



5G DEPLOYMENT FOR SMART INDUSTRY USAGE

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1 Executive Summary

In this document, we outline the requirements for a private **Fifth generation (5G)** network for a typical manufacturing plant from Magna. Based on these requirements we derive a traffic profile for the **5G** system. These performance numbers are input for radio planning. The **5G** standard is continuously evolving but does not cover all possible requirements that have been identified for a production plant. In the gap analysis, we compared the requirements from Magna with the available systems, technology, and **5G** standards.

2 Introduction

In today's fast-paced technological landscape, the need for 5G in industrial automation becomes increasingly apparent. The targeted use cases outlined in this project deliverable specifically underscore the transformative potential of 5G in enhancing industrial processes. The deployment of 5G in industrial automation is not merely an upgrade but a fundamental shift towards a more efficient, responsive, and interconnected industrial ecosystem. It is important to also deduce the requirements that such automation use cases put on the communication network. By bridging the current technological gaps through our gap analysis, this deliverable aims to not only highlight the imperative role of 5G in driving innovation but also present the current state of 5G technology ready for deployment. As industries continue to embrace smart technologies, 5G emerges as a catalyst for heightened productivity, precision, and overall advancement in the industrial landscape.

2.1 Objective of the report

The primary objective of this deliverable is to comprehensively analyze and present key aspects related to the implementation of use cases targeting within this project for the deployment of 5G technology. The deliverable aims to provide a detailed examination of the identified use cases, offering insights into their practical applications and potential benefits & challenges. Additionally, the deliverable delves into the traffic profiling of these use cases, summarizing the expected data patterns, network demands, and user behavior to facilitate effective network design. Furthermore, the document outlines the specific requirements for radio planning in the context of 5G deployment for the reference use case. Lastly, the deliverable includes a gap analysis of 5G for the presented use cases, identifying any shortcomings or areas that may require further development or improvement to achieve practical implementation of the targetted use cases. Overall, the project deliverable serves as a comprehensive guide for stakeholders involved in the planning and implementation of 5G private networks, providing valuable insights for informed decision-making.

2.2 Structure of the document

Section 3, "Terms and Definitions," establishes a common understanding of terminology. In Section 4, "Use Cases," targeted applications are outlined. Section 5, "Key Values and Key Value Indicators," defines success metrics. Section 6, "Traffic Profiling of Use Cases," analyzes data patterns and network demands. Section 7, the "Summary of Requirements for Radio Planning," consolidates essential criteria. Section 8, the "Gap Analysis of 5G," evaluates the existing framework's compatibility with use cases. Finally, Section 9, "Conclusions," summarizes key findings and recommendations.

3 Terms and Definitions

This section presents a few fundamental terms that the reader should be familiar with while reading the document in Table 1. The definitions of these terms are provided by the document's authors and may vary in different contexts.

Table 1: Terms and definitions

Term	Definition
Latency	Latency refers to the time needed to transmit a packet from a specific sender to a specific receiver across a particular network.
Communication cardinality	Cardinality refers to the number of participants engaged in a communication relationship from both the sender and receiver perspectives. For example, a 1:1 scenario indicates that one sender is communicating with one receiver, whereas a 1:N scenario indicates that one sender is communicating with multiple (N) receivers.
Communication duration	The communication duration refers to the period during which a consistent communication connection must be sustained to achieve the communication's intended goal. For example, in the context of two collaborative autonomous vehicles, the communication link only needs to be maintained for the duration of the collaborative task they are performing.
Periodic	Category of repetition. In the context of communication relationships, periodic recurrence pertains to communication that occurs at regular intervals, often with a specified time gap, such as 1 ms. It is expected that the time gap between consecutive communication events will stay within predetermined limits.
Jitter	Jitter quantifies the degree of fluctuation in latencies experienced when a sequence of messages is sent from a specific sender to a specific receiver via a particular network.
Recurrence	Recurrence refers to how frequently an event occurs in a consistent pattern.

4 Use cases

As a mobility technology company and one of the largest suppliers in the world, Magna depends on continual advancements in manufacturing excellence to stay ahead of the industry. Magna always set the goal to be a world-class company on a global scale. To achieve this, all Magna Divisions must reflect the same world class image and performance to our customers, employees,

and shareholders. As a minimum, this means that each plant should reflect clean, organized work areas, with good visual controls always. Production targets should be visual with ongoing monitoring of outputs to targets. People should be well-trained in their responsibilities and in charge of the operation, performing work in a standardized way and everything from product development through purchased components, to the shipping of finished products, should be well controlled. In essence, each plant should have similar systems in place to achieve this. This is what we refer to as our Mafact or the Magna Factory Concept approach.

The Magna Factory Concept approach is an initiative lived for decades and serves manufacturing excellence globally. With 351 globally distributed manufacturing plants (as of Q2/2023) this is a necessity to keep up with Magna's demanding high standards.

The desired benefits of 5G in manufacturing are listed hereunder:

- Enhanced flexibility within manufacturing
- Real-time monitoring and maintenance
- Improved productivity
- Traceability of goods
- Streamlined supply chain management
- Worker safety

All improvements or benefits are only a value-add in case the cost trade-off and business case are valid and applicable. For Magna, it is important to understand the impact of 5G within manufacturing. The use cases are based on state-of-the-art production processes while considering future needs at scale.

4.1 Introduction

4.1.1 Manufacturing plant

Manufacturing plants in an industry sector are serving a certain purpose and therefore the construction of the plants is somehow similar, but even different. For the considerations and investigations within this program, a reference plant was chosen as a baseline, as shown in Figure 1. Based on the reference we can summarize the following characteristics for radio planning:

- Indoor manufacturing area with about 40,000 m²
- a ceiling height of 6 m
- Some columns and beams out of concrete
- 2 light weight walls incl. glass windows in the middle of the building

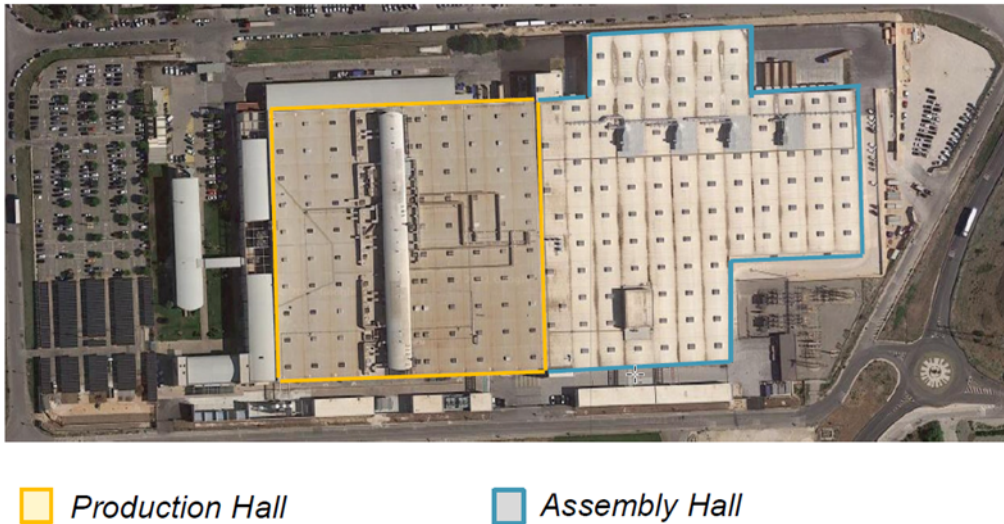


Figure 1: A reference Magna plant top view; source: Magna

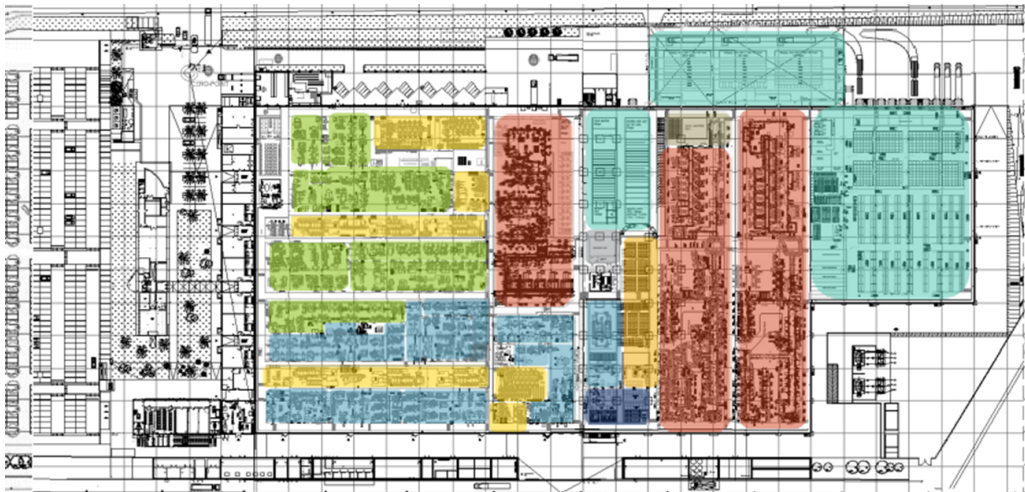


Figure 2: A reference Magna plant; source: Magna

- Outdoor area about 60,000 m²

In each manufacturing site a certain structure is in place to optimize the material flow and throughput of a manufacturing plant. In the figures provided the material flow can be seen. From the left to the right, as shown in Figure 2:

- Delivery of materials (raw materials, operating supplies, auxiliary supplies)
- Delivery of sub-assemblies, intermediate goods, or components
- Goods receipt, quality control and temporary storage
- Production area (green, yellow, blue color)
- Assembly area (red color)

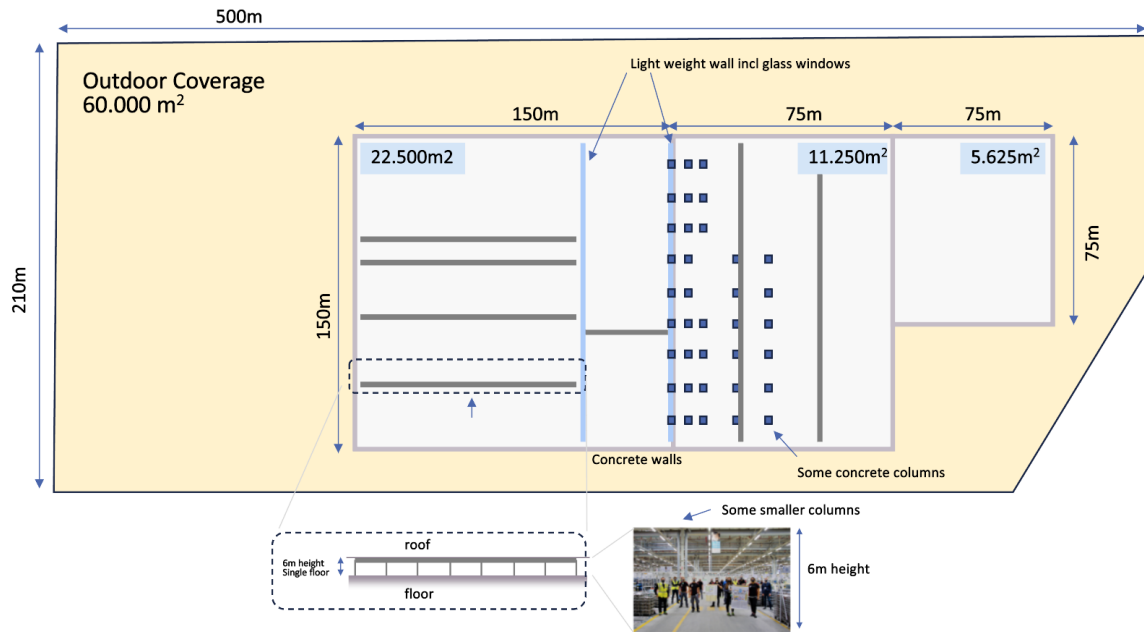


Figure 3: A reference Magna plant - geometrical considerations; source: k-business

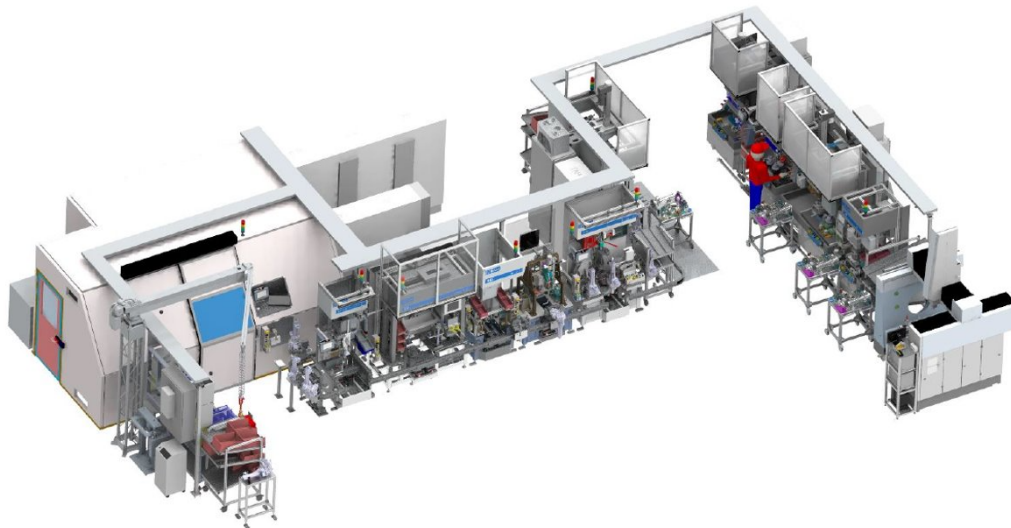


Figure 4: A semi-automated production/assembly line as reference; source: Magna

- Goods output area, incl. quality control (Turquoise color)
- Shipping area (Turquoise color)

From a layout and geometrical perspective, the reference plant fits very well with 5GEARING, as it is very similar to the [Linz institute of technology \(LIT\)](#) Factory characteristics, where the LIT factory could be considered as a scaled version of the reference plant. The LIT factory will be used for demonstrations in WP5 of 5GEARING. Geometric considerations of the reference plant are shown in Figure 3.

4.1.2 Production Lines

In today's manufacturing plants there is a blend of fully-automated and semi-automatic manufacturing and assembly lines. Semi-automated assembly line systems involve a combination of human labor and machines, as shown in Figure 4. This type of automation is suitable for low-volume production lines that require customization and flexibility. Semi-automated systems require human operators to load and unload materials, monitor production processes, and perform quality control checks. Fully automated assembly line systems use robots and machines to perform all the tasks, from loading raw materials to packaging finished products. This type of automation is suitable for high-volume production lines with a consistent product design. Fully automated systems can operate 24/7 with minimal human intervention, leading to increased productivity and reduced labor costs.

As a reference for the use cases, a semi-automated production/assembly line is used and described hereunder:

In Figure 5 the following working stations are indicated. At work station 1 the first parts are measured and labeled, respectively scanned, so that the traceability is given. At stations 2 and 3 a pre-assembly is done. At station 4 another measurement is performed for quality control purpose. Work station 5 is a assembly station, where the parts out of two and three are brought together and are mounted on station 6. Station 7 is a press station and at station 8 the sub-components are screwed together. Next, station 9, is a measurements station before an alignment and calibration (station 10) is performed. Thereafter, at station 11 additional sub-components are mounted. Next, station 12, is a leakage test area, before the manufactured part is filled with operating supplies (station 13). another mounting system (station 14) has to be passed before the final part will be mounted to the end-of-line test (EOL), station 15. Besides the hydraulic system for the EOL-test (station 16) and the EOL housing (station 21) are two important stations to name. At station 20, the reference part repository, a reference part is always visible there for reference, as well as station 18 - the rework-station - in case a part did not pass a measurement in one of the stations listed before.

Rework - OK vs. NOK

Each station provides a OK/NOK assessment. In case of a NOK, the product will be forwarded to the re-work station. This has to be traced and documented accordingly. In both cases, a quality report is generated with proper documentation. For NOK parts the documentation has a higher degree of detail, as additional measurements are performed and documented to achieve the expected high quality standards. In case the product does not fulfill the specifications - the product is NOK - and the process has to guarantee that this NOK-part is scrapped and documented accordingly.

The entire production line includes 15 stand-alone work stages, and each of them is separately controlled, and they have their own electric cabinet. Each work stage generates a different amount of data at its own communication behavior.

For scalability it is important to mention that the area used for such an assembly line is about

150 m² (15 × 10 m) and the throughput per line is approximately 55 pcs. per shift. For the investigations within this program, it is defined, that the production is running in 3 shifts (24/7).

Data acquisition

For traceability, documentation purposes, and quality control data acquisition is performed at every step throughout the production process. For a given assembly line following data acquisitions are executed:

- at each work stage geometrical measurements are recorded and each part will be scanned
- approximately 50% of the workstations are equipped with temperature and pressure sensors
- 3 work stations [1, 4, and 9] are equipped with visual inspection arrangements
 - Each camera is approx. 8 Mb/s (duration: 8 to 10 sec.)
 - Analysis is done in the back-end (for documentation a picture is stored)
- The EOL-Test station is a propulsion test rig with 3 e-machines.
 - Defined test-cycle containing acceleration and deceleration runs for a NVH fingerprint measurement (320 kb/s for one sensor).
 - x,y,z - direction plus torque and speed of each machine. (approx. 2.9 Mbps).
 - Recording (stream) of test operation and NVH measurement. (duration: 90 s)

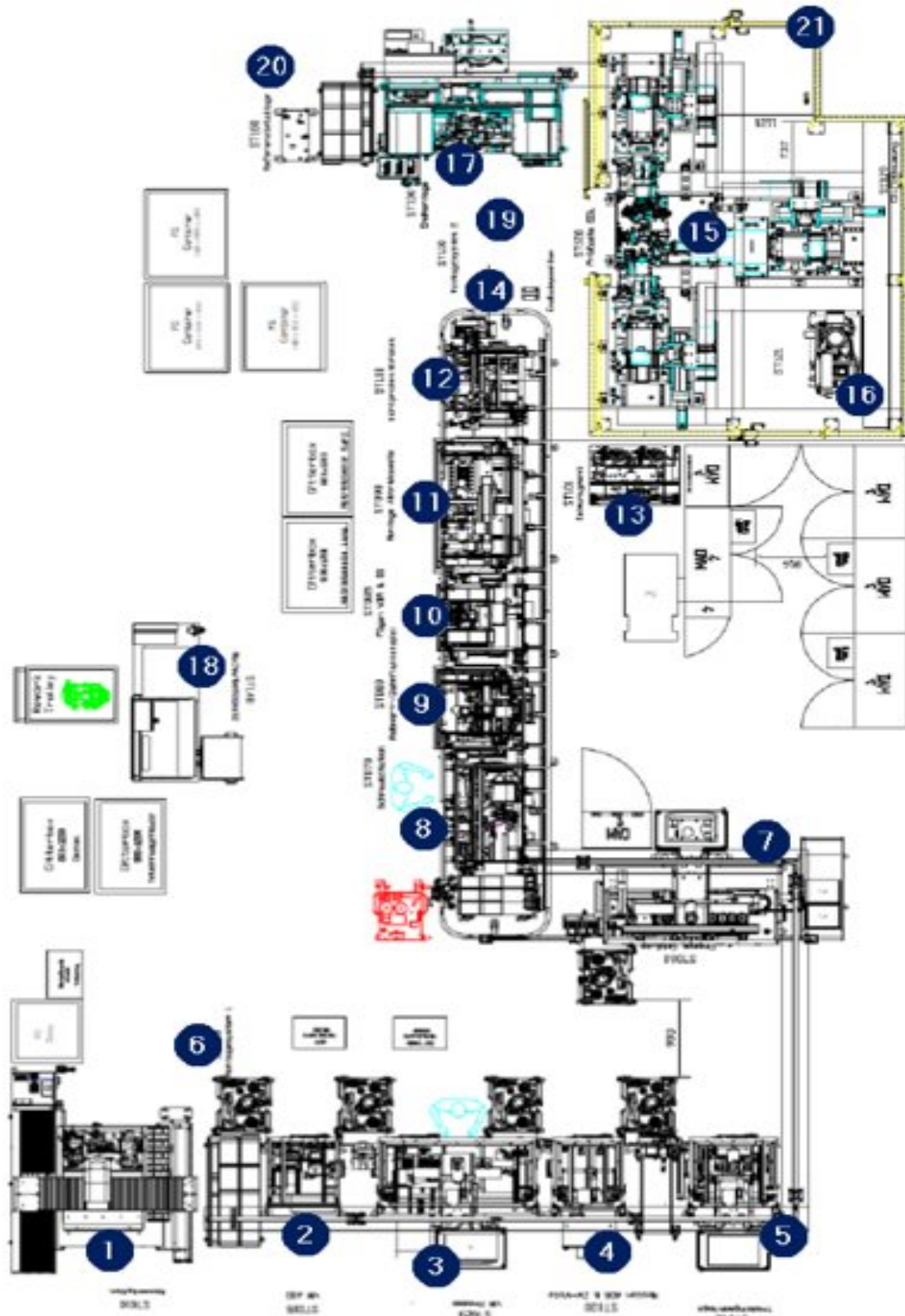


Figure 5: Semi-automated production/assembly line Work Stations; source: Magna

4.1.3 Robotics

Autonomous Mobile Robots (AMRs) In all industries, including the automotive industry, all are looking for new and innovative ways to improve operational efficiency, enhance speed, ensure precision, and increase safety. Many are turning to autonomous mobile robots for help. An autonomous mobile robot is a type of robot that can envision and move through its environment independently. **Autonomous mobile robots (AMRs)** differ from their predecessors, **autonomous guided vehicle (AGV)**, which rely on tracks or predefined paths and often require operator oversight.

AMRs use a sophisticated set of sensors, artificial intelligence, machine learning, and compute for path planning to interpret and navigate through their environment, untethered from wired power. Because **AMRs** are equipped with cameras, lidars, time-of-flight (ToF) sensors and laser sensors, if they experience an unexpected obstacle while navigating their environments, such as a fallen box or a crowd of people, they will use a navigation technique like collision avoidance to slow, stop, or reroute their path around the object and then continue with their task.

In an industrial real-life environment, in the size of 40,000 m², or even more, one **AMR** will not make the difference, but a fleet of approximately 100 different kind of robots can make the difference to improve the operational efficiency, and higher throughput respectively. A holistic fleet management is key. Leveraging artificial intelligence, machine learning, swarm intelligence, and performance compute for path planning to interpret and navigate through their environment plays a major role in success.

AMRs are designed to perform a variety of tasks in different industries. In the context of manufacturing and logistics, including automotive production, the major tasks of **AMRs** include:

1. **Material Transport:** **AMRs** are often used to transport raw materials, components, and finished products within a facility. They can navigate through the environment using sensors and mapping technology, avoiding obstacles and optimizing paths to efficiently move materials from one location to another.
2. **Assembly Line Support:** **AMRs** can assist in assembly processes by delivering components or tools to human operators on the assembly line. This collaborative approach improves the overall efficiency of assembly tasks and allows human workers to focus on more complex or intricate aspects of the assembly process.
3. **Inventory Management:** **AMRs** play a crucial role in managing inventory by autonomously moving items between storage locations and production areas. They can help in maintaining accurate real-time inventory data, reducing the likelihood of stockouts or overstock situations.
4. **Goods Transportation in Warehouses:** In logistics and distribution centers, **AMRs** are used for the movement of goods within warehouses. They can efficiently pick up items from stor-

age locations and deliver them to shipping or packing areas, contributing to faster order fulfillment.

5. **Quality Inspection:** Some [AMRs](#) are equipped with sensors and cameras for quality inspection purposes. They can autonomously navigate around products, scan for defects, and contribute to the identification of quality issues in the manufacturing process.
6. **Workflow Optimization:** [AMRs](#) can adapt to changes in production demands, optimizing workflow by dynamically adjusting routes and schedules. This flexibility is especially valuable in industries with changing production volumes or frequent product variations.
7. **Autonomous Mapping and Navigation:** [AMRs](#) use advanced mapping and navigation technologies such as LiDAR, cameras, and sensors to autonomously navigate through their environment. They can avoid obstacles, reroute in case of disruptions, and ensure safe and efficient movement within the facility.
8. **Collaboration with Other Robots:** In certain manufacturing scenarios, [AMRs](#) may collaborate with other types of robots, such as robotic arms or [AGVs](#) , to perform more complex tasks collectively.

The overarching goal of [AMRs](#) is to enhance efficiency, reduce operational costs, and improve the overall productivity of manufacturing and logistics processes by automating material handling and related tasks.

The collaboration between different types of robots in manufacturing scenarios often involves leveraging the unique capabilities of each type to perform more complex tasks collectively. Within this program, the consideration of roles and tasks for different types of robots in a collaborative manufacturing environment should include:

1. [AMRs](#):

- **Material Transport:** [AMRs](#) can autonomously transport materials, components, and finished products within the manufacturing facility.
- **Inventory Management:** [AMRs](#) contribute to managing and optimizing inventory by moving items between storage locations and production areas.
- **Workflow Optimization:** [AMRs](#) dynamically adapt to changes in production demands, optimizing the workflow by adjusting routes and schedules.

2. **Robotic Arms:**

- **Assembly and Manipulation:** Robotic arms are well-suited for precision assembly tasks and manipulation of components. They can handle intricate tasks that require dexterity and accuracy.

- **Pick-and-Place Operations:** Robotic arms excel at picking up items from one location and placing them in another, making them valuable for assembly and packing processes.
- **Welding and Finishing:** In manufacturing, robotic arms are often employed for tasks such as welding, painting, and finishing.

3. Collaborative Tasks:

- **Combined Material Handling:** AMRs, robotic arms, and AGVs can collaborate to handle materials seamlessly. For instance, an AMR may transport materials to a robotic arm for assembly, and then an AGV could transport the assembled product to the next stage.
- **Quality Inspection Line:** AMRs equipped with inspection sensors may transport products to a station where robotic arms perform detailed inspections, ensuring quality control.

4. Communication and Coordination:

- **Task Synchronization:** Collaborative robots can communicate and synchronize their actions to ensure a smooth and efficient workflow.
- **Adaptive Planning:** Robots may dynamically adjust their activities based on real-time data, such as changes in production schedules or unexpected disruptions.

By combining the strengths of different robotic systems, manufacturers can create a more versatile and adaptable production environment, ultimately improving efficiency and productivity.

4.2 Use cases

4.2.1 Overview

As described in the introduction we will focus on a reference plant and a reference assembly line to provide the ability to scale. Additionally to this reference setup AMRs and robot arms are introduced to deploy a general view of an entire production location.

The major use cases are listed hereunder and described later:

- **Production Line:**
 1. Data logging
 2. Centralized Visual Inspection
 3. Traceability of goods
 4. Centralized EoL analysis and documentation

- **AMRs:**
 1. Indoor / outdoor Localization
 2. Mobile Sensor Data Streaming and Analysis
 3. Fleet Management
- **Robot Arm:**
 1. Collaborative Manufacturing
 2. Pick and Place Operations

The Use Cases are designed to be investigated as stand-alone cases, as well as related to each other. Focus should be a very holistic and scalable assessment of 5G in automotive production, its applicability, scalability and business case related financials for further activities.

4.2.2 Scenarios

Based on an entire manufacturing plant, according to the material throughput, the focus will be in connecting the delivery of materials area with the shipping area. Especially at the start- and end-point of the material flow through a plant, these two areas are most likely related to outdoor positioning areas of AMRs. It is of importance for a holistic fleet management of AMRs, to know at any time the accurate position of each fleet member - indoors and outdoors.

Autonomous Mobile Robots (AMRs) in Industry 4.0 with real-time Video Streaming for Collision Avoidance, Localization, and Material Tracing.

In the context of Industry 4.0, autonomous mobile robots equipped with real-time video streaming capabilities play a crucial role in enhancing efficiency, safety, and traceability within manufacturing and logistics operations. This use case focuses on the application of these robots to achieve collision avoidance, localization, and material tracing features.

The autonomous mobile robots are equipped with advanced sensors, cameras, and communication systems. It is foreseen to equip the AMRs with four cameras to achieve a surround view stream incl. object detection and further functionalities to navigate through the production or warehouse environment, performing various tasks such as material handling, inventory management, and transportation. The robots are designed to operate autonomously, making real-time decisions based on the data they collect.

To achieve collision avoidance, the robots utilize their video streaming capabilities combined with real-time protocols. The cameras on the robots capture live video feeds of their surroundings, which are then streamed in real-time to a central control system. The real-time protocols (RTP, AVTP, ...) ensure minimal latency in video transmission, enabling the control system to analyze the video feeds and detect potential obstacles or hazards in the robot's path. Based on this analysis, the

control system sends immediate instructions to the robot to adjust its trajectory or speed, avoiding collisions with other robots, humans, or objects.

With the usage of 5G, a permanent localization accuracy in the sub-10cm range should be possible, with an update sampling rate of 50 Hz. Related to the material flow, it has to be expected that materials will be delivered to the machinery or assembly lines in different ways, which leads to different AMR setups (forklift, box staples, conveyor system, ...). This means that different kinds of AMRs are deployed in a production environment. The scenarios have to consider, entire fleet management of AMRs to grant optimized utilization of the AMRs and optimized material throughput in the plant. The AMRs are equipped with scanners to ensure traceability of components, sub-components, as well as bulk material. The AMR has to scan the material to be delivered to a desired location and give feedback when the task has been finished.

Localization is another critical feature and supported by the video streaming capabilities. The control system uses computer vision algorithms to process the video feeds and accurately determine the robot's position and orientation within the facility. This information is continuously updated in real-time, allowing the control system to track the robot's movements and plan its path accordingly. Localization enables efficient coordination between multiple robots, optimizing their routes and minimizing unnecessary travel.

Material tracing is facilitated by the combination of video streaming and advanced data analytics. As the robots move through the facility, the cameras capture video footage of the materials they handle or transport. This video data is streamed to the control system, where it is analyzed and processed using machine learning algorithms. The system can identify and track specific materials or products, associating them with relevant information such as batch numbers, production dates, or quality control data. This enables accurate and real-time traceability of materials throughout the production or logistics process, enhancing quality control, inventory management, and supply chain transparency.

Overall, this use case demonstrates how autonomous mobile robots equipped with time-sensitive video streaming capabilities can significantly enhance operations in Industry 4.0 environments. By leveraging collision avoidance, localization, and material tracing features, these robots contribute to improved safety, efficiency, and traceability, ultimately driving productivity and customer satisfaction.

Semi-automated production line In the context of Industry 4.0, a semi-automated production line incorporates advanced technologies to improve efficiency, quality control, traceability, and analysis. This use case focuses on the integration of data logging, centralized visual quality inspection, traceability of goods, and centralized end-of-line (EoL) analysis and documentation.

The semi-automated production line is equipped with sensors and data logging capabilities that capture real-time data during the manufacturing process. This data includes parameters such as temperature, pressure, speed, and other relevant variables. The data logging system collects and stores this information, providing a comprehensive record of the production line's performance

and enabling analysis for process optimization.

Centralized visual quality inspection is a key feature of the production line. High-resolution cameras and computer vision algorithms are employed to inspect products at various stages of the production process. The cameras capture images or videos of the products, and the algorithms analyze them to detect defects, inconsistencies, or deviations from quality standards. Any non-conforming products are flagged for further investigation or removal from the production line, ensuring that only high-quality products proceed to the next stage, or respectively will be forwarded to a rework station including documentation according the description given in section 4.1.

Traceability of goods is achieved through the integration of unique identifiers, such as barcodes or RFID tags, assigned to each product or component. These identifiers are scanned and recorded at different checkpoints along the production line, creating a traceable record of the product's journey. This traceability enables efficient recall management, quality control, and supply chain transparency.

At the end of the production line, a centralized analysis and documentation system is implemented. This system collects data from various sources, including the data logging system, visual inspection results, of the EoL test and traceability records. It performs comprehensive analysis, identifying trends, patterns, and potential areas for improvement. The system generates detailed reports and documentation, summarizing the production line's performance, quality metrics, and any identified issues. This centralized analysis and documentation facilitate decision-making, process optimization, and continuous improvement efforts.

Robot arms in production have revolutionized manufacturing processes, particularly in collaborative manufacturing and pick and place operations. This use case focuses on the application of robot arms to enhance efficiency, flexibility, and safety in production environments.

Robot arms are integrated into the production line, working alongside human operators in a collaborative manner. These robot arms are equipped with advanced sensors, vision systems, and programming capabilities, allowing them to perform a variety of tasks with precision and adaptability.

In collaborative manufacturing, robot arms work alongside human operators to perform tasks that require strength, precision, or repetitive actions. The robot arms can assist in heavy lifting, assembly, or other physically demanding tasks, reducing the risk of strain or injury to human workers. The collaborative nature of these operations allows for efficient utilization of both human and robotic capabilities, resulting in increased productivity and improved ergonomics.

One of the primary functions of robot arms in production is pick and place operations. The robot arms are programmed to identify and pick up objects from one location (e.g.; pick parts out of a bulk cargo and place them accurately into a stoker) and accurately place them in another. This can include transferring components between workstations, loading and unloading materials, or sorting and organizing items. The robot arms utilize vision systems and sensors to identify and

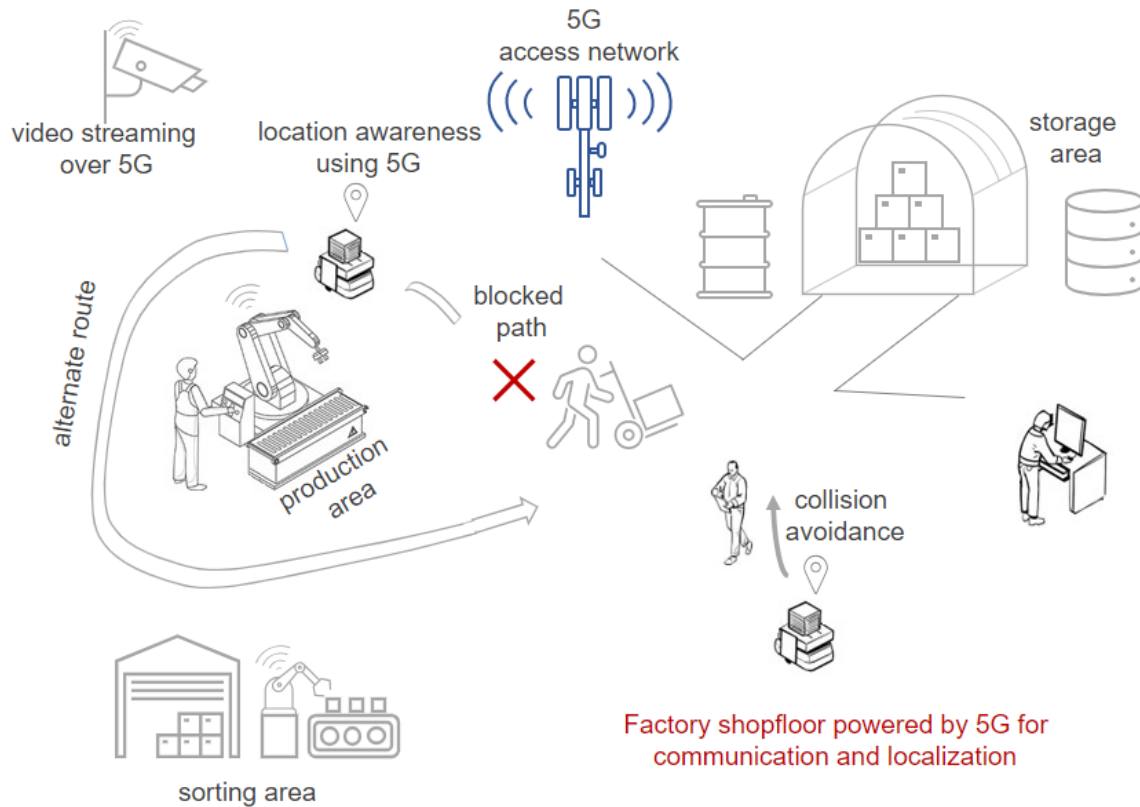


Figure 6: Schematic of Use case Scenarios

locate objects, ensuring precise and reliable pick and place operations.

In Industry 4.0, robot arms are seamlessly integrated into the production line, communicating and coordinating with other machines and systems (e.g.; AMRs). They can receive instructions and data from the central control system, allowing for real-time adjustments and adaptability. This integration enables efficient coordination and synchronization with other production processes, optimizing overall productivity and reducing cycle times.

Safety is a paramount consideration in collaborative manufacturing. Robot arms are equipped with safety features such as force sensors, collision detection, and speed monitoring. These features ensure that the robot arms can operate safely alongside human workers, automatically adjusting their movements or stopping when necessary to prevent accidents or injuries.

In summary, the use of robot arms in production for collaborative manufacturing and pick and place operations in Industry 4.0 offers numerous benefits. It enhances efficiency, flexibility, and safety in the production environment. By working collaboratively with human operators, robot arms optimize productivity, improve ergonomics, and enable the seamless integration of tasks within the production line. The precise and adaptable nature of robot arms in pick and place operations ensures accurate and efficient handling of objects, contributing to streamlined production processes and increased overall productivity.

Collaborative manufacturing is the use case that combines a couple of topics mentioned above.

Purpose	Application	Periodic	Recurrence (min)	Bandwidth (Mbps/s)	Cardinality (1:1, 1:n, n:1)	Latency (ms)	Jitter (ms)	Packet loss (%)	Priority	Duration	Number per production line
Optical inspection-camera streaming	Optical inspection of a part takes 10 seconds. Two cameras with 4 megapixel and 60 frames are used. Each camera stream will be H264 coded with results in 8 Mbps. These two camera streams are transferred to a back-end analysis tool.	No	4 to 10	8	1:1	20	10	0.5	High	10	2
Optical inspection-status	The back-end analysis tool sends back the status of the tested component.	No	4 to 10	0.000001	1:1	500	100	0.00	Low	0.001	2
Handover to next station	If processing at the station was completed correctly, a data record with the component number and status of the component is sent to the next station and to the server.	No	4 to 10	0.000002	1:2	500	100	0.00	Low	0.001	14
Handover to rework station	If processing at the station fails, a data record with the component number and number of stations that failed is sent to the rework station and to the server.	No	4 to 10	0.000002	1:2	500	100	0.00	Low	0.001	14
Impression	If processing at the station was completed correctly, a data record with component number and impression pressure is sent to the server	No	4 to 10	0.000002	1:1	500	100	0.00	Low	0.001	1
Screwing data	If processing at the station was completed correctly, a data record with component number and tightening torque of each screw is sent to the server	No	4 to 10	0.000004	1:1	500	100	0.00	Low	0.001	1
Handover from rework station	If processing at the station was completed correctly, a data record with component number and status of component is sent to the station where the part is returned to production and to the server.	No	4 to 10	0.000002	1:2	500	100	0.00	Low	0.001	1

End of Line Test - data stream	End of Line Test takes 90 seconds. Acceleration sensors in three orthogonal directions and a torque sensor are attached to the test part. In addition, the speed signal of the three drives is transmitted. Each sensor has a data rate of 320 kbps, this results in a transfer rate of 2.9 Mbps to a backend analysis tool.	No	4 to 10	2.9	1:1	20	10	0.50	High	90	1
End of Line - status	The backend analysis tool sends back the status of the tested component	No	4 to 10	0.000001	1:1	500	100	0.00	Low	0.001	1
Surround View	Permanent streaming of four cameras with 4 megapixel and 35 frames are used. Each camera stream will be H264 coded which results in approx. 18.7 Mbps. These four camera streams are permanently transferred to the back-end HPC, where additional algorithms are applied (e.g.; object detection)	yes	perm.	18.67	1:1	20	10	0.5	High	perm.	3
Robot - Pick and Place	Permanent streaming of one camera with 4 megapixel and 35 frames is used. The camera stream will be H264 coded which results in approx. 4.7 Mbps. The camera stream is permanently transferred to the back-end HPC, where additional algorithms are applied (e.g.; object detection)	yes	perm.	4.67	1:1	20	10	0.5	High	perm.	1

Table 2: Communication requirements for the use cases

5 Key Values and Key Value Indicators

Key Performance Indicators (KPIs) are essential metrics used to evaluate the performance and progress of a company or specific processes within it. In the context of production or Industry 4.0, there are several Key Value Indicators (KVI) that are commonly used. Hereunder are the most important KVI listed:

1. **Overall Equipment Effectiveness (OEE):** OEE measures the efficiency of equipment utilization by considering factors such as availability, performance, and quality. It provides insights into how effectively the production equipment is being used.
2. **Cycle Time:** Cycle time refers to the time it takes to complete one cycle of a specific process or operation. It helps identify bottlenecks and inefficiencies in the production line.
3. **Downtime:** Downtime measures the amount of time that production equipment is not operational due to various reasons such as breakdowns, maintenance, or changeovers. Minimizing downtime is crucial for maximizing productivity.
4. **Scrap and Rework Rates:** These indicators measure the amount of defective or non-conforming products that need to be scrapped or reworked. Lower scrap and rework rates indicate better quality control and efficiency.
5. **Lead Time:** Lead time measures the time it takes for a product to move through the entire production process, from order placement to delivery. Reducing lead time is important for meeting customer demands and improving overall efficiency.
6. **First Pass Yield (FPY):** FPY measures the percentage of products that pass all quality checks and inspections during the first attempt. A higher FPY indicates better quality control and reduces the need for rework or scrap.
7. **Lost Time Injury Frequency Rate (LTIFR):** LTIFR measures the number of lost time injuries per million hours worked. It provides an indication of the frequency of injuries that result in lost work time.
8. **Total Recordable Incident Rate (TRIR):** TRIR measures the number of work-related injuries and illnesses per 100 full-time employees. It includes both minor injuries and more severe incidents.
9. **Near Miss Reporting Rate:** This indicator measures the number of near-miss incidents reported by workers. Near misses are incidents that could have resulted in an injury or illness but did not. Encouraging near miss reporting helps identify potential hazards and prevent future incidents.

10. **Safety Training Compliance:** This KVI measures the percentage of employees who have completed required safety training. It ensures that workers are adequately trained to perform their tasks safely.
11. **Safety Observation Participation Rate:** This indicator measures the percentage of employees who actively participate in safety observations or inspections. It encourages employees to identify and report potential safety hazards.
12. **Safety Culture Perception Survey:** This KVI involves conducting surveys to assess employees' perception of the safety culture within the organization. It helps identify areas for improvement and gauge the effectiveness of safety programs.
13. **Days Away, Restricted, or Transferred (DART) Rate:** DART rate measures the number of work-related injuries and illnesses that result in days away from work, restricted work activity, or job transfers per 100 full-time employees. It provides insights into the severity of injuries and their impact on workers' ability to perform their duties.
14. **Overall Labor Productivity:** This indicator measures the efficiency and productivity of the workforce. It considers factors such as output per employee, labor cost per unit, and employee utilization.

While the specific KVIs may vary depending on the industry and company goals, the overall target is to achieve exceptional performance in four key areas: efficiency, quality, employee's safety, and sustainability.

Efficiency is a crucial aspect of any organization's success. By monitoring KVIs such as Overall Equipment Effectiveness (OEE), cycle time, and lead time, companies strive to optimize their production processes, minimize waste, and maximize productivity. Improving efficiency not only enhances profitability but also enables organizations to meet customer demands more effectively. Quality is another critical factor that directly impacts customer satisfaction and brand reputation. KVIs like scrap and rework rates, first pass yield (FPY), and total recordable incident rate (TRIR) help organizations assess and improve their quality control measures. By reducing defects, ensuring compliance with standards, and continuously monitoring quality metrics, companies aim to deliver products and services that consistently meet or exceed customer expectations.

Employee's safety is of paramount importance in any workplace. KVIs related to worker safety, such as lost time injury frequency rate (LTIFR), near miss reporting rate, and safety training compliance, enable organizations to proactively identify and address potential hazards. By fostering a strong safety culture, providing adequate training, and encouraging employee participation, companies strive to create a safe and healthy work environment for their workforce.

Sustainability has become increasingly important in today's business landscape. Organizations are recognizing the need to minimize their environmental impact and contribute to a more sustainable future. KVIs related to sustainability may include energy consumption, waste manage-

ment, and carbon footprint reduction. By setting targets and monitoring these indicators, companies aim to improve their environmental performance and align with sustainable practices. In summary, while KVs provide specific metrics for evaluating performance, the ultimate goal is to achieve exceptional results in efficiency, quality, employee's safety, and sustainability. By continuously monitoring and improving these areas, organizations can enhance their competitiveness, build a positive reputation, and contribute to a better future for all stakeholders.

6 Traffic Profiling of Use cases

In order to plan radio cells and coverage in the production plant, we need to consider traffic profiles and total capacity requirements for the production plant. Together with the radio frequency band and available radio bandwidth, we can derive the number of radio cells satisfying the capacity demand based on indoor radio planning.

The following applications were considered for traffic profiling:

1. Semi-automated production/assembly line Work Station - derived from the requirements listed in [Table 2](#)
2. Mobile Robots
3. Mobile Data Terminals like Barcode scanners

6.1 Semi-automated production/assembly line Work Station

Looking at the traffic values listed in [Table 2](#), four items have a significant impact on the overall traffic: Optical inspection - camera streaming (2×8 Mbps), End of Line Test - data stream (1×2.9 Mbps), Surround View (3×18.67 Mbps) and Robot - Pick and Place (1×4.67 Mbps). All other data streams have much lower data rates. These signals are not periodic. Therefore we consider the worst-case scenario, where all data transfer in the assembly line happens at the same time. Most of the traffic will be from the Workstation to the network, consuming [uplink \(UL\)](#) capacity on the [5G](#) network.

We assume the area of a Semi-automated production/assembly line Work Station of about 170 m^2 . A total indoor coverage area of $40,000 \text{ m}^2$ would allow space for 165 production lines. With 165 production lines, the total traffic of the whole plant is 13.107 Mbps. From [Table 2](#), column "Number per production line" we get the number of endpoints per production line. Each production line has 41 endpoints. In total, there are $41 \times 165 = 6,753$ endpoints in the whole factory.

6.2 Mobile Robots

Mobile Robots vendors are currently investigating integration with [5G](#) radio technology. Commercial systems do not yet rely on [5G](#) for control or for building up a dynamic and central map of the

Purpose	peak per production line [Mbps]	duty cycle	average per pro- duction line [Mbps]
Optical inspection - camera streaming	16	4.17%	0.67
Optical inspection - status	0.000002	0.00%	8.3E-12
Handover to next station	0.00028	0.00%	1.2E-09
Handover to rework station	0.00028	0.00%	1.2E-09
Impression	0.00002	0.00%	8.3E-11
Screwing data	0.00004	0.00%	1.7E-10
Handover from rework station	0.00002	0.00%	8.3E-11
End of Line Test - data stream	2.9	37.50%	1.09
End of Line - status	0.000001	0.00%	0.00
Surround View	56.01	100%	56.01
Robot - Pick and Place	4.67	100%	4.67
	79.58		62.43

Table 3: Capacity per Semi-automated production/assembly line Work Station

Coverage Area	40,000 m ²
Area of Semi-automated production/assembly line Work Station	170 m ²
% of area covered by production line	70%
Number of production lines per plant	165
Total traffic for all production lines	13.107 Mbps
Total number of devices for all production lines	6,753 devices

Table 4: Scaling up to the whole Coverage Area

environment. Up to now, decisions are made individually in each robot and only non-critical control data is being transferred. There are systems on the market, where all robots are connected in a meshed architecture which certainly has its limitations when the number of robots increases. For the time being we work with assumptions on the estimated data throughput and performance to derive the needs on the 5G system for future Mobile Robots. Similar to the requirements on 5G for the production lines, the highest bandwidth will be required for video streaming. We assume that mobile robots will capture environmental video data and transfer the video to a central server for processing and decision-making. It has to be mentioned that today not all Mobile Robots have cameras (as in the case of Mobile Robots from Omron).

We assume that 2 parallel video streams with 8 Mbps are needed per Mobile Robot. Video needs to be transferred from the Robot to the network, so the capacity requirement is on the UL. A typical production plant is assumed to have 100 Mobile Robots in total. The Mobile Robots are flexible and shall not be assigned to a specific production line, but shall be used based on availability (charging,...), location (optimize routing) and capability (extensions for certain tasks).

Based on these assumptions, the total capacity needed for Mobile Robots is 16 Mbps per robot and 1,600 Mbps in total for the whole production plant.

6.3 Mobile Data Terminals like Barcode scanners

We assume 3 Mobile Data Terminals per production line leading to a total of 494 for the whole production plant. The actual traffic demand heavily depends on the data applications used, but we assume an average throughput of 100 kbps per device leading to a total demand of 49 Mbps.

7 Summary of requirements for radio planning

We use the reference plant (see Figure 3) as a basis for the simulations. The indoor coverage area consists of concrete beams and columns with two lightweight walls with glass windows in the middle of the building. The summary of requirements for radio planning is provided in table 5.

8 Gap analysis of 5G

8.1 Indoor Positioning

One of the features promoted by manufacturers for Private 5G systems is high-precision positioning as enabler for use cases like mobile robots or asset tracking. Different technologies are supported by the 3GPP standard and are based on [time of arrival \(ToA\)](#), [angle of arrival \(AoA\)](#), or more sophisticated technologies which consider multiple factors and machine learning. Several pre-conditions have to be met for indoor positioning and are dependent on the intended application scenario. It is obvious that a precise time source is necessary for time measurements (speed of

Coverage Area	Size	40.000 m2
RF requirements	Band	n78
	Bandwidth	80 MHz
	Framing: DL/UL Framing Structure	8:2
Number of de- vices	Stationary Low-tier (low throughput) devices	5,600
	Stationary high-tier (high throughput / video) devices	1153
	Mobile high-tier /high throughput / video) devices	100
	Mobile data terminals	494
	Total	7,347
Total Capacity per plant	Stationary applications	13,107 Mbps
	Mobile applications	1,649 Mbps
	Total	14,759 Mbps

Table 5: Summary radio and capacity requirements

light = $(3 \times 10^8 \text{ m/s} \Rightarrow 1 \text{ m} \hat{=} 3.3 \text{ ns})$). Measuring AoA requires a radio unit that uses beam forming on the UL. This could be feasible with mmWave spectrum and massive multi input multi output (MIMO). For sub-6 GHz frequency bands, this method seems not to be feasible for indoor use. Time delay measurement is normally done on the UL from the use equipment (UE) to the base station (BS)/remote radio unit (RRU). For triangulation, at least 3 RRUs need to receive the signal from the UE. That means that indoor radio planning needs to consider this requirement in advance. Moreover, the UEs more or less have to have a direct line of sight with the RRUs in order to measure the time of flight and calculate the position. The main advantage of measuring on the UL is the fact that regular UEs can be used and no special chipsets or protocols are needed on the air interface. Recently some manufacturers have released indoor radio access network (RAN) equipment with support of time of arrival measurement. Accuracy under ideal conditions is around 1 m.

8.2 Manufacturers of mobile robot equipment

From the market analysis and discussion with the manufacturer of mobile robots Omron we conclude that 5G technology is not yet deeply integrated with mobile robots. Omrons robots act more or less autonomously, but also have a central component called enterprise manager, which can orchestrate multiple robots, give commands and visualize the location. The mobile robots from Omron are equipped with LIDAR and other sensors. Video is not used by Omron as sensor for



Figure 7: Omron LD-Series autonomous robot (source: [Omron](#))

orientation. More sophisticated use cases could involve video cameras for tracking but also for remote operation. Such cameras could be fitted on the robot for testing purpose. Later on, robot manufacturer like Omron could integrate these optical systems. In an initial learning phase, the mobile robots learn their environment and keep a local map of the working area. Today commands are sent to the robot over [wireless fidelity \(WiFi\)](#). A command could for instance define a destination location. As the mobile robots are not yet equipped with [5G](#) modems, which could be used in a Private [5G](#) system, the modem would have to be fitted on or into the robot and be connected via Ethernet or other means to the central processor of the robot.

8.2.1 Fleet Management

A bigger manufacturing plant will have a high number of mobile robots for different applications, like transport of material between warehouse and production lines. For the reference plant as shown in [Figure 1](#) we can assume between 50 and 100 mobile robots continuously moving and performing different tasks. Each of these robots is equipped with different sensors and gathers valuable environmental data which can be used by all other robots or for other applications. Therefore it makes sense to share and process this data centrally.

8.2.2 Accessories

Mobile robots can be equipped with different accessories, for example for picking up trays with material. In the current program, we cannot customize the robot for the specific use case of Magna.

8.3 Manufacturers of robotic arm

Robotic arms like the UR5e from Universal Robots use the position of the joints to determine their exact pose. Therefore, high accuracy of less than 0.05mm on the pose repeatability is achievable. Communication is usually realized over a TCP/IP Ethernet socket. The UR5e has a realtime inter-



Figure 8: Omron AMR with tray feeder (source: [Omron](#))

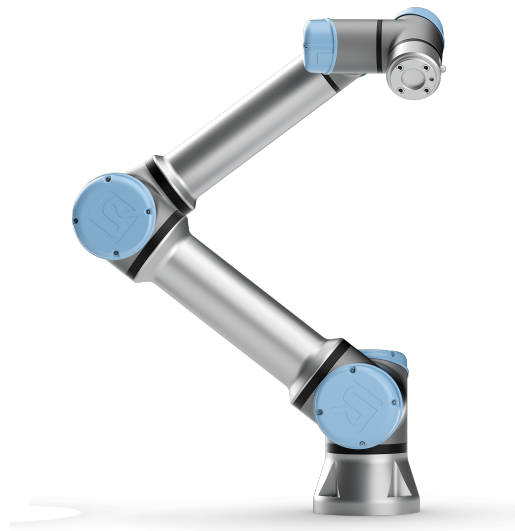


Figure 9: UR5e cobot; source: [universal-robots.com](#)

face that enables the robotic arm to send and receive data every 2ms. Utilizing a 5G system a fast reaction to commands could also be achieved in a wireless network.

8.4 Frequency Bands

One of the biggest issues for Private 5G networks today is the fragmented spectrum landscape. Other than WiFi, there is no globally harmonized band for private networks, but every country implements its own spectrum plan. Many countries do not yet assign dedicated spectrum for Private 5G networks. Governments seem to be more willing to auction spectrum on a country-wide basis with high revenues rather than granting licenses for local operation. Nevertheless there are positive examples as well like Germany, the US, UK and some nordic countries, where private spectrum already is available.

The lack of globally harmonized spectrum for private 5G networks also leads to challenges for

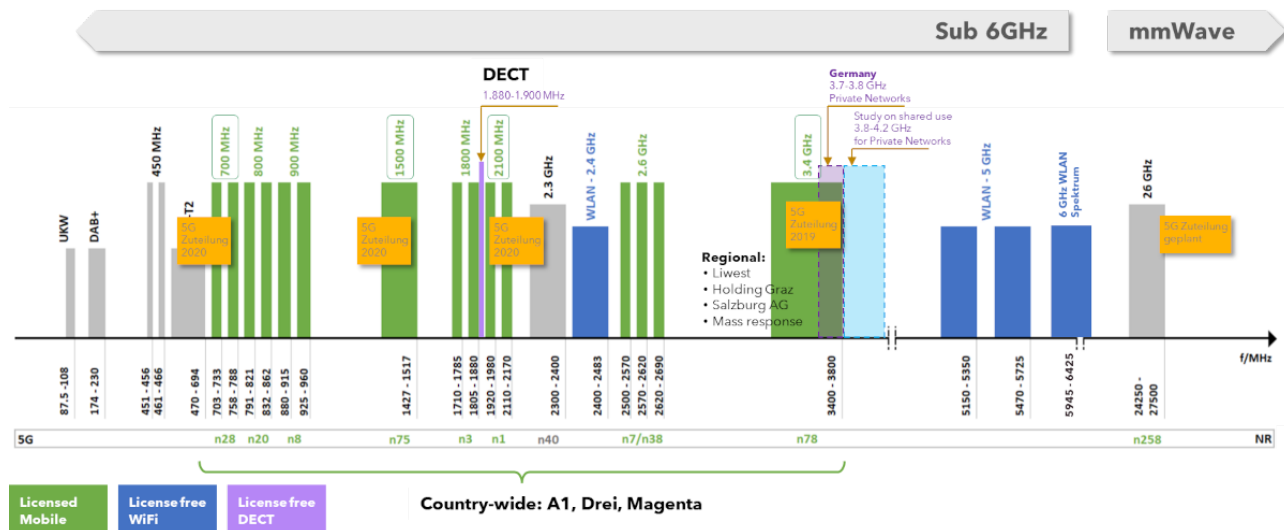


Figure 10: 5G Spectrum in Austria (source RTR, with additional information on DECT, WIFI and Operators holding the licenses)

equipment manufacturers. They need to adapt their equipment to different deployment scenarios which also challenges system integrators and end users. Manufacturers like Magna are operating globally, but would like to define standards and blueprints for production plants independent of the specific location of the plant.

8.5 Frequency situation in Austria

Two auctions for 5G spectrum have been held in Austria in 2019 and 2020. Spectrum from the 5G pioneer band n78 (3.4-3.8 GHz) has been licensed to regional Austrian operators Liwest, Salzburg AG, Holding Graz and mass response as well as to the 3 main mobile network operators (MNOs) A1, Drei and Magenta. Some spectrum remained unallocated after the auction in 2019. For this remaining unallocated spectrum there is a public tender closing early 2024 (see [RTR homepage](#)). The 2020 auction was for the 700, 1500 and 2100 MHz band. Spectrum was awarded to the 3 main Austrian operators A1, Drei and Magenta. As there is no spectrum dedicated to private 5G networks in Austria, companies planning to implement a private 5G network need to cooperate with a MNO.

8.5.1 Sub-Licensing spectrum

From the regulators point of view, spectrum can be sub-licensed by the spectrum owner for instance for a local campus network. In this case, all the licensing obligations need to be transferred from the license owner to the sub-licensee. From the license owners perspective it is crucial that the network performance is not degraded by the sub-licensees network. In many cases an interference analysis will be necessary.

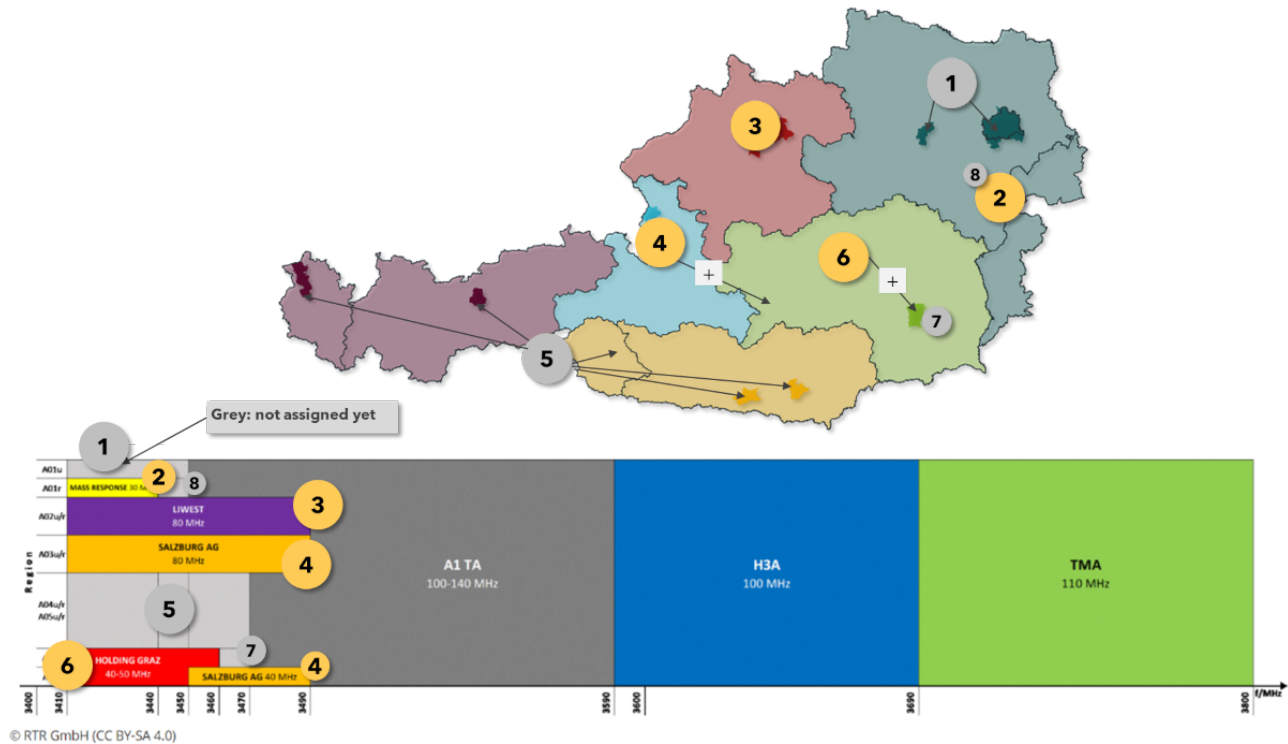


Figure 11: n78 5G Spectrum allocation in Austria (source RTR with visualisation on allocation areas)

8.5.2 mmWave

5G is not only specified in the so called Sub 6 GHz band, but also in the so called Frequency Range 2 or mmWave band above 24GHz. The standard specifies bands n257 to n263, whereby spectrum in n258 is allocated for 5G applications in Austria. 24.3 - 24.9 GHz (600MHz) are allocated for local, campus networks. The upper part of the spectrum is publicly tendered on a national level until early 2024 (see [RTR homepage](#)).

8.5.3 Framing structure

The 5G Band N78 is a **time division duplex (TDD)** band, which means that **UL** and **downlink (DL)** are alternating on the same radio frequency. Certain time slots are used on the **UL** and others on the **DL**. The RF carrier is not strictly limited (an ideal, rectangular filter cannot be implemented in practice), but RF signals are emitted by **UE** and **BS** on frequencies below and above the actual band used. These emissions can cause interference. To reduce the impact of interference, the regulator in Austria defines a Block Edge Mask (BEM, definitions see [\(2014/276/EU\)](#)) and a standard framing structure with **DL/UL** ratio of 3:1. The conditions can be found in the Frequency Assignment Certificate on the RTR homepage (see Chapter 2 in the [Frequenzzuteilungsurkunde, which is part of the spectrum assignment Bescheid der TTK vom 08.04.2019](#)). Synchronization needs to be with an accuracy of +/- 1,5 us and the standard framing structure is based on the LTE Frame Structure Type 2 (DSUDD) and Special Subframe configuration 6. Details on the LTE framing structure can

DL/UL ratio	Timeslot or Subframe number									
	0	1	2	3	4	5	6	7	8	9
3:1	D	S	U	D	D	D	S	U	D	D

Figure 12: LTE TD framing structure

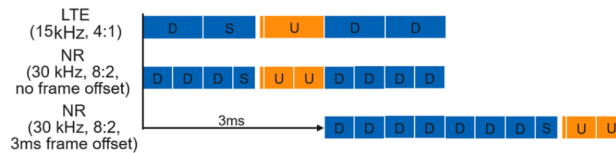


Figure 13: Aligning LTE and 5G framing Structure (source: [GSMA](#))

be found in [3GPP TS 36.211](#) Chapter 4.2. D stands for DL, U for UL and S is a Special Subframe. Each LTE Timeslot is 1ms long. Special Subframe are partially used for DL as well as UL. It is to be noted that the specifications define seven slot configurations in LTE with varying UL/DL sub-slot patterns. For 5G New Radio, a similar framing structure as in LTE has to be applied. The Frequency Assignment Certificate also allows alternative framing structures in Band N78 (Frequenzzuteilungsurkunde Chapter 2.1.5). In this case the network operators are asked to cooperate, and additional measures to reduce the level of interference may be applied. Measures could be guard bands or reduced power at the upper or lower limit of the spectrum. Using a guard band reduces interference between operators, but also reduces capacity. Small Cells within buildings are excepted from synchronisation as long as there is no interference with other networks. In practice this constraint could be difficult to fulfil.

8.6 Standardised framework for sensors

Automated device integration through device description language significantly simplifies the complex process of incorporating new devices into a network. Rather than relying on extensive manual efforts from engineers to scrutinize device interfaces and study protocols, automated systems utilize standardized device description languages, streamlining the connection establishment process. This approach eliminates the need for hacking practices, addressing the common lack of standards in both hardware and software. As the variety of available devices expands, automated integration leverages a unified language to manage interfaces, connections, and protocols efficiently. This not only reduces the challenges faced by system developers but also makes the inte-

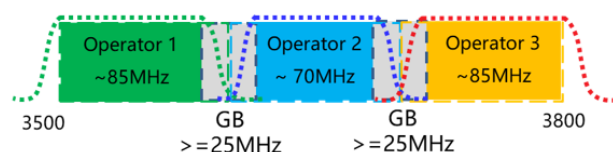


Figure 14: Reducing interference with a guard band (source: [GSMA](#))

gration of devices into large-scale enterprise systems more manageable and cost-effective. Several standards have been proposed to facilitate device description and integration and focus on different aspects of devices [1]. Different standards adopt a scalable approach by defining descriptive languages instead of specifying individual devices. SensorML [5] and DeviceKit [2] use XML encodings. Whereas, the IEEE 1451 standard [3] utilizes a concise [interface definition language \(IDL\)](#) to describe device interfaces.

The IEEE 1451 is of interest in the scope of industrial environments with [5G](#) networks as it aims to create open and network-neutral interfaces for connecting transducers to data communication networks. The IEEE 1451 standard defines a framework for the development of [transducer electronic data sheet \(TEDS\)](#), which contains information about a transducer's characteristics, calibration data, and other relevant information. This standardized format allows for plug-and-play functionality, where devices can be easily connected to a network without requiring extensive configuration.

The IEEE 1451 family of standards includes several parts, each addressing specific aspects of sensor and actuator interfaces. Some key parts of the IEEE 1451 standard include:

- IEEE 1451.0: Standard for a Smart Transducer Interface for Sensors and Actuators - Common Functions, Communication Protocols, and [TEDS](#) Formats.
- IEEE 1451.1: Standard for a Smart Transducer Interface for Sensors and Actuators - Network Capable Application Processor (NCAP) Information Model.
- IEEE 1451.2: Standard for a Smart Transducer Interface for Sensors and Actuators - Transducer to Microprocessor Communication Protocols and [TEDS](#) Formats.
- IEEE 1451.4: Standard for a Smart Transducer Interface for Sensors and Actuators - Mixed-Mode Communication Protocols and [TEDS](#) Formats.

These standards are designed to facilitate the development of intelligent, networked systems in various industries, such as industrial automation, healthcare, environmental monitoring, and more. The use of IEEE 1451 standards helps ensure the compatibility and interchangeability of sensors and actuators from different manufacturers within a networked environment.

IEEE 1451 faces slow adoption in industrial environments due to established legacy systems, a lack of awareness in industrial engineers about the standard, interoperability concerns, and the complexity of implementation. Furthermore, with regard to the specific use cases addressed in the 5GEARING project, it's worth noting the absence of a standardized interface description for video sensors. While there are some non-standardized interface descriptions available [4], the lack of a universally accepted standard poses a challenge in ensuring seamless integration and interoperability. In summary, while IEEE 1451 offers a robust standard for smart transducer interfaces, challenges related to legacy systems, awareness, interoperability, and implementation complexity have contributed to its limited adoption in industrial environments. Overcoming these challenges

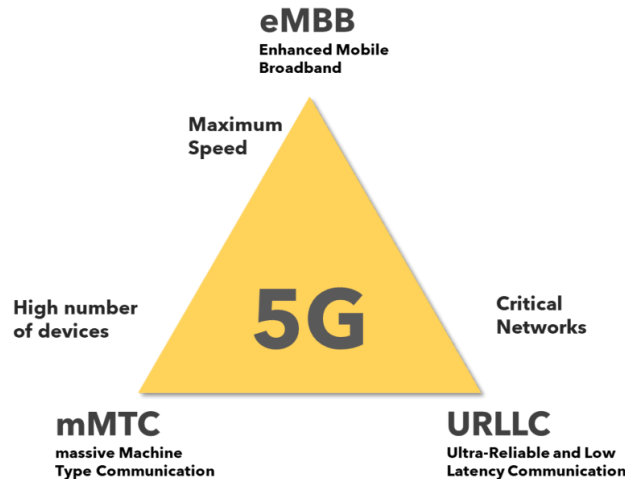


Figure 15: The 5G pillars eMBB, URLLC and mMTC

will require concerted efforts from industry stakeholders and a gradual shift towards embracing standardized, inter-operable solutions.

8.7 Devices for low throughput M2M applications

5G was initially focusing on 3 different profiles which are [enhanced Mobile Broadband \(eMBB\)](#), [ultra reliability low latency communication \(URLLC\)](#) and [massive machine type communication \(MMTC\)](#). eMBB increased the maximum throughput compared to LTE significantly. URLLC allows the implementation of critical applications with a high demand on availability and deterministic behavior. mMTC is the further development of [low power wide area network \(LPWAN\)](#) technologies like NB-IoT into the 5G standard. For certain applications in an industrial / campus environment (e.g. a battery powered vibration sensor), mMTC could be of interest. Unfortunately, so far LPWAN standard and technology has only been adapted for the lower LTE frequency range below 2.2 GHz and for Frequency Domain Duplexing. As a consequence, these technologies cannot be used on 5G band N78 at 3.5 GHz. Today, commercial 5G devices have a certain complexity and are not yet cheap. Most of these devices are based on Qualcomm Snapdragon (R) X65 platform which was introduced in 2021. 3GPP recently introduced RedCap in Release 17 as additional "mode" of 5G. RedCap reduces the complexity and allows "Light" devices with lower power consumption and lower production cost (see related [Article by Qualcomm](#)). Qualcomm recently announced the 1st 5G RedCap NR-light platform [Snapdragon \(R\) X35](#). Commercial products based on this chipset will follow soon.

9 Conclusions

In conclusion, this project deliverable has provided a comprehensive overview of targetted industrial automation use cases within the 5Gearing project, the key values, and key value indicators

essential for understanding its significance in modern industries. Through traffic profiling, we gained insights into the diverse nature of these use cases and their respective demands on network resources. Moreover, the outlined requirements for radio planning underscore the critical need for robust communication infrastructure to support seamless operation of the targetted use cases.

Additionally, the thorough gap analysis conducted for 5G implementation within the targeted use cases has highlighted areas where advancements in technology are necessary to fully realize the potential of these use cases. By identifying these gaps, stakeholders can prioritize research and development efforts to address key challenges and enhance the effectiveness of future automation initiatives.

Overall, this deliverable serves as a valuable resource for industry professionals, researchers, and policymakers, offering actionable insights to guide strategic decision-making and drive innovation in the realm of industrial automation with private 5G networks. As technology continues to evolve, leveraging these findings will be instrumental in fostering greater efficiency, productivity, and competitiveness across various industrial sectors.

Acronyms

5G Fifth generation. [3](#), [4](#), [6](#), [15](#), [16](#), [23](#), [25–33](#)

AGV autonomous guided vehicle. [12–14](#)

AMR autonomous mobile robot. [12–16](#), [28](#)

AoA angel of arrival. [25](#), [26](#)

BS base station. [26](#), [30](#)

DL downlink. [30](#), [31](#)

eMBB enhanced Mobile Broadband. [33](#)

IDL interface definition language. [32](#)

LIT Linz institute of technology. [8](#)

LPWAN low power wide area network. [33](#)

MIMO multi input multi output. [26](#)

MMTC massive machine type communication. [33](#)

MNO mobile network operator. [29](#)

RAN radio access network. 26

RRU remote radio unit. 26, *Glossary*: RRU

TDD time division duplex. 30

TEDS transducer electronic data sheet. 32

ToA time of arrival. 25

UE use equipment. 26, 30

UL uplink. 23, 25, 26, 30, 31

URLLC ultra reliability low latency communication. 33

WiFi wireless fidelity. 27

References

- [1] Chao Chen and Sumi Helal. “Sifting through the jungle of sensor standards”. In: *IEEE Pervasive Computing* 7.4 (2008), pp. 84–88.
- [2] *DeviceKit Website*. URL: www.eclipse.org/ohf/components/soda/index.php..
- [3] *IEEE 1451 Standard*. URL: <http://ieee1451.nist.gov>..
- [4] Cai Limin. “Design and research of a kind of smart sensor”. In: *International Conference on Computer Science & Education (ICCSE)*. 2012, pp. 1208–1211. DOI: 10.1109/ICCSE.2012.6295281.
- [5] *Sensor Model Language*, URL: www.opengeospatial.org/standards/sensorml..