White paper

5G in Production

By: Dr. Julius Mennig, Laura Hajek, Philipp Münder

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1. Intro

Industry 4.0, smart factory, Industrial Internet of Things (IIoT) – these are buzzwords describing the future of industrial manufacturing. The goal is to establish a fully digitalized and connected factory and production network to increase flexibility, efficiency and the level of autonomy. Designing production plants and logistics to meet the requirements of the digital age, the right IT backbone, communication framework and comprehensive connectivity need to be established. The new 5G communication standard opens up important new prospects.

Purpose of interactive white paper

This white paper analyzes the application of Industry 4.0 technologies and trends as well as their requirements for communication and connectivity. In doing so, this paper examines how 5G can create benefits in production compared to other telecommunication standards. For this examination it is essential to understand the aspects of value creation in manufacturing companies and in the plant of the future. Therefore, current and future use cases in the manufacturing field will be derived and their benefit, state of the art and telecommunication requirements will be mapped.

White paper structure

The white paper is structured into two spotlights. One spotlight is focusing on the telecommunication technologies WiFi 4/5, WiFi 6, 4G, 5G including their technical details and limitations.

The second spotlight first introduces and defines Industry 4.0, assesses the levels of value creation for new manufacturing technologies and trends as well as it classifies the different use cases according to their application. The use cases will then be thoroughly explained, while connectivity requirements are analyzed to perform a matching with the telecommunication standards considered and scored in spotlight one. This allows a statement about the telecommunication technology needed for each use case.

2. Spotlight 1 – Telecommunication technologies WiFi/4G/5G

In the following chapter the telecommunication technologies WiFi, 4G and 5G are introduced and their main characteristics are explained. Further they are compared concerning their main differences, technical details and advantages. These details are then translated into a competitive rating which will serve as the basis for the use case matching.

Introduction of Network Standards (WiFi)

WiFi refers to the different IEEE 802.11 networking standards. It is commonly used to create wireless local area networks (WLAN) and thus, connecting devices to the internet. However, it still faces challenges, as will be outlined in the following chapter. Standardizations for WiFi 4 and WiFi 5 were finalized in October 2009 and December 2013. Since WiFi 5 only employs the 5GHz spectrum, routers combine the use of WiFi 4 and 5, in order to ensure backward compatibility and supplementary utilization of the 2,4 GHz spectrum. For that reason, WiFi 4 and 5 will be combined for comparison. WiFi 6 (or 802.11ax) was standardized in September 2019. As of now, routers are available, but preceding standards are still used predominately because deployment just started. WiFi 6 primarily improves features that were introduced in WiFi 4 and 5. According to the WiFi Alliance, key benefits are higher data rates, increased capacity, better performance in device–teeming environments and improved power efficiency. Because of its availability and simplicity to deploy, WLAN has also become the de facto standard for office connectivity.

Introduction of 4G / LTE–A

Long–Term–Evolution–Advanced (LTE–A) is the fourth–generation mobile communications standard. Being standardized since April 2011, it is used to create mobile networks. It builds upon LTE, which was standardized in 2008 and only requires a software update There is some debate whether the initial release of LTE is considered a 4G network, as it did not formally fulfill the requirements of the responsible certification authority, the International Telecommunication Union Radiocommunication Sector (ITU–R). The focus of improvement, compared to LTE, are higher data rates: LTE provides up to 300 Mbit/s in the downlink, but typically only realistically only reached 12,5 Mbit/s, while LTE–A provides up to 1200 Mbit/s with 100 Mbit/s being reached typically. Other areas of improvement are faster switching between power states to save energy and improved performance at the cell edge. Base stations only require a software upgrade. In manufacturing, LTE–A is primarily used to connect networks, rather than single devices, to the internet, often only as a fail–safe solution.

Introduction of 5G

5G is the fifth mobile communications standard. Besides being the next generation of mobile networks, 5G was developed with the intention to make it the next standard for connectivity within the industry. To that end, ITU–R identified three usage scenarios for 5G networks, based on ongoing changes and trends, such as the need for low latency communications and greater device density:

1. Enhanced Mobile Broadband (eMBB) use cases focus on human–centric access to multi–media content, services and data. Therefore, higher data rates are the main requirement. Included use cases are edge– or cloud–computing as well as virtual– and augmented reality.
2. Ultra–Reliable Low–Latency Communications (URLLC) use cases entail time– or otherwise critical data, such as control of industrial manufacturing or human–machine interaction. Thus, strict requirements regarding latency and availability must be met.
3. Massive Machine–Type Communications (mMTC) use cases are centered around massive numbers of devices that typically require only low data rates but high energy efficiency.

Based on those application scenarios, the requirements of the network of the future were derived. Standardization of the initial deployment, phase 1, was finished by June 2019. Phase 2, which will bring further improvements to latency and IoT support, is expected to be finished by June 2020. Deployments will widely be in the non–standalone (NSA) mode, i.e., a 5G radio access network (RAN) in combination with a 4G core network because investment costs are significantly lower. The RAN establishes the connection to the client, while the core network handles network functions such as user authentication and connection to the internet or different networks. As a result, some features of 5G will not be possible with existing infrastructure, rather, additional upgrades to base stations would be necessary.

5G is not a single technology but a close integration of multiple technologies and therefore, not all use cases may be realized by a single deployment. Instead, a network will be comprised of different deployment options, i.e., base stations with different cell sizes. Smaller cells use higher frequencies. In consequence, their range is lower, but allow higher data rates and device density. Therefore, a network will not offer the same capabilities ubiquitously. Instead, capabilities will be realized locally to meet the requirements of the usage. Thus, the full potential of 5G can only be realized by a combination of those deployment options.

Comparison of WiFi and cellular telecommunication technologies

5G was designed to become the new standard for industrial connectivity. Therefore, it offers different configurations fitted to the usage scenarios identified by the ITU–R. As development is ongoing and empirical values are yet to be collected, it is complex to derive the actual benefits of 5G.

To further understand the abilities of 5G, it is compared to the other network technologies named before. Differences between 5G, 4G and WiFi that ultimately result in the distinct characteristics of each network are the used frequency bands, key technologies to achieve the desired ability profile as well as the approach to cyber–security and roaming, i.e., the change of base stations. In the following, each difference will be presented in detail.

As aforementioned, 5G, 4G and WiFi employ different **frequencies** to transmit data. WiFi utilizes the unlicensed frequencies at 2,4 GHz and 5 GHz. These frequencies are part of the industrial–, medical– and scientific (ISM) bands, resulting in two main obstacles.

Firstly, **interference management** is challenging. As the ISM–Bands do not require any license, they are used quite heavily by a variety of network standards, e.g., Bluetooth, ZigBee and various other proprietary standards operate at 2,4 GHz. ZigBee is a so–called low–power wide–area network (LPWAN) that allows large coverage and little energy consumption, but only small data rates. Proprietary standards range from garage door openers to input devices for computers. Interference management is not only challenging because of the noise level and heavy usage, but because of the different standards operating parallelly. The 5 GHz ISM–Band is used less but suffers from bad propagation properties, especially for non–line–of–sight propagation, i.e., when obstacles are between the sender and receiver. 5G and 4G on the hand use licensed frequency bands. As a result, the noise level is lower and interference management is simple.

Secondly, there is a **legal limit** to the strength of emitted radiation, i.e., signal strength, and to the radiation present in the surrounding environment. The equivalent isotropically radiated power (EIRP) in the 2,4 GHz bands is limited to 100 mW, in the 5 GHz bands to 0,2 W (5,15 GHz–5,35 GHz) and 1 W (5,47 GHz–5,725 GHz). The former is only permitted for indoor use. For that reason, the signal strength of WiFi networks is limited. As a result, range and penetration are low. In 4G, the base stations send out up to two magnitudes more depending on the frequency range. Furthermore, the spectral power density, i.e., the power of radiation present in each frequency range in the surrounding environment, is limited. If the limit is reached, the device is prohibited from emitting additional radiation, i.e., transmit data. That way, increased device density leads to increased latency and decreased reliability. Therefore, even mobile devices such as smartphones can lead to disturbances. Furthermore, WiFi networks are especially susceptible to disturbances due to older standards being present, because of the backward combability in WiFi. As a result, a significant loss in efficiency can occur. In contrast, 4G and 5G networks are not backward compatible and the network manages used frequencies centrally, i.e., devices are told which frequency they should use. Therefore, mobile networks are very resilient.

To increase reliability and scalability, WiFi 6 employs **technologies** known from mobile networks, namely multi–user multiple–input multiple–output (MU–MIMO) and orthogonal frequency–division multiple access (OFDMA). As a result, the throughput per user is quadrupled in crowded areas, although single–user speed has only increased by 37%. Also, up to 8 devices will be able to communicate with the base station simultaneously. Depending on the base station, LTE networks allow several hundred up to a few thousand devices to communicate simultaneously. The scheduling in WiFi 6 changed. While access to older WiFi standards was contention–based, i.e., clients competed for resources, uplinks in WiFi 6 are scheduled to minimize conflicts. Because the device can sleep until the next scheduled transmission, energy efficiency is increased. However, prioritization of data is still not possible. In contrast, 4G has multiple mechanisms to manage traffic. Therefore, prioritized traffic is deterministic, i.e., it can be processed within a constant time frame. Only non–prioritized traffic can suffer from high latencies and high loss probabilities in areas of high device density. That is because there is no constant connection in 4G networks and thus, accesses are random. In 5G, prioritization will be an inherent component. Additionally, in 5G stand–alone (SA) network slices will be available and capable of reserving resources. To increase connection stability within areas with multiple WiFi networks present, WiFi 6 introduces basic service set coloring (BSS), i.e., adding a locally unique identifier to each network's transmissions. That way, devices can distinguish transmissions of their network from those of neighboring networks. As a result, the transmissions of neighboring networks can be ignored, making simultaneous transmissions in neighboring cells possible. Therefore, WiFi 6 networks are better expandable than WiFi 4/5 networks, although many devices still cause problems due to legal limits and interference. Modifications to WiFi networks are limited because of the narrow capability profile. Mobile networks, such as 4G and 5G, on the other hand, are designed to combine many different base stations into a single network. For that reason, expansion is straightforward. However, modifications to a 4G network are costly, as core functions are realized by specialized hardware. 5G introduces software–defined Networking (SDN) and network functions virtualization (NFV) to remedy that. SDN solves network tasks through software instead of specialized hardware, while NFV centralizes control over network functions, previously done by routers and switches. Therefore, modification of a 5G network is simple. For all those reasons, 5G is best suited for (time–)critical application scenarios and for application scenarios with incomplete specifications that might require adaptation later on, such as Industry 4.0 use cases. Despite that, WiFi 6 improves the capabilities of WiFi networks greatly compared to WiFi 4/5.

Another aspect is **cyber–security**. WiFi only requires the SSID (network name) and a password. As a result, WiFi networks are inherently vulnerable to man–in–the–middle (MITM) attacks. Unfortunately, whitelisting MAC addresses to increase security does not prevent MITM attacks, as MAC addresses can be spoofed, i.e., faked. As data security of WiFi networks cannot be ensured, drastic measures for critical data were enacted within the industry. Critical data was secured using air–gap–security, i.e., separating the secured computer or wired network by a physical or mechanical gap. To transfer data to or from these secured computers or networks, removable storage mediums, e.g., USB drives, are necessary. However, air–gap–security is not the optimal solution either, as it results in significant downsides in usability and has been compromised nonetheless, e.g., by Stuxnet. Although WiFi 6 introduces a new security protocol with WPA3 (as opposed to WPA2), MITM attacks are still possible. Furthermore, new exploits were already found. To remedy these exploits, a non–backward compatible upgrade could be necessary. As a result, already rolled out hardware would become obsolete. Despite that, WPA3 is generally regarded as safer than WPA2. In contrast, 4G and 5G networks require unique sim cards to access the network, making them inherently hard to hack. While designing 5G, a key consideration was safety. To achieve improved safety, 5G employs well–proven 4G security mechanisms as well as new enhancements, e.g., mutual authentication, which prevents MITM attacks, and encryption of end–user data within the mobile network. For that reason, 5G is believed to be safer than 4G, although Software–defined Networking (SDN) and Network Functions Virtualization (NFV) might pose new risks. As outlined above, SDN and NFV result in the omission of hardware and centralization of network functions. Therefore, there are no more physical limits, i.e., hardware bottlenecks, to limit the access of hackers, as all services are centrally provided by software.

The different approach to **roaming**, i.e., how a client leaving a network or the coverage of a single access point (AP) is handled, has major implications for a particular set of use cases. Although WiFi has a protocol for seamless roaming, many clients do not support them. As a result, clients must connect anew once they lost connection to the access point due to being out of reach. Up to that point, the client would have suffered from sub–optimal performance, as there is no automatic handover. For use cases that require mobility, such as AGVs, those reconnects mean breaks until a connection to the new access point has been established. That way, AGV–traffic jams might occur, as every cell edge is a bottleneck. In contrast, mobile networks, such as 4G and 5G, incorporated seamless handovers a long time ago. As a result, clients are automatically connected to the optimal available access point. Therefore, 4G and 5G are better suited for those use–cases.

To derive a rating for each wireless technology, we considered the differences outlined above as well as the key performance indicators commonly stated, shown in Table 1.

Table 1: Performance overview

	4G/LTE (Release 14)	5G/NR (Release 15)	WiFi 4 (802.11n)	WiFi 5 (802.11ac)	WiFi 6 (802.11 ax)
Carrier frequency[1]	700, 800, 1.800, 2.600MHz	700MHz, 900MHz, 2100MHz, 3,5GHz, 26GHz	2,4GHz, 5GHz	5GHz	2,4GHz, 5GHz
MIMO	bis 8x8	bis 64x64	bis 4x4	bis 8x8	bis 8x8
Carrier bandwidth [MHz]	5 – 100MHz	5 – 400MHz (currently)	20, 40	20, 40, 80, 160	20, 40, 80, 160
Max. throughput [Mbit/s] – theo. Max. / typical	900 / 100 (@20MHz)	>10.000 / 1.000	800 / 200	3.500/ 700	6.900 / 1.200
Maximum spectral efficiency [bit/s 1/Hz]	>15(UL), >30 (DL)	>15(UL), >30(DL)	5	14,4	20
Latency [ms], minimal / typical	10 / <50	1 / <10	50 / 100	30 / 50	10 / 50
Access management / Load control[2]	SIM / Network	SIM / Network	SSID & PW (pot. MAC) / none	SSID & PW (pot. MAC) / none	SSID & PW (pot. MAC) / none
Access security	High	High	Medium	Medium	high
Communication security	very high	very high	high	High	high
Data security	High	very high	Medium	Medium	medium
Roaming[3]	Automatically	Automatically	manually	manually	manually
Handover[3]	automatically, immediate	automatically, immediate	manually, 500 ms	manually, 500 ms	manually, 500 ms
Cell radius outdoors typical / max [m][4]	800 / 15.000	300 / 15.000	50 / 100	80 / 250	80 / 250
Cell radius indoors typical / max [m] [4]	30 / 200	30 / 200	20 / 100	20 / 100	20 / 100

[1] Perspectively all cellular frequencies will be re–framed to 4G respectively 5G. In Germany these are (at least until 2025): 700, 800, 900, 1.800, 2.100, 2.300, 2.600, 3,500 MHz and in the future 26 and 72GHz. However, so far Release 17 only considers frequencies up to 71 GHz.

[2] Mechanism to ensure successful transmission and processing of prioritized data.

[3] Roaming in WiFi networks is the connection to access points with better signal strength / quality of the same network, while in mobile networks, roaming relates to connecting to base stations of different providers when the original network is unavailable. The handover is the disconnect and following re–establishment of a connection when either base station or access point are changed, manually or automatically.

[4] Cell ranges are highly frequency dependent, the higher the frequency the smaller. Because of the various different frequencies available for 4G and 5G, cell radiuses vary substantially. Further to that, the transmitting power has a large influence on the cell size. The transmitting power is in licensed cellular bands up to two orders of magnitude higher than in unlicensed WiFi bands. Using WiFi outdoors is critical due to the fact that it is the WiFi router's operator's responsibility to avoid interference with other devices operating in the same band.

Translation into competitive rating

Derived from the differences between WiFi and 4G / 5G outlined in the previous chapter, each wireless technology's suitability will be rated for the different usage scenarios. To classify networks, a magnitude of different key performance indicators (KPIs) are commonly used. Among the many KPIs, some differentiate networks more distinctively than others. For reasons of clarity and simplicity, we will focus on the following KPIs: **Latency**, defined as the time it takes a data packet to reach its destination once it is sent. **Data throughput** per area as the upper total traffic throughput per geographic area. **Connection density** corresponding to the total number of connected devices per area. **Reliability**, defined as the success probability of transmitting a data packet before a given deadline. For the rating, usage scenarios that put a strain on the network, e.g., by mobility or high number of connected devices, have been considered. **Penetration** as the network performance in areas with many obstructions, such as walls or machines. **Range** as the typical distance to the base station without major losses in network performance. **User experience data rate** corresponding to the 5% point of the cumulative distribution function of the user throughput. Thus, it represents the minimal user experienced data rate in the coverage area. **Security** as the safety of a network against malicious attacks, including manipulation of the signal, maliciously or unintentionally. However, those KPIs cannot be quantified or compared out of the box. Thus, only a qualitative rating of a technology's capabilities in that area is given.

	4G	5G	WIFI 4/5	WIFI 6
Latency	3	4	2	3
Data throughput per area	3	4	3	4
Connection density	3	4	1	3
Reliability (Mobility & Load)	3	4	2	2
Penetration	2	1	3	1
Range (coverage)	4	3	2	2
User experience data rate	3	4	2	4
Security (incl. Anti Interference)	3	4	1	2

1 – low 2 – medium 3 – high 4 – very high

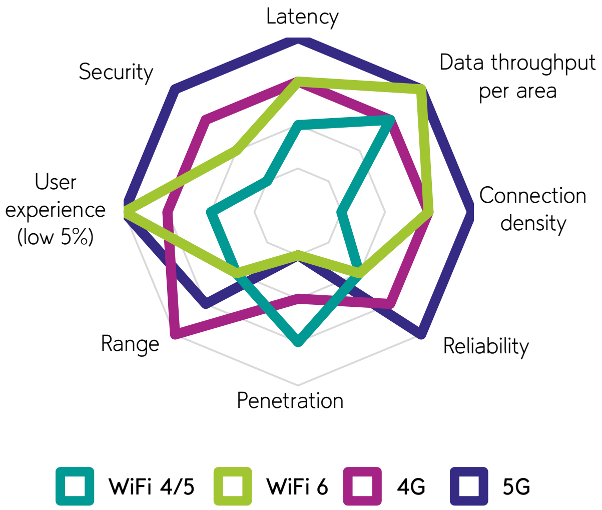

Figure 1: Qualitative assessment of technologies

3. Spotlight 2 – Industry 4.0 Use Cases

An introduction to Industry 4.0

Originating from the context of a funding project of the German government, the expression "Industry 4.0" was developed in 2011 and stands for the fourth industrial revolution. It represents the progress from widely automated production compounds, as they were introduced and propagated during the previous third industrial revolution, towards industrial networks providing integral connection of all components. While being described as the merge of the virtual and the physical world enabled by real–time data use, Industry 4.0 drives the change in the architecture of modern manufacturing systems towards highly connected cyber physical structures.

Trending innovations such as Cyber Physical Production Systems (CPPS) or Industrial Internet of Things (IIoT) demand the ability to deliver and process large amounts of data in real–time and thus create the need for a high–performance and reliable network. This raises the need for a solution providing necessary technical fundament.

Levels of value creation in production

Considering the most relevant factors for manufacturing companies, digitalization can mean great leverage. Therefore, a closer look at these factors is critical for ensuring economic success of manufacturing companies. While the goal is to comply with the rising challenges on the global market, Industry 4.0 technologies cover the following seven levels of value creation:

According to ISO 9000, **quality** is the degree to which a set of inherent characteristics meets requirements. Quality rates the output of the production process as a whole, but also of its every stage. It is affected by parameters like, temperature or accuracy and speed which are typically weighed up mutually and determine quantity. Digitalization enables operators to produce products of higher quality using several methods that improve process transparency. These methods and techniques include early detection of deviations and correction within control circuits as well as optimization and prevention using data analytics.

Taking up output volume, **process efficiency** drives the input–output ratio and production reject rates, which can be optimized by fluent, faster and real–time coordinated production flows. In order to enhance production flows accordingly, **worker guidance and assistance systems**, for instance machine–to–machine or machine–to–man communication and cooperation can be implemented.

Faster production flows also support **lead time optimization**, which describes the shortening of the time passing between initiation and completion of the production process including all preparation and waiting times. **Production planning and control**, in the sense of digitalization, comprises monitoring, analyzing and interpreting data that is collected and transmitting orders throughout a company–wide IT network. Part of planning the manufacturing processes is **resource allocation**. Via assigning resources and scheduling activities, businesses ensure the fluent production processes named above. Finally, **asset utilization** provides a sophisticated view on the actual performance status, which is expressed in KPIs such as the overall equipment efficiency (OEE).

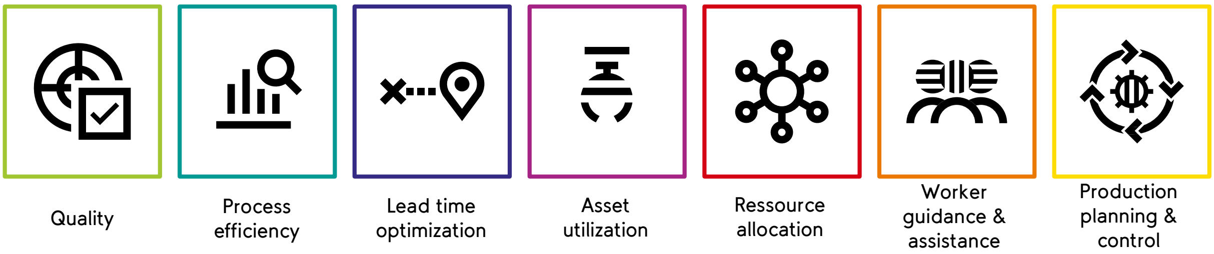

Figure 2: Levels of value creation

Industry 4.0 Use Cases

To identify the key use case cluster in this white paper key design principals of Industry 4.0 technologies and applications are considered. First, the development of I4.0 is driven by providing an interconnection between different objects and assets in the production ecosystem. This enables interaction like machine communication. In this context also setting communication standards and security regulation is a key aspect. Deriving from established interconnection the next key driver is information transparency. Through the interconnection of the physical and virtual world, a new level of information is provided and the complex correlation between information can be analyzed. This also acts as a base for decision making. More information available offers the opportunity to decentralize intelligence and therefore the decision–making process. In the last step, this can be used to assist workers. Through the responsible shift of workers from executive force to decision–making force information needs to be aggregated and visualized comprehensively. Also, physical assistance is implemented in this process.

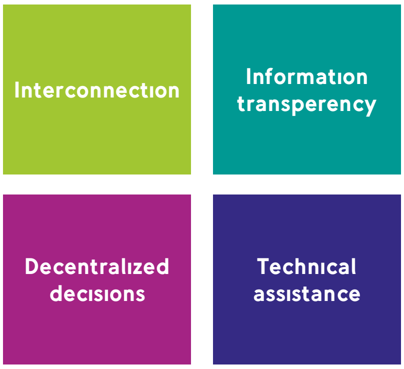

Figure 3: Industry 4.0 drivers

After deriving the main design levels for I4.0 applications the use cases are clustered in a two–step approach. The first level of the use case list is defined as the use case clusters. These are determined by key I4.0 technologies and trends and on the other hand by the main activity levels of a manufacturing company. In a second step the use case clusters are further divided into subclasses. Subclasses represent the different variations of a use case cluster. These are distinguished by the level of automation, connectivity requirements and amount of data present. The illustration of each cluster follows the same structure:

- Cluster description and benefits,
- Explanation of different subclasses and application examples
- State of the art concerning the application in production for each subclass as well as derived telecommunication technology requirements and a resulting recommendation according to 4G/5G/WiFi.

The telecommunication requirements are derived from a qualitative rating in the predefined categories from spotlight 1. For each use case an evaluation from 1–4 (low–very high) in the categories is provided. The evaluation is derived from the key characteristics of the use cases. It is a high–level rating. Therefore the exact hardware and software which are used as well as the local conditions of each factory are not considered. In a second step this score is compared to the capabilities of the different telecommunication technologies. Through the matching the suitability (fully functional, partly functional and inoperable) is derived.

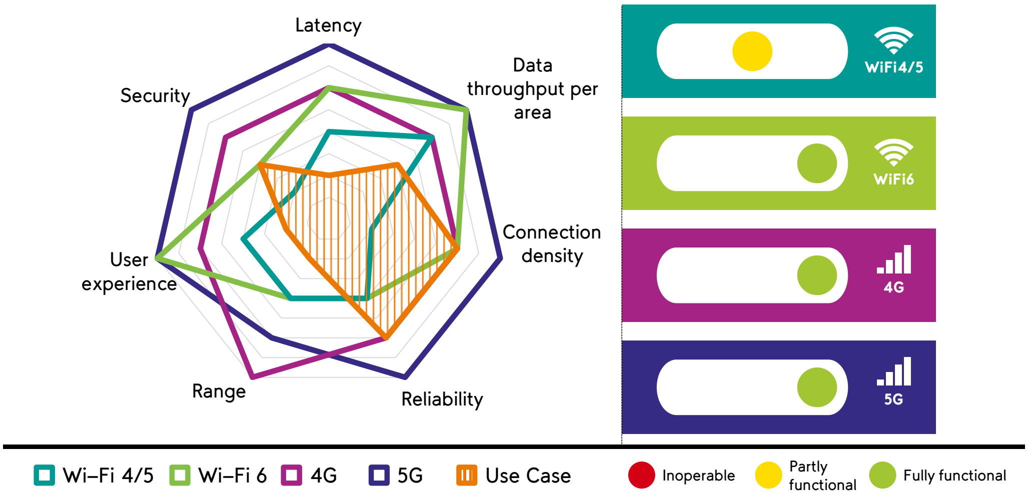

Figure 4: Example presentation of use case matching and evaluation

Track and Trace

The term Track and Trace (T&T) describes the localization and route monitoring of assets and products during their way through the manufacturing facility and beyond. Tracking is the ability to determine the current status of an asset while tracing is the ability to determine the past states of an asset. Track and Trace systems can be used throughout the intralogistics and supply chain to provide visibility of the products, to minimize search times, optimize routes and regulate inventory. They can be used to track assets indoors, outdoors or based on real–time data. The solutions offer the possibility to gain various insights into the production process and gather information about the location, events, status, and condition of assets and products.

Benefits and reasons for the application

How fast a manufacturer gains insight and takes action on process and lead time challenges can mean the difference in winning new customers and expanding into new markets. Track and Trace systems provide the data, insights and intelligence which manufacturers need to become more competitive. The manufacturing process can gain benefits through T&T in multiple ways. Through tracking of assets in the manufacturing site, the handover between different production steps can be improved, which leads to a superior machine and tool utilization. Furthermore, by making quality and traceability data available at all production locations quality standards can be obtained. Having an accurate history of each product available also reduces the expenses, impact, and risk of a product recall.

Indoor Track and Trace

The characteristic of indoor Track and Trace is the localization of monitored assets by scanning the tag on the object at a certain position in the production. This predefined position can be assigned to a certain process step, machine, production area or warehouse. The technical solution to this use case consists of a tag and a scanner station or reading unit. Objects are tagged with barcodes or RFID tags to provide them with identification. Indoor Track and Trace enables the identification of assets by marking them with a uniquely assigned tag. Through the scanning at defined process stations the current position, dwell time and routes in the process chain can be tracked. Therefore, the solution increases process transparency leading to the detection of speed losses, bottlenecks and search times.

Application examples

An application example for Indoor Track and Trace is the position tracking of materials in the production hall and warehouse. Also, the position and usage tracking of hand tools at different working stations and areas is possible.

State of the art (production technology)

Indoor tracking with barcodes and RFID tags is the most implemented identification method. The tag design is determined by the code position on the object and readability. The tracking with barcodes or RFID tags is based on visual contact with the reading unit. The position of the reading units is identified with a specific position and can either be directly connected with a computer or via a wireless internet connection.

Resulting telecommunication requirements

The communication requirements for this use case subclass focus on the data transmission at defined workspaces, since the barcode and RFID scanners are located at these positions. The connection for information exchange is provided by a desktop computer with an internet connection and connection to other systems like an ERP system. For the requirement categories connection density can be rated high since multiple assets are tracked and scan stations are used. Also, high reliability is needed to ensure no asset data and status is lost.

Due to the fixed position of the scanner units these use cases are feasible with a WiFi connection, which is also in line with the current state of the art and provides a cost–efficient solution. Comparing WIFI 4 and 6 WIFI 4 is partly functional for the use case since it limits the asset number connected with the network. 4G and 5G do not limit the asset number but are not the cost–efficient solution for this use case subclass.

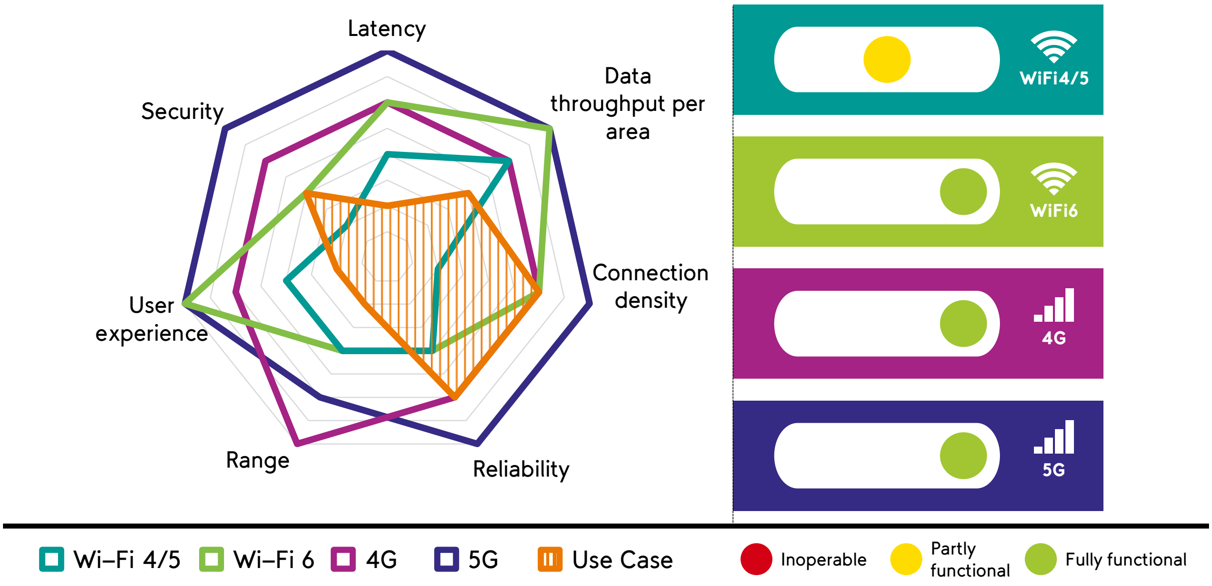

Figure 5: Indoor Track and Trace

Outdoor Track and Trace

Outdoor Track and Trace includes all tracking activities placed outside a production hall or warehouse. Often manufacturers have multiple production sites where different steps in the production process chain are executed. It can be used to track the positions of trucks of the transportation fleet. Outdoor tracking with a continuous signal is enabled by mobile tracking based on positioning via GPS or cellular connection.

The load tracking of trucks allows production planning depending on the arrival time. Further it optimizes the handover between sites and can also be applied to control the external supply chain.

Application Examples

One application example is the just–in–time supply chain. The current position and arrival time will be constantly updated to the recipient. This allows improved production planning and resource allocation.

State of the art (production technology)

Outdoor tracking between different facilities is mainly used for the transport of valuable goods as well as for time–critical transports.

The tracking solution is only feasible with a GPS signal or localization based on the mobile phone position. Other solutions are limited to signaling inside production halls. The application of cellular tracking is also more appropriate for outdoor tracking since inaccuracies up to 45m are possible.

Resulting telecommunication requirements

For outdoor tracking of transports between different production locations as presented in this application example the telecommunication requirements in the defined categories are low to medium. However outdoor T&T needs high connection security since its often applied to track the transport of valuable goods. Outdoor tracking with WIFI is not possible, therefore only 4G and 5G can be considered for the scoring. 4G would be the recommended technologies among the considered technologies. It provides sufficient coverage and localization with an accuracy of 45 m.

5G would not be cost-efficient for the use case presented here for outdoor T&T. However outdoor tracking with 5G could be considered for extensive logistics areas like freight depots, container terminals and ports. In these areas an application of a 5G campus network, with a localization function yet to be developed, could be conceivable.

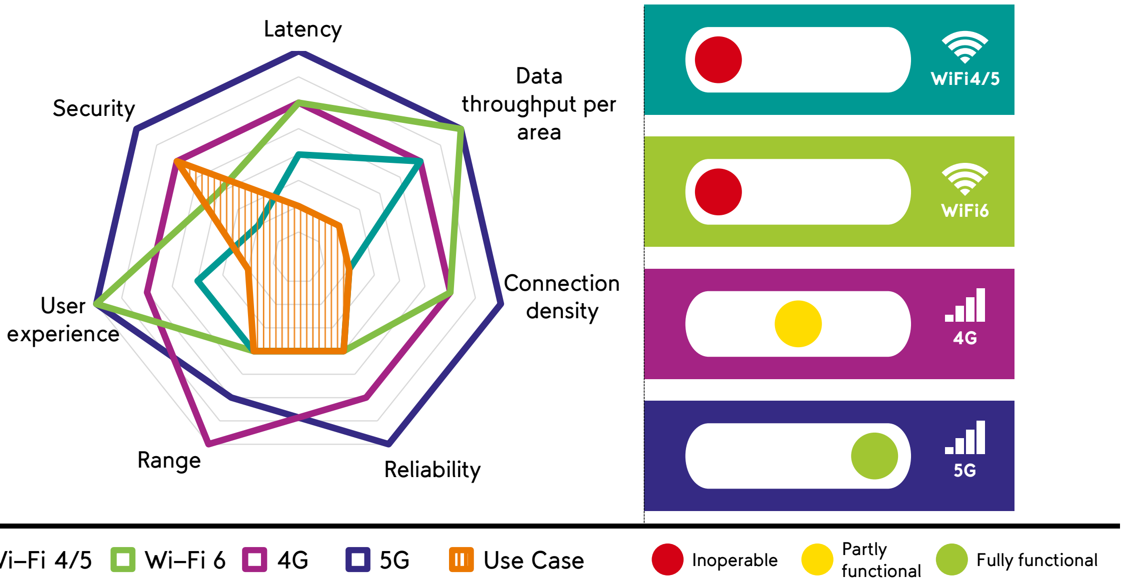

Figure 6: Outdoor Track and Trace

Real-time Location Systems

In contrast Real-time location systems (RTLS) rely on real-time data about assets tracked in the production facility. RTLS consist of tags placed on the monitored assets and antennas providing the areas with even signal coverage to enable wireless communication. The exchange of information and data between transmitting and reading units is not only possible in spatial proximity or in the case of targeted encounters between transmitters and receivers like in the subclass "Indoor T&T". The communication can be based on different tag variations. These not only enable map-based location tracking of assets but offer the possibility to track further information. This includes the asset status (e.g. battery status), condition (e.g.

progress, scrap), history and detailed product information (e.g. order number, final product properties, and characteristics). Also, the tracing data saved on the advanced tags can be edited and further information added by the worker.

The solution allows a holistic real–time visualization of material and process flow throughout the production facility. This provides the basis for process optimization and intelligent just–in–sequence production leading to reduced costs and lead times.

Application Examples

The RTLS can be used to track the processing status of a product route through the manufacturing processes. Also, real–time AGV tracking with information about loaded orders, materials or tools and real–time arrival notification for the worker is possible.

State of the art (production technology)

RTLSs are applied in a highly automized manufacturing surroundings, for standardized processes and in areas with decentralized process control.

For the data transmitting different communication standards are available on the Track and Trace market and are implemented in production halls. The most popular solutions for wireless communication between tags and antennas are Bluetooth, Ultra–wideband (UWB) or ZigBee. Telecommunication technology based on the current 4G standard is not common. Further the localization within a 4G network is not precise enough to track assets inside a production site.

Resulting telecommunication requirements

In order to implement real–time tracking of different assets like orders, material, AGVs or tools special requirements have to be considered. Firstly, production halls have special requirements according to the signal quality and even illumination is needed to ensure real–time tracking. Signal disturbance can be caused by metal objects like shelves and machines. Secondly, location tracking based on different zones requires accurate geofencing for clear differentiation of process steps.

The requirements for data throughput and connection density are driven by the number of assets to be tracked, the higher the number of assets tracked the higher the requirements. Since it's a real–time application the latency requirements are high, but latency also needs to be considered with regard to information and data recipient. The latency requirement for a worker is lower than for the handover of information between machines, because of different reaction times. Furthermore, the integration of larger numbers of assets tracked and the handover between process steps results in a high security requirement.

State of the art for data transfer and communication in RTLS systems are standards like Bluetooth, UWB or ZigBee. These technologies provide high accuracy in localizing the objects and can be expanded modular to provide even signal coverage. Looking at cellular communication, location tracking with 4G is not feasible for this use case subclass since the localization is too imprecise.

However, 5G could be the enabling force for cellular RTLSs. Its technology aims to provide new localization possibilities which enable a tracking function with a cellular network. Also, 5G technologies can build a reliable and secure network allowing high connection and data density to provide a holistic T&T solution.

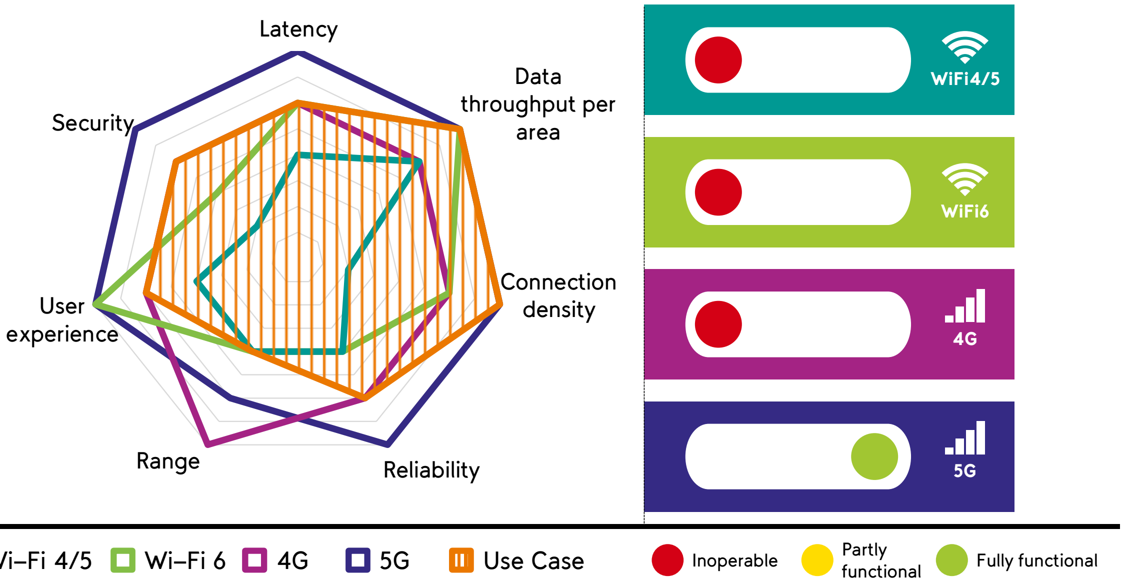

Figure 7: Real–time Location Systems

Autonomous Transport

Automated guided vehicles (AGVs) in production environments are moving robots, that are used to regulate material flow through the factory or warehouse. The navigation of the vehicles can be based on predefined paths, through autonomous routing or intelligent fleet management. Equipment and navigation of these vehicles are based on different designs according to the application. Vehicles can be equipped with various kinds of sensors to navigate through the facility and provide further route coverage information, arrival notifications, carried orders or information about tracked environments.

Benefits and reasons for the application

Often AGVs are implemented in case of a repetitive movement of materials and heavy goods over a certain distance. This offers relief and assistance to workers in the facility. A similar criterion is a transportation in hazardous areas where safe human transport is not possible. Also, AGVs are in use when on–time delivery is critical and process tracking of the material is important. The implementation of AGVs, the automation of intra–logistics, can benefit the overall efficiency by reducing waiting times and idle periods, as well as regulating the material and process flow throughout the production line.

Defined Path Transportation

A fixed or designed path is an actual physical guide path for the vehicle. They can move by following a path defined by inductive wires that are buried or embedded into the ground. Other options are surface mounted magnetic or optical strips for vehicle guidance. These paths are defined during the layout planning of the production hall. Predefined transport paths offer restricted but secure transport. Set within separate areas, paths ensure independent transport without interfering with other assets and workers in the facility. The goal is to implement a lean and efficient intra–logistics to realize cost and time savings.

Application Examples

A possible application for defined path transportation is the transport of heavy and bulky goods to discharge workers and improve occupational safety. Another example is speed line transportations, where smaller goods and batches are transported with increased speed.

State of the art (production technology)

Defined path AGVs based on magnetic tapes, wires or laser orientation are in common use in different industries and realizing transport in hazardous areas to improve efficiency and worker safety. The market also offers a variety of different AGVs carrying different technical features to lift, grab, hold and load goods. Defined paths AGVs provide a cost–efficient solution for intralogistics. Also, WiFi mesh solutions allowing communication of these vehicles are available on the market.

Resulting telecommunication requirements

Since the AGVs move along a defined path, the communication requirements are lower than those of other use cases in this cluster. Communication is based on the position and status of the AGV. An exchange between the vehicles is not necessary. Workers receiving deliveries from the AGV have access to a computer in order to confirm tasks which can then be sent to the AGV without critical requirements. Also, paths for AGVs are defined at the planning stage of a site so signal coverage can be considered. The communication and data transfer is feasible with all the presented technologies, but the application is most cost–efficient and practicable with a WiFi 4 communication.

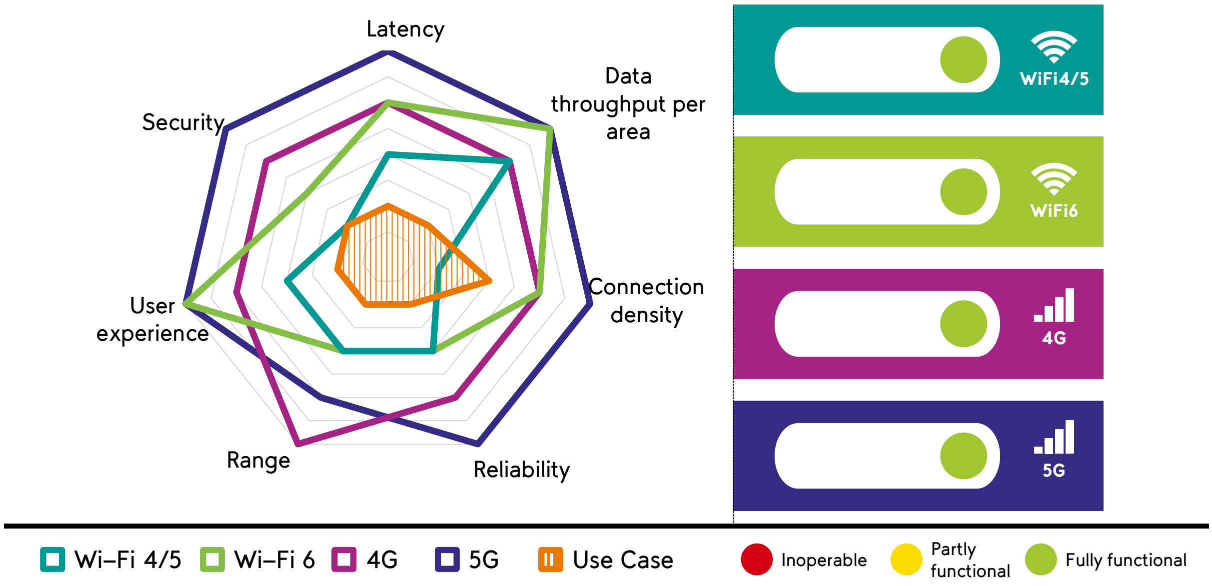

Figure 8: Defined path transportation

Autonomous independent routing

In this subclass, AGV transport is carried out on varying routes within defined areas. AGVs are equipped with additional sensors and technology facilitating navigation on production sites or in warehouses and reacting to obstacles and crossing workers. Autonomous routed vehicles have functions of environment awareness, real–time decision–making as well as behavior control and execution. It is one of the key equipment of flexible modern production lines, assembly lines and warehouse automation systems. AGVs can take on multiple tasks in one transport and routes can be adjusted according to the altering needs in production. The implementation of these AGVs can be retrofitted without defining restricted areas. The AGVs have advanced equipment and are therefore more expensive but can be applied in a set system, providing automated material flow and worker support.

Application Examples

Mostly autonomous AGVs are used to transport smaller goods which can be navigated through the plant faster and more reliable than through manual transport by the workers. Destinations of transports can be adjusted to deliver goods to workers. Furthermore, goods can be transported from the warehouse to the ordering worker on demand.

State of the art (production technology)

Regarding the state of the art of independent routing inside production sites and warehouses, different technologies for the AGV navigation and sensors for surrounding recognition are implemented. A geo–guided AGV recognizes its environment to establish its location. Without any infrastructure, the AGV equipped with geoguidance technology detects and identifies columns, racks, and walls on the shop floor. Using these fixed references, it can position itself, in real–time and determine its route. Vision–guided AGVs can be installed with no modifications to the environment or infrastructure. They operate by using cameras to record features along the route. The vision–guided AGV uses 360–degree images and builds a 3D map to follow a trained route without human assistance and additional special features, landmarks or positioning systems.

Navigation without retrofitting of the workspace is called Natural Features or Natural Targeting Navigation. One method uses one or more range–finding sensors, such as a laser range–finder, as well as gyroscopes or inertial measurement units to understand its whereabouts and dynamically plans the shortest permitted path to its goal. The advantage of such systems is that they are highly flexible for on–demand delivery to any location. AGVs can handle failure without bringing down the entire manufacturing operation since they can plan paths around failed devices. To enable these functions the AGVs need a real–time connection to send their location, receive new tasks and plan their routes accordingly.

Resulting telecommunication requirements

The communication requirements for AGVs with an independent routing function are higher compared to defined path solutions. Providing independent routing, they need a continuous connection to the control system to receive their task and send the current status. In order to enable a dependable system and ensure continuous material flow, requirements for reliability and security are higher. Furthermore, the AGVs need to react to changes faster, which results in higher dependency on the latency. Due to the mobility of the AGVs a reliable cell handover is required. For WiFi 4 a fast cell handover is not feasible. This function is improved with WiFi 6, but still handover speed depends on the number of devices connected to a cell. To enable seamless cell handover 4G would provide the needed reliability and connection density among the options considered. However, similar to RTLSs there are wireless cost–efficient communication technologies like Bluetooth or UWB available.

A use case implementation with 5G is also conceivable, since 5G will provide new localization functionalities as well as providing higher reliability and security. Further a higher number of AGVs can be connected and the integration of different use cases with one communication technology can be considered here.

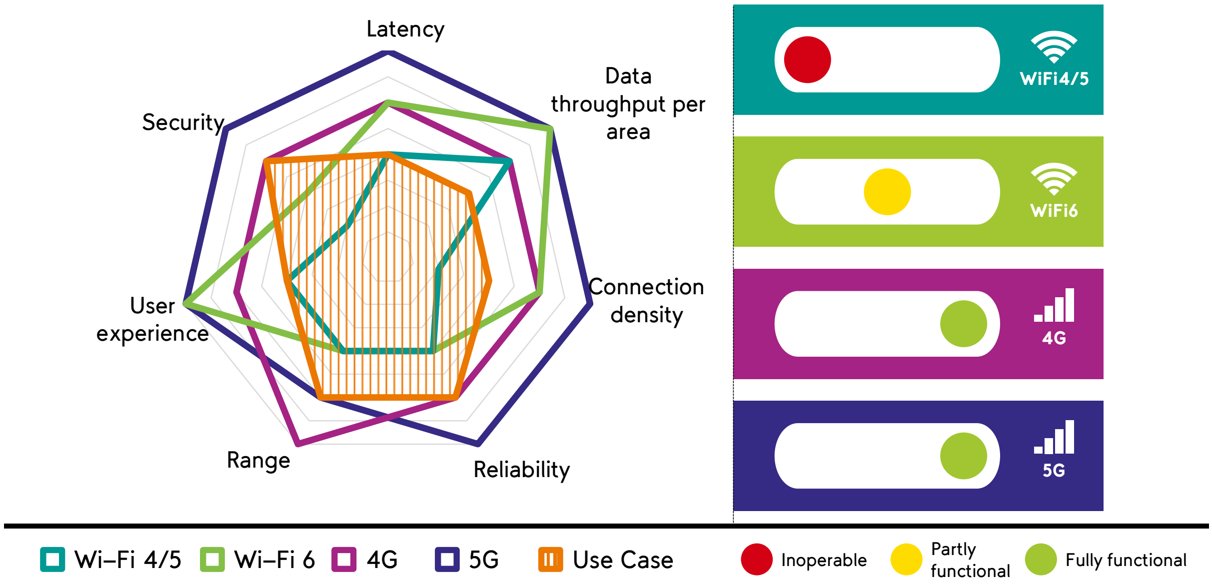

Figure 9: Autonomous independent routing

Intelligent (central) guided routing

Other transport solutions follow the trend shifting towards a centralized intelligence which the AGVs access and act upon. The route planning of the AGVs is organized for the whole transportation fleet in mutual dependence. Therefore, the AGVs need to communicate and cooperate with each other, so that material transportation and loads are optimized. The basis is distributed data management and handling between the whole fleet. This central data is used to perform intelligent road mapping, plan the shortest path based on the AGV position and status, as well as realize the smartest dispatch possible. Permanent communication regarding routes, orders and current position is necessary.

Further functions added to AGVs also enable observation of production grounds and find missing items with camera–based object recognition.

The intelligent routed AGVs provide continuously improving autonomous transport that enables just–in–sequence deliveries with a smaller fleet compared to the other.

Application Examples

Using intelligent guided AGV fleets, various goods from materials to hand tools can be transported through the production hall and warehouse. Orders placed by workers can be delivered to their destination on the shortest way. Also, efficiency and reliability can be ensured.

State of the art (production technology)

Because of the enormous complexity and required IT infrastructure a decentralized intelligent fleet is challenging to implement into a production environment. The needed IT infrastructure is partly still in development for broad application.

Through the decentralized routing intelligence, the AGVs are more compact, mobile and cheaper because of the minimization of needed on–board computing power. Further the system allows updates on the go.

As constant connection and collaboration of the AGVs are required, connectivity requirements are very high. The central intelligence is based on continuous data streams and data analytics. Different mathematical models, which are adopted from optimization algorithms, are implemented to serve as the basis for route calculation.

Resulting telecommunication requirements

Resulting from dependent task assignments, dispatching, and coordinating the AGV fleet requires a permanent connection and communication. Vehicles need the ability to react rapidly, therefore latency requirement is high. Also, the amount of data exchanged between clients is higher compared to the other AGV options presented. This also results in higher data throughput as well as a higher requirement for the user experience data rate. As the intelligent AGV fleet is designed to optimize efficiency and material flow in the manufacturing process, it needs to be highly reliable. Following the requirements and the mobility assumption as stated in the use case subclass before implantation with WiFi 4 and 6 is not feasible. To ensure a permanent and reliable connection between the vehicles 4G can be recommended.

As this use case subclass further follows the trends of I4.0 for interconnection, transparency and decentralized decision–making value could be added through 5G on different levels. With 5G more assets could be tracked and more data could be recorded. A 5G network could also enable updates on the go for AGVs and provide them with continuously improved models for the routing calculation. Further, as AGVs regulate the process flow 5G provides higher security levels. Another aspect of the value creation of deploying 5G could be the integration of other use cases, for example, an RTLS into one network without having multiple technologies present in the production site.

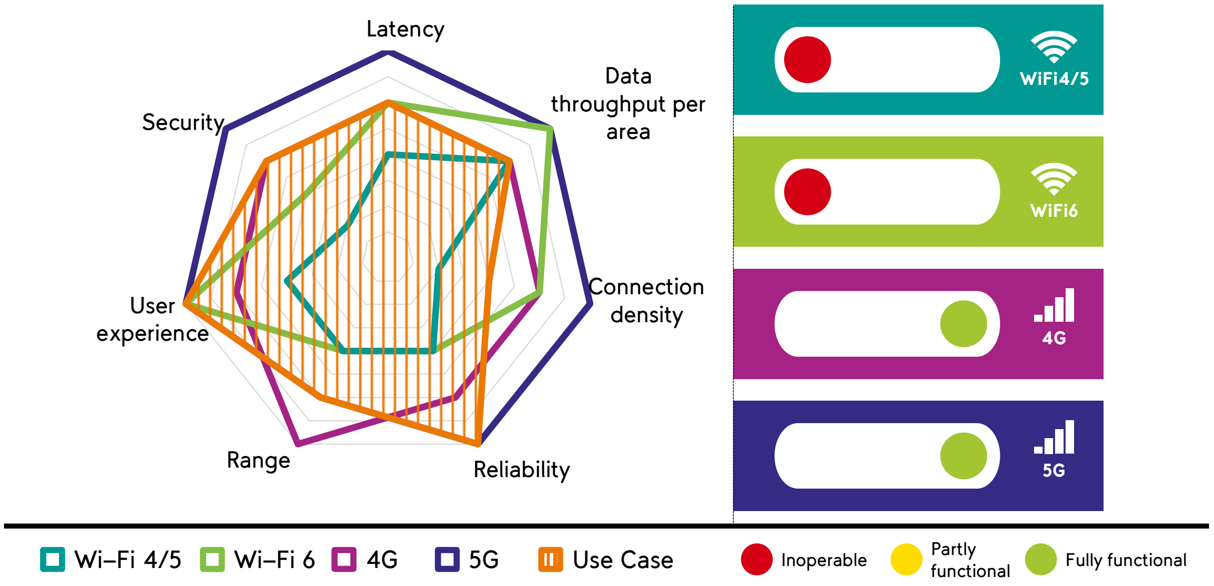

Figure 10: Intelligent (central) guided routing

Augmented and Virtual Reality

As manufacturing becoming increasingly flexible and is challenging continuous improvements, innovative technologies can support the creation of information transparency for workers and support them to adjust to new workflows and tasks. The human workforce is integrated into the manufacturing system which must be flexible and adaptive. Augmented and virtual realities (AR, VR) can be adopted for workforce training, with the result of better interaction between humans and machines. The main idea of VR is to create a digital world in which the user can be immersed and interact. A VR system places the user in a synthetic, virtual environment with a coherent set of rules and interactions with this environment and other participants in this environment. In AR, the user can see the real world as well as digital objects superimposed over it. An AR system inserts a virtual layer over the user's perception of the real objects. AR combines both real and virtual objects in such a way that they function in relation to each other, with synchronicity and the proper depth of perception in three dimensions. These functions offer various application scenarios to give support to the worker and enable a new form of human-machine-interface (HMI).

The use cases displayed in this cluster focus on hardware like wearables or mobile phones that stream content from a central platform, to analyze the communication requirements for the hardware. Further, these kinds of VR or AR devices would also have fewer demands concerning memory capacity as well as they will be adaptable to different applications in the production site.

Benefits and reasons for the application

Assisting the worker in different phases of the production process and in the warehouse can lead to improvements in the reconfiguration speed of a production line. The reconfiguration of production lines could be sped up and improve overall equipment efficiency. Overall support for shop–floor operators is possible with crucial live information e.g. arrival times of material or the display of alarms at machines. Virtual training for assembling parts could be implemented to reduce the failure rate and scrap. Warehouse management can be improved and actions like advanced diagnostics and maintenance can be integrated to minimize the risk of machine failure.

VR as support for engineering and product development

In production, VR is mostly used in production hall design as well as supporting product development and engineering processes. VR content is displayed via a VR headset. Played video content is specially designed and rendered for VR applications.

Through the visualization of product and construction data, development can be made more accessible. Engineers have the possibility to engage virtually with products or experience work surroundings in the planning phase. These showcases are also often used in marketing. Through VR different visualizing data like CAD files can be streamed and made perceptible. Therefore, the planning process can be supported and enables early detection of planning errors.

Application Examples

An application example for VR in manufacturing is shop floor planning. A manufacturer plans a new assembly line, which includes workstations for human workers and process steps which will be performed by robots. To simulate the workflows, check collaboration and security between robots and humans, data about machines and future workplaces can be experienced in the production hall.

State of the art (production technology)

Currently, VR is focused on development actions as stated above. VR elements are technologically mature and the market offers different products. To further engage VR in a manufacturing process heterogeneous VR element technologies have to be connected efficiently, and research for further application in manufacturing has to be carried out. The development of standards and the extension of existing standards for dynamic integration are needed. Also, techniques that enable handling the whole factory at an instance, analyze it rapidly, and provide fast feedback to the shop floor are very important.

Resulting telecommunication requirements

The content presented in a VR environment can be saved on the VR device directly or streamed from a central platform. If videos will be streamed to the end device special requirements apply. In VR environments, stringent latency requirements are of most importance for providing a pleasant immersive VR experience. The human eye needs to perceive accurate and smooth movements with low motion–to–photon (MTP) latency, which is the lapse between a movement (e.g. head rotation) and a pixel frame shown to the eyes. High MTP values send conflicting signals to the vestibulo–ocular reflex (VOR), a dissonance that might lead to motion sickness. There is broad consensus in setting the upper bound for MTP to less than 15–20 ms. To achieve this latency requirements streamed content is often buffered on the device. Crucial for the provision of video data in this regard is the data downlink. This results in very high requirements for the user experience data rate.

Comparing these findings with the considered telecommunication technologies a VR implementation on the factory level is feasible with WiFi, if the application is set in a static surrounding. This means, if the user streams content in one set position. If the user is moving through the production hall to experience the VR content, cell handover could be difficult to implement, and inconsistent transmission could result. Since the requirements for latency are very high a use case realization with 4G could be limited due to available properties. These obstacles are not present with a 5G communication and also a seamless handover will be possible.

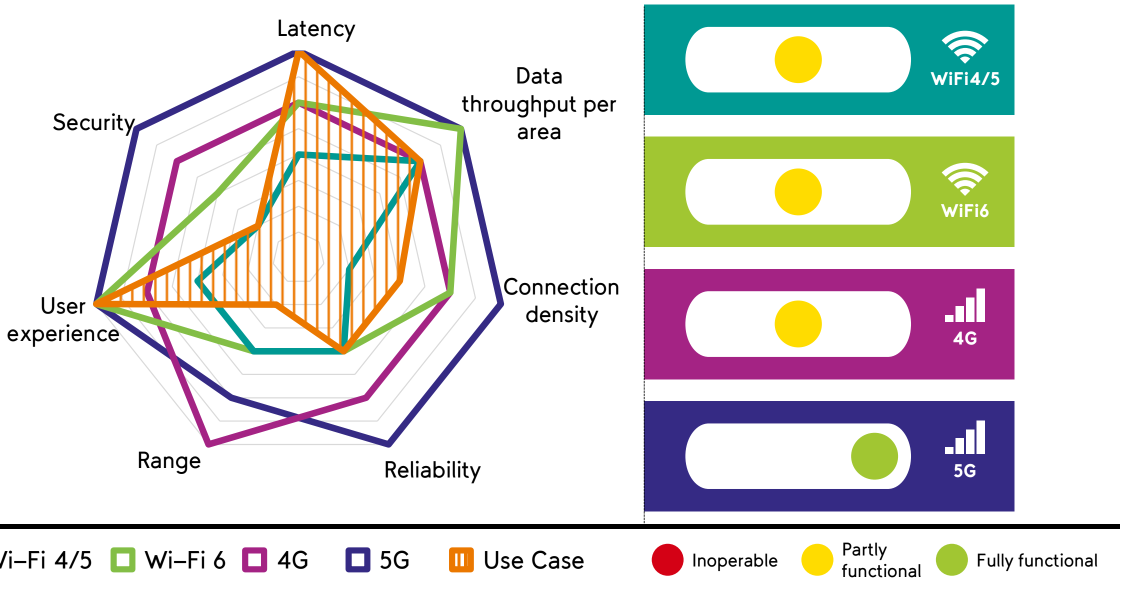

Figure 11: VR as support for engineering and product development

AR for worker guidance

The key feature for AR in manufacturing is the support of workers with manuals and additional information about processes and machines. The information can be provided by using wearables (e.g. smart glasses) or content can be accessed via a mobile device like a smartphone or tablet. This offers portable access to all relevant documentation (e.g. manuals, videos, photos) and an overview of required tools and materials is provided. It can also provide workflow guidance with the help of 3D animations. In advanced systems editing of existing documentation during the task by taking notes or pictures etc. is enabled.

Through AR support of workers, the demanded quality is assured, learning processes and training is improved as well as non–value adding process time can be minimized.

Another possible application area could be maintenance support. The access to live telemetry data of specific machine parts while being present at the regarded machine. Also, cross–referencing of prior maintenance cases to reuse solutions established in similar cases could make the maintenance process more effective and quality–driven. This also demands to record statistical machine data for future planning of similar tasks.

Application Examples

An application example is worker guidance in an assembly line. The worker is equipped with safety glasses that provide AR features. Thus, he can access an assembly manual according to his position in the assembly line and access specific information about parts he has to process.

Another application example could be a navigation feature in AR glasses supporting the worker navigating his way through the production hall or warehouse.

Another possible application area could be maintenance support. The access to live telemetry data of specific machine parts while being present at the regarded machine. The worker can scan a QR–Code on the machine with his phone and see the parameters and characteristics of different parts of the machine. Also, cross–referencing of prior maintenance cases to reuse solutions established in similar cases could make the maintenance process more effective and quality–driven. This also demands to record statistical machine data for future planning of similar tasks.

Quality insurance for final product approval for cars could be conceivable. At the final approval cars could be checked by AR supported workers who final check e.g. the cap dimensions of the parts.

State of the art (production technology)

The application of wearables for staff in production is an important trend in Industry 4.0 technologies. The usage of mobile devices to display information is common. Since the hardware is constantly developing and standards are defined by research, hardware with a suitable performance for the industry application is developed. For a broad industrial application, it is desired that workers will be equipped with an AR compatible device that provides support and information in regard to daily changing tasks. Therefore, the content and relating instructions need to be streamed to the devices and be continuously updated.

Resulting telecommunication requirements

For the worker guidance with AR, virtual content is layered over the real–world perception. Therefore, the data amount streamed to the AR devices is smaller than for VR applications. Latency and user experience data rate requirements are still very high. Further for the application in manufacturing surroundings, the number of devices connected to the system is high, which results in a high connection density demand. Compared to VR, worker guidance with AR not only needs to provide a downlink, but further needs to enable a fast uplink to react to the worker's action. For example, in quality control with AR the worker needs sufficient feedback from the system about parameters, values and status of the part and the defined quality limits. Therefore, the user must be equipped with a channel towards the server hierarchy to signal its position and what view it is observing in the virtual environment. He also must be equipped with a channel in the other direction to receive the data pertaining to this virtual environment. For application examples of AR for navigation also a seamless handover and reliable connection are needed. Hence as a result the presented AR use cases are partly functional with WiFi and 4G, depending on the mobility demand of the specific application and the latency required. An integration with 5G is fully functional and provides advanced security to ensure data safety for generated expertise and knowledge.

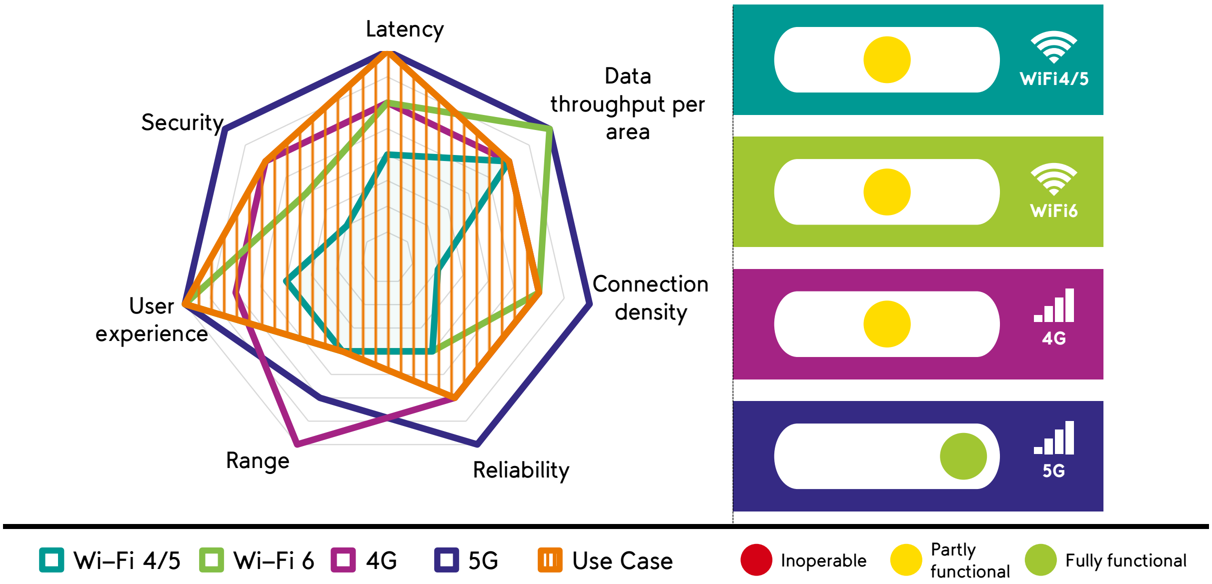

Figure 12: AR for worker guidance

Data Analytics

Recent improvements in data storage and processing technologies have led many decision–makers to change their decision–making styles, relying less on intuition and more on data. This trend is especially notable for the manufacturing industry. Through the digitalization of factories, the amount of available data increases exponentially. The development of IIoT enables the continuous gathering of sensor, process and product data. This data needs to be stored in a relational database or a data lake. It can be used for statistical data analytics. To find unknown correlations and generating deep insights intelligent data analytics is performed. Because of increasing processing power and the development in the field of artificial intelligence more complex data analytics processes can be realized. These data analytics applications exceed the analytic ability of a human being considerably. The goal is to create a fully transparent manufacturing process which is the foundation for predictive analytics. The usage of data analytics tools is the basis for use cases in the UC classes process control, dashboarding & monitoring and automation.

Benefits and reasons for the application

The knowledge gained through data analytics represents a significant competitive advantage for companies. Using data analytics in production can lead to reducing operational costs, improving the efficiency and dynamics of processes as well as the quality of the product. The more data is collected in all areas of the company the higher the benefit of using data analytics.

Data storage / Data Lake

In order to be able to use advanced analytics in production, all generated data has to be stored. In the field of industry 4.0, the collected data is characterized by high volume, velocity, and variety. This kind of data is called Big Data. In the past, data has been stored in relational databases with a certain syntax. These databases are limited in speed and flexibility. Therefore, they do not meet the requirements for dealing with Big Data. To offset these limitations data lakes are implemented. In data lakes, any kind of raw data can be saved and used flexibly for data analytics. The data is stored in a cloud and can be accessed from everywhere. Therefore, one data lake can be used for more than one production site.

Application Examples

As an example, the results of AI–based optical quality control can be correlated with sensors and process data to understand the impact of certain parameters on the final product. By using a data lake, these totally different types of data (e.g. image data, KPIs and process parameters) can be stored in the same data storage and processed much quicker than in a relational database.

State of the art (production technology)

Data lakes are increasingly common in manufacturing enterprises. The demand for analysis of enormous data amounts occurring in Industry 4.0 manufacturing sites makes data lakes an attractive solution for pattern recognition and process optimization. Nonetheless, as the usage of data lakes is spreading out the requirements concerning data transparency, quality and compliance rise. The demand for analysis of enormous data amounts occurring in Industry 4.0 manufacturing sites makes data lakes an attractive solution for pattern recognition and process optimization. Since there are no uniform connectivity demands, specifications need to be formulated according to the highest standards considered

Resulting telecommunication requirements

In an ideal environment, all company data is collected in a data lake. Cybersecurity standards of a data lake are extremely strict. Therefore, the requirements for the security of the telecommunication technology are very high. The collected data can be used for various process–critical data analytics, resulting in a very high need for the network. Today data lakes are realized by using WiFi. For all other criteria, this is sufficient. But as the result of data leaks is increasingly expensive for companies, only the implementation of a campus network covers reliability and security fully. Therefore, it can be viewed as an enabler to the full potential of this use case.

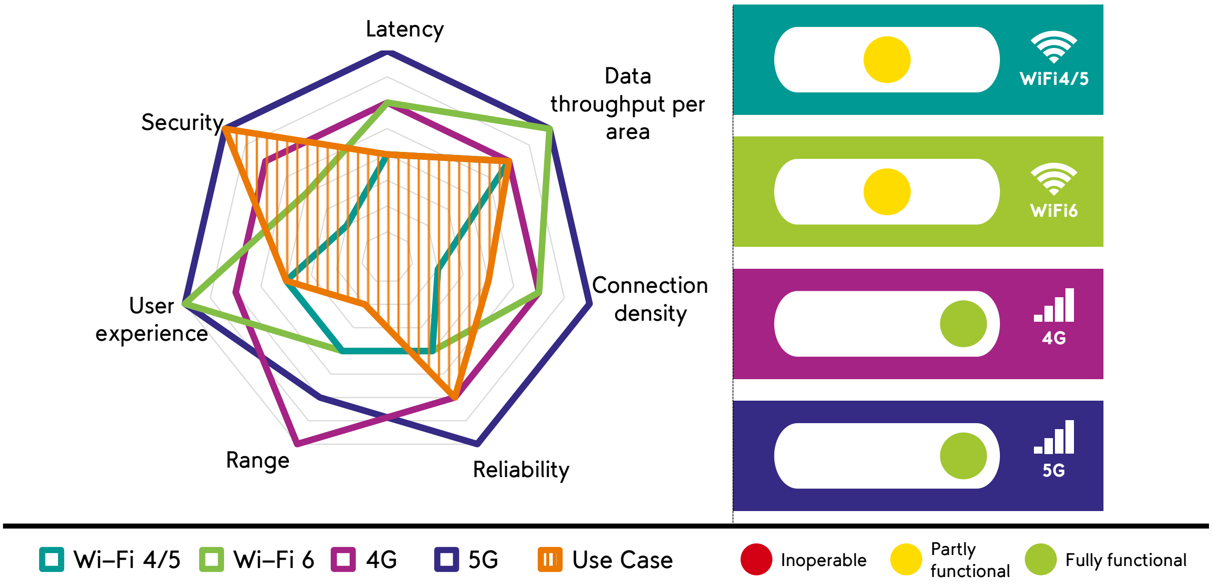

Figure 13: Data Storage / Data Lake

Statistic data analytics (descriptive analytics)

Statistic data analytics adapts performance characteristics like the process capability index, which is a statistical measurement of the process capability: the ability of a process to produce output within specification limits. Framework conditions, parameter limits and alternative courses of action are defined. Typically, data is being sent to a centralized database (relational database) or a cloud (e.g. data lake) and processed by a central algorithm. The processing of the data often involves manual process steps and the interference of a responsible human being. Therefore, descriptive analytics is not time–critical and is usually performed periodically. Descriptive analytics creates knowledge out of raw data leading to improved process transparency and lays the foundation for improvement measures for action.

Application Examples

As an example, quality data can be used to calculate the mean and standard deviation. The data is processed by statistical analytics software. This can be used to calculate different key performance indicators (e.g. OEE) and improve the process based on the results manually. Statistic data analytics is performed disconnected from the production hall and the results are used time–delayed.

State of the art (production technology)

Statistic data analytics has been used for the last decades. Through the creation of massive amounts of data (Big Data) in production, statistic data analytics is as effective as it has ever been. The challenge is being able to filter and process all existing data. A relational database is sufficient for statistical data analytics, but a data lake can also be used. More allocated data sets higher demands for the provided connectivity.

Resulting telecommunication requirements

Statistic analytics is based on historical data and used for non–real–time decisions. Therefore, it is not time–critical to transmit the data. The amount of data of each machine, that is used in statistic analytics, is low. This leads to a low need in latency, range and connection density. The security requirement is high, because of the transfer of process data. Therefore, WiFi 4 can be used for statistical data analytics. The more data is collected and used the more sensible it is to switch to 4G or 5G. They provide higher security standards, lower latency and higher data rates.

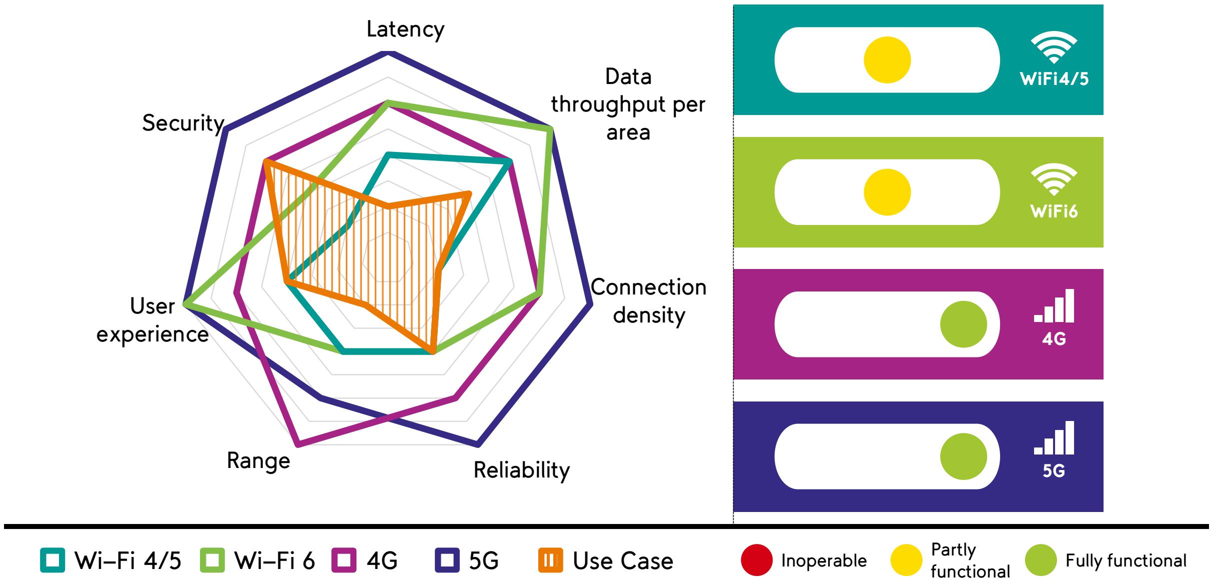

Figure 14: Statistic data analytics (descriptive analytics)

Intelligent real–time data analytics

New technologies provide more data. To use the full potential of big data, this data needs to be processed in real–time. Smart algorithms use machine learning to generate deep insights and find unknown correlations beyond the human analytics capacity to improve the process design and explore external influences not directly linked to the processes and machines. The more data is created and the longer these algorithms are in use, the better the results will be.

Application Examples

By implementing intelligent real–time data analytics of a production process, unknown correlations can be discovered. When using data analytics to improve the quality of a product, all parameters of the production process are analyzed. The result of the analysis shows, that a parameter needs to be adapted, which has not been associated with the production process of the product before.

State of the art (production technology)

The intelligent data analytics software which allows complex data analytics is expensive as well as implementing the needed IT–infrastructure. The results of the algorithms are only as good as the collected data. The amount of data that is collected differs immensely in various factories. It depends on the digital maturity of the machines. The degree of connectivity of older machines can be improved by retro–fitting, which describes adding new features, sensors or control panels.

Resulting telecommunication requirements

This use case poses high requirements for fitting telecommunication technology. The real–time analysis of complex machine, process and company data (Big Data) requires low latency, a high connection density and data throughput per area. Unique and complex AI–algorithms help to get deep insights. Used in the right way, this leads to a competitive advantage over other competitors. This is the reason why security standards have to be high. Up to a certain degree, WiFi 4 and 6, as well as 4G, can meet the demands. But in a fully digitalized and connected factory only 5G can elevate intelligent data analytics to reach its full potential. It allows a very high data throughput per area, ultra–low latency and provides very high security.

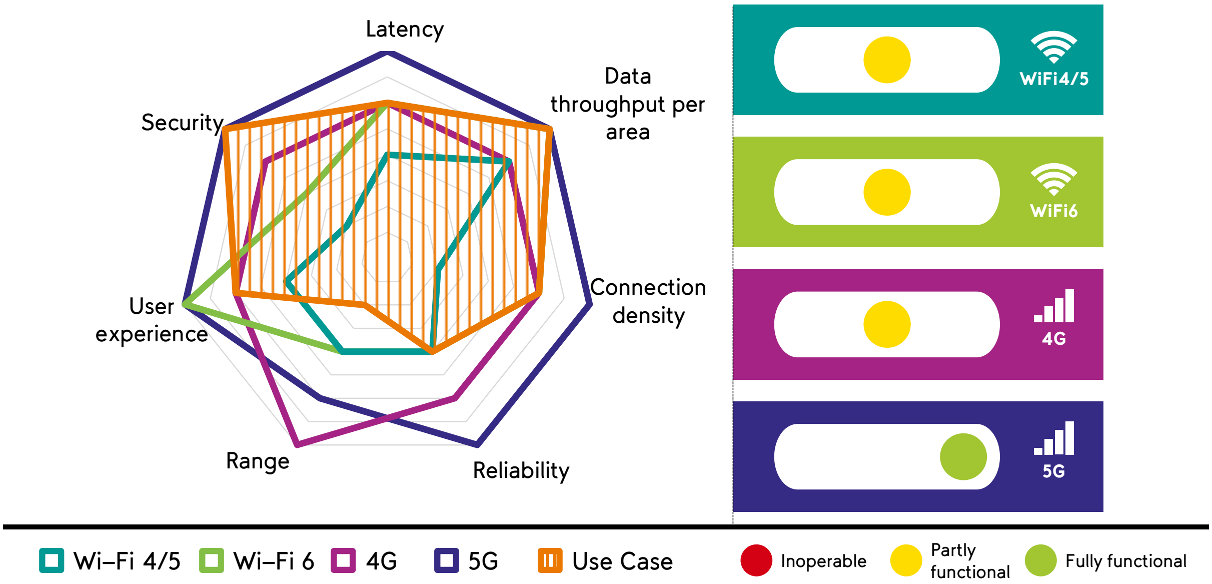

Figure 15: Intelligent real–time data analytics

Predictive Analytics

The enhancement of intelligence analytics is predictive analytics, which not only provides insights on current and past data but allows statements about future developments. In digitalized manufacturing, maintenance must take a key role to reduce the risk and minimize the consequences of unplanned stops and disruptions. Predictive analytics can help to predict deviations in data, to trigger preventive actions to avoid failures or to reduce their consequences resulting in increased machine uptime and higher productivity. In order to do so, data is collected in real–time and compared to historical data. This is an infinite process ensuring, that parts are only changed when it is needed and before a machine breaks down.

Application Examples

Long–time milling machine data is used to predict the need for a tool change. This ensures that quality requirements are reached, and scrap is minimized. Furthermore, downtimes and maintenance costs are reduced. In this example data shows that a tool change is needed in a certain time frame. The right tool can be ordered beforehand. The service worker who changes the tool can be scheduled for the right time and change the tool in a designated time slot. Therefore, the only downtime occurring is the time it takes to change the tool.

State of the art (production technology)

This technology is increasingly used. The issue with predictive maintenance is, that the prediction is only as good as the collected data. Predictive models based on machine learning have to be efficiently programmed, continuously updated and provided with data.

Resulting telecommunication requirements

The telecommunication requirements are identical to the requirements for intelligent data analytics. The required data throughput per area and security are very high. The effectiveness of the predictive analytics algorithm depends on the amount of collected data. In the vision of the factory 4.0 all machines are fully connected. Nowadays, in order to retro–fit machines all sensors need to be connected to a PLC. By using 5G technology, all sensors could be connected wirelessly to an IoT–Platform. This allows an easier retrofit. For example, a moving part could be equipped with an acceleration sensor without worrying about the cable. Therefore, 5G helps in enabling a more efficient and effective way of performing predictive analytics.

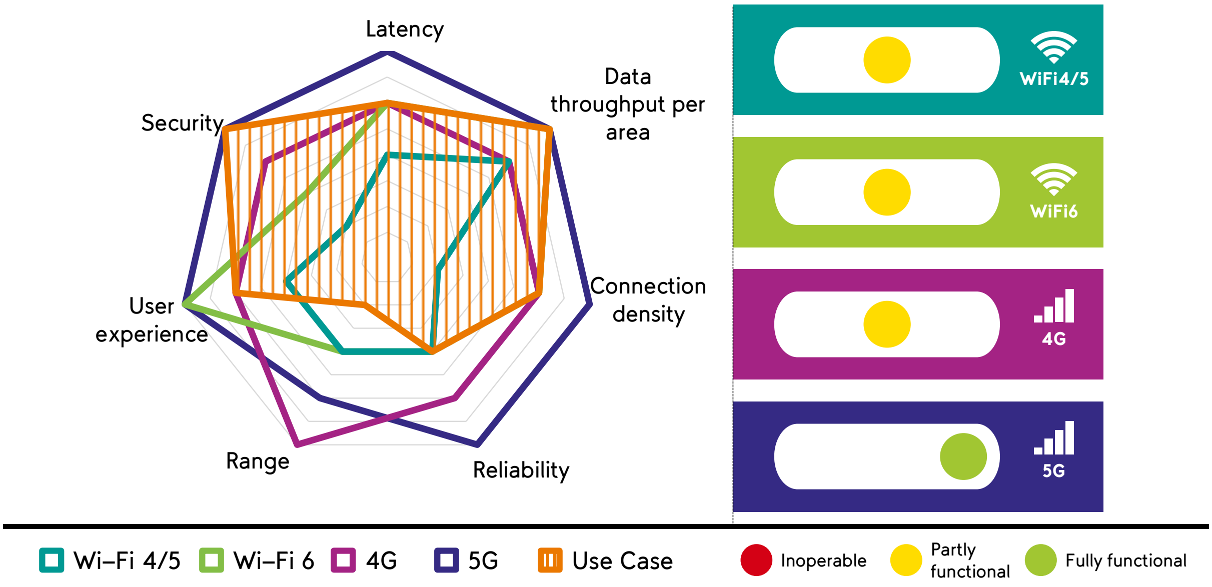

Figure 16: Predictive analytics

Dashboarding and Monitoring

The use case cluster ″Dashboarding and Monitoring″ describes use cases that allow the visualization and contextualization of process and product data. A dashboard can be described as a single–screen display that visualizes production data. Dashboards are used to monitor and evaluate the performance of a machine, a production line, an entire factory or the entire enterprise. The digitalization of process data and central storage based in a relational database or a data lake is the prerequisite for dashboarding and monitoring in a complex and agile manufacturing environment. Underlying is a network of sensors that generates all process data. Process and machine data can either be visualized based on a digital shadow or the generated data can be mapped against a predefined desired state to assess performance manually.

Benefits and reasons for the application

The visualization of production data across all hierarchy levels gives the shop floor worker and the management a detailed overview of the process performance. Dashboarding is the first step in creating full transparency and generating almost real–time information out of raw data. It allows the responsible persons to monitor the processes and react to anomalies manually. Dashboarding and Monitoring can be viewed as the start of the implementation of an efficient and adaptive manufacturing system using Industry 4.0 principles.

Machine monitoring

Machine monitoring represents the simplest use case in the use case cluster dashboarding & monitoring. In order to monitor a machine, process and condition, data is collected. Therefore, a digital copy of the current state is created. If the digital copy represents the current state of a machine fully, it is called the digital shadow. It is the basis for all data visualization and analytics. A connected sensor network providing all key parameters and values of the machine or asset is a necessity. By using a Manufacturing Execution System (MES) or IoT–platform, this data can be accessed remotely. Key performance indicators (KPIs) are defined and visualized on a dashboard to monitor the data using a mobile device or stationary screen. This increases process transparency and the data can be used for manual process interventions to ensure performance and efficiency.

Application Examples

Machine data from a milling machine is collected and sent to an IoT–Platform. In the programming environment of the IoT–Platform, a dashboard is created. This dashboard visualizing machine data can be displayed on the smartphone of the production manager. The manager can act manually if the displayed data shows abnormalities. Generating this data and visualizing it is typically the first step in a digitalized production.

State of the art (production technology)

Monitoring machines is common in today’s manufacturing environment. Usually, the created data is created using sensors collected centrally at the machine. Then the data is transmitted to the MES or IoT–Platform via cable or WiFi. The collected data is processed and visualized in a dashboard. The dashboards can be displayed directly at the machine or accessed on different mobile devices.

Resulting telecommunication requirements

Machine monitoring is one of the first use cases implemented on the way to a fully connected factory. Therefore, the telecommunication requirements which have to be met to implement machine monitoring are low. The most important category is the user experience data rate because of a fluent display of data. WiFi 4 covers this use case completely. WiFi 6, 4G and 5G could be used as well, but the application does not add any value in this use case and is more costly.

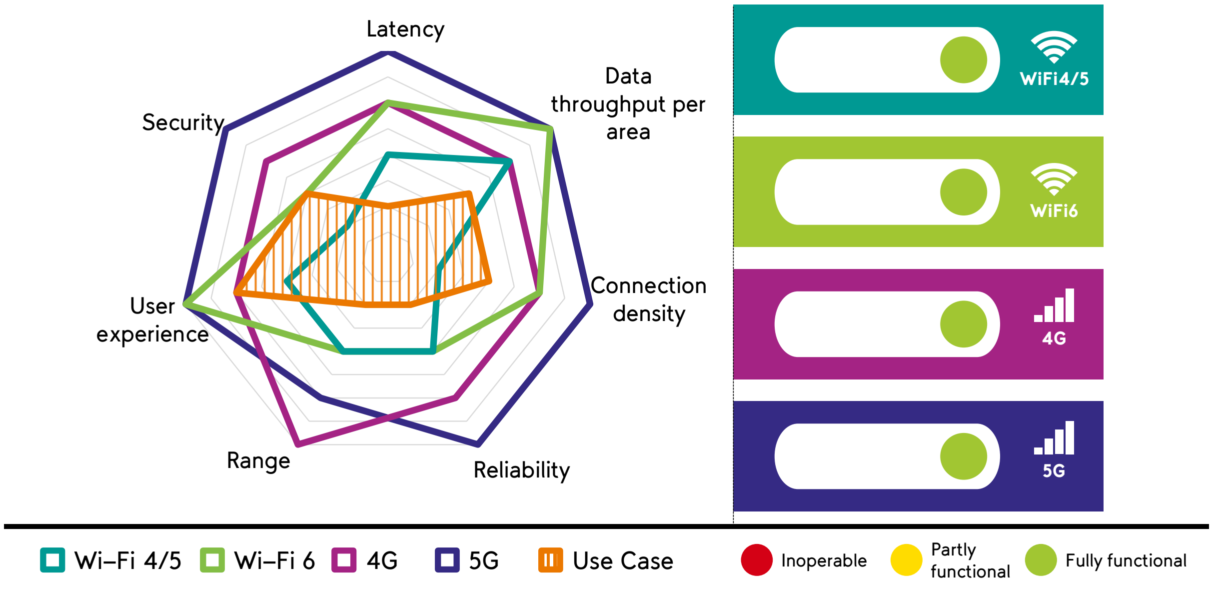

Figure 17: Machine monitoring

Mapping of target and actual state

The use case of comparing the target with the actual state builds on the monitoring use case. The monitored process and machine data are collected and immediately compared to predefined targets. These targets are stored centrally, e.g. in an Enterprise Resource Planning System (ERP). If anomalies are detected, an automatic notification is sent to the responsible person. Anomalies are for example quality issues, process stops or shortages of material. The immediate comparison between actual and target state requires real–time data and remote data access. This leads to quicker response times and allows the comparison between the current and desired state of process efficiency. Therefore, cost and time management are improved and process quality ensured.

Application Examples

Building on the example of the milling machine in the monitoring use case, the collected milling machine data is automatically compared to other data sources from the cloud in real–

time to evaluate the current machine status. The findings can lead to adaptions of the following process steps. They will be carried out by the responsible worker.

State of the art (production technology)

The mapping of the actual and target state is performed regularly in manufacturing companies for manual process control. It is often limited by the connectivity of heterogeneous systems, the lack of processing power and data creation. Therefore, data is often compared periodically and not in real–time.

Resulting telecommunication requirements

The mapping should be executed in near real–time. It needs to be reliable and secure because confidential company data is compared to the actual state of the machine. This requires high security, high reliability and low latency. The basic requirements are met by WiFi. But if more machines are connected and the more diverse data with high velocity needs to be processed and compared in a secure way, a campus network using 4G or 5G enables reaching the full potential of the use case.

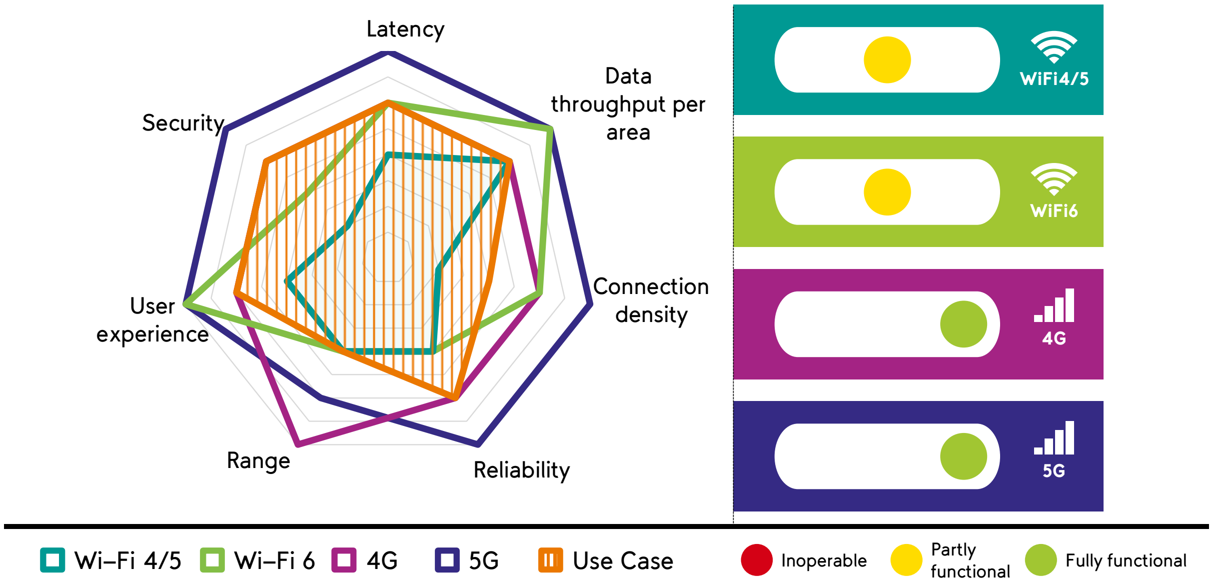

Figure 18: Mapping of target and actual state

Automated Process Control

Based on process monitoring and increasing digitalization a further development is implementing self–regulating process control. This use case cluster is defined by not only mapping the actual and target state of data but also implementing a control loop. These control loops enable machines or manufacturing systems to act independently. When abnormalities in control loops are discovered, counter–measurements can be taken automatically. Machine–to–machine and machine–to–cloud communication are necessary.

Benefits and reasons for the application

Automated process control is the consequent further development of process monitoring. By ″closing the loop″ and using the collected data to improve the process and machines, further process optimization is possible. Machine–to–machine communication also improves quality control, reduces lead–times and makes the processes more efficient and sustainable. It also improves quality control and energy consumption.

Closed control loops for machines

In a digitalized production, all kind of machine and product data is collected during the manufacturing process. This data is stored and processed in a cloud. The results are used to optimize machine usage, parameters, and output. This optimization is called a ″closed loop″. The optimization is performed autonomously without a human being (e.g. an operator) interfering. The goal of implementing closed control loops for single machines is to improve the stability and lead time of the machine as well as the quality of the process step. The reaction time is reduced immensely by eliminating worker involvement. Each machine earns the ability to react to errors or anomalies immediately. Data–based parameter optimization can be viewed as more efficient and effective than manual optimization.

Application Examples

All sensors and the control of a milling machine are connected to an IoT–Platform. Through applying machine learning algorithms and models, the process can be optimized. The result is then looped back to the machine controls. With adapted parameters the milling process becomes more efficient. This loop is repeated continuously.

State of the art (production technology)

Closed control loops for machines go beyond process control as it has been the norm in manufacturing for decades. The status quo of connecting machines is the usage of hard wires and WiFi. This limits the flexibility, the minimum latency and the maximum amount of data that can be transferred. An IoT–Platform with the right algorithms needs to be established. Once the IT–infrastructure is installed, closed control loops can be implemented in production which is technologically possible nowadays.

Resulting telecommunication requirements

The usage of an automated control loop of a machine poses very high requirements for the category’s latency, reliability and security. If the connection is interrupted, the production process is affected. In the worst–case scenario, the entire production process is stopped. Due to these requirements, WiFi 4 & 6 as well as 4G would limit the effectiveness of a real–time control loop for a machine. A 5G network meets all the requirements.

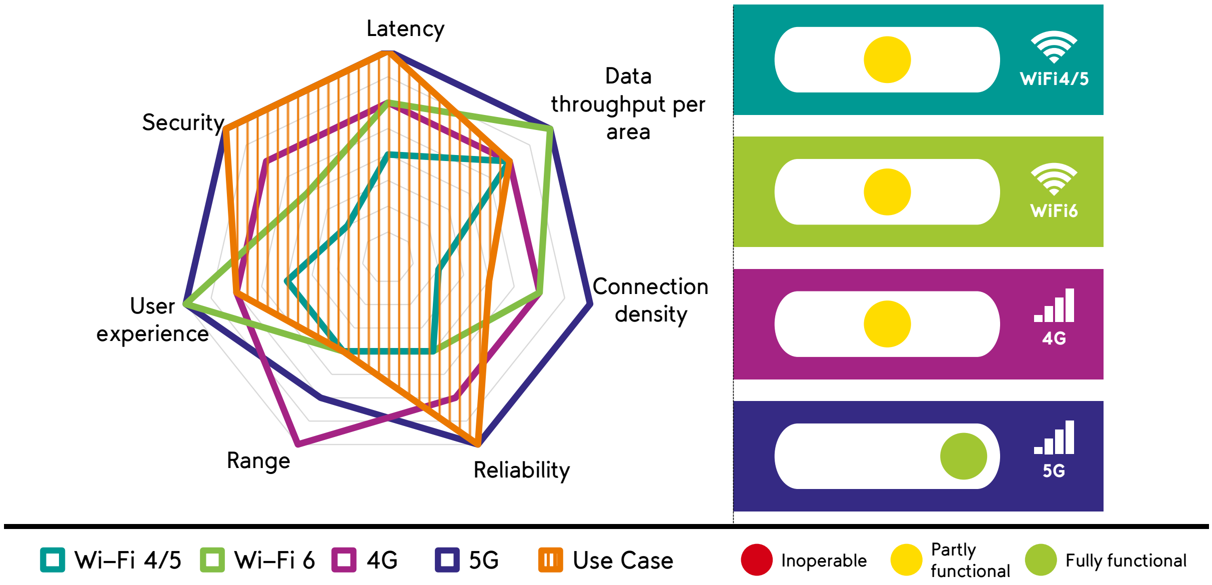

Figure 19: Closed control loops for machines

Closed control loops for process line

In this use case, more than one machine communicates to a centralized platform e.g. an IoT–Platform. The collected data is not only monitored but also used to control the process. This bidirectional communication is fully automated. In order to control the process, all machines in the production line have to be interconnected. It is necessary that the implications of changes at the beginning of the process are known for the following steps. Therefore, mathematical models and algorithms describing the process and implications have to be implemented. By combining the digital shadow with those models and algorithms, a digital twin of the process is developed. The continuous comparison of the actual and target state combined with optimization models leads to autonomous improvement of process flows. Ultimately a full interconnection of machines and closed control loops over the production process would result in the spectrum of automated process control as well as automated utilization and performance adjustments.

Application Examples

Interconnected machines in one production line enable optimized and dynamic route planning in case of machine failure as described in the following scenario:

The production line has three production steps and two machines for each step. When Machine 1 in step one has an error, there is an automatic feedback to the other machines and the production capacity and speed can be changed and counter–measurements (e.g. producing other parts in steps two and three) can be taken.

State of the art (production technology)

Fully autonomous production lines are the holistic vision of Industry 4.0, which is admired to reach in the future of manufacturing. In order to reach this state in a factory, many steps have to be taken beforehand. By creating a digital twin of the entire factory, the amount of data being transferred and processed will increase exponentially compared to the status quo. Today's networking technology is not capable of fulfilling all requirements of ultra–low latency, high–reliability and speed.

Resulting telecommunication requirements

If the vision of a fully connected factory becomes reality, a 4G network, which can be used for implementing a control loop for a machine, is insufficient. It does not offer the needed connection density, latency and stability. Additionally, WiFi 4 and 6 are not secure enough. Only a 5G network enables a closed control loop for the entire production process. Machine control and communication between all assets is highly challenging for telecommunication technologies. 5G serves as an enabler for realizing a completely smart factory.

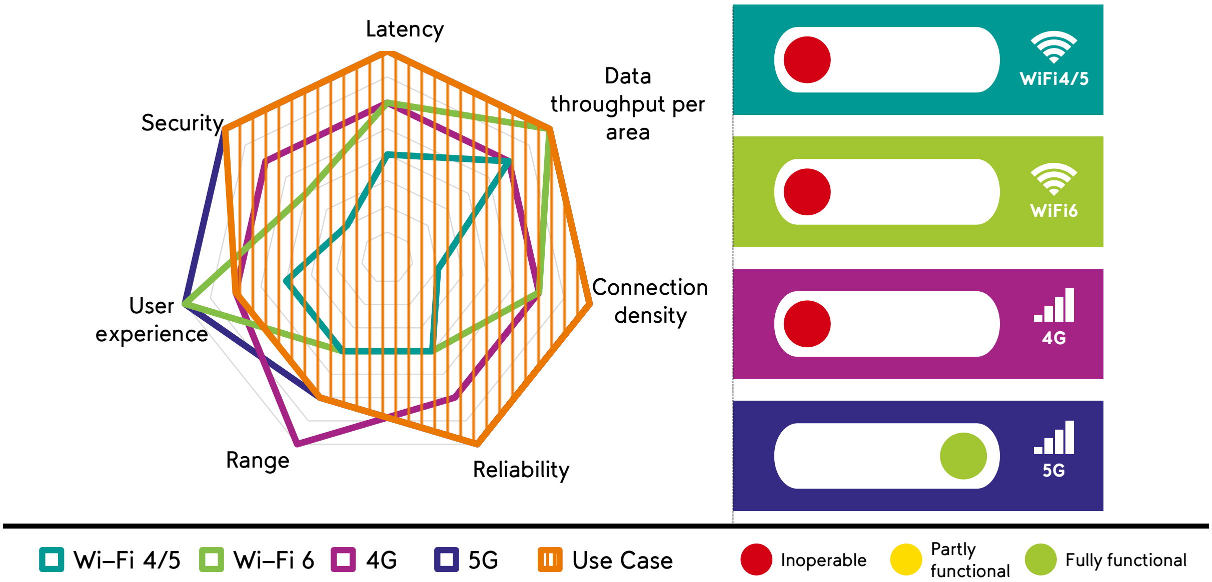

Figure 20: Closed control loops for process line

Process automation – robotics

The degree of automation and therefore the usage of robots is increasing continuously in the manufacturing industry. In the past, robots were deployed on the shop floor to automate either simple and labor–intensive tasks or lifting dangerous as well as heavy objects. However recently, the tasks of robots have become more challenging. They are being used in high–precision, high–speed applications and becoming one of the major manufacturing pillars. Yet, robots are rather inflexible as they are oftentimes fixed and dedicated to performing one task. While Industry 4.0 and CPPS are aiming to increase not only the degree of automation and enhance flexibility, but also process transparency, the field of robotics needs to adapt to the new challenges in production. For example, the rise of mobile and collaborative robots ("Cobots") are being enormously deployed to increase the automation degree.

Benefits and reasons for application

Process automation and the usage of robots has multiple benefits. Generally, a robot is used to automate a process if it is cheaper, faster, more efficient, more precise or if the process is too monotonous or dangerous. The results are reducing production costs and process time and increasing manufacturing or production quality. Regarding Industry 4.0 and creating full process transparency more data is produced by robots than in a comparable manual process.

Robotic application with predefined motion control

The standard robotic application possesses predefined motion control. The motion of the robot is programmed in so–called motion scripts before the usage (offline). The robot arms etc. move in predefined repetitive motions. Those motion programs can be stored locally on the robot's CPU or remotely to enable agility of the motion scripts. Those robots can be working for years without changing the script or the operation place. They are a cost–efficient and reliable way to automate certain manufacturing steps. Robots can replace manpower and minimize the dependency on human beings in the process.

Application Examples

An assembly robot in a car production line is a typical robot with predefined motion control. Standard tasks of these robots are pick and place movements. Only one type of car can be produced on these lines also because of the lack of flexibility of the robot. Changing the process and therefore the field of application of the robot is complex and expensive.

State of the art (production technology)

These kinds of robots are the status quo in many factories. They are the standard way to automize a process. They have been the norm for many years and still will have an important role in the future. One of the biggest disadvantages of these robots is the lack of collaboration. Robots with predefined motion control cannot work in the same manufacturing cell as a human being. Safety measures have to be taken into consideration. Often robotic cells are a fenced–off area in a production hall.

Resulting telecommunication requirements

Once these robots are implemented, there is no need for a time–critical, highly stable connection. The data transfer is only one way: from the robot to an IoT–Platform or MES. This data can then be used for various analytics. Robots are, as previously mentioned, implemented in critical processes. The transferred data could hold confidential process information. Therefore, the security of the telecommunication technology is rather important. This use case is covered by all considered telecommunication technologies.

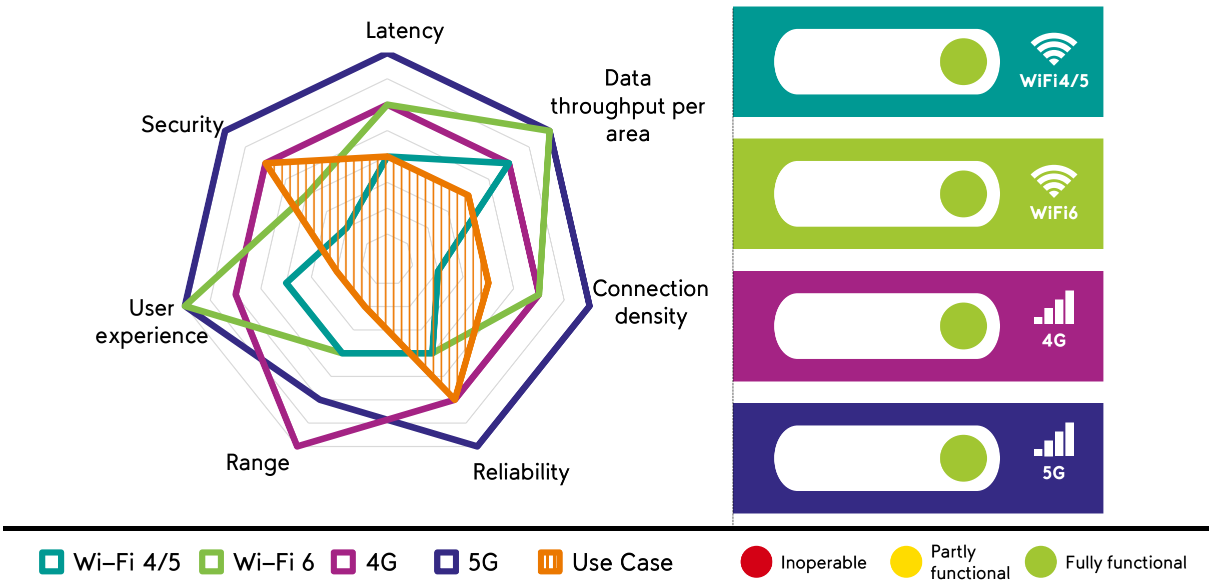

Figure 21: Robotic application predefined motion control

Robotic application with reactive motion control

Robots with reactive motion control are based on the standard robots with predefined motion control. Additionally, they can react directly to errors or abnormalities in the process and adjust motions or tasks in real–time. Sensors integration might be needed. This can be helpful if the robot is used as a mobile robot. The reactive motion control also supports the usage of robots in a collaborative manner. They can work without additional safety measures like a fence because they are able to alter their motion reacting to their dynamic surroundings. It is also possible to have these robots interacting with other robots or human beings. Also, their operation location can be adjusted to current needs and flexible human support is possible.

Application Examples

A mobile cobot can be used in many ways. For example, for half of the day, the robot can support a worker with a simple pick and place use case. Then it can change its gripper/end–effector and be used to operate on its own during night shifts. In order to do that, it positions itself autonomously in the environment and fulfills the task in a smart way without the need for manual calibration or teaching.

State of the art (production technology)

This use case is rather new and not common yet. But with the increasing automation and digitalization of factories, robots will take over more complex and diverse tasks. Mobile applications will become the norm. The goal will be to construct the robots as lean and as flexible as possible. Therefore, the processing unit will be centralized, and the robot control will be streamed.

A consistent connection with other robots in line and a data hub is needed to ensure harmonized work as well as a proper IT–infrastructure needs to be implemented. Cloud–

computing, machine learning algorithms and adaptive control are the key enabler for this use case.

Resulting telecommunication requirements

The collected data of a robot needs to be sent to a cloud, be filtered and used by machine learning models to update robot control and sent back to the robot in real–time. Entire fleets can be managed and automatically optimized centrally. Therefore, this use case depends on an ultra–reliable low–latency network with a high data throughput per area. If the network fails to meet the requirements, then the entire robot fleets and factories will not be able to function properly. Very high security standards are required because any malicious external interference with cloud–based robot control can possibly shut down the entire production site. Only a 5G campus network meets the requirements of this use case. It is an enabler for the vision of fully digitalized and self–regulating robot applications in a smart factory.

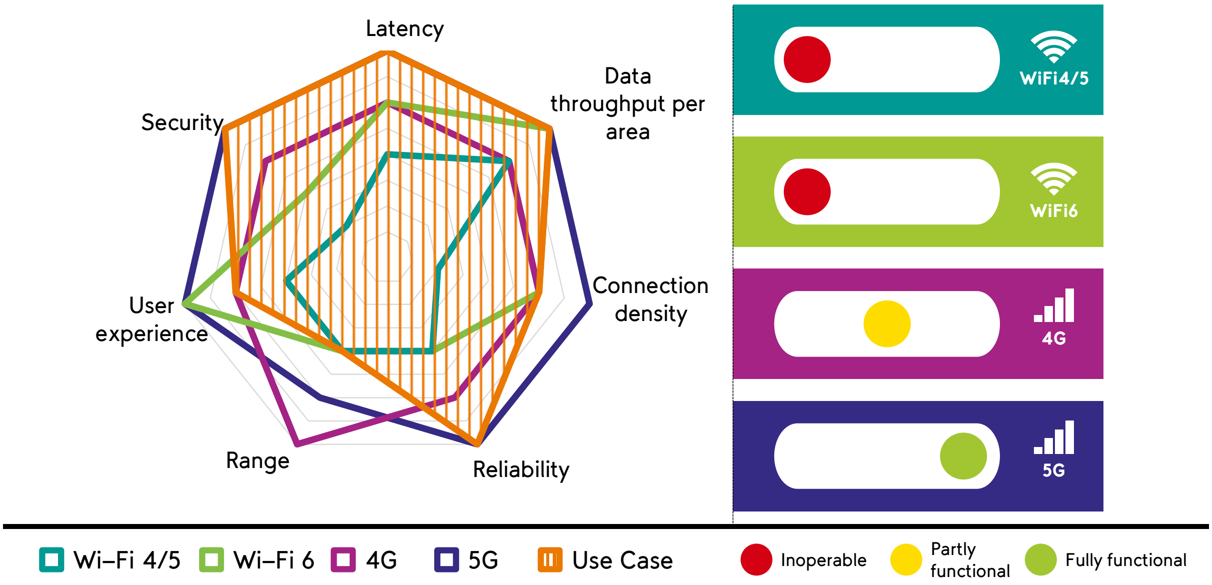

Figure 22: Robotic application with reactive motion control

4. Summary

In this white paper network technologies are compared and matched with relevant use cases in the field of Industry 4.0. The comparison shows that all technologies are capable of realizing high data rates. However, WiFi 4/5 proves unsuited for demanding environments and critical use cases. WiFi 6 seeks to remedy this, and is, to some extent, successful. In contrast, the inherent prioritization of data and licensed spectrum results in advantages for 4G and 5G. 5G expands the capabilities of 4G by adding safety–related features and incorporating technologies to make network deployment simple and flexible. Thereby, 5G not only incorporates the distinguishing feature, that leads to the success of WiFi, but expands on it. In view of not yet fully specified use cases of Industry 4.0, that capability poses a unique feature that holds great potential. However, the 5G hardware development and standardization are a work in progress.

Based on the trends in the manufacturing environment, seven use case classes: Track & Trace, AGVs, Augmented and Virtual Reality, Dashboarding & Monitoring, Data Analytics, Automated Process Control, Process Automation – Robotics are derived. In these seven classes 18 use case subclasses are defined. Each use case is explained, an application example is given and the state of the art in the manufacturing environment is highlighted. It is considered how the technical framework conditions and the value–added as well as the usability of the use cases influence the connectivity requirements. These connectivity requirements are then evaluated based on the defined assessment criteria. In addition, it is explained why and how the individual ratings are derived and by which use case parameters they are influenced.

In the next step, the network requirements are matched with the rating of the considered telecommunication technologies. This allows a determination of the interoperability of the communication technology with the requirements of the use cases. Furthermore, an indicator is given, if the use case is fully enabled by a communication technology, only partly functional or inoperable. The result shows that three use cases can be fully implemented by using WiFi 4/5. Six use cases are not operable with a WiFi 4/5 connection. The other ones are limited. Implementing WiFi 6 does not change the tendency. WiFi is especially limited in mobility (cell handover) and security. Compared to WiFi, security and mobility increases by using a cellular 4G network. More use cases are partly and fully functional using a 4G connectivity. Half of the defined use cases can be performed by 4G. However, it must be noted that for some use cases a 4G application does not correspond to the state of the art, as the market offers various alternative wireless communication solutions. 4G has its limitations in real–time operations with very high demands on ultra–low latency, connection density and reliability. 5G enables the vision of a fully connected and autonomous factory because it is more secure, reliable and faster compared to the other technologies.

		WiFi 4/5	WiFi 6	4G	5G
Track & Trace	Indoor T&T	◐	◐	◐	●
	Outdoor T&T	○	○	◐	●
	RLTS	○	○	○	🟪 ●
Automated Transport – AGVs	Defined path transport	●	●	●	●
	Autonomous transport	○	◐	●	●
	Intelligent routing	○	○	◐	●
Augmented/ Virtual Reality	Virtual Reality	◐	◐	◐	●
	Augmented Reality	◐	◐	◐	●
Data Analytics	Data storage / Data Lake	◐	◐	●	●
	Statistic data analytics	◐	◐	●	●
	Intelligent real–time analytics	◐	◐	◐	●
	Predictive analytics	◐	◐	◐	●
Dashboarding & Monitoring	Machine monitoring	●	●	●	●
	Mapping of target/actual state	◐	◐	●	●
Automated Process Control	Closed control loops for each machine	◐	◐	◐	●
	Closed control loops for process line	○	○	○	🟪 ●
Process Automation – Robotics	Robotics with predefined motion control	●	●	●	●
	Robitics with reactive motion control	○	○	◐	🟪 ●

○ Inoperable ◐ Partly functional ● Fully functional 🟪 5G enabled

Figure 23: Matching of use cases with network technologies

The matching of use cases and telecommunication technologies occurs while viewing all use cases separately. In a smart factory many of the defined use cases are realized in a parallel manner. All of them need a certain bandwidth. This leads to WiFi 4/5, WiFi 6 and 4G reaching their limitations concerning the provided connectivity. In production not only manufacturing process bottlenecks but also data transfer bottlenecks will occur. In the future vision of a smart factory 5G could solve these bottlenecks. Therefore, the business case for implementing or upgrading to a different network technology, depends strongly on the digitalization strategy of the production site and the enterprise. Further the holistic digitalization strategy has to be considered for the use case and technology selection. Investing in a more expensive communication like 5G can lead to higher benefits. However, the trade–off between benefit and investment is only created by the integration of multiple use cases, making the implementation scalable.

Choosing the right communication technology needs to be done after carefully gathering, analyzing and interpreting relevant data, understanding the production processes and deriving digitalization. It is highly dependent on the present machines and assets in the production site. Therefore, this white paper can only give an overview of the main aspects of the connectivity requirements for each use case class. To further analyze the requirements and identify the best fitting communication for the individual manufacturer, information about the number of connected assets, data streams, real–time dependency, data processing and the IT infrastructure is needed. Overall, 5G enables a new level of digitalization in an industrial setting with a real–time connection of all assets, stakeholders and machines unlocking new value–adding mechanisms.

5. Appendix

List of abbreviations

Abbreviation	Definition
AGV	Automated guided vehicles
AP	Access point
AR/VR	Augmented/Virtual reality
BSS	Basic service Set
CPPS	Cyber physical production system
CPU	Central processing unit
EIRP	Equivalent isotropically radiated power
eMBB	Enhanced Mobile Broadband
ERP	Enterprise resource planning
IEEE	Institute of Electrical and Electronics Engineers
IIoT	Industrial internet of things
ISM–band	Industrial, scientific and medical band
ITU–R	International Telecommunication Union, Radiocommunication Sector
LTE–A	Long Term Evolution Advanced
WLAN	Wireless local area network
MITM attack	Man in the middle attack
MNO	Mobile network operators
MU–MIMO	Multi–User, Multiple In, Multiple Out
MTP	motion–to–photon
NFV	Network functions virtualization
OEE	Overall equipment efficiency

RFID	Radio frequency identification
RTLS	Real time location systems
SDN	Software–defined Networking
T&T	Track and Trace
UWB	Ultra–wideband
WPA	WiFi protected access

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umlaut AG
Am Kraftversorgungsturm 3
52070 Aachen
Germany

www.umlaut.com
beyond@umlaut.com
Veröffentlicht am 31.10.2019