/h	-	-	5km/h
	Outdoor terminal location accuracy	<1m	0,1 m	1 m	0,1 m	0,1 m	0,1 m	10 m	10 m	-	0,1 m
	Multi-tenant support	yes (Network Slices)	yes								
Operation and maintenance	Non-standard operating conditions	Energy consumption reduced by factor 10	• Battery powered devices with >10years lifetime • Harsh environments (weather, vibrations, heat, dust, hazardous gases, etc.)								
	Ease of use	-	• Communication Services approach • Plug and Play Device (Sensor, Actuator, Controller) integration								
	SLA Tooling	-	Service Level Agreement (SLA) monitoring and management tools for provider and consumer								
	Service deployment time (time between service request and service realization)	90 min	hours								
	private 5G infrastructures	-	yes	-	yes	yes	yes	-	optional	yes	optional
Non-technical	Scalability: Number of devices per km^2	10^6	10^5	10^5	10^4	10^5 (high density of devices)	10^5 (high density of devices)	10^4	10^3	10^3	10^5
	Globally harmonized definition of Service Qualities	-	yes	-	yes	yes (for long distance)	yes (for long distance)	-	yes	yes	-
	Technology availability	-	>20 years								
	Globally simplified certification of ICT components	-	Yes								
Assured Guarantees		-	Mandatory	Relaxed	Mandatory	Mandatory	Mandatory	Relaxed	Mandatory	Mandatory	Relaxed

4.6.2 Scenarios for low latency and high reliability

4.6.2.1 Overview

Several scenarios require the support of very low latency and very high communications service availability. The overall service latency depends on the delay on the radio interface, transmission within the 5G system, transmission to a server which may be outside the 5G system, and data processing. Some of these factors depend directly on the 5G system itself, whereas for others the impact can be reduced by suitable interconnections between the 5G system and services or servers outside of the 5G system, for example, to allow local hosting of the services. The scenarios and their performance requirements can be found in table 3.

4.6.2.2 Candidate scenarios for URLLC

Scenarios requiring very low latency and very high communication service availability can be found below:

- Motion control - Conventional motion control is characterized by high requirements on the communications system regarding latency, reliability, and availability. Systems supporting motion control are usually deployed in geographically limited areas but may also be deployed in wider areas (e.g. city- or country-wide networks), access to them may be limited to authorized users, and they may be isolated from networks or network resources used by other cellular customers.

- Discrete automation - Discrete automation is characterized by high requirements on the communications system regarding reliability and availability. Systems supporting discrete automation are usually deployed in geographically limited areas, access to them may be limited to authorized users, and they may be isolated from networks or network resources used by other cellular customers.

- Process automation - Automation for (reactive) flows, e.g. refineries and water distribution networks. Process automation is characterized by high requirements on the communications system regarding communication service availability. Systems supporting process automation are usually deployed in geographically limited areas, access to them is usually limited to authorized users, and it will usually be served by private networks.

- Automation for electricity distribution (mainly medium and high voltage). Electricity distribution is characterized by high requirements on the communications service availability. In contrast to the above use cases, electricity distribution is deeply immersed into the public space. Since electricity distribution is an essential infrastructure, it will, as a rule, be served by private networks.

- Intelligent transport systems - Automation solutions for the infrastructure supporting street-based traffic. This use case addresses the connection of the road-side infrastructure, e.g. road side units, with other infrastructure, e.g. a traffic guidance system. As is the case for automation electricity, the nodes are deeply immersed into the public space.

- Tactile interaction - Tactile interaction is characterized by a human being interacting with the environment or people, or controlling a UE, and relying on tactile feedback.

- Remote control - Remote control is characterized by a UE being operated remotely, either by a human or a computer.

Table 3: Performance requirements for low-latency and high-reliability scenarios

Scenario	End-to-end latency (note 3)	Jitter	Survival time	Communication service availability (note 4)	Reliability (note 4)	User experienced data rate	Payload size (note 5)	Traffic density (note 6)	Connection density (note 7)	Service area dimension (note 8)
Discrete automation - motion control (note 1)	1 ms	1 µs	0 ms	99,9999 %	99,9999 %	1 Mbps up to 10 Mbps	Small	1 Tbps/km^2	100 000/km^2	100 x 100 x 30 m
Discrete automation	10 ms	100 µs	0 ms	99,99 %	99,99 %	10 Mbps	Small to big	1 Tbps/km^2	100 000/km^2	1000 x 1000 x 30 m
Process automation - remote control	50 ms	20 ms	100 ms	99,9999 %	99,9999 %	1 Mbps up to 100 Mbps	Small to big	100 Gbps/km^2	1 000/km^2	300 x 300 x 50 m
Process automation – monitoring	50 ms	20 ms	100 ms	99,9 %	99,9 %	1 Mbps	Small	10 Gbps/km^2	10 000/km^2	300 x 300 x 50
Electricity distribution - medium voltage	25 ms	25 ms	25 ms	99,9 %	99,9 %	10 Mbps	Small to big	10 Gbps/km^2	1 000/km^2	100 km along power line
Electricity distribution - high voltage (note 2)	5 ms	1 ms	10 ms	99,9999 %	99,9999 %	10 Mbps	Small	100 Gbps/km^2	1 000/km^2 (note 9)	200 km along power line
Intelligent transport systems - infrastructure backhaul	10 ms	20 ms	100 ms	99,9999 %	99,9999 %	10 Mbps	Small to big	10 Gbps/km^2	1 000/km^2	2 km along a road
Tactile interaction (note 1)	0,5 ms	TBC	TBC	99,999 %	99,999 %	Low]	Small	Low	Low	TBC
Remote control	5 ms	TBC	TBC	99,999 %	99,999 %	From low to 10 Mbps	Small to big	Low	Low	TBC

NOTE 1: Traffic prioritization and hosting services close to the end-user may be helpful in reaching the lowest latency values.
NOTE 2: Currently realized via wired communication lines.
NOTE 3: This is the end-to-end latency the service requires. The end-to-end latency is not completely allocated to the 5G system in case other networks are in the communication path.
NOTE 4: Communication service availability relates to the service interfaces, reliability relates to a given node. Reliability should be equal or higher than communication service availability.
NOTE 5: Small: payload typically ≤ 256 bytes
NOTE 6: Based on the assumption that all connected applications within the service volume require the user experienced data rate.
NOTE 7: Under the assumption of 100 % 5G penetration.
NOTE 8 Estimates of maximum dimensions; the last figure is the vertical dimension.
NOTE 9: In dense urban areas.
NOTE 10: All the values in this table are targeted values and not strict requirements.

Source: 3GPP TS 22.261 (V15.2.0) [i.28].

5 Description of use cases and their Requirements

5.1 List of use cases considered as candidate for DECT evolution or DECT-2020 solutions

After analysis, the following use cases from [i.26] have been considered as candidate for implementation using DECT evolution and DECT-2020 technologies:

Home and Building Automation, including Smart Living

- Building automation (clause 5.2 of 3GPP TR 22.804 V1.0.0 [i.26]);
- Environmental monitoring (clause 5.2.2 of ETSI TR 121 905 [i.27]);
- Fire detection (clause 5.2.3 of ETSI TR 121 905 [i.27]);
- Feedback control (clause 5.2.4 of ETSI TR 121 905 [i.27]);
- Smart Living - Health Care (clause 5.4 of ETSI TR 121 905 [i.27]);
- Telecare data traffic between home and remote monitoring centre (clause 5.4.2 of ETSI TR 121 905 [i.27]).

Industry automation - Factories of the Future

- Factories of the Future (clause 5.3 of ETSI TR 121 905 [i.27]);
- Motion control (clause 5.3.2 of ETSI TR 121 905 [i.27]);
- Motion control - transmission of non-real-time data (clause 5.3.3 of ETSI TR 121 905 [i.27]);
- Motion control - seamless integration with Industrial Ethernet (clause 5.3.4 of ETSI TR 121 905 [i.27]);
- Control-to-control communication (motion subsystems) (clause 5.3.15 of ETSI TR 121 905 [i.27]);
- Mobile control panels with safety functions (clause 5.3.6 of ETSI TR 121 905 [i.27]);
- Mobile robots (clause 5.3.7 of ETSI TR 121 905 [i.27]);
- Massive wireless sensor networks (clause 5.3.8 of ETSI TR 121 905 [i.27]);
- Remote access and maintenance (clause 5.3.9 of ETSI TR 121 905 [i.27]);
- Augmented reality (clause 5.3.10 of ETSI TR 121 905 [i.27])
- Process automation - closed-loop control (clause 5.3.11 of ETSI TR 121 905 [i.27]);
- Process automation - process monitoring (clause 5.3.12 of ETSI TR 121 905 [i.27]);
- Process automation - plant asset management (clause 5.3.13 of ETSI TR 121 905 [i.27]);
- Connectivity for the factory floor (clause 5.3.14 of ETSI TR 121 905 [i.27]);
- Inbound logistics for manufacturing (clause 5.3.15 of ETSI TR 121 905 [i.27]);
- Variable message reliability (clause 5.3.17 of ETSI TR 121 905 [i.27]);
- Flexible, modular assembly area (clause 5.3.18 of ETSI TR 121 905 [i.27]);
- Plug and produce for field devices (clause 5.3.19 of ETSI TR 121 905 [i.27]);
- Private-public interaction (clause 5.3.20 of ETSI TR 121 905 [i.27]).

Media and entertainment industry - Programme Making and Special Events (PMSE)

- Programme Making and Special Events (PMSE) (clause 5.8 of ETSI TR 121 905 [i.27]);
- Low-latency audio streaming for live performance (clause 5.8.2 of ETSI TR 121 905 [i.27]);
- Low-latency audio streaming for local conference systems (clause 5.8.3 of ETSI TR 121 905 [i.27]);
- High data rate video streaming / professional video production (clause 5.8.4 of ETSI TR 121 905 [i.27]).

Some a Use Cases from ETSI TR 121 905 [i.27] have not been considered for the present revision of the present document. They are listed in clause 5.6 as reference to allow further study, together with the reasons for not inclusion. These use cases may, however, be reconsidered in further revisions of the present document.

Finally, clause 5.7 will show an initial assessment on the suitability of implementation of the use case using DECT-2020 or DECT evolution technologies and the clarification of the use case regarding Reliability and Latency, according to the ITU-R definitions, as given in clause 4.5.

5.2 Use cases for home and building automation

5.2.1 Description of vertical

Building automation refers to the management of equipment in buildings such as heaters, coolers, and ventilators. Automation of such systems brings several benefits, including the reduction of energy consumption, the improvement of comfort level for people using the building, and the handling of failure and emergency situations. Sensors installed in the building perform measurements of the environment and report these measurements to Local Controllers. Local Controllers (LC), in turn, report these results to a Building Management System.

A Building Management System (BMS) may then execute different operations:

- Store the information into a database (e.g. for histogram purpose);
- Send an alarm to a (third-party) Building Management System;
- The Building Management System sends a command to an actuator (e.g. command to increase room temperature, turn on a light).

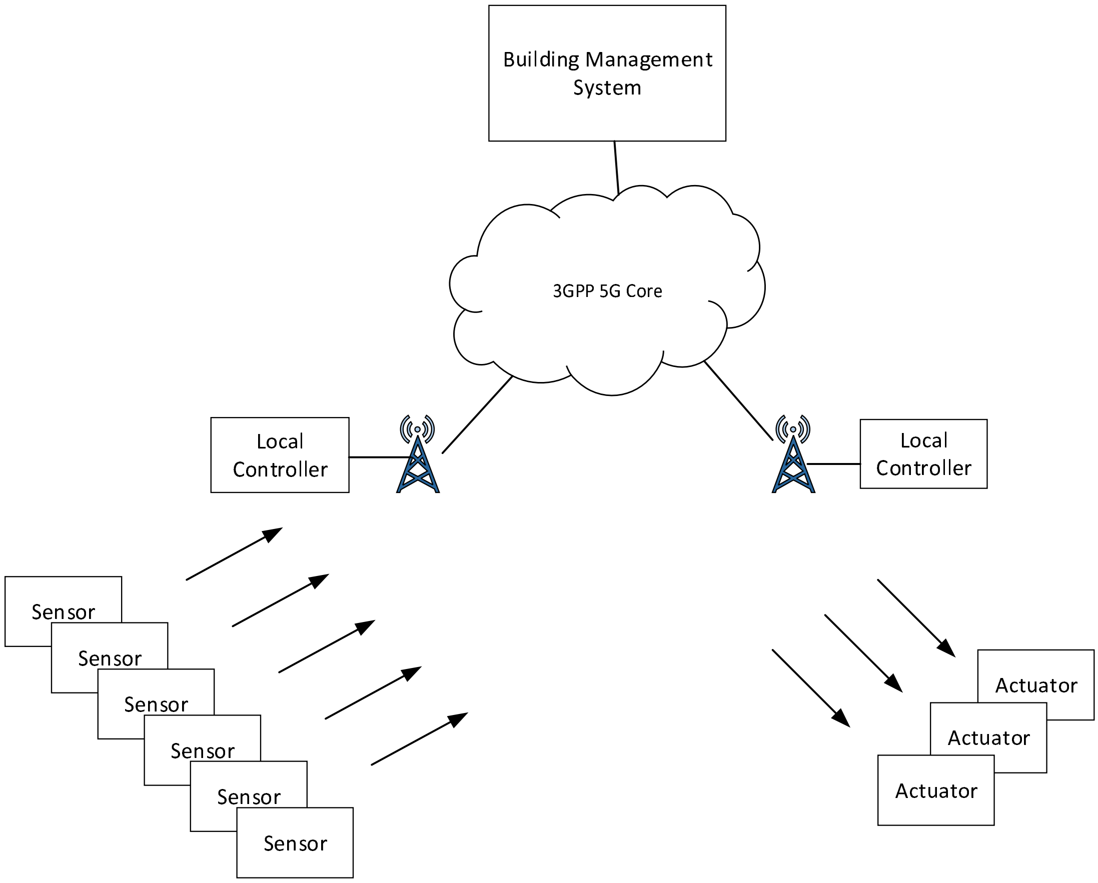


Figure 2: Building automation system - Local Controller in Mobile Edge System and Building Management System

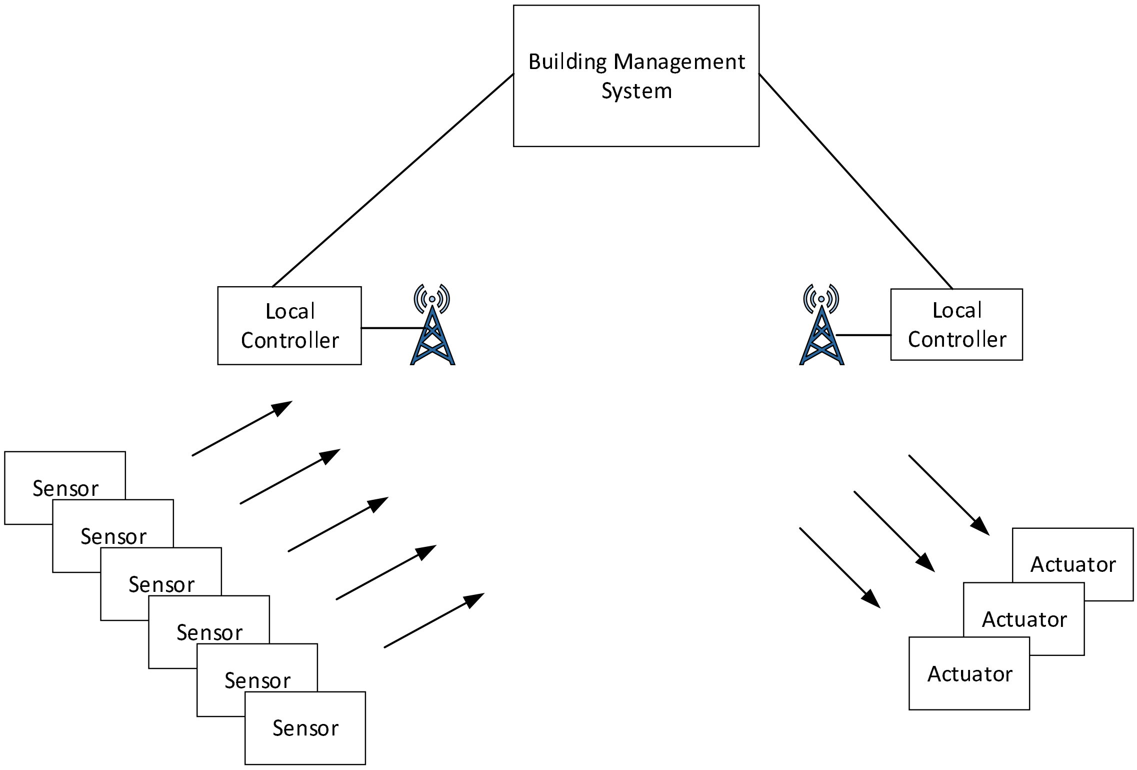


Figure 3: Building automation system with Building Management System with local controllers

5.2.2 Environmental monitoring

5.2.2.1 Description

In this use case, several sensors are installed in a building and each sensor performs measurements following a pre-defined measurement interval. The measurement data might be used for drawing a histogram with as detailed as 1 s granularity and a 10 times sampling rate, i.e. 10 times per second. A Local Controller collects the measurement data from its sensors and may transmit it to the Building Management System at a certain interval. The latency in this use case is not a concern, but it is important that the transmission is reliable and all sensor values are collected within the measurement interval.

5.2.2.2 Preconditions

There are several Local Controllers installed in the building, each connected with many sensors (up to 100 sensors).

5.2.2.3 Service flows

At the measurement interval, which might be as low as 1 second, and with the needed sampling rate (e.g. 10/s), the Local Controller sends a request to all its sensors in the building to report their measurements.

5.2.2.4 Post-conditions

Every sensor reports their measurements and measurements are received with 99,999 % reliability. The Local Controller collects these measurements and may transmit them to the building management System.

5.2.2.5 Potential requirements

Reference Number	Requirement text	Application / Transport	Comments
Building Automation 1.1	The 5G system should support 99,999 % communication service availability for data transmission every second.	Transport	

5.2.3.6 Notes on possible DECT implementation

Requirements:

- This Use Case requires Ultra Reliability.
- This Use Case does not require Low Latency.
- The required range is consistent with DECT solutions.
- The Use Case is consistent with license-exempt operation regimen.
- This Use Cases does not require synchronous operation.

Possible implementation paths:

- This Use Case seems implementable over DECT-2020.
- This Use Case seems also implementable over DECT evolution.

5.2.3 Fire detection

5.2.3.1 Description

In this use case, when fire is detected, the system triggers several actions, such as closing fire shutters and turning on fire sprinklers.

5.2.3.2 Preconditions

There are 10 connected sensors and one Local Controller installed in the building.

5.2.3.3 Service flows

1) Fire is detected by the building sensors.
2) Building sensors send an alarm to the Local Controller.
3) Local controller sends information to Building Management System.
4) Building Management System sends commands to the actuators in the building.

5.2.3.4 Post-conditions

Fire shutters are closed and fire sprinklers are turned on within 1 to 2 seconds from the time the fire is detected.

5.2.3.5 Potential requirements

Reference Number	Requirement text	Application / Transport	Comments
Building Automation 2.1	The 5G system should support an end-to-end latency of 10 ms with a 99,9999 % communication service availability for data transmission.	Transport	

5.2.3.6 Notes on possible DECT implementation

Requirements:

- This Use Case requires Ultra Reliability.
- This Use Case requires reduced Latency (< 10 ms), but not Low latency as defined in clause 4.5.
- The required range is consistent with DECT solutions.
- The Use Case is consistent with license-exempt operation regimen.
- This Use Cases does not require synchronous operation.

Possible implementation paths:

- This Use Case seems implementable over DECT-2020.
- This Use Case seems also implementable over DECT evolution.

5.2.4 Feedback control

5.2.4.1 Description

In this use case, a (device) state is controlled. For example, a room temperature is kept at a certain value. Low latency and jitter are required in this use case in order to provide high quality of feedback control.

5.2.4.2 Preconditions

There are 10 sensors and one Local Controller installed in the building. The Local Controllers is configured with a target temperature for a connected sensor and thus the room in which the sensor is installed.

5.2.4.3 Service flows

1) The Local Controller requests measurements from a target sensor to establish the state of the sensor.

2) The Local Controller calculates a control value based on the measured target sensor state.

3) The Local Controller sends the control value to a target actuator.

5.2.4.4 Post-conditions

The target actuator receives the command and adjusts the temperature based on the control value and the temperature reaches the target temperature.

5.2.4.5 Potential requirements

Reference Number	Requirement text	Application / Transport	Comments
Building Automation 3.1	The 5G system should support and end-to-end latency of 10 ms with a communication service availability of 99,9999 % for data transmission.	Transport	
Building Automation 3.2	The 5G system should support a jitter of up to 1 ms.	Transport	

5.2.4.6 Notes on possible DECT implementation

Requirements:

- This Use Case requires Ultra Reliability.
- This Use Case requires reduced Latency (< 10 ms), but not Low latency as defined in clause 4.5.
- The required range is consistent with DECT solutions.
- The Use Case is consistent with license-exempt operation regimen.
- This Use Cases may require synchronous operation due to the 1 ms jitter requirement.

Possible implementation paths:

- This Use Case seems implementable over DECT-2020.
- This Use Case seems also implementable over DECT evolution, with restrictions regarding the < 1ms jitter.

5.3 Use cases for factories of the future

5.3.1 Description of vertical

5.3.1.1 Overview

The manufacturing industry is currently subject to a fundamental change, which is often referred to as the "Fourth Industrial Revolution" or simply "Industry 4.0" [i.43]. The main goals of Industry 4.0 are -among others- the improvement of flexibility, versatility, resource efficiency, cost efficiency, worker support, and quality of industrial production and logistics. These improvements are important for addressing the needs of increasingly volatile and globalized markets. A major enabler for all this are cyber-physical production systems based on a ubiquitous and powerful connectivity and computing infrastructure, which interconnects people, machines, products, and all kinds of other devices in a flexible, secure and consistent manner. Instead of static sequential production systems, future smart factories will be characterized by flexible, modular production systems. This includes more mobile and versatile production assets, which require powerful and efficient wireless communication and localization services.

Today, the vast majority of communication technologies used in industry is still wire-bound. This includes a variety of dedicated Industrial Ethernet technologies (e.g. Sercos®, PROFINET® and EtherCAT®) and fieldbuses (e.g. PROFIBUS®, CC-Link® and CAN®) [i.44], [i.45] and [i.46]. These communication technologies are used, for example, for interconnecting sensors, actuators and controllers in an automation system.

Nowadays, wireless communication is primarily used for special applications and scenarios, for example in the process industry, or for connecting standard IT hardware to a production network and similar rather non-critical applications. On the one hand, this is because there was no need for wireless connectivity in the past, due to relatively static and long-lasting production facilities. On the other hand, this is because most existing wireless technologies fall short of the demanding requirements of industrial applications, especially with respect to end-to-end latency, communication service availability, jitter, and determinism.

With the advent of Industry 4.0 and 5G, however, this may change fundamentally, since only wireless connectivity can provide the degree of flexibility, mobility, versatility, and ergonomics that is required for the Factories of the Future. Thus, 5G may significantly contribute to revolutionising the way how goods are produced, shipped, and serviced throughout their whole lifecycle.

In this respect, several different application areas can be distinguished, as shown in figure 4.

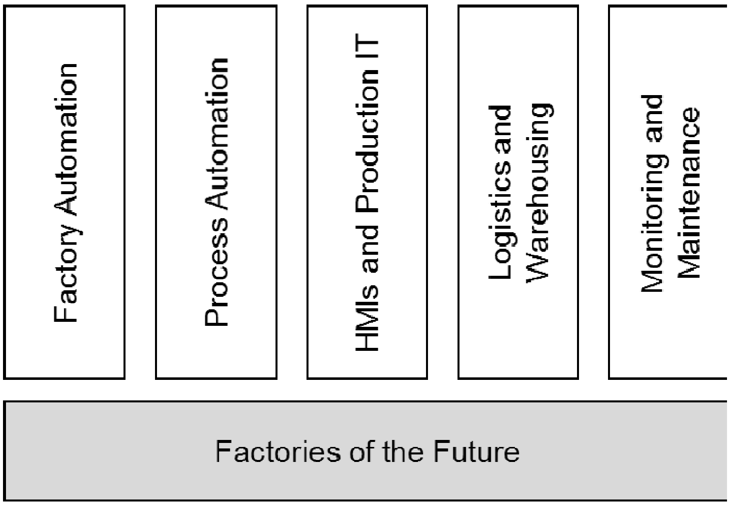


Figure 4: Overview of the different application areas of the vertical "Factories of the Future"

These areas can be briefly characterized as follows:

1) **Factory automation:** Factory automation deals with the automated control, monitoring and optimization of processes and workflows within a factory. This includes aspects like closed-loop control applications (e.g. based on programmable logic or motion controllers), robotics, as well as aspects of computer-integrated manufacturing. Factory automation generally represents a key enabler for industrial mass production with high quality and cost-efficiency and corresponding applications are often characterized by highest requirements on the underlying connectivity infrastructure, especially in terms of latency, communication service availability and determinism. 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 localization services are required.

2) **Process automation:** Process automation refers to the control of production and handling of substances like chemicals, food & beverage, etc. Process automation improves the efficiency of production processes, energy consumption and safety of the facilities. Sensors measuring process values, such as pressures or temperatures, are working in a closed loop via centralized and decentralised controllers with actuators, e.g. valves, pumps, heaters. Also monitoring of attributes such as the filling levels of tanks, quality of material or environmental data are important, as well as safety warnings or plant shut downs. Workers in the plant are supported by mobile devices. A process automation facility may range from a few 100 m² to km² or may be geographically distributed over a certain geographic region. Depending on the size, a production plant may have several 10 000 measurement points and actuators. Autarkic device power supply for years is needed in order to stay flexible and to keep the total costs of ownership low.

3) **HMIs and Production IT:** Human-machine interfaces (HMIs) include all sorts of devices for the interaction between people and production facilities, such as panels attached to a machine or production line, but also standard IT devices, such as laptops, tablet PCs, smartphones, etc. In addition to that, also augmented and virtual reality (AR/VR) applications are expected to play an increasingly important role in future, which may be enabled by special AR/VR glasses, but also by more standard devices, such as tablet PCs or the like.

Production IT, on the other hand, encompasses IT-based applications, such as manufacturing execution systems (MES) as well as enterprise resource planning (ERP) systems. The overall goal of an MES system, for example, is to monitor and document how raw materials and/or basic components are transformed into finished goods, whereas an ERP system generally provide an integrated and continuously updated view of important business processes. Both systems rely on the timely availability of large amounts of data from the production process.

Since both HMIs and Production IT are more related to traditional IT systems than to factory-specific operational technology (OT) systems, they are bundled in one application area.

- **Logistics and warehousing:** Logistics and warehousing refers to the organization and control of the flow and storage of materials and goods in the context of industrial production. In this respect, intra-logistics is dealing with logistics within a certain property (e.g. within a factory), for example by ensuring the uninterrupted supply of raw materials on the shopfloor level using automated guided vehicles (AGVs), fork lifts, etc. This is to be seen in contrast to logistics between different sites, for example for the transport of goods from a supplier to a factory or from a factory to the end customer. Warehousing particularly refers to the storage of materials and goods, which is also getting more and more automated, for example based on conveyors, cranes and automated storage and retrieval systems. For all kinds of logistics applications, generally also the localization, tracking and monitoring of assets is of high importance.

- **Monitoring and maintenance:** Monitoring and maintenance refers to the monitoring of certain processes and/or assets without an immediate impact on the processes themselves (in contrast to a typical closed-loop control system in factory automation, for example). This particularly includes applications such as condition monitoring and predictive maintenance based on sensor data, but also big data analytics for optimizing future parameter sets of a certain process, for instance. For these use cases, the data acquisition process is typically not latency-critical, but a large number of sensors may have to be efficiently interconnected, especially since many of these sensors may only be battery-driven.

For each of these application areas, a multitude of potential use cases exists, some of which are outlined in the following clauses. These use cases can be mapped to the given application areas as shown in table 4.

Table 4: Mapping of the considered use cases (columns) to application areas (rows)

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

5.3.1.2 Major challenges and particularities

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

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

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

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

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

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

6) 5G systems should support private operation within a factory or plant, which are isolated from PLMNs. This is required by many factory/plant owners for security, liability, availability and business reasons. Nevertheless, standardized and flexible interfaces should be supported for seamless interoperability and seamless handovers between 5G PLMNs and private 5G systems.

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

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

5.3.1.3 Deployment aspects

Separate communication services may need to be provided for different application areas. Note that "separate" communication service can be physically, logically or virtually separate.

The application area "factory automation" consists of the use cases "motion control", "control-to-control", "mobile robots" and "massive wireless sensor networks". Communication services for factory automation meet stringent requirements; and operation is limited to a relatively small service area where no interworking with the public network (e.g. mobility, roaming) is required.

The application area "process automation" consists of the use cases "mobile robots", "massive wireless sensor networks", "closed-loop process control", "process monitoring" and "plant asset management". Communication services for process automation meet stringent requirements. Interworking with the public network (e.g. mobility, roaming) is required.

The application area "HMIs and production IT" consists of the use cases "mobile control panels with safety" and "augmented reality". Communication services for HMIs and Production IT meet stringent requirements; and are limited to a local service area where no interworking with the public network (e.g. mobility, roaming) is required.

The application area "logistics and warehousing" consists of the use cases "control-to-control" and "mobile robots". Communication service for logistics and warehousing meet very stringent requirements; and are limited to a local service area (both indoor and outdoor). Interworking with the public network (e.g. mobility, roaming) is required.

The application area "monitoring and maintenance" consists of the use cases "massive wireless sensor networks" and "remote access and maintenance". Communication services for monitoring and maintenance meet stringent requirements; and are limited to a local service area (both indoor and outdoor). Interworking with the public network (e.g. mobility, roaming) is required.

5.3.2 Motion control

5.3.2.1 Description

Motion control is among the most challenging and demanding closed-loop control applications in industry. A motion control system is responsible for controlling moving and/or rotating parts of machines in a well-defined manner, for example in printing machines, machine tools or packaging machines. Due to the movements/rotations of components, wireless communications based on powerful 5G systems constitutes a promising approach. On the one hand this is because with wirelessly connected devices, slip rings, cable carriers, etc. which are typically used for these applications today, can be avoided, thus reducing abrasion, maintenance effort and costs. On the other hand, this is because machines and production lines may be built with less restrictions, allowing for novel (and potentially much more compact and modular) setups.

A schematic representation of a motion control system is depicted in figure 5. A motion controller periodically sends desired set points to one or several actuators (e.g. a linear actuator or a servo drive) which thereupon perform a corresponding action on one or several processes (in this case usually a movement or rotation of a certain component). At the same time, sensors determine the current state of the process(es) (in this case for example the current position and/or rotation of one or multiple components) and send the actual values back to the motion controller. This is done in a strictly cyclic and deterministic manner, such that during one communication cycle time T_{cycle} the motion controller sends updated set points to all actuators, and all sensors send their actual values back to the motion controller. Nowadays, typically Industrial Ethernet technologies are used for motion control systems. Examples for such technologies are Sercos®, PROFINET® IRT or EtherCAT®, which support cycle times below 50 µs. In general, lower cycle times allow for faster and more accurate movements/rotations.

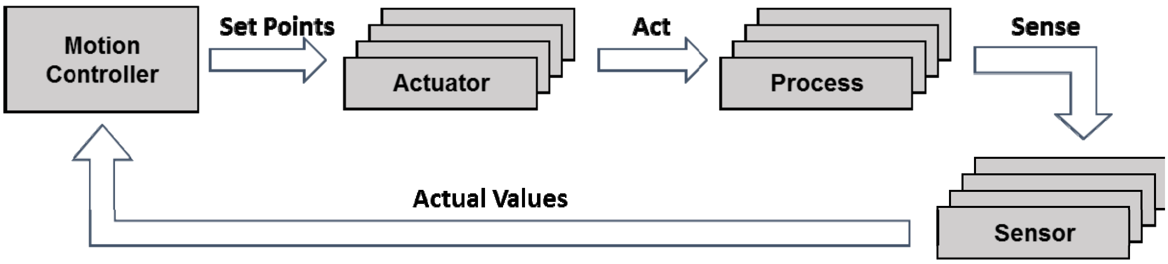


Figure 5: Schematic representation of a motion control system

While it might be possible to move away from the strictly cyclic communication pattern for motion control systems in the long-term, it is hard to do so in the short-term since the whole ecosystem (tools, machines, communication technologies, servo drives, etc.) is based on the cyclic communication paradigm. In order to support a seamless migration path, the 5G system therefore should support such a highly deterministic cyclic data communication service.

Furthermore, there are many scenarios where some devices (e.g. sensors or actuators) are added / activated or removed / deactivated while the overall control system keeps on running. In order to support such cases, hot-plugging support is required without any (observable) impact on the rest of the system.

Table 5 shows some typical values for the number of nodes, cycle times and payload sizes for some of the most important application areas of motion control systems. However, it should be noted that these values may vary widely in practice and that not all sensors and/or actuators in a motion control system may have to be connected using a 5G system. Instead, it is expected that there will be a seamless coexistence between Industrial Ethernet and the 5G system in the future.

Table 5: Typical characteristics of motion control systems for three major applications

Application	# of sensors / actuators	Typical message size	Cycle time T_{cycle}	Service area
Printing Machine	> 100	20 B	< 2 ms	100 m x 100 m x 30 m
Machine Tool	~ 20	50 B	< 0,5 ms	15 m x 15 m x 3 m
Packaging Machine	~ 50	40 B	< 1 ms	10 m x 5 m x 3 m

In general, this use case has the most stringent requirements in terms of latency and service availability. The operation is limited to a relatively small service area, where no interworking with the public network (e.g. mobility, roaming) is required.

5.3.2.2 Preconditions

All sensors, actuators and the motion controller are switched on and connected to the 5G system.

5.3.2.3 Service flows

Within each communication cycle of duration T_{cycle}, the following steps are performed in a strictly cyclic manner:

1) The motion controller sends set points to all actuators.

2) The actuators take these set points and put them into an internal buffer.

3) All sensors transmit their current actual values from their internal buffer to the motion controller.

4) At a well-defined time instant within the current cycle, which is commonly referred to as the "global sampling point", the actuators retrieve the latest set points received from the motion controller from their internal buffer and act accordingly on the process(es) (see figure 5). At exactly the same time, the sensors determine the current state of the process(es) and put them as new actual values in their internal buffer, ready to be transmitted to the motion controller. It is important that there is a very high synchronicity in the order of 1 μs between all involved devices (motion controller, sensors, actuators) with respect to this global sampling point.

All messages exchanged have to be properly secured (especially in terms of data integrity and authenticity) and the probability of two consecutive packet errors should be negligible. This is because a single packet error may be tolerable, but two consecutive packet errors may damage a machine and may lead to a production downtime with possibly huge financial damage.

Some of the sensors/actuators may be moving and/or rotating, with typical maximum speeds up to about 20 m/s.

5.3.2.4 Post-conditions

The components controlled by the motion control system move/rotate as requested by the motion controller.

5.3.2.5 Challenges to the 5G system

Special challenges to the 5G system associated with this use case include the following aspects:

- Very high requirements on latency, communication service availability, and determinism.
- Very high requirements on clock synchronicity between different nodes.
- Transmission of rather small chunks of data, resulting in potentially significant relative overhead due to signalling, security, etc.
- Potentially high density of UEs (sensors/actuators).

5.3.2.6 Potential requirements

Reference Number	Requirement text	Application / Transport	Comments
Factories of the Future 2.1	The 5G system should support cyclic traffic with cycle times in the order of 1 ms for a communication group of about 50 UEs and payload sizes of about 40 B.	T	
Factories of the Future 2.2	The 5G system should support cyclic traffic with cycle times in the order of 0,5 ms for a communication group of about 20 UEs and payload sizes of about 50 B.	T	
Factories of the Future 2.3	The 5G system should support cyclic traffic with cycle times in the order of 2 ms for a communication group of about 100 UEs and payload sizes of about 20 B.	T	
Factories of the Future 2.4	The 5G system should support a very high synchronicity between a communication group of 50 - 100 UEs in the order of 1 µs or below.	T	
Factories of the Future 2.5	The 5G system should support data integrity protection and message authentication, even for communication services with ultra-low latency and ultra-high reliability requirements	T	
Factories of the Future 2.6	The 5G system should support communication service availability exceeding at least 99.9999%, ideally even 99.999999 %.	T	
Factories of the Future 2.7	The 5G system should support hot-plugging in the sense that new devices may be dynamically added to and removed from a motion control application, without any observable impact on the other nodes.	T	
Factories of the Future 2.8	The 5G system should support UE speeds up to 20 m/s, even for communication services with ultra-low latency and ultra-high reliability.	T	
Factories of the Future 2.9	The cyclic data communication service of the 5G system should be able to support satisfy the safety requirements according to [i.42] for safety integrity level 3 (SIL-3).	T	
Factories of the Future 2.10	The 5G system should ensure error-free transmission of a second message within the survival time if the transmission of the previous message failed.	T	

5.3.2.7 Notes on possible DECT implementation

Requirements:

- This Use Case requires Ultra Reliability, ideally ($1\text{-}10^{-8}$).
- This Use Case requires Low Latency, going further from ITU-R definition to 0,5 ms.
- The required range is consistent with DECT solutions.
- The Use Case is consistent with license-exempt operation regimen.
- This Use Cases requires synchronous operation with < 1 µs jitter requirement.
- The use case requires the support UE speeds up to 20 m/s.

Possible implementation paths:

- This Use Case seems implementable over DECT-2020.
- This Use Case seems only implementable over DECT evolution accepting restriction regarding the reliability, latency, mobility, and jitter.

5.3.3 Motion control - transmission of non-real-time data

5.3.3.1 Description

In this use case, some additional non-real-time (NRT) data are transmitted from the motion controller to one or several nodes (see figure 5). This is done in parallel to the regular cyclic data transmission service as described in the previous clause. Examples for this NRT data are software/firmware updates or maintenance information.

5.3.3.2 Preconditions

All sensors, actuators and the motion controller are switched on and connected to the 5G system. The strictly cyclic data communication service between the motion controller and the sensors/actuators has been successfully set up (see previous use case) and is running.

5.3.3.3 Service flows

The cyclic data communication service as described in the previous clause is running without any interruptions. In addition to that, the following service flow occurs, assuming a downstream NRT data transmission from the motion controller to one (or several) sensor(s) and/or actuator(s):

1) The motion controller initiates a NRT data transmission service to one or several sensor(s)/actuator(s).

2) The motion controller transmits the NRT data to the respective sensor(s)/actuator(s) with a data rate of at least 1 Mbit/s.

3) The recipient(s) confirm(s) the successful reception of the NRT data.

4) The NRT data transmission service is disengaged.

An alternative flow with an upstream NRT data transmission service may look as follows:

1) A sensor/actuator requests a NRT data transmission service to the motion controller

2) The motion controller approves the request to establish a NRT data transmission service from the requesting sensor/actuator to the motion controller.

3) The respective sensor/actuator initiates a NRT data transmission service to the motion controller.

4) The respective sensor/actuator transmits the NRT data to the motion controller with a data rate of at least 1 Mbit/s.

5) The motion controller confirms the successful reception of the NRT data.

6) The NRT data transmission service is disengaged.

5.3.3.4 Post-conditions

The NRT data has been successfully transmitted.

The strictly cyclic data communication service between the motion controller and the sensors/ actuators has not been affected.

5.3.3.5 Challenges to the 5G system

Special challenges to the 5G system associated with this use case include the following aspects:

- Simultaneous transmission of non-critical NRT data and highly-critical motion control data with highest requirements in terms of latency and communication service availability over the same link and to the same device.

- Dynamic and efficient establishment and disengagement of NRT data transmission services.

5.3.3.6 Potential requirements

Reference Number	Requirement text	Application / Transport	Comments
Factories of the Future 3.1	The strictly cyclic data communication service between a motion controller and several sensors/actuators and data service between the motion controller and a subset of the sensors/actuators or between one of the sensors/actuators and the motion controller can be simultaneously supported.	T	
Factories of the Future 3.2	The low-priority NRT data service support a data rate of at least 1 Mb/s (in addition to the cyclic data communication service).	T	

5.3.3.7 Notes on possible DECT implementation

Requirements:

- This Use Case does not require Ultra Reliability. It can be considered best effort according to ITU-R definition (see clause 4.5).
- This Use Case does not require Low Latency.
- The required range is consistent with DECT solutions.
- The Use Case is consistent with license-exempt operation regimen.
- This Use Cases does not require synchronous operation.

Possible implementation paths:

- This Use Case seems implementable over DECT-2020.
- This Use Case seems implementable over DECT evolution.

5.3.4 Motion control - seamless integration with Industrial Ethernet

5.3.4.1 Description

In this use case, not all sensors and actuators in a motion control system are connected using a 5G system. Instead, a single motion control system could integrate components of a wire-bound Industrial Ethernet system and components of a 5G system. Therefore the 5G system should support the seamless integration and interplay with Industrial Ethernet.

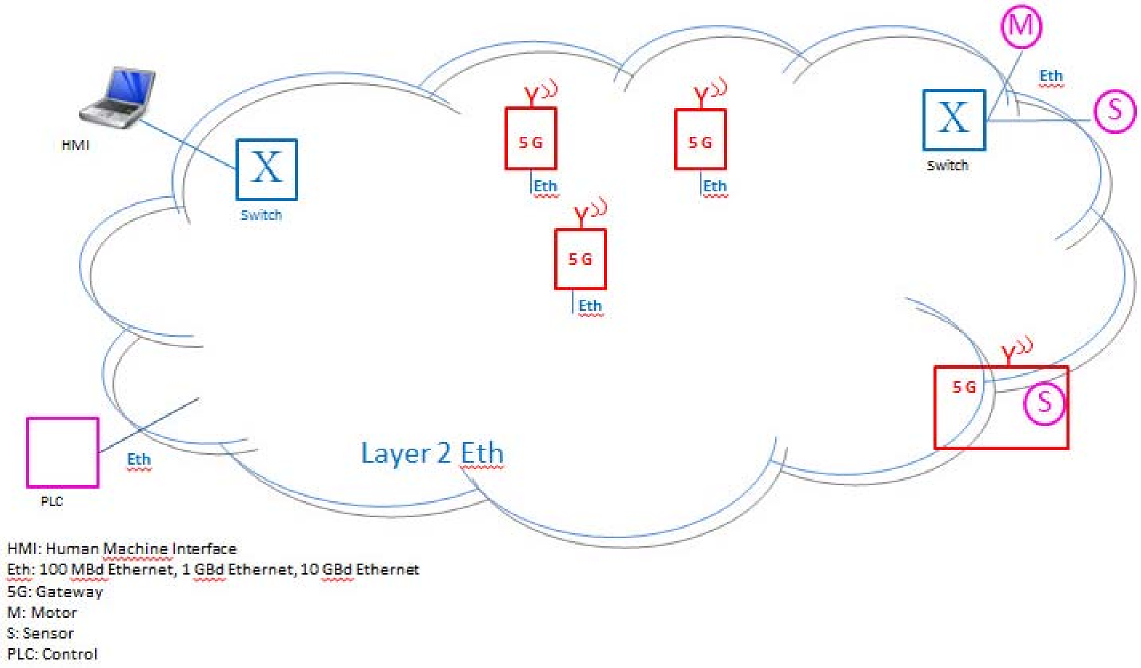


Figure 6: Example for an Industrial Ethernet network including 5G links for motion control

5.3.4.2 Preconditions

Sensors, actuators and motion controller are switched on and some of them are connected using a 5G system and the others are connected using Industrial Ethernet. The interconnection between Industrial Ethernet and 5G is realized using gateway UEs connected to Ethernet switches or a device is connected directly to a PDN using an Ethernet adapter.

5.3.4.3 Service flows

The conditions for cyclic and NRT communication flows apply to this use case, with the addition that communication flows are initiated on devices connected via (Industrial) Ethernet and directed to devices connected via 5G or vice versa.

As Industrial Ethernet typically operates on the Ethernet Data Link layer (Layer 2), the communication flow establishment can only be successful if the 5G network is able to forward frames from Ethernet sources towards 5G destinations and vice versa. In general this also includes the handling of broadcast packets.

The Ethernet devices of a single motion control could be separated from others on the same physical Ethernet network using Virtual LAN (IEEE 802.1Q [i.61]). Therefore the 5G system should be aware of the Virtual LAN associations when forwarding Ethernet frames. Furthermore, the Virtual LANs Priority Code Point assignment could be utilized to determine the 5G traffic priority.

The precise time synchronization between multiple motions controllers connected to Industrial Ethernet and 5G may be realized using the Precise Time Protocol (IEEE 1588 [i.59]). This protocol enables the estimation of clock offsets between network end-points and in this case the motion controllers. The support of IEEE 1588 in a 5G system introduces the expedited processing and transmission of certain messages at any of the intermediate devices in the communication path.

A single motion control might share the available network resources with other applications. Current and future Industrial Ethernet protocols offer the reservation of network resources to overcome communication bottlenecks. Since resource reservation considers the complete communication path, the flow of resource reservation is introduced to the 5G system. The 5G system could be aware of the standard Ethernet protocols as e.g. Time-Aware Scheduling defined in IEEE 802.1Qbv [i.58].

5.3.4.4 Post-conditions

The components controlled by the motion control system move/rotate as requested by the motion controller.

5.3.4.5 Challenges to the 5G system

Special challenges to the 5G system associated with this use case include the following aspects:

- Seamless integration with (Industrial) Ethernet systems.
- Support of certain mechanisms of the IEEE 802.1 protocol family, including IEEE 802.1Qbv [i.58] (time-aware scheduling) and IEEE 802.1Q [i.61] (VLANs).
- Support of time synchronization based on IEEE 1588 [i.59].

5.3.4.6 Potential requirements

Reference Number	Requirement text	Application / Transport	Comments
Factories of the Future 4.1	The 5G system should support the basic Ethernet Layer-2 bridge functions as bridge learning and broadcast handling.	T	
Factories of the Future 4.2	The 5G system should support and be aware of VLANs (IEEE 802.1Q [i.61])	T	
Factories of the Future 4.3	The 5G system should support the expedited processing and transmission of IEEE1588 [i.59]/Precise Time Protocol messages	T	
Factories of the Future 4.4	The 5G system should support IEEE 802.1Qbv [i.58] (time-aware scheduling)	T	

5.3.4.7 Notes on possible DECT implementation

Requirements:

- This Use Case seems to be merely a problem of integration with Industrial Ethernet IEEE 802.1Q [i.61].
- It requires further study but no major conceptual difference is seen regarding integration with 3GPP 5G.

Possible implementation paths:

- It seems implementable over both DECT-2020 and DECT evolution.

5.3.5 Control-to-control communication (motion subsystems)

5.3.5.1 Description

Control-to-control (C2C) communication, i.e. the communication between different industrial controllers (e.g. programmable logic controllers or motion controllers) is already used today for a number of different use cases, such as the following ones:

- Large machines (e.g. newspaper printing machines), where several controls are used to cluster machine functions, which need to communicate with each other. These controls typically need to be synchronized and exchange real-time data.
- Individual machines that are used for fulfilling a common task (e.g. machines in an assembly line) often need to communicate, for example for controlling and coordinating the handover of work pieces from one machine to another.

Typically, a C2C network has no fixed configuration of certain controls that need to be present. The control nodes present in the network often vary with the status of machines and the manufacturing plant as a whole. Therefore, hot-plugging support for different control nodes is important and often used.

Protocols that are used for C2C communications today include Industrial Ethernet standards, such as Sercos, PROFINET®, and EtherCAT®, as well as OPC UA®-based communication and other protocols, which are often based on Fast Ethernet.

With the introduction of "Connected Industries" or "Industrial IoT" scenarios, the amount of networking between controls is assumed to rise. Especially the number of controls participating and the amount of data being exchanged is assumed to rise significantly. In this respect, wireless communication using a 5G system may pave the way for highly modular and flexible production modules that efficiently and flexibly interact with each other.

In the following, the main focus is on control-to-control communication between different motion (control) subsystems, as outlined in clause 5.3.2. An exemplary application for that are large printing machines, where it is not possible or desired to control all actuators and sensors by one motion controller only. Such C2C systems typically have the most demanding requirements on the underlying connectivity infrastructure. For other C2C applications, the corresponding requirements (e.g. in terms of clock synchronicity) become often more relaxed.

In general, this use case has very stringent requirements in terms of latency and service availability. The required service area is usually bigger than for "motion control" (see clause 5.3.2), and interworking with the public network (e.g. mobility, roaming) is not required.

5.3.5.2 Preconditions

At least a subset of the controls are switched on and connected to the 5G network. The remaining controls may be interconnected with the other controls using state-of-the-art wire-bound communication technologies, such as the ones mentioned above.

5.3.5.3 Service flows

Data transmission in control-to-control networks typically consists of cyclic and acyclic data transfers. Both types may have real-time requirements. However, the real-time requirements typically are lower than in the case of communication between controls and sensors or actuators (for example in case of motion control applications). Typical cycle times for C2C communication are in the order of 4 to 10 ms. However, the amounts of cyclic data typically are higher compared to the communication between controls and sensors / actuators and may be more than 1 kB per cycle.

Many C2C networks make heavy use of hot-plug features, so that additional control nodes may be added to a running network as well as being removed without affecting the data transfer between other nodes.

5.3.5.4 Post-conditions

The different types of data transfers between the controls function as required. The different controls act in a coordinated and tightly coupled manner.

5.3.5.5 Challenges to the 5G system

Special challenges to the 5G system associated with this use case include the following aspects:

- High requirements on end-to-end latency, communication service availability, and determinism.
- Very high requirements on synchronicity between different nodes.
- Transmission of possibly large amounts of data per cyclic data transmission.
- Potentially high density of UEs in the future.

5.3.5.6 Potential requirements

Reference Number	Requirement text	Application / Transport	Comments
Factories of the Future 5.1	The 5G system should support strictly deterministic cyclic traffic with cycle times down to at least 4 ms for a communication group of 5 - 10 controls (in the future up to 100) and payload sizes up to 1 kB.	T	
Factories of the Future 5.2	The 5G system should support strictly deterministic acyclic traffic with response times of less than 10 ms, i.e. any acyclic (bi-directional) message transfer should be successfully completed in less than 10 ms.	T	
Factories of the Future 5.3	The 5G system should support a very high synchronicity between a communication group of 5-10 controls (in the future up to 100) in the order of 1 µs or below.	T	
Factories of the Future 5.4	The 5G system should be able to support non-real-time traffic, both cyclic and acyclic.	T	
Factories of the Future 5.5	The 5G system should support data integrity protection and message authentication, even for communication services with low end-to-end latency and ultra-high availability requirements	T	
Factories of the Future 5.6	The 5G system should support communication service availability exceeding at least 99,9999 %, ideally even 99,999999 %.	T	
Factories of the Future 5.7	The cyclic data communication service of the 5G system should be able support to satisfy the safety requirements according to [i.42] for safety integrity level 3 (SIL-3).	T	

5.3.5.7 Notes on possible DECT implementation

Requirements:

- This Use Case requires Ultra Reliability, ideally ($1\text{-}10^{-8}$).
- This Use Case requires Low Latency, (4 ms cyclic).
- The required range is consistent with DECT solutions.
- The Use Case is consistent with license-exempt operation regimen.
- This Use Cases requires synchronous operation with < 1 µs jitter requirement.

Possible implementation paths:

- This Use Case seems implementable over DECT-2020.
- This Use Case seems only implementable over DECT evolution accepting restriction regarding the reliability, latency, and jitter.

5.3.6 Mobile control panels with safety functions

5.3.6.1 Description

Control panels are crucial devices for the interaction between people and production machinery as well as for the interaction with moving devices. These panels are mainly used for configuring, monitoring, debugging, controlling and maintaining machines, robots, cranes or complete production lines. In addition to that, (safety) control panels are typically equipped with an emergency stop button and an enabling device, which an operator can use in case of a safety event in order to avoid damage to humans or machinery. When the emergency stop button is pushed, the controlled equipment immediately has to come to a safe stationary position. Likewise, if a machine, robot, etc. is operated in the so-called special 'enabling device mode', the operator has to manually keep the enabling device switch in a special stationary position. If the operator pushes this switch too much or releases it, the controlled equipment immediately has to come to a safe stationary position as well. This way, it can be ensured that the hand(s) of the operator are on the panel (and not under a moulding press, for example) and that the operator does-for instance-not suffer from any electric shock or the like. A common use case for this 'enabling device mode' is the installation, testing or maintenance of a machine, during which other safety mechanisms (such as a safety fence) have to be deactivated.

Due to the criticality of these safety functions, safety control panels currently have mostly a wire-bound connection to the equipment they control. In consequence, there tend to be many such panels for the many machines and production units that typically can be found in a factory. With an ultra-reliable low-latency wireless link, it would be possible to connect such mobile control panels with safety functions wirelessly. This would lead to a higher usability and would allow for the flexible and easy re-use of panels for controlling different machines.

One way to realize the safety functions is to make use of a special safety protocol in conjunction with the "black channel" principle [i.47]. These safety protocols can ensure a certain safety level as specified in [i.48] with no or only minor requirements on the communication channel between the mobile control panel and the controlled equipment. To this end, a strictly cyclic data communication service is required between both ends. If the connectivity is interrupted, an emergency stop is triggered, even if no real safety event has occurred. That means the mobile control panel and the safety controller (e.g. a safety programmable logic controller (PLC)) it is attached to cyclically exchange messages and the machine stops if either the connection is lost or if the exchanged messages explicitly indicate that a safety event has been triggered (e.g. that the emergency stop button has been pushed). Thus, guaranteeing the required safety level is not difficult, but achieving at the same time a high availability of the controlled equipment/production machinery is. To that end, an ultra-reliable ultra-low-latency link is required.

The cycle times for the safety traffic always depend on the process/machinery/equipment whose safety has to be ensured. For a fast-moving robot, for example, the cycle times are lower than for a slowly moving linear actuator.

In general, this use case has very stringent requirements in terms of latency and service availability. The required service area is usually bigger than for "motion control" (see clause 5.3.2), and interworking with the public network (e.g. mobility, roaming) is not required.

5.3.6.2 Preconditions

The mobile control panel with safety functions is connected to a safety PLC of the machine/equipment it is supposed to control. The mobile control panel is in a predefined geographical position related to the controlled device (defined area, free field of view). A cyclic data communication service matching the cycle time requirements of the used safety protocol has successfully been set up. The emergency stop button is not pushed. The panel is not operated in enabling device mode, i.e. the operator does not have to keep the enabling device switch in a dedicated stationary position for proper operation of the controlled equipment.

5.3.6.3 Service flows

A typical service flow may look as follows:

1) The mobile control panel and safety PLC periodically exchange safety messages in intervals of T_{cycle} with a payload size of 40-250 bytes, indicating absence of any safety event. The value of the cycle time T_{cycle} depends on the controlled equipment and some examples can be found in the requirements given below.

2) In parallel, a non-cyclic bi-directional data communication service with a data rate of at least 5 Mbit/s in each direction is set up between the mobile control panel and the safety PLC for facilitating human interaction with the machine for configuring, monitoring, maintaining, etc. the machine.

3) Various bursts of acyclic data traffic are exchanged between the mobile control panel and the safety PLC in parallel to the cyclic data communication service for the safety traffic.

4) The operator pushes the emergency stop button on the control panel, triggering the transmission of corresponding safety messages to the safety PLC.

5) The controlled machine stops within a pre-defined time.

An alternative service flow covering the case of a broken link (which should be avoided) may look as follows:

1) The mobile control panel and safety PLC periodically exchange safety messages in intervals of T_{cycle} with a payload size of 40-250 bytes, indicating absence of any safety event. The value of the cycle time T_{cycle} depends on the controlled equipment and some examples can be found in the requirements given below.

2) In parallel, a non-cyclic bi-directional data communication service with a data rate of at least 5 Mbit/s in each direction is set up between the mobile control panel and the safety PLC for facilitating human interaction with the machine for configuring, monitoring, maintaining, etc. the machine.

3) Various bursts of acyclic messages are exchanged between the mobile control panel and the safety PLC in parallel to the enduring cyclic data communication service for the safety traffic.

4) The cyclic data communication service between the mobile control panel and the safety PLC is interrupted or disturbed (in the sense that the cycle times requirement cannot be met anymore, for example), triggering a timeout at the safety PLC.

5) The controlled machine stops within a pre-defined time.

All messages exchanged have to be properly secured (especially data integrity and authenticity) and the probability of two consecutive packet errors should be negligible. This is because a single packet error may be tolerable, but two consecutive packet errors may lead to a false safety alarm and thus may lead to a lengthy production downtime.

5.3.6.4 Post-conditions

Machines can be controlled in a safe way while meeting the requirements. The controlled machine has stopped within a pre-defined time after the emergency button has been pushed or the communication link was disturbed. Nobody got hurt.

5.3.6.5 Challenges to the 5G system

Special challenges to the 5G system associated with this use case include the following aspects:

- High requirements on end-to-end latency and jitter along with very high requirements on communication service availability.
- Simultaneous transmission of non-critical (bi-directional) data and highly-critical safety traffic with high requirements in terms of latency and communication service availability to the same device.
- The need for seamless mobility support (see the first item above).

5.3.6.6 Potential requirements

Reference Number	Requirement text	Application / Transport	Comments
Factories of the Future 6.1	The 5G system should support a bidirectional, cyclic data communication service characterized by at least the following parameters (e.g. for assembly robots or milling machines): Cycle time of T_{cycle} = 4-8 ms Jitter < 50 % of cycle time Data packet size 40-250 B Typical work space: 10 m x 10 m Parallel active safety services: max. 4 in a workspace	T	
Factories of the Future 6.2	The 5G system should support a non-cyclic bi-directional data communication service in parallel to the cyclic data transmission service with at least the following parameters: User experienced data rate > 5 Mbit/s Average end-to-end latency < 30 ms Jitter < 50 % of latency	T	
Factories of the Future 6.3	The 5G system should support seamless handovers between two base stations without any observable impact on the (safety) application.	T	
Factories of the Future 6.4	The 5G system should support a cyclic data communication service characterised by at least the following parameters (e.g. for mobile cranes, mobile concrete pumps, fixed portal cranes, etc.): Cycle time of T_{cycle} = 12 ms Jitter < 50 % of cycle time Data packet size 40-250 B Typical work space: 40 m x 60 m Max. workspace: 200 m x 300 m Parallel active safety services: 2 in a workspace	T	
Factories of the Future 6.5	The 5G system should support an indoor localization service with at least the following parameters: Accuracy better than 1 m Heading < 30 degrees	T	
Factories of the Future 6.6	The 5G system should support a communication service availability exceeding at least 99,9999 %, ideally even 99,999999 %.	T	

5.3.6.7 Notes on possible DECT implementation

This Use Case requires further study.

5.3.7 Mobile robots

5.3.7.1 Description

Mobile robots and mobile platforms, such as automated guided vehicles (AGV), have numerous applications in industrial and intra-logistics environments and will play an increasingly important role in the Factory of the Future. A mobile robot essentially is a programmable machine able to execute multiple operations, following programmed paths to fulfil a large variety of tasks. This means, a mobile robot is able to perform activities like assistance in work steps and transport of goods, materials and other objects and can have a large mobility within the industrial environment. Mobile robot systems are characterized by a maximum flexibility in mobility relative to the environment, with a certain level of autonomy and perception ability, i.e. they can sense and react with their environment. AGVs are a sub-group of mobile robots. AGVs are automatically steered and are driverless vehicles used to move materials efficiently in a restricted facility. Mobile robots and AGVs are monitored and controlled from a guidance control system. Radio controlled guidance control is necessary to get an up-to-date process information to avoid collisions between mobile robots, to assign driving jobs to the mobile robots and manage the traffic of mobile robots. The mobile robots are track-guided by the infrastructure with markers or wires in the floor or guided by own surround sensors, like cameras or laser scanners, for instance.

Mobile robot systems are sophisticated machines that represent a complete material handling solution and which are installed in numerous industries with a wide range of applications and environments. A detailed overview of the state of the art of AGV systems with modern areas of applications, AGV categories and AGV technologies is given in [i.55].

The key aspects of mobile robots and AGV systems include:

- processes for handling goods and materials, especially incoming and outgoing goods, in warehousing and commissioning, in transportation as well as transfer and provision of goods;
- followed by information flows, namely the communication of inventory and movement reports, the outstanding order situation, throughput times and availability forecasts, presenting data to support tracking, monitoring and if needed to make decisions on measures to be taken, as well as the selection and implementation of means of data transfer;
- the use of means of transportation (cranes, lifters, conveyors, industrial trucks, etc.), as well as monitoring and control elements (sensory and actuating equipment);
- and finally the use of techniques (for active/passive security, data management, goods and wares recognition/identification, image processing, goods transfer, namely provision, sorting commissioning, palletising, packaging).

Mobile robot systems can be divided in operation in indoor, outdoor and both indoor and outdoor areas. These environmental conditions have an impact on the requirements of the communication system, e.g. the handover process, to guarantee the required cycle times. Some examples are given in table 6.

Table 6: Overview of different operational areas including corresponding examples for mobile robots / AGVs

Environment	Indoor	Outdoor	Indoor and outdoor
Area of operation	Several meters up to several hundreds of meters, possibly divided in different factory buildings.	Several meters up to several kilometres in container terminals or in open pit mines.	Combination of both, factory buildings and open areas, as described at the indoor and outdoor areas of operation.
Examples	Light load - transport with work-in process movement of goods. Unit load vehicles (e.g. car body) movement with work-in-process in a production and decoupled operating times as an advantage over conveyor belts. Pallet trucks.	Unit load vehicles for container transport in automated ports Mining trucks. Combinations of vehicles for platooning and convoy Heavy-load transport crosses the outside area.	Towing vehicles that operate between stock and production Cow/animal feeding robots on farms. Automated fork lifters for use in truck loading.

Depending on the operation area, this use case may have different requirements:

- in a limited service area (likely indoor), ultra-low latency is required and not interworking with the public network (e.g. mobility, roaming);
- in a wide service area (several kilometres, likely outdoors), the latency requirement is relatively relaxed and interworking with the public network (e.g. mobility, roaming) may be required.

5.3.7.2 Preconditions

All mobile robots and the guidance control system are switched on and connected to the 5G network. The communication between the guidance control system and mobile robots has been successfully set up and is running.

5.3.7.3 Service flows

In the following, three different cases can be distinguished, depending on who is communicating with whom:

a) Communication between mobile robot and guidance control system:

- A number of mobile robots (up to 100, with a potential enrolment of up to 1 000) are commonly in use, always guided by a guidance control system. The mostly centralized guidance control system communicates bidirectional with each mobile robot. In this respect, the following data is typically exchanged:

    ▪ - Communication direction from guidance control system to mobile robot:

        - Process data for control and management of mobile robots.

        - Emergency stop.

    ▪ - Communication direction from mobile robot to guidance control system:

        - Process data (control and management data).

        - Video or image data.

b) Communication between mobile robots:

- The mobile robots can exchange real-time control data with each other and provide a collision-free operation of autonomous mobile robots and synchronized actions between multiple mobile robots. For this purpose, the mobile robots exchange real-time control data.

c) Communication between mobile robots and peripheral facilities:

- The mobile robots communicate with the peripheral facilities. For example, mobile robots are able to open and close doors or gates. For this purpose, the mobile robots transmit the control data to the door or gate control. Furthermore, mobile robots can be working together with fixed installations like cranes or manufacturing machines. To this end, the mobile robots exchange real-time control data with cranes or manufacturing machines.

5.3.7.4 Post-conditions

Mobile robots and AGVs can be controlled in a safe way while satisfying the requirements.

5.3.7.5 Challenges to the 5G system

Special challenges to the 5G system associated with this use case include the following aspects:

- Very high requirements on latency, communication service availability, and determinism.
- Very high requirements on clock synchronicity between different mobile robots.
- Simultaneous transmission of non-real time data, real-time streaming data (video) and highly-critical, real-time control data with highest requirements in terms of latency and communication service availability over the same link and to the same mobile robot.
- Potentially high density of mobile robots.
- Good 5G coverage in indoor (from basement to roof), outdoor (plant/factory wide) and indoor/ outdoor environment is needed due to mobility of the robots.
- Seamless mobility support such that there is no impairment of the application in case of movements of a mobile robot within a factory or plant.

5.3.7.6 Potential requirements

Reference Number	Requirement text	Application / Transport	Comments
Factories of the Future 7.1	The 5G system should support a cyclic data communication service, characterized by at least the following parameters: Cycle time of 1 ms for precise cooperative robotic motion control. 1-10 ms for machine control. 10-50 ms for cooperative driving. 10-100 ms for video operated remote control. 40 ms to 500 ms for standard mobile robot operation and traffic management. Jitter < 50 % of cycle time. Communication service availability > 99,9999 %. Max. number of mobile robots: 100.	A	The size of messages at the application layer are 15 kbytes to 150 kbytes for video frames in video-operated remote control. The size of all other messages in all use cases, e.g. control messages to an actuator, is 40 bytes to 250 bytes.
Factories of the Future 7.2	For certain applications, the 5G system should support real-time streaming data transmission (video data) from each mobile robot to the guidance control system by at least the following parameter: Data transmission rate per mobile robot: > 10 Mb/s. Number of mobile robots: 100.	A	
Factories of the Future 7.3	The 5G system should support seamless mobility such that there is no impairment of the application in case of movements of a mobile robot within a factory or plant.	A	
Factories of the Future 7.4	The 5G system should support user equipment ground speeds of up to 50 km/h.	A	
Factories of the Future 7.5	The 5G system should support uniform and unequivocal parameters for interfaces to allow dependability monitoring (see section 4.3.4 of [i.26]).	T	
Factories of the Future 7.6	Communication complying with the above requirements should be available over a service area of 1 km^2 and less.	T	

5.3.7.7 Notes on possible DECT implementation

Requirements:

- This Use Case requires Ultra Reliability, ideally ($1\text{-}10^{-8}$).
- This Use Case requires Low Latency, (down to 1 ms).
- The required range for indoor operation is consistent with DECT solutions. However the 1 km^2 requires further study and special requirements (in DECT-2020).
- The Use Case is consistent with license-exempt operation regimen. However the impact in power consequence of the 1 km^2 requirement requires further study.
- This Use Cases requires probably synchronous and asynchronous operation.

Possible implementation paths:

- This Use Case seems implementable over DECT-2020 but requires detailed study.

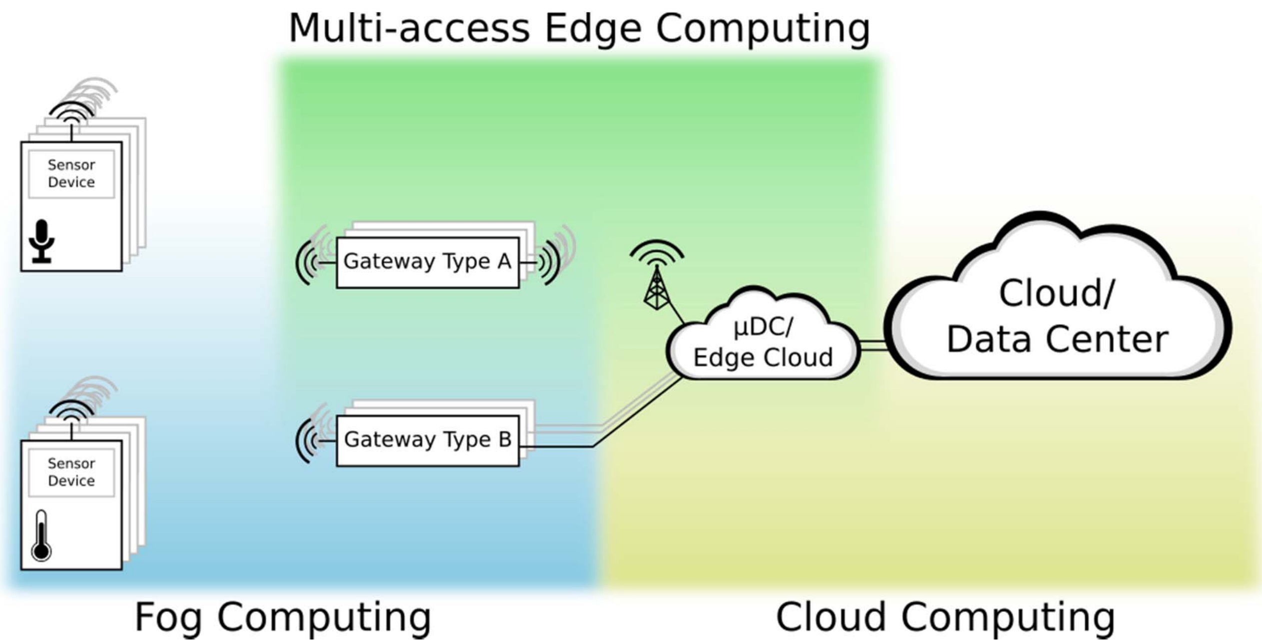
- This Use Case does not seem candidate for implementable over DECT evolution.

5.3.8 Massive wireless sensor networks

5.3.8.1 Description

Sensor networks aim at monitoring the state or behaviour of a particular environment. In the context of the Factory of the Future, wireless sensor networks (WSN) are targeting the monitoring of a process and the corresponding parameters in an industrial environment. This environment is typically monitored using various types of sensors such as microphones, CO_2 sensors, pressure sensors, humidity sensors, and thermometers. In particular, these sensors usually form a distributed monitoring system. The monitored data, from such a system, is used to detect anomalies in the data, i.e. by leveraging machine learning (ML) algorithms. These algorithms usually require a training phase before a trained ML algorithm can later work on a subset of the available measured data. However, the training as well as the analysis of the data may be realized in a centralized or distributed manner.

The placement of the monitoring function can be dynamic and thus, may vary over time to enable dynamic up- and down-scaling of computing resources. In particular, the placement may also be constrained by the available WSN hardware. Given rather simple sensing devices, the functionality needs to be placed into a centralized computing infrastructure such as a mobile data or data centre cloud. Opposed to that, functionality may be placed inside the sensor network, i.e. the sensing devices, with additional external computational resources. The computation is referred to as fog computing, multi-access edge computing (MEC), and cloud computing, see figure 7, when sensor devices and gateways, gateways and edge cloud, and edge cloud and data centre resources are involved, respectively. A more local approach, e.g. fog computing or multi-access edge computing, is preferred over a more centralized approach in order to keep sensitive data in a fabrication site and keep the automated process independent of an internet connection.



NOTE: It may comprise a set of heterogeneous measurement-units, wirelessly connected to gateways, which in turn are connected to a computing infrastructure such as a micro data centre (µDC). Other setups that contain grouped sensor devices are possible and may assist in reducing load on central instances.

Figure 7: High level component view of a scalable massive sensor network

Sensor networks facilitate the complex task of monitoring an industrial environment to detect malfunctioning and broken elements in the surrounding environment. An appropriate detection approach along with a classification of the anomaly can help choosing a countermeasure or proper action to take in case of predictive maintenance. Such actions can aid in improving the safety by automatically triggering a machine's emergency stop in case of the detection of a critical problem. At the same time, production efficiency can be increased as machines can continue running in case the detected problem is not safety relevant and only disrupts service of some elements.

Measuring the environment and propagating events may be realized in different scenarios. In the simplest scenario, which is the least scalable, the sensors propagate each newly measured value without any pre-processing, i.e. in a solely proactive scenario.

A more advanced approach is to solely react to the environmental changes to reduce traffic, e.g. by only propagating events under certain circumstances whenever a value exceeds a certain threshold [i.49]. In such a case, each sensor keeps measuring data but only propagates it whenever it detects a relevant change in the environment. Depending on the hardware, the sensing device may also be able to pause any active handling (i.e. polling data from sensor) as long as the given threshold is not exceeded, e.g. by receiving an interrupt when the sensor itself measures a sudden significant change of the environment. Usually, active handling in such a case is triggered by a call back from the sensor or a (remote) control unit. This optimization enhances the sensing devices durability by reducing its power consumption. The power consumption reduction is an important task in WSNs since sensors are often just equipped with a battery. Thus, the power consumption reduction has gained a significant momentum in the WSN research. Moreover, a lot of effort is put on specifying new messaging protocols to reduce overhead of messaging protocols while still maintaining a high reliability and low latency [i.50]. Additionally, the reduction of message generation, e.g. by analysing measurements in local groups has thoroughly been investigated.

The traffic patterns generated by the sensor network vary with the type of measurement and the aforementioned setup. Traffic patterns may arise in the form of self-similar and/or periodic patterns, i.e. the latter is usually the case in proactive setups. Moreover, low-bandwidth and high-bandwidth streams might be transmitted. Depending on the computational resources of the gateway(s), some pre-processing of the sensor data may reduce the network load, and with that, the uplink requirements.

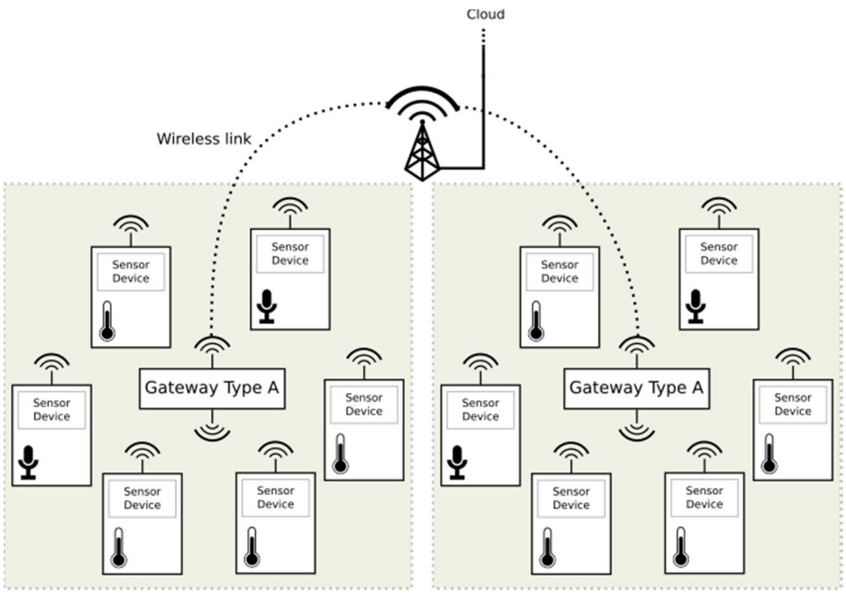


Figure 8: Sensor devices in star topology are connected to a local gateway (i.e. small cell), which provides connectivity to a base station

Figure 8 depicts a massive sensor network deployment. A number of sensor devices are connected to a local gateway (small cell) which connects to a base station at the edge to the cloud network. Hence, the local gateway aggregates and forwards monitoring data. Also, while aggregating, the local gateway may pre-process the incoming data to reduce traffic load to the cloud and computational resource requirements on the cloud. A local gateway needs to dynamically handle the attachment requests and detachment events of sensor devices without disruption of the monitoring service.

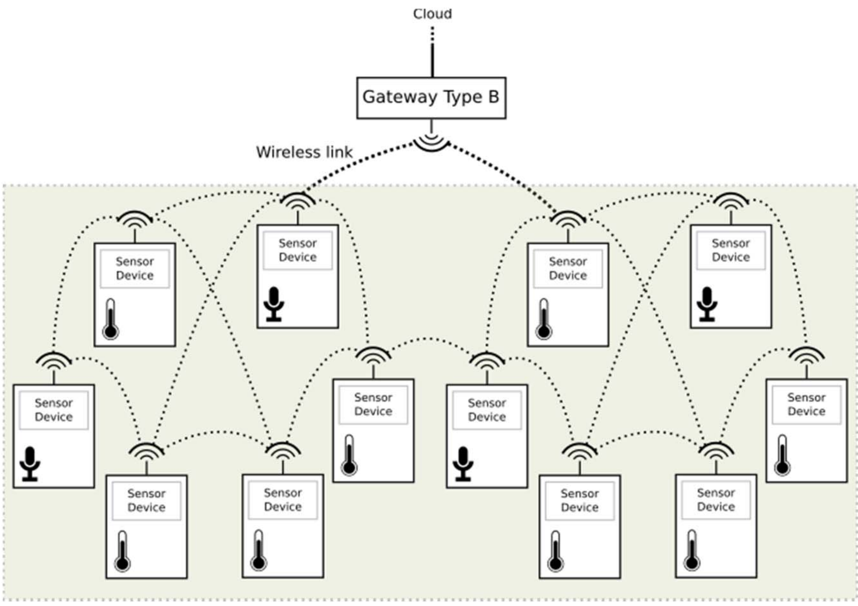


Figure 9: Sensor devices in a mesh topology realizing multi-hop connectivity to gateway (via edge devices)

Another topology for a massive sensor network is shown in figure 9. Here, a set of sensor nodes is directly interconnected as a mesh, where one sensor nodes provides an uplink to the serving gateway (small cell). This reduces the number of locally deployed cells. In such a topology the sensor nodes may communicate just locally to reduce the load on more central instances such as gateways and cloud resources.

In both topologies, star and mesh, a sensor node needs to perform a proper bootstrapping to connect to the network. It needs to be able to attach itself to the network automatically by attaching itself to a local cell or neighbouring mesh devices. Additionally, time synchronization of sensor nodes, base stations, and gateways can enhance and ease monitoring. Time synchronization in a massive sensor network may be realized in local groups, using the gateways or base stations. However, the bootstrapping of sensor nodes and the time synchronization is out of the scope of the present document.

Table 7: Typical monitoring service requirements

Scenario	End-to-end latency (note 1)	Priority	Data Update Time	Communication service availability	Connections per gateway	Network scalability	Node density	Communication range per node
Condition monitoring for safety	5 - 10 ms	Highest (= 1)	Up to 100 packets/ second	> 99,9999 % - 99,999999 %	10 - 100	> 100 - 1 000 nodes	0,05 - 1 /m²	< 30 m
Interval-based condition monitoring	50 ms - 1 s	Medium (= 3)	Up to 10 packets/ second	> 99,9 % (note 2)	10 - 100	> 1 000 - 10 000 nodes	0,05 - 1 /m²	< 30 m
Event-based condition monitoring	50 ms - 1 s	High (= 2)	Event-triggered	> 99,9 % (note 2)	10 - 1 000	> 1 000 - 10 000 nodes	0,05 - 1 /m²	< 30 m
NOTE 1: This is the end-to-end latency the service requires. The end-to-end latency is not completely allocated to the 5G system in case other networks are in the communication path. NOTE 2: Missing/corrupt messages from single device may be tolerated as input from multiple devices is considered on detection of anomaly.								

Table 8: Example of data generation per sensor

Measurement	Sampling Rate in Hz	Sample Size	Data generation in kbit/s
Temperature, humidity, pressure (note 1)	182	32 b	~ 6
Acceleration (note 1)	2 000	96 - 192 b	192 - 384
Audio (WAV) (note 2)	50 - 192 000	8 - 24 b	2,4 - ~ 4 600
Audio (MP3) [i.53] (note 3)	50 - 192 000 (WAV)	8 - 24 b (WAV)	8 - 320
NOTE 1: Values found in [i.51]; may vary with different hardware. NOTE 2: WAV is only a container; the pulse code modulation (PCM) [i.52] encoding is considered in this example. NOTE 3: Variable bit rate option of MP3 is not considered. With a variable bit rate the data rate may be lower. Additionally, other encodings are possible as well.			

Table 7 provides an overview of typical service requirements in condition monitoring. Condition monitoring for safety, i.e. monitoring which may result in an emergency stop, requires reduced delay and increased reliability to properly react in time. Thus, such a service might be operated as dedicated network.

Table 8 exemplifies salient properties of commercial off-the-shelf sensor nodes and the expected amount of data from a sensor device. The amount and type of traffic engendered by this generated data strongly depends on further processing of this data, e.g. compression of raw audio or local analysis, as well as on the implemented messaging protocol. The protocol overhead increases the amount of data due to additional headers, redundancy, and/or acknowledgement and retransmission mechanisms [i.50].

As provided in table 8, an example for low traffic monitoring is thermal monitoring. Thermostats usually slowly adapt to temperature changes. Thus, a fairly low sampling rate is sufficient and a threshold based propagation mechanism can be used. Accordingly, the thermal monitoring may generate "bursty" traffic patterns with small data packets, since the measured data is typically a single integer or set of integers for a specific time frame. The audio sampling rate strongly depends on the application. For instance, a sampling rate of 50 Hz is only able to record a maximum frequency of up to 25 Hz, which is the lower bound of human hearing. For machine applications, sampling rates of 192 kHz with frequencies up to 96 kHz may be recorded, which can be easily beyond the human hearing range.

Audio monitoring is a typical application for a sensor network with high traffic demands. Audio sensors produce a continuous data stream per device of tens of kilobits per second, depending on the audio encoding and targeted frequency range. Some sensor nodes may not have the computational resources to pre-process the audio stream. This, however, would eliminate the possibility to realize a threshold based propagation mechanism. A typical monitoring system needs be scalable up to hundreds or thousands of sensor nodes with up to 100 wireless sensor nodes per gateway [i.54].

This use case has relatively moderate latency requirements. The required service area is usually bigger than for "motion control" (see clause 5.3.2). Interworking with the public network (e.g. mobility, roaming) is likely not required.

5.3.8.2 Preconditions

- Wireless devices are attached to local gateways
- Local gateways are connected to Cloud/MEC (via base station/wired)

5.3.8.3 Service flows

1) Sensing devices continuously send current sensor status to centralized computing instance for learning of the environment.

2) After completion of learning, devices send:

   - Less data to centralized instance. A reduced data set is either pre-processed data or raw data which sent less frequently.

   - Data to neighbouring sensor devices or local gateway for group/mesh processing of environmental state. Further processing may also be realized on MEC/Cloud.

3) An anomaly in the measurements, e.g. a rapidly rising temperature or an unusual scraping sound, is detected on either of:

   - Fog.
   - MEC.
   - Cloud.

4) Detected event is propagated to factory's controlling instance.

5) Action is taken by controlling instance.

5.3.8.4 Post-conditions

The proper action was executed that is optimum for safety and productivity (no operation/ machine stop/ warning) for given anomaly.

5.3.8.5 Challenges to the 5G system

Special challenges to the 5G system associated with this use case include the following aspects:

- Large number of UEs per radio cell
- High aggregate user experienced data rate
- Local groups need to be formed; mesh topologies need to be realized
- Low-latency requirements combined with high reliability
- Automated attachment of UEs without services disruption for connected UEs
- Interfaces to allow programmability of gateways
- Packet prioritization techniques to meet constraints for critical messages

5.3.8.6 Potential requirements

Reference Number	Requirement text	Application / Transport	Comments
Factories of the Future 8.1	The 5G system should support "bursty" and possibly internet-like self-similar traffic patterns from a massive set of devices	T	
Factories of the Future 8.2	The 5G system should support high-bandwidth streams from a massive set of devices with a user experienced data rate of up to 100 Mbit/s	T	
Factories of the Future 8.3	The 5G system should support user equipment (UE) mesh networks with multi-hop functionality	A	In order to build local sensor groups
Factories of the Future 8.4	The 5G system should support the combination of the requirements "Factories of the Future 8.1" and "Factories of the Future 8.2"	T	
Factories of the Future 8.5	The 5G system should support gateways with additional programmability to support multi-access edge computing (MEC) functionality	A	
Factories of the Future 8.6	The 5G system should support automatic attachment (authentication and association) of previously unattached UE devices whilst providing service continuity for other UE devices in the network	T	
Factories of the Future 8.7	The 5G system should optimize the energy consumption per bit sent on a UE device	A/T	
Factories of the Future 8.8	The 5G system should support prioritization of critical messages	T	
Factories of the Future 8.9	The 5G system should support a maximum end-to-end latency of 10 ms for critical messages (i.e. message from source to final destination, possibly multi-hop)	T	
Factories of the Future 8.10	The 5G system should support a very high communication service availability (> 99,9999 %) for critical messages	T	
Factories of the Future 8.11	The 5G system should support a very high connection density of up to 10^6 connections per km^2 (i.e. 1 per m^2). NOTE: Connection density is the total number of connected and/or accessible devices per unit area (per km^2). Normally, all connected devices are not sending or receiving messages at the same time.	T	

5.3.8.7 Notes on possible DECT implementation

Requirements:

- This Use Case requires Ultra Reliability, ideally ($1\text{-}10^{-8}$).
- This Use Case requires reduced Latency, (down to 10 ms).
- This use case may require high bandwidth (100 Mb/s).
- This Use Case requires a massive number of devices.

Possible implementation paths:

- This Use Case requires further study.

5.3.9 Remote access and maintenance

5.3.9.1 Description

Remote Access and Maintenance is a key motivation for looking beyond conventionally wired device networks in automation. Typical industrial networks are isolated from the internet and often based on very specific protocols. In such industrial networks (peer-to-peer communication links between just two devices, fieldbus with multiple devices and controllers, LAN or WLANs), a remote access is often possible already today, but requires gateway functionality at any transition of the automation pyramid between bus systems, as shown in figure 10. Mapping of data formats, addresses, coding, units, and status is required for a remote access to device data going down the automation pyramid, which comes along with a huge engineering effort. This data mapping implemented in the gateway(s) is quite static and is not suitable for a flexible access on event-based conditions rather than a permanent connection and data exchange, e.g. reading the device revision in case of a diagnostic event.

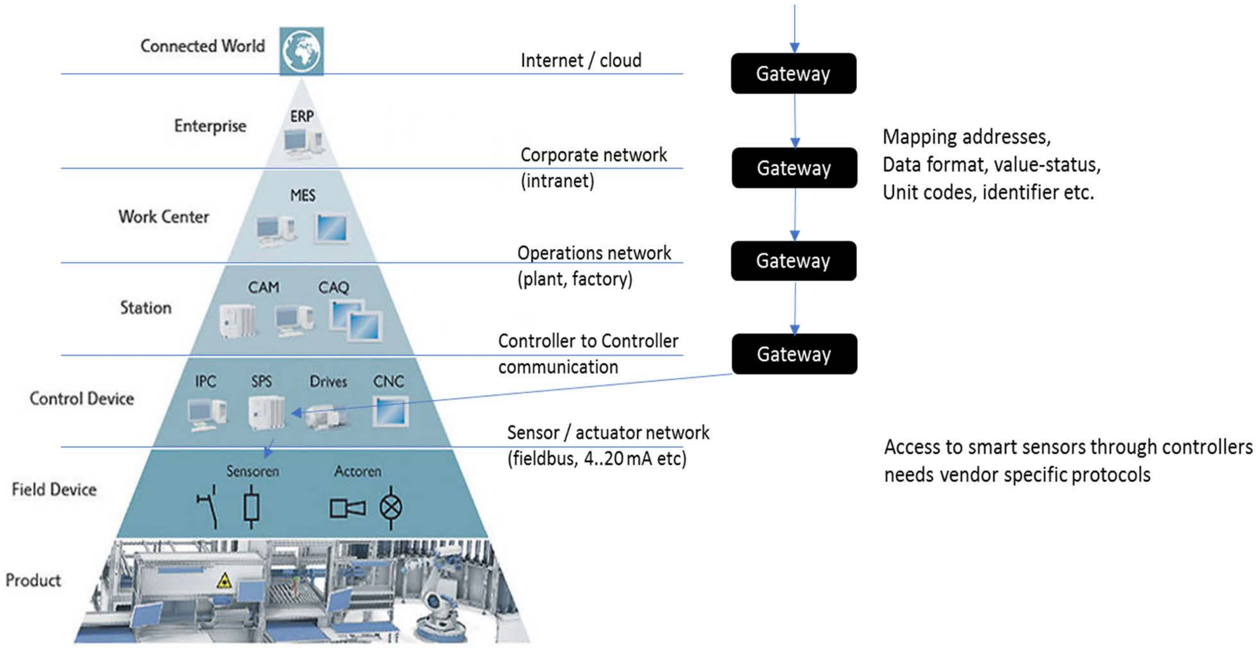


Figure 10: Remote access to field devices in existing systems through controllers via gateways at each transition point of the automation pyramid

Remote Access and Maintenance scenarios apply to:

- Devices which already have a "cyclic" connection through a communication service for transmitting data regularly. This ad-hoc communication might be requested by the same end device and just runs in parallel from time to time.
- Devices which act almost autonomously, i.e. they have local computing power to run algorithms like measurement and data analytics, but they do not have a regular, cyclic connected communication service.
- Devices which have local personnel to interact with, such as a machine or even a car. A remote connection could be requested during a service case or if the local operator needs remote assistance.
- Devices which sleep most of the time and which should be woken up by establishing a connection via a dedicated wireless network.

A special sub-set of remote accesses is when the partner is a mobile device (geographically) near the device instead of a service far away from the device. The device might not differentiate if it is accessed remotely or "locally" via the 5G network. Use cases described here would be the same from the device's point of view. A remote user would expect to parse a list with devices and have them organized in trees. A local operator has the intention to "talk with the device in front of her/him" instead of walking through a list of 10 000 devices installed at this plant. There should be means to automatically discover which 5G devices belonging to a certain group (e.g. all 5G devices installed in a process plant) are in the immediate vicinity of a local operator and to provide the user with a list of all those 5G devices.

Another use case is the inventory of devices and periodic readouts of configuration data, event logs, revision data, and predictive maintenance information. This is often called "asset management", and tools for collecting and displaying data from many connected devices are called "asset monitors". Such a system may work autonomously (set of configured periodical checks) or it is interacting with a user ("show me status of this device"). A remote diagnostic system might be connected to many or all devices of a certain plant or location. A remote diagnostic system might be connected to many or all devices the operator is responsible for. A remote diagnostic system could also run as a device vendor's service to maintain all devices independent of the device owner (plant, location).

There exist many protocols for reading and writing data to smart devices. Some of these protocols are standardized and many others proprietary. Assuming an IP-capability of a 5G system, it should be possible to either use:

- Standardized IP-based protocols (such as OPC UA®, ModbusTCP®, HARTip®).
- Pack non-IP-based protocols into IP-frames in a proprietary way. This can be inside standardized protocols such as http (port 80) or proprietary IP-based protocols (device specific ports).
- Proprietary IP-based protocols (device specific ports).

Communicated data could be of any kind from single bytes, longer telegrams of a few kilobytes to continuous streams. Volume applications are expected with power and memory limited devices. The full range from power-optimized applications on the one end to high performance real-time data on the other end should be covered.

Remote access to a device may happen at any time (in case the user does authorize). So the remote access should be non-reactive to other communication in the 5G network and operation and performance to other devices. Remote access should have impact only on the contacted device. Prioritized traffic mechanisms may solve the problem to not violate configured real time conditions when upgrading a firmware of a device in the same network.

The trigger to remotely access a device may come from the device itself, based on a certain event or condition. In this case, a device initiates a connection to another (known) device and submits data which alerts a service to read / write specific data from / to that device.

A major concern associated with remote access and maintenance is the potential vulnerability of devices in terms of cyber security. Most classical wired communication protocols in industry do not consider any cyber security relevant scenarios. Physical access to devices and networks is almost restricted to skilled and authorized personnel. Furthermore, protocols are not widely used outside these specific industries and so the knowledge is kept to a limited community of specialists.

Users might want to block a device for any remote access, others might restrict access to only read data or just parts of data, such as operating hour meter, but no configuration data. Some restriction levels might be specific to the device and as such not standardized. Those restrictions should be fully transparent to the lower communication layers (5G in this case). A basic set of restriction levels are expected from 5G, what could be an adoption of existing mobile communication standards,

Electronic industrial devices do have a typical life cycle between 5 and 25 years. Customers expect old devices to remain accessible during this time with (at least) the same functionality that was provided when they were installed. Installations in process industry and factory automation are continuously extended and changed, so new devices are operated in parallel to old ones.

The operation for this use case can be in a wide service area, and interworking with the public network (e.g. mobility, roaming) may be required.

5.3.9.2 Preconditions

- Device is connected to the 5G network.
- Service tool (asset management system or asset monitor) is connected to the 5G network via a gateway.

5.3.9.3 Service flows

An example service flow may look as follows:

1) Device detects a condition that "call for maintenance" is required and sends a message to a predefined address, i.e. that of the asset management tool OR an asset management tool opens a connection to the device.

2) The tool checks device type and identity (starting with 5G information elements, going further down to device, customer, location specific information).

3) The tool reads / writes data from / to the device. This could be a few bytes, new firmware, or read real-time monitoring data. This is done for a limited time.

4) The tool closes the connection to the device.

5.3.9.4 Post-conditions

The maintenance case has been successfully completed.

5.3.9.5 Challenges to the 5G system

Special challenges to the 5G system associated with this use case include the following aspects:

- "Un-configured", sporadic network load, i.e. remote access injects traffic at a time not known during network setup.
- Sporadic network traffic with a particular device should not disturb configured and already running communication.
- Low power operation of devices, i.e. long time periods without any communication but always ready to receive a request (or to open a session, link, etc.).
- Compatibility for > 25 years. Compatible means here that a device can be used in a 5G network for 25 years or more with the same or more functionality as during its initial setup (installation).

5.3.9.6 Potential requirements

Reference Number	Requirement text	Application / Transport	Comments
Factories of the Future 9.1	Spontaneous connection to a device in a 5G network initiated by a remote service should be supported.	T	
Factories of the Future 9.2	Spontaneous connection to a service connected to a 5G network initiated by a 5G device should be supported.	T	
Factories of the Future 9.3	Spontaneous connection and associated data traffic should not disturb other communication running through the 5G network.	T	
Factories of the Future 9.4	The 5G system should be able to classify data as RT (real-time) and non-RT.	T	RT data transmission (either regular / cyclic or sporadic/burst) might need prior configuration.
Factories of the Future 9.5	The 5G system should support the automated discovery of 5G devices belonging to a certain group (for example all 5G devices installed in a process plant) in the immediate vicinity of a user (radius of about 20 m around the user) and provide the user with a list of all detected 5G devices.	A	This is required in case a person (e.g. a service technician) without prior knowledge of the plant wants to connect to a certain device he/she is seeing (e.g. a valve). One could think of using a label as a simple alternative, but since the device to connect to may not be directly accessible due to pipes, etc. around it and since it may not be possible to read a label anymore after some time due to dirt, de-saturation, etc., the described automated discovery service would be a nice feature for the given use case.
Factories of the Future 9.6	A 5G system should support IP addressable devices.	T	
Factories of the Future 9.7	A 5G system should allow to use standardized and proprietary IP-based protocols.	A/T	Not supported standardized protocols should be explicitly listed.
Factories of the Future 9.8	5G networks should provide backward compatibility for > 25 years at the user equipment level.	T	Installed devices should be accessible through the 3GPP network for a long time, even when the network standard further evolves.

5.3.9.7 Notes on possible DECT implementation

Requirements:

- This Use Case seems to be mostly a problem of high layer protocols and integration with external networks.

Possible implementation paths:

- This Use Case seems implementable over DECT-2020.
- This Use Case seems implementable over DECT evolution, or over evolution of DECT-ULE.

5.3.10 Augmented reality

5.3.10.1 Description

It is envisioned that in future smart factories and production facilities, people will continue to play an important and substantial role. However, due to the envisaged high flexibility and versatility of the Factories of the Future, shop floor workers should be optimally supported in getting quickly prepared for new tasks and activities and in ensuring smooth operations in an efficient and ergonomic manner. To this end, augmented reality (AR) may play a crucial role, for example for the following applications:

- Monitoring of processes and production flows.

- Step-by-step instructions for specific tasks, for example in manual assembly workplaces.
- Ad-hoc support from a remote expert, for example for maintenance or service tasks.

In this respect, especially head-mounted AR devices are very attractive since they allow for a maximum degree of ergonomics, flexibility and mobility and leave the hands of workers free for other tasks. However, if such AR devices are worn for a longer period of time (e.g. one work shift), these devices have to be lightweight and highly energy-efficient and they should not become very warm. A very promising approach therefore is to offload complex (video) processing tasks to the network (e.g. an edge cloud) and to reduce the AR device essentially to a connected camera and display. This has the additional benefit that the AR application may have easy access to different context information (e.g. information about the environment, production machinery, the current link state, etc.) if executed in the network. A possible processing chain for such a setup is depicted in figure 11.

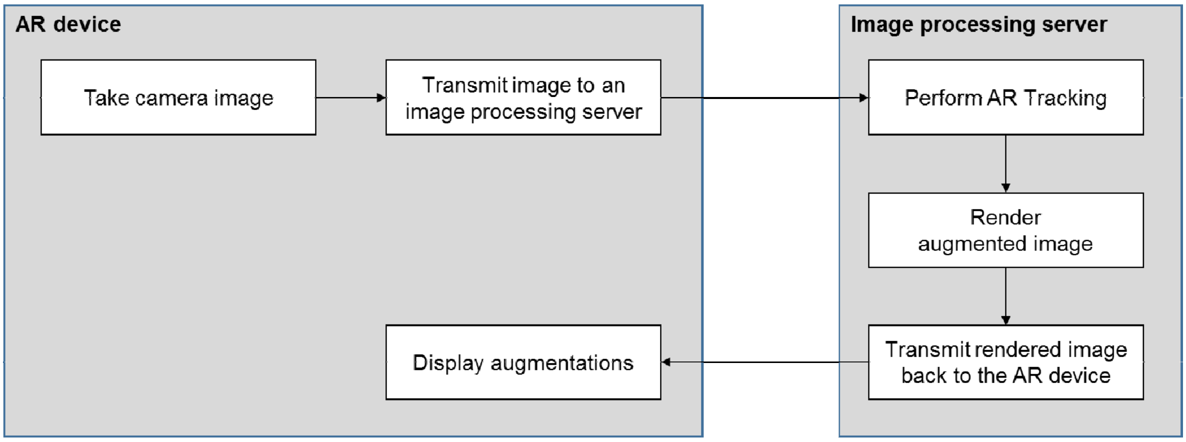


Figure 11: Possible processing chain for an augmented reality system with offloaded tracking and rendering

Here, the AR tracking algorithm determines the current viewpoint of the AR device and places the desired augmentations at the right positions in the current image. One of the main challenges with such a setup is that the displayed augmentations have to timely follow any movements of the camera in the AR device (which may be caused by any movements of the person wearing the AR device) since otherwise the AR user may get sick after some time and a reasonable usage would not be possible. Therefore, also a compression of the video stream from the AR device to the image processing server and back should be avoided if possible in order to reduce the overall processing latency and requirements.

This use case has relatively moderate latency requirements. The required service area is usually bigger than for "motion control" (see clause 5.3.2). Interworking with the public network (e.g. mobility, roaming) is likely not required.

5.3.10.2 Preconditions

A user is wearing a head-mounted AR device, which is connected to an image processing server in a (local) edge cloud via a 5G system. Some augmentations have already been registered in the field of view of the user and should be tracked and rendered by the image processing server.

5.3.10.3 Service flows

A possible service flow is as follows:

1) A camera integrated into the AR device permanently takes new images, with a frame rate ≥ 60 Hz and at least HD (1 280 x 720) or Full HD (1 920 x 1 080) resolution.

2) The AR device continuously transmits all images via the 5G system to the image processing server, which may run in a (local) edge cloud, for example.

3) The image processing server determines the current field of view of the camera integrated into the AR device based on the received image(s).

4) The image processing server determines the optimal placements of the previously registered augmentations in the current image based on the updated viewpoint and potentially places additional augmentations in the current image.

5) The image processing server renders the augmented image and sends it back to the AR device via the 5G system.

6) The AR device displays the augmented image.

5.3.10.4 Post-conditions

The augmentations in the view field of the user smoothly follow any movements of the AR device in an appropriate way, offering an excellent user experience and preventing the user to get sick after some time.

5.3.10.5 Challenges to the 5G system

Special challenges to the 5G system associated with this use case include the following aspects:

- Very high data rate requirements along with low latency requirements.
- The need for seamless mobility support.

5.3.10.6 Potential requirements

Reference Number	Requirement text	Application / Transport	Comments
Factories of the Future 10.1	The 5G system should support the bi-directional transmission of uncompressed video streams with a frame rate ≥ 60 Hz, HD (1 280 x 720) or Full HD (1 920 x 1 080) resolution and at least 24-bit colour depth, resulting in user experienced data rates of about 1,33 and 3 Gb/s, respectively.	T	
Factories of the Future 10.2	The end-to-end latency between capturing a new image and displaying the augmented image based on the newly captured image should be smaller than 50 ms, in order to avoid cyber-sickness. The one-way end-to-end latency of the 5G system should therefore be (significantly) smaller than 10 ms.	A	
Factories of the Future 10.3	The communication service availability should be higher than 99,9 % with respect to successfully delivered video frames. That means 99,9 % of all video frames should be successfully delivered within the given latency constraints.	A	
Factories of the Future 10.4	The 5G system should support seamless mobility in such a way that a handover from one base station to another one does not have any observable impact on the application.	T	
Factories of the Future 10.5	The 5G system should support the simultaneous usage of at least 3 AR devices per base station.	T	
Factories of the Future 10.6	The (bi-directional) video stream between the AR device and the image processing server should be encrypted and authenticated by the 5G system.	T	

5.3.10.7 Notes on possible DECT implementation

Requirements:

- This Use Case does not require Ultra Reliability.
- This Use Case requires Reduced Latency (10 ms).
- This Use Case requires high bit rates.

Possible implementation paths:

- This Use Case seems implementable over DECT-2020. However, bit rate needs require further study and consideration in the design of the technology i.e MIMO).

- This Use Case seems implementable over DECT evolution, accepting substantial restrictions to the data rate.

5.3.11 Process automation - closed-loop control

5.3.11.1 Description

In this use case, several sensors are installed in a plant and each sensor performs continuous measurements. The measurement data are transported to a controller, which takes decision to set actuators. The latency and determinism in this use case are crucial.

This use case has very stringent requirements in terms of latency and service availability. The required service area is usually bigger than for "motion control" (see clause 5.3.2). Interworking with the public network (e.g. mobility, roaming) is not required.

5.3.11.2 Preconditions

There are several control loops running in parallel at the same time in the plant. All sensors, actuators, and controllers are connected to the 5G network.

5.3.11.3 Service flows

The sensors continuously send data to the controller and the controller sends control data to the actuators. Actuators may send back acknowledgements of their status.

5.3.11.4 Post-conditions

The production plant is running as expected.

5.3.11.5 Challenges to the 5G system

Special challenges to the 5G system associated with this use case include the following aspects:

- High requirements on latency, communication service availability, and determinism (small jitter).
- Potentially high density of UEs in future.

5.3.11.6 Potential requirements

Reference Number	Requirement text	Application / Transport	Comments
Factories of the Future 11.1	The 5G system should support strictly deterministic cyclic traffic with cycle times down to 10 ms and a maximum jitter of less than 10 % of the cycle time.	T	
Factories of the Future 11.2	The 5G system should support communication service availability exceeding at least 99,9999 %, ideally even 99,999999 %.	T	

5.3.11.7 Notes on possible DECT implementation

Requirements:

- This Use Case requires Ultra Reliability, ideally ($1\text{-}10^{-8}$).
- This Use Case requires reduced Latency, (10 ms cyclic).
- The required range is consistent with DECT solutions.
- The Use Case is consistent with license-exempt operation regimen.
- This Use Cases requires synchronous operation due to 10 % cycle time jitter requirement.

Possible implementation paths:

- This Use Case seems implementable over DECT-2020.
- This Use Case may be also implementable over DECT evolution accepting restriction regarding the reliability, latency, and jitter.

5.3.12 Process automation - process monitoring

5.3.12.1 Description

Several sensors are installed in the plant to give insight into process or environmental conditions or inventory of material. The data are transported to displays for observation and/or to databases for registration and trending.

The operation for this use case can be in a wide service area, and interworking with the public network (e.g. mobility, roaming) may be required.

5.3.12.2 Preconditions

Multiple sensors and observation points are distributed over the plant. All of them are connected to the 5G system.

5.3.12.3 Service flows

The sensors measure in defined time intervals and send the measurement data to storage. Intermediate data logging within the sensor and acyclic data transmission is sometimes used in order to reduce power consumption.

5.3.12.4 Post-conditions

Measurement data are available at the places where needed and can be processed.

5.3.12.5 Challenges to the 5G system

Special challenges to the 5G system associated with this use case include the following aspects:

- Potentially harsh propagation environments with many metallic parts (pipes, tanks, supports).
- Potentially high density of UEs.
- Potentially large communication distance over multiple kilometres.
- High energy-efficiency required in case of battery-driven sensors.

5.3.12.6 Potential requirements

Reference Number	Requirement text	Application / Transport	Comments
Factories of the Future 12.1	The 5G system should support a communication service availability of about 99,99 % with a data transmission in intervals between 50 ms up to several seconds.	T	
Factories of the Future 12.2	The 5G system should support a very high user equipment density with up to 10 000 UEs per km².	T	

5.3.12.7 Notes on possible DECT implementation

Requirements:

- This Use Case does not require Ultra Reliability.
- This Use Case does not require reduced Latency.

- The required range is consistent with DECT solutions.
- The Use Case is consistent with license-exempt operation regimen.
- This Use Cases does not require synchronous operation.
- The Use Case requires high user equipment density.

Possible implementation paths:

- This Use Case seems implementable over DECT-2020.
- This Use Case seems also implementable over DECT.

5.3.13 Process automation - plant asset management

5.3.13.1 Description

To keep a plant running, it is essential that the assets, such as pumps, valves, heaters, instruments, etc., are maintained. Timely recognition of any degradation and continuous self-diagnosis of components are used to support and plan maintenance. Remote software updates enhance and adapt the components to changing conditions and advances in technology.

The operation for this use case can be in a wide service area, and interworking with the public network (e.g. mobility, roaming) may be required.

5.3.13.2 Preconditions

Smart assets including self-diagnosis and sensors providing relevant data for asset condition are distributed over the plant. All nodes are connected to the 5G system.

5.3.13.3 Service flows

Data from smart assets and sensors are transmitted to storage within a defined time interval. In the case of an actual failure, an event is transmitted immediately.

In the case of a software update of smart devices, block data are transferred to the devices. Multiple devices may be updated at the same time.

5.3.13.4 Post-conditions

Data and event information are available where needed for processing and displaying. Assets are maintained in an optimal manner.

5.3.13.5 Challenges to the 5G system

Special challenges to the 5G system associated with this use case include the following aspects:

- Potentially harsh propagation environments with many metallic parts (pipes, tanks, supports).
- Potentially high density of UEs.
- Potentially large communication distance over multiple kilometres.
- High energy-efficiency required in case of battery-driven sensors.

5.3.13.6 Potential requirements

Reference Number	Requirement text	Application / Transport	Comments
Factories of the Future 13.1	The 5G system should support a communication service availability of about 99,99 % with a data transmission in intervals in the order of several seconds.	T	
Factories of the Future 13.2	The 5G system should support a very high user equipment density with up to 10 000 UEs per km².	T	

5.3.13.7 Notes on possible DECT implementation

Requirements:

- This Use Case does not require Ultra Reliability.
- This Use Case does not require reduced Latency.
- The required range is consistent with DECT solutions.
- The Use Case is consistent with license-exempt operation regimen.
- This Use Cases does not require synchronous operation.
- The Use Case requires high user equipment density.

Possible implementation paths:

- This Use Case seems implementable over DECT-2020.
- This Use Case seems also implementable over DECT.

5.3.14 Connectivity for the factory floor

5.3.14.1 Description

A factory floor has adopted 5G networks for wireless automation, where a variety of sensors, devices, machines, robots, actuators, and terminals are communicating to coordinate and share data. Some of these devices may be directly connected to a local private network and some may be connected via gateway(s).

An example of the deployment scenario is in figure 12.

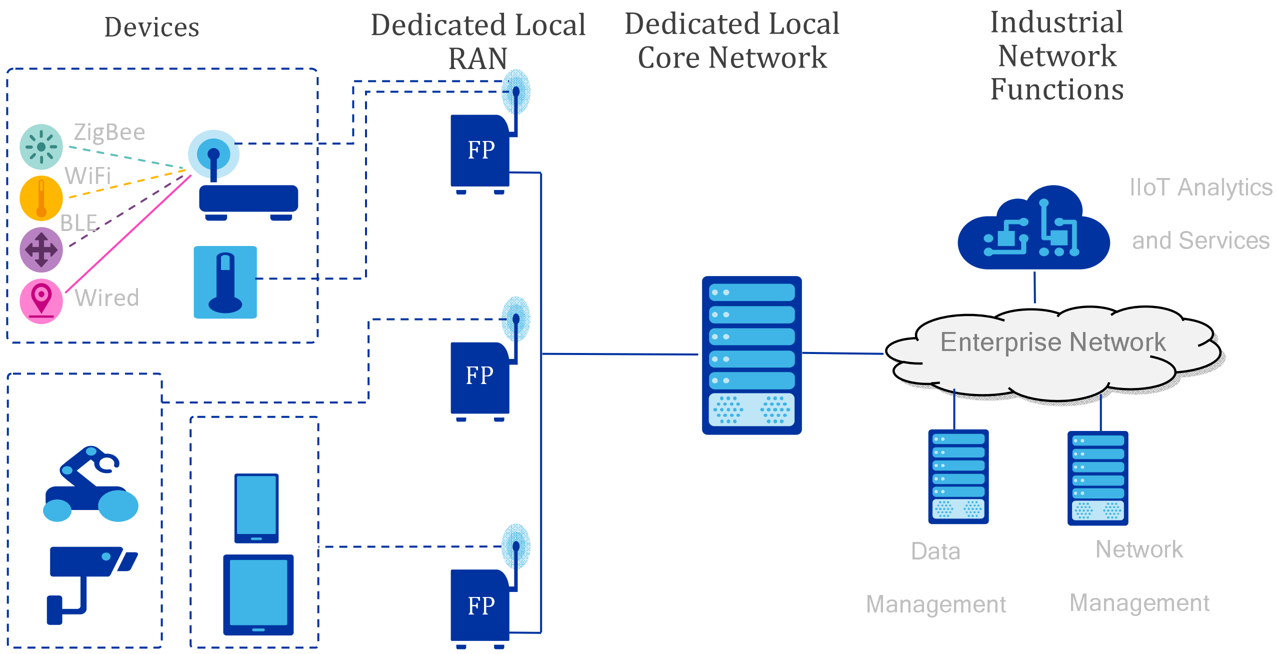


Figure 12: Factory of the future using a dedicated local private network for industrial automation

5.3.14.2 Pre-conditions

An industrial factory has been provisioned with a dedicated RAN based on local dedicated cells and a local dedicated core network.

Factory floor equipment like sensors, controllers, operator terminals, and actuators have been provisioned with 5G connectivity modules. These modules have subscription information to access the local network.

Operators, technicians, and engineers have 5G enabled devices. These devices have subscription information to access the local network. These devices may also have subscription information for other networks.

5.3.14.3 Service flows

Factory equipment and human operators and technicians have sufficient connectivity and credentials to connect to the local network, authenticating with the local core network. Typical closed-loop control applications run over this network with extremely low latency and high reliability. Due to the dedicated nature of the network there is also high availability and consistency of latency and throughput.

In the case of a device which does not have subscription information for the network, the local core network will reject the attempt resulting in the local RAN refusing access to the device.

Technicians can access the network on site and ensure high availability due to pre-emptive maintenance for the local network. Network optimization can also be performed with a higher level of aptitude due to tighter integration with the process control. In the case of catastrophic failure, technicians can repair the network on-site.

Devices can be on-boarded directly by the factory owner.

5.3.14.4 Post-conditions

Typical closed-loop control applications operate with consistent and appropriate performance.

5.3.14.5 Challenges to the 5G system

- Integration and connectivity with factory LANs, in particular real-time Ethernet.
- Support of local private deployment with KPIs that meet specific industrial requirements.

- Providing isolation between machines involved in specific production processes and other parts of a factory network. For example, in figure 12, there could be some firewall functions in the dedicated local core to allow for isolation.

5.3.14.6 Potential requirements

Reference Number	Requirement text	Application / Transport	Comments
Factories of the Future 14.1	The 5G system should support private network deployments, e.g. within a factory or plant.	A	
Factories of the Future 14.2	The 5G system should support isolation of private network with public network e.g. within a factory or plant.	A	
Factories of the Future 14.3	The 5G system should support interworking with wired devices and legacy end-user equipment (e.g. devices supporting Ethernet).	A	

5.3.14.7 Notes on possible DECT implementation

Requirements:

- This Use Case is centred on interconnectivity and interworking issues. No special requirements at RAN level.
- The required range is consistent with DECT solutions.
- The Use Case is consistent with license-exempt operation regimen.

Possible implementation paths:

- This Use Case seems implementable over DECT-2020.
- This Use Case seems also implementable over DECT evolution.

5.3.15 Inbound logistics for manufacturing

5.3.15.1 Description

In this example, a supply-chain company moves products between multiple different independent manufacturing, distribution, and retail centres. The container traverses the networks of various port operators, liner ships, trucking companies, and warehouses. The heavy good vehicles (HGVs) operated by the supply-chain company are wirelessly connected to the PLMN to enable real time tracking and telematics. In these cases, the use case often changes when the actor is in range of one or another network. What these use cases have in common is that the actor needs to be able to connect to the correct network at any given time to operate correctly. The pallets carrying the materials for delivery have also been connected via 5G UEs or IoT devices for tracking and inventory control purposes.

This use case describes the scenario where a HGV arrives at the receiving area of a factory and delivers a pallet of materials which is subsequently incorporated into the local factory inventory management system in an automated manner.

5.3.15.2 Pre-conditions

A factory has been provisioned with a private local 5G network. A supply-chain company which delivers palletised goods supplies this factory (amongst others).

The distribution vehicle has subscription credentials for the public macro network.

The pallet(s) for delivery to the factory have subscription credentials for the public macro network and either (a) subscription credentials for the factory local private networks or (b) facility to obtain and use subscription credentials for the factory local private network.

The supply-chain company tracks the pallets and vehicles via MNO network when in transit.

5.3.15.3 Service Flows

PLMN as each item has a separate subscription. This connection is used to report the HGVs location and telematics, and the location of the pallets.

The HGV arrives at the industrial factory. The HGV remains connected to the macro network but the pallet is expected to connect to the local private network to track its arrival and integrate with the stock control systems of the factory. The pallet detects the presence of the local network of the destination factory, obtains the credentials to attach to the network (if not already provisioned), and connects to the local private network. For example, the home operator may remotely provision the credentials via a secure mechanism, or the local private network may provision the credentials via a secure mechanism.

No other pallets on the HGV (which are destined for different locations) attempt to attach to the local private network.

The pallet identifies itself to the factory's stock control system and is now tracked by the factory processes.

5.3.15.4 Post-conditions

The HGV leaves the industrial premises whilst still connected to the macro MNO network and the pallet remains, connected to the private network of the factory.

5.3.15.5 Challenges to the 5G system

5.3.15.5.1 Identification of private networks and method of connection

The following provisions only apply to devices that implements connectivity to both; a private network based on DECT or DECT-2020 and a public mobile network (typically based on 3GPP). In general, these challenges does not apply to devices implement only connectivity to a private network.

As the use cases for local private networks are required to be scalable for massive numbers of deployments, including by non-traditional MNO actors, identification of the local private network need to avoid bottleneck into PLMN ID allocation (the PLMN IDs with limited number space might quickly exhausted in those countries with high uptake of local private networks).

In this scenario, when the 5G or IoT device attached to the pallet detects the presence of a local private network, there are some options on how the 5G UE or IoT device connects to the local private network:

- Dual subscription: the 5G device has independent subscriptions for public and private 5G networks.
- Dual registration: the 5G UE or IoT Device remains registered on and connected to the PLMN and establishes a second registration and connection to the local private network.
- Manual PLMN selection: where the 5G UE or IoT Device performs a manual PLMN selection procedure (although this process may be initiated by an automatic procedure outside of 3GPP scope). As a consequence, the network should have a human readable name to enable manual selection of the private network.

5.3.15.6 Potential requirements

Reference Number	Requirement text	Application / Transport	Comments
Factories of the Future 15.1	The 5G system should support unique identifiers for private networks. See note.	T	
Factories of the Future 15.2	A UE should be able to detect the identity of a private network before attempting to attach.	T	
Facories of the Future15.3	A UE should be required to have a subscription for each particular private network from which it can receive communication services.		
Factories of the Future15.4	The 5G system should support devices that can access independently both public 5G network and private 5G network, potentially at the same time.	A	
NOTE: Identification of a private network needs to be possible, even for a potentially very large number of private networks that are needed for numerous enterprises. This might require identification schemes that extend or replace current network identification based on PLMN IDs.			

5.3.15.7 Notes on possible DECT implementation

Requirements:

- This Use Case is centred on higher layers and device identity matters, as well as devices supporting multiple RANs, including public.
- Most of this requirements are already considered in DECT technology. A review is recommended due to evolution in public RANs, but no special issues are found.
- The required range is consistent with DECT solutions.
- The Use Case is consistent with license-exempt operation regimen.

Possible implementation paths:

- This Use Case seems implementable over DECT-2020.
- This Use Case seems also implementable over DECT evolution.

5.3.16 Variable message reliability

5.3.16.1 Description

Many control systems operate synchronously based on a periodic control cycle. Measurements (sent by the sensors) are usually periodic. This allows the controller to request the actuators to perform small adjustments in order to maintain the desired output response and a stable system. A stable system will be operating within a desired output response during a predefined time window.

The reliability of the transmissions has to be very high: the measurements need to be received successfully and any commands sent to the actuator should also be received successfully, all within tight latency bounds.

There are some processes (or plants) that may already be in a stable situation. As an example, a robotic arm which performs a repetitive task (e.g. pick up a package), will require the arm to be positioned within a target area A at a given time window T. As long as the arm is within the target area A within window T, the system is considered stable. When the system is stable, commands to adjust the position of the arm may not be necessary. On the other hand, if the arm is outside the area at the target time window, the controller will request the actuator to move the arm toward the target area A, and such actions will have a high priority or urgency, and therefore the command sent requires a higher reliability from the network.

Therefore, the information regarding system state or the "urgency" of the message, or the desired reliability of the message transmission, can be used by the network to manage resources more efficiently by scheduling resources for each of the transmissions. Similarly, if the process or plant under control is stable, the data may not be as urgent, and the network can give fewer resources to the sensor device to send the measurements to the controller or to a command to keep the actuator at the same position. That means that the desired reliability for the message can vary dynamically, and if this information can be provided from the controller to the network, the network can use that information to optimize resource allocation.

The alternative to adjusting the reliability dynamically is provisioning the system for the highest possible reliability required, which would require more resources and therefore reduce the network efficiency.

5.3.16.2 Preconditions

A robotic arm performs a repetitive task to pick up a package.

The system is considered stable if the robot's arm is positioned within a target area A at a given time window T.

The control system operates synchronously, based on a periodic control cycle.

5.3.16.3 Service flows

The robot's sensors report measurements to the application function (controller) in an application server.

The application function recognizes that the system is stable and the robot's arm is within the target area A within time window T.

The application function sends a command to the actuator in the next cycle.

5.3.16.4 Post-conditions

The message is sent with lower reliability.

5.3.16.5 Challenges to the 5G system

External interface needed between external network and application function.

5.3.16.6 Potential requirements

Reference Number	Requirement text	Application / Transport	Comments
Factories of the Future 17.1	The 5G system should provide means for an application function outside the RAN domain to request specific reliability for each (set of) message(s) transmitted.		
Factories of the Future 17.2	The 5G system should provide means for 3rd party application servers to provide information about the required transmission QoS desired for different granularity of data transmitted by the 3rd party application server. The data granularity can be each packet or a set of packets. This information may be used by the 5G system to optimize resource usage.		

5.3.16.7 Notes on possible DECT implementation

Requirements:

- This Use Case is centred on interconnectivity and interworking issues. No special requirements at RAN level.
- The Use Case does not clarify required range. It is assumed that in factory indoor use, the required range is consistent with DECT solutions.
- The Use Case is consistent with license-exempt operation regimen.

Possible implementation paths:

- This Use Case seems implementable over DECT-2020.
- This Use Case seems also implementable over DECT evolution.

5.3.17 Flexible, modular assembly area

5.3.17.1 Description

In the Factories of the Future, static sequential production systems will increasingly be replaced by novel modular production systems offering high production flexibility and versatility. This concept encompasses a large number of increasingly mobile production assets, for which powerful wireless communication and localization services are required.

NOTE: The communication streams in this use case will usually have to coexist with those for other applications, e.g. massive wireless sensor networks (clause 5.3.8) and/or remote access and maintenance (clause 5.3.9).

5.3.17.2 Preconditions

Life cycle chain status: A modular production environment adaptable to the different variants of orders is up and running. Modular assembly stations can be added or moved inside the production area.

Communication infrastructure: A private, local network inside the manufacturing hall is installed, and the deployment is adapted to the flexible production layout. The local, private network is realized by a 5G system.

Mobile assets that are in a ready state, i.e. they are ready for factory production:

- Lift and lowering AGV (moveable assembly platforms);
- Convey and lift AGV;
- Mobile robots with video support for unstructured goods in stock;
- Root trains;
- Workers assistance support by aid of video up and download;
- Portable assembly tools (power screwdriver, riveting tools, staple gun, etc.);
- Portal cranes.

5.3.17.3 Service flows

Communication flows in the assembly area:

- Vertical: ERP - MES (order and resource management);
- Vertical (MES): centralized orchestration of assets, material and quality status;
- MES (decentralised production): in many cases, communication will be initiated by the assembled part itself.

  In the present document this unit is called MPSC (manufactured product as a smart client). This MPSC is often moved by an AGV. Associated communication patterns:

  - MPSC - MES;
  - MPSC - asset, worker (e.g. request for processing);
  - Asset - MES (e.g. status);
  - Asset - asset (e.g. collaborating robots);
  - Asset - material (e.g. Ident, localization);

  - Worker - MES (e.g. request for assistance);
  - Worker - asset (e.g. request for localization);
  - Worker - material (e.g. Ident, localization).
- ERP, MES and MPSC communication:
  - Status information exchange between the MPSC, MES and ERP;
  - MES or MPSC resource request for mobile assets, workers, and tools (identification, localization, status, commands);
  - Material request based on order management: mobile robots, AGVs, and root trains are instructed to bring parts and material to the assembly station just in time. Sending of status information;
  - At an assembly station:
    - Workers get the task of assembling parts according instructions with real-time video assistance;
    - Mobile robots get the task to assemble parts according to instructions from the MES or MPSC. Particular collaboration with a second robot or workers is requested;
    - Data are reported: during and after the assembly process; status and quality information-combined with position info-are contributed.

5.3.17.4 Post-conditions

The MPSC is moved to the next process step & assembly station by an AGV.

5.3.17.5 Challenges to the 5G system

- Ultra-reliable wireless communication of a variety communication services adhering to negotiated and guaranteed QoS parameters.
- Communication bursts when several parallel actions occur (e.g. parallel actions supported by real-time video assistance).
- High density of mobile assets.
- Changing the 5G network configuration in the production when the layout of the assembly area is altered. The 5G network configuration change is carried out by the production staff, supported by self-optimizing algorithm. In some cases this only involves the UEs. In other cases, base stations might have to be relocated or more base stations would have to be added to the 5G network.
- 5G network maintenance and assurance:
  - Monitoring the production environment and processes related to communication; detect potential communication bottlenecks in the production area.
  - The diagnosis of network error, faults, underperformance, etc. contains recommendations for what to do for fulfilling the requested QoS.

5.3.17.6 Potential requirements

For further study.

5.3.17.7 Notes on possible DECT implementation

For further study.

5.3.18 Plug and produce for field devices

5.3.18.1 Description

This use case covers the realization of plug-and-produce for intelligent field devices that utilize 5G communication services. This use case is based on the plug-and-produce use case described in [i.56].

Plug-and-produce addresses the automated integration and configuration of a (new) field device into an existing production system. The plug-and-produce use case is applicable to discrete manufacturing as well as continuous and batch processing. The goal of plug-and-produce is to increase the flexibility and adaptability of production systems and to speed up the commissioning process of field devices by reducing manual overhead. The field device in question may be an individual sensor or actuator or a more complex production unit. After being connected and being discovered by the production system, the field device automatically obtains the configuration required to participate in the production process.

The plug-and-produce use case is divided into 6 steps/scenarios, starting from the physical connection of the device until the device is fully integrated into the production process (see figure 13).

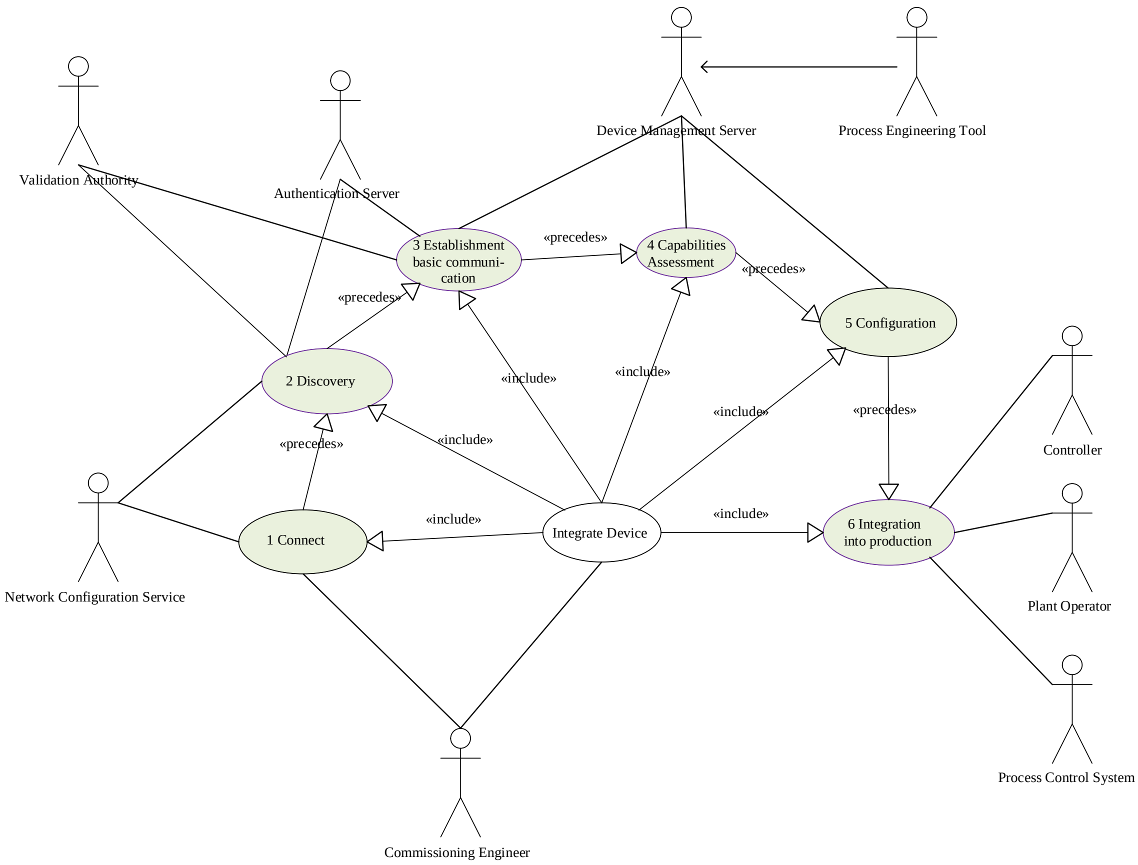


Figure 13: Integration of field devices into a production network (based on [i.56])

Connection: the commissioning engineer establishes physical network connection: device is switched on, wired network connection is plugged in or device is in wireless reach of the 5G base station.

1) Discovery: the device obtains an IP address and advertises its services in the network.

2) Establishment of basic communication: the device certificate is validated and the connection towards the production system device management server is authenticated (e.g. OPC UA connectivity, see note 1).

3) Capabilities assessment: the device management server knows the production services offered by the device and is able to configure the devices' production services.

4) Configuration: the device is configured and set up for performing the desired task within the production system.

5) Integration into production: the device contributes to the production process.

NOTE 1: OPC UA is a platform-independent application layer protocol running over TCP/IP. It is commonly used for M2M communication in automation systems (e.g. MES, SCADA). Apart from providing a client-server based communication framework, it also defines a sophisticated information model to describe the semantics of exchanged information.

In addition to the six steps above, two alternative scenarios concerning the identification (validation of device certificate failed) and the replacement of a device are considered.

Plug-and-produce may be realized using either wired or wireless networking infrastructure. The following clauses consider wireless network connectivity using a 5G communication infrastructure for plug-and-produce.

Note that the communication network and the application of the production system need to be distinguished. On the one hand, there is the communication network providing connectivity between the individual network nodes (OSI network layers 1-3/4, setup by steps 1 and 2 of the use case). The topology of this network is determined by the wiring of the nodes and the wireless connectivity of the devices. This functionality is assumed to be provided by the wireless 5G network. On the other hand, there is the automation application of the production system (OSI application layers 5 to 7, setup by steps 3 to 6). The communication topology of the automation application is determined by the tasks to be performed by the production system, e.g. the collaborations required between individual automation devices in order to complete a manufacturing step.

In classic automation systems (i.e. before Industrie 4.0), the topologies of the communication network and the automation application are typically closely aligned. The topology of the physical communication network is derived from the requirements of the automation process in the engineering phase. Automation devices that need to cooperate are placed in the same network zone (e.g. a LAN, a network segment, or a fieldbus section).

Classic automation systems are structured hierarchically. Exchange of data between hierarchies or zones is only allowed between well-defined groups of devices (zones and conduits, see note 2). This approach is an important building block for the security concept for industrial control and automation systems. 5G needs to provide an equivalent way to realize restricted data flow and implement (network) access control, etc. for industrial control and automation systems.

NOTE 2: A zone is a well-defined (physical) substructure of the automation network containing devices needed for a production step and sharing the same security requirements (e.g. confidentiality level), e.g. a production line. Data between devices belonging into different zones can only be exchanged using defined conduits. A conduits defines which data is allowed to be exchanged between two zones.

5.3.18.2 Preconditions

The field device possesses a set of authentication credentials. The authentication credentials were issued by either the plant operator or the device manufacturer. Different types of credentials are possible, e.g.:

- Challenge response (e.g. CHAP);
- Generic token cards;
- One-time passwords;
- X.509 credentials (e.g. TLS Authentication);
- SIM/AKA.

The selection of credentials depends on the automation solution in use. X.509 certificates are a popular choice for automation systems relying on OPC UA. It is likely that an automation solution uses a variety of communication protocols. However, TCP/IP technologies like OPC UA are usually deployed throughout the entire plant and are therefore an important driver for the selection of the authentication mechanisms to be used.

The following services have been set up:

- Network configuration service: used to provide network (e.g. DHCP) and service access (e.g. OPC UA discovery) configuration.
- Validation authority: this service provides information about the validity of a digital certificate (here: X.509) within the scope of the automation system.

- Authentication server: verifies the authentication information sent by the clients. An authentication server may support different types of authentication, depending on the authentication mechanisms and credentials available on the field device. The Authentication server can provide additional information on user/client access rights.

5.3.18.3 Service flows

The following sequences describe the individual service flows (see [i.56]). Modifications and additions specific to 5G (compared to the original wired scenario in [i.56]) are set in *italics*.

A. Connection - connect device physically

This step includes the preparation and physical installation of the field device in the automation system.

Step	Event	Name of process/activity	Description of process/activity
1	Device mounting request	Prepare device for connection	Bring the device to the location it should be plugged in, unpack it, plug-in power cable into power supply (*if not battery-powered*).
2	Device prepared	Plug-in device	*Bring the device into the proximity of the 5G radio access point.*
3	Device plugged	Turn on device	Switch power button on.

Note, the device may have multiple, different communication ports, both wireless and wired.

B. Discover - discover device

This step includes the establishment of a network connection to the 5G network.

Step	Event	Name of process/activity	Description of process/activity
1	Device switched on	Recognize newly connected device	Device detects lower network layer
2	Device recognized	Assign network address	*Mutual authentication of field device and network using the available, persistent device credential.* *The type of credential is determined by the automation application (see step C).* *The choice of the persistent device credential is not dependent on the port. This includes the 5G port.* *Field device and network establish temporary session credentials to secure the radio link.* Determine an available network address, assign it to the device, send it to the device *Using a wired network, the communication is initially restricted to the physical network segment to which the device is connected. 5G could be used to realize a similar restriction.* *Restrict access to logical zones/services.*
3	Device is addressable via the network	Notify device management	Announce the device to the device management server to start configuring it.

C. Establishment of basic communication of the automation application

This step includes the establishment of a connection to the automation network (e.g. via OPC UA). These sub-steps use the communication network but are independent of the underlying communication technology (5G, Bluetooth LE, WiFi, etc.).

Step	Event	Name of process/activity	Description of process/activity
1	Notification of device availability	Connect to the device	Contact the device and create a new session context on the device for the following interaction.
2	Connected to device	Get device certificate	Retrieve device certificate from the device.
3	Device certificate available	Validate certificate	Contact validation authority and validate the certificate to ensure valid identity of the device.
4	Device certificate validated	Authorize connection	Contact authentication service to authorize the device management server for reading and writing device parameters.
NOTE: The field device possesses a set of different authentication credentials. The selection of the actually used types of credentials depends on the automation solution in use (see clause 5.3.18.2). The Extensible Authentication Protocol (EAP) is used as a common authentication framework in order to provide the necessary flexibility, extensibility, and for being future-proof.			

D. Integrate device into production

Step	Event	Name of Process/Activity	Description of process/activity
1		*Refine network access/visibility*	*Configure network in order to allow communication with other devices required to complete the current production task. Restrict communication with other field devices accordingly.* *Adapt or establish virtual zones and conduits.*

E. Identity validation failed (alternative service flow)

This is an alternative scenario to scenario C (Establishment of basic communication). In contrast to scenario C, the outcome of the validation of the certificate is negative.

Steps 1-3 are the same as in scenario C (Establishment of basic communication).

Step	Event	Name of Process/Activity	Description of process/activity
1-3	see C	see C	see C
4	Device identity validation failed	Disconnect and discard the device	Disconnect from the device or quarantine the device; mark it as not reliable, notify other systems.
NOTE: Step 4 corresponds to the action of the automation application. Basic network access, as established in step B, might not be affected by these actions. It is advantageous if the 5G network can support the quarantining of unreliable devices.			

5.3.18.4 Post-conditions

The intelligent field device is able to communicate in the 5G network. The communication might be constrained according to the needs of the actual production scenario (e.g. QoS settings, limited subset of communication partners (automation system zone), virtual zones and conduits established).

5.3.18.5 Challenges to the 5G system

- Authentication for automation systems in networks with different technology stacks, e.g. Ethernet, Bluetooth, WLAN, 5G, etc., needs to be possible with the same type of credentials.
- Support of different types of authentication credentials depending on the credentials available in a specific industrial site/application.
- Allow automation system functions (e.g. MES/SCADA) to control network access properties.

NOTE: Field device communication is typically not an all-to-all or many-to-many communication scenario. Wireless field networking needs to support the enforcement of predefined communication paths based on engineering and resource planning information ("virtual zones and conduits").

- Integration of 5G communication links within a local automation network zone, i.e. enforcement of network isolation.

- Assurance of high availability; the communication services required to realize the plug-and-produce use-case have to be available locally even if back-end connectivity should not be available (island mode).

5.3.18.6 Potential requirements

For further study.

5.3.18.7 Notes on possible DECT implementation

For further study.

5.3.19 Private-public interaction

5.3.19.1 Description

An enterprise deploys a 5G private network within its factory complex. The network supports robotic controls for the manufacturing equipment; communications between the equipment and the UEs of the responsible employees; and communications between employee UEs. The manufacturing equipment is limited to receiving service only on the private network. The employee UEs are capable of being used both on the private network-for communicating with other devices on that network-and on the PLMN, for communicating to other UEs outside of the private network.

The robotic controls require URLLC capabilities that ensure appropriate actions are taken by the robots. As these requirements can be quite different from those for supporting the employee UEs, the network resources providing URLLC capabilities may be reserved for use by the robotic controllers. This separation of resources is needed to prevent an employee UE from using the URLLC radio or network resources, and potentially interfering with a robotic controller's ability to precisely control a factory robot.

UEs that do not belong to the factory are not allowed to access the private network, to avoid any use of private network resources by non-authorized UEs. Since the private network may overlap the coverage are of one or more PLMNs, there is a risk of excessive resource usage and churn if a UE that does not belong the factory finds a stronger signal from the private network and attempts to attach to the private network, only to be rejected later based on authentication or authorization validation. This is of particular concern for a URLLC type capability where the churn may impact the ability of a time sensitive factory UE (e.g. robotic controller) in receiving access to the network.

Since some UEs also need to be able to communicate over the PLMN as well as within the private network, the enterprise provides employees with a selection of UEs and service providers/MNOs for their PLMN usage. These UEs need to be able to support simultaneous service on both the private network and PLMN, as in the case where the employee is receiving communication from a piece of manufacturing equipment regarding a processing problem and simultaneously consulting with a remote colleague for the appropriate corrective action.

The system needs to support service continuity for UEs that cross between the PLMN and the private network while actively engaged in a communication. For example, an employee may call a colleague while driving to work. When the employee reaches work and enters the building, the UE is handed over to the private network, at which time the communication continues with no disruption in service. The private network may provide better coverage within the building as well as support additional functionality related to the factory business that is not available in the PLMN.

5.3.19.2 Pre-conditions

The factory equipment is only able to access the private network.

The employee UEs may access both the private network and a PLMN.

The employee UEs may simultaneously be active on both the private network and a PLMN.

The employee UEs may handover between the private network and PLMN when entering or leaving the factory complex.

Non-authorized UEs are not allowed access to the private network.

5.3.19.3 Service Flows

A piece of factory equipment detects an error condition and reports the problem to the human supervisor. This communication may take place in a variety of data formats, from a short text message to streaming video.

A robotic controller responds in a timely and efficient manner to an alert from one of the factory robots, providing corrective instructions that prevent an accident.

The supervisor needs to consult a colleague to address the issue. The colleague is on the way to the factory, but currently outside the range of the private network, so the remote colleague is currently receiving service from the PLMN. If dual coverage is available by both the private network and PLMN, the supervisor can select which to use for the external call.

As the two colleagues are talking, the remote colleague reaches the factory and the UE is handed over to receive service from the private network where better coverage is available.

A person walking past the factory attempts to make a call using their personal UE. The UE is only able to access the PLMN.

5.3.19.4 Post-conditions

There is no disruption of service when the supervisor uses the private network for communication with the factory equipment and the PLMN for communication with the remote colleague.

There is no resource conflict between the robotic controller and the employee UEs using the private network.

There is no disruption of service when the remote colleague reaches the factory and is switched from PLMN to private network service.

There is no use of private network resources by the non-authorized UE.

5.3.19.5 Potential Requirements

Reference Number	Requirement text	Application / Transport	Comments
Factories of the Future 20.1	The 5G system should support the deployment of private networks.		A private network may be realized as e.g. private equipment, contracted with an MNO, network slice This is a deployment requirement rather than a technical requirement.
Factories of the Future20.2	The 5G system should support a mechanism for a UE to identify a private network.		This requirement may be met in different ways, depending on how the private network is realized (e.g. private equipment, contracted with an MNO, network slice).
Factories of the Future 20.3	The 5G system should support a mechanism to allow a UE to select a private network it is authorized to access.		This requirement may be met in different ways, depending on how the private network is realized (e.g. private equipment, contracted with an MNO, network slice).
Factories of the Future 20.4	A UE should be able to detect the availability of a private network supported by a cell before attempting to access the cell.		This requirement may be met in different ways, depending on how the private network is realized (e.g. private equipment, contracted with an MNO, network slice).
Factories of the Future 20.5	The 5G system should support a mechanism to prevent a UE from accessing a private network it is not authorized to select.		This requirement may be met in different ways, depending on how the private network is realized (e.g. private equipment, contracted with an MNO, network slice).
Factories of the Future20.6	A UE should support multiple simultaneously active subscriptions.		
Factories of the Future 20.7	A UE should support a mechanism to simultaneously receive services using multiple subscriptions and connections to multiple private and/or public networks.		
Factories of the Future 20.8	Subject to an agreement between the operators/service providers, operator policies and the regional or national regulatory requirements, the 5G system should support intersystem mobility between a private network and a PLMN.		Supporting intersystem mobility between a private and public network depends on several factors e.g. having the appropriate business relationship in place between the network operators. Using common identifiers. Using common authentication.
Factories of the Future 20.9	A private network should be able to provide service for UEs with subscriptions to different private and/or public *network* operators.		This requirement allows the case where the private network provides service for both UE1 and UE2 where UE1 also has a subscription with MNO-A and UE2 also has a subscription with MNO-B.
Factories of the Future 20.10	A private network should be able to operate in either licensed or unlicensed bands.		

5.3.19.7 Notes on possible DECT implementation

Requirements:

- This Use Case seems to be a problem of dual RAN capability (public/private networks), discrimination and security (restriction to use public network for some devices).
- The use case explicitly states the existence of devices connecting only to private RANs (DECT implements a private RAN).
- The required range is consistent with DECT solutions.
- The Use Case is consistent with license-exempt operation regimen.

Possible implementation paths:

- This Use Case seems implementable over DECT-2020.
- This Use Case seems implementable over DECT evolution, or over evolution of DECT-ULE.

5.4 Use cases for Smart Living - Health Care

5.4.1 Description of vertical

Smart living is one of the verticals that is focused on transforming healthcare through mobile health delivery, personalized medicine, and social media e-health applications. Medical data is very sensitive and private and requires a high degree of reliability in transporting the data. There is already a lot of work done in this area, but 5G mobile will play a significant part in advancing this area of study. Some of the information transferred is low data readings and if they are consistent then they can be transferred with low priority until there is exceptional data that will generate an alarm to be raised. The use case described here can be likened to any other use cases for monitoring data. The uniqueness here is the sensitivity and privacy that is required.

5.4.2 Telecare data traffic between home and remote monitoring centre

5.4.2.1 Description

eHealth provides the capability for remote monitoring and care, this eliminates the need for frequent visit to the doctors and it allows for efficient management of chronic diseases for both patient and the medics. This use case is about the automated monitoring of data and suggests that such sensitive information should be managed in a secure way and in some cases can allow for different level of authorization of this information. In some cases regular monitoring of patient data can trigger an alarm to the patient depending on the information received or in other cases it can trigger authorization to some other parts of the patient information received by other medical care bodies and finally the same information with different level of authorization can trigger a warming from a consultant which requires a different but maybe higher level of authorization.

5.4.2.2 Preconditions

Rules used to categorize different authorization levels and criticality of information are set in place using a policy server.

5.4.2.3 Service flows

Most telecare data will need to be transferred to support real-time critical alarm situations. Alarm situations normally initiate a voice call. In such alarm situations, link availability and reliability are major considerations.

In this use case it is assumed that the patient has a number of monitoring device (wearables) which could also be part of or connected to a 5G device. In this scenario there are different types of information that are collected and transferred via an external network (I.e, internet) to a medical centre (data measuring and policy decision centre) which could be on an internet server belonging to a service provider or network operator.

The medical centre will determine the alarm level based on a policy and based on this level will automatically request a call or text to be initiated to either the patient (level1 decision maker), a medical advisor (a nurse: Level2 decision maker) and or to a consultant (level 3 decision maker) informing them that the critical level has been reached and the necessary contingency plan should be taken depending on the severity of the alarm.

The external network will automatically set up a dedicated line of communication in a secure manner, depending of the level of the alarm and this will allow for the right level of confidentiality for the information recipient warning them they need to either take their medication or prepare to come to the hospital for further investigation.

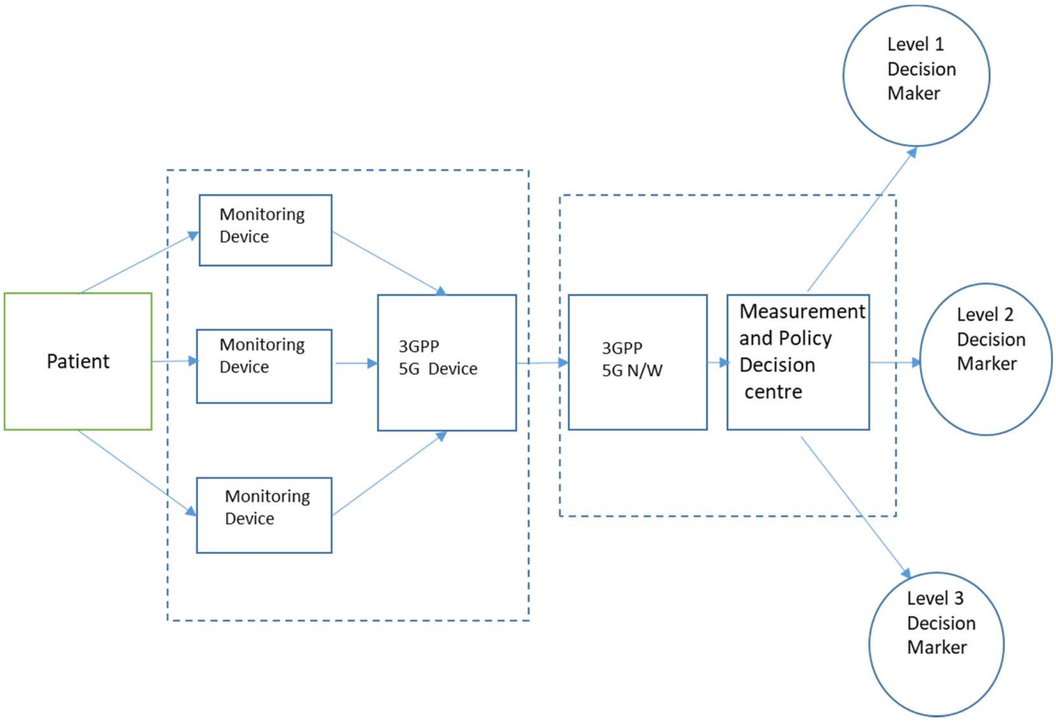


Figure 14: Remote Monitoring and authorization in Tele Care Management

5.4.2.4 Post-conditions

The system resets itself to the default state and measuring and monitoring of data resumes.

5.4.2.5 Challenges to the 5G system

Medical devices are often wearables. Sometimes the medical devices are even implantable (e.g. an insulin pump). Wearable devices have a small form factor. This implies that also the battery has to be small. A small battery has two implications:

- the battery standby time will be limited unless power saving is used;
- the maximum output power is limited, which limits the uplink range.

Companies that supply medical devices generally want to be as much as possible independent of local conditions. E.g. they prefer not to be dependent on a specific subscription or application that the patient has on his/her mobile phone (if the patient has a mobile phone) or not dependent on specific fixed network subscriptions for in-home coverage. Therefore, an independent mobile connection is generally preferred. This can be implemented with power-efficient mobile access technology (e.g. eMTC).

In cases where a direct connection to the network is not feasible, a transparent Relay UE may be used. This combines the advantage of the subscription for the medical device being independent from the Relay UE with battery and power efficient connectivity.

5.4.2.6 Potential requirements

Reference Number	Requirement text	Application / Transport	Comments
Smart Living 1.1	The 5G system should support mechanisms to differentiate between levels of authorization required for decision.	Transport	
Smart Living 1.2	The 5G system should support battery- and power-efficient communication for constraint IoT devices.	Transport	This requirement is already addressed by the existing CIoT optimizations.
Smart Living 1.3	The 5G system should support the remote UE to access to the same services whether using indirect communication or using direct communications.	Transport	This requirement is already covered by the existing REAR feature as specified in 3GPP TS 22.278 (Rel-15) [i.57].
Smart Living 1.4	The 5G system should be able to ensure the confidentiality and integrity of data for/from the remote UE data in indirect communications.	Transport	This requirement is already covered by the existing REAR feature as specified in 3GPP TS 22.278 (Rel-15) [i.57].
Smart Living 1.5	The 5G system should be able to support remote UE and relays with different subscriptions from different PLMNs.	Transport	This requirement is **not yet** covered by the existing REAR feature as specified in 3GPP TS 22.278 (Rel-15) [i.57].

5.4.2.7 Notes on possible DECT implementation

Requirements:

- This Use Case does not require Ultra Reliability nor Low latency.
- Indoor operation is consistent with DECT solutions.
- Indoor operation is consistent with license-exempt operation regimen.
- This Use Case does not require synchronous operation.

Possible implementation paths:

- This Use Case seems implementable over DECT-2020.
- This Use Case seems also implementable over DECT evolution, or even over DECT-ULE.

5.5 Use cases for Programme Making and Special Events (PMSE)

5.5.1 Description of vertical

5.5.1.1 Overview

The Programme Making and Special Events (PMSE) industry is the main driver behind professional equipment for the culture and creative industry (CCI). The PMSE industry comprises all kind of production, event and conference technologies. It can be categorized into audio (e.g. microphones, in-ear monitor), video (e.g. cameras, displays and projectors) and stage control systems.

In today's typical professional live production setups, lot of wireless PMSE equipment is in use. For instance, artists on stage use wireless microphones in combination with wireless in-ear monitoring systems. Another example is the delivery of live content from wireless cameras to big video panels placed around the stage. Every wireless audio/video link is composed of one transmitter and its destined receiver, which provides the input data for the further processing chain, or in case of an in-ear monitor system the audio stream for the artist on stage.

From a PMSE point of view, the complete on-site 5G system may be seen as part of a local high quality PMSE network (see figure 15), processing audio and video data streams with a guaranteed quality of service regarding latency, audio/video quality, number of wireless links per site and reliability, as well as control data for remote control of wireless devices. Such local, high-quality wireless networks for audio and video are relevant for all kind of live production sites, such as concerts, TV shows, sports events, theatres and musicals, press conferences, and electronic news gathering.

The live event scenario, based on a local high-quality wireless network, offers the possibility to establish new kinds of audience services, e. g. individualized audio mixes or different camera angles, both of which provide new means of user experience. The respective content can be received with future standard consumer hardware (e.g. smartphones). These services also might help people with impaired vision or hearing to follow live events.

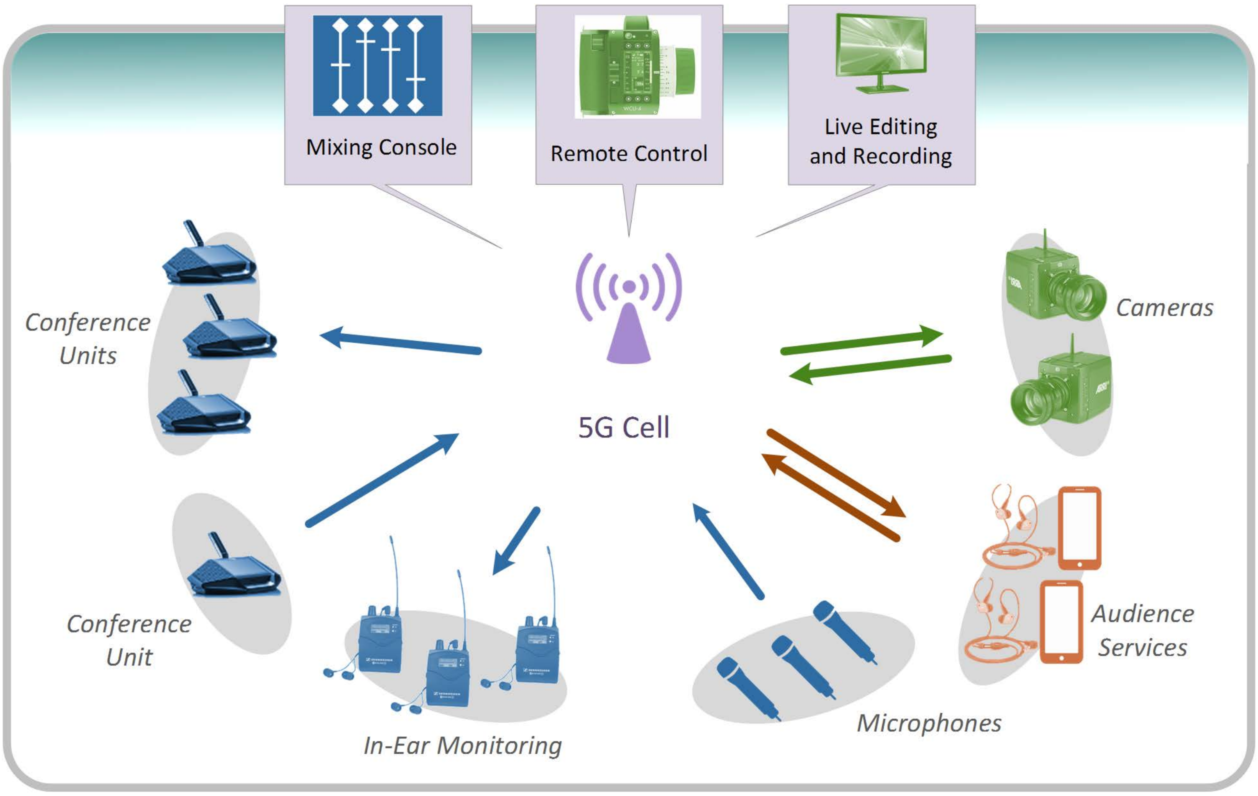


Figure 15: Vision of PMSE applications within 5G

In the following, some of the most relevant PMSE use cases are described and analysed in detail. These use cases can be mapped to relevant PMSE application areas as shown in table 9.

Table 9: Mapping of the considered use cases (columns) to PMSE application areas (rows)

	Live performance	Local Conferencing	High Data Rate Video Streaming	Immersive Audio
Audio	X	X		X
Video			X	
Stage Control				
Audience Services				X

5.5.1.2 Major challenges and particularities

Major general challenges and particularities of the PMSE industry include the following aspects:

1) There is not only a single class of use cases, but there are several different use cases with a wide variety of different requirements. This implies the need for adaptability and scalability of the 5G system.

2) Typical PMSE deployment scenarios are confined in a local geographical area and show short-term (e.g. from some hours to some weeks) to long-term (e.g. from some months to some years) durations.

3) Typical professional live production setups come with stringent requirements in terms of end-to-end latency, communication service availability, communication service reliability, jitter, audio/video quality, number of wireless links per site, and synchronicity. Failures of wireless links during a live event or a live production are unacceptable for the CCI and their customers. Therefore, additional efforts towards improved transmission robustness and a more effective interference management have to be considered.

4) For reliable operation of the wireless equipment, professional PMSE requires controlled interference environments, e. g. through appropriate spectrum access and interference mitigation techniques.

5) There is a growing demand from the end users for new and more differentiated services. Examples are augmented reality (AR), virtual reality (VR) and other new immersive experiences. These services will require increasing spectrum availability.

6) Use cases of typical PMSE applications, as described in the following clauses, are not yet covered by the technical requirements of the ongoing discussions within Media & Entertainment (M&E) sector by 3GPP. This is because, so far, the M&E sector has focused only on media distribution and reception rather than on production and live audio/video production that brings in requirements of an URLLC use-case.

7) 5G systems need to support private network deployment and operation within an event location. This is required by many PMSE operators for security, liability, availability and business reasons. Nevertheless, standardized and flexible interfaces should be supported for seamless interoperability and seamless handovers between 5G PLMNs and private 5G deployments.

8) The 5G system should be able to support continuous monitoring of the current network state in real-time, to take quick and automated actions in case of problems, and to conduct efficient root-cause analyses in order to avoid any undesired interruption of the A/V content production, which may incur huge financial damage. Particularly, if a third-party network operator is involved, accurate run-time SLA monitoring is needed as the basis for possible liability disputes in case of SLA violations (see clauses 4.3.4.2 and 4.3.4.3 of [i.26]).

5.5.2 Low-latency audio streaming for live performance

5.5.2.1 Description

The low latency audio streaming use case addresses key issues of wireless audio productions, focusing on low-latency and high-reliability aspects. Even if the number of active wireless audio links or data rates of the respective wireless audio streams may vary, the requirements regarding end-to-end latency, communication service availability and communication service reliability remain principally the same. Reliability is a strongly required feature for all kind of live audio streaming applications. In fact, due to their on-line transmission nature, such applications cannot accommodate the repetition of audio transmissions in case of error.

Latency should be much lower than the latency of other speech transmissions systems, like cellular services, because the audio source (e.g. a microphone) and audio sink (e.g. an in-ear monitor [IEM]) are co-located and the performing artist, or conference participant, can accept only a small time difference between the original and the processed audio signal.

Streaming applications with low latency require high synchronicity between all related devices. Therefore, a system clock, e. g. word clock, is provided by an external word clock generator. This generator can be a dedicated device or it can be integrated, e.g. into the audio mixing console. Timestamps are typically used to determine playback times of digital audio data. All wireless audio devices involved in the live performance production network should be enabled to capture and reproduce their audio samples at the exact same time, i.e. every audio sample has a precise and unique relation to the system time. Thereby, the system time and synchronization accuracy should be much higher than the audio sampling clock and respective clock jitters much smaller than the audio sampling period.

In order to support today's and future professional productions, a synchronicity of 1 µs (see table 10) with respect to the system clock should be met at the application level of all involved devices (wireless microphones, in-ears monitors, audio mixing).

A typical live performance scenario is an artist on stage using a wireless microphone while hearing himself via the wireless IEM system. The artist may be wearing roller skaters. The audio signal coming from the microphone is streamed to a mixing console, where the different incoming audio streams are mixed.

After mixing, several audio streams can be distinguished, e.g. the Public Address (PA), the individual IEM, or recording mixes. Here, IEM mixes are transmitted wirelessly, whereas most of the other signals are streamed via wired connections.

Figure 16 shows a typical topology of current live performance use cases. The whole setup follows a link-based approach, meaning that every wireless audio link is based on one specific mobile terminal connected to one specific installed transmitter (IEM) or receiver (microphone). Similar setups can be found in live events such as TV shows, sports events, musicals, and press conferences.

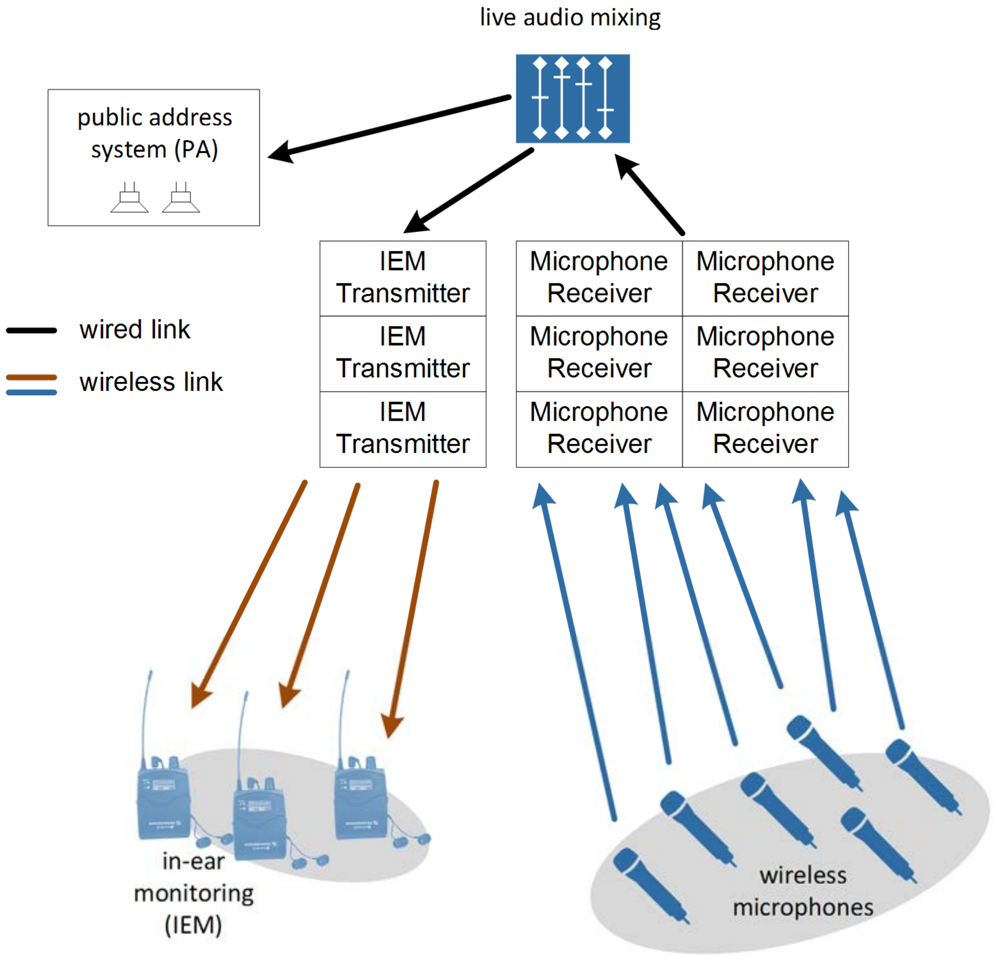


Figure 16: Logical topology of the live performance use case

In table 10, typical system characteristic parameters of the live performance use case such as end-to-end delay, system delay, data rates, reliability, and synchronicity are listed. Not all system parameters presented in the table are defined in the present document; they are provided for guidance.

Table 10: System parameters of the live performance use case

	Characteristic system parameter	Comments
Application latency	< 4 ms	End-to-end maximum allowable latency of the use case in focus, which includes application and application interfacing, see figure 17.
End-to-end latency	< 1 ms	Latency that is introduced per link of the wireless communication system, excluding application and application interfacing, see figure 17.
User experienced data rate	150 kb/s to 4,61 Mb/s	Different user data rates per audio link need to be supported for different audio demands.
Control data rate	≤ 50 kb/s	Data rate per control link.
Communication service availability	99,9999 %	
Reliability	99,99 %	The packet error ratio (PER) of the system should be below 10^{-4} for a packet size corresponding to 1 ms audio data, with the following exemplary error distribution: - maximum continuous error duration = 30 ms, - consecutive minimum continuous error-free duration = 100 ms. To make packet errors inaudible, error concealment is used at application level. Every concealment is capable of handling one specific kind of error distribution. Therefore, the above numbers describe only one more or less typical concealment case.
# of audio links	50 to 300	Simultaneous audio links.
Service area	≤ 10 000 m^2	Event area, indoor and outdoor. Typical heights of indoor stages: 5 m to 10 m.
Synchronicity	0,25 µs to 1 µs	All wireless mobile devices of one local high quality network should be synchronized at the application level within the specified accuracy.
User speed	≤ 50 km/h	For instance, in musical events like the "Starlight Express" artists are moving on with speeds up to 50 km/h.
Security/ Integrity	The user data is encrypted	

The relation between application latency and end-to-end latency for the live performance use case is depicted in figure 17. End-to-end latency is to be understood as the user plane latency between two terminal devices, communicating via potentially more than one hop. Without having the audio mix function integrated, additional wireless hops will be required for the complete round trip (end-to-end latency in figure 17) from the microphone of the artist back into his/her IEM system. Furthermore, the application latency in the live performance use case should be guaranteed for every packet of every audio stream, independently of the system load, with the specified data rates, and for pre-defined durations.

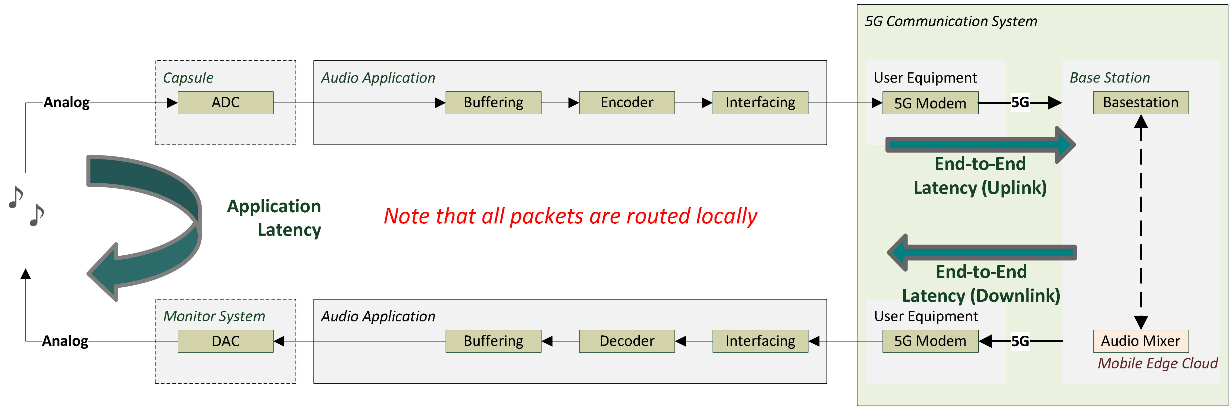


Figure 17: End-to-end delay shown for a live performance use case (system delay refers to an internal latency introduced per wireless hop)

5.5.2.2 Pre-conditions

All wireless audio devices on-site (figure 15) are switched on and connected to a PMSE production 5G network.

5.5.2.3 Service Flows

A typical service flow in a live performance production network may look as follows:

1) A number of wireless audio devices (microphones) capture and process audio signals, for instance from the artists or music instruments. Each audio signal is sampled and processed into an isochronous audio stream.

2) The isochronous audio streams are transmitted wirelessly to the audio mixing console.

3) The received audio streams are mixed according to the application requirements and several audio streams are produced (e.g. for the PA system and individual IEM mixings for the artists and recording mixings).

4) The IEM mixes are transmitted wirelessly as isochronous audio streams to the corresponding artists.

5.5.2.4 Post-conditions

The live performance devices run as required by the application and without any perceivable impairments.

5.5.2.5 Challenges to the 5G System

Special challenges to the 5G system associated with this use case include the following aspects:

- Very stringent requirements on communication service availability, PER and end-to-end latency throughout the whole operation time. Here, end-to-end latency requirements are to be understood not as an average value for the data stream, but as a limit for every packet of the stream.

- Very stringent requirements on clock synchronicity between different nodes at application level. This implies that the 5G system should support deterministic packet transfer and ultra-precise time synchronization, even in the user equipment. Time-sensitive networking features may be revealed to the application or equivalent interfaces implemented.

- Transmission of rather small chunks of data, resulting in potentially significant overhead due to signalling, local routing, security, etc.

5.5.2.6 Potential Requirements

Reference Number	Requirement text	Application / Transport
PMSE 1.1	The 5G system should support ultra-low latency communication. Maximum end-to-end latency should be 1 ms for user experienced data rates between 150 kb/s and 4,61 Mb/s. See note.	A
PMSE 1.2	The 5G system should support a clock synchronicity of a communication group of 50 to 300 UEs of 1 μs.	A
PMSE 1.3	The 5G system should support communication service availability of 99,9999 %.	T
PMSE 1.4	The 5G system should support data integrity and confidentiality protection, even for communication services with ultra-low latency and ultra-high reliability requirements.	T
PMSE 1.5	The 5G system should support hot-plugging in the sense that new devices may be dynamically added to and removed from a live performance application, without any observable impact on the other devices.	T
PMSE 1.6	The 5G system should support UE speeds up to 14 m/s (50 km/h), even for communication services with ultra-low latency and ultra-high reliability.	T
NOTE: The end-to-end latency is the requirement for uplink (microphone to mixer) or downlink (mixer to ear piece).		

5.5.2.7 Notes on possible DECT implementation

Requirements:

- This Use Case requires Ultra Reliability.
- This Use Case requires Low Latency.
- The required range is consistent with DECT solutions.
- The Use Case is consistent with license-exempt operation regimen.
- This Use Cases requires synchronous operation.

Possible implementation paths:

- This Use Case seems implementable over DECT-2020.
- This Use Case seems also implementable over DECT evolution with certain restrictions in the minimum latency.

5.5.3 Low-latency audio streaming for local conference systems

5.5.3.1 Description

In a conference system the voice of several speakers is captured by a conference unit, transmitted to the base station of the Local High Quality Network (see figure 18), where the mixing of the different audio streams is done, and distributed to all other conference units connected to the network, which replay the received audio stream. Low latency is an issue because the speakers always hear themselves speaking.

The main task of a conference system is to distribute voice from one participant to other participants either within the same location, e.g. a room or the conference venue, or to a remote location. The conference units can be centrally configured and controlled, and can start a poll among the participants. As a concrete example, the *local conference system* is described in more details and its typical system parameters are listed in table 11.

Figure 18 describes the logical topology of a local conference system. Each conference unit can act as a transmitter or receiver of an audio stream. The speakers' voices are transmitted to a conference service application via a central base station (red arrow) from where the processed audio streams are distributed again to the other conference units (blue arrows). The receiving conference units can select between different channels, e.g. each one containing a different mixture of the speakers' voices or their respective language translations. The conference system can be deployed either in a fixed installation setup or in a moving/portable setup. In the fixed installation case the surrounding conditions, e.g. the presence of cellular network coverage, stay constant over a longer period in time. In the portable setup case, the conference system is deployed in an ad-hoc manner. The location and time of deployment are only known at short-term and indeed can change even across country-borders.

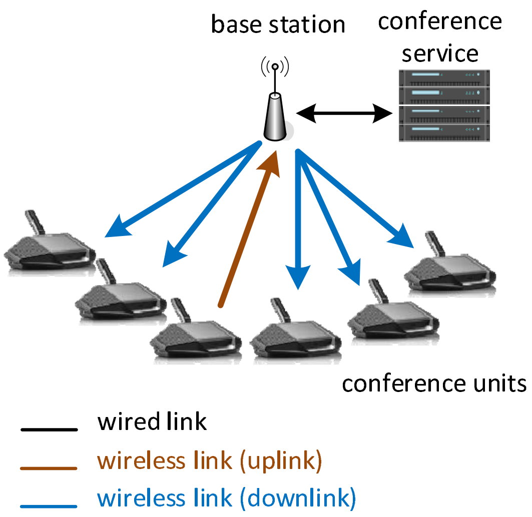


Figure 18: Logical topology of the local conference system use case

Table 11: System parameters of the local conference system use case

	Local Conference System	Comments
Application latency	< 20 ms	End-to-end maximum allowable latency of the use case in focus (i.e. between the microphone and the speaker/headphone), includes application and application interfacing.
End-to-end latency	< 4 ms	Latency that is introduced per link of the 5G wireless communication system excluding application and application interfacing.
User experienced data rate	150 kb/s to768 kb/s	4x in UL, 42x in DL.
Control data rate	≤ 50 kb/s	Data rate per control link.
Communication service availability	99,9999 %	
Packet error ratio	99,99 %	The audio frames (with a packet duration of 4 ms) provided to the application layer should have a packet error ratio (PER) below 10-4.
# of audio links	Up to 500	The system should support the control of 500 user terminals per cell
Service area	≤ 2 500 m^2	Conference area, typically indoor. Typical heights: 3 m to 5 m.
Synchronicity	≤ 20 µs	All wireless mobile devices should be synchronized inside one local high quality network, for instance with respect to a reference system clock provided by one master device, e.g. the 5G base station.
System setup time	≤ 10 ms	
Internet access	optional	The system should be able to work without access to the Internet.

5.5.3.2 Pre-conditions

All wireless audio devices on-site (figure 18) are switched on and connected to a PMSE production network through a local 5G base station.

5.5.3.3 Service Flows

A typical service flow in a local conference network may look as follows:

1) The voice of several speakers is captured by a conference unit and wirelessly transmitted to a conference system where the mixing of the different audio streams is done and transferred into the floor channel.

2) The floor channel is wirelessly transmitted as a multicast stream to all other conference units connected to the network.

3) Additional audio mixes (e.g. interpretation channels) are distributed wirelessly to dedicated conference units (unicast transmission) connected to the network.

5.5.3.4 Post-conditions

The local conferences devices run as required by the application.

5.5.3.5 Challenges to the 5G System

Special challenges to the 5G system associated with this use case include the following aspects:

1) Very stringent requirements on end-to-end latency, PER and communication service availability.

2) Very stringent requirements on clock synchronicity between different nodes at application level. This implies that the 5G system should support deterministic packet transfer and ultra-precise time synchronization, even in the user equipment. Time-sensitive networking features may be revealed to the application or equivalent interfaces implemented.

3) Transmission of rather small chunks of data, resulting in potentially significant overhead due to signalling, routing, security, etc.

4) Multichannel operation and *multicast* support.

5.5.3.6 Potential Requirements

Reference Number	Requirement text	Application / Transport	Comments
PMSE 2.1	The 5G system should support a clock synchronicity at application level between a communication group of 50 to 500 UEs in the order 20 µs or below. See note.	T	
PMSE 2.2	The 5G system should support data integrity and confidentiality protection, even for communication services with ultra-low latency and ultra-high reliability requirements.	T	
PMSE 2.3	The 5G system should support communication service availability exceeding at least 99,9999 %	T	
PMSE 2.4	The 5G system should support hot-plugging in the sense that new devices may be dynamically added to and removed from a local conference application, without any observable impact on the other devices.	T	
PMSE 2.5	The 5G system should support industry standards for precision clock synchronization (e.g. IEEE 1588 [i.59]) for IP-based A/V systems in a way that the synchronization requirements outlined in table 11 can be met.	T	
NOTE: In multicast operation.			

5.5.3.7 Notes on possible DECT implementation

Requirements:

- This Use Case requires Ultra Reliability.
- This Use Case requires reduced Latency.(< 4 ms), but not Low latency as defined in clause 4.5.
- The required range is consistent with DECT solutions.
- The Use Case is consistent with license-exempt operation regimen.
- This Use Cases requires synchronous operation.

Possible implementation paths:

- This Use Case seems implementable over DECT-2020.
- This Use Case seems also implementable over DECT evolution.

5.5.4 High data rate video streaming / professional video production

5.5.4.1 Description

The use case High data rate video streaming / professional video production addresses demanding applications that partially require extensive post-processing of the material supplied by cameras. The post processing increases the quality requirements on the source material and thus also on the bandwidth required for transmission. In particular, scenically produced productions, which due to the time pressure can be considered "quasi-live" productions, place high demands.

In this use case, high quality video data is streamed wirelessly from one or several cameras to the base station of the Local High Quality Network (see figure 19), where it can be recorded or edited. Moreover, the system should allow remote operation of the cameras (e.g. focus control) by sending and receiving control data to and from the cameras.

The video stream sent from a camera is used for two purposes:

- As the useful camera signal for e.g. "quasi live" editing and recording.
- For viewing by remote camera operators, e.g. crane operators and focus pullers (i.e. to maintain image sharpness on whatever subject or action is being filmed).

Currently, several dedicated wireless systems for video and control need to be used in parallel. This is disadvantageous and potentially can be improved by the use of 5G wireless systems.

The professional video production use case is quite demanding, as high data rate is required in parallel with low latency. Especially, for the remote lens control application, performed by the focus pullers, low latency is a critical issue. This is because focus tracking of moving objects based on delayed monitoring inevitably would result in focus faults. Further demanding is the fact that the focus control data are sent back wirelessly to the filming camera again. Two scenarios are defined for this use case:

- *Portable high data rate video production system*: The location and time of deployment are not fixed and can change from one occasion to the next. The system is in worldwide use. It is typically shipped in flight cases from one location to another. This scenario places major requirements on the wireless system, especially to delay, data rate and error behaviour.
- *Fix installation high data rate video production system*: The camera part is the same as for the portable scenario. However, the base station(s) including antennas and system wiring can be permanently installed and can make use of the characteristics and infrastructure of a typical production studio.

The separation in two scenarios should mainly be considered for a later product definition with respect to the base station side. The camera part and the typical requirements for the performance of the wireless system should be the same for both scenarios. The latter are summarized in table 12.

Professional video systems rely on ultra-precise time synchronization at application level. Each professional video terminal should independently refer to an accurate reference signal that reaches all terminal devices simultaneously, i.e. within a phase jitter much smaller than the video sampling period.

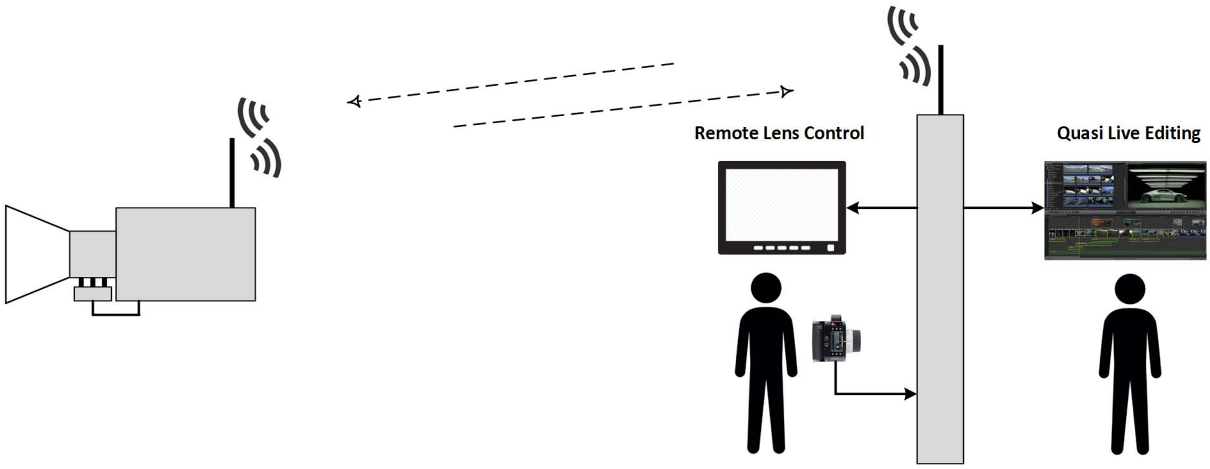


Figure 19: Logical topology of high data rate video streaming use case

Table 12: System parameters of the high data rate video streaming use case / Professional Video Production

	Local Conference System	Comments
Application latency	< 50 ms	End-to-end delay from the camera image sensor back to the camera lens motors including sensor integration time and delay of all components in-between.
End-to-end latency	< 2 ms (no transmission errors) < 10 ms (including retransmissions)	Latency that is introduced per link of the wireless communication system excluding application and application interfacing. The end-to-end latency of the wireless system should be below 2 ms for a nominal transmission without transmission errors. In case of transmission errors the packet should be resent autonomously by the wireless system. The system delay including retransmission(s) should be below 10 ms.
User experienced data rate	UL (Camera to base station): 100 Mb/s to 200 Mb/s DL (Base station to Camera) 20 Mb/s	
Reliability	99,999 %	The number represents one defect video frame per one hour of operation. One video frame comprises about 300 packets, each 1 280 bytes in length. A video frame is defect if one or more bits or packets representing this frame are corrupted or missing.
# of video links	3	The system should support 3 video cameras per cell.
Range	1 m to 50 m	Distance from the camera to the base station.
Service area	≤ 2 500 m^2	Indoor and Outdoor.
Synchronicity	≤ 1 ms	All wireless video devices should be synchronized inside one local high quality network.
Mobility	≤ 50 km/h, rotation < 0,52 rad/s.	The wireless system should allow camera movements of at least pedestrian speed and camera rotations of 0,52 rad/s.
Security	Secured data transmission is required	

5.5.4.2 Pre-conditions

All wireless video devices on-site (see figure 19) are switched on and connected to a PMSE production network through a local 5G base station.

5.5.4.3 Service Flows

A typical service flow in a professional video production network may look as follows:

1) High quality video data is streamed wirelessly from one or several cameras to the professional video production network, where it can be recorded or edited.

2) Control data to allow the remote operation of the cameras (e.g. focus control) is sent from the professional video production network to the wireless cameras and vice versa.

5.5.4.4 Post-conditions

The video production devices run as required by the application.

5.5.4.5 Challenges to the 5G System

Special challenges to the 5G system associated with this use case include the following aspects:

- Very stringent requirements on communication service availability, PER and end-to-end latency throughout the whole operation time.
- Very stringent requirements on clock synchronicity between different nodes at application level. This implies that the 5G system should support deterministic packet transfer and ultra-precise time synchronization, even in the user equipment. Time-sensitive networking features may be revealed to the application or equivalent interfaces implemented.
- Professional video systems rely on ultra-precise time synchronization at application level and would benefit from IEEE 1588 [i.59] PTP and Time Sensitive Networking-like features.

5.5.4.6 Potential Requirements

Reference Number	Requirement text	Application / Transport	Comments
PMSE 3.1	The 5G system should support a clock synchronicity between a communication group of 3 to 10 UEs in the order of 1 ms or below.	T	
PMSE 3.2	The 5G system should support data integrity and confidentiality protection, even for communication services with high data rate, low latency and high reliability requirements.	T	
PMSE 3.3	The 5G system should support communication service availability exceeding at least 99,999 %.	T	
PMSE 3.4	The 5G system should support hot-plugging in the sense that new devices may be dynamically added to and removed from a live performance application, without any observable impact on the other devices.	T	
PMSE 3.5	The 5G system should support UE speeds of up to 14 m/s and UE rotations of 0,52 rad/s, even for communication services with high data rate, low latency and high reliability.	T	
PMSE 3.6	The 5G system should support industry standards for precision clock synchronization (e.g. IEEE 1588 [i.59]) for IP based A/V systems in a way that the synchronization requirements outlined in table 12 can be met.		

5.5.4.7 Notes on possible DECT implementation

Requirements:

- This Use Case requires Ultra Reliability.

- This Use Case requires reduced Latency.(< 4 ms), but not Low latency as defined by ITU-R [i.40] (see clause 4.5).
- The required range is consistent with DECT solutions.
- The Use Case is consistent with license-exempt operation regimen.
- This Use Cases requires synchronous operation.
- Speed requirements need further investigation but do not seem to be an issue.
- This Use Case requires high data rates.

Possible implementation paths:

- This Use Case seems implementable over DECT-2020 but probably not over DECT evolution.

5.6 Use cases not (yet) considered

The following use cases proposed in ETS TR 121 905 [i.27] have not been considered for the present document. This has been done due to the following reasons:

- technical difficulty vs. potential benefit;
- business case for a DECT based solution unclear;
- coverage needs exceeds possibility of DECT or DECT-2020;
- use cases seem more suitable for public mobile networks.

These use cases are listed in the following list as reference to allow further study. These use cases may, however, be reconsidered in further revisions of the present document.

- Rail-bound mass transit (clause 5.1 of ETSI TR 121 905 [i.27]).
- Smart city (clause 5.5 of ETSI TR 121 905 [i.27]).
- Electric-power distribution (clause 5.6 of ETSI TR 121 905 [i.27]).
- Centralized power generation (clause 5.7 of ETSI TR 121 905 [i.27]).
- Factories of the Future - Wide-area connectivity for fleet maintenance (clause 5.3.16 of ETSI TR 121 905 [i.27]).

5.7 Classification of the use cases regarding reliability and latency and feasibility for DECT implementation

Table 13 shows the classification of the use cases regarding the reliability and latency, according to the ITU-R definitions given in clause 4.5. The table also shows an initial assessment on DECT implementation feasibility based on required range and suitability for a license-exempt operation.

Table 13: Classification of the use cases regarding Reliability and Latency and feasibility for DECT implementation

Clause	Use Case	DECT feasibility		Possible Implementation path		URLLC classification			
		by range	*by license regimen*	*DECT-2020*	*DECT evolution*	*UR*	*LL*	*Synchronicity*	*Other requirements*
				Home and building automation					
5.2.2	Environmental monitoring	Y	Y	Y	Y	Y	N	N	
5.2.3	Fire detection	Y	Y	Y	Y	Y	<10 ms	N	
5.2.4	Feedback control	Y	Y	Y	Y	Y	<10 ms	maybe (1 ms jitter)	
				Industry Automation -Factories of the Future					
5.3.2	Motion control	Y	Y	Y	w/ restrictions	Y + ($1\text{-}10^{-8}$)	Y + (0,5 ms)	Y (1 μs)	
5.3.3	Motion control - transmission of non-real-time data	Y	Y	Y	Y	N	N	N	
5.3.4	Motion control - seamless integration with Industrial Ethernet	Y	Y	requires further study	requires further study				
5.3.5	Control-to-control communication (motion subsystems)	Y	Y	Y	w/ restrictions	Y + ($1\text{-}10^{-8}$)	Y (4 ms cyclic)	Y (1 μs)	
5.3.6	Mobile control panels with safety functions	Y	Y	requires further study	requires further study				
5.3.7	Mobile robots	Y	Y	Probably, but requires further study	N	Y	Y	probably	
5.3.8	Massive wireless sensor networks	Y	Y	Probably, but requires further study	requires further study	Y + ($1\text{-}10^{-8}$)	10 ms	N	High bit rate Low power operation required (see clause 5.3.8 for details)
5.3.9	Remote access and maintenance	Y	Y	Y	Y	N/A	N/A	N/A	backward compatibility for > 25 years (see clause 5.3.9 for details)
5.3.10	Augmented reality	Y	Y	Y	N	N	10 ms	N	High bit rate required (see clause 5.3.10 for details)
5.3.11	Process automation - closed-loop control	Y	Y	Y	w/ restrictions	Y + ($1\text{-}10^{-8}$)	10 ms cyclic	Y	
5.3.12	Process automation - process monitoring	Y	Y	Y	Y	N	N	N	high user equipment density (see clause 5.3.12 for details)
5.3.13	Process automation - plant asset management	Y	Y	Y	Y	N	N	N	high user equipment density (see clause 5.3.13 for details)
5.3.14	Connectivity for the factory floor	Y	Y	Y	Y	N/A	N/A	N/A	

Clause	Use Case	DECT feasibility		Possible Implementation path		URLLC classification			
5.3.15	Inbound logistics for manufacturing	Y	Y	Y	Y	N/A	N/A	N/A	
5.3.16	Variable message reliability	Y	Y	Y	Y	N/A	N/A	N/A	
5.3.17	Flexible, modular assembly area	Y	Y	requires further study	requires further study				
5.3.18	Plug and produce for field devices	Y	Y	requires further study	requires further study				
5.3.19	Private-public interaction	Y	Y	Y	Y	N/A	N/A	N/A	
Use cases for Smart Living - Health Care									
5.4.2	Telecare data traffic between home and remote monitoring centre	Indoor only	Indoor only	Y	Y	N	N	N	
Use cases for Programme Making and Special Events (PMSE)									
5.5.2	Low-latency audio streaming for live performance	Y	Y	Y	w/ restrictions	Y	Y	Y	
5.5.3	Low-latency audio streaming for local conference systems	Y	Y	Y	Y	Y	< 4 ms	Y	
5.5.4	High data rate video streaming / professional video production	Y	Y	Y	N	Y	< 4 ms	Y	Very high data rates (see clause 5.5.4 for details)
Y	YES								
Y+	YES and goes beyond ITU-R requirement								

6 Initial thoughts on use case implementation

6.1 General

The scope of the present clause is analysing how the identified requirements can be mapped into the DECT standard and proposing a structure or normative specifications (either EN or TS) for implementing the required functionality.

6.2 Overview of existing DECT standard architecture

Current DECT standard, envisioned at the beginning of the 1990's is basically composed of the following elements:

- The DECT Common Interface, also known as "DECT base standard", code as the eight parts of ETSI EN 300 175 (parts 1 [i.1] to 8 [i.8]). This is the main specification of DECT and is structured as a library organized by layers. It has been continuously maintained during the last 25 years adding new functions required by the evolution of the technology. ETSI EN 300 175 series (parts 1 [i.1] to 8 [i.8]) is an European Norm (EN).

- The Application profiles (AP): These are normative specifications intended to define specific types or DECT products. The most famous AP is the Generic Access Profile (GAP) [i.9] with more than 1 000 million manufactured. Other applications profiles are the New Generations series (ETSI TS 102 527 parts 1 [i.13] to 5 [i.17]), the DECT Packet radio Service (DPRS) [i.12], the RAP parts 1 [i.20] and 2 [i.21], and several data service profiles.

- The specification for Wireless Relay Stations [i.10].

- The several test specifications, (i.e. for radio test [i.11]) not covered in detail by this present document.

- Several Technical Reports intended to provide overviews and guides for implementers, or to study specific technical areas.

The Application Profiles (AP) include specific selection of mandatory and optional services and features for the given applications and may contain detailed procedure descriptions, flowcharts, and additional specifications.

The data service profiles are Application profiles (AP) for data related applications.

Within the Application profiles, there exist a few of them that may be considered "specials". These Application profiles contain procedure descriptions that have been considered an essential part of the DECT technology and therefore have been used and referred by other Application Profiles. Therefore, these Application Profiles, in addition to keep their original scope of defining specific type of products, have gained some status of being part of the fundamental DECT standard -in their own merit. The most obvious examples of this category are the Generic Access Profile (GAP) [i.9], the DECT Packet radio Service (DPRS) [i.12] and the DECT ULE [i.18], and [i.19].

6.3 DECT evolution and DECT-2020 development paths

An analysis of the required functionality from the captured use cases shows that part of them may be implemented with different levels of evolution of the current DECT technology. On the other hand, the most demanding use cases require a new radio interface technology. The boundary between both groups has been set as follows:

- Those applications that can be implemented using current DECT GFSK interface, or evolutions based on xPSK or QAM are consider as group 1. These evolution paths were already foreseen in the DECT base standard and provision for them was considered in part 2 (PHY layer) [i.2] and part 3 [i.3] (MAC layer). This evolution path named "DECT evolution", under development at TC DECT, has the advantage of being available in a relatively short timeframe.

- On the other hand, the more demanding scenario, requiring higher data rates or state of the art bandwidth efficiency are classified as group 2. These use cases require a new radio interface approach based on OFDM FDMA/TDMA combined with MIMO. This new radio interface, named DECT-2020, is under development at TC DECT and will be the long term evolution of the technology.

- DECT-2020 and DECT evolution solutions are not exclusive and will coexist in the market. Therefore, DECT-2020 is not intended as a replacement of DECT or DECT evolution. DECT evolution will continue to be in use for certain products even when DECT-2020 is available.

6.4 Identification of use cases for DECT evolution and DECT-2020 development paths

In general it is not possible establishing a perfect separation between use cases candidate for one or other development paths. The overall vision of the study conducted by the present document is that:

- Near all use cases will be implementable over the new DECT-2020 radio interface; and
- Some Use cases and restricted versions of others are also implementable over evolutions of current DECT technology.

An analysis of the required functionality from the captured use cases shows that restricted versions of some of them may be implemented with different levels of evolution of the current DECT technology. On the other hand, implementation of the full set of requirements (i.e. latency) of most use cases requires a new radio interface technology.

The boundary between both groups has been set as follows:

Those application scenarios that can be implemented using current DECT GFSK interface, or evolutions based on xPSK or QAM, are consider as candidate for DECT evolution. These evolution paths were already foreseen in the DECT base standard and provision for them was considered in part 2 (PHY layer) [i.2] and part 3 [i.3] (MAC layer). This group is considered the short-term evolution of the technology. On the other hand, full implementation of the requirements of all scenarios is considered possible only using the new DECT-2020 radio interface.

Since implementations over evolutions of existing DECT technology, may be available sooner than DECT-2020, time-to-market considerations may recommend the developing of both development paths in parallel.

6.5 Possible standard structure for DECT evolution (based on DECT technology)

The suggested approach for DECT evolution is keeping existing DECT standard structure and expansion methodology. With this approach a possible implementation path would be as follows:

The DECT CI (Common Interface) will continue being the core standard of the evolution. Therefore, all new base functions, messages, formats, Information Elements (IE) and other CI elements would be added to the ETSI EN 300 175 series, Due to the number of required new functions, this would be a major update of the series.

Keeping the same library has several technical advantages:

- reuse of messages and elements
- back compatibility handling
- design of dual products, implementing new and existing functions
- common editorial structure, already known by the DECT community

The "special" application profiles GAP, DPRS and ULE may be reused, if needed. They would require an update adding several new functions and procedures, but with far less impact than in the base standard.

New dedicated application profiles would need to be created. They may cover the different vertical applications to be implemented using existing technologies.

An historic data service profile that deserves mention due to its relation with isochronous data transmission is the data service profile for circuit mode data (data profile D1 [i.22]). This standard is basically obsolete today and does not support high data rate scenarios (multi-bearer or HLM). Therefore reusing this profile as basis for circuit-mode data (as DPRS for packet-data) would require rebuilding it completely.

6.6 Possible standard structure for DECT-2020 (based on new 5G radio interface)

DECT-2020 is basically a new radio interface based on a completely different technology approach (OFDM + MIMO). It seems more convenient defining a new base library (new common interface) for the DECT-2020 technology. The new library would also be distributed by layers, but may have different layer boundaries according to current uses in OFDM technologies. I.e. PHY layer may be combined with lower MAC.

From standard perspective the new DECT-2020 library may be either a TS or an EN. TS will be easier to maintain, while EN may have some advantages if EC funded projects are involved in the technology development.

While PHY and MAC layers would be very different from DECT (ETSI EN 300 175-2 [i.2] and ETSI EN 300 175-3 [i.3]), some reuse may be expected in NWK layer (current ETSI EN 300 175-5 [i.5]), security (current ETSI EN 300 175-7 [i.7]), identities (current ETSI EN 300 175-6 [i.6]) and audio and speech functions (current ETSI EN 300 175-8 [i.8]).

On top of the new library, dedicated core standards for packet data (DPRS-2020), voice signalling procedures (GAP-2020), Ultra Low power operation (ULE-2020) and potentially circuit-mode communications may be created.

Finally, application specific profiles, defining the detailed procedures and the set of features for each application would be created. As today, the target would be that each of these application specific profiles define a category of interoperable products.

Annex A: Survey conducted by STF 537

A.1 Survey on Internet of Things (IoT) use cases for license exempt radio

A.1.1 Scope of the survey

A survey was made to collect data from the IoT community on use cases requiring license exempt radio. This survey was presented to AIOTI WG3 on a Face-to-face meeting help on 27 November 2017. Under the direction of AIOTI WG3 (standardization) it will be distributed to other AIOTI WGs and to EC funded LSP (Large Scale Pilots) projects.

A.1.2 Content of the survey

==

ETSI STF 537 survey on IoT use cases for license-exempt radio technologies

Introduction

STF537 is a group of experts, funded by ETSI and under the direction of the TC DECT that has, within other objectives, the task of providing an analysis of Use Cases requiring license-exempt radio technologies in the IoT and other landscapes. The results of this survey will help ETSI in identifying the use cases and associated vertical industries for the conception of new 5G radio technologies operating over license-exempt spectrum. The result of the survey will initially be used to refine the requirements for the DECT-2020 radio technology (a license-.exempt radio technology under development by the ETSI TC DECT). The results of the survey will also be available to be used by other potential ETSI technologies.

This investigation is specially oriented to the identification of use cases requiring Ultra Reliability and Low Latency Communications (URLLC) and, in general, use cases not solved by existing license-exempt radio technologies

License-exempt is a term used to cover all radio regimens where the user gets the right to use the applicable spectrum with the purchase of the equipment, does not need to apply for individual licenses and does not depend on any spectrum owner. The end user usually (but not always) owns and operate both Fixed and Portable radio terminations. Several specific radio regulations exist. All of them are covered by this survey.

The survey is limited to frequencies below 30 GHz. Extreme high frequency (> 30 GHz) and Infrared are out of scope.

If you organization is involved in IoT scenarios that require or may benefit from license-exempt radio technologies, you are kindly invited to participate by filling in the following response form. You can attach documents if needed.

For your convenience, this template is provided in .pdf and in MS-word formats.

------------------------ Beginning of the survey---------------------------

1 Submitter identification

Company/organization:______________________________________ Date:____________

Contact:______________________________ e-mail:____

Type of organization: (manufacturer, SDO, industry alliance, etc.):
____

Address and country: ____ Number of use cases provided:_______-This is the nr.:_____

------------------------ Beginning of the use case description---------------------------

For providing multiple use cases, please use multiple forms or repeat sections 2 to 5

2 Use case description Use case: ____of____

2.1 Use case name:____

2.2 Use case detailed description

Please describe your use case (external documents may be attached if needed)

2.3 Use case application area

From the list of application domains indicated below, please indicate the domain(s) that best describe the use case area (several domains are possible).

- ☐ Smart Cities
- ☐ Smart Home including smart living environments for ageing well
- ☐ Smart Farming and food security
- ☐ Wearables
- ☐ Smart Mobility (smart transport/smart vehicles/connected cars)
- ☐ Industry automation/ Smart manufacturing: machine control and other real time applications
- ☐ Industry automation/ Smart manufacturing: non real time applications
- ☐ Energy related (i.e. smart grid, smart meters, energy saving)
- ☐ Other smart environment (i.e. smart water management)
- ☐ Horizontal/Telecommunications
- ☐ Devices and sensor technology
- ☐ PMSE professional audio/video
- ☐ Consumer electronics audio/video
- ☐ Cordless telephony , audio-conferencing, other audio applications
- ☐ Other (please specify): ____

3 Technical requirements

Describe the technical requirements of the use case regarding the radio interface. External documents may be attached if needed

3.1 Basic description of expected traffic pattern

General description of the expected traffic pattern

3.2 Required Delay

Specification of required one-way and roundtrip radio delay

3.3 Required Reliability

Specification of required reliability

3.4 Required range

Specification of expected maximum and typical radio range (indicate if LOS/NoLOS)

3.5 Multicell required?

Systems with multiple cells (in the same system) required?

- ☐ YES
- ☐ NO

If YES, seamless handover between cells required?

- ☐ YES
- ☐ NO

If YES, estimated deployment size (max nr. of cells):______________________

3.6 Estimated bitrate needs

Describe maximum and average bitrate needs. Indicate if uni or bidirectional

3.6 Power

Battery operated devices?

- ☐ YES
- ☐ NO

If YES. rechargeable or primary battery?

- ☐ Rechargeable
- ☐ Primary (non-rechargeable)

Acceptable battery capacity (mAh) :____________________

How often the battery should be changed (primary) or charged (rechargeable):__________________________

3.7 Other technical requirements

Describe other technical requirements

4 Frequency / spectrum considerations

4.1 License-exempt / licensed spectrum considerations

Describe the desired radio regimen:

☐ Only license-exempt radio is considered
☐ License exempt desired, licensed radio (inc. cellular) may be considered as alternative
☐ License exempt possible, licensed radio (inc. cellular) is the target assumption
☐ Licensed radio is required

If licensed radio options have been selected:
☐ Licensed radio is understood as public mobile telephony service
☐ Licensed radio is understood as other operated mobile service
☐ Specific licensed regimen for the service (i.e individual licenses to end user, aeronautic and railway communication, etc.)

If "only license-exempt" or "license-exempt desired" options have been selected:
Reasons of the preference for license-exempt regimen:
(several options may be selected)

☐ Cost considerations
☐ Reliability considerations
☐ Delay considerations
☐ Full control of the radio system
☐ Avoid dependence from third parties
☐ Other:____

4.2 Geographic area

Indicate the geographic area(s) target for the application:
First priority area(s): ____
Other priority area(s):____

4.3 Frequency band considerations

Is there any candidate frequency band identified ?: For which geographic area?

(several responses possible) Geographic area:______________ Frequency bands:____ Geographic area:______________ Frequency bands:____ Geographic area:______________ Frequency bands:____

Which band regimen is desired or accepted

- ☐ ISM band
- ☐ Specific bands allocated to the service
- ☐ License-exempt technology exclusive bands (i.e DECT)
- ☐ IMT-2020 allocations for license-exempt radio

5 Security and privacy

- ☐ Full authentication and encryption required (similar to a cellular system)
- ☐ Authentication required, encryption can be provided at higher layers

Other____

Level of encryption (key size) required :____________________-

Special security requirements:____

____

6 Comments

Please feel free to provide additional feedback to the reviewers

------------------------ End of the survey---------------------------

Thank you very much for your input

Submission instructions

You can fill in the survey in either .pdf or MS-word format.

Please submit the survey to : STF537survey@etsi.org

Deadline: 31 January 2018

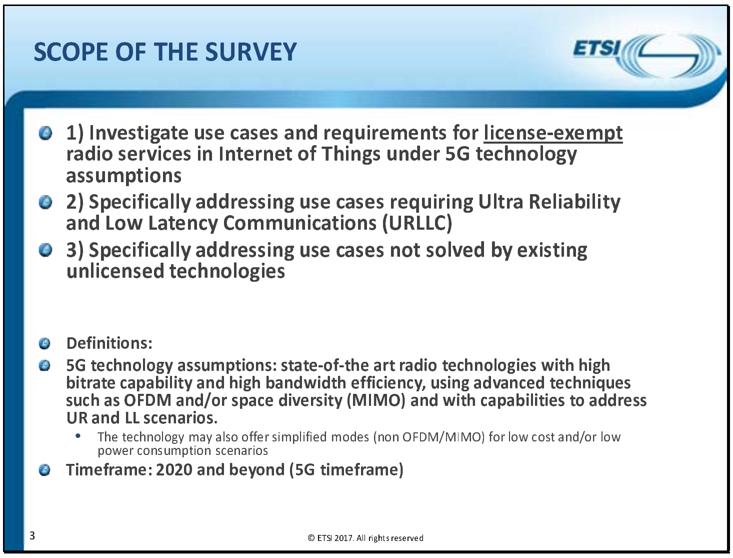
To contact the reviewers:

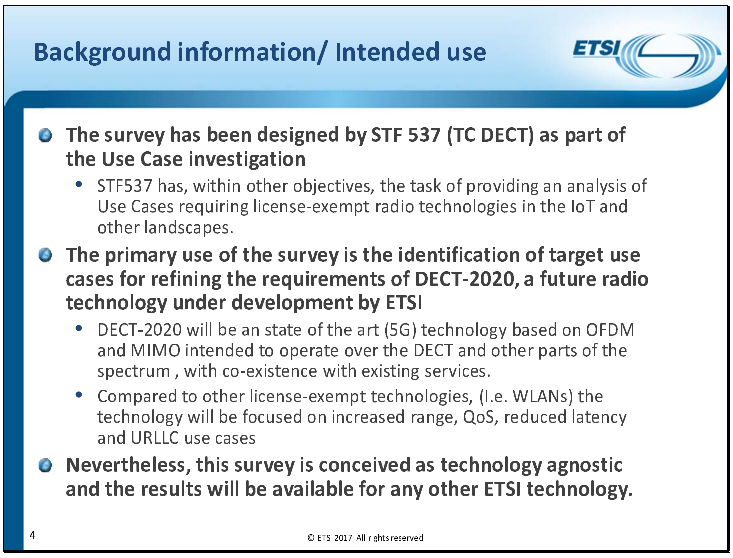
Angel Bóveda /STF 537/: phone: +34 609111283 e-mail: angel.boveda@wirelesspartners.es

e-mail: angel.boveda@wirelesspartners.es

A.1.3 Presentation of the survey

The survey was formally launched on 27 November 2017 at an AIOTI WG3 (standardization) meeting. The following slides were used to present the survey to the participants.




Background information/ Intended use
ETSI
The survey has been designed by STF 537 (TC DECT) as part of the Use Case investigation
STF537 has, within other objectives, the task of providing an analysis of Use Cases requiring license-exempt radio technologies in the IoT and other landscapes.
The primary use of the survey is the identification of target use cases for refining the requirements of DECT-2020, a future radio technology under development by ETSI
DECT-2020 will be an state of the art (5G) technology based on OFDM and MIMO intended to operate over the DECT and other parts of the spectrum , with co-existence with existing services.
Compared to other license-exempt technologies, (I.e. WLANs) the technology will be focused on increased range, QoS, reduced latency and URLLC use cases
Nevertheless, this survey is conceived as technology agnostic and the results will be available for any other ETSI technology.
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Target: license-exempt radio

- The survey is specifically focused on license-exempt radio
- Definition:
- License-exempt radio: radio technologies where the user can own and operate radio devices without requesting individual license
  - Also known (commonly): "unlicensed" radio
  - Several specific regulations (i.e.: ISM bands, technology specific bands, etc)
  - In most cases (but not always) the user own and operates both radio terminations (i.e. base station and portable devices)
  - In most cases (but not always) the equipment is used indoors or inside property of the user/"operator"
  - By practical reasons, Extreme high frequency (> 30 GHz) and Infrared are out of scope
- This survey does not enter in the debate cellular vs. unlicensed
  - This survey assumes as a fact that unlicensed radio exist and will continue to exist in 5G timeframe
    - It is not the scope of this survey addressing "Cellular only " paradigms
- Geographical scope: worldwide with some "European bias"
  - Although the study is conceived as "worldwide, it has some "European bias" (due to the spectrum considerations)

5

The bottom line

- This study provides to the potential users the (rare) opportunity to influence the design of a new OFDM license-exempt technology from the beginning

7

To participate

- Template available at ETSI AIOTI WG3 portal area
  - .pdf and MS-word versions available
- Send your replies to STF537survey@etsi.org
  - Deadline: 31 January 2018
- If you wish you influence, please contribute!

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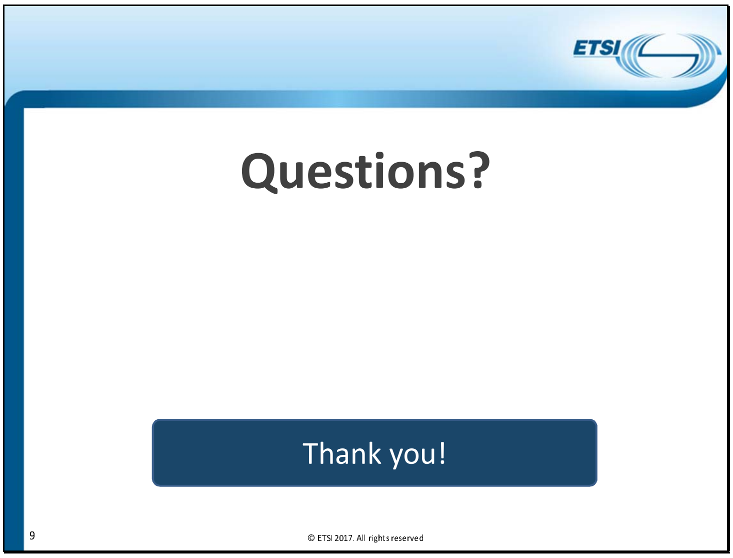
ETSI
Questions?
Thank you!
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Annex B: Bibliography

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History

Document history		
V1.1.1	March 2018	Publication