6G BRAINS Deliverable D2.1

Definition and Description of the 6G BRAINS Primary Use Cases and Derivation of User Requirements

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Abstract

Wireless connectivity is an important enabler for many modern applications in various segments. The need for further improvement of wireless communication technologies is still very large. New transmission techniques, smart communication resource planning and utilization, novel optimization methods including Artificial Intelligence and Machine Learning etc., can bring known applications to a new level of their performance or can even enable totally new applications that were impossible until now.

With this deliverable, we do the first step towards identifying the most obvious applications that can benefit from 6G BRAINS technologies. While carefully reviewing the segments like production manufacturing, automotive industry, smart agriculture, etc., a list of relevant use cases is created. The most challenging use cases build the basis for our requirements analysis summarized in this document in form of technical use case descriptions, derived user requirements, KPI specifications, as well as user concerns.

[End of abstract]

Disclaimer

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Executive summary

"Wireless" has already become a synonym for freedom, high flexibility, speed, independence, etc. Wireless connectivity was a crucial enabler for many modern applications in our private as well as business life. However, the need for further improvement of wireless communication technologies is still growing, especially in such applications areas like production manufacturing, automotive industry, smart agriculture, etc.

We do the first step for identifying challenging applications that seek for capabilities beyond current state-of-the-art technologies like WiFi 6 or 5G. For these applications, 6G BRAINS is preparing a new solution represented by a combination of Artificial Intelligence (AI) methods with new communication techniques including optical wireless communication (OWC) and terahertz (THz) to perform resource allocation over and beyond massive machine-type communications and to enhance performance with regard to capacity, reliability and latency. New transmission techniques, smart communication resource planning and utilization, AI-based optimization methods bring known applications to a new level of their performance and can enable totally new applications that were impossible until now.

In this deliverable, we present a list of relevant use cases collected from different application areas. The most challenging use cases build the basis for our requirements analysis summarized in this document in form of technical use case descriptions, KPI specifications, as well as user concerns. In our analysis, the focus has been set on future industrial manufacturing aka Industry 4.0. This sector is represented by four use cases out of six, which we analysed in detail in this work.

A very important input to the use case identification process has been the list of the innovation aspects from the 6G BRAINS technology partners. The summary of those aspects provided the directions for the development of new applications. Some innovations that have been considered are (i) AI-driven multi-agent deep reinforcement learning (DRL) to perform resource allocation, (ii) a novel combination of spectrum links like THz and OWC to enhance the performance with regard to capacity, reliability and latency, (iii) a novel comprehensive cross-layer DRL driven resource allocation solution to support the massive connections over device-to-device (D2D) assisted highly dynamic cell-free network enabled by Sub-6 GHz/mmWave/THz/OWC and (iv) high resolution 3D Simultaneous Localization And Mapping (SLAM) of up to 1 mm accuracy.

Our analysis showed a high need for low-latency, low-jitter and high availability data transmission in applications that include closed-loop control on one side and ultra-high data rate communication in applications that include video or large sensor data traffic on the other side. Also the data differentiation and corresponding prioritization have been identified as one of the major pain points of the use cases considered in this work. As a result, an advanced network slicing has been considered as an important enabler for future applications.

One of the important use case requirements is the localization accuracy required in future application scenarios. Here, localization precision up to 1 mm can be an essential enabler that opens up a lot of new possibilities. As example, tracking of animals in indoor farming scenarios or autonomous movements of robots as well as transportation systems in large warehouses and production halls seek urgently for new and improved localization techniques.

This document present analysis results focusing on the primary usage of the 6G BRAINS technologies. However, with use of THz and OWC, new possibilities for secondary usage of these technologies arises, e.g., vital data monitoring, communication-enabled radar, ultra-precise localization, secure distributed connections and many more. This secondary application is a focus of the Deliverable D2.4 of 6G BRAINS project.

List of authors

Company	Author	Contribution
BOSCH	Alexander Artemenko	Lead Abstract, Executive summary, Sections 1, 1.2, 2.1.1, 2.1.2, 3.2, 3.3, 4.1, 4.2, 5.2 Contributing to Sections 4.4, 5.1, 6
BOSCH	Uwe Wostradowski	Lead Sections 1.3, 3.1, Annex A
UBrunel	John Cosmas	Lead Sections 2.1.3, 2.1.4, 4.3, 4.5, 4.6
UWS	Qi Wang, Jose M. Alcaraz Calero, Enrique Chirivella Perez, Pablo Salva Garcia, Ruben Ricart Sanchez	Lead Sections 2.2, 4.4 Contributing to use case template and Section 5.1
ALPT	Bruno Parreira, Marco Araújo	Contributing to Sections 3.2, 4.3, 4.4, 4.6, 5.1
REL	Israel	Lead Sections 1.1, 6
THALES	Alexandre Kazmierowski, BISSON Pascal Bisson, Jerome Kodjabachian	Contributing to Sections 3.1, 5.1
Eurescom	Anastasius Gavras	Review

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Abbreviations

3GPP	3rd Generation Partnership Project
5G	Fifth Generation (mobile/cellular networks)
5G PPP	5G Infrastructure Public Private Partnership
6G BRAINS	Internet of Radio Light (project)
AGV	Automated Guided Vehicle
AI	Artificial Intelligence
CAPEX	Capital Expenditure
DRL	Deep reinforcement learning
DTS	Driverless Transport Systems
E2E	End to End
I 4.0	Industry 4.0
IAB	Integrated Access and Backhaul
IoT	Internet of Things
ISAC	Information Sharing and Analysis Center
IP	Internet Protocol
ITU-T	International Telecommunications Union - Transmission
IMU	Inertial Measurement Unit
JRC	Joint Radio Communications
KPI	Key Performance Indicator
M2M	Machine to Machine
MANO	Management and Orchestration
MCU	Motion Control Unit
MIMO	Multiple Input Multiple Output

ML	Machine Learning
mMTC	Massive Machine Type Communications
Mosaic5G	Non-profit initiative fostering a community of industrial as well as academic contributors for open-source software development to realize an agile data-driven 5G service delivery platform
mUE	Mobile user equipment
NLP	Neuro-linguistic programming
OAI	Open Archives Initiative
OPEX	Operational Expenditure
PCB	Printed circuit board assembly
PLC	Programmable logic controller
QoE	Quality of Experience
QoS	Quality of Service
R&D	Research and Development
RAN	Radio Access Network
SDN	Software Defined Networks
SLA	Service Level Agreement
SWOT	Strengths, Weaknesses, Opportunities, and Threats analysis
SLAM	Simultaneous Localization and Mapping
UE	User equipment

Definitions

User story: A user story is an informal and abstract description of the problems/solutions. It should focus on who are the users that will use the solution, and on the results and benefits (and how they can be quantified), in such a way that it can also be understood by non-technical people. It should capture production and industrial aspects, but also highlight the benefits of the applied networks (e.g., compared to the current state of the art).

Use case: A use case should be at a finer granularity than a user story (such that from a user story several use cases could be derived). It should also be more technical and describing in detail how the users of 6G BRAINS network solutions will accomplish a specific goal, including also technical requirements.

1 Introduction

Wireless connectivity is an important enabler for many modern applications in various segments. The need for further improvement of wireless communication technologies is still very large. New transmission techniques, smart communication resource planning and utilization, novel optimization methods incl. AI, etc. can bring known applications to a new level of their performance or even can enable totally new applications that were impossible until now.

6G BRAINS project plans to combine AI-driven methods with new communication techniques incl. optical wireless communication (OWC) and terahertz (THz) to perform resource allocation over and beyond massive machine-type communications and to enhance the performance with regard to capacity, reliability and latency as required for future application scenarios in such business segments like production manufacturing, automotive industry, smart agriculture, etc.

With this deliverable, we do the first step towards identifying the most obvious applications that can benefit from 6G BRAINS technologies. While carefully reviewing the segments mentioned above, a list of relevant use cases has been created as shown in Annex 0. The most challenging use cases build the basis for our requirements analysis summarized in this document in form of technical use case descriptions, KPI specifications, as well as user concerns.

1.1 Objective of this document

The main objectives of this document are to define and describe the 6G BRAINS primary use cases and derive the most important user requirements from each one of them.

The "user story", which describes what exactly the user wants the system to do, provides the high-level overview of the relationships between the actors of different use cases, and the Wireless Cellular Communication system and is the basis of the work done in this document.

The primary use cases are analysed from the end user perspective by describing how the user interacts with the system and by deriving end-to-end usage scenarios. Following this analysis, 5G/6G technologies that are required to provide such services are identified and the appropriate set of Key Performance Indicators (KPIs) are derived and justified.

Following the main use cases identification, analysis and KPIs derivation, it is the objective of this document also to consolidate the results in a comprehensive table that summarizes the use cases main requirements from the network point of view and to derive a set of KPIs that meet most of the primary use cases needs. This set of consolidated KPIs can be useful as a guideline for future communication system development of vertical networks.

1.2 Project Approach

The project 6G BRAINS intends to address a broad spectrum of novel technological aspects, which are going to have an impact on the next generation of the mobile communication. The motivation for these aspects comes from the analysis of user needs in different vertical sectors. We reviewed the results of market prediction and selected application sectors that are expected to have a significant market share in mobile communication technologies in the next decade. These sectors include representatives from the vertical industries like future industrial manufacturing, smart transportation and mobility services, smart agriculture, airports and large warehouses. For each of the selected sector, we collected a list of appealing user stories that directly benefit from the mobile communication. After a careful review of the publicly available results out of the most recent EU and German national projects in the area of mobile communications, we selected a list of use cases that show significant challenge to the current 5G technology and require further improvements going beyond the possibilities of 5G. The analysis of these use cases, the derivation of their user requirements and impact on future wireless networks represent the core of this document.

1.3 Structure of this document

The rest of the document is organized as follows. In Chapter 2, there is an overview of vertical industries of interest like Factory of the Future / Industry 4.0, smart transportation and mobility, smart agriculture, airports and warehouses followed by an overview of the Innovation Aspects of 6G BRAINS Project from all project partners. In Chapter 3, the related work is reviewed, starting with 6G BRAINS relation to 3GPP primary use cases, automotive use cases from 5GAA and industrial uses cases from 5G-ACIA.

In Chapter 4, a more detailed description of use cases enabled by 6G BRAINS is presented, starting with computational offloading to the edge of the PLC control function as well as localization and video processing for smart transportation vehicles, to maintenance video guides, advanced network slicing, animal tracking in indoor farming and finishing with use cases in airports and warehouses. Chapter 5 consolidates all requirements from Chapter 4 including an overview of KPIs and wider user concerns. The document ends with a summary of the findings and future recommendations in Chapter 6.

2 Motivation for the Usage of 6G BRAINS in Vertical Industries

As mentioned in the previous chapter, we analysed the trends in the adoption of 5G technology in the current market as well as the available predictions. Figure 1 shows an example of such prediction for the US 5G services. Based on our observations, we selected the following vertical sectors that represent a significant share in applying mobile technologies (incl. 5G and B5G) as well as fit to the expertise available in 6G BRAINS project:

- Factory of the future,
- Smart transportation and mobility,
- Smart agriculture,
- Airports.

These sectors are described in the next section. The section thereafter gives an overview of the technological innovations that are expected within this project. Moreover, we show the match between the vertical sectors and corresponding innovations to strengthen the motivation for our work.

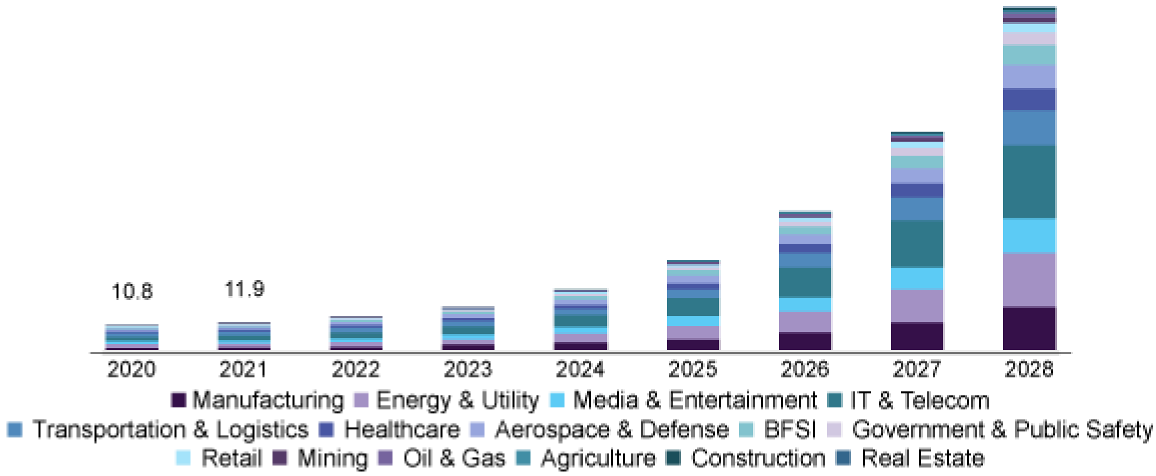

Figure 1: 5G mobile services market prediction in U.S., by vertical, 2020-2028, in USD Billion

[Source: https://www.grandviewresearch.com/industry-analysis/5g-services-market]

2.1 Vertical Industries of Interest

This section provides a short description of each sector of interest.

2.1.1 Factory of the Future / Industry 4.0

Industry 4.0 (I4.0) represents the next step in the development of the industrial manufacturing. Although the fourth industrial revolution is known for some time already, the process is still ongoing and there is a lot to do. Moreover, the current state of the development towards the smart factory concept is rather modest.

There are many theories and initiatives about I4.0, which have not been implemented or tested in reality. Solitary products and solutions dominate over massive roll-outs of the I4.0 concepts. Even the Big Picture I4.0 shown by different companies is often too unspecific for clear use cases. The developments are rather technology-driven and not customer-driven. Newly built factories tend to implement many I4.0 concepts right away though the manufacturing process remains mostly fixed.

On the other hand, the customer requirements start to change more and more frequently showing a challenge to a fixed production concept. The large batch production principles tend to shift towards small and individual batch production. Such novel requirements like lot size 1 production at large-scale conditions, highly variable factories, reduction of set up times, significant reduction of investments and fast integration of the newest manufacturing technologies become the new standard.

To overcome these challenges, we consider several steps. The first step is a transition from fixed production lines to a flexible manufacturing process. This transition includes among many well-known I4.0 concepts the introduction of cyber-physical systems, digital twins, artificial intelligence and massive connectivity incl. mobile technologies to the shop floor (see Figure 2). These techniques enable a higher level of variability and flexibility of the production.

The following step should result in a highly flexible factory. Such a factory offers complete variability. Although the walls, the floor, the ceiling will all be fixed, everything else will be mobile. Assembly lines will be modular, and their constituent machines will move and reorganize themselves into new lines for new purposes. They'll communicate wirelessly with one another and with other process functions via mobile networks, and they will be powered through the floor via an inductive charging system. The factory of the future is going to be highly adaptable, flexible and fully connected.

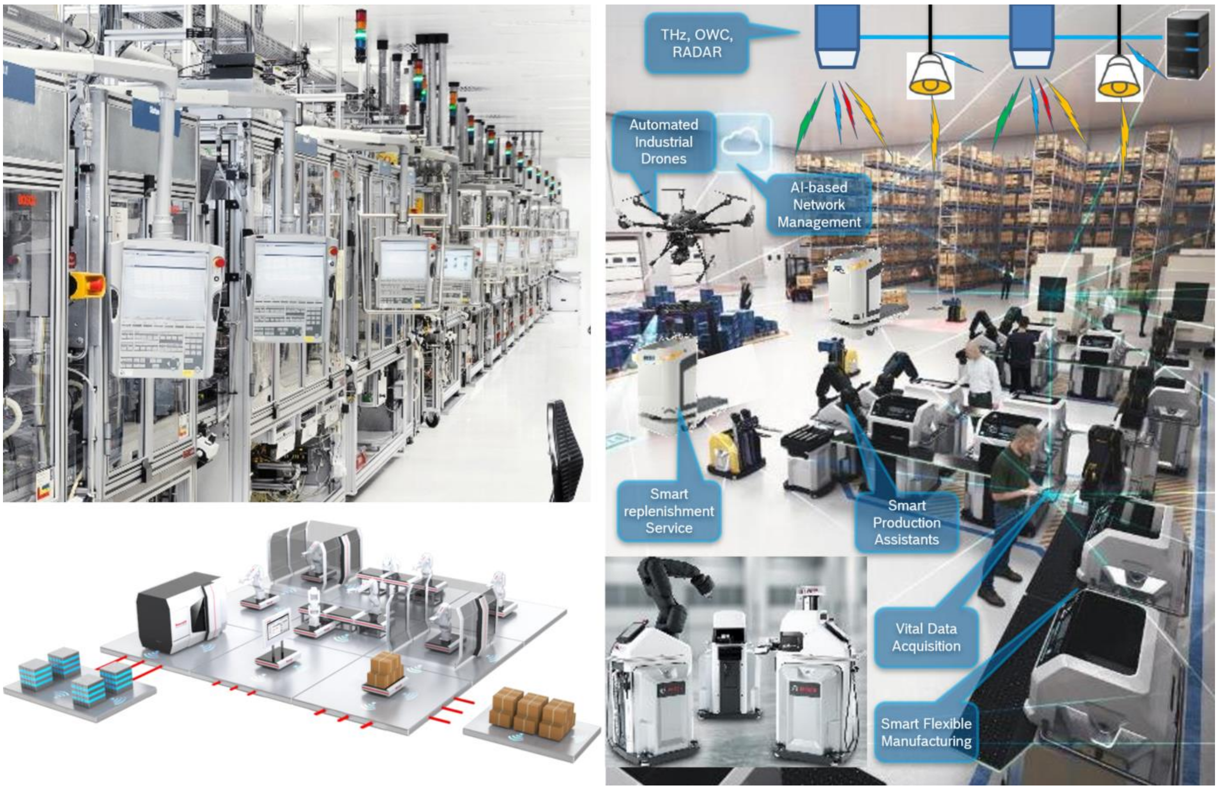

Figure 2: Factory of the future vision of the company Robert Bosch GmbH [Pictures: Bosch]

2.1.2 Smart Transportation and Mobility

Future transportation and mobility services are one of the central challenges of our time. The main drivers can be expressed by the key requirements on the new services: safer, more convenient, greener. Independent if it is urban mobility, global logistics or small-scale mobility applications, connected and sustainable service is essential. Sustainable generated electrical energy will be the dominant energy source of the future transportation. This energy must be handled carefully with the highest efficiency in conversion processes. The future of mobility services is highly integrated in many ways, while also reduced in complexity. In the long term, a wide variety of vehicle concepts from scooters to driverless shuttles will promise to transport people and goods over short and long distances (see Figure 3).

Connected vehicles that can communicate with the infrastructure in real time reduce emissions and the risk of accidents. This communication requires a stable and reliable data link provided by high-performance 5G or by Wi-Fi-based alternatives (ITS-G5). However, an increasing number of autonomous vehicles with different services and requirements on the communication networks represent still a very high challenge for the above technologies. New network concepts and more efficient data transmission services are required to cover the user needs.

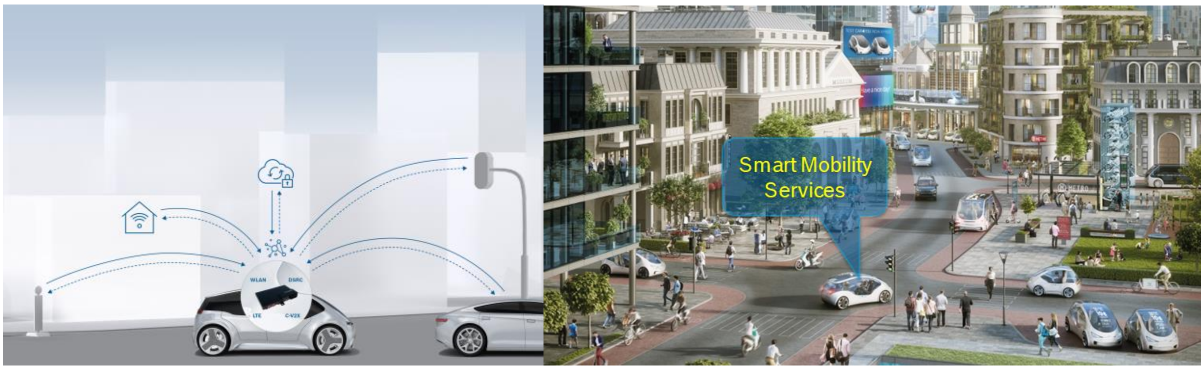

Figure 3: Smart transportation and mobility services [Pictures: Bosch]

2.1.3 Smart Agriculture

Smart agriculture (see Figure 4) uses technologies like Internet of Things, sensors, location systems, robots and artificial intelligence on farms where the ultimate goal is increasing the quality and quantity of the crops and livestock, while optimizing the human labour used.

Indoor smart agriculture for looking after livestock or plants within warehouse or glasshouse environments, is comparable to the Industry 4.0 factory use case in a variety of functionalities as described below. IoT localization can be used in combination with augmented reality to assist farmers in identifying animals' location and IoT sensors can monitor their health and well-being. Automated Guided Vehicles (AGV) can be used for carrying feed to animals and mobile robots with cameras on them can be used for identifying and removing droppings, and cleaning their living spaces.

Within glasshouses precision irrigation and precise plant nutrition can be provided by mobile robots and precise climate management and control can be guided by sensors for the soil, water, light, moisture, for temperature management. Location systems can be used for measuring plant growth. Robot systems can be used for harvesting the fruit of plant's root or tuber.

Figure 4: Smart agriculture [Picture: Bosch]

Therefore, the smart agriculture use case requirements on the Wireless Networks are similar to those from Industry 4.0 AGV use case. For example, 1 mm accuracy is required for handling fruits whilst 1 cm location accuracy is required for location of the AGVs. Furthermore, object recognition and collision avoidance software functions are required to be processed on the Multi-access Edge Computing (MEC) cloud with Artificial Intelligence for the purposes of speed and security of processing, conservation of energy of the AGV and coordination of actions of fleets of AGVs and robots.

2.1.4 Service and Baggage Handling Robots in Airports

Service robots greet passengers at airports (see Figure 5) and guide them (see Figure 6) to their destinations (e.g., check-in service desk, restaurants, shops, etc.). Service robots recognize, translate speech and synthesize answers in different languages. They present video of guides to passengers on how to find different general destinations such as specific restaurants and shops but also provide specialized guides to passengers such identification and directions to check-in desk based on flight number of airline carrier or guidance on where to go if there is a security or emergency situation occurring in the airport. They also provide physical guidance to passengers to their point of destination within the airport.

Baggage handling AGVs, within the baggage handling area, pick up baggage from one baggage handing conveyor belt and drop them off at another baggage handling conveyor belt depending on their bar code identified flight destination.

Baggage handling AGVs, within the passenger concourse area, assist passengers in carrying baggage from one part of the passenger concourse area to another without colliding with other passengers or objects through the use of object recognition and collision avoidance artificial intelligence software functions. These may work in coordination with service robots within airports.

Passenger handling AGVs, within the passenger concourse area, assist passengers in ferrying them from one part of the passenger concourse area to another without colliding with other passengers or objects through the use of object recognition and collision avoidance artificial intelligence software functions. These may work in coordination with service robots within airports.

Figure 5: Service Robot Greeting Passenger

[Source: YouTube https://www.youtube.com/watch?v=K6kRZQJ8PgM Visualisations in Airports Bellos Xenofon Brunel 2014]

Figure 6: Service Robots Guide Passengers to their Destinations

[Source: YouTube https://www.youtube.com/watch?v=K6kRZQJ8PgM Visualisations in Airports Bellos Xenofon Brunel 2014]

These airport use cases are similar to Industry 4.0 AGV use case, where 1 cm location accuracy of the AGVs is required and where object recognition and collision avoidance artificial intelligence software functions are required to be processed on the Multi-access Edge Computing (MEC) cloud for the purposes of speed and security of processing, conservation of energy usage on the AGV and coordination of actions of fleets of AGVs and service robots.

2.2 Overview of the Innovation Aspects of 6G BRAINS Project

The key aspects of the technological innovations expected in 6G BRAINS project have been collected from all project partners. These aspects can be seen in Table 1 below.

Table 1: Key aspects of the technological innovations

Partner	Innovation aspects of 6G BRAINS (expected to be present in one of the use cases)	Short description of the aspect incl. its expected value/quality (i.e., requirement)	Comments from partners, corresponding use cases
ULEIC	Industry E2E Reliability (low package loss) over D2D	In industrial scenarios, closed-loop control applications will require E2E reliability of up to 10^{-7} to maintain close synchronization at E2E, per-link reliability of around 10^{-9}.	Instant optimization based on real-time monitoring of sensors and the performance of components, collaboration between a new generation of robots, and the introduction of wirelessly connected wearables and augmented reality on the shop floor by using AI.
	E2E Latency	Latencies as low as 1 ms, and user plane latency around 0.1 ms.	New approach is required by massive IoT devices for the management and implementation of radio access networks. Some examples of improvements include adding ML to baseband processes, using a virtualised container- based RAN compute architecture, and running the containers close to mobile edge computing (MEC) servers to achieve latency as low as 1 ms.
	Area traffic capacity	>1 Gb/s/m^2	Complementing the wide-area coverage achieved at sub-6 GHz frequencies by using higher and higher carrier frequencies, beyond the millimetre wave and up to the visible light band, to provide high-capacity point-to-point links.
VIAVI	Peak UE data rate (L3)	>1 Gbps/UE	For high data rate video streaming scenario, to support up to 32 UEs video streaming simultaneously.
	UE latency	1 ms	For low latency scenario, UE air interface ACK/NACK latency down to 1~2 slot and UL (Uplink) scheduling latency down to 2~3 slots.

	UE density	$>10^4$ per base station	To emulate mIoT scenario and this includes full UE C-plane procedure and UE traffic.
UBrunel	Traffic Analyser and Scheduler	Time required to change traffic schedule = one subframe slot interval, e.g., 1 ms for SCS = 15kHz. Time required to change slice capacity occurring maximum three times a day (i.e., once every new shift) for Flexible Factory IoT use case scenario and maximum once a week for Highly Flexible and Customised Factory IoT use case scenario. Detect packet size, inter-packet arrival time and jitter statistics. 10^{-9} reliability.	Using RL to learn features of traffic (packet size, inter-arrival time/variability and type) and radio channel (Channel Frequency Response and Exponential Effective Signal to Noise Ratio Mapping) to facilitate scheduling of traffic on resource blocks of a transport block's subframe slots to minimise packet loss and maximise throughput. Used in Flexible Factory IoT use case scenario for agile manufacturing where different image processing algorithms are required at the MEC cloud depending on what is being manufactured. Used in Highly Flexible and Customised Factory IoT use case scenario for highly agile manufacturing where different image processing algorithms are required from moveable camera equipment in different parts of the factory at the MEC cloud depending on what is being manufactured in different production line configurations.
	Heterogeneous traffic generator	Time required to update schedule = 1 slot interval, e.g., 1 ms for SCS = 15 kHz and change slice capacity occurring maximum three times a day (i.e. once every new shift) for Flexible Factory IoT use case scenario and maximum once a week for Highly Flexible and Customised Factory IoT use case scenario. 10^{-9} reliability.	Generating traffic mixes that emulates traffic generated from a manufacturing facility. Could be used for generating traffic to test an adaptive slicing system in backhaul network. Could also be used for predicting traffic variability using RL. See above for use case scenario descriptions
	Localization Precision	1 cm accuracy every 10 ms.	Tracking moving assets (e.g., Automated Guided Vehicles) directly from RAN using data fusion of IMU, mmWave AoA, TDoA and OWC RSS.
	Localization Precision	1.0 m accuracy every 60 seconds.	Tracking low performance assets or environments indirectly from Anchor UEs that are connected to RAN using multilateration, NOMA

			RSS, light weight OpenStack on Anchor UEs and block chain database.
ISEP	Localization reliability, visible light and RF	PD angle error (+/-3°)	Acceptable photo-diode angle range; AoA angle range;
	Localization coverage	99%	sub-cm accuracy area should be close to 100%.
REL	RAN (PHY) Latency	< slot interval (e.g., 1 ms) per hop	In URLLC use cases with IAB (research)
	RAN (PHY) reliability	< 10 exp (-6)	In URLLC use cases
	RAN capacity/ UE	> 1 Gbps	
UWS	High-speed backbone network slicing capacity	10+ Gbps network slicing capacity at data plane switches	Real-time control, monitoring and management of backbone network slices across edge, transport network and core network at the speed of 10+ Gbps in data plane switches. Slice number depends on the complexity of one slice.
	Low delay to change/stop/start/ create a backbone network slice	In the order of seconds in worst cases, and under 1 second in best cases	Real-time life-cycle management of network slices for rapid service deployment and reconfiguration.
	High flexibility in backbone slice definition	Allowing flexible definition of network slices in terms of multi-tenancy, flows at various levels of granularity, industrial protocols, and so on.	Addressing flexible and adaptive network slicing in response to highly dynamic, on-demand traffic control in the industrial use cases.
ECOM	RAN network slicing capacity	RAN slicing with 2-4 ms latency and 200 Mbps DL and UL	RAN bitrate: up to 200 Mbps for both DL and UL (ECOM) RAN latency: dynamic TDD based to reduce radio latency (MODEM to MODEM in OAI platform) from 10 ms to 2-4 ms (RUNEL PHY latency)
	AI-based RAN slicing	Optimised/Enhanced radio resource allocation and scheduling for both inter-slice and intra-slice cases	Enlarge the potential number of network slices in RAN, with more customizable SLAs and optimization objectives.
	Directional RAN slicing	Exploit UE (relative) positions when performing inter-slice resource partitioning/allocation or coupling with beamforming informed by CSI	Isolate the slice in Space in addition to time and frequency domain Enlarge the coverage of RAN slicing for use cases (only applicable when using beamforming).

OLED	Light source & photo-receiver modulation bandwidth	The light source modulation bandwidth (BW) may limit the achievable data rate (e.g., white LED with 2 MHz BW = data rate < 50 Mbps). Infrared sources may be preferred (e.g., 200 MHz IR source with high SNR = 1Gbps+ data rate)	The light source type is to be defined depending on the use case targeted. If lighting from the OWC system is required, then white LED have to be used. Otherwise, infrared LED or laser should be preferred, unless only low data rates are needed.
	Sigal to noise ratio of the received OWC signal	The data rate, bit error rate and coverage of any OWC system are closely related to the SNR of the received signal (uplink or downlink). An SNR target must thus be fixed depending on the QoS and service area needed for each use case.	Example of SNR target: 27 dB with light source modulation bandwidth of 200 MHz = data rate of 1 Gbps+
BOSCH	Example: High data rate	Data rate up to 3 Gbps, peak data rate 5 Gbps	Uses with high data rates requirements like camera-based use cases.
	Example: Self-optimized management of campus networks	Using feedback from and monitoring of UEs, network optimizes itself with the help AI	Complex scenarios that include different use cases and frequent changes in the environment
	Example: Low transmit jitter	To support deterministic communication, data transfer system identifies deterministic flows and guarantees low jitter in the range from 100 till 200 ns	Use cases with deterministic communication like industrial control traffic
FhG	Multi-band measurements in large scenarios	Integration of multi-band channel sounders in sub-6 Ghz, mm-waves, sub-THz, and VLC to analyse propagation in the different frequencies	Simultaneous measurements of different frequencies in complex scenarios allows to shorten the gap in the understanding of propagation at higher frequencies by comparing with the well-known sub-6 GHz channel
	Multi-band propagation parameters	Influence of frequency and system aspects (antenna's directivity) on coverage, DS, and Ass	Key parameters as DS and ASs are of special importance to design and optimize communication and positioning systems.
	RT model to test applications	RT model verified from measurements that can simulate flexible scenarios	Channel models verified with measurements allow the test of different systems and applications in complex scenarios where measurements cannot always be conducted
ALPT	User authentication accuracy	The industrial virtual assistant should be able to authenticate	Users can use the industrial virtual assistant to request network and

		users via voice recognition with an accuracy of >99.99%	cloud services as long as they authorized to do so. To perform authorization is first needed to authenticate individual users.
	Cloud-based service reliability	The NFV Orchestrator should be able to guarantee a reliability of >99.99% for services through the use of healing mechanisms	The NFV Orchestrator is able to deploy industrial applications on top of cloud (centralized or edge) datacentres. Considering the critical nature of some of these services, it is important to guarantee their uptime and availability
DTAG	Value from caching, caching efficiency	Value of placing and using caches on the RmUE; for various scenarios that could benefit from (content) caching; caching strategies; caching efficiency KPIs	Caching of distance and IoT data on Multiaccess Edge Computing (MEC) Fog server before forwarding onto MEC cloud server.
TSG	Deep Reinforcement Learning agents usability	The MA-DRL scheme should guarantee that trained agents are exploitable in their application context.	This involves several aspects; all of these won't be necessarily covered by 6G-BRAINS: • Real-time: the agent must compute its action at the system control frequency • Safety: the agent actions must not be harmful to the overall system, at exploitation phase or during online training. • Robustness: the MA-DRL agents should be robust to inputs with small deviations (e.g., noisy sensors) to their training data.
	Deep Reinforcement Learning adaptation to real-world systems	The MA-DRL scheme should provide algorithms that address real-world challenges.	This involves several aspects; all of these won't be necessarily covered by 6G-BRAINS: • - Dynamic Environment: the MA-DRL agents should adapt to inputs whose dynamics may vary over time. • - Many-agents: the MA-DRL scheme should accommodate with high number of agents acting in the same environment
	Deep Reinforcement Learning efficiency	The MA-DRL online training procedure and exploitation (or inference) should not harm the system performance.	Use an adequate amount of compute, memory, bandwidth, etc.

Towards that vision, 6G BRAINS aims to bring AI-driven multi-agent DRL to perform the resource allocation over the high dynamic ultra-dense D2D cell free network with new spectrum links including THz and OWC to achieve up to 100 devices per m^3 network density, up to 99.999% reliability and up to 0.1 ms air interface latency for the future industrial network. 6G BRAINS project is the first project to propose a comprehensive cross-layer AI driven resource allocation solution to support the massive connections over D2D assisted high dynamic cell free network enabled by THz/OWC and high-resolution 3D SLAM of up to 1 mm accuracy. In order to achieve this, the enabling technologies in 6G BRAINS have been divided into four major parts including the disruptive new spectrum links, the high dynamic D2D cell free network modelling, the intelligent end-to-end network architecture integrating the multi-agent DRL and smart network slicing, and AI-enhanced high-resolution radio-light 3D SLAM data fusion.

BOSCH has set out a vision for a Beyond 5G (B5G)-enabled industrial network where every part of the production environment is fluid/flexible, except for the walls and ceilings. Industrial machines, devices, and vehicles will be made mobile and made intelligent by edge and cloud-based analytics, enabling factory owners to change their production lines according to demand in a short period of time. The massive connected IoT solution is envisioned to be one of the most promising drivers for many of the emerging use cases, including industrial automation as a means to deploy reconfigurable production systems, which can be raised up and torn down according to real-time demand. 6G BRAINS solution will have very few fixed elements, and even these elements will be intelligent. The building will be static, but flexible. Every piece of equipment in these new plants can be wireless, and mapped as a digital twin with the high-resolution radio-light 3D SLAM. AI enabled RAN slicing for 6G BRAINS networks will liberate factories from their fixed production lines. The MEC (multi-access edge computing) of 6G BRAINS will organise retrofitted connectivity and enable analytical applications like predictive maintenance even in old machines. The multi-agent DRL framework of this project will bring real-time intelligence and learning, and response capabilities to help humans to handle more changeable production routines. The AI-enabled massive D2D clusters' modelling, enhanced by the multi-band channel models for the 200 GHz and 300 GHz as well as OWC band in 6G BRAINS over the high dynamic ultra-dense D2D industrial network is essential to open the path to 6G in industrial environment for THz and optical spectrum to bring the real scenarios into the controllable platform. The innovative disruptive technologies in 6G BRAINS like the Grant-free Non-Orthogonal Multiple Access (GF-NOMA) over cell free massive MIMO with underlaid D2D clusters, optimizing content placement in edge caches aiming at low delay and traffic offloading, user-centric interfaces enabling intent-based networking, new radio waveform for THz and OWC and evolved E2E directional network slicing management and orchestration (DNS MANO) allow a higher capacity and extended coverage to meet massive URLLC connectivity requirements. The mobile robots use case demands very high requirements on latency, communication service availability, and determinism. This application can involve simultaneous transmission of non-real time data, real-time streaming data (video) and highly critical, real-time control data. The latter involves very high requirements in terms of latency and communication service availability over the same link and to the same mobile robot. Enhanced coverage in indoor (from basement to roof), outdoor (plant/factory wide) and indoor/ outdoor environment is needed due to mobility of the robots. 6G BRAINS will 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.

3 Review of the Related Work

Here, the main activities with the focus on the primary usage of the mobile communication technologies like 3GPP, 5GAA and 5G-ACIA are listed. Their results of the use case analysis are briefly summarized.

3.1 Relevant Use Cases in 3GPP

Here, the main observations from the use case analysis work in 3GPP is shown. The most relevant studies in 3GPP include:

- 3GPP TR 22.804 V16.3.0 (2020-07), 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Study on Communication for Automation in Vertical Domains (Release 16) [[6]]
- 3GPP TR 22.855 V1.0.0 (2021-03), 3GPP TR 22.804 V16.3.0 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Study on Ranging-based Services (Release 18) [[7]]

The latter study is focusing rather on a secondary usage of the communication system and thus will be analysed in the second part of the Task 2.1. Correspondingly, the study 3GPP TR 22.804 V16.3.0 will be the focus of this section.

In Table 2, we present a brief overview of the most relevant use cases, which we identified from [59]. Out of the analysis of these use cases, we conclude several important facts:

- For very challenging (in terms of the data transmission) use cases, the requirements have been reduced to meet the expected capabilities of the 5G system. Example: an increased cycle time values in robotics, motion control and closed-loop control applications.
- The expected reliability of the communication link is not clearly defined in the document.

6G BRAINS projects is going to address the above shortcomings.

Table 2: Overview of the relevant 3GPP use cases

Use Cases	**Overview of the key aspects of the use case relevant for 6G BRAINS**
Motion control	Closed-loop control applications in industry for example in printing machines, machine tools or packaging machines.
Motion control – transmission of non-real-time data	Examples are software/firmware updates or maintenance information parallel to highly-critical motion control data
Motion control – seamless integration with Industrial Ethernet	Not all sensors and actuators in a motion control system are connected using a 5G system, but a single motion control system could integrate components of a wire-bound Industrial Ethernet system and components of a 5G system.

Control-to-control communication (motion subsystems)	Communication between different industrial controllers in large machines (e.g., newspaper printing machines) or machines in an assembly line
Mobile control panels with safety functions	Used for configuring, monitoring, debugging, controlling and maintaining machines, robots, cranes or complete production lines and typically equipped with an emergency stop button and an “enabling device mode”
Mobile robots	Communication between mobile robots and guidance control system (e.g., for emergency stop), other mobile robots exchanging real-time control data and peripheral facilities to open and close doors or gates.
Augmented reality	Offloaded tracking and rendering by transmitting video stream from AR device to edge and receiving rendered video stream to display in AR device
Process automation closed-loop control	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.
Connectivity for the factory floor	Using a dedicated local type-b network for industrial automation for direct connection or via gateways
Inbound logistics for manufacturing	Heavy goods vehicles arrive at the receiving area of a factory and deliver pallets of material which are subsequently incorporated into the local factory inventory management system in an automated manner.
Variable message reliability	Information on system state or the "urgency" of the message or the desired reliability of the message transmission is used by the network to manage resources more efficiently by scheduling resources for each of the transmissions.
Flexible, modular assembly area	Modular production systems encompass a large number of increasingly mobile production assets, for which powerful wireless communication and localisation services are required.
Plug-and-produce for field devices	Reduce manual overhead to increase the flexibility and adaptability of production systems and to speed up the commissioning process. The field device may be an individual sensor or actuator, or a more complex production unit always complying with the automation system security requirements.

3.2 Relevant Use Cases in 5GAA

5GAA is a global, cross-industry organisation of companies from the automotive, technology, and telecommunications industries (ICT) that work together to develop end-to-end solutions for future mobility and transportation services [https://5gaa.org/].

The work on the use cases is the focus of Working Group 1 in 5GAA. The most relevant results of WG1 are presented in the Document "C-V2X Use Cases, Methodology, Examples and Service Level Requirements" [[4]]. 5GAA has identified the following groups of use cases:

- Safety
- Vehicle Operations Management
- Convenience
- Autonomous driving
- Platooning
- Traffic Efficiency and Environmental friendliness
- Society and Community

In Table 2Table 3, we present a brief overview of the most relevant use cases from 5GAA, which we identified from [59]. Out of the analysis of these use cases, we conclude several important facts:

- The description of different use cases is not unified over the document.
- The elements of the description are not alighted with the 3GPP use case description template.

6G BRAINS project is going to address the above shortcomings.

Table 3: Overview of the relevant 5GAA use cases

Use Cases	**Overview of the key aspects of the use case relevant for 6G BRAINS**
Cross-Traffic Left-Turn Assist	Automated vehicles are able to exchange awareness messages. No information about future trajectories is exchanged. Instead, a risk for collision is calculated based on the data collected in the past and present. A warning is displayed to the driver after the corresponding information exchange over the network.
Intersection Movement Assist	Two vehicles are approaching an intersection and exchange their current odometry information over the network. The vehicles determine the risk for a collision based on the vehicles' estimated trajectories.
Emergency Brake Warning	Host vehicle is moving at very high speed different from remote vehicle in a highly congested traffic scenario. The latter applies brake in order to make an emergency stop. Host vehicle is at distance D behind the remote vehicle and its driver does not see braking manoeuvre or is distracted. Communication between vehicles should help to increase the safety.
Traffic Jam Warning	Traffic jams ahead of host vehicle can be notified by ahead remote vehicles over the network. Multiple scenarios apply, e.g., urban, rural, highway, etc.

Tunnel Traffic	The vehicle is travelling inside a tunnel, which represents a challenge of connectivity and the network infrastructure must react and adapt to provide seamless connectivity.
Software Update	Software updates can be provided over an existing network connection. The software is downloaded securely and reliably, as coverage and bandwidth are available. Its transmission must not adversely affect any safety-critical or user experience-critical functions. Software installation is a separate process that occurs when safe and the controlling party conditions are met.
Remote Vehicle Health Monitoring	A vehicle is travelling on a highway and is losing air pressure in one or more of its tires. A road or fleet operator needs to be made aware of the situation over the corresponding information update through the network.
Hazardous Location Warning	This use case mainly refers to a real time map update service. The host vehicle is receiving information that is relevant for the road/route ahead from a backend, containing information that might allow the vehicle to adjust its route accordingly.
High-Definition Sensor Sharing	Sensors of nearby vehicles can exchange information over the network to increase the road awareness.
Lane Change Warning	To improve safety during lane change manoeuvres, information exchange between close vehicles can be used.
Vulnerable Road User	This use case describes a scenario, in which a presence warning at crossings and spots without line-of-sight, e.g., automatic detection of pedestrians waiting and/or crossing from infrastructure is intended. Such vulnerable users are watched via infrastructure support as surveillance cameras / wireless detection mechanisms and/or are equipped with mobile devices (UE). Awareness notifications are shared with drivers e.g., via roadside units / monitoring system attached to a 3GPP system sending messages to drivers or drivers systems monitor actively road users that are equipped with a device.

3.3 Relevant Use Cases in 5G-ACIA

5G-ACIA is the central global initiative for shaping 5G in the industrial domain. Here, various industries from all over the world discuss and create a new ICT and OT ecosystem and set the frameworks for a highly attractive emerging market [https://www.5g-acia.org/].

The work on the use cases is the focus of Working Group 1 in 5G-ACIA. The most relevant results of WG1 are presented in the Document “Key 5G Use Cases and Requirements” [[5]]. This document describes the following use case categories i.e. user stories:

- Connectivity for the factory floor
- Seamless integration of wired and wireless components for motion control
- Local control-to-control communication
- Remote control-to-control communication
- Mobile robots and automated guided vehicles (AGVs)
- Closed-loop control for process automation
- Remote monitoring for process automation

For each of the above user stories, a single or multiple use cases have been analyzed and presented in the document. These corresponding use cases are differentiated as “local” or “remote”. A “local” use case is restricted to a local area and is based on a 5G non-public network. A “remote” use case requires a combination of (multiple) non-public and/or public 5G networks that allow remote access.

In Table 2Table 3, we present a brief overview of the most relevant use cases from 5G-ACIA, which we identified from [59]. Out of the analysis of these use cases, we conclude several important facts:

- The description of different use cases is not unified over the document (similar as in 5GAA studies).
- The elements of the description are not aligned with the 3GPP use case description template.

6G BRAINS project is going to address the above shortcomings.

Table 4: Overview of the relevant 5G-ACIA use cases

Use Cases	**Overview of the key aspects of the use case relevant for 6G BRAINS**
Safety light curtain Machine layout planning	Connectivity is an important pre-requisite for many fixed-position or mobile devices on the factory floor such as drives, robots, machines, sensors like safety light curtains, actuators, screen terminals, and other systems that interact with each other and require fast and reliable connectivity. Wireless transmission can open new opportunities and greater flexibility by accommodating traffic for closed-loop control applications and eventually improving machine layouts. Safety is a key component on the factory floor. If safety-relevant components communicate wireless, ultra-high reliability is absolutely essential and response time is an extremely important parameter.
Body-chassis marriage in automobile manufacturing	As an example, for seamless integration of wired and wireless components for motion control, body-chassis joining process represents an emerging use case that can benefit from wireless communication. Due to very demanding performance requirements of motion control applications, ultra-reliable low latency and low jitter are essential.
Shuttles in a packaging machine	As examples of local control-to-control communication, these use cases can benefit from mobile communication in exchanging position or other control

Collaborative component handling	data via wireless transmission system. Such aspects like real-time communication between close components and high precision localization are the major aspects here.
Remotely controlled PCB assembly lines	Printed circuit board (PCB) assembly lines, operating autonomously, can be remotely controlled to implement product changes or to capture in-process data. Communication from a remote controller is required for the setting of parameters of various components/devices on the assembly line and can be implemented using wireless transmission system.
Mobile robots AGVs in a chemical plant	Mobile robots and autonomous guided vehicles (AGVs) represent mobile systems on a shop floor. Wireless communication is essential for such devices, as wired data transmission is not an option. A large range of communication use cases is associated with such devices. From simple file transfer to real-time control data exchange. Furthermore, such devices can carry various camera systems creating large video frames to be processed in a local or remote data centre.
Controlled conditions in a chemical reactor	As an example, for the closed-loop control in process automation, such components like pumps, valves, heaters, coolers, stirrers, etc. can be monitored continuously by sensors in order to keep conditions in the reactor within tight thresholds and use wireless transmission systems for reaching a new level of flexibility. Here, high availability and reliability of the networking technology are crucial.
Oil/gas field	This use case shows benefits of the remote monitoring in process automation by using data exchange for observation, diagnosis or monitoring of equipment distributed over a large geographical area. Wireless communication improves flexibility and implementation time of such use cases. Availability, reliability, security and energy efficiency in communication are essential aspects here.

The work in 5G-ACIA on the analysis of the use cases listed above concludes the most important technical requirements from industrial use cases. These include reliability and availability, security, transmission time (latency), diagnostics and network isolation.

4 6G BRAINS Enabling Use Cases / Technical Description

This chapter represents the most content-rich part of the document presenting our results of the analysis of seven use cases preselected from a larger list collected at the beginning of the Task 2.1. The full list is shown in Annex 0 As mentioned above, Industry of the Future has been selected as the main application sector for 6G BRAINS technologies and will be covered by five out of seven use cases. Two use cases have been merged to a single section since they share the same transport platform carrying the transmitter (Section 4.2).

At this point, we want to highlight that 6G BRAINS is not aiming to prepare a full-blown demonstration of any of the use cases listed below. However, many of the technological innovations from 6G BRAINS will be demonstrated without an integration in all-in-one demonstrator. Here, every work package (WP 3, 4, 5, and 6) creates its own local demonstration focusing on the aspects being under investigation in the corresponding package.

4.1 Offloading of the PLC Control Function to the Edge

A so called "factory of the future" represents one the most challenging applications of the future mobile communication systems. A large number of specific use cases representing this scenario have been described in different bodies including 3GPP and 5G-ACIA. From the vast list of specific "factory of the future" use cases, 6G BRAINS identified several, which require further improvement of the current 5G technology. The first use case is described in this section and represents the offloading of the control logic from the industrial controller running as part of a production cell on the shop floor to a more centralized computing area called "factory edge" in a virtualized form as a virtual machine or a container (see Figure 7).

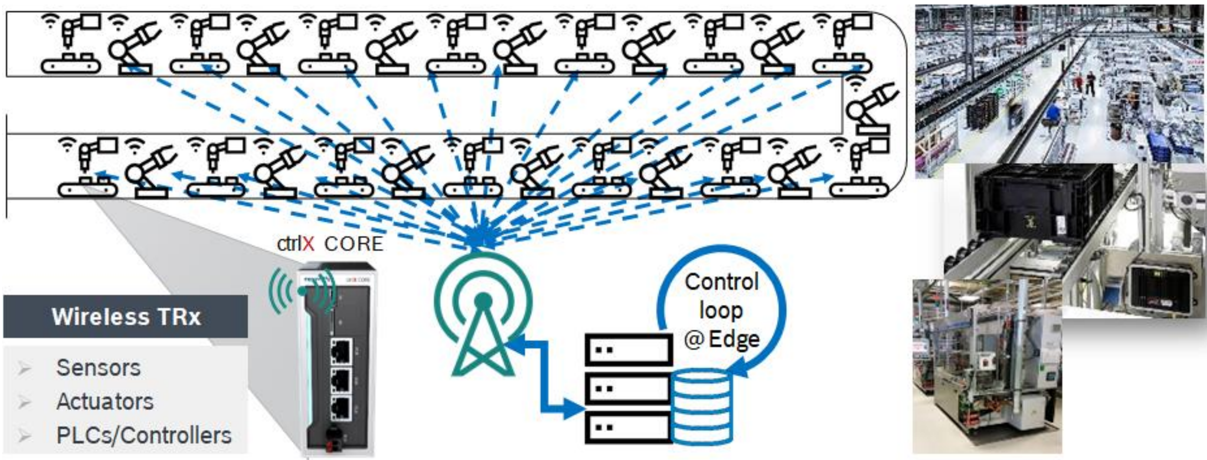

Figure 7: Offloading of a PLC control function to an edge computing node [Pictures: Bosch]

4.1.1 Description

Overview	
User story	Factory of the Future requires very high level of flexibility of the involved software and hardware components. For this, "soft" controllers running in a virtualized environment are going to replace solid and fixed machine controllers like PLCs. The communication networks between "soft"

	controllers and machine components get an important role in realization of the new control methods.
Use case	Offloading of the PLC control function to a neighbour data centre aka edge servers provides a lot of benefits for controlling the production process in a most flexible way. Such “soft” controllers can run as containers or virtual machines on a classical IT infrastructure. The communication between these “soft” controllers and the machine components requires high QoS provisioning. To enable the ease of product line modification, the communication should include wireless segments.
Storyline	A more centralized approach, where all controllers (real or virtualized) are placed in the same area will significantly increase the flexibility of the production process by introducing the possibility of seamless function update and reduce the cost (see Figure 7). Connecting the production cells through the 6G BRAINS communication system to the “factory edge” shall enable the ease of reconfiguration of hardware and software components on demand. This use case sets very high expectations on the guaranteed latency and deterministic communication that should support low industrial application cycle times and very precise synchronicity.
Goal/Aim	With this use case, we want to analyse the requirements on the transmission latency and jitter with respect to the current state of the art in communication between PLCs and machine components.
Main challenges	The current production machines do not allow wireless communication networks to be part of the control loop, because current wireless network technologies do not support very low latency and jitter required in bus systems. The majority of the PLCs in production support cycle times below 1 ms and expect jitter in data transmission as low as 100 ns or lower. Within a single cycle time, data exchange among hundreds of machine components. However, cabling is one of the most popular pain points in the production and costs a lot of effort.

4.1.2 Actors, Tools and Services

Actors, Tools & Services	
Actors and Stakeholders	• Production machine designer and developer • Plant owner that provides assignments, orders and commissioning • Product customer that defines the parameters of the product • Production machine operator
Databases	• Database for storing the customer orders

	• Database of production machine configurations (also in form of registry for storing container images)
Sensors	All kind of sensors (e.g., reed contacts) used in production cells; such sensors are part of the control loop and exchange data with the control entity over communication network.
AI/ML and other control loop algorithms	• Control loop functions, which run in a virtualized environment outside of the production cell, e.g., in a close edge cloud. • Production line orchestration and management functions that run in edge computing environment. • AI/ML algorithms for optimization of the network and compute resources in case of automated redesign of the production line to produce different products. • Fail-over methods to keep the required QoS of the network communication service.
Actuators	• All actuators (e.g., drives, rotors, robots, axes, etc.) that participate as slaves in the same bus system as the controller. • Production line orchestration agent • Network and compute resources optimization agent
Communication platform	• Communication platform must support ultra-low latency and jitter for data transmission and can include such technologies like THz, mmWave, sub-6 GHz, OWC, cell-free, IAB, etc. • The support of edge computing services like offloading of industrial controller functions must be part of the communication platform. • QoS must be provisioned by means of network slicing.

4.1.3 Execution

Execution	
Preconditions (inputs)	• Machine power is supplied and machine initialization process is finished. • Communication and compute platform is available.
Trigger	After the finalization of the initialization process, a production cell requests for a machine control function running in an edge compute node.
Service flow	After the service request reaches the production line orchestration agent, it bootstraps the required function on one of the available compute nodes and triggers the provisioning of the QoS for the upcoming data traffic among machine slaves and the control function by means of activating/updating the corresponding network slice. Fail-over mechanism can be triggered in case of packet losses or bit errors.

Post conditions (outcomes)	After the offloading of the control function stop operation, the network and compute resources must be relieved and reallocated to a different service in a short period of time.

4.1.4 Requirements

Requirements	
User requirements	• Optical and haptic feedback of the machine state during and after its initialization as well as during its operation • Low delay of service initialization • Machine must run safe and correspond to functional safety requirements from IEC 61508, ISO/IEC 17025 and ISO/IEC 17020
Functional architectural requirements	• All operational technology components belong into a safety and security critical zone of the production and have no direct connection to the outside world incl. Internet. • To enable high flexibility of the production process, virtualized control function must run on secure IT components with Internet connection. • The communication between the compute node that runs the control function and machine components is controlled by a firewall.
Technical KPIs	• Support of control cycle times between 250 μs and 10 ms • Ultra-low latency below 0.1 ms (E2E) • High reliability of the network service with packet error rate below 10^{-8} • Data rates up to 100 Mbps • Coverage in indoor environments within the factory facility • Low speed mobility support up to 1 m/s • Fail-over service within recovery time t = n x cycle time, where n ∈ [0,2] • High service availability of 99.999 % • Slice configuration/reconfiguration within 1 s
Relevant standards	• Communication networks: 3GPP 22.804, 3GPP 22.855 • Functional safety: IEC 61508, ISO/IEC 17025 and ISO/IEC 17020

4.2 Smart Transportation Vehicles: Localization and Video Processing Offloading

This use case describes a typical driverless transport system (DTS) scenario in production environments. In this document, we focus only on two important functions of DTS often referred to as automated guided vehicles (AGV):

- Video processing offloading from an AGV camera to the neighbour edge computing node (see Figure 8) with high requirements on data rate (>500 Mbps),

- Localization of an AGV in different scenarios with high requirements on accuracy for the localization (< 1cm).

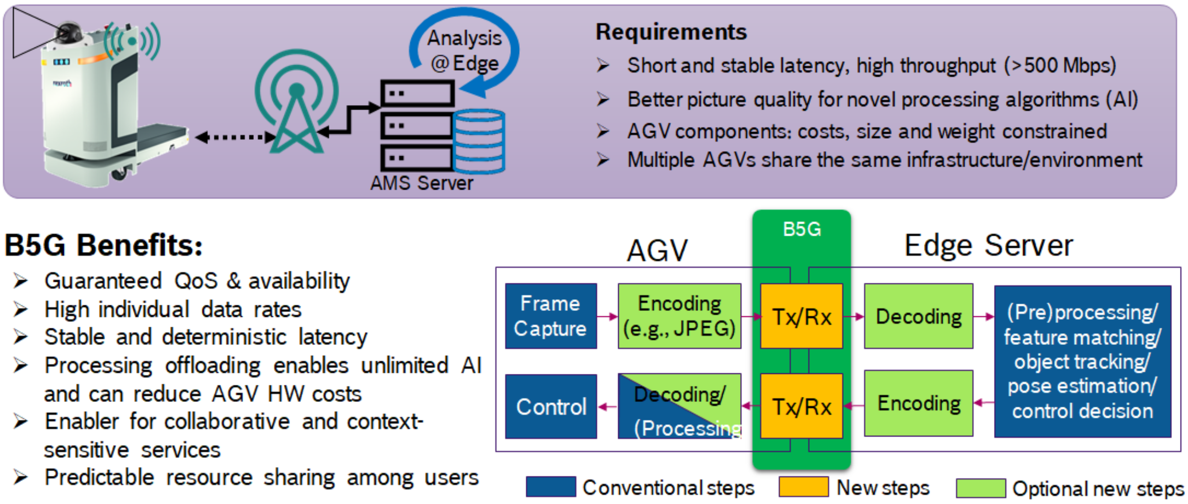

Figure 8: Video processing offloading from a smart transportation vehicle [Pictures: Bosch]

4.2.1 Description

Overview	
User story	In Factory of the Future, AGVs play an important role and take care of such tasks like driverless and autonomous transport of material and goods from and to production lines. They also can carry robot equipment (e.g., a robot or gripper arm) to flexibly support the assembly process.
Use case	In this use case, we focus on two important features of AGVs: • Video capturing using an on-board camera and video processing offloading to an edge computing node for object detection, • Autonomous navigation in indoor and outdoor environments. These functions require a wireless communication network for data transfer and localization purposes.
Storyline	An AGV fleet provides intra-logistic transportation and traversing in the factory. An AGV can also be part of an assembly process by picking and placing parts using a gripper arm with sensors mounted on the AGV. Wireless high-quality video cameras are easily deployed on mobile platforms like AGVs. The video from these cameras can be used to send high-quality and high frame rate video to an image analysing system located at the “factory edge”. By this, a new level of production monitoring is unleashed enabling a long list of new features such as accurate object detection and tracking around AGVs, anomaly detection on the shop floor, improved safety, process tracking and logging, etc. This use case has high requirements on the data rate consuming up to 3 Gbps per camera in case of state-of-the-art industrial camera systems (130 uncompressed HD frames per s: 130 x 1280 x

	720 x 24 = 2.8 Gbps). In this project, however, we consider lower data rate of up to 600 Mbps for only 30 frames per s (30 x 1280 x 720 x 24 = 632 Mbps). Since the compression is very time-consuming process, we consider an uncompressed video stream. With this use case, we want to analyse the requirements on the data rate and localization accuracy with respect to the current state of the art in driverless transportation systems.
Goal/Aim	With low initial and recurring effort, AGVs significantly improve factory efficiency.
Main challenges	• Ultra-high bandwidth (up to 3 Gbps) for video processing offloading • Ultra-high precision (1 cm and 1 degree) positioning for AGVs • 3D localization, i.e., position estimation of AGV, in radio multi-path shop floor environments • Position estimation with limited number of reference points Reliable connection to AGV (see Mobile robots use-case in 3GPP)

4.2.2 Actors, Tools and Services

Actors, Tools & Services	
Actors and Stakeholders	• Factory AGV Fleet manager (according to VDA 5050) • Network provider and operator • Factory owner • Production process manager
Databases	• Database for storing AGV fleet positions and job scheduling and logging • Database for storing results of the object detection and tracking mapped to the shop floor coordinate system
Sensors	• Video camera for capturing video frames of the environment around AGV • AGV accommodates sensors for safety reasons, e.g., to provide an anti-collision system
AI/ML and other control loop algorithms	• AI/ML-based object detection and tracking • Teach-in of docking and path navigation • Scheduling of AGV fleet • Redirection of AGVs in case of path blocking • AI/ML-based network scheduling for QoS provisioning
Actuators	• AGV motion control system and Motion Control Unit (MCU) • Production process orchestration agent

	• Factory AGV fleet job planning agent • Network optimization and QoS provisioning (based on network slicing) agent
Communication platform	• Communication platform must support ultra-low latency and jitter for data transmission and can include such technologies like THz, mmWave, sub-6 GHz, OWC, cell-free, IAB, localization, etc. • The support of edge computing services like offloading of video processing must be part of the communication platform. • QoS must be provisioned by means of network slicing.

4.2.3 Execution

Execution	
Preconditions (inputs)	• AGVs have enough power to operate • Communication, compute and localization platform is available and stable
Trigger	AGV fleet job planing agent triggers / schedules AGV to run a job.
Service flow	After receiving a request for a transport job, a fleet planning agent assigns a new job to an available AGV and informs the communication and compute system about new participant along with requirements for communication and localization functions. The network optimization and QoS provisioning agent assigns/modifies a corresponding network slice to provide the required QoS for time of the operation.
Post conditions (outcomes)	• AGV docks in home base. • Network optimization and QoS provisioning agent is informed about stop of the operation. • The network and compute resources must be relieved and reallocated to a different service in a short period of time.

4.2.4 Requirements

Requirements	
User requirements	• Optical and haptic feedback of the AGV state during and after its initialization as well as during and after its operation • Low delay of service initialization • Machine must run safely and correspond to functional safety requirements from IEC 61508, ISO/IEC 17025 and ISO/IEC 17020

	• System operates in “zero-touch” mode after teach-in: AGV switched on and is triggered to “go” by fleet management agent based on Enterprise Resource Planning System
Functional architectural requirements	• All operational technology components belong to a safety and security critical zone of the production and have no direct connection to the outside world incl. Internet. • To enable high flexibility of the production process, video processing functions must run on secure IT components with Internet connection. • The communication between the compute node that runs the video processing function and AGVs is controlled by a firewall.
Technical KPIs	• Low latency for video frame transmission from AGV towards edge compute node below 33 ms • High reliability of the network service with packet error rate below 10^{-6} • Data rates up to 600 Mbps for multiple AGV (10 AGVs for 10000 m^2) • Coverage in indoor environments within the factory facility • Medium speed mobility support up to 10 m/s • Fail-over service within recovery time t = 100 ms • High service availability of 99.999 % • Slice configuration/reconfiguration within 1 s • Localization accuracy during navigation/traversing: 2 cm • Localization accuracy during docking in supply area for on- or offload: 1 cm • Localization accuracy during AGV operation as part of assembly process: 5 mm
Relevant standards	• Communication networks: 3GPP 22.804, 3GPP 22.855 • Functional safety: IEC 61508, ISO/IEC 17025 and ISO/IEC 17020 • EU machinery directive 2006/42/EC • **Error! Hyperlink reference not valid.**

4.3 Maintenance Video Guides in Factories and Warehouses

4.3.1 Description

Overview	
User story	Video guides for facilitating maintenance of equipment and graphics superposed on Augmented Reality field of view of factory or warehouse scene for location of electric, gas and pneumatic facilities.
Use case	Main innovation is for accurate location (close to 1 cm) and orientation (1 degree) every 20 ms of augmented reality glasses, which would allow its use

	throughout the factory or warehouse with the graphics superposed in the right location in its field of view. H264 encoded HDTV resolution video (~3M bits/sec) is required for presentation of instructional videos of maintenance guides. Hands free navigation of user interface for access to data requires voice activated commands to be used by technician. Video recording of maintenance operations for storage on database by maintenance staff for future reference and access.
Storyline	Maintenance supervisor arrives at the factory and requests information on scheduled maintenance operations using voice commands. The information may be presented in two ways, the first using infographics in an overlay manner over the respective equipment, and the second using traditional lists and tables similar to a PC display. Additionally, (s)he may request the maintenance team assignments and edit them as (s)he sees fit. Next, the maintenance technician is assigned to repair some equipment that (s)he is unfamiliar with. Augmented Reality glasses display video guides for the technician to perform test procedures to diagnose possible equipment failures and video instructions on how to repair it. Through the voice assistant, (s)he may interface with specific maintenance software running on a local or centralized DC, enabling the technician to update maintenance information or to request additional operations pertaining the maintenance procedures. Maintenance technician works on electric, gas and pneumatic facilities whose location is hidden from view within conduits behind walls or embedded within floor ducting. Augmented Reality glasses present graphic guides that help the technician to locate electric, gas and pneumatic installations. The motivation is for more efficient operation of existing technicians and training of new technicians by producing and making video guides more readily available.
Goal/Aim	Hands free use of Augmented Reality glasses anywhere in a factory or warehouse with the location of the headset to an accuracy of 1 mm to 1 cm. 5G broadband access anywhere in the factory or warehouse for supporting downlink and uplink video streaming.
Main challenges	Current solution for Augmented reality glasses / Virtual Reality headsets use beacons to identify their location, which is restricted to their coverage area (usually about 5m x 5m) of the beacons. The use of 5G within factories and warehouses would mean that the location and orientation of user equipment will be available to use anywhere within 5G network coverage area. This is needed to correctly position graphics within the physical environment and provide access to the HDTV video and graphics for the AR maintenance guides.

	Current solutions do not integrate voice recognition to provide hands free operation of the maintenance guide and do not have access across the whole factory or warehouse coverage area for location and streaming data access.

4.3.2 Actors, Tools and Services

Actors, Tools & Services	
Actors and Stakeholders	Maintenance Supervisors and Technicians to use video maintenance manuals and infographics regarding equipment status and maintenance history, equipment manufacturers to produce video maintenance manuals and software.
Databases	Database of video maintenance guides. Database of gas, water, electric and pneumatic resources within factory or warehouse. Database of materials used for the production as well as products and their current location in a supermarket or warehouse.
Sensors	Hands free operated Augmented Reality user interface.
AI/ML and other control loop algorithms	Machine Learning required for potential location data fusion of distance measurements obtained from mmWave radio, Optical Wireless Communications IR and THz access points to produce location of object.
Actuators	Voice recognition system for voice activated computer commands.
Communication platform	OWC, mmWave and THz access points.

4.3.3 Execution

Execution	
Preconditions (inputs)	Operational 5G network within factory or warehouse with user equipment location to within 1mm to 1cm accuracy. Hand free navigation of Augmented Reality user interface.
Trigger	Maintenance technician initiating an AR maintenance session by accessing app.

Service flow	Initiate AR maintenance session by accessing app, specify type of equipment and fault symptoms to view and access from database, view video of equipment with pausing and/or rewinding if required using voice commands. Initiate AR maintenance session by accessing app, specify type of infrastructure and fault symptoms to view and access from database, view graphics of infrastructure correctly overlaid onto screen and use voice commands to change types of infrastructure. During maintenance session, enable access to an interface with virtualized software regarding maintenance systems, equipment control software or other relevant software systems.
Post conditions (outcomes)	Upload record of maintenance procedure videos on database and voice key words for hash searches. Update any modifications/enhancements to gas, water, electricity, pneumatics infrastructure after completion of a maintenance job on graphics of infrastructure.

4.3.4 Requirements

Requirements	
User requirements	Hands free use with voice commands to navigate user interface, option of equipment maintenance or factory or warehouse gas, water, electric, pneumatics infrastructure, pause and/or rewind on voice command, store HDTV video of session on database on voice command.
Functional architectural requirements	Voice to text recognition system to navigate computer user interface, to interface with virtualized software and access/store video and/or graphics data on database. 1mm to 1cm location and 1 degree orientation accuracy for superposing graphics onto correct location on visual field of view.
Technical KPIs	1mm to 1cm location and 1 degree orientation accuracy Coverage of whole factory or warehouse floorspace Broadband 3 Mbit/s video streaming
Relevant standards	3GPP 22.804, 22.855

4.4 Advanced Network Slicing

The use cases discussed above represent mostly a single type of traffic. However, customers tend to co-locate multiple use cases in the same environment that need to share the resources of the communication system. In case of industrial manufacturing, the requirements of separate use cases may be almost orthogonal to each other (e.g., highly deterministic traffic of small data packets, or non-deterministic traffic of large data packets as shown in Figure 9). This represents a new challenge scenario, which accommodates heterogeneous traffic types and is presented below in this section.

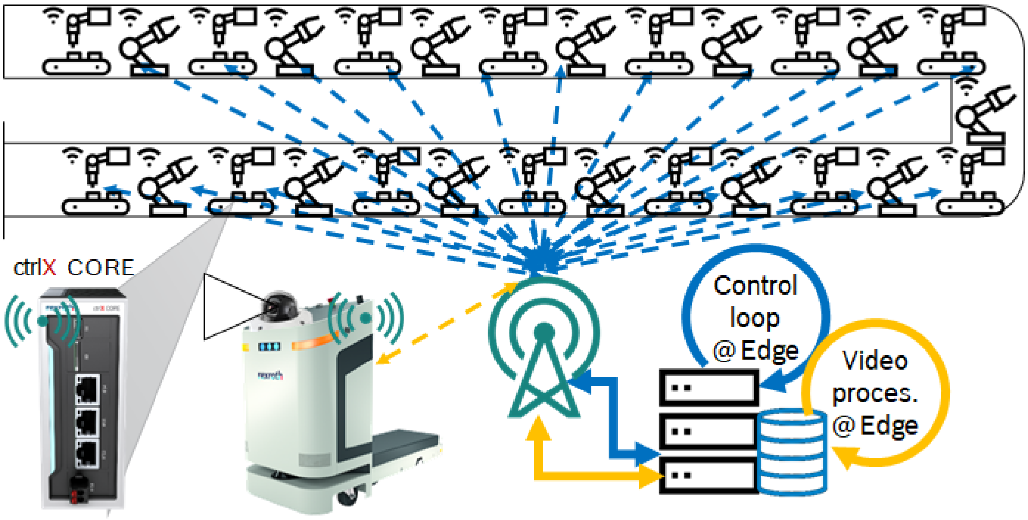

Figure 9: Example of a combination of two use cases with heterogeneous traffic types [Pictures: Bosch]

4.4.1 Description

Overview	
User story	Advanced network slicing addresses the highly dynamic and heterogeneous traffic control with controlled or guaranteed QoS in real time for the Factory of the Future.
Use case	Advanced network slicing provides E2E customizable service and controlled or guaranteed QoS for different user traffic of divergent requirements; it enables highly flexible definition of network slices of various granularity levels and does this on demand without needing a pre-definition; it supports rapid network slice instantiation as fast as about a second to be highly available for service creation, deployment and reconfiguration; it allows intent-based network slicing management, greatly facilitating the management tasks in a complex industrial environment, and guarantees the corresponding QoS for independent traffic flows.
Storyline	Advanced network slicing addresses the challenges in service customization and traffic control in compliant to the SLAs in complex industrial operational environments. It is thus demanded in the context of either a use case that features such requirements or for a combination of different use cases, as described in Sections 4.1, 4.2 and 4.3, which represent a very challenging approach for a system that is required to provide a precise QoS differentiation by creating individual slices for each of the required services. In particular, two network slices can be created and managed to support the

	edge offloading for machine control and video respectively. The vertical will order the two slices with QoS/SLA requirements through an intelligent virtual assistant, which discards the need for technological jargon focusing instead on user requirements. Afterward, the virtual assistant maps the user intents into a technical specification that is forwarded to the 6G BRAINS system, which the latter will use to define, create and deploy these two slices rapidly. Then in response to different dynamic scenarios, various advanced network slicing technologies can be triggered, such as AI RAN slicing, directional RAN slicing, high-speed backbone slicing, etc. to maintain or optimise the committed QoS/SLA.
Goal/Aim	The main objectives and targeted outcomes of this use case are to showcase the advanced network slicing technologies developed in this project in addressing the challenges of service customization and provisioning for dynamic and complex industrial use cases. Additionally, the intent-based interface through the virtual assistant will be validated as a mechanism to ease the adoption of novel telecommunication technologies by industrial stakeholders who sometimes lack the expertise to take full advantage of these.
Main challenges	The technical gaps in the current solutions include the following: • Lack of flexible on-demand network slice definition mechanism that is suitable for complex industrial traffic control; • Lack of network traffic controllers that are able to achieve the network slicing over industrial application traffic using industrial networking protocols; • Lack of intuitive and efficient user interface for network slicing subscription and instantiation, among other management tasks; • Lack of online learning capabilities for real-time RAN slicing in order to maximise the usage of the precious wireless resources; • Lack of real-time high-speed backbone network slicing to cope with the increasing aggregated traffic load in the non-RAN segments of the E2E data path; • Lack of integration of the various network slicing enablers to achieve E2E network slice control, management and orchestration.

4.4.2 Actors, Tools and Services

Actors, Tools & Services	
Actors and Stakeholders	Vertical end user, network slice service provider, 6G network operator and infrastructure manager.
Databases	Databases for ML operations and E2E network slice management, etc.

Sensors	Video cameras for industrial use case (production line monitoring), network segment slicing monitoring and control tools (built-in monitoring capabilities in controllers, controller Apps, etc.), and ML reward monitoring for reinforcement learning.
AI/ML and other control loop algorithms	Reinforcement learning based RAN slicing algorithms and closed control loops for both inter-slice and intra-slice cases.
Actuators	Network segment specific controllers to enforce network slicing actions, MANO actions for resource management etc.
Communication platform	E2E platform comprising cross-domain industrial segment, RAN/IAB, edge computing and services (industrial IoT controller), transport network, and core network, based on an evolved OAI and Mosaic platform towards 6G.

4.4.3 Execution

Execution	
Preconditions (inputs)	6G BRAINS network slicing subsystem is up and running; Industrial segment is up and running, with the involved devices and services deployed and operating.
Trigger	First trigger: A vertical user starts to subscribe to the network slicing subsystem in the 6G BRAINS framework. Subsequent triggers: dynamic scenarios to trigger corresponding advanced solutions (refer to the service flow below).
Service flow	1. First trigger: Network slice service subscription by a vertical user through the voice-controlled user interface. 2. Network slice definition and creation/instantiation through intent-based management and control. 3. Network slice instances are up and running end to end. 4. Trigger: intra-slicing issue. 5. Response: intra-slicing AI control loop solution. 6. Trigger: inter-slicing issue. 7. Response: inter-slicing AI control loop solution. 8. Trigger: UE out of range. 9. Response: directional RAN slicing solution. 10. Trigger: backbone slicing issue. 11. Response: hybrid backbone slicing solution.

Post conditions (outcomes)	The issues that trigger the responses are resolved, and the committed QoS/SLAs are fulfilled.

4.4.4 Requirements

Requirements	
User requirements	• Usability: easy and self-explanatory UI to the slice triggering service • Feedback: haptic mechanisms are present to provide immediate feedback to user requests (the system visualizes the execution progress as soon as user triggers a service) • Time from the user request and slice becomes operational is limited to 1 s
Functional architectural requirements	• Closed control loop for AI-based RAN slicing; • High-speed backbone slicing; • Network segment specific network slicing controllers and monitoring capabilities; • Intent-based network slicing management; • Cross-domain consideration for industrial segment integration and management.
Technical KPIs	• Network slice service creation/deployment/reconfiguration time. • Improved service performance (AI RAN slicing). • Enlarged service coverage (directional RAN slicing). • High-speed backbone slicing.
Relevant standards	3GPP 22.804, 22.855, ITU-T Y.ML-IMT2020-E2E-MGMT, ITU-T Y.ML-IMT2020-VNS etc.

4.5 Animal Tracking in Indoor Farming Scenarios

4.5.1 Description

Overview	
User story	Animals such as cows, pigs and chickens wear collars that monitors animal's well-being and health and if contraventions occur to animal welfare regulations, regulatory bodies are immediately notified. Augmented Reality glasses guide farmer to individual animals if they require attention.
Use case	Main innovation is for all farm animals to wear collar that monitors their well-being (e.g., position, how much movement they perform, how much time is

	spent outdoors and indoors) and health (e.g., body temperature, oestrus cycle, audio from animal). Accurate location (1cm) and orientation (1 degree) every 200ms allows monitoring of the mobility of the animals. Sensing data of the animals' health data is monitored every 1 minute.
Storyline	Animals being reared in intensive farming sheds are monitored using IoT sensors. Monitoring data is transmitted to Multiaccess Edge Computer where an AI software processes the mobility and health data of the animal to assess its well-being and health. Augmented Reality glasses presents graphic guides to the farmer to help him/her to locate the animal that has been identified as having issues. The motivation is for more efficient operation of farmers to look after the well-being and health of their animals which can be reported to regulatory bodies to assess compliance with animal well fare regulations.
Goal/Aim	Hands free use of Augmented Reality glasses anywhere in a farming shed with the location of the headset to an accuracy of 1 cm to 1mm. 5G broadband access anywhere in the farming shed to monitor the health, location and well-being of large numbers of animals.
Main challenges	Current solution for Augmented reality glasses / Virtual Reality headsets use beacons to identify their location, which is restricted to the coverage area (usually about 5m x 5m) of the beacons. Use of 5G within farming sheds' location and orientation of user equipment will be available to use anywhere within 5G network coverage area. This is needed to correctly position graphics within the physical environment and provide access to the HDTV video and graphics for the AR maintenance guides. Current intensive farming solutions do not integrate IoT sensors on animals to monitor their health, well-being and position. 5G solution would provide access to IoT data from a large number of animals.

4.5.2 Actors, Tools and Services

Actors, Tools & Services	
Actors and Stakeholders	Farmer to add IoT collar to animal, to monitor its health and well-being using AI analysis and to use Augmented Reality glasses to identify animal in distress.
Databases	Data of animals' mobility and health status.

Sensors	IoT sensors on animal: mobility, body temperature, oestrus cycle, audio from animal. Augmented Reality glasses for farmer to help identify location of animal in distress.
AI/ML and other control loop algorithms	Machine Learning required for potential location data fusion of distance measurements obtained from mmWave radio, Optical Wireless Communications IR and THz access points. AI required for identification of animal health.
Actuators	None
Communication platform	OWC, mmWave and THz access points.

4.5.3 Execution

Execution	
Preconditions (inputs)	Operational 5G network within farming shed with animal location to within 1cm accuracy and Augmented Reality Glasses accuracy within 1mm to 1cm accuracy Hand free navigation of Augmented Reality user interface.
Trigger	Animal monitoring system notifying farmer of likely distress state of animal.
Service flow	Animal monitoring system notifying farmer of likely distress state of animal and identification of the distressed animal so that the farmer can find it with the help of augmented reality glasses.
Post conditions (outcomes)	Upload record of animal health on regulatory body database and voice key words for hash searches.

4.5.4 Requirements

Requirements	
User requirements	Hands free use with voice commands to navigate user interface, option of identification of position of distressed animals or of any animal in database required for inspection IoT monitoring of up to 10,000 to 20,000 animals in a single farming shed, with 10 to 20 chickens per square meter.

Functional architectural requirements	Voice to text recognition system to navigate computer user interface and access/store video and/or graphics data on database. 1mm to 1cm location and 1 degree orientation accuracy for superposing graphics onto correct location on visual field of view.
Technical KPIs	1mm to 1cm location and 1 degree orientation accuracy for Augmented Reality glasses and 1cm accuracy for location of animal. Coverage of whole factory shed floorspace broadband for Massive Machine Type Communications (mMTC) of IoT data from 10 to 20 thousand animals.
Relevant standards	3GPP 22.804, 22.855

4.6 Airports Service and Baggage Handling Robots

This section describes the usage of mobile robots in airports as seen in the following sub-sections.

4.6.1 Description

Overview	
User story	We consider the following two application scenarios for mobile robots in airports: • Service robots in airports for answering passenger questions and for physically guiding passengers through airport. • Automated Guided Vehicle (AGV) robots for carrying passenger luggage between baggage handing conveyor belt locations in airport.
Use case	The main aspects of the use case are: • Accurate location (1 mm - 1 cm) every 20 ms for guiding the service robots and AGVs using path planning throughout the airport. • H264 encoded HDTV resolution video (~3 Mbits/sec) is required for presentation of instructional videos to passengers. • Natural language processing (NLP) of passenger questions and voice synthesized responses to passenger questions using a voice-based virtual assistance. • Video and/or Lidar live streaming of objects in path of service robots and AGVs in order to perform object recognition and collision avoidance of objects in their path.
Storyline	Service robots combined with voice-based virtual assistants recognize and translate speech and synthesizes answers in different languages. Passenger arrives at an airport that (s)he is unfamiliar with. Service Robot presents answers to questions using synthesized speech and helps passenger with

	video guides to direct the passenger depending what question was asked (e.g., where are the check-in desks for British Airways? where can I find help for carrying my luggage? where can I buy a present for my children?). The Service Robot then optionally accompanies passengers to their destination avoiding objects in its path using object recognition and avoidance system. Moreover, if available, the service robot is also able to use the integrated virtual assistant to request services that are available through an API, e.g., request a taxi or call for medical assistance. Passenger arrives at an airport with a lot of luggage. An AGV takes luggage that has just been self-checked in and carries it to the right conveyor belt for it to be transported to the destination aircraft producing an automated and sustainable baggage sorting system with minimal amount of baggage handling staff. The motivation is for an AGV system to be controlled by 1 cm to 1 mm location accuracy system, which means that the configuration of the routes that the AGV can take is the most flexible and not dependent on fixed location beacons for guiding the AGVs.
Goal/Aim	• Service Robots that are able to answer questions posed to it and also guide passengers to their destination without colliding with objects on its route. • AGVs that are able to sort baggage in the passenger and baggage areas by automatically transferring baggage from one conveyor belt to another. • The integrated virtual assistant may provide voice-based access to airport services or third-party services.
Main challenges	Current solution for advising passengers is through an Inquiry Desk, which can become quickly overwhelmed particularly when an emergency situation occurs in the airport. Use of 5G controlled service robots means that passenger questions can be answered and passengers guided to the destination autonomously. This would provide a sustainable solution that can more easily cope with emergency situations. Current solution for baggage handling uses manual labour, which can be slow and inconsistent. A 5G automated baggage handling system using AGVs means faster and more reliably consistent handling of baggage as well as more easily reconfigurable baggage handling between conveyor belts.

4.6.2 Actors, Tools and Services

Actors, Tools & Services	
Actors and	• Passengers to ask Service Robots for guidance.

Stakeholders	• Passengers dropping off baggage in self-check-in kiosk. • Baggage Handling Managers to configure baggage sorting assignments.
Databases	• Database of video guides for passengers, routes to requested passenger destinations. • Database of baggage handling configurations depending on which flight departures/arrivals occur at which gates.
Sensors	Cameras and Lidar for Service Robots and AGVs operating in passenger area for object collision avoidance.
AI/ML and other control loop algorithms	• Machine Learning is required for potential location data fusion of distance measurements obtained from mmWave radio, Optical Wireless Communications IR and THz access points. • AI for object recognition and collision avoidance. • AI for destination route planning.
Actuators	• Motors on the Service Robots and AGVs. • Mini conveyor belt on AGV to transfer baggage to/from baggage conveyor belts. • Speech recognition and synthesis systems via an integrated virtual assistant on the Service Robots.
Communication platform	OWC, mmWave and THz access points.

4.6.3 Execution

Execution	
Preconditions (inputs)	Operational 5G/B5G network within airport with Service Robots and AGVs localized within 1 mm to 1 cm accuracy.
Trigger	• Passenger posing questions to service robot or requesting a service through the integrated virtual assistant. • Passengers check in at self-check-in kiosk and AGVs handle their baggage by transporting them to the correct conveyor belt. • Baggage handling manager configuring new baggage sorting assignments.
Service flow	Passenger initiates service session by asking questions to the Service Robot. Service Robot responds by producing answer to passenger’s questions. Service Robot can accompany passengers to their destination (e.g., gate, toilet, shop, restaurant, etc.) if requested and then return to its original location for serving further newly arrived passengers.

	Passenger arrives at the destination airport and requests a taxi service through the virtual assistant. The service robot leads the passenger to the taxi pickup location. Passenger initiates a baggage handling task by checking-in baggage at self-check-in area. AGV takes passenger luggage and transfers it to the correct baggage conveyor belt. Baggage handling manager configures new baggage sorting assignments for AGVs to sort baggage in the passenger area or in the baggage handling area.
Post conditions (outcomes)	Upload a record of service operation on database and input key words for hash searches.

4.6.4 Requirements

Requirements	
User requirements	The following features are expected: • Interaction with service robots through speech by asking questions and receiving answers in the form of synthesized voice replies or video instructions. • Provisioning of direction to requested destination within airport and according escort by Service Robot. • Baggage transport service: Passenger checks in baggage at self check-in kiosk and deposits baggage on AGV once ticket has been issued. AGV looks after baggage by taking them to the correct conveyor belt. Alternatively, Baggage Handling Manager configures baggage handling assignment for baggage handling AGVs depending on which gate flights have arrived or will depart. Note, the latter task can also be performed automatically.
Functional architectural requirements	• Voice recognition system using NLP at Service Robot that captures passenger's questions, parses them and finds appropriate answer from a database. • Text to speech synthesizer to voice answer from database to passenger. • 1 mm to 1 cm location and 1 degree orientation accuracy for navigating Service Robot and AGVs to their correct destinations.
Technical KPIs	• 1 mm to 1 cm location and 1 degree orientation accuracy • Coverage of whole airport floorspace • Broadband 3 Mbit/s video streaming
Relevant standards	3GPP 22.804, 22.855

5 Consolidated Requirements

In this chapter, we present the summary of the requirements.

5.1 Overview of the Key Requirements

Below, we list an overview of the key requirements as a result of the use case analysis based on the previous chapter.

Table 5: Overview of the key requirements

	Offloading of the PLC Control Function to the Edge	Smart Transportation Vehicles		Maintenance Video Guides	Advanced Network Slicing	Animal Tracking in Indoor Farming Scenarios	Airports Service and Baggage Handling Robots
		Localization	Video Processing Offloading				
Round trip time (sensor to controller to actuator)	< 10 ms (250 µs - 10 ms)	50 ms	50 ms	>50ms	5-15ms	>50 ms to seconds	10 ms
Reliability (packet error rate within latency reqs.)	10^{-8}	10^{-6}	10^{-4}	10^{-2}	10^{-6}	10^{-5}	10^{-6}
Data rate	kbit/s-Mbit/s	kbit/s-Mbit/s	Mbit/s-Gbit/s	kbit/s-Mbit/s	kbit/s-Mbit/s; 10+Gbps at backbone	kbit/s	Mbit/s-Gbit/s
Packet size	up to 1500 Byte	20-50 Byte	1500 Byte	<300 Byte	<300 Byte	<80 Byte	>200 Byte
Covered distance (from an access point)	within the facility	within the facility	within the facility	<200 m	within the facility	100 m-1 km	<100 m
Movement speed of the user	< 1 m/s	<10 m/s	<10 m/s	<40 m/s	< 10 m/s	< 10 m/s	< 3 m/s

Time critical handover support	Yes	Yes	Yes	No	Yes	No	No
User equipment density	0.33-3 per m^2	0.001 per m^2	0.001 per m^2	0.1 per m^2	0.3 per m^2	10000 per plant	0.03-0.02 per m^2
Energy efficiency (user equipment battery lifetime)	n/a	n/a	n/a	n/a	< 8h	1 years	1 day
Location detection accuracy	<50 cm	1 cm	n/a	<1 cm	<5 cm	from 1 mm to <10 cm	< 1 cm
Service availability	99.999 %	99.999 %	99.999 %	99.9 %	99.999 %	99.9 %	99.9 %
Slice configuration / reconfiguration time	1 s	1 s	1 s	1 s	1 s	1 s	1 s

The following is a concluded list of the key performance indicators as a result of the use case analysis in 6G BRAINS:

- Capacity: Selected if the UC requires broadband capacity due to streaming video or downloading large amount of information in a short period of time;
- Latency: Selected if the UC requires interactive conversational communications;
- Data rate:
- Localization accuracy
- Slice establishment and maintenance

[Disclaimer] At this point, we want to highlight that the presented values show the result of our use case analysis. These values indicate the user expectations and do not represent a commitment for the outcomes of the 6G BRAINS project.

5.2 Wider General User Concerns

Based on the project approach described in Section 1.2, more wider concerns and requirements towards an industrial ICT infrastructure are derived from the presented use cases. Although these concerns do not have a direct impact on the technological aspects of 6G BRAINS work items, they represent an important set of boundary conditions and will only be partially addressed in 6G BRAINS project (e.g., blockchain-based security method in Work Package 6).

5.2.1 Security

Industry 4.0 enables a simpler networked production and maintenance through a coherent communication architecture, which has an enormous impact on the economy, efficiency and flexibility of the entire production chain. In principle, Industry 4.0 implies cross-company networking at all levels of traditional production, so machines, products, system components, and processes communicate beyond company boundaries. Flexibility in the design and arrangement of components for production purposes represents simultaneously a great benefit and a great challenge.

Moreover, IT security risks arise from the far-reaching networking of production in the context of Industry 4.0, leading to a wealth of new and highly complex security requirements. The number of possible weaknesses increase because, apart from remote attacks on the systems, attacks by physical access have also to be considered. For example, whilst remote access facilitates the maintenance and control of systems enormously, it requires a higher level of security in order to prevent system manipulations. Since we cannot eliminate threats completely, the goal must be to reduce them to an acceptable level. Security techniques are continually improved, but the attack tactics are becoming more and more sophisticated as well.

In summary, it can be said that concerning secure connectivity requirements in the production and office area, the protection of data with regard to

- privacy,
- integrity and authenticity,
- proof of data authorship,
- non-repudiation of the receipt of data, and
- availability must be ensured.

This requires the possibility of a clear assessment and classification for IT security. Cyber-Physical Systems are the essential building blocks for making the visions of an Internet of Things and the industrial Internet a new reality. Different physical objects of varying size and complexity are equipped with sensors and connected to other systems over the Internet. Such a broad diversity requires a correspondingly wide range of security solutions, which in turn can only be achieved through high modularity and scalability.

5.2.2 Dependability

Distributed automation functions need to exchange messages with one another. Transport properties are in focus such as length of the messages to be transmitted, capacity of a communication channel, and timeliness of the message arrival at the target automation function. A concern in automation is to guarantee and maintain a high dependability of the production system. The traditionally, dependable distributed automation functions rely on dependable communication. Dependability is intimately related to the productivity and safety of the automation system. The productivity of the system is characterized by aid of three properties:

- Availability: continuity of correct operation
- Maintainability: ability to undergo modifications and repairs
- Reliability: continuity of correct operation

5.2.3 Wide Range of Performance Needs

The Factory of the Future domain is a very heterogeneous environment, where different parallel existing use cases and corresponding performance needs towards the ICT infrastructure coexist. The challenge of the future will be that the communication among devices/machines/robots for different use cases will be done with different technologies or communication techniques considering sometimes orthogonal priorities/criticality QoS.

Use cases such as video monitoring or PLC offloading have different requirements for the communication. Many of those use cases are today supported with proprietary solutions. With the trend of digitalization and industrial IoT, the complexity of having multiple systems will pose a barrier for adoption. A perfect ICT system would be able to support multiple scenarios and a wide range of performance spectrum, either by modular architecture or software definable features.

The idea of having a standalone in-house ICT solution is changing. Mixed- or hybrid solutions between private and public become increasingly feasible for commercial use, for example, private and public cloud infrastructure or private and public wireless network coverage. Seamless interworking allows the flexibility to deal with the different performance needs.

6 Summary of the Findings

6G BRAINS followed the vision that BOSCH has set out for a B5G-enabled industrial network focusing on the **Factory of the Future** use case, in which every part of the production environment is fluid, except for the walls and ceilings. This vision was adopted also for the other 6G BRAINS primary uses cases such as: **smart transportation and mobility**, **smart agriculture** and **airports services**.

Summarizing, industrial machines, devices, and vehicles will be made mobile by 5G or B5G and made intelligent by edge and cloud-based analytics, enabling factory owners to change their production lines according to demand in a short period of time. The massive connected IoT solution is envisioned to be one of the most promising drivers for many of the emerging use cases, including industrial automation as a means to deploy reconfigurable production systems, which can be torn up and down according to real-time demand. 6G BRAINS solution should also have very few fixed elements, and even these elements must be intelligent. The building being static must become flexible. Every piece of equipment in these new plants should have a possibility to become wireless, and be mapped as a digital twin with the high-resolution radio-light 3D SLAM. AI-enabled Non-Public Network (NPN) slicing for 6G BRAINS networks should liberate factories from their fixed production lines. The MEC (multi-access edge computing) of 6G BRAINS should organize retrofitted connectivity and enable analytical applications like predictive maintenance even in old machines. The multi-agent DRL framework of this project should bring real-time intelligence and orchestration capabilities to help humans handle more changeable production routines. The Cell-Free Network Architecture should increase the reliability of the communication to the end devices (e.g., sensors and machines) and drastically reduce the latency by eliminating the handover delay. Novel techniques mentioned in this document should be analyzed and considered for the development to become a part of B5G and future 6G networks: e.g., Grant-free Non-Orthogonal Multiple Access (GF-NOMA) over cell-free massive MIMO with underlaid D2D clusters, optimization of content placement in edge caches aiming at low delay and traffic offloading, user-centric interfaces enabling intent-based networking, new radio waveforms incl. THz and OWC and evolved E2E directional network slicing management and orchestration (DNS MANO).

Reviewing the most challenging requirements, we identified the flexible production facility use case. It demands very high requirements on latency, communication service availability, and determinism. This application assumes simultaneous transmission of non-real time data, real-time streaming data (video) and highly critical, real-time control data. The latter involves very high requirements in terms of latency (0.1 ms E2E latency) and communication service availability over the same link and to the same device. Enhanced coverage in indoor (from basement to roof), outdoor (plant/factory wide) and indoor/ outdoor environment is needed due to mobility of the industrial components, e.g., smart transportation vehicles. 6G BRAINS must 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.

The main findings of our analysis regarding the Cellular Network KPIs requirements for the variety of use cases considered by the 6G BRAINS team are listed in Table 5 above. It is clearly understood that there is a big spread of parameters requirements for various use cases, but it looks like that if a low cost and secure solution can be developed, which meets the following minimum requirements (see Table 6), it will fit most of the use cases.

Table 6: Summarized key requirements

KPI	Minimum requirements
Round trip time (sensor to controller to actuator)	0.1 ms
Reliability (packet error rate within latency requirements)	10^{-6}
Data rate	Gbit/sec
Packet size	up to 1500 Bytes
Covered distance (from an access point)	200 m
Movement speed of the user	< 10 m/s
Time critical handover support	Yes
User equipment density combining all use cases	1 per m^2
Energy efficiency (user equipment battery lifetime)	1 day
Location detection accuracy	<1 cm
Service availability	99.999 %
Slice configuration / reconfiguration time	1 sec

The values in Table 6 show a summary of our use case analysis. These values indicate the user expectations and do not represent a commitment for the outcomes of the 6G BRAINS project. However, all work packages in this project use the results from the use case analysis making the first step towards meeting these requirements by development of the key building blocks like novel architecture design, integration of new transmission techniques like THz and OWC, new management and orchestration methods based of AI/ML, etc.

Next, we want to highlight that 6G BRAINS is not aiming to prepare a full-blown demonstration of any of the use cases listed in this document. However, many of the technological innovations from 6G BRAINS will be demonstrated without an integration in all-in-one demonstrator. Here, every work package (WP 3, 4, 5, and 6) creates its own local demonstration focusing on the aspects being under investigation in the corresponding package.

Moreover, the outcomes mentioned in this deliverable will be propagated into the relevant consortia like 5GAA and 5G-ACIA as well as standardization bodies like 3GPP as part of 6G BRAINS dissemination activities.

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Annex A Overview of the Relevant Use Cases

Below a subset of the state-of-the-art use cases in relevant sectors is presented. This overview has been created to identify the most interesting use cases that motivate the work in 6G BRAINS project and provide valuable insights in the user needs. Many aspects presented below served as an input for requirements analysis in this project.

Application areas	Sub-areas	User stories	Use cases	Key requirement	Links
Production, manufacturing	Connected production	Wireless sensors are used to improve the production process	Sensors in production cells to detect changes in quality, machinery condition and quantity of materials	Data rate: low, 60 B Cycle time: 10 - 100 ms	https://www.bosch.com/stories/nexeed-smart-factory/
			Safety sensors detect workers that come close to the machinery and notify the controller to slow down / stop the process	Data rate: low, 60 B Cycle time: 10 - 100 ms	n.a.
			environmental monitoring or detection of hazardous substances, for video-based security, or for asset tracking	n.a.	n.a.
			Wireless cameras create live video streams that are analysed in the edge cloud	n.a.	Suggested by Bosch. Can be combined with an AGV use case since cams are attached to AGVs as well.
			Locate moving assets such as welding jigs for automotive exhaust silencer system welding assemblies that are randomly stored in different places in factory/warehouse	Data rate: low, 60B Cycle time: 60s location to nearest 0.5m	Suggested by UBrunel based on experience at a company similar to PowerFlow Exhausts: https://www.powerflowex

					hausts.co.uk/stainless-steel-exhaust
		Collaboration robots reduce the production time making the manufacturing process more efficient	collaborating static robots (cobots)	n.a.	n.a.
			collaborating mobile robots (cobots)	Cycle time of motion control function: 1 ms, synchronicity 10 ns	Suggested by Bosch
		Collaborative AGV	for delivering heavier weight components to assembly points to reload for example circuit boards for an automated PCB assembly machine	Data rate: low, 60B Cycle time: 1s location to nearest 0.01m	Suggested by UBrunel based on placement student visit at Renishaw PCB assembly plant in Stroud, UK - https://www.renishaw.com/en/electronics--39160
		Collaborative Drones	for delivering light weight components to assembly points to reload for example ICs for an automated PCB assembly machine	Data rate: low, 60B Cycle time: 1s location to nearest 0.01m	Suggested by UBrunel based on placement student visit at Renishaw PCB assembly plant in Stroud, UK - https://www.renishaw.com/en/electronics--39160
		Ultrasonic Non-Destructive Testing	Ultrasonic testing is a non-destructive test method which utilizes sound waves in order to detect cracks and defects in parts and materials. Ultrasonic testing can also be used to test how thick a material is, for instance the thickness of a wall pipe. Ultrasonic inspection transmits high-frequency sound waves to a material, which can be processed to produce very clear images that	High resolution video Data rate ~8Mbits/sec location to nearest 0.01m Image analysis on the MEC cloud to detect different types of material properties for	Suggested by UBrunel based on research on use of ultrasonics in organ analysis of humans: https://www.formatndt.co.uk/different-types-of-non-destructive-testing-methods/

			can reveal the characteristics of a material's properties, indicating cracks, weld grooves and fractures. They can also show the thickness of a material and any moving components. In flexible manufacturing different parts may require to be inspected for detecting different range of properties at different times.	different components on the production line using AI image analysis.	
		Imaging Non-Destructive Testing	This involves imaging to assess for flaws for internal and external surface inspection of many different types of equipment including storage tanks, pressure vessels and piping. In flexible manufacturing different parts may require to be inspected for detecting different range of properties at different times.	High resolution video Data rate ~8 Mbits/sec location to nearest 0.01m Image analysis on the MEC cloud to detect different types of defects for different components on the production line using AI image analysis.	Suggested by UBrunel based on visual inspection of assemblies: https://www.formatndt.co.uk/different-types-of-non-destructive-testing-methods/
		Infrared Spectroscopy to identify and quantify chemical substances or functional groups in solid, liquid, or gaseous forms	This is used to chemically analyse industrial gaseous substances in a manufacturing process to ascertain if the correct mix of chemicals has been obtained or gas leak detection or detecting contaminants in food manufacturing etc.	Data rate ~2Mbits/sec location to nearest 0.01m To detect different types of gas composition in the production line using AI analysis.	Suggested by UBrunel based on an industrial visit to placement student to Stanhope Set a Ltd who construct sniffing equipment for the oil industry
		X-ray Inspection and Industrial Computed Tomography uses x-rays to view a component	This is used in the inspection of die cast metal objects or injected moulded plastic objects or metallic and plastic extruded tubes or different cross section shaped objects	High resolution video Data rate ~8Mbits/sec location to nearest 0.01m	Suggested by UBrunel based on an industrial visit to Technology Welding Institute (TWI) who

		internally for non-destructive testing of objects and materials, see: https://www.youtube.com/watch?v=IcWjZbXiFkM		Image analysis on the MEC cloud to tomographically reconstruct object and analyse detect different types of defects in material using AI image analysis.	construct different types of equipment to inspect the result of metal processing and welding
	Zero downtime factory	Seamless production modification/update, lot size one production, seamless reconfiguration of the production process	Offloading of the control function from PLCs installed on the highly flexible production cells into the edge over wireless communication	A very challenging use case that cannot be implemented with the current technology incl. 5G Key features and requirements: • Deterministic communication with synchronicity as low as 100 ns • Cycle times as low as 100 us • Data rates up to 100 Mbps	Suggested by Bosch
		Remote service and maintenance	Use of Augmented Reality glasses to help maintenance staff locate hidden assets such as electric and fibre ducting and guide new maintenance staff by identifying locations of parts in maintenance of a boiler or machine tool	High resolution video Data rate ~8Mbits/sec location to nearest 0.01m 3D Graphics over a 3D Browser 5kbits/sec Session Time: 1 hour	Suggested by UBrunel based on joint Fujitsu-British Gas presentation at Cambridge Wireless Meeting: 07.06.16DDCDavidTaylor, Fujitsu.pdf also available in Reference Documents

				Total data download: 12 Mbits	folder in OnlyOffice: https://onlyoffice.eurescom.eu/Products/Files/DocEditor.aspx?fileid=42799&action=view
		Maintenance video guides	Use of steamed ffmpeg or vlc video guides from a server to help train maintenance staff to repair broken down equipment	compressed HD video 3Mbits/sec	Suggested by UBrunel based on experiences on configuration of equipment in recent field trials and integration meetings
		Maintenance video conferences	Use of Skype and Teams video conferencing for collaborative maintenance of equipment using the guidance from remote experts	Skype or Teams video conferencing	Suggested by UBrunel based on experiences on configuration of equipment in recent field trials and integration meetings
Logistics	Intralogistics	Materials flows are monitored in real time and transport jobs are triggered correspondingly to guarantee zero downtime production	Mapping of material flows to provide a completely transparent view of their movements from warehouse to production-line workstation	n.a.	n.a.
			Transport job orders throughout the plant are triggered centrally. Other vendor's transport systems can also be integrated. This software provides real-time information on where materials are headed, the status of the vehicle fleet, and transport routes.	n.a.	Reduce the time to collect information on materials flow and status. The milk runs that keep workstations on the shop floor supplied with components can become more efficient. The drivers of milk-run vehicles get

					tablets to guide them and check the map showing the most efficient delivery route on the fly. In the past, milk-run routes were fixed. A vehicle would stop at every location on the tour, irrespective of whether drop-off points needed new materials or not.
		Smart transportation vehicles, AGVs	Localization of AGVs, smart transportation systems	1 cm precision every 1s	n.a.
Agriculture		Livestock grazing on public land is used widely in large parts of Africa and also in some part of UK, where livestock are allowed to graze freely on public land. This has problems of livestock owners not knowing where their cattle are located and also cattle eating tree samplings thus contributing to deforestation.	IoT location sensor for cattle	IoT location sensors for cattle	Suggested by UBrunel based on a proposal by an African student

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