5G-ACIA White Paper

5G for Connected Industries and Automation

(Second Edition)

5G Alliance for Connected Industries and Automation

5G Alliance for Connected Industries and Automation

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Executive Summary

One of the main differences between 5G and previous generations of cellular networks lies in 5G's strong focus on machine-type communication and the Internet of Things (IoT). The capabilities of 5G thus extend far beyond mobile broadband with ever increasing data rates. In particular, 5G supports communication with unprecedented reliability and very low latencies, and also massive IoT connectivity. This paves the way for numerous new use cases and applications in many different vertical domains, including the automotive, healthcare, agriculture, energy and manufacturing sectors. In manufacturing in particular, 5G may have a disruptive impact as related building blocks, such as wireless connectivity, edge computing or network slicing, find their way into future smart factories.

In order to ensure that the specific needs and requirements of a particular vertical industry are adequately understood and considered by the telecom industry and, likewise, the capabilities of 5G are fully realized and exploited by the vertical industries, close collaboration is required between all relevant players. With this in mind, the 5G Alliance for Connected Industries and Automation (5G-ACIA) has been established, which serves as the central and global forum for addressing, discussing, and evaluating relevant technical, regulatory, and business aspects with respect to 5G for the industrial domain. It reflects the entire ecosystem, encompassing all relevant stakeholder groups from the OT (operational technology) industry, the ICT (information and communication technology) industry and academia.

In this white paper, we provide an overview of 5G's basic potential for manufacturing industry, and outline relevant use cases and requirements. Furthermore, we introduce some of the main building blocks of 5G and certain major challenges that have not yet been resolved. Finally, the afore mentioned 5G-ACIA is presented in more detail as an important initiative to ensure that 5G for the industrial domain is ultimately successful.

Content

1 Introduction

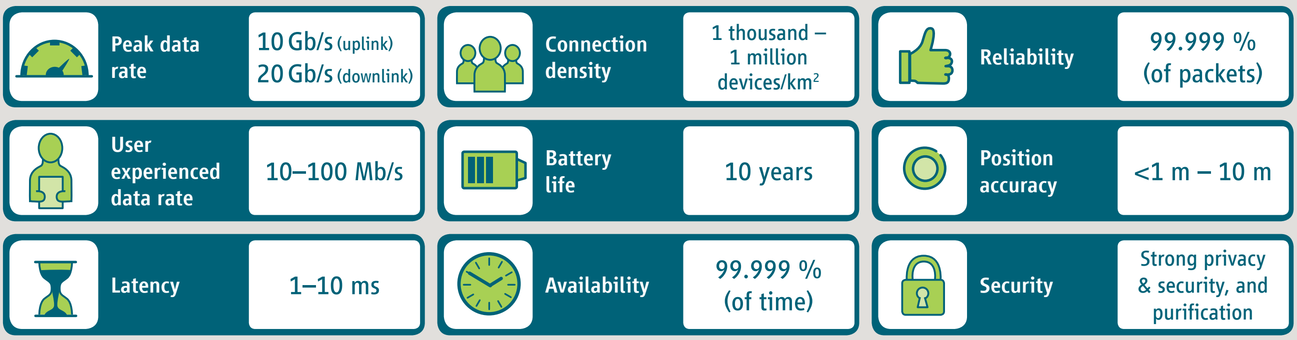
The rationale for the development of the 5th generation of mobile communications (5G) was not only to expand the broadband capabilities of mobile networks, but also to provide advanced wireless connectivity for a wide variety of vertical industries, such as the manufacturing, automotive and agricultural sectors. To achieve this, 5G supports three essential types of communication: enhanced mobile broadband (eMBB), massive machine-type communication (mMTC), and ultra-reliable low-latency communications (URLLC).

Key Characteristics of 5G

eMBB provides extremely high data rates (of up to several Gb/s) and offers enhanced coverage, well beyond that of 4G. mMTC is designed to provide wide-area coverage and deep indoor penetration for hundreds of thousands of IoT devices per square kilometer. In addition, mMTC is designed to provide ubiquitous connectivity with low software and hardware requirements from the devices, and will support battery-saving low-energy operation. URLLC can facilitate highly critical applications with very demanding requirements in terms of end-to-end (E2E) latency (down to the millisecond level), reliability and availability. This includes, for example, high-performance connectivity for applications in industrial automation and control.

Some of the target key performance indicators of 5G as specified by the International Telecommunications Union (ITU) are summarized in Figure 1 (cf. [1] and Chapters 1-2 in [2]). In order to support the three service types defined above and the diverse requirements of the anticipated 5G use cases by a common cellular infrastructure, network slicing, a new concept introduced in 5G, will allow simultaneous but isolated provisioning of diverse services by the same network infrastructure.

Figure 1: Selected target key performance indicators of 5G according to ITU-R (cf. [1])



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Industrie 4.0 and the Role of 5G

The fourth stage of the Industrial Revolution, also termed "Industrie 4.0", is the next era in industrial production, aiming at significantly improving the flexibility, versatility, usability and efficiency of future smart factories. Industrie 4.0 integrates the Internet of Things (IoT) and related services in industrial manufacturing, and delivers seamless vertical and horizontal integration down the entire value chain and across all layers of the automation pyramid [3]. Connectivity is a key component of Industrie 4.0 and will support the ongoing developments by providing powerful and pervasive connectivity between machines, people and objects. Moreover, wireless communication, and in particular 5G, is an important means of achieving the required flexibility of production, supporting new advanced mobile applications for workers, and allowing mobile robots and autonomous vehicles to collaborate on the shop floor – these being just a few examples.

5G Roadmap

The 3GPP (3rd Generation Partnership Project, www.3gpp.org) organization began work on the specification of 5G in early 2017. The standardization work has been divided into two major phases: standardization of the fundamental 5G building-blocks has already been completed in June 2018 (Release 15), and further enhancements will be added until the end of 2019 (Release 16). Although the first limited deployments of 5G will be seen in the second half of 2018 (mainly in order to provide eMBB), large-scale 5G deployments can be expected only from the year 2020 onwards. 5G will combine two radio technologies: a novel radio interface technology denoted as new radio (NR), and the evolution of LTE.

Looking ahead to 2026, digitalization revenues from 5G for ICT players are estimated to exceed 1,200 billion USD, of which approximately 234 billion USD is accounted for by the corresponding vertical manufacturing [4]. In business terms, this constitutes an incredibly large and fast-growing market.

Goal of this White Paper

The aim of this white paper is threefold. Firstly, to provide a glimpse of the use cases and requirements of the industrial domain; secondly, to explain the main building blocks and features of 5G; and thirdly, to rationalize the need for a joint initiative by all relevant players in the emerging 5G ecosystem in manufacturing, such as the newly established "5G Alliance for Connected Industries and Automation" (5G-ACIA). Such an alliance will ultimately ensure that a sustainable 5G ecosystem for industries and automation becomes a reality.

2 Industrial Use Cases and Requirements

The industrial domain is diverse and heterogeneous and is characterized by a large number of different use cases and applications, with sometimes very diverse requirements. Major areas, such as discrete manufacturing, may differ substantially from others, such as the process industry. This holds true with respect not only to quality-of-service requirements, but also to typical deployment scenarios and the like. In general, however, common to all relevant areas of application is that a new generation of industrial connectivity solutions may lead to substantial improvements and optimizations [5].

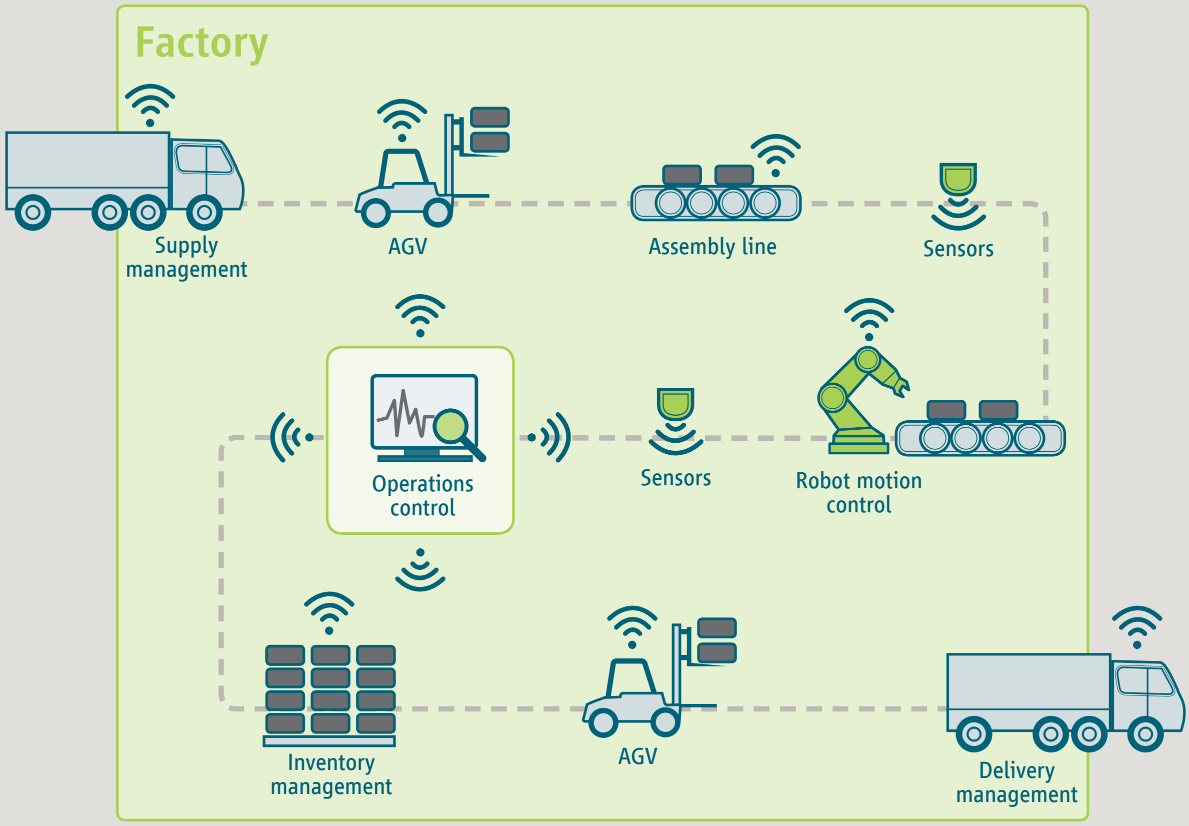
Among the important aspects of different use cases that need to be considered are quality of service, security and safety, reliability and availability, brownfield support, backward and forward compatibility, cost-efficiency, and maintainability and manageability of the solutions by domain-specific personnel. An exhaustive discussion of a large number of different use cases and associated requirements lies beyond the scope of this white paper. Only representative examples will therefore be outlined and discussed below. In this respect, Section 2.1 describes some example use cases, including various performance requirements, whereas Section 2.2 focuses on requirements related to more operational and functional aspects.

2.1 Use Cases and Performance Requirements

5G has the potential to provide (wireless) connectivity for a wide range of different use cases and applications in industry. In the long-term, it may actually lead to convergence of the many different communication technologies that are in use today, thus significantly reducing the number of relevant industrial connectivity solutions. Just as there is an ongoing trend towards Time-Sensitive Networking (TSN) for established (wired) Industrial Ethernet solutions, 5G is likely to become the standard wireless technology of choice, as it may for the first time enable direct and seamless wireless communication from the field level to the cloud.

Figure 2 illustrates different examples of where the benefits of 5G can be used in a factory in the future. Promising application areas range from logistics for supply and inventory management, through robot and motion control applications, to operations control and the localization of devices and items. Interestingly, 5G is likely to support various Industrial Ethernet and TSN features, thereby enabling it to be integrated easily into the existing (wired) infrastructure, and in turn enabling applications to exploit the full potential of 5G with ease.

Figure 2: Exemplary application areas of 5G in the factory of the future

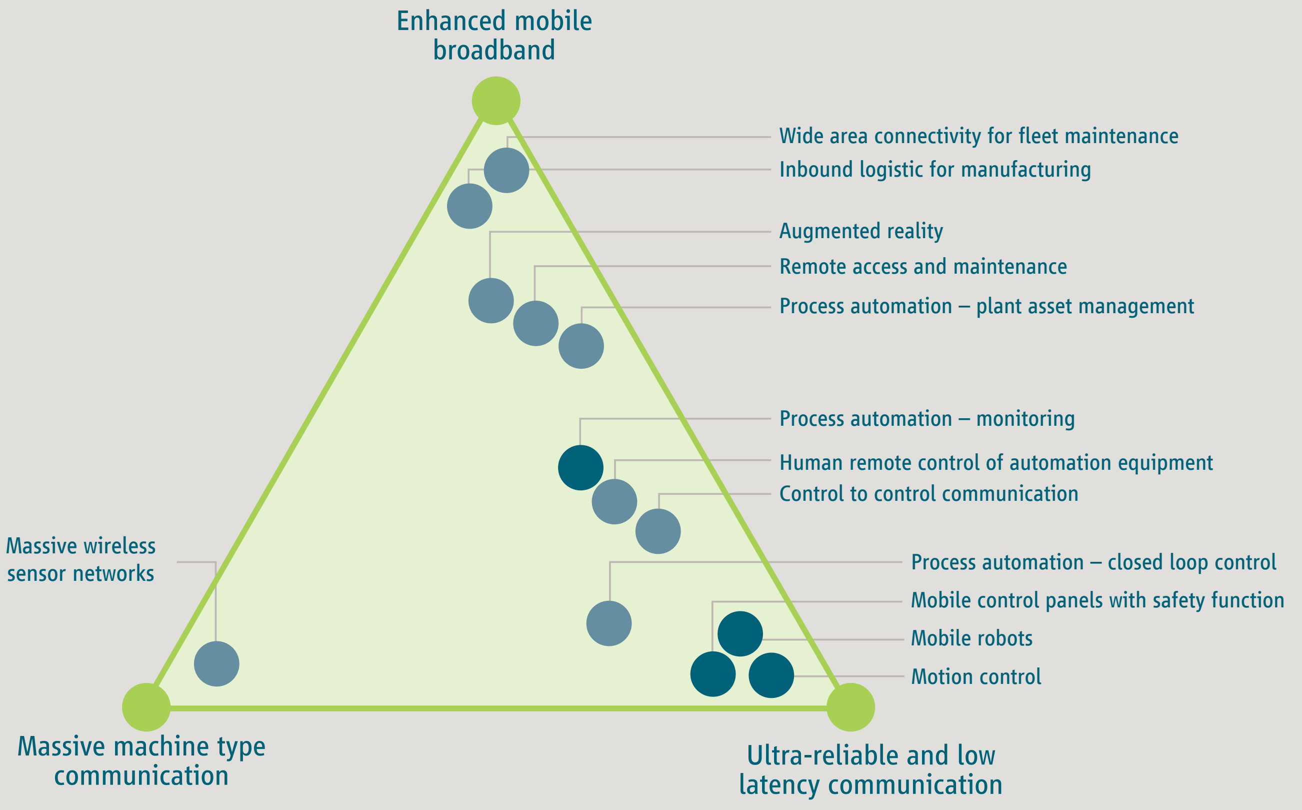


Source: ZVEI

Certain more concrete use cases for the "Factory of the Future" have already been defined and analyzed by 3GPP, with considerable support from a number of vertical industry players, in technical report TR 22.804 [7]. In this respect, wireless communication and in particular 5G may support achievement of the fundamental goals of Industrie 4.0, namely to improve the flexibility, versatility and productivity of future smart factories. An illustrative overview of some of the use cases outlined in TR 22.804 is shown in Figure 3, in which the individual use cases are arranged according to their major performance requirements, classified according to the basic 5G service types eMBB, mMTC and URLLC. As can be seen, industrial use cases, such as motion control or mobile robotics, may have very stringent requirements in terms of reliability and latency, whereas others, such as wireless sensor networks, require more mMTC-based services. However, use cases and applications also exist that require very high data rates as offered by eMBB, such as augmented or virtual reality.

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

Figure 3: Overview of selected industrial use cases and arrangement according to their basic service requirements



Source: ZVEI

Certain more detailed performance requirements of selected factory / process automation use cases (those indicated with a blue circle in Figure 3) are provided in Table 1 (see also 3GPP TR 22.804 [7] for further information). As can be seen, industrial use cases may have the highest requirements in terms of availability and latency/cycle time and are often characterized by somewhat small payload sizes. The cycle time is the transmission interval in periodic communication, which is often used in industrial automation. The latency is usually smaller than the cycle time.

In this respect, "availability" refers to the "communication service availability". This means that a system is considered to be available only if it satisfies all other required quality-of-service parameters, such as latency, data rate, etc. It is therefore typically quantified by the percentage of time during which a system operates correctly. In contrast, reliability – another important indicator – represents how long correct operation continues. This in turn is typically defined as the (mean) time between failures. Availability and reliability are closely related to the productivity of a system. A system exhibiting low availability is rarely ready for operation and is characterised by low productivity. If the system reliability is low, the system often comes to a halt, preventing continuous productivity [6] [7]. The 5G system is envisioned as being capable of meeting or even exceeding the industrial availability/reliability requirements of today's production lines.

Comparison of the 5G requirements listed in Figure 1 with those in Table 1 shows clearly that some of the industrial automation requirements will not be addressed in the first release of 5G, which mainly focuses on eMBB. Instead, these requirements are expected to be addressed in future releases, in particular Release 16.

Table 1: Industrial use cases

Use case (high level)		Availability	Cycle time	Typical payload size	# of devices	Typical service area
Motion control	Printing machine	>99.9999%	< 2 ms	20 bytes	>100	100 m x 100 m x 30 m
	Machine tool	>99.9999%	< 0.5 ms	50 bytes	~20	15 m x 15 m x 3 m
	Packaging machine	>99.9999%	< 1 ms	40 bytes	~50	10 m x 5 m x 3 m
Mobile robots	Cooperative motion control	>99.9999%	1 ms	40-250 bytes	100	< 1 km^2
	Video-operated remote control	>99.9999%	10 – 100 ms	15 – 150 kbytes	100	< 1 km^2
Mobile control panels with safety functions	Assembly robots or milling machines	>99.9999%	4-8 ms	40-250 bytes	4	10 m x 10 m
	Mobile cranes	>99.9999%	12 ms	40-250 bytes	2	40 m x 60 m
Process automation (process monitoring)		>99.99%	> 50 ms	Varies	10000 devices per km^2	

Source: ZVEI

2.2 Operational and Functional Requirements

In addition to operational and functional requirements, industrial use cases typically also present operational or functional requirements. Examples of operational requirements include the demands for simple system configuration, operation, management, SLA assurance mechanisms (e.g. monitoring, fault management, etc.), and the like. Examples of functional requirements include aspects such as security, functional safety, authentication, identity management, etc. In the following sections, we briefly introduce and discuss a number of requirements originating but not exclusively from the manufacturing and process industry.

Dependable communication

A critical operational requirement is for a production line to operate smoothly and faultlessly; this implies that every station and component should work as intended. This requirement can be subsumed as the dependability (of an item). This is the "ability to perform as and when required", and is an important property of any automation system. Dependability can be broken down into five properties: reliability, availability, maintainability, safety, and integrity [6] [7]. Reliability and availability were introduced in Section 2.1. A brief definition of the remaining properties is as follows:

- Network maintainability is the "ability to be retained in, or restored to, a state in which it can perform as required under given conditions of use and maintenance" [6].
- Safety stands for the absence of catastrophic consequences on user(s) and environment.
- Network integrity is the "ability to ensure that the data throughput contents are not contaminated, corrupted, lost or altered between transmission and reception" [6].

Many industrial use cases have quite high requirements on dependability, especially compared to traditional use cases in the consumer domain.

Support of Functional Safety

Functional safety is one of the most crucial aspects in the operation of industrial sites. Accidents can potentially harm people and the environment. Safety measures must be applied in order to reduce risks to an acceptable level, particularly if the severity and likelihood of hazards are high. Like an industrial control system, the safety system also conveys specific information from and to the equipment under control. Some industrial network technologies are able to transport both industrial control information and safety-critical information. This could be achieved by implementing functional safety (e.g. based on suitable safety protocols) as a native network service, which would ensure proper safety provisioning.

A 5G system applied in industrial automation should also support functional safety. It is important for the safety design to determine the target safety level, including the range of applications in hazardous settings. In accordance with this level, safety measures can be developed for and used by 5G based on proven methods.

Security

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

In addition, device authentication, and message confidentiality and integrity are crucial for industrial communication systems. While data confidentiality is very important in order to protect company IP and prevent industrial espionage, data integrity becomes of paramount concern for industrial applications. This particularly applies to machine-to-machine communication in which data is used to either feed the control loop or control actuators. In this context, checks for data manipulation are not usually applied, resulting in compromised data being accepted as long as the values lie within a valid data range. This can lead for instance to machine failure or quality issues if not detected.

Finally, the security architecture must support the deterministic nature of communication, scalability, energy efficiency, and low latency requirements for industrial applications.

Cost efficient and flexible processes

Due to the trend towards increasingly individualized products, the number of parts in a given production batch is decreasing significantly. Indirect and horizontal operational processes such as bid proposals, order management, billing, production planning or programming of machine tools must also be considered, since their impact increases accordingly. Production and operational processes must become more cost-efficient and flexible. Reductions in CAPEX and OPEX could be attained through reduced engineering costs (e.g. by the provision of on-demand infrastructures, system automation, etc.). Achieving flexibility in processes can be done by using virtualization, process modularization, and cloudification.

Rethinking existing processes and introducing new processes for the transmission, handling and calculation of production data is essential for developing new solutions for accomplishing the afore mentioned cost efficiency and flexibility. One example are local data centers that support critical industrial applications by way of an edge computing approach. In this case, existing infrastructures must be modified to tackle the new challenges. For instance, industrial applications can be deployed locally within an edge data center to reduce latency. Many other examples exist, all having in common that a shift to software-based solutions resolves traditional borders in the IT system environment and presents new opportunities in business models.

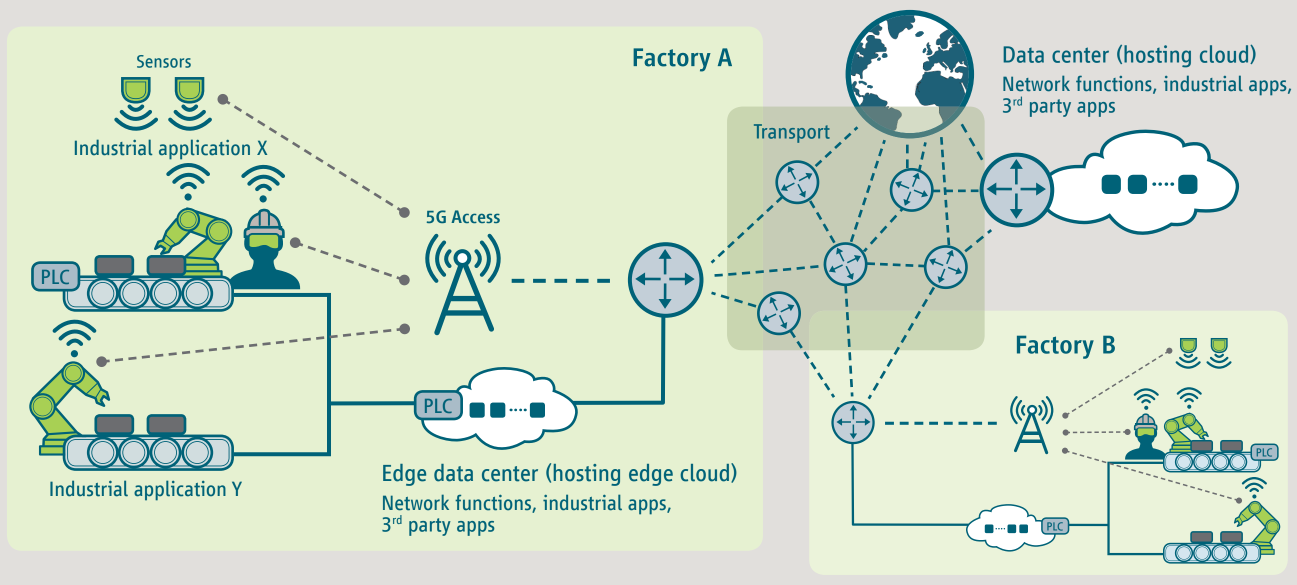
3 5G Key Technologies and Main Features

This section provides a brief overview of the basic 5G system architecture in Section 3.1, together with some of the key technologies for achieving the unprecedented and highly flexible performance of the 5G system in Section 3.2.

3.1 Basic 5G System Architecture

The main domains of a 5G system are access, transport, management, cloud, and applications (including network functions and 3rd party applications). Traditionally, access, transport and management have been key areas in the cellular industries. Cloud and applications are traditional IT areas that have progressively become an integral part of cellular systems. The access domain provides wireless connectivity between the devices and the access nodes (e.g. a base station (BS)). The transport domain enables connectivity between remote sites and equipment/devices. The transport networks are interconnected via backbone nodes that carry information from the access nodes to the data centers, where most of the data is stored and the network is managed. An exemplary 5G system architecture for a smart factory scenario is shown in Figure 4. It illustrates that 5G may provide both communication within the factory and with other factories.

Figure 4: 5G-enabled smart factory scenario



Source: ZVEI

5G systems comprise control and data planes. Most of the control plane intelligence (mobility management, session management, etc.) resides in the data center, while most of the data plane intelligence resides in the access network (scheduling, QoS, multi-user).

Similarly to TSN, a 5G network contains a management and application domain, which may partly run on cloud technologies. The network management entities in 5G systems automate and manage a range of lifecycle management processes. Furthermore, they coordinate complex dynamic systems consisting of applications, cloud, transport and access resources. Finally, applications, including many network applications, can run in cloud environments (with the exception of dedicated functions in the access nodes). The applications can be logically centralized or distributed, depending on the requirements.

5G can be characterized as a modular communication system, with in-built privacy and security, which is built upon the cloud approach and can be flexibly configured to meet different service requirements.

3.2 5G Key Technologies

A brief overview is provided below of some of the main key technologies for each of the basic 5G services (i.e. URLLC, eMBB and mMTC). In addition, further important aspects, such as mobility, QoS, security and slicing, are briefly presented.

Latency & Reliability for Ultra-Reliable Low-Latency Communication (URLLC)

For URLLC, the first release of 5G (Release 15) already has the capability to achieve a latency of 1 ms with a reliability of 99.999% over the 5G radio interface. This permits reliable transmission of small data packets (with a size of only a few bytes) over the air within a specified time limit, as required for closed-loop control applications, for example. Low-latency communication is enabled by the introduction of short transmission slots, allowing faster uplink and downlink transmissions. By reducing the transmission duration and interval by flexible adjustments, both the time over the air and the delay introduced at the transmitter while waiting for the next transmission opportunity are reduced.

Higher reliability can be achieved for instance by the use of robust modulation and coding schemes (MCS) and diversity/redundancy techniques. Known channel coding schemes are used (such as Turbo codes or low-density parity check (LDPC) codes for data channels in 3GPP Release 15; and tail-biting convolutional or Reed-Müller codes or Polar codes for control channels). Further improvements are expected to be introduced to satisfy the requirements of smart factories. Redundancy can be provided by various means, e.g. multi-antenna, frequency or time diversity. Multi-connectivity via multi-carrier or multiple transmission points is a further possible diversity technique, in which the device is connected to the radio network via multiple frequency carriers. Several flavors of multi-connectivity have been defined in 3GPP. While these features previously focused on improving the user throughput by aggregating the resources of the different carriers used, the focus has recently shifted to improving the transmission reliability.

Data Rate for eMBB

For eMBB, 5G will support peak rates of 20 Gb/s in the downlink and 10 Gb/s in the uplink [1]. Such high data rates are mainly enabled by a wide system bandwidth (up to 400 MHz), massive MIMO using a large number of antennas[1] , and high modulation orders, such as 256 QAM or even higher in future releases. 5G intends to support operation at carrier frequencies from below 1 GHz to up to 86 GHz, and also operation in both the licensed and license-exempt spectrum. At quite high carrier frequencies above 6 GHz, in particular, large chunks of the spectrum are still available; it must however be taken into account that the propagation conditions at such high frequencies can be quite challenging, since signals may easily be blocked by walls or even the human body.

Low Complexity, Battery Life, Coverage and Device Density for mMTC

For mMTC usage, 5G will provide connection densities far exceeding the requirement of 1,000,000 devices per km^2 [1], 20 dB coverage improvements (resulting in a coupling loss of 164 dB), and battery lifetimes exceeding 10 years: see Chapter 3 in [2]. The support of a large device population per km^2 is achieved by the use of efficient signaling. The coverage extension (20 dB better than 4G) is attained by the use of time repetition of the transmitted information and the reduction of active frequency bandwidth.

[1] In theory, the supported number of antennas is unlimited in 3GPP Release 15 for LTE and NR. In practice, the number is limited to hundreds of antennas due to implementation design constraints.

The low device complexity and cost (of less than a few dollars) is achieved by limiting the transmission bandwidth (to 1 MHz or less), the peak rate (to a few hundreds of kb/s) and the output power (20 dBm). In addition, half-duplex transmission is used to avoid duplex filters. Finally, the long battery lifetime (5 - 10 years) is achieved by allowing extended discontinuous reception to extend the sleep mode of a device.

Mobility

Some use cases, such as autonomous guided vehicles, mobile robots and mobile control panels with safety functions, require seamless mobility for reliable operation and ubiquitous connectivity. 5G can support these use cases, as it has robust mobility mechanisms capable of supporting seamless mobility across the network in a variety of scenarios, such as different cell sizes, high-speed devices and heterogeneous propagation environments. Mobility procedures are configured by the network, allowing for fine-grained control of performance trade-offs. Mobility performance can be further enhanced through multi-connectivity, in which a device is connected simultaneously to more than one base station.

Quality of Service

Traffic classification and prioritization are important requirements for industrial networks. 5G provides a flexible QoS framework that can support traffic flows with a range of QoS requirements over the same network. Traffic classification rules have recently been enhanced in 3GPP with the inclusion of Ethernet frame headers, to provide better support for protocols used in industrial networks (cf. 3GPP TS 23.501)[8] .

Security

5G includes strong E2E security. In particular, mutual authentication between the device and the network is supported. All transmitted data is encrypted E2E between the device and the network. 5G also supports a flexible authentication framework with the Extensible Authentication Protocol (EAP) and strong encryption, while meeting strict latency requirements.

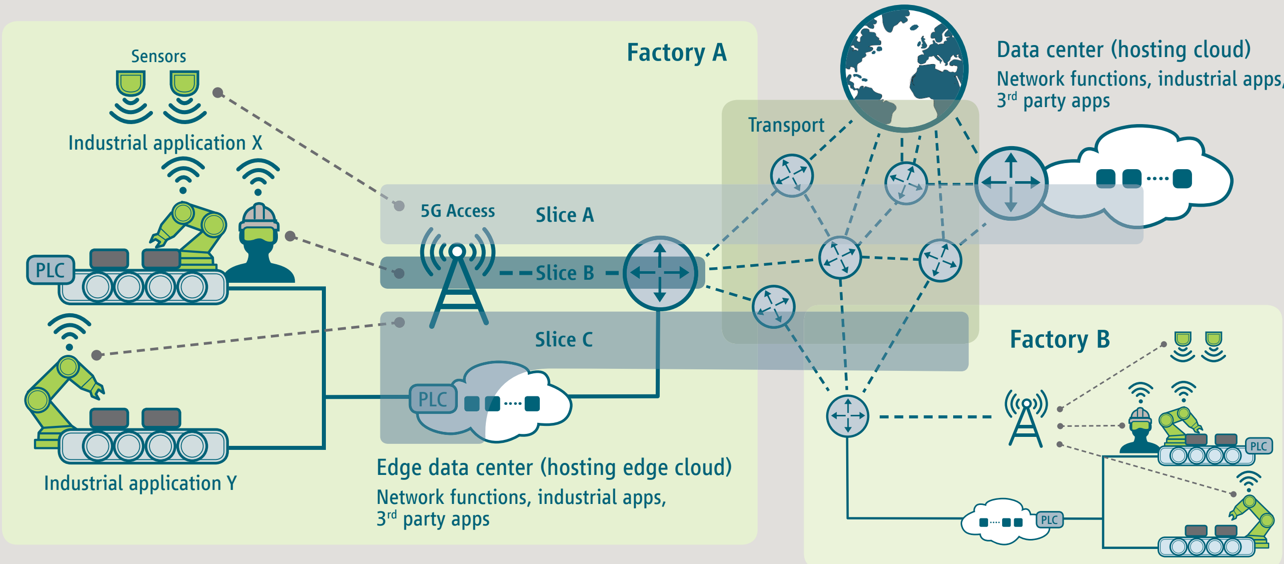
Network Slicing

TTraditional telecommunication systems have been built upon physical entities providing a monolithic network for services of all kinds; this network has been configured statically without flexibility for service provisioning. Although service differentiation was possible by means of QoS methods, there were no strict performance guarantees, particularly for critical types of services. The concept of network slicing, which is one of the key novel features of 5G, enables use cases with very diverse requirements to be addressed, based on a common physical infrastructure. In particular, network slicing permits the establishment of multiple logical/virtual networks to handle different use cases, these logical networks running simultaneously on the common physical infrastructure. Different logical networks could be customized with guaranteed SLA according to the requirements of the use cases of a particular vertical industry. Such logical networks are denoted as network slices in 5G terminology.

As mentioned previously, 3GPP Release 15 considers three basic types of service, namely eMBB, mMTC and URLLC. Slicing can be used as a means of separating these services in an optimal and desirable way: a separate slice can be set up for each service, for example. In performance terms (for example with respect to latency, throughput, availability/resilience, reliability), each slice could well cover the requirements from the different use cases, such as the industrial cases introduced in Section 2. Besides satisfying performance requirements, network slicing could also resolve the functional requirements of the manufacturing use cases, such as safety and security. For instance, a network slice can be designed with more advanced and customized security protection mechanisms, which could be very different to those used in other network slices. Moreover, in order to achieve a high degree of isolation, dedicated resources could be allocated exclusively to a network slice without sharing it with the other network slices.

Last but not least, network slicing can resolve the operational requirements of different manufacturing use cases. Different industrial applications may have different monitoring and data collection requirements. Moreover, one plant may dynamically host its own production load as well as the production load of their customers; charging/billing mechanisms could therefore be customized for a specific network slice that is used by its customers. In order to attain this vision, network slicing is an E2E system architecture solution that is applied to each of the 5G domains, i.e. access, transport, cloud, etc., as indicated in Figure 5. Figure 5 also shows that a slice may be purely local within a factory (such as "Slice B"), but may also include public networks, for example for connecting two different factories (such as "Slice C") or for establishing a connection to a cloud (such as "Slice A"). Services provided by 5G network slicing will change traditional engineering approaches in the manufacturing industry, as it will permit on-demand dynamic engineering solutions ranging from the agile reconfiguration of adaptive machines to the rapid ramping up of equipment, machines and systems by providing deterministic, secure, and reliable connectivity. Network slicing could also extend beyond a single plant, as it allows cross-plant communication on a global scale.

Figure 5: Network slicing concept



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4 Major Challenges

Besides the highly promising opportunities presented by 5G for Industrie 4.0, certain major challenges must also be addressed in order for the full potential of 5G to be unleashed. Some of these challenges are outlined in more detail below.

Challenge 1: Timing to influence 5G standardization

Even though 5G is envisioned to support a wide range of use cases in manufacturing, 5G-related standardization bodies and the manufacturing industry are not yet fully aligned. Telecom vendors and mobile network operators should collaborate closely with the manufacturing industry on 5G-enabled manufacturing solutions. With 3GPP Release 15, the first 5G standard has already been frozen in June 2018. It is mainly focusing on eMBB services. Vertical-specific services, like URLLC, will be enhanced in Release 16, which is expected to be finalized by the end of 2019, as well as Release 17 following afterwards. Hence, there is not too much time left to contribute input from the industrial domain to 3GPP Release 16 in order to guide the 5G system design in such a way that the needs and requirements of the industrial domain are adequately addressed.

Challenge 2: How to develop 5G to support e.g. the manufacturing industry?

Manufacturing industry must communicate its requirements to the 5G community (e.g. 3GPP, ETSI, etc.) and cooperate with it to produce technical solutions to address these requirements properly. A first step towards considering the use cases and requirements of the industrial domain has already been made in 3GPP through the study items on "Communication for Automation in Vertical domains" (CAV) (3GPP TR 22.804) [7], and "LAN Support in 5G" (3GPP TR 22.821) [9]. However, it may be challenging for many players in the OT industry to participate directly in relevant standardization bodies. The existence of a suitable platform/organization outside the actual standardization groups, on/in which different views on relevant use cases and requirements will be aligned in advance, is therefore essential. Such a platform/organization could also support the development of appropriate technical concepts and solutions, and should be highly focused on the industrial domain.

Challenge 3: Spectrum and operator models

The availability of a suitable spectrum is an important aspect in the deployment of 5G services for industrial applications. In order to meet extremely demanding latency and reliability requirements, a licensed spectrum is highly preferred. Alternative means of accessing a licensed spectrum may exist, for example through regional licenses or by subleasing from (nationwide) mobile network operators; these differ in their benefits and drawbacks. It is important for suitable spectrum usage options and operator models to be found that take the specific requirements of the industrial domain into account and represent a fruitful basis for the success of 5G in industry. This requires constructive discussions between all relevant stakeholders, including factory owners, mobile network operators, regulators and technology providers.

Challenge 4: Safety and security

The current security architectures and solutions must be investigated with respect to the requirements of industrial (real-time) applications under the 5G umbrella. A clear safety policy must be elaborated, including a thorough analysis of the extent to which safety-critical industrial applications can be supported by 5G infrastructures. Gaps must be identified and existing architectures and solutions adjusted/extended until the requirements of both security and safety are fulfilled.

Challenge 5: 5G-enabled industrial components

Industrial components such as machines and robots differ significantly from existing mobile devices such as smartphones. At present, considerations concerning 5G in manufacturing are focused primarily on the network side. However, it is also essential to understand the implications for a 5G-capable industrial device. For instance, a connectivity module may be upgraded more frequently than an industrial component. In addition, the 5G system must be closely compatible with other established communication technologies, such as Industrial Ethernet systems or fieldbuses, since factories are typically characterized by brownfield installations. A seamless integration and migration path should therefore be thought through clearly from the very beginning. Furthermore, since industrial machinery is typically in use for significantly long periods, specific requirements also exist with respect to the required support for communication services and 5G components, such as corresponding 5G chipsets.

Challenge 6: Establishment of a common language

The manufacturing ecosystem will be extended from the conventional setup (including, for example, component providers, machine builders, system integrators, certification bodies, etc.) to embrace the entire ICT field, including telecom vendors and operators, the electronics industry (chip providers) and the IT domain (e.g. cloud computing). The overall success of 5G in manufacturing depends strongly on close collaboration between players throughout the ecosystem. However, each industry has developed its own terminology and conceptual structures. In order for all affected industries to work together smoothly and efficiently, one of the major challenges is for them to join in developing a common language.

Challenge 7: Testbeds and trials

From concept to reality, from research lab to commercial market, 5G-enabled manufacturing industry-related technologies require sufficient validation from testbed/trail activities based on close collaboration across the entire ecosystem. Players from different industries must therefore develop a new knowledge base, for instance by means of common testbeds and extended field trials.

Challenge 8: Transparency of 5G connection in the radio access and core network

The existing cellular networks (2G, 3G, 4G) possess no standardized method by which industrial applications can access diagnostic information on wireless communication in the cell, on Internet connectivity in the connected backbone, etc. 5G must however offer transparent diagnostic information on the connectivity, the level of service, the E2E performance, etc. and expose this information to third parties. This is essential for real-time monitoring of the network performance and for efficient root-cause analysis in the event of connectivity problems.

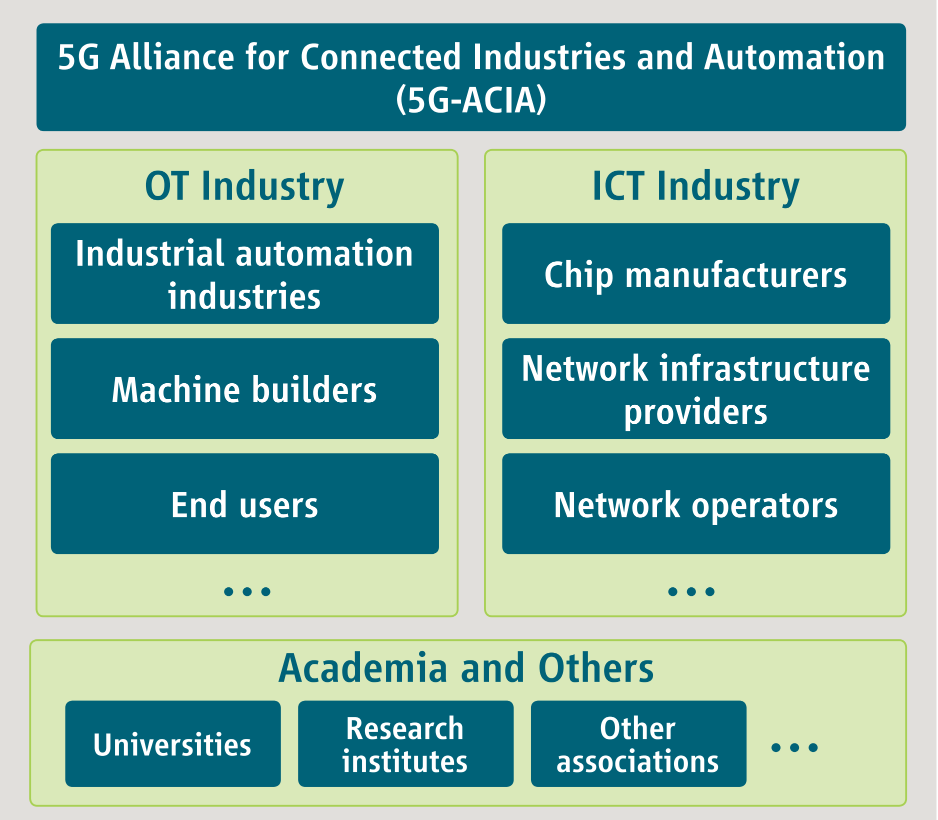
5 5G Alliance for Connected Industries and Automation

One of the main differences between 5G and previous generations of mobile networks is 5G's strong focus on machine-type communication and the IoT. As has been outlined before, this paves the way for numerous new use cases and applications in many different vertical domains, including the automotive, healthcare, agriculture and energy sectors, and in particular, industrial manufacturing and production. In order to ensure that the specific needs and requirements of a particular vertical industry are adequately understood and considered by the telecom industry and, likewise, the capabilities of 5G are fully realized and exploited by the vertical industries, close collaboration is required. Only when all relevant players in the emerging new ecosystem join forces can the full potential of 5G be realized. This particularly holds true for the industrial domain, which is characterized by a large number of potential use cases with potentially highly demanding and versatile requirements and specific general conditions. However, since the industrial domain is only one of many new potential application areas of 5G, it is even more important for it to acquire a strong voice in the relevant communities and organizations.

5.1 Objectives of 5G-ACIA

The 5G Alliance for Connected Industries and Automation (5G-ACIA) has been established to serve as the central and global forum for addressing, discussing, and evaluating relevant technical, regulatory, and business aspects with respect to 5G for the industrial domain. It reflects the whole ecosystem and all relevant stakeholder groups from the OT industry (industrial automation, machine builders, end users, etc.), ICT industry (chip manufacturers, network infrastructure vendors, mobile network operators, etc.), academia and other groups, as shown in Figure 6.

Figure 6: Overview of selected main stakeholder groups participating in 5G-ACIA



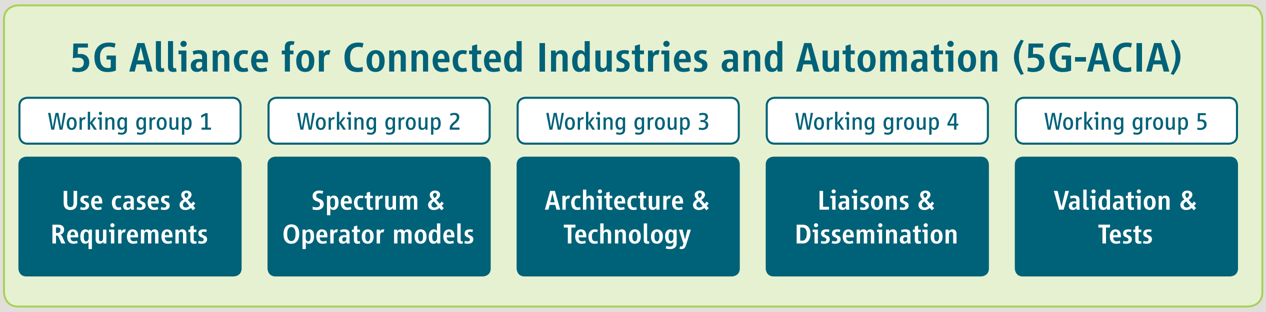
Source: ZVEI

The paramount objective of 5G-ACIA is to ensure the best possible applicability of 5G technology and 5G networks for connected industries, particularly including the manufacturing and process industry. 5G-ACIA will ensure that the interests and particular aspects of the industrial domain are adequately considered in 5G standardization and regulation. 5G-ACIA will further ensure that the ongoing 5G developments are understood by and transferred to the industrial domain. Standardization and regulation are extremely important, since 5G is emerging at a rapid pace, and many players from the industrial domain have not been engaged in relevant telecom standardization processes in the past, and vice versa. Furthermore, a common language and understanding of relevant aspects are being established by bringing the whole ecosystem together. In addition, industry-specific needs are being discussed and elaborated, such as the possible need for dedicated certification and similar processes. As a first result, several aspects that should be considered in order to ensure the success of 5G for the industrial domain can be found in the appendix.

5.2 Structure

The activities of the 5G-ACIA are currently structured in five different working groups (WGs), as depicted in Figure 7.

Figure 7: Current 5G-ACIA working group structure



Source: ZVEI

WG 1 discusses potential use cases and requirements and defines a common body of terminology. WG 2 identifies and articulates the specific spectrum needs for industrial 5G networks and explores new operator models, for example for operating private or neutral-host 5G networks within a plant or factory. The overall architecture of future 5G-enabled industrial connectivity infrastructures is considered in WG 3, which also includes possible integration concepts and migration paths, together with the evaluation of key technologies emerging from 5G standardization bodies. WG 4 takes care of interaction with other initiatives and organizations by establishing liaison activities and initiating suitable promotional measures. Finally, WG 5 deals with the final validation of 5G for industrial applications, which includes the initiation of interoperability tests, larger trials, and potentially dedicated certification procedures. Horizontal topics, such as safety and security, along with pre-consensus building for relevant standardization activities, will be covered in some form or other by all working groups.

5.3 Who Should Join 5G-ACIA?

5G-ACIA is open to all organizations actively supporting its objectives. Companies from the industrial domain may wish to join the initiative in order to prepare themselves in good time for the disruptive changes potentially accompanying 5G in the future, and in order to ensure proactively that 5G fits their specific needs and requirements. Likewise, companies from the ICT domain may wish to join the 5G-ACIA in order to obtain a better understanding of the industrial domain and to gain insights into a highly attractive new market.

6 Standardization and Regulation

A number of key prerequisites for leveraging the benefits of 5G for the industrial domain are introduced and briefly discussed below. This particularly includes aligned standardization roadmaps and compatible regulatory environments that enable the ICT and OT industries to work together efficiently.

Standardization – collaborative standardization including harmonized roadmaps involving ICT and OT players must guarantee the timely availability of products.

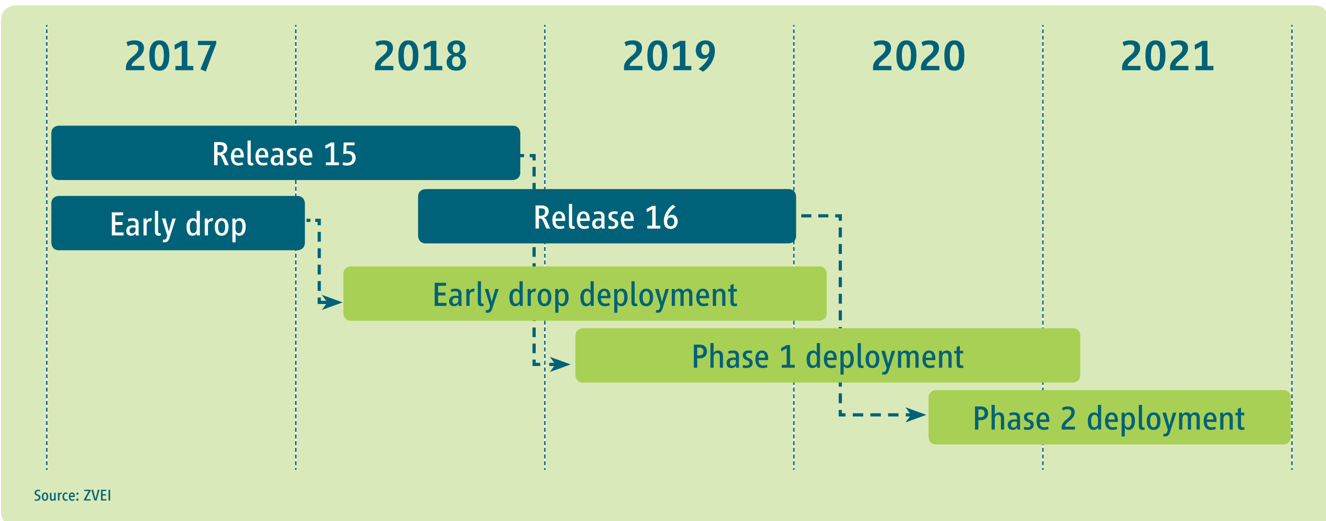
Since, before now, industrial OT and ICT have been two almost disjoint market segments, the respective standardization roadmaps and even the responsible standardization groups and organizations have not yet been fully aligned. Moreover, the 3GPP organization, which is responsible for 5G standardization, will benefit from the support of industrial stakeholders in order fully to understand their requirements and the potential technical implications of 5G. Finally, addressing brownfield scenarios and supporting industrial private network concepts will require the integration of 3GPP and industrial communication technologies as defined by other standardization organizations, such as IEEE or IEC. Close collaboration and coordination between ICT and industrial OT players and organizations is therefore required.

5G-ACIA is supporting the work of 3GPP and other relevant standardization bodies (e.g. ETSI) and driving the preparation of harmonized contributions, e.g. for 3GPP Technical Specification Group SA (Service and System Aspects).

The specific interests of the industrial domain will be addressed more thoroughly in 3GPP Release 16, although some features have already become available in Release 15. Figure 8 shows the roadmap for the 3GPP standardization (Releases 15 and 16) and the 5G deployment; this may however be subject to changes. "Early Drop" marks an early version of Re-lease 15 that is not finally frozen but is sufficiently stable to allow initial product development and deployments, e.g. for major sporting events.

5G-ACIA is prepared to support this process. In 5G-ACIA, all working groups will address standardization within their specific scope and all relevant standardization activities (e.g. 3GPP SA and RAN, IEEE, ETSI, IEC) will be monitored.

Figure 8: Timeline of 5G standardization (blue) and deployments (green)



Spectrum – 5G requires careful choice of spectrum usage for meeting the industrial requirements.

The usage of unlicensed spectrum for industrial applications will not satisfy the more demanding quality requirements e.g. latency and reliability. For this reason, the full potential of wireless technologies in industry has not yet been fully realized.

To satisfy the requirements for the industrial applications, there are several spectrum usage options or combination of those options – all with specific benefits and drawbacks – including the following

- Dedicated spectrum for local private industrial networks being realized either by dedicated assignments on a local basis or subleasing from national mobile operators
- Use of dedicated technologies such as network slicing in order to establish dedicated virtual networks on the basis of a mobile operator licensed spectrum

A portfolio of spectrum usage options must be developed and implemented, taking the special requirements of industrial use cases into account.

5G-ACIA is already working on these topics and is supporting the ITU-R process and national regulatory activities, and also promoting appropriate spectrum usage options and role models.

Net neutrality and network slice engineering – connectivity as a key enabler for connected industries must be available on fair and transparent terms.

With connectivity becoming a key enabler for digitalization in industry, fair and transparent access to connectivity services becomes a prerequisite for the acceptance of 5G. It is important that net neutrality policies take into account industry-specific requirements, for example with regard to latency and reliability. In addition, the use of network slices should be covered by a regulatory framework that supports this usage for industry-grade services and innovations with rapidly changing requirements.

5G-ACIA is addressing this topic by raising discussion of network slicing, role models and overall 5G concepts between all relevant stakeholders and preparing joint input for relevant standardization and regulatory bodies, government authorities, etc.

Product qualification – an efficient and timely qualification process for 5G products intended for use in industry must be defined and implemented.

Industrial use cases, particularly safety-critical applications, are covered by a wide range of specific requirements and regulations governing the equipment to be used. Such requirements and regulations are however not generally addressed by the ICT industry. In order to guarantee that 5G can be used for these industrial applications and that the interoperability of ICT and OT components is supported, the equipment must be qualified to meet the respective regulations. An efficient process providing the required profiling, performance validation and certification must be defined and implemented in a timely fashion.

5G-ACIA has defined a working group, WG 5, to address this topic. Product qualification, interoperability trials and conformance tests will be organized by this working group.

7 Conclusion

Industrie 4.0 and manufacturing industry stand to benefit greatly from 5G communication technologies. Various promising use cases have been outlined, with somewhat diverse and often challenging requirements. Key technologies of 5G networks have been described that are potential candidates for the realization of 5G in Industrie 4.0 deployments. However, as great as the benefits of 5G for the industrial domain may appear, challenges of equal magnitude must still be addressed. This applies not only to the technological feasibility of key performance indicators and functional requirements of industrial use cases, but also to challenges regarding cross-industry communication, interaction, harmonization, standardization and regulation. In particular, it is important that mutual understanding between the ICT industry and manufacturing industry be facilitated further. This is one of the reasons for establishment of the 5G Alliance for Connected Industries and Automation (5G-ACIA), which has the goal of ensuring that 5G for Industrie 4.0 ultimately becomes a great success.

8 Appendix

8.1 Key Aspects for Ensuring the Success of 5G for the Industrial Domain

5G-ACIA recommends that future mobile networks and in particular 5G should provide:

(1) Industry-grade quality of service with very low E2E latencies (<1 ms), high synchronicity between different devices (<1 μs), high data rates (up to several Gb/s) and potentially ultra-high communication service availability (>99.9999%), even under challenging industrial propagation conditions with very rich multipath propagation and potentially significant interference.

(2) The ability to deploy and operate private 5G networks in well-defined areas (e.g. within a factory). The required spectrum could be acquired directly from the spectrum regulators through regional/ local licenses or – in some cases – obtained from a mobile network operator through subleasing in a specific geographic area.

(3) Standardized, open and flexible interfaces for seamless interoperability and seamless handovers between public and private (local) 5G networks.

(4) E2E network slicing across heterogeneous technologies, countries and network operators, with facility for dynamic and user-friendly establishment and release of fine-granular, application-specific network slices characterized by well-defined QoS and security properties.

(5) Seamless integration into the existing connectivity infrastructure (e.g. with technologies such as Industrial Ethernet and TSN), taking the special characteristics and requirements of industrial applications into consideration.

(6) Globally or regionally harmonized spectrum, for both licensed and license-exempt allocations.

(7) Appropriate security concepts that consider both remote and local attacks and include appropriate means of device authentication and assuring E2E message confidentiality, authentication and integrity.

(8) A highly flexible and versatile air interface capable of satisfying the highly diverse requirements of the different use cases and applications, ranging from ultra-reliable low-latency communication, through massive machine-type communication, to enhanced mobile broadband.

(9) Support of multiple (well-separated) tenants using the same physical connectivity infrastructure in a factory.

(10) The ability to monitor the current network state continuously in real-time even as a user, to take quick and automated action in the event of problems and to perform efficient root-cause analyzes.

(11) In-built indoor and outdoor user equipment localization with an accuracy of at least 10 cm.

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10 List of Acronyms

3GPP	3rd Generation Partnership Project
5G-ACIA	5G Alliance for Connected Industries and Automation
AI	Artificial Intelligence
BS	Base station
B2C	Business-to-Consumer
CAPEX	Capital expenditures
CAV	Communication for Automation in Vertical
DECT	Digital Enhanced Cordless Telecommunications
E2E	End-to-End
EAP	Extensible Authentication Protocol
eMBB	Enhanced Mobile Broadband
ERP	Enterprise Resource Planning
ETSI	European Telecommunications Standards Institute
ICT	Information and Communication Technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
ITU-R	International Telecommunication Union- Radiocommunication sector
KPI	Key Performance Indicator
LDPC	Low-Density-Parity-Check
MCS	Modulation and Coding Scheme
mMTC	Massive Machine-Type Communication
MNO	Mobile Network Operator
NR	New Radio
OPEX	Operating Expenses
OT	Operational Technology
PER	Packet Error Rate
PLC	Programmable Logic Controller
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RAN	Radio Access Network
SA	Service and System Aspects
SLA	Service Level Agreement
TSN	Time-Sensitive Networking
URLLC	Ultra-reliable low-latency communications

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