Feasibility assessment of 5G use cases in intralogistics

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Abstract
The fifth mobile communications generation (5G) can lead to a substantial change in companies enabling the full capability of wireless industrial communication. 5G with its key features of providing Enhanced Mobile Broadband, Ultra-Reliable and Low-Latency Communication, and Massive Machine Type Communication will support the implementation of Industry 4.0 applications. In particular, the possibility to set-up Non-Public Networks provides the opportunity of 5G communication in factories and ensures sole access to the 5G infrastructure offering new opportunities for companies to implement innovative mobile applications. Currently there exist various concepts, ideas, and projects for 5G applications in an industrial environment. However, the global rollout of 5G systems is a continuous process based on various stages defined by the global initiative 3rd Generation Partnership Project that develops and specifies the 5G telecommunication standard. Accordingly, some services are currently still far from their final performance capability or not yet implemented. Additionally, research lacks in clarifying the general suitability of 5G regarding frequently mentioned 5G use cases. This paper aims to identify relevant 5G use cases for intralogistics and evaluates their technical requirements regarding their practical feasibility throughout the upcoming 5G specifications.

Keywords
5G, Use Cases, Feasibility Assessment, Intralogistics, Non-Public Networks

1 INTRODUCTION

The fifth mobile communication generation (5G) represents the further development of the fourth mobile communications standard (4G) commonly known as LTE (Long Term Evolution) [1]. While 4G aims to meet the need of people for internet access, 5G aims to specifically meet the increasing needs of the industry for internet access [2]. Therefore, 5G technology promises to improve the Internet of Things (IoT) communication in order to increase the efficiency of industrial processes [2]. The International Telecommunication Union (ITU) and its particular Radiocommunication Sector (ITU-R) defines the following key capabilities of 5G technology [2]:

- Enhanced Mobile Broadband (eMBB): Provides data rates of up to 20 Gbits/s for down and 10 Gbits/s for upload.
- Massive Machine Type Communication (mMTC): Large-scale possibility to connect IoT devices with a density of up to 1 million connections/m² and traffic density of 10 Mbit/s per square meter.
- Ultra-Reliable Low-Latency Communication (uRLLC): Enables latencies of less than 1ms air-interface round-trip time.

In addition, 5G provides Quality of Service (QoS) for critical industrial applications such as the mobility management service in industrial environments and the high precision positioning service [3]. To ensure the development of new telecommunication standards, the 3rd Generation Partnership Project (3GPP) provides so called *releases* forming a foundation for developers and engineers regarding the implementation of features as well as the addition of new functionalities for subsequent *releases* [4]. 3GPP established the transition from 4G to 5G in Release 15 with Non-Standalone (NSA) networks. NSA 5G networks leverage existing LTE core networks and only carry out the communication between the terminal and the antenna based on 5G protocols [5]. In June 2020, 3GPP initiated Release 16 (R16) to enable first standalone (SA) 5G network solutions. SA networks are completely based on a 5G core without the need of leveraging 4G network elements [5]. Release 17 (R17) is planned for June 2022 [4] with further enhancements relating to the capability of 5G and its services. Currently, only R16 and R17 are specified by 3GPP. Release 18 and further *releases* are in the preparation phase and so far only defined regarding their timeline, but not with respect to its 5G specifications [6]. Experience with R16 has shown that it takes around 18 months until the specifications are commercially available in 5G infrastructure. Another difference to 4G is the establishment of Non-Public Networks (NPNs). A NPN is a local area network based on 5G New Radio technology for dedicated wireless connectivity in a specific region. This offers companies to create and manage their own local 5G networks [3]. One advantage of a NPN is the exclusive coverage in industrial facilities, making them independent of public networks and offer its owner the possibility of total control (intrinsic control) to guarantee user transparency and security [3]. In particular with respect to 5G NPNs, the industry has high expectations to enable use cases in the context of Industry 4.0 [7]. However, the establishment of 5G is a complex continuous process that is characterised by the already mentioned *releases* [4]. The high expectations of the 5G technology are oriented towards the technological target state of the 5G technology. This creates a distorted picture of the actual current performance of the technology leading to difficulties when assessing the feasibility of industrial use cases [8]. In this context, the early development of prototypes in test environments is necessary to gather knowledge about the feasibility of intralogistics use cases before the 5G technology reaches its technological target state. In particular, development and transfer centres such as academic research institutions with learning factories play an important role in testing and investigating 5G use cases in its early stages [9]. The literature review methodology of this paper is structured into four phases. In the first phase, the databases Scopus, Google Scholar, IEEE Xplore, and the libraries of Stellenbosch and Reutlingen Universities are searched with the keywords '5G applications', '5G use cases', 'intralogistics'. In the second phase, the found intralogistics use cases are investigated to define their technical requirements. Thirdly, the key characteristics of the current 5G *releases* R16 and R17 with regards to intralogistics use cases are identified. Finally, the use case requirements are assessed for their feasibility with the 5G technology with respect to R16 and R17. The paper consequently aims to identify relevant and feasible intralogistics use cases and their possible applications for initial research activities.

2 LITERATURE REVIEW

Several publications exist defining and summarising important use cases in an industrial environment that are frequently connected to 5G technology. For example [10] consider 5G as important enabler technology for use cases in the context of Industry 4.0. This publication subdivides the suitability of 5G technology for three general use case types: Time critical and reliable processes, non time critical communication, and remote control. The authors do not consider the holistic requirements of the respective 5G use cases and only mention individual requirements such as latency, broadband, or reliability. Moreover, the authors only mention the necessary target state of 5G's capabilities when describing the technical requirements of the use cases. A further publication [11], summarises the use cases provided by 3GPP and derive their key characteristics in terms of NPN attributes such as QoS customisation, autonomy, isolation, and security. However, this publication does not consider an assessment of the use cases with respect to the 5G key capabilities of 5G technology described in the introduction. A survey by [12] provides an extensive collection of 5G use cases with the aim of covering all possible areas of wireless communication. It includes usage scenarios outside industrial environments, such as automated traffic control and open air festivals. Compared to previous publications, this survey only covers a partial collection of industrial use cases and focuses primarily on the capabilities latency, data rate and device density. However, these properties are not consistently specified for all usage scenarios and the respective use cases are not evaluated according to their technical feasibility. According to the aforementioned publications, the use and suitability of wireless communication technologies in an industrial environment depends on the technical requirements of the respective application. These requirements can differ between the application cases resulting in different requirements, e.g. in terms of broadband, latency, or machine communication [10–12]. To generate a first decision-making foundation regarding the suitability of wireless communication technologies, technical requirements of use case categories can be classified based on their core requirements. [1] provides an extensive classification of possible industrial use cases in the fields of discrete manufacturing, logistics, process automation, diagnostics and maintenance, augmented reality (AR), and functional safety. Subsequently, [1] evaluates the feasibility of the identified use cases based on reliability, latency, and data rate. As a result, the publication points out, that many use cases cannot be implemented with the state-of-the-art wireless communication standards and additionally addresses the overstressing of the 2.4GHz band as reason to further research wireless alternatives. However, the publication does not include 5G technology in the evaluation procedure. A recent study conducted by [13] specifies the technological characteristics of 5G and summarises the standardisation and release process by 3GPP while pointing out the release specifications with industrial relevance and compares them to wireless communication technologies such as 4G, WLAN, and Bluetooth. In this study, the technical properties only refer to the 5G services itself and are only briefly translated to the requirements of concrete industrial use cases. In the remainder of this paper a holistic overview of important 5G related intralogistics use cases are provided and these are evaluated for its feasibility and its implementation potential with respect to 5G and its *releases* defined by 3GPP. Relevant use cases are also identified together with its technical requirements. Lastly, the use cases are assessed for its feasibility with respect to 5G and its technical specifications TS 22.261 [14,15] of R16 and R17.

3 CLASSIFICATION OF 5G USE CASES

In this section the relevant intralogistics 5G use cases are summarised. Then, the identified use cases are specified with requirement parameters as foundation for the evaluation process. The 5G performance parameters of the current R16 and the upcoming R17 are listed and finally, the use case requirements are compared to the performance parameters of the 5G R16 and R17. Table 1 presents a list with relevant intralogistics 5G use cases and their corresponing applications based on [1], the 3GPP Service Level [14,15], [13] and [16–18]. These use cases are supplemented with applications identified within industrial cooperation with Small and Medium-sized Enterprises (SMEs) and workshop activities in the course of the German project 5G4KMU. The use cases presented in Table 1 place different technical requirements on the 5G network. Table 2 lists and defines key requirement categories for use case feasibility identified by 3GPP TS 22.104 [19–21]. Table 3 shows a summary of the use cases and their technical requirements. The use cases presented in Table 1 are specified with parameters representing specific requirements to make the use cases feasible. The parameters represent a summary based on the specifications of [1,13,17,18,20,22–24].

Use Case	Description	Identified Applications
Augmented and Virtual Reality (AR/ VR) in Intra-logistics	3D visualisation of resources for warehouse planning or pick-by-vision applications. AR applications require large data rates transmitted with low-latencies to synchronise the VR with the physical reality without any time delay.	• Warehouse Planning (3D visualisation of resources and assets) • Pick-by-vision (targeted item picking, virtual warehouse navigation by visual routing system)
Automated Guided Vehicles (AGVs)	AGVs that transport products within the production/warehouse. The services of 5G enable a reduction of on-board computation power (optimisation of battery lifetime) and can support wireless communication of AGVs to enable a centralised fleet management.	• AGV (Reduction of on-board processing power, localisation and navigation, autonomous tugger train platooning, remote control, and fleet management in the edge-cloud)
Unmanned Aerial Vehicles (UAVs)	Visual inventory control and management, camera inspection and monitoring, and indoor item delivery. UAV require ultra-high reliable communication. Furthermore, the 5G services enable a localisation and the outsourcing of on-board hardware to reduce the UAV's weight.	• Inventory Management (item search and buffer stock maintenance, cycle counting, stock taking) • Inspection and Monitoring (inspection of racks in high-bay warehouses, pallet placements, facility inspections, monitoring of hazardous or non-accessible areas)
Condition Monitoring	Real-time condition monitoring of AGVs, UAVs, and technical devices/wearables for maintenance and diagnostic reasons.	• Condition Monitoring (real-time monitoring of robot conditions, e.g. battery lifetime of AGV and UAV fleets)
Crane Systems	Wireless control and remote access to crane systems for precise loading and unloading of goods with high requirements regarding accuracy to reduce cable wear in rotating movements.	• Crane Control (wireless control of mobile crane systems and static ceiling cranes for precise loading and unloading of heavy items)
Factory Monitoring and Flexible Factory Layout	Holistic process and asset monitoring through connected sensors and visual systems to control and manage processes and to monitor product states (e.g. temperature) and modular production systems.	• Digital Shadow of Factory (process monitoring, process quality control and cycle counting) • Localisation determination of modular production and warehouse infrastructure
Indoor Item Tracking	Tracking and Tracing of items in warehouses to optimise processes and enable a just-in-time/just-in-sequence delivery. Item tracking requires a high device density and an accurate localisation service.	• Tracking and Tracing (positon determination of items, just-in-time and just-in-sequence delivery of items to assembly stations)
Robot Motion Control (Tactile Internet)	High precision robot-human-interaction with real-time tactile feedback in closed-loop control applications. Control of acceleration, pose, speed, grippers and tools or a combination of these actuators. Motion control in closed-loops place high requirements in terms of ultra-reliable low-latencies.	• Motion Control (closed-loop and high precision control of actuators such as grippers and remote real-time human-machine interaction for high precision assembly processes) • Precise unloading/placing of items in non-accessible or hazardous areas (chemistry or laboratory, clinically hygienic environment)

Table 1 – 5G use cases and identified applications [1,13–18].

Requirement [20]	Definition/ Description
Accuracy	Closeness of the measured position of the User Equipment (UE) to its true position value. The accuracy can describe the accuracy either of an absolute position or of a relative position [19].
Availability	Percentage of time when a system is able to provide the required data within the performance targets or requirements [19]. Divided into availability classes from 1 to 7 [22]: 90% = 1; 99% = 2; 99.9% = 3; 99.99% = 4; 99.999% = 5; 99.9999% = 6; 99.99999% = 7.
End-to-end latency	Duration between the transmission of a data packet from the source node and the successful reception at destination node [21]. At initialisation of positioning systems, the latency is also defined as the Time to First Fix [19].
UE Speed	Closeness of the measured magnitude of the User UE's velocity to the true magnitude of the UE's velocity [19].
Data rate	Describes the data rate per second per user. A distinction can be made between peak data rate and user experience data rate (minimum achievable data rate for a user in real network environment) [21].
Density	Amount of devices for which the system can determine related data per time unit, and/or a specific update rate [19].

Table 2 – Requirement definition.

Requirements / Use Cases	Accuracy (cm)	Availability class	Latency (ms)	UE Speed (m/s)	Data rate (up to)	Density (UE/m²)
AR/VR in Logistics	n/a	≥3	10	3	Gbit/s	0,02 - 0,03
AGVs	<5	5 - 7	15 - 20	<10	Mbit/s	0,1
UAV	<10	≥6	10 - 40	<14	Mbit/s	0,1
Condition Monitoring	<50	4	100	<10	kbit/s	10 - 20
Crane System	<10	≥6	15 - 20	<5	Mbit/s	0,1
Factory Monitoring and Flexible Factory Layout	50	4	>100	<10	Gbit/s	n/a
Indoor Item tracking	<50	2	<200	<10	Mbit/s	10 - 20
Robot Motion Control (Tactile Internet)	n/a	≥5	0,25 - 1	<10	Mbit/s	5

Table 3 – 5G use cases with respective technical requirement parameters based on [1,13,17,18,20,22–25].

Requirement	Standalone Non-Public Network			
	Release 16		Release 17	
Accuracy (cm)	1000		300-20	
Availability (%)	95		99-99.99999	
End-to-end latency (ms)	4>x>1		<1	
UE speed (m/s)	<10		<10	
Peak data rate (Gbit/s)	Downlink: 20	Uplink: 10	Downlink: 20	Uplink: 10
User experience data rate (Gbit/s)	Downlink: 1	Uplink: 0.5	n/a	n/a
Density (devices/m²)	1		1	

Table 4 – 5G key characteristics and targeted performance for intralogistics scenarios based on [13,15,26,27].

The global rollout of 5G systems is a continuous process based on various release stages defined by 3GPP. Some services are currently not at their final performance capability or not yet implemented [4]. The feasibility evaluation of the use cases presented in Table 1 requires an investigation of the 5G performance parameters in the course of the upcoming release notes R16 and R17, and are presented in Table 4.

4 RESULTS

The assessment of the feasibility of intralogistics use cases with respect to the technical requirements of R16 and R17 is presented in Table 5. All use cases state high requirements in terms of the availability of the network. Due to the specified accuracy of 95% in R16, none of the use cases are feasible. Nevertheless, accuracy is not a critical parameter for all use cases. Time-uncritical use cases such as Factory Monitoring/Flexible Factory Layout are feasibly and can already be implemented for test purposes in learning factories under R16. However, in use cases such as AGVs, UAVs and Crane Systems with a need for mobility and safety, the accuracy parameter is considered necessary. In the upcoming R17, all requirements up to availability class 7 can be met. Especially for mobile applications, all use cases require an accuracy of at least 0.5cm, which is higher than the 1000cm specified in R16. For the use cases AGVs, UAVs and Crane Systems, the required parameters even cannot be met with R17, which would only allow a localisation accuracy of a maximum of 20cm. For the required latency, only the use case, Robot Motion Control places strict requirements in the sub-ms range. These latencies of 1ms or less will only be achieved in R17. The use cases, Factory Monitoring/Flexible Factory Layout and AR/VR in Smart Factories can require data rates up to the Gbit/s-range, depending on the application. Therefore, these use cases are only partially feasible in R16. The device density in highly IoT-oriented use cases such as Indoor Item Tracking and Condition Monitoring can also pose challenges within learning factories. Densities of 20 devices/m² or more may require infrastructure upgrades to ensure stable connectivity of all devices. As reference, the density in NPN provided by Nokia depends on the AirScale System Module. In test networks, this AirScale System Module can typically manage up to 8,000 devices. The learning factory 'Werk150' at Reutlingen University is approx. 800m² large, which results in 10 devices/m². In case of increased connectivity needs of 10 devices/m² or more, currently the Nokia's AirScale system modules can be upgraded up to 60,000 users.

Use Case	Feasibility Release 16	Feasibility Release 17
AR/VR in Smart Logistics	o	+
AGVs	-	o
UAV	-	o
Condition Monitoring	-	+
Crane Systems	-	o
Factory Monitoring and Flexible Factory Layout	-	+
Indoor Item Tracking	-	+
Robot Motion Control (Tactile Internet)	-	+

Table 5 – 5G intralogitics use cases and identified applications (+ Use case is feasible; o Feasibility depends on the prioritisation and accuracy of one important parameter; - Use case is not feasible).

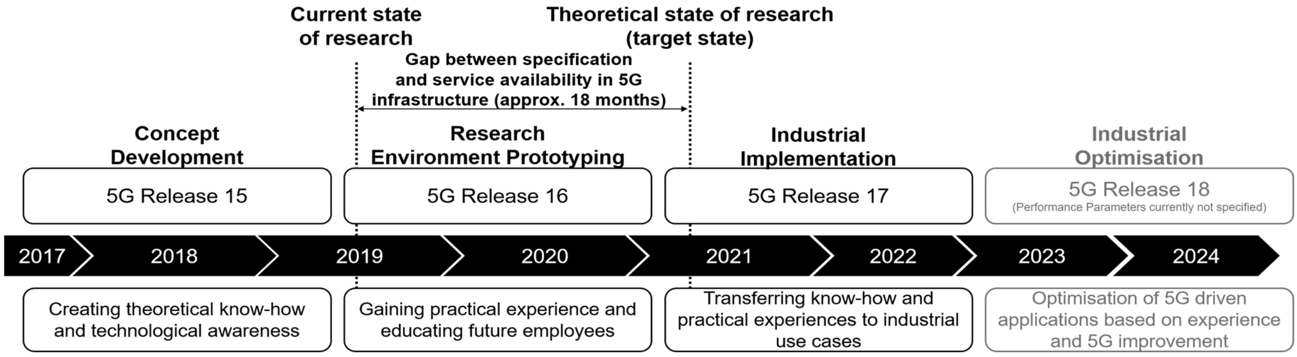

Figure 1 – Implementation framework for 5G use cases by means of learning factories.

In closing the presented results are transferred to an implementation framework shown in Figure 1. The proposed framework consists of four application implementation phases including Concept Development, Research Environment Prototyping, Industrial Implementation, and Industrial Optimisation. It is evident from Figure 1 that there currently exists a gap of approximately 18 months between the specified 5G *releases* and their service availability in 5G infrastructure.

5 OPPORTUNITIES FOR FURTHER RESEARCH

The 5G technology is frequently mentioned as a suitable solution to meet the technical requirements of several intralogistical use cases. As this paper shows, none of the specified use cases are fully feasible in R16. The availability of 95% in R16 represents an obstacle regarding the feasibility of the identified use cases, in particular with higher safety and mobility requirements. In terms of localisation accuracy, the requirements are higher than what R16 will provide. Even with R17, the requirements of AGVs, UAVs and Crane Systems cannot be achieved. However, use cases with high localisation requirements could still be successfully implemented if alternative technologies are used and only the data transmission takes place via 5G itself (e.g. Factory Monitoring). As the results indicate, a large part of the identified use cases can be implemented with R17. However, there currently exists a significant gap between the specified 5G *releases* and their service availability in 5G infrastructure. In this context, research environments play a crucial role to test the use cases on a small scale and thus gain initial experience before they are ready for an industrial implementation in the course of the upcoming 5G *releases*.

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