

MCP- Mobil Controlled Production / 5G for Digital Factories

Working Paper

Status: Technology Scenario, V1.1

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1 Technology Scenario Classification

MCP – „Mobile Controlled Production – 5G for Digital Factories“: This scenario describes the potentials and new tasks that arise when (mobile) production resources are decentrally controlled, analyzed and optimized using 5G technology. The essential features are real-time capability, high reliability, high data rates and the connectivity to a multitude of transmitters and receivers (scalability).

This first technology scenario "MCP" is complementary to the application scenarios published in 2016 by addressing 5G based, deterministic wireless interfaces and new services in the RAMI 4.0 model, thus representing a technological migration step. Also new business models will arise due to the interaction of involved stakeholders and industries encompassing mechanical engineering, microelectronics and mobile communications to support solutions and infrastructures for digital factories.

2 Abstract

Key is the increase of adaptivity and transparency of distributed production resources in manufacturing ecosystems through the telecommunications standard 5G with focus on cloud-based control of factory automation, adaptive systems and the deployment of new services in the field of logistics, production and quality assurance.

The trend of increasing adaptivity in production plants has led to introduce Plug & Produce capability for modular equipment. Using deterministic wireless telecommunications standards, the effort of commissioning individual components and production cells will be reduced to connecting to the power supply only. Connectivity to the cloud then supports function and configuration of cells by their digital twins. This connectivity facilitates the order-dynamic setup of production resources within or even beyond plant limits giving rise to adaptive digital factories, addressed in this 5G technology scenario.

Orchestration and automation control of the individual modules of adaptive production lines as well as the loading of material are carried out by IT systems in the cloud, which use real-time data analytics and closed loop robot control, facilitated by 5G. The application spectrum ranges from the synchronization of cooperating robots to the fleet management of driverless transport systems. Also Big Data analytics (e.g. real-time processing of large volumes of data derived from video streams of object and environment) is one of the use cases that will benefit from 5G in production.

Already existing standards of CAT-M1 and CAT-NB1 (Narrowband Internet of Things) can be used as part of the current 4G / LTE standard, being continued under 5G in the context of mMTC (massive Machine Type Communication). The narrow-band technology (Low Power Wide Area) for the "Internet of Things" enables large-scale coverage and deep reception in buildings, fueling the trend towards infrastructure-free networking of (partially) autonomous cyber-physical systems via NB-IoT.

3 Technology Features and System Boundary

5G is the next generation of mobile network technology that is envisioned as an essential enabler to achieve Internet of Everything (IoE) vision. Compared to the 4G mobile telecommunication system, 5G will support diverse use cases with very different performance requirements:

- Ultra-low latency which could be less than one millisecond
- Ultra-high reliability of the delivery of data packets within a given delay of 99.999% and more
- Always-on and few hundred to several millions connection per km²
- Peak data rate of up to 10Gbps per connection

Figure 1 depicts a multi-dimensional overview in terms of throughput, latency and number of connections required for the many types of services 5G networks will need to run [7]:

- Immersive experience at least 1Gb/s or more data rates to support ultrahigh definition video and virtual reality applications
- Fiber – like user experience: 10Gb/s data rates to support mobile cloud service
- Response times less than one millisecond latency to support real time mobile control and machine-to-machine applications and communications
- Less than 10 millisecond switching time between different radio access technologies to ensure a consistently seamless delivery of services
- Massive capacity and always on-current mobile network system already supports 5 billion users, this will need to expand to also support billions of machines.

- Energy consumption: energy-per-bit usage should be reduced by a factor of one thousand to improve upon connected device battery life of more than 10 years.

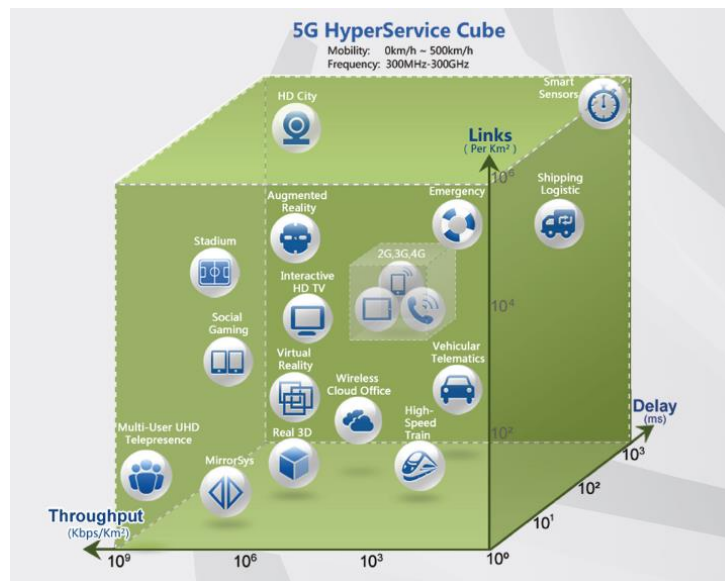


Figure 1: 5G Services [7]

5G radio access infrastructures based on cloud architecture technologies will provide on-demand resource processing, storage and network capacity wherever needed. The evolution of Radio Access Network (RAN) sites will develop toward a “hyper transceiver” approach to mobile access, and will help realize the joint-layer optimization of how radio resources are efficiently utilized. 5G core networks will be designed to seamlessly integrate with current 4G core networks. To support services with a diverse range of requirements, the network slicing concept is expected to be one of the key building blocks of 5G networks according to the recent agreements within standardization bodies [11]. It enables a service-tailored network function provisioning scheme, which aims especially at vertical industries integration, e.g. manufacturing industry.

Currently, three type of network slices are considered in 5G as common understanding within telecom industry: enhanced Mobile Broadband (eMBB), massive Machine Type Communication (mMTC) and Ultra Reliable and Low Latency Communication (URLLC). These three slice types could well capture the requirements from 5G Digital Factory use cases. Services as provided by 5G end-to-end network slicing will change classical engineering approaches in manufacturing industry, as it will enable on-demand, dynamic engineering solutions spanning from agile certification of adaptive machines [20] to fast ramp up of equipment, machines and systems by providing deterministic, safe and reliable connectivity to the cloud or edge. While 4G/LTE as previous technology can be located at levels 1 to 3 within the ISO-OSI model, 5G as successor technology addresses all levels 1 to 7 and is also extending the model. The conventional „bit pipe“ model is no longer applicable because both, the data and its transport from source to recipient may

be subject to dynamic modification. The physical layer is amended by wireline and wireless connectivity within machines and between production modules of production lines on the shopfloor.

Since the deterministic QoS parameter ("Quality of Service" within SLA: Service Level Agreement) of 5G allows network planning and also a model based load forecasting for planning of new applications, this feature supports agile engineering of new plants as well as demand specific update of production equipment matching V-model based systems engineering approaches from design stage on [17].

3.1 Technology Scenario in Relation to Industrie 4.0

5G as a new technology accelerates the convergence of the Internet of Data, the Internet of People, the Internet of Services and the Internet of Things to the "Internet of Everything", the main driver of the evolution of traditional products into smart products [17], see figure 2.

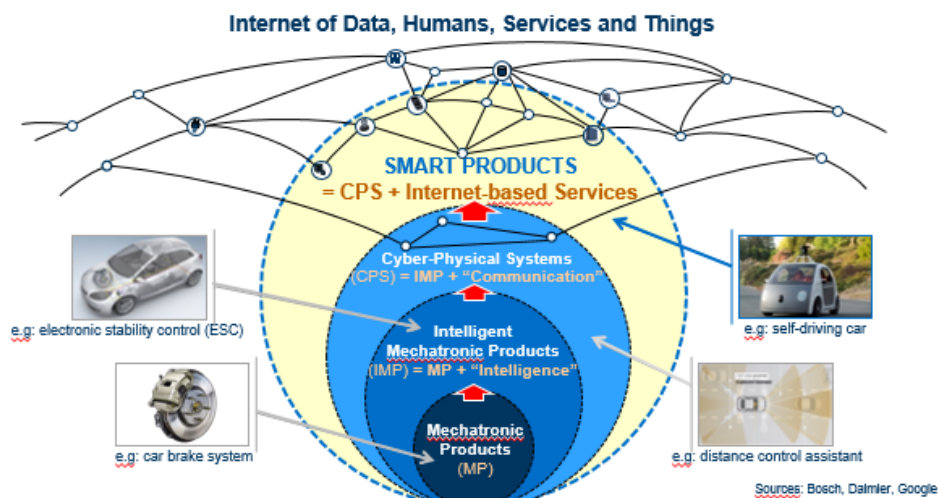


Figure 2: Evolution of mechatronic products to smart products [17]

The increasing miniaturization of microcomputers, sensors, and actuators including more and more software to be embedded has led to an increase of local intelligence of mechatronic products. An example of such intelligent mechatronic product is the Electronic Stability Program (ESP) in cars. Following the evolution path, networking and communication capabilities have been added to the product (or system) in the next step enabling it to connect with other systems. This step makes them "Cyber-Physical Systems" (CPS), such as the Distance Control Assistant in cars. Smart products (SP) then are advanced cyber-physical systems that are linked to intelligent, Internet-based services, so-called smart services [16].

Table 1: Layers of the RAMI 4.0 Model amended by 5G capabilities

<i>Layer</i>	<i>Amendment by 5G Capabilities</i>
<i>Business</i> Organization & Business Process	New roles and service-based business models among stakeholders: -Production: fleet management in logistics, "Robot as a Service", "Video Stream Processing" for quality management - Network Operator: new public-private operator models (LSA) - Infrastructure suppliers: infrastructure as a service
<i>Functional</i> Asset Functions	-Configuration of network elements: rules, intelligence, computing power (e.g., integration of "big data analytics" into the network element) - Demand-specific slicing for customer applications
<i>Information</i> Data	The asset administration shell of the network can - in future- be used already for design and engineering phases in the development process incl. the customer-specific adaptation of equipment during production. Efficiency gain through on demand connectivity -creating value at times and locations, previously lacking network access before (i.e. for mobile robots in logistics).
<i>Communication</i> Access to Data	Flexible configuration of E2E connectivity of I4.0 components. Model-based prediction of network loads in applications. Customer specific tailoring of the network for applications by: - deterministic QoS features (guaranteed SLA) - flexible placement of gateways - Interaction with M2M protocols (MQTT, AMQP, CoAP), OPC UA (IEC 62541) and Ethernet TSN (IEEE 802.1) - Network Management and Orchestration (slicing)
<i>Integration</i> From real world to digital	The different 5G properties: mMTC, eMBB, URLLC allow simultaneous application-specific communications, matching conflicting requirements. Aggregability of data and intelligence (from first node on: edge)
<i>Asset</i> Real World Asset: Field Level	Network components (wireless and wireline: routers and switches, base stations, access points, gateways ...) become RAMI4.0 assets. Frequencies and 5GNR (new radio) can become RAMI4.0 assets.

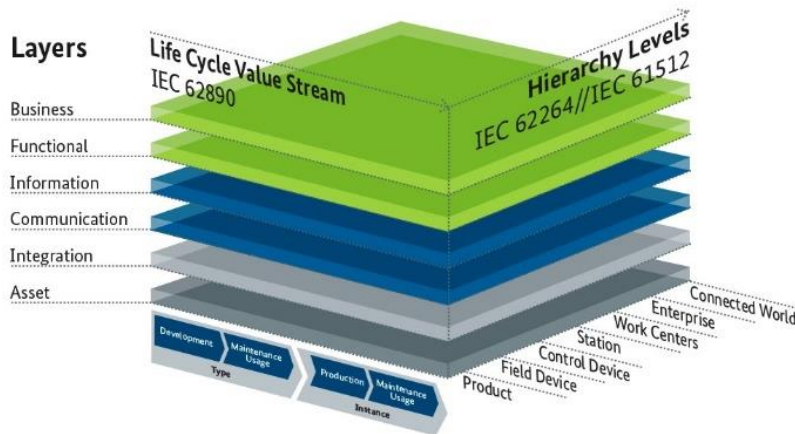


Figure 3 Reference Architecture Model for Industrie 4.0 RAMI4.0, [2]

The relevance of 5G technology for Industrie 4.0 lies in the new capability to now address the network itself as an industry 4.0 component in the "Internet of Everything", consisting of the asset (physical network) and its administration shell. This allows interoperability between network and production technology, not possible before. Further reference to Industrie 4.0 is shown below, based on the RAMI4.0 model, see Figure 3. For interoperability, Industrie 4.0 prefers general TCP / UDP / IP communication (wired and wireless), in the future also Time Sensitive Networking (TSN) and 5G will be added.

3.2 The 5G Value Chain and Stakeholder Benefits

Digitalization has risen industrywide across the globe, and it is predicted that digital revenue for ICT players will be worth around USD 3.5 trillion by 2026 across the 10 key industries studied, see figure 4a. Manufacturing will have the largest share with 18%. [18].

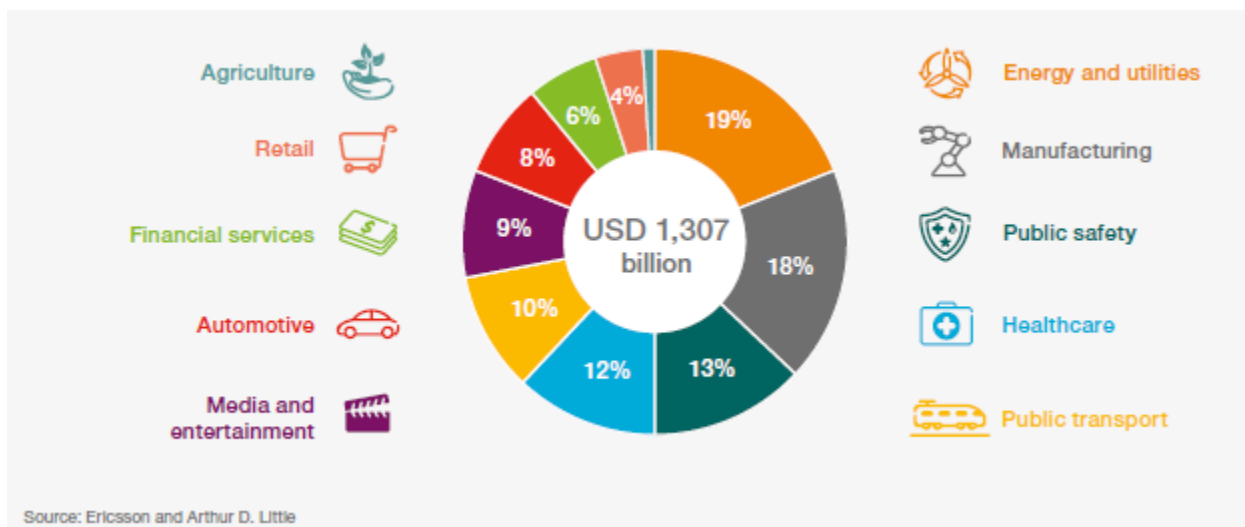


Figure 4a: 5G – enabled industry digitization revenues for ICT players, 2026 [18]

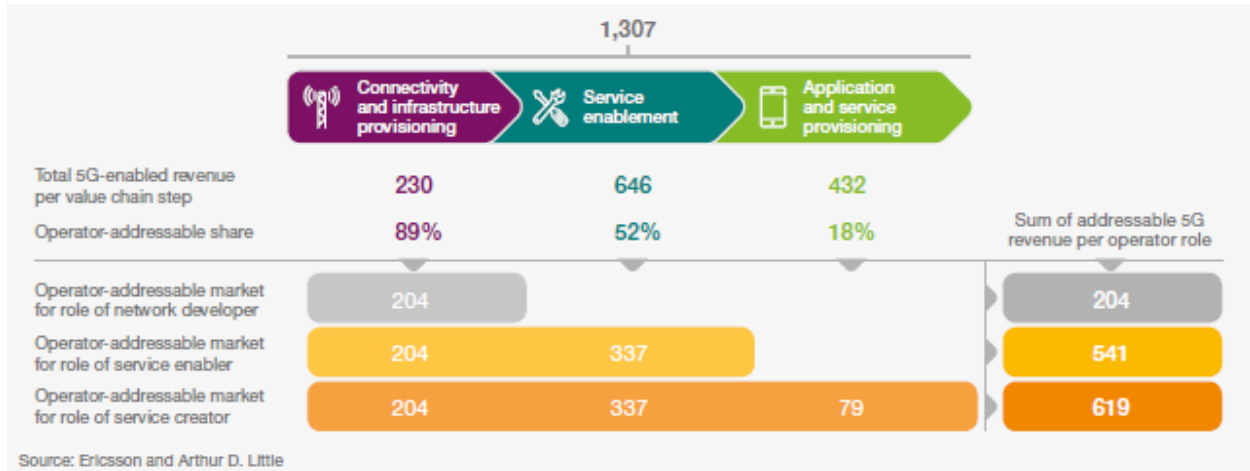


Figure 4b: Total 5G-enabled revenue (2026, USD billion) per value step and operator addressable share [18]

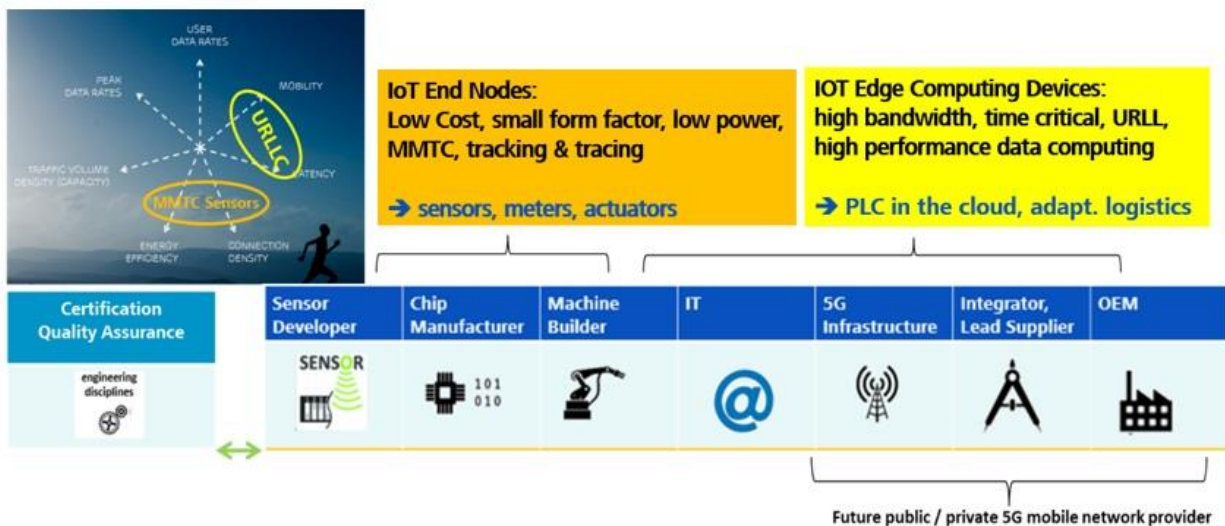


Figure 5: Actors in the value chain

To yield this potential for Industrie 4.0 (Manufacturing), the cooperation of the various interest groups is mandatory, (see figure 5) including:

- Provider of 5G technologies (infrastructure, components)
- Mobile operators (network slicing, new operator models)
- Providers of production systems (engineering: connectivity to the digital twin)
- operator of production equipment (virtual ramp up, effectivity, mobile control)
- Application developer and provider of software platforms (new data and service-based business areas)

Unlike 4G, which supports only single scenarios, 5G can support a variety of scenarios requesting Enhanced Mobile Broadband (eMBB), massive Machine Type Communications (mMTC), and ultra-Reliable and Low Latency Communications (uRLLC) capabilities.

Until now, value chains have been built under the assumption that deterministic, real-time control of production facilities, as well as analytics of large data streams, would require wireline network connections.

The scenario "Mobile Controlled Production" now allows a spatial separation of production automation (e.g. robots) and its control units. The same applies for smart data analytics and real-time image or video processing. As result deterministic and real-time control of a large number of robots gets possible with computing units in the cloud (or edge) supporting fleet management as well as synchronizing cooperating robots and human robot cooperations, sharing tasks in production.

Depending on the application, 5G technology has to meet a wide range of requirements in terms of availability, security and capacity. Such requirements can only be ensured if they can rely on a dynamic, flexible and scalable security architecture.

For 5G technology providers, e.g. chip manufacturers new markets evolve for hardware-based security products for 5G network technologies that meet the industrial requirements for an adaptive, scalable and reliable IT security. But also other stakeholders downstream the value chain will benefit from these security products, e.g. machine builders and system integrators and plant operators. There is a growing exploitation potential of H / W and S / W security products as part of the Industrie 4.0 strategy in future application scenarios for production.

For suppliers of production systems, further improvements of existing systems as well as new business models are coming up. Ramp-up of machines and equipment will gain efficiency through 5G data links resulting in reduced commissioning times. As example one can think of a usecase in adaptive logistics, where a production cell gets loaded on a truck to be transported from production site A to site B, while diagnostic routines and control logic being deployed from the cloud during transport to enable fast ramp-up at location B. More adaptive production lines can be engineered beyond the limits of production locations with transport time being used for value creation, already plannable in the design and engineering stage of production lines.

Logistics and supply chain management will be among the first applications of the new technology. Decentralization and autonomous local control are concepts that can work with narrow bandwidths and relatively high latencies due to local preprocessing.

New business models are based on the data being sent from the production systems to the cloud. One can imagine the operation of smart services taking charge of the control for hundreds, even spatially widely distributed robots. Centralized analytics -fed by data gathered across sites with different plant operators engaged- may lead to swarm intelligence models to be used for system adaptation and optimization.

Also cloud-based services are on the rise benefitting from process data and video data being uploaded from products and processes on the shopfloor to be deployed as quality assurance service in real time. This way the investment in local hardware and software can be avoided, not profitable for small and medium enterprises. But also plant operators benefit from better services to improve process maturity to compensate from unforeseen process shifts during production in reduced time.

The added value of 5G technology providers and Mobile Network Operators (MNO) lies in the expected use in industry 4.0 applications and expected increase of demands for smart services offered, i.e. slicing. Regarding the MNO, the opportunities come from integrating private (enterprise) operated networks into public mobile networks. The total 5G –enabled revenue per value step and operator addressable share is depicted by figure 4b [18].

For this purpose, however, the business and operator models of the mobile industry and the industrial users must be aligned so that the requirements of the manufacturing end users can be met, i.e. with respect to availability, liability and transparency. In figure 6 different implementation alternatives are listed and compared.

Geographically limited, dedicated networks based on the use of licensed spectrum are the preferred option from industrial users' point of view.

The related expectations are:

- Complete operational control for network operation, especially for the production-critical infrastructure, with regards to resource control in emergency situations.
- Clear assignment of liability promoting physical separation and control over critical data.
- Benefits in terms of cost transparency and control.

	Licensed spectrum	Licence-exempt spectrum
Public mobile Networks	(1) Verticals 🚫 MNOs 🟢 3GPP vendors 🟡 Non-3GPP vendors 🚫	(2) Verticals 🚫🚫 MNOs 😊 3GPP vendors 🟡 Non-3GPP vendors 🟢
Private (dedicated) Networks	(3) Geographic Verticals 🟡 MNOs 😊 3GPP vendors 🟡 Non-3GPP vendors 🚫	(4) Verticals 🚫 MNOs 🚫 3GPP vendors 😊 Non-3GPP vendors 🟢

(1) MNOs can deploy small cells in licensed spectrum harmonized for MFCNs. But the verticals are reluctant to rely on MNOs for mission critical applications. 3GPP vendors can supply 4.5G/5G. Non-3GPP technologies are not spectrally efficient for licensed spectrum.

(2) MNOs can –in principle- deploy small cells using 3GPP technologies (e.g. LTE-LAA Multefire) in licensed-exempt spectrum, but their role is not essential. The absence of OoS guarantees means verticals will be even less interested than in Case-1. 3GPP vendors can supply LAA-LTE/Multefire, but will need to compete with non-3GPP vendors (IEEE 802).

(3) The verticals prefer this case, relying on geographically restricted network coverage. MNOs may engage with campus network offerings. The 3GPP vendors can supply 4.5G/5G technology. Non-3GPP technologies are not spectrally efficient for licensed spectrum.

(4) The absence of OoS guarantees means that verticals will not be interested in this case, even though MNOs are not in the value chain. 3GPP vendors can supply LAA-LTE/Multefire, but will need to compete with non-3GPP vendors (IEEE 802.11)

Figure 6: Implementation alternatives for 5G networks at production sites

3.3 Use Cases in Production

According to the EFFRA (European Factory of the Future Research Association) study and white paper [1] on 5G, five use case families have been identified that each represent a different subset of stringent requirements along supply chain and manufacturing networks, as depicted in figure 7:

- UC1: Time-critical process optimization inside factory to support zero-defect manufacturing, increased efficiencies, worker satisfaction and safety, leveraging the integration of massive sensing technologies including 3D scanning technologies, adoption of wearables, and collaborative robots in closed-loop control systems. This use case family requires communication latencies that may go below 1ms.

- UC2: Non time-critical optimizations inside factory to realize increased flexibility and ecosustainability, and to increase operational efficiency e.g. through minimal stock levels. Given the harsh and metalized industrial environments, indoor coverage and high availability are key requirements.
- UC3: Remote maintenance and control optimizing the cost of operation while increasing uptime. This use case family involves the integration of 3D virtual reality, and will require increased capacity to facilitate video-supported remote maintenance, from any place in the world.
- UC4: Seamless intra-/inter-enterprise communication, allowing the monitoring of assets distributed in larger areas, the efficient coordination of cross value chain activities and the optimization of logistic flows. To support these use case, there is a specific need for flexible, reliable and seamless connectivity across different access technologies, as well as the support for mobility.
- UC5: Connected goods, to facilitate the creation of new value added services and the optimization of the product design driven by real-time data, collected during the complete lifetime of a product. There is the need for ultra-low-power (high autonomy), and ultra-low-cost communication platforms.

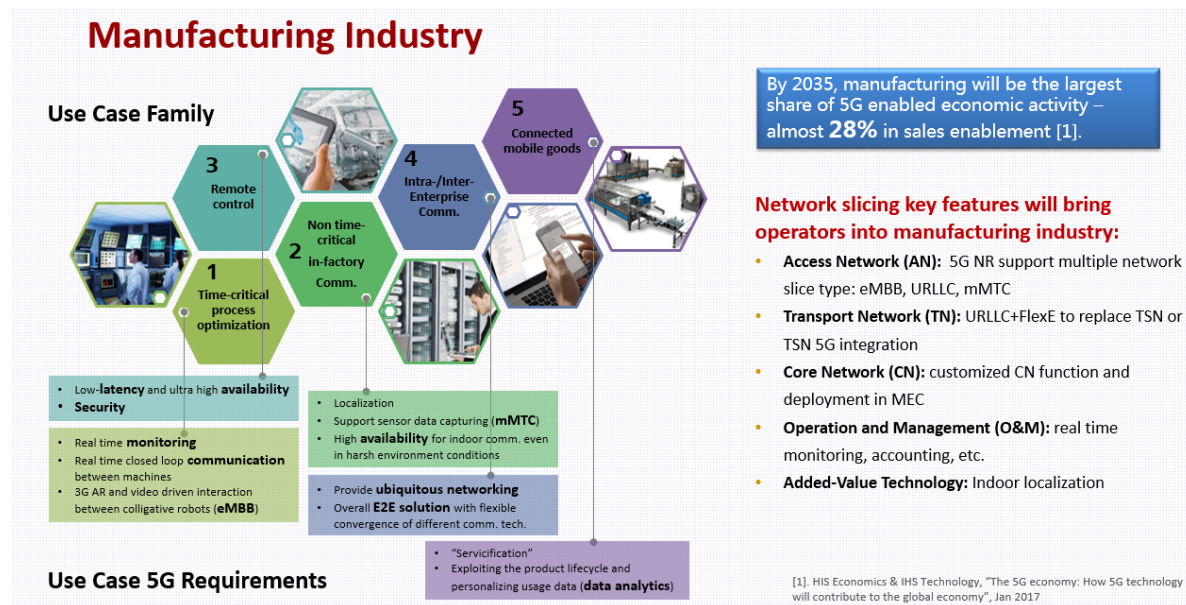


Figure 7: Five use cases in production and communication requirements (UC1-UC5) [1]

The use cases that are currently introduced in the 3GPP standardization process with respect to "Factory of the Future" are shown in figure 8 below together with their requirements. [1]

5G E2E Network Slicing, as shown in figure 9, provides the ability to run a multitude of logical networks on a common physical infrastructure as virtually independent entities. Each one being application specific and tailor made to meet custom specific performance parameters (guaranteed SLA, including such contradictory requirements as: eMBB, URLLC, mMTC).

With this approach, 5GE2E slicing can already be integrated into the engineering process of smart products and systems according to figure 2, also supporting model based reengineering of existing production systems to adapt to changes of customer-specific requirements.

KPIs for Factories of the Future (3GPP SA1 SI CAV)

		Cycle time (T_{cycle})	Payload size	#UEs	Service area	Data transmission time jitter	Clock (Jitter) synchronicity	Communication service availability	UE speed	Asyclic traffic	Localization accuracy	Other
Motion Control	Machine tool	0.5ms	50byte	20	15m x 15m x 3m		1 us	99.999999% (>>99.99999%)	20 m/s	1Mbit/s		
	Packaging machine	1ms	40byte	50	10m x 5m x 3m							
	Printing machine	2ms	20byte	100	100m x 100m x 30m							
Control-to-Control		4ms	1kbyte	100			1 us	99.999999% (>>99.99999%)		10ms		
Mobile Control Panels with Safety Functions	Assembly robots, milling machines	4-8ms	40-250byte		10m x 10m	$T_{cycle}/2$		99.999999% (>>99.99999%)		5Mbit/s 30ms Jitter<latency/2	1m 30°	
	Mobile cranes, mobile concrete pumps	12ms	40-250byte		40m x 60m							
Mobile Robots	Cooperative robot motion control	1ms	40-250byte	100		$T_{cycle}/2$		99.99999%	50 km/h	10Mbit/s (real-time video streaming to guidance control system)		
	Machine control	1-10ms										
	Cooperative driving	10-50ms										
	Video-operated remote control	10-100ms	15-150kbyte									
	Standard mobile robot operation and traffic management	40-500ms	40-250byte									

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Figure 8: 3GPP Use Cases [TR22.804, Study on Communication for Automation in Vertical Domains] [9]

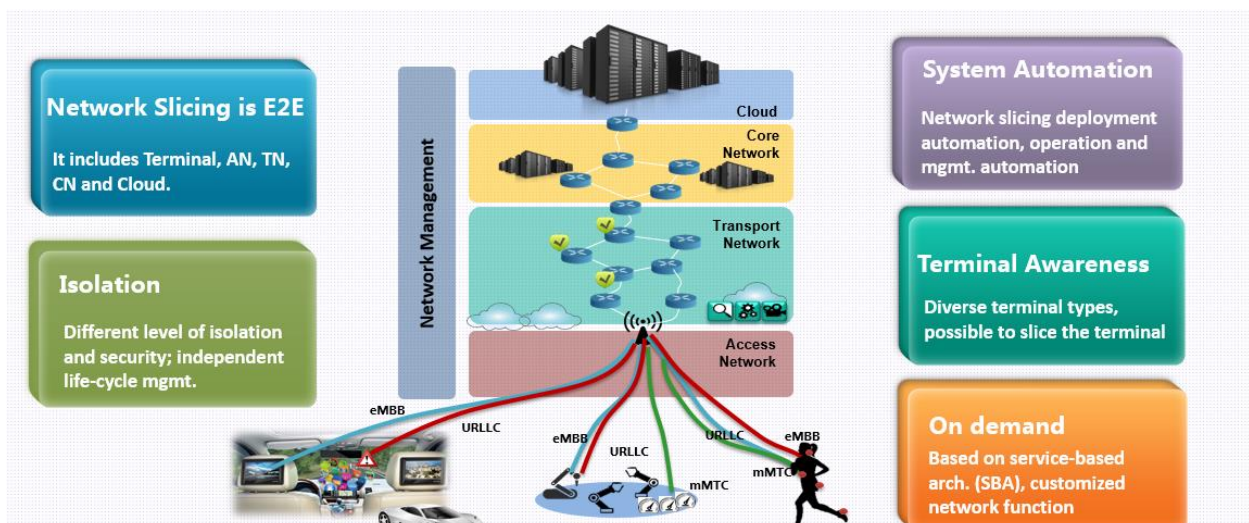
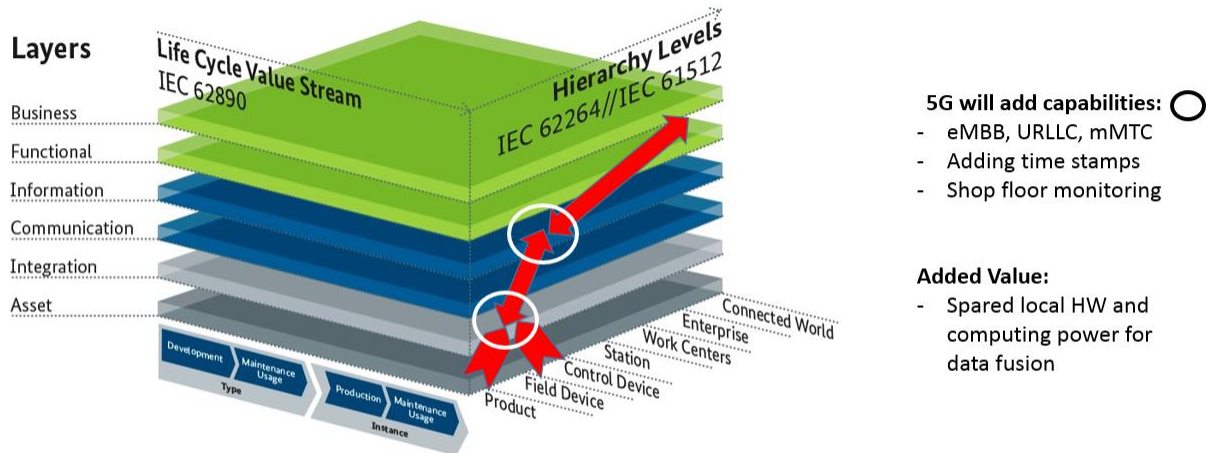


Figure 9: Tailor made E2E connectivity in production through „5G Network Slicing“

3.4 5G Capability & Added Value in Selected Use Cases

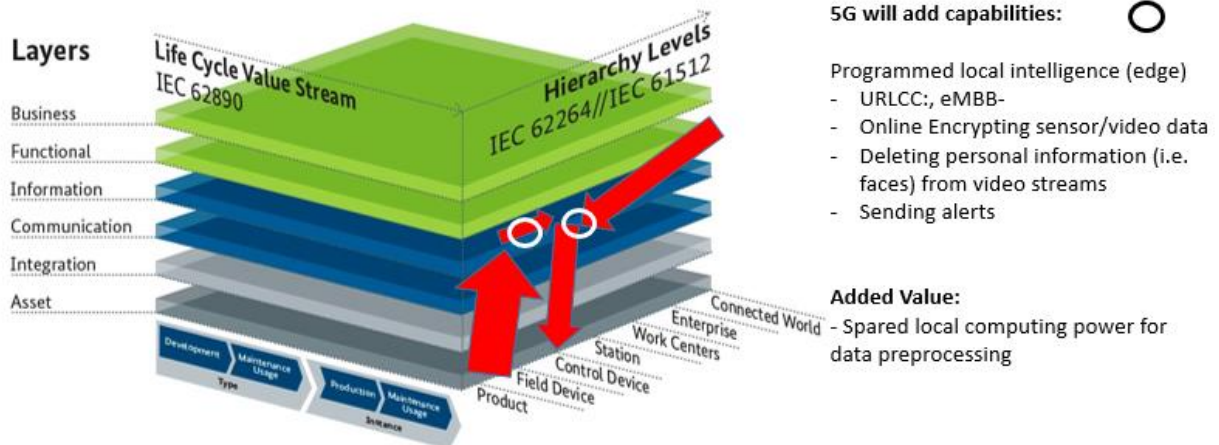
The next figures 10 and 11 showcase 5G capabilities related to the RAMI 4.0 model with reference to the use cases introduced in figure 7.

Sensor data fusion:



Use Cases: Multi Sensor Data Fusion, i.e. for UC1: Augmented Reality Operator Assistance , UC2: Adaptive Logistics (AGV fleet management, Environment Screening)

Sensor data Preprocessing :

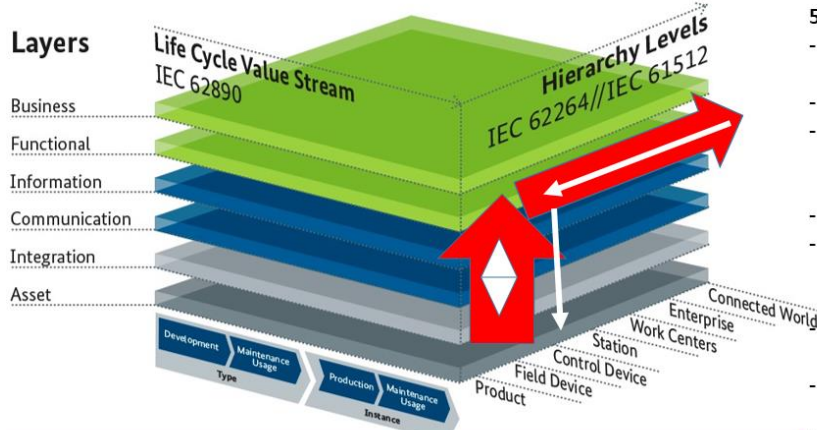


Use Cases:
i.e. UC3: Remote Control of machines, UC5: Track and Tracing of mobile and stationary goods

Figure 10: 5G Capabilities for data fusion of different sensors (above) and data preprocessing (below)

„PLC in the cloud“ und „Condition Monitoring“

Practical Relevance: Big Data Transfer from Sensor(s), data from multitude numbers of sensors, Services from edge provided to field devices on Shop Floor (PLC in the cloud, „robot as a service“, adaptive production, adaptive logistics)



5G will add capabilities:

- eMBB: Big data from sensor (i.e. Video streams from AGV)
- mMTC: Data from multitude of sensors:
- URLLC: Access to smart services from edge, cloud to shop floor, i.e. „PLC in the cloud“, „Robot as a Service“
- Fleet Management of AGV in logistics
- Value creation during transport (video based quality control, software updating, 3D printing)
- „Retro-Fitting“ of stations not connected to the internet
- New Human – Machine Communications

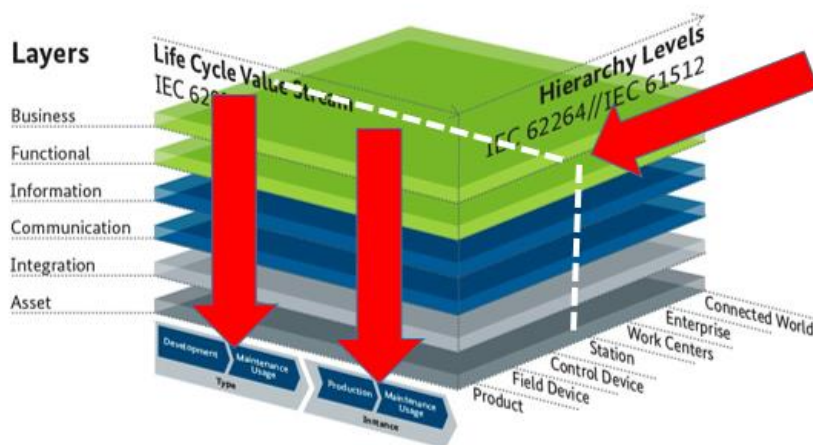
Use Cases: i.e. UC1: „PLC in the cloud“ UC3: Condition Monitoring Off Shore Wind Mills, UC5: Track & Tracing of mobile & stat. goods adaptive logistics: i.e. container tracing and shipment control in harbor environment

Added Value:

- Access to scalable services from edge to shopfloor, reducing HW needs on shopfloor

New Roles and Business Models

Practical Relevance: New Service oriented Roles & Business for smart manufacturing embracing engineering and production phase



5G will add capabilities:

- Network Management Services
- Load Forecasting Capabilities from previous application experience
- Network management becomes plannable part in engineering process of systems
- Enabling demand dynamic engineering of systems

Added Value:

- Access to new services for engineering and production phases

Use Cases: i.e. UC2 / UC4: Intra-/Inter- Enterprise Communication: Ecosystem Collaboration, Digital Engineering, Certification of adaptive systems & machines

Figure 11: 5G Capability for „Big Data“, „plc in the cloud“ (above). New evolving roles and services (below)

3.5 Disruptive Potential

5G will not only bring changes in technology, but also in the processes and business models of plant operators and suppliers of industrial equipment. This also includes the responsibility for the "Total Cost of Ownership", which means investing in the installation and operation of machinery and equipment together with 5G globally standardized guarantees for availability, bandwidth and communication quality (QoS, Quality of Service and SLA - Service Level Agreements).

4 Relation to Other Work Groups of the Platform

Relevance	Content
WG1	<p>Contribution to the sub-work group “Networks” to update the structure concept “RAMI4.0 Communication Layer” to now include a proposed “5G AAS” (5G Asset Administration Shell)</p> <p>Standardization of a permeable communication medium, covering all layers and applications.</p>
WG2	Elaboration of 5G Use Cases in production (URLCC, eMBB, e2e,..)
WG3	Data Security, Safety and reliability in networks, edge and local computing nodes (Different standards for CN- computing nodes are necessary as are regulated for computing centers. CN-computing nodes will serve for data preprocessing close to shop floors).
WG4	New Operator Models (e.g. LSA) between industry and MNO
WG 5	New 5G based human - machine communication and interaction models (HMI, AR)
Joint WG IIC-I4.0	IIRA-RAMI4.0 Updating: Integrate 5G capabilities in phys. Layer & Services
ZVEI –5GACIA	5G ACIA: „5G Alliance for Connected Industries and Automation“ Supporting WGs

5 Glossary

Acronym	Definition
CPS	Cyber Physical System, see I4.0 Komponente
eMBB	enhanced Mobile Broadband
I4.0	Industrie 4.0 (origin is german), Industry 4.0
I4.0 Component	I4.0 Component – previously called CPS– maps the runtime data of assets into the information world
mMTC	massive Machine Type Communication
MNO	Mobile Network Operators
RAN	Radio Access Network
URLLC	Ultra Reliable and Low Latency Communication
WG, SWG	Work Group, sub work group
RAMI 4.0, IIRA	RAMI4.0: Reference Architecture Model Industrie 4.0, IIRA: Industrial Internet reference architecture

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