Ultra-Reliable and Low-Latency Communication for Wireless Factory Automation: From LTE to 5G

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Abstract—Wireless factory automation has been receiving much interest in recent years due to its advantages of low cost and high flexibility over the traditional wired networks. Factory automation is also considered as one of the important use-cases of the 5th generation (5G) cellular system. In this paper, we present comprehensive system level simulation results to evaluate the performance of LTE and new 5G radio-interface design concepts in a realistic factory deployment scenario. We believe that our detailed evaluation studies bring valuable insights to show the potential of 3GPP technologies for different factory use-cases.

Keywords—Wireless factory automation, LTE/-A, 5G, machine-to-machine, low latency, high reliability, cyber-physical systems.

I. INTRODUCTION

In factory automation, wireless communication technologies have traditionally been only used for diagnostics and open-loop control applications having less stringent requirements on the communication latency and reliability [1]. However, the use of wireless technologies for providing connectivity to movable machine parts and closed-loop control applications, such as packaging machines and filling stations, is limited. It is mainly due to the strict latency and reliability requirements posed by these factory applications. During the past few years, wireless technologies for factory automation have gained much more interest owing to their advantages of low installation and maintenance cost, higher flexibility and extendibility options over the wired communication systems. In addition, they also suit to the demands of the Industry 4.0 vision [2].

The major challenges for wireless factory automation are the strict requirements of communication latency and reliability. Typically, an automated manufacturing step forms a closed-loop involving several sensors and actuators controlled by a single controller (e.g., Programmable Logical Controller, PLC). In this context, latency relates to the end-to-end (e2e) communication, where one fraction of the loop begins with the collection of sensor data and its delivery to the PLC. Respectively, the actuators are instructed accordingly based on the internal logic of the PLC constituting the other fraction of the automation loop. The latency requirements for some of the factory applications can be even lower than 1ms [3]. Reliability is defined as the probability that a certain data packet from an end device is successfully delivered to another peer device within a pre-defined delay. Packet error rate (PER) is used as a measure of reliability at the application level, which is often also referred as block error probability (BLEP) at the lower layers of the protocol stack. The high reliability demands of factory automation systems require BLEP as low as 10^{-9} [3]. Please note that the exact requirements on latency and reliability are application dependent and can be fairly different which we discuss in Section II.

In recent years, several wireless technologies have been developed for factory applications. Most widely used existing factory communication technologies include WirelessHART, ISA 100.11a and Industrial WLAN [4]. Besides these technologies, many proprietary wireless solutions are also currently in-use for various factory applications. However, most of these technologies operate on unlicensed frequency spectrum and suffer from interference in the shared frequency bands. Therefore, in order to mitigate the effects of spectral interference and to support coexistence with other collocated devices, wireless technologies operating in unlicensed spectrum often cannot provide deterministic response needed for strict real-time automation applications.

3GPP's cellular technologies, such as LTE and the upcoming 5G, can potentially bring inherent advantages of operation in the licensed spectrum for factory applications, for example, guaranteeing the packet delivery within the targeted latency. Secondly, the current automation industry is lacking one global solution making it difficult to inter-operate between the devices from different manufacturers. 3GPP can fill in the gap for the much needed globally acceptable single wireless factory automation standard. Realizing this, 3GPP has initiated several new studies to enhance the capabilities of the current cellular standard, i.e. LTE, to fulfil the demands of latency critical use-cases [5]. Moreover, factory automation is also defined as one of the most important use-cases of 5G under IMT-2020 [6].

In this paper, we show the performance of LTE and 5G cellular systems as underlying communication technologies for several factory applications. In particular, we simulate a realistic factory environment and evaluate the performance of different radio-interface design features of both LTE and upcoming 5G cellular system. Here, radio base station (BS) is considered to be connected to automation PLC with negligible latency. Therefore, e2e requirements for closed-loop applications are measured as a combination of both uplink and downlink communications. Based on our classification of factory applications, we show that LTE system is able to fulfill

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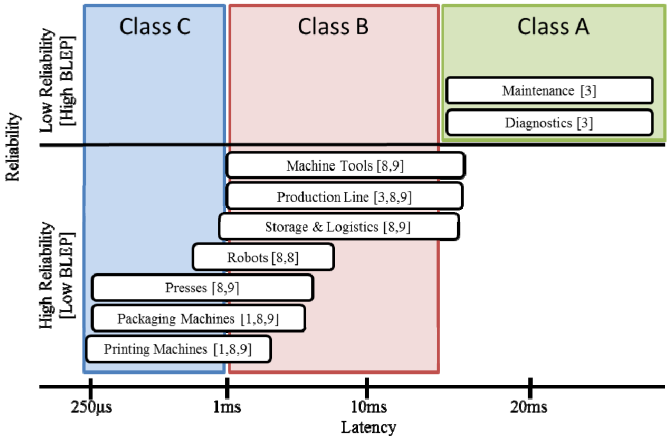

Figure 1: Overview and classification of different factory applications and their requirements. While low BLEP indicates a range between 10^{-8} and 10^{-9}, high BLEP indicates a range between 10^{-4} and 10^{-5}.

the demands of some of the factory applications. Furthermore, for factory automation use-cases with the most stringent latency and reliability requirements, we emphasize the need of 5G radio-interface design features as mentioned in [7].

The remainder of this paper is organized as follows. In Section II, we introduce different factory applications classes and their requirements. Section III presents the conceptual overview of the relevant radio-interface design for LTE and 5G systems to meet the requirements. Our simulation methodology is presented in Section IV followed by evaluations in Section V. Finally, in Section VI we conclude our work and discuss future work directions.

II. Factory Applications And Their Requirements

Based on our use-cases analysis, we have classified different factory applications with respect to their latency and reliability requirements as shown in Figure 1. The requirements among different applications differ significantly. In terms of latency (above 15ms) and reliability (around 10^{-4} or 10^{-5} BLEP), the least demanding applications are for diagnostics and maintenance in factory halls, which we classify as class A. Class B refers to closed-loop applications which have significantly higher demands on latency (between 1ms and 15ms) and reliability (around 10^{-8} or 10^{-9} BLEP) such as machine tools and production lines. We classify applications with most stringent requirements as class C. While class C applications have similar requirements on reliability as that of class B, they have much lower requirements of latency (i.e. even below 1ms). Please note that some applications can fall into different categories. For instance, robots may belong to both class B and class C applications depending on their requirements. Our classification as shown in Figure 1 will help us later in Section V to systematically evaluate different radio-interface design features of LTE and 5G systems in a factory environment.

III. Radio-Interface Design Feautres

We believe that some design changes are required at both physical (PHY) and medium access control (MAC) layers of the LTE release 8-12 systems to meet the applications requirements in all factory scenarios. This section describes the details of the key design features that enable low latency and high reliability in wireless factory automation.

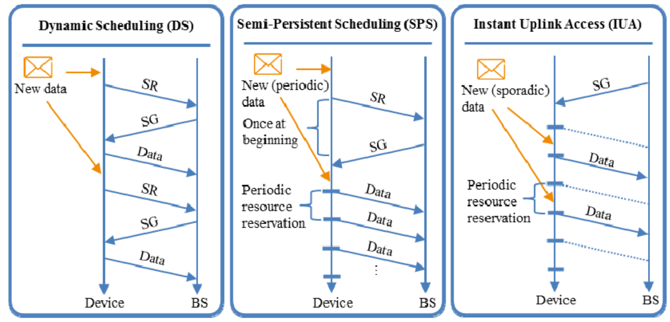

Figure 2: Different uplink scheduling schemes: for mobile broadband (MBB) traditional dynamic scheduling (left); for factory automation applications the use of semi-persistent scheduling (SPS) for periodic traffic (middle) and instant uplink access (IUA) for sporadic traffic (right).

A) Low Latency Features

There are several factors which contribute to the overall latency in wireless systems. However in this paper, we only focus on the PHY and MAC layer aspects. In the following, we describe the technical details of the relevant design choices for factory automation on the respective layers beginning with the MAC layer enhancements.

1) MAC layer (scheduling enhancements): Medium access delay is considered to be very critical for low-latency applications. Therefore, it is very important that the data transmission occurs as soon as it appears in the transmission buffer. In cellular networks, all the channel resources (both in time and frequency domain) are coordinated among several devices by the central entity referred to as BS. However, the traditional LTE dynamic scheduling (DS) is optimized for mobile broadband (MBB) traffic with less stringent requirements on latency. According to dynamic scheduling, a connected device always sends the scheduling request (SR) to the BS whenever a transmission needs to be carried out in the uplink as shown in Figure 2 (left). SR is then followed by the scheduling grant (SG) from the BS notifying the device regarding the allocated resources and other related parameters such as modulation and coding schemes. Data is then transmitted by the device based on the received information. Such signaling procedure increases the time delay between the data arrival in the transmission buffer and its actual transmission. On the other hand, factory automation applications do not only have entirely different traffic characteristics but they also pose very strict latency requirements as compared to MBB applications. Hence, we believe that a scheduling scheme needs to be chosen properly to enable low latency wireless communication for factory applications. In factory automation, two types of traffic can appear which are periodic and sporadic. For the traffic of periodic nature, semi-persistent scheduling (SPS) [10] provides latency benefits by exploiting the prior knowledge about the traffic characteristics such as data size and its inter-

TABLE 1: SCALED NUMEROLOGY OF 5G/NX USED FOR FACTORY AUTOMATION AND ITS COMPARISON WITH LTE

	LTE [14]	5G/NX [15]
Subcarrier spacing	15kHz	75kHz
Symbol duration	67µs	13.4µs
Cyclic prefix	4.7µs (normal) and 16.7µs (extended)	0.9µs (normal) and 3.3µs (extended)
Sub-frame	1ms	0.2ms
Slot	0.5ms	0.1ms

arrival time (or periodicity). The SR and SG signaling procedure is performed once at the initial attempt of transmission, afterwards the channel resources are allocated periodically enabling early transmission of data as shown in Figure 2 (middle). Originally, SPS has been intended in LTE for VoIP traffic [11]. We adjust the periodicity of SPS to match the needs of the factory application in-use. On the other hand, sporadic traffic differs significantly from periodic traffic as it has a highly unpredictable nature. Nevertheless, due to the criticality of such traffic, channel resources can still be pre-allocated to the devices so that they can perform the relevant data transmission without an extra signaling delay for medium access. Evidently, this happens at the cost of spectral efficiency due to over-provisioning of resources. A similar over-provisioning approach, which is referred to as instant uplink access (IUA) is currently been proposed in LTE release 13 and beyond [5]. According to IUA, the resources are pre-allocated which decreases the overall latency. Figure 2 (right) illustrates the IUA scheduling procedure for factory application uplink traffic of sporadic nature.

2) PHY-layer (transmission time interval reductions and forward error correction schemes): In LTE, the transmission time interval (TTI) is 1ms, which is equal to the size of 1 sub-frame, i.e., 14 OFDM symbols. Please note that the TTI is defined to be the minimum time unit allocated for any uplink or downlink transmission and accordingly, its duration impacts the latency. Therefore, low latency use-cases require shorter TTIs which are being considered in LTE release 13 and beyond [5]. However, the shortest possible TTI that can be achieved in LTE is ca. 72µs corresponding to the OFDM symbol duration plus the cyclic prefix (CP), and contains both data and reference signals. However, even if the reference signals are located in the first OFDM symbol, it can only be processed after the symbol has been completely received, i.e. after 72µs. If the over-the-air transmission time required to meet the allowed latency is 0.1ms [12], the processing (i.e., channel estimation, demodulation and decoding of the transmitted data) starts very late in time. Therefore, using LTE for the factory applications demanding over-the-air transmission time of 0.1ms can be challenging. Furthermore, having a TTI duration equals to an OFDM symbol length leads to an increase of control overhead per TTI. In order to meet the most challenging latency requirements, we use a scaled LTE numerology for the non-backward compatible 5G radio-interface termed as '5G/NX'. In this paper, we assume a

TABLE 2: COMPARISON OF THE THEORETICAL MINIMUM UPLINK LATENCY IN LTE AND 5G/NX WHEN USING DYNAMIC AND SEMI-PERSISTENT SCHEDULING

Description	**LTE DS**	**LTE SPS**	**5G/NX SPS**	**5G/NX-MTC SPS**
Scheduling Request (SR)	1ms	--	--	--
Processing Time @BS	3ms	--	--	--
Scheduling Grant (SG)	1ms	--	--	--
Processing Time @UE	3ms	--	--	--
Data	1ms	1ms	0.2ms	0.2ms
Processing Time @BS	3ms	3ms	0.6ms	0.2ms
Total latency	12ms	4ms	0.8ms	0.4ms

scaling factor of five unless explicitly mentioned otherwise. Please note that the five times scaled numerology of LTE fulfills the deployment demands of a realistic factory automation scenario based on the propagation measurements done in [13]. Table 1 shows the numerology of the 5G/NX radio-interface proposed for factory automation and its comparison with LTE numerology.

Processing time is another major contributor of the overall latency and hence, it should also be reduced to the minimum. In particular, processing time associates to the hardware capability and computation complexity of the used algorithms. In [7], it is proposed to use convolutional codes (CC) as the forward error correction (FEC) scheme for factory automation instead of turbo codes (TC). The reason to choose convolutional codes for mission-critical use-cases is mainly two-fold. First, its simple decoder reduces the processing delay significantly as compared to that of LTE turbo codes. Second, for small data sizes as in factory applications (e.g. up to a few hundred bits) convolutional codes perform similar to LTE turbo codes without introducing any error floors as mentioned in [16]. Therefore, in this paper, we assume that the processing time at both BS and device side can be reduced significantly as compared to the LTE systems, thanks to the low decoding complexity of convolutional codes and processing enhancements of modern radios.

To summarize, we compare the impact of the presented latency reduction mechanisms in Table 2. As a baseline, we provide the minimum possible uplink latency for LTE when using the dynamic scheduling procedure, i.e., 12ms (cf. LTE DS in Table 2). Since in case of semi-persistent scheduling, the SR and SG occur rarely (only in the initial attempt and based on the pre-determined periodicity), its impact can be neglected which results in uplink latency of around 4ms (cf. LTE SPS). The reduction of the TTI further reduces the uplink latency down to 0.8ms (cf. 5G/NX SPS). Dependent on the improvements of the processing time (i.e., faster coding/decoding), this value can even be further reduced. With the assumption of a processing time reduction from 0.6ms to 0.2ms at the BS, an uplink latency of 0.4ms can be achieved (cf. 5G/NX-MTC SPS).

B) High Reliability Features

Diversity is considered to be the most important scheme to fulfill the high reliability demands in wireless factory automation. In [7], it is shown that the diversity gains in terms of required average SNR are around 60-70dB for diversity orders increasing from one to eight. Diversity can be achieved (i) via spatial diversity using multiple transmit and receive antennas, (ii) via frequency diversity using multiple resource blocks with independent fading coefficients, and (iii) via time diversity using time slots of the independent fading coefficients. Unfortunately, time diversity is not suitable for some factory use-cases due to the very stringent latency requirements. We believe that employing high diversity orders through multiple antennas is practically feasible in a factory setup, for instance, by installing several antennas at the BS side. Similarly, several antennas can be mounted at the device side, although their number will highly depend on the device characteristics.

Spatial diversity through multiple antennas can be exploited both on the receiver and/or transmitter side leading to receive and/or transmit diversity gains. Receive diversity not only achieves a diversity gain but also has an additional receiver processing gain due to coherent combining of the desired signal. Furthermore, if spatial degrees of freedom would be used for interference rejection combining (IRC), there will also be an interference rejection gain at the expense of a diversity gain reduction. On the other side, transmit diversity can be achieved with space-time coding such as Alamouti code which is applicable only to a diversity order of two. When using more than two transmit antennas, FEC coding can be combined with Alamouti code to ensure that the coded bits that may affect the decision on a particular information bit are transmitted from all the transmit antennas [17].

Similarly, frequency diversity is achieved by mapping the coded bits to multiple resource blocks (in frequency) that have independent channel coefficients. In an indoor factory automation environment, a typical coherence bandwidth of 2-3MHz can be expected as shown in [13]. Therefore, frequency diversity can be exploited on top of spatial diversity.

IV. Simulation Environment

To show the potentials of the above mentioned radio-interface design features for ultra-reliable and low-latency communication in a realistic factory deployment, we have used our in-house event-based system simulator. The details of modeling description of the factory scenario and simulation assumptions are described below.

A. Deployment Model

The simulation studies are carried out using the deployment of a medium size factory hall, i.e. 80m x 80m, with height of 12m, as shown in Figure 3. A BS with a transmission power of 1Watt (or 30dBm) is positioned in the

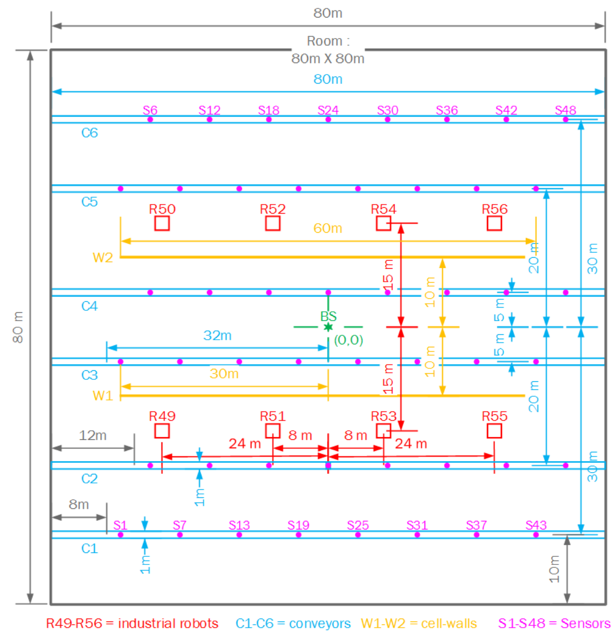

Figure 3: Deployment sketch for the simulated factory hall of 80x80m^2 with 56 sensors and actuators uniformly placed on 3 production lines and 8 robots.

middle of the factory hall. Inside the factory hall, we model three production lines (or conveyor belts) separated by two walls with a penetration loss of 6dB-per-wall. 56 devices are considered to be present in the factory hall, out of which 48 sensors are deployed along the production lines and 8 sensors/actuators are considered to be positioned on the robots. The deployment represents a factory automation scenario as described in [18].

B. Traffic Model

As mentioned in Section III, both periodic as well as sporadic traffic are present in factory communication networks. The former is defined as a time-triggered traffic with packets arriving periodically. The latter is triggered as a result of particular events such as alarms and appears sporadically. However in this paper, we focus only on the case of periodic traffic.

We consider a data packet size of 100bits with control overhead of ca. 30%. The data packets are modeled to arrive in a periodic manner with an inter-arrival time of 10ms. Furthermore, both uplink and downlink traffic are simulated for each device. However, downlink traffic is modeled in a way that it always follows the uplink traffic for a particular device after a pre-defined processing delay at the BS. In factory automation, this behavior can be seen as an equivalent to a device collecting the sensory data and forwarding it to the PLC (i.e., uplink traffic) which is then processed and transmitted to the actuator by the PLC (i.e. followed by a downlink traffic). Please note that PLC is assumed to be connected to the BS with negligible latency.

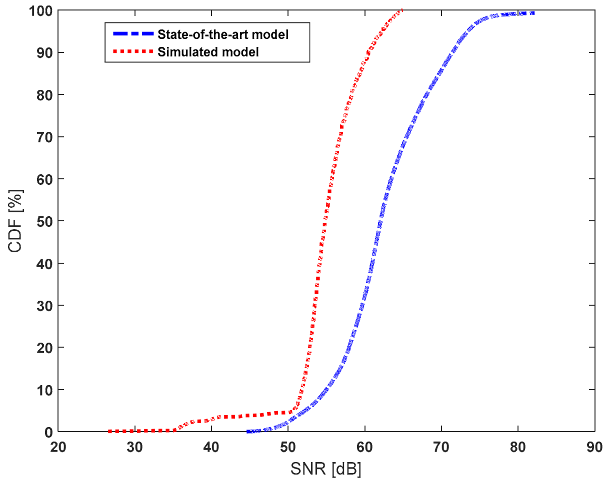

Figure 4: SNR maps for the simulated and the state-of-the-art (statistical) factory channel model.

C. *Propagation Model*

The carrier frequency is considered to be 2.4GHz with an available system bandwidth of 5MHz which is chosen in relevance to the capacity analysis of [19]. An unlicensed frequency spectrum (without following the regulations for unlicensed operations) is used due to the availability of a measurements-based factory propagation model [20], which we consider as the state-of-the-art channel model. However, since the spectrum behavior in adjacent licensed spectrum (e.g., 2GHz) is not significantly different, the presented results are considered to be valid in those frequencies as well. The simulated large scale fading model is based on the indoor propagation model as described in [21] and modified according to realistic factory environment characteristics. In particular, as the radio channel in the factory environment behave significantly different due to the open floor layout, high ceilings, presence of machinery and highly reflective material like metals, fading characteristics with obstructed line-of-sight (OBS) are also taken into account in the model. Here, we consider an OBS loss of 9dB. Figure 4 shows the comparison of SNR maps for the used channel model and the well-trusted path loss model [20] for factory automation. It can be observed that the achieved SNR for the used model is lower as compared to that of literature-based model [20] and can be seen as a worst case analysis.

In addition, we also model fast-fading channel effects. In order to save considerable computational overhead and simulation time, our simulator relies on pre-calculated fast-fading parameters. Based on the earlier empirical studies [13], we assume a delay spread of 500ns in the simulated factory environment leading to a coherence bandwidth of ca. 2MHz.

V. SIMULATION RESULTS

This section describes the system level simulation results for both LTE and 5G radio-interface design features using a realistic factory deployment as described in Section III and Section IV. In order to better visualize the performance gains of each design feature with respect to the achieved latency and

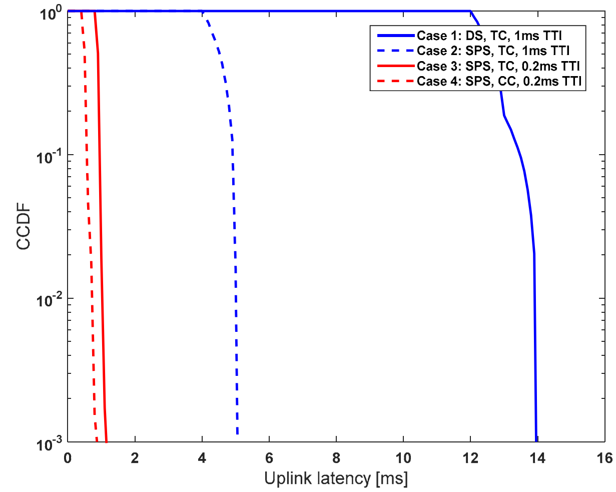

Figure 5: CCDF of uplink latencies achieved with LTE (blue) and 5G/NX (red) systems.

TABLE 3: CATEGORIZATION OF ADDED DESIGN FEATURES IN TERMS OF STAGES

Case	Design Features			
	Scheduling technique	***Coding model***	***TTI***	***Diversity order***
1	Dynamic scheduling	Turbo code	1ms	1
2	Semi-persistent scheduling	Turbo code	1ms	1
3	Semi-persistent scheduling	Turbo code	0.2ms	1
4	Semi-persistent scheduling	Convolutional code	0.2ms	1
5	Semi-persistent scheduling	Convolutional code	0.2ms	8

reliability, we categorize our simulations into five different cases as shown in Table 3.

A. *Latency Improvements*

The complimentary cumulative density function (CCDF) for the uplink latency is shown in Figure 5. It can be observed that a decrease in uplink latencies is achieved when we move from case 1 to case 4. Please note that the BLEP (i.e. reliability) target of 10^{-4} is considered here which can be mapped to the requirements of class A factory applications (cf. Figure 1). However, similar trends for latency reduction are expected for lower BLEP targets with the respective reliability enhancement features in-place. Figure 6 shows the 99^{th}-percentile of uplink latencies as cumulative density function (CDF) calculated over the devices. A significant decrease in uplink latency can be observed in Figure 6 when going stepwise from DS (cf. case 1) to SPS for periodic traffic (cf. case 2). Uplink latency is reduced in SPS due to the fact that the resources are available at the time of packet arrival and extra delay due to SR-SG signaling can be avoided. This decreases the medium access delay by approximately 8ms (considering the TTI duration and processing delays of 1ms and 3ms, respectively) and hence, the overall latency.

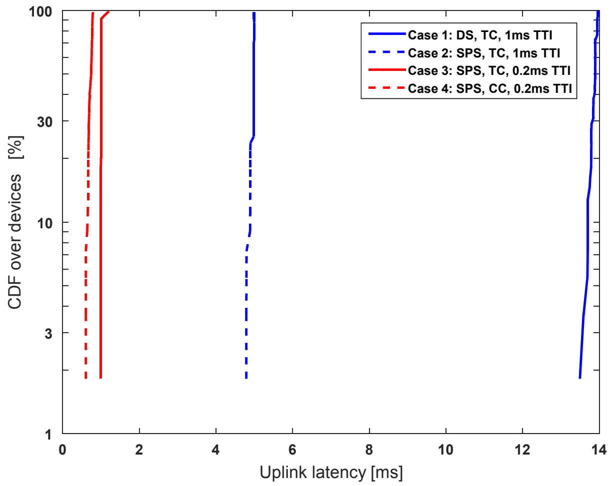

Figure 6: 99th-percentile CDF of uplink latency over devices for LTE (blue) and 5G/NX (red) systems.

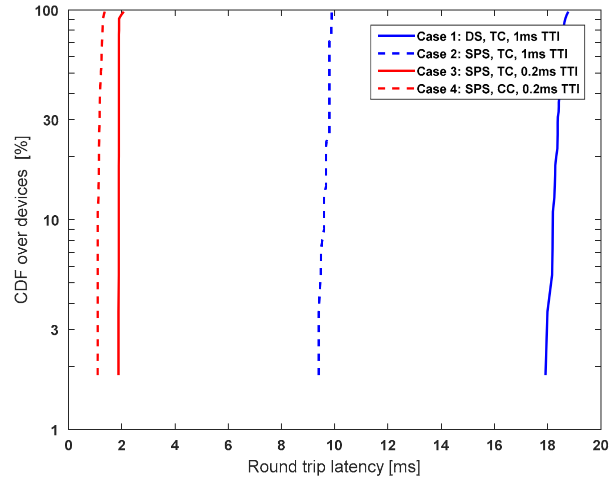

Figure 7: 99th-percentile CDF of round trip latency over devices for LTE (blue) and 5G/NX (red) systems.

As described earlier, several factory applications do not have very strict requirements on latencies. Examples include diagnostics and maintenance applications as mentioned in Section II. Hence, these factory use-cases can be fulfilled by using an LTE system with semi-persistent or even with dynamic scheduling. Nevertheless, in order to further decrease the latency, the TTI size needs to be reduced. As described in Section III, a scaled numerology of LTE is used in 5G/NX to meet the low-latency requirements. The exact scaling factor is dependent on the deployment scenario and the service requirements. Given the considered factory deployment, we consider to scale the LTE numerology by a factor of five resulting in a TTI size of 0.2ms in 5G/NX. Case 3 in Figure 6 shows the achieved uplink latency using the 5G/NX numerology for factory automation use-cases. It can be observed that the uplink latency is further reduced by a factor of five (approximately) as compared to that in case 2, resulting in an uplink latency of around 1ms.

Another important contributor to the latency is considered to be the processing delays at both device and BS side. In this regard, convolutional coding is considered instead of traditional LTE turbo codes as a scheme for error correction. In LTE system, processing (decoding) delays are considered to be equal to 3 TTIs at both the BS and device sides. In our simulations, we assume that processing (decoding) delays for convolutional codes can be reduced from 3 TTIs to 1 TTI in 5G/NX. This effect can be observed by uplink latency improvements of around 0.4ms (i.e. equals to 2 TTIs of NX) when going from case 3 to case 4 in Figure 6. This results in an uplink latency of around 0.6ms.

As mentioned in Section I, typically latency requirements in factory applications are defined for end-to-end communication. Therefore, in a centralized communication hierarchy as considered here, it is equivalent to the round trip latency through the BS. Assumption here is that the automation PLC is connected to the BS with negligible delay. In this regard, Figure 7 shows the CDF of the 99th-percentile round trip latency which is plotted over all devices in the network. Similar improvements in round trip latency are also observed when employing different radio-interface design features, i.e. from case 1 to case 4. From Figure 7, we see that 5G/NX with convolutional codes (i.e. case 4) can meet the end-to-end latency requirement of 1ms and hence, the stringent requirements of some of the class C factory applications (cf. Section II). We believe that the TTI can be further reduced in 5G/NX by choosing an even higher scaling factor to meet the end-to-end latency requirements lower than 1ms as well. However, such investigations will be part of our future evaluations.

B. *Reliability Improvements*

Factory applications can require a very high degree of reliability which in communication terms is interpreted as BLEP down to 10^{-9}. As mentioned in Section III, such low BLEP requirements demand exploitation of high diversity orders in a communication system. In our simulations, spatial diversity is implemented using up to eight antennas at the BS side and one antenna at the device side, respectively. Figure 8 shows the uplink BLEP improvement when increasing the diversity order from one to eight. Results show that it is possible to achieve low BLEP requirements by harvesting diversity gains in a factory environment. Although we carried out only simulations for a single cell scenario without considering any interference, we believe that a diversity order of up to 16 is sufficient to achieve the target reliability in multi-cell deployments as shown in [22].

C. *Evaluation Summary*

Table 4 shows the summary of the simulation results for both the uplink latency and reliability with respect to different design features. Significant reduction in latency and BLEP are observed when different radio-interface design features like semi-persistent scheduling, 5G/NX numerology, low complexity decoders and higher diversity orders are added respectively. Furthermore, as a reference we list theoretically

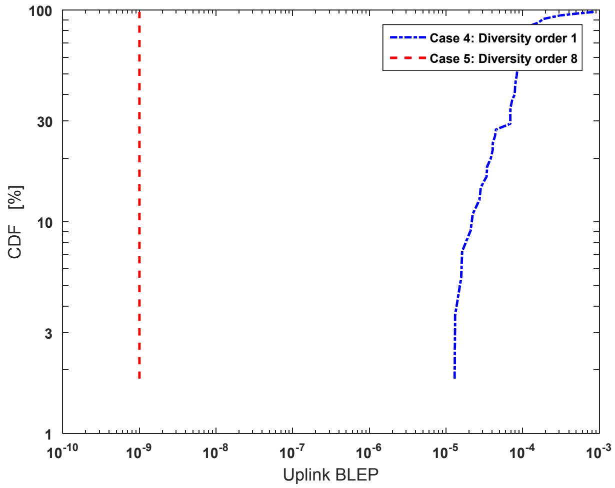

Figure 8: CDF of uplink BLEP with a diversity order 1 (blue) and a diversity order 8 (red).

calculated uplink latency for different cases (cf. Section III) to validate the performance gains observed through simulations. Table 4 shows that the achieved uplink latency in simulations comes quite close to the theoretically derived values which can be seen as the lower bound on achievable uplink latency.

VI. Conclusions And Future Work

In the wireless community, factory automation is considered as one of the most challenging use-cases in terms of latency and reliability requirements. This paper presents the viability of 3GPP technologies such as LTE and 5G/NX for various factory use-cases. Without having to deal with external spectrum interference in licensed frequencies, 3GPP technologies have an inherent advantage in satisfying stringent application requirements over wireless technologies operating in the unlicensed spectrum. In this paper, we describe potential radio-interface design features for LTE and 5G systems that can enable low-latency and highly reliable communication for factory applications. We present detailed system level simulation results in realistic deployment settings for factory environment showing an increased performance in terms of latency and reliability when moving from LTE towards 5G systems. Our simulation results indicate that the existing LTE-based systems (i.e. release 8-12) can support factory scenarios which do not demand very low latency communication (cf. Figure 1). However, for application scenarios with reliability requirements of more than $1\text{-}10^{-9}$ and an allowed end-to-end latency margin of less than 1ms, a new 5G radio-interface is needed. Our evaluation studies show that a 3GPP 5G/NX system will be able to satisfy the requirements of these highly demanding factory applications.

As part of our on-going and future work, we are investigating advanced radio resource management and interference coordination schemes for multi-cell deployments as well. Moreover, we are looking into network-assisted device-to-device (D2D) communication aspects to achieve further reduction in end-to-end communication latency.

Table 4 Comparison of analytical and simulated results

Cases	Analytical uplink latency [ms]	Simulated 99th-percentile uplink latency (maximum) [ms]	Simulated uplink BLEP [$\log_{10}$]
1	12	14	[-4,-3]
2	4	5	[-4,-3]
3	0.8	1	[-4,-3]
4	0.4	0.6	[-5,-3]
5	0.4	0.6	-9

In our future simulation studies, we will consider mixed traffic with different priority classes having both periodic and sporadic patterns.

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