



Report on 5G system configuration parameters and their effects on communication behavior in relation to the application requirements

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D4.2 REPORT ON 5G SYSTEM CONFIGURATION PARAMETERS AND THEIR EFFECTS ON COMMUNICATION BEHAVIOR IN RELATION TO THE APPLICATION REQUIREMENTS



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Lead Author(s):	Damir Hamidovic
Co-author(s):	Armin Hadziaganovic
	Raheeb Muzaffar
	Alexander Heinz
	Dalibor Mitrovic

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1 Executive Summary

In this deliverable, we explain the measurement setup of the 5G campus network in an industrial environment and provide performance evaluation of packet-level measurements, i.e., **downlink (DL)** and **uplink (UL) throughput (TP)** as well as one-way **over-the-air (OTA)** latency measurements in varying channel conditions and different **quality of service (QoS)** parameters. Moreover, detailed coverage measurements of a factory floor environment, including various physical and network layer 5G parameters such as **channel quality indicator (CQI)**, **modulation and coding scheme (MCS)**, **reference signal received power (RSRP)**, **reference signal received quality (RSRQ)**, **signal to interference and noise ratio (SINR)** and **TP coverage maps**, are presented. Through example scenarios it is shown how the 5G **QoS** parameters influence one-way **DL** and **UL OTA** latency and **TP** performance.

2 Introduction

Many applications from industrial automation to health care, automotive, etc., require reliable low-latency communication preferably with wireless connectivity [13]. In that regard, the 3rd generation partnership project (3GPP) promises novel opportunities for various industrial internet-of-things (IoT) and smart manufacturing use cases that have stringent communication requirements [16, 1, 2, 5]. More specifically, 3GPP specifications include 5G campus (non-public) network [2] that is meant to provide service to a specific organization over the geographic scope of a campus area, e.g., an indoor factory floor.

Evaluation of the 5G campus network has been performed in a few existing studies such as [13, 3, 4, 10, 7, 6, 14, 9, 11, 15, 17]. However, only some reported valuable one-way OTA measurements which are critical for the characterization of end to end (E2E) delays. Others focused only on TP or physical-layer measurements, e.g., RSRP coverage whereby only some measurements were conducted for indoor industrial environments.

In this work, we provide performance evaluation of packet-level measurements, i.e., DL and UL TP as well as one-way OTA latency measurements in varying channel conditions and different QoS parameters. Moreover, detailed coverage measurements of a factory floor environment, including various 5G parameters such as CQI, MCS, RSRP, RSRQ, SINR, rank indicator (RI) and TP coverage maps, are presented. The high-resolution coverage map or various parameters was done using a 5G module, mounted on an OMRON mobile robot, which provides a precise location with a millimeter precision, based on the integrated LIDAR sensors. The parameters were taken every 1-5ms, while the robot was moving through the entire factory floor. On the one hand, the detailed coverage maps could serve as a guideline for remote radio unit (RRU)s placement and planning of a 5G deployment in factory floor environments and can provide continuous monitoring of the communication channel quality. On the other hand, the packet-level measurements can help decide which parameters should be considered more specifically in order to fulfill the requirements of certain industrial use cases, as defined by 3GPP [16]. Some of 5G QoS parameters that can be used for guaranteed or non-guaranteed traffic control are 5G QoS Identifier (5QI), guaranteed flow bit rate (GFBR), maximum flow bit rate (MFBR) or aggregated maximum bit rate (AMBR) [12]. Certainly, ultra-reliable low-latency communication (URLLC) can provide new possibilities for mission-critical or high-demanding industrial applications, however, URLLC features are still not commercially available.

In this work, we show through example scenarios how the 5G QoS allocation and retention priority (ARP) parameter influences one-way DL and UL OTA latency and

TP performance. We also show that a specific QoS flow can be prioritized by allocating a higher number of resources. Similarly, we present how the 5G QoS parameters can be configured to increase reliability for specific industrial applications.

The remainder of the deliverable is organized as follows. Section 3 presents the detailed measurement setup. Section 4 explains the measurement results in three subsections: (i) factory floor heatmaps of various measured parameters, (ii) TP performance results, and (iii) one-way latency results, each with varying channel conditions, QoS flow priorities, and traffic load. Finally, section 5 emphasizes the most important results.

3 Measurement setup of the 5G testbed

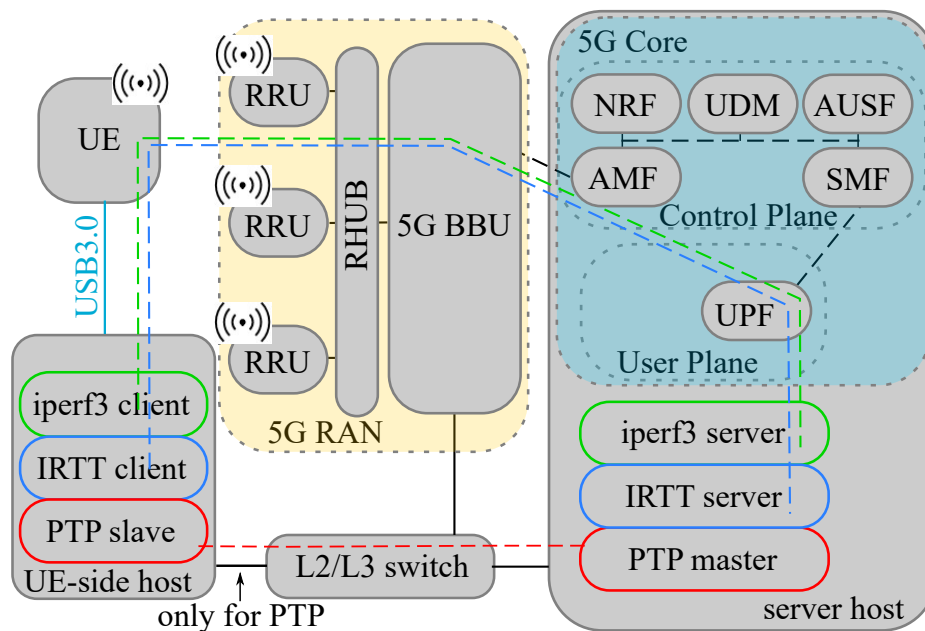


Figure 1: Logical measurement setup of the 5G testbed.

The measurement setup is reflected in Fig. 1, where the solid black lines represent wired Ethernet connections, while the dashed lines represent logical connections of the setup. The 5G system (5GS) consists of the 5G core, 5G radio access network (RAN), and user equipments (UEs). This standalone (SA) 5G testbed setup uses 80 MHz of bandwidth (BW) at 3.41-3.49 GHz in band n78, full resource block (RB) allocation, sub-carrier spacing (SCS) of 30 kHz and a time division duplex (TDD) configuration 4:1 (DDDDU).

One of 5G cores used in this project is Open5GCore¹ and is deployed as bare-metal. In such a deployment, the 5G core components including the access and mobility management function (AMF), session management function (SMF), network

¹[Online]: <https://www.open5gcore.org/>

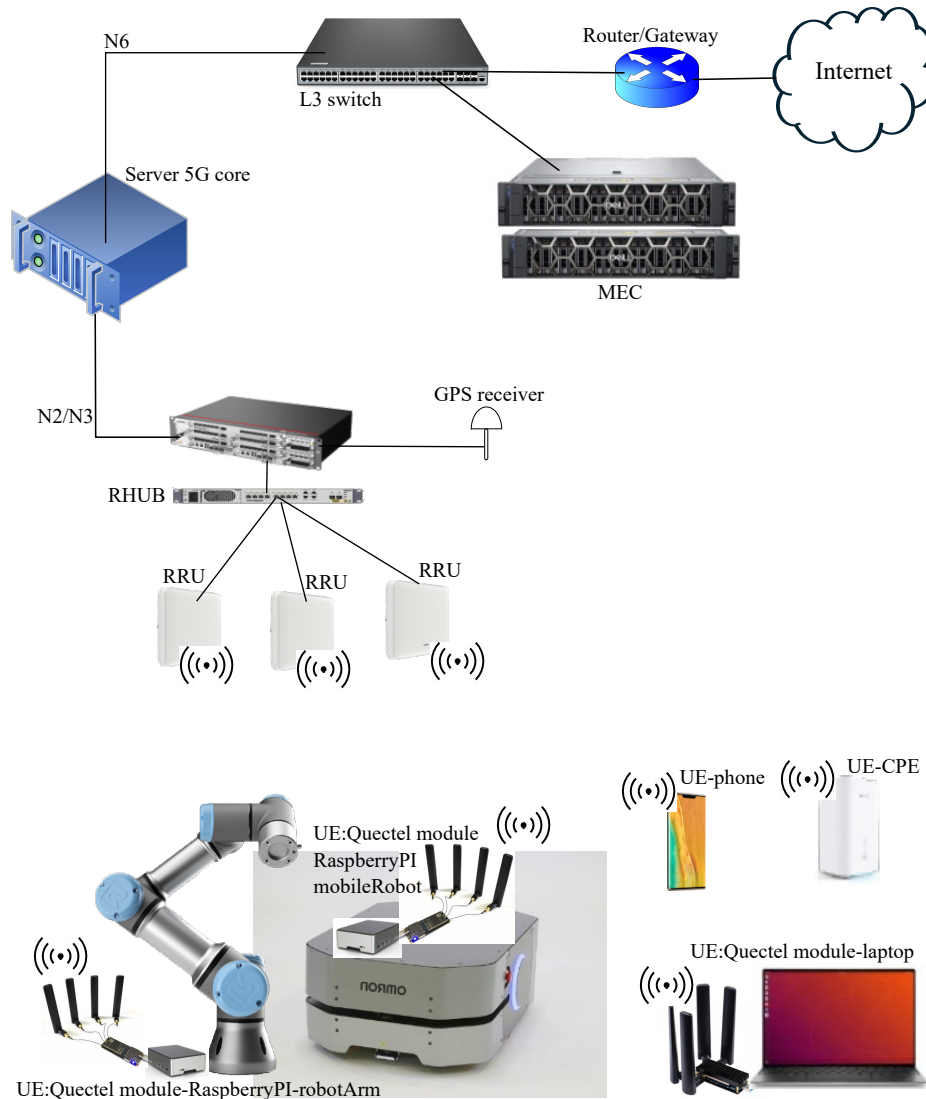


Figure 2: Hardware setup for the industrial use-case of the project.

repository function (NRF), unified data management (UDM), authentication server function (AUSF), and user plane function (UPF) are running directly (without virtualization) on a host machine. The 5G core host is a Dell EMC PowerEdge R740XD server machine with Ubuntu 20.04 LTS operating system (OS).

The other 5G core used in the work is from Druid Software. This 5G core is a commercial 5G core that is not open-source-based.

The RAN part consists of a Huawei baseband unit (BBU) 5900, three RRUs 5973, each with 4 transmit (TX) and 4 receive (RX) antennas with maximum TX power set to 24 dBm, and a RRU HUB (RHUB) 5963e. Quectel RM502Q-GL² and 5G RM530N-GL 5G modules with Qualcomm Snapdragon 5G modems inside, supporting 4×4 multiple-input, multiple-output (MIMO) in DL and 2×2 MIMO in UL, were used as the UEs. Each UE is connected to its host machine (e.g., a Raspberry Pi 4 or

²[Online]: <https://www.quectel.com/product/5g-rm50xq-series>

Raspberry Pi 5 module) via a USB 3.0 interface.

The measurements were performed using three server-client applications executed on the server-host and UE-side hosts, respectively. These applications include the *internet performance working group (iperf)*³ for real-time DL and UL TP measurements and for the traffic generation, *isochronous round-trip tester (IRTT)* for one-way OTA latency measurements and *PTP for Linux (ptp4l)* for synchronization between the server host and the UE-side host network interface cards (NICs). In order to synchronize the *IRTT*³ server and client applications with their NICs, the *phy2sys* tool was used. In our setup, hardware timestamps were used for precise precision time protocol (PTP) synchronization. Therefore, to synchronize UE hosts using PTP, Ethernet interface between the UE-side host and the switch was used to exchange PTP packets only, as it is depicted in Fig. 1. The PTP synchronization precision was under 2 μs for the measurement duration lasting for an hour. The hardware setup for an industrial use-case in this project is shown in Fig. 2.

Definition of the used configuration and measured parameters

- TP and latency are measured E2E based on server-client applications between hosts connected to a UE on one side and a 5G core on the other side.
- The RSRP, RSRQ, SINR and RI were collected at the UE side per antenna port of a UE. These are the physical layer parameters which directly describe the wireless interface between the UE antenna and the RRU. The RSRP represents the received power of a reference symbol (known symbol). It is measured on all reference symbols and averaged among them. RSRQ represents the RSRP normalized by the SINR which is the index of the averaged quality of a received reference symbol.
- The CQI, MCS, and RI are the network layer parameters of the wireless interface of the 5G. CQI represents the quality index of the communication channel, calculated based on the physical layer parameters described above. Based on the CQI parameter, modulation and coding scheme - MCS is chosen such that the bit error rate is kept within a predefined limit (typically under 10%). The TP is directly correlated with the MCS because with a higher modulation scheme and more efficient coding scheme, more bits per subcarrier can be transported over the wireless channel. The RI parameter represents the number of independent streams sent in DL from the RRU to the UE. The RI is also chosen based on the channel quality values, and depending on the robustness of the channel, this parameter can have values in the range 1-4.

³[Online]: <https://github.com/heistp/irtt>

This also directly influences the achievable TP because with e.g., 4 independent streams, the TP is 4 times higher compared with transmission of only one stream. These parameters were also collected at the UE side.

- ARP priority levels are defined in the RAN configuration (in BBU), while specific levels for specific users/QoS streams are set in the 5G core - UDM database.
- SCS and TDD are specified in the RAN configuration and those are wireless interface parameters. A specific configuration needs to be supported by a UE.

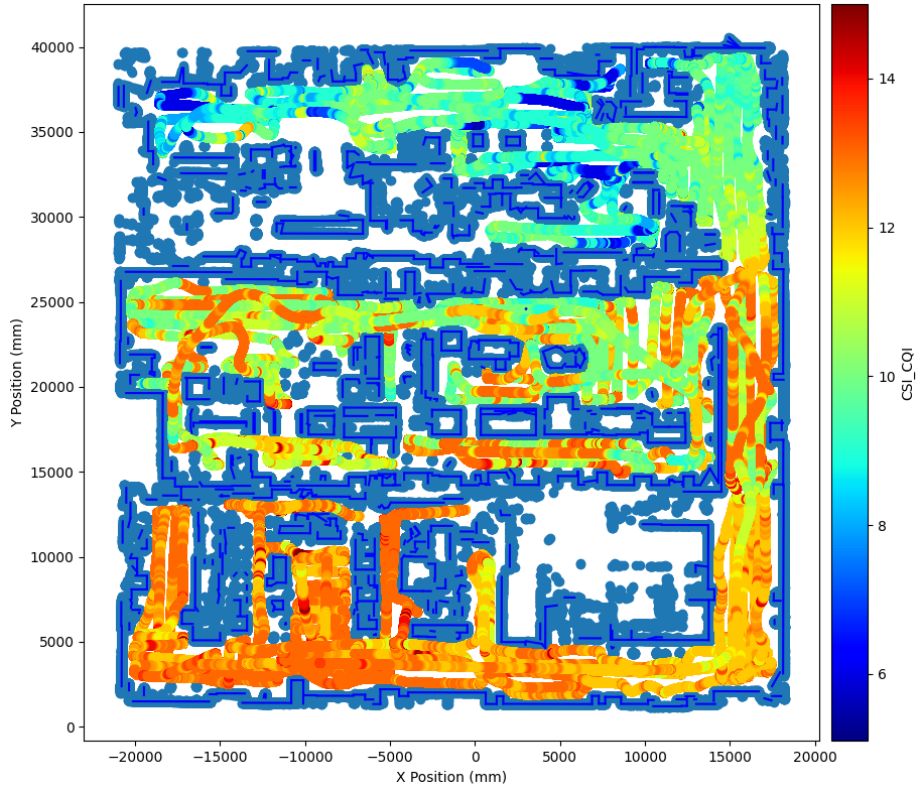
4 Measurement results

In this section, we present coverage measurement results of the 5GS performed on the [Linz institute of technology \(LIT\)](#) factory floor with dimensions 38 m × 38 m, located in the [Johannes Kepler University, Linz \(JKU\)](#) campus. The obstacles on the factory floor are predominantly steel machines. Note that horizontal and vertical axes in Fig. 3-6 represent distance in millimeters.

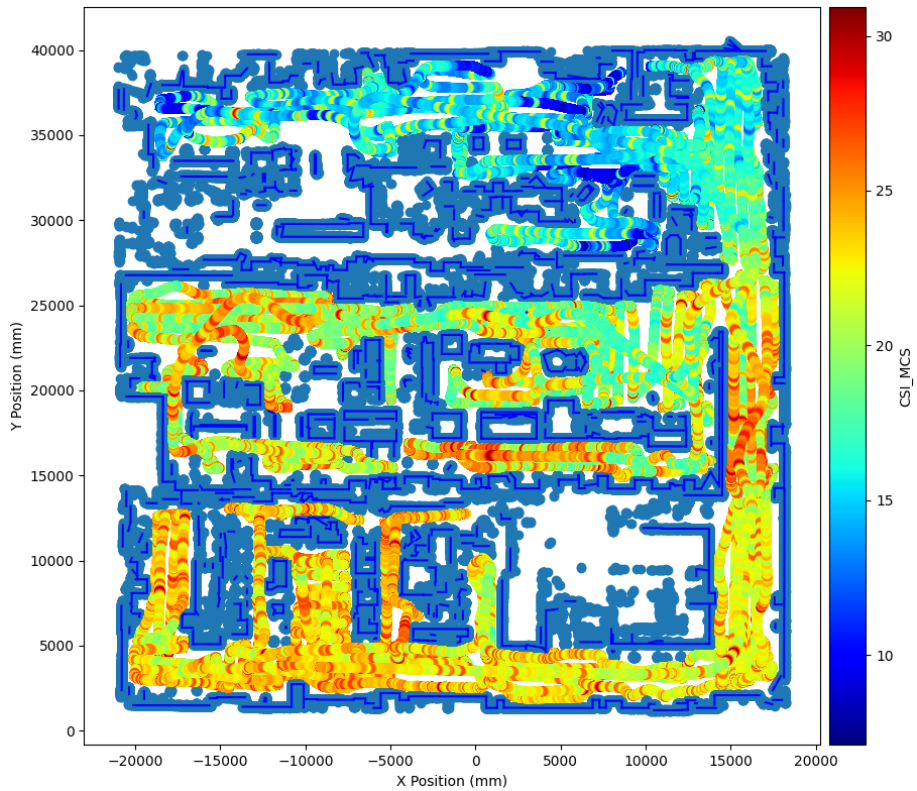
4.1 Factory floor performance heatmaps

Fig. 3a and 3b show heatmaps of the [channel state information \(CSI\)](#) parameters, [CQI](#) (range: 0-15) and [physical downlink shared channel \(PDSCH\) MCS](#) (range: 0-28), measured during an *iperf3* test for maximum DL TP. Note that [256-quadrature amplitude modulation \(QAM\)](#) scheme is supported in both UL and DL. Fig. 4 shows the heatmap of the [RSRP](#) values (range: from -140 to -44 dBm), Fig. 5 shows the heatmap of the [RSRQ](#) values, Fig. 7 shows the heatmap of the [RI](#) values, while Fig. 6 shows the heatmap of [SINR](#) values. Fig. 8a and 8b show heatmaps of the DL and UL TP, measured on the positions highlighted with blue circles and averaged over a duration of 5 s of an *iperf3* test for maximum DL and UL traffic load, respectively. The measurements are obtained from each of the 4 antennas of the UE module. However, the results shown in the document are all from antenna 1 of the UE. Moreover, all the measurements were taken from all three RRU. The results shown in this document are the results from one RRU.

From the presented heatmaps in Fig. 8, it can be seen that the entire factory floor area has good coverage with 5G signals, i.e., more than 450 Mbps of DL TP and more than 120 Mbps of UL TP is available in the entire area, except very few measurement points. In the primary area, i.e., from coordinate points (0,0) to (38,12), excellent TP performance with a minimum of 800 Mbps of DL TP and 180 Mbps of UL TP was recorded except several measurement points. It can be noted that the wooden walls, separating the factory floor in three areas, also attenuate the signal. However, high signal power and good TP performance are available beyond the wooden



(a) PDSCH CQI (range 0-15).



(b) PDSCH MCS (range 0-28 (29-31 reserved), 256-QAM supported).

Figure 3: CSI heatmaps of the factory floor.

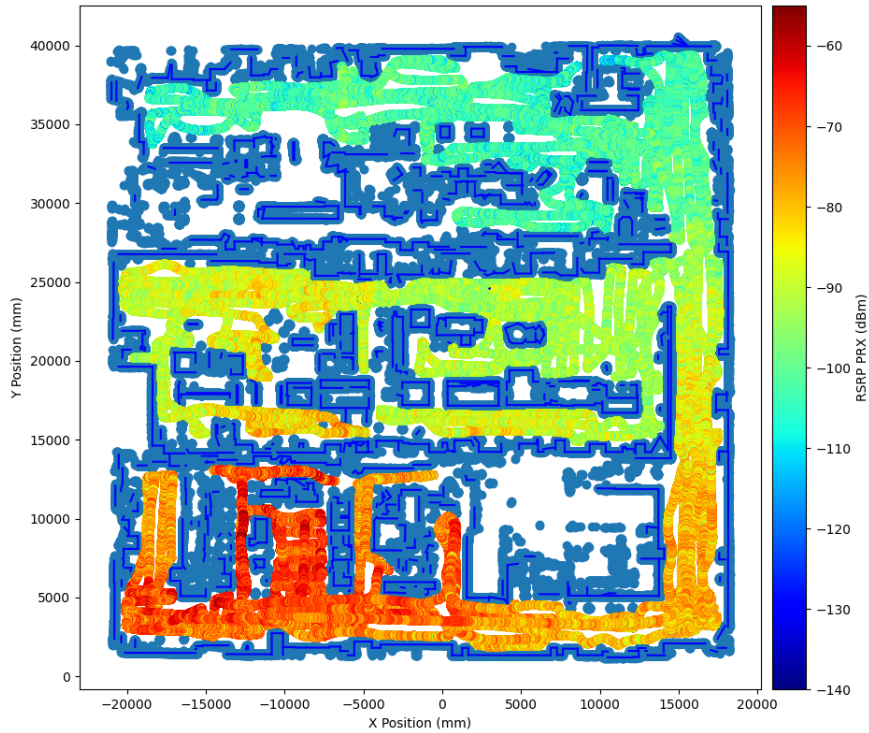


Figure 4: RSRP (dBm) heatmap of the factory floor.

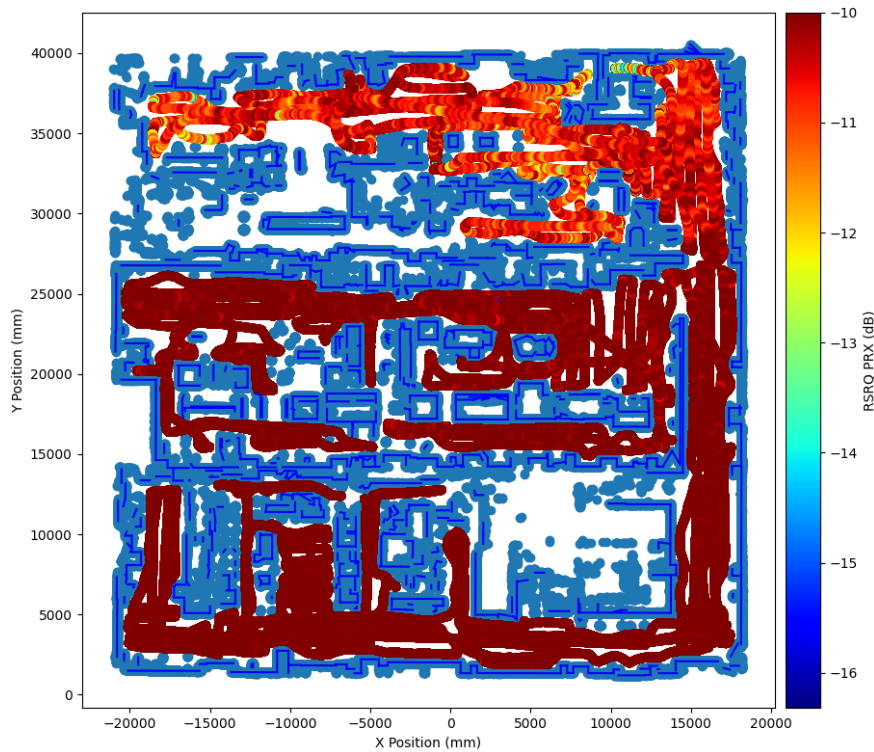


Figure 5: RSRQ (dB) heatmap of the factory floor.

walls. The height of the obstacles shows a significant impact on the signal power and quality. It is also important to note that significant signal attenuation is caused by the glass wall positioned on the right side of the second sub-area. Moreover, the

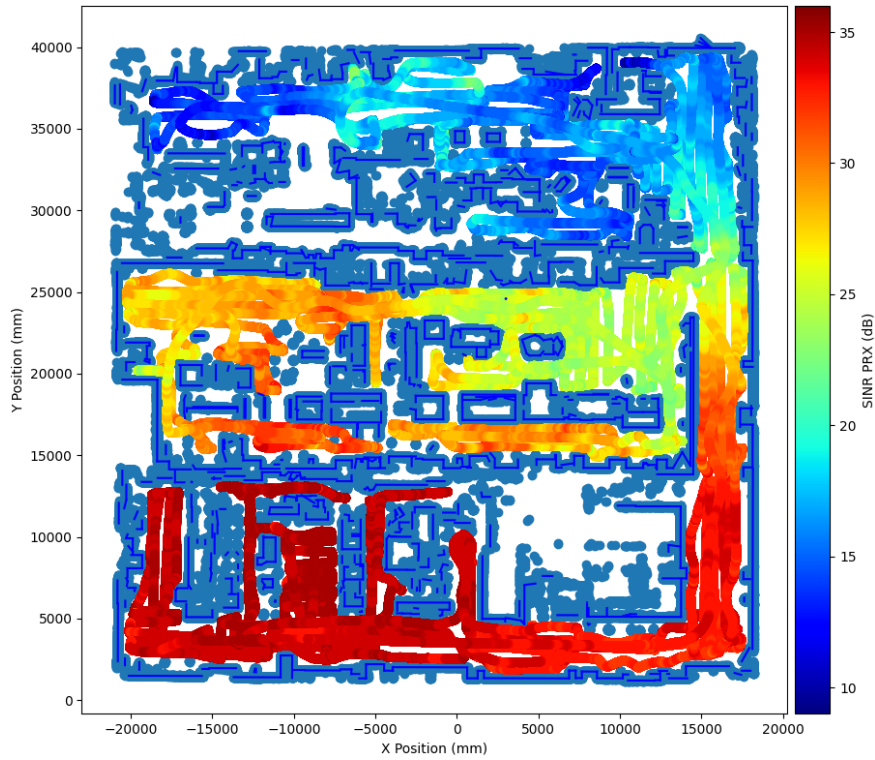


Figure 6: SINR (dBm) heatmap of the factory floor.

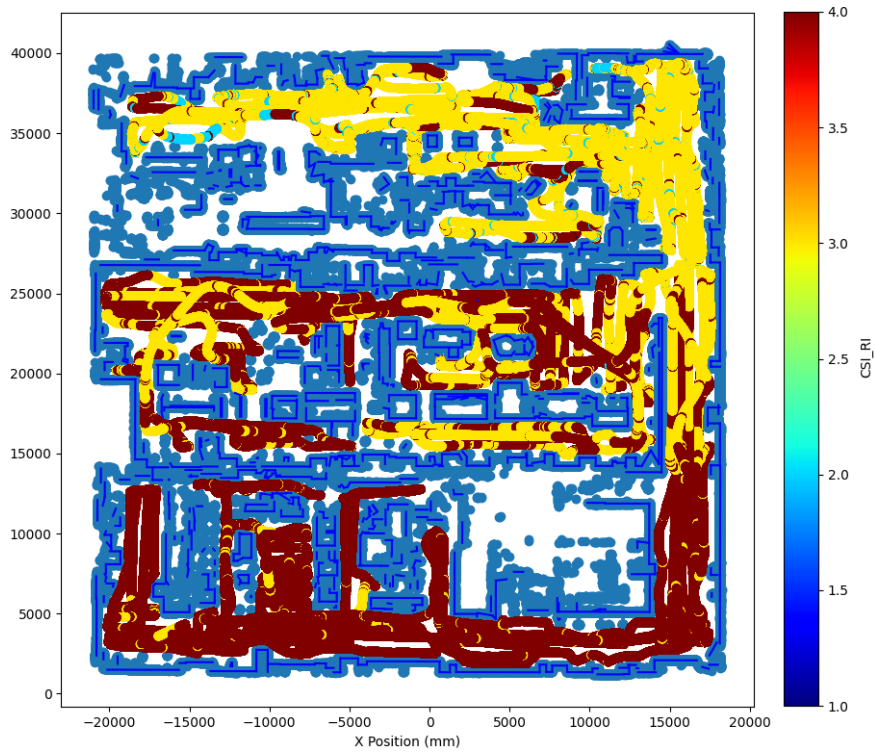
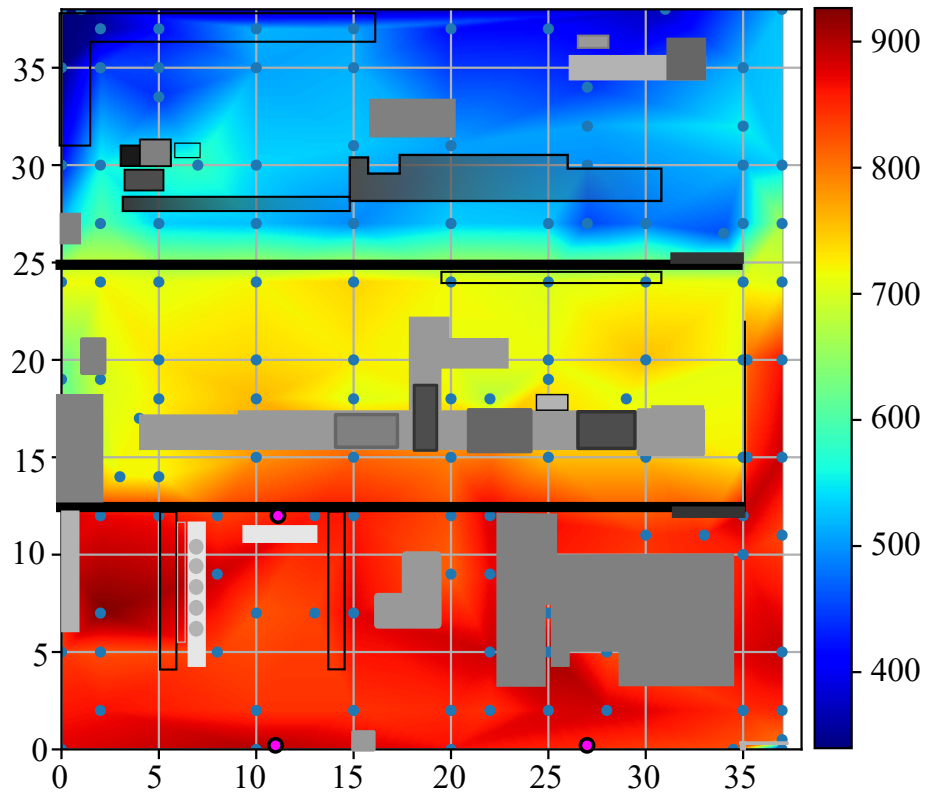


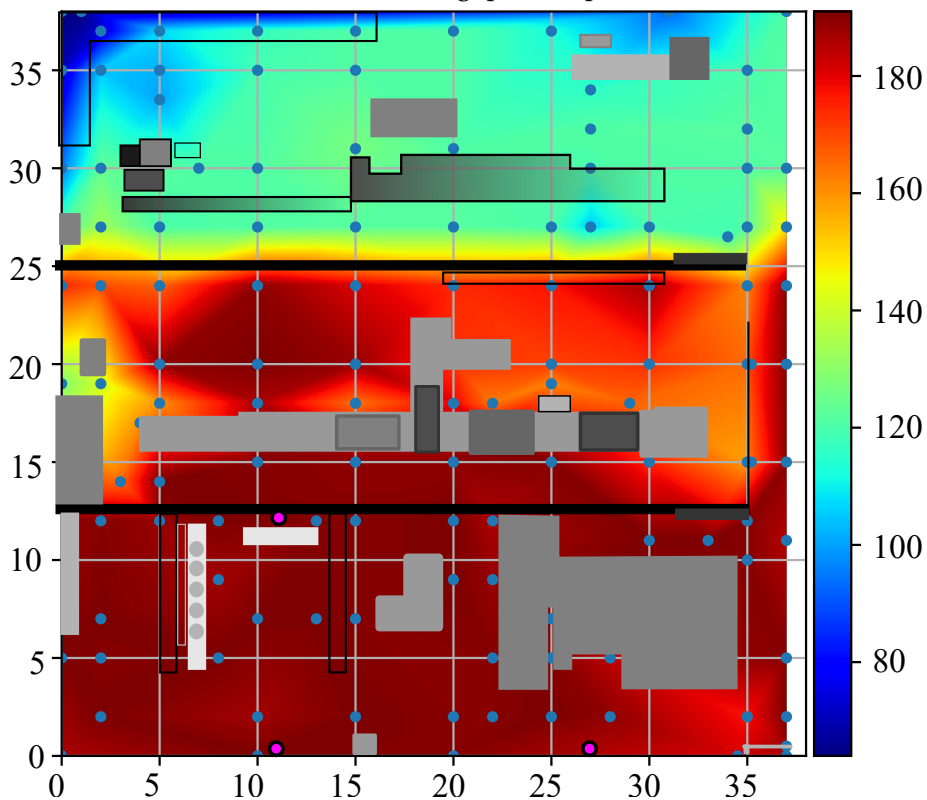
Figure 7: RI (dBm) heatmap of the factory floor.

distance from RRUs shows a significant impact on the RSRP and the TP due to path loss.

Note that the TP measurement values are obtained on a coarser grid, highlighted



(a) DL Throughput (Mbps).



(b) UL Throughput (Mbps).

Figure 8: TP heatmaps of the factory floor.

in blue circles in Fig.8 where the TP values on other points on the factory floor are interpolated, based on the measurement points. The reason is that the TP measurements were obtained in a different measurement campaign earlier before the mobile robot was available.

4.2 DL and UL TP measurements with varying channel conditions and QoS priorities

In this section, the TP performance in different channel quality scenarios is characterized and the impact of the 5G QoS ARP parameter [12] is shown. The ARP priority level defines the relative importance of a QoS flow, where the range of priority levels is 1 to 15, with 1 being the highest priority. Priority weight w_i defines the relative amount of resources R_i , that can be allocated to a 'QoS flow' i and can be formulated in a simple form as

$$R_i = \frac{w_i}{\sum_{n=1}^N w_n}, \quad (1)$$

where N is the number of competing QoS flows. However, a QoS flow can get more than R_i resources, if available, i.e., if no other QoS flows are competing for the same resources. The weights w are configured in the BBU, while the priority level for a specific QoS flow is defined in the 5G core, specifically in the UDM database. Note that the weights w can be controlled independently for DL and UL, however, in our scenarios, the same weights were used for DL and UL. We measured the TP performance in 5 different scenarios:

- S1: Equal QoS parameters with good channel conditions.
- S2: Equal QoS parameters. UE1 has poor, while UE2 and UE3 have good channel conditions.
- S3: Different QoS with good channel conditions.
- S4: Different QoS. UE1 has poor channel conditions, while UE2 and UE3 have good channel conditions.
- S5: Different QoS with good channel conditions. UE1 requests limited 300Mbps in DL or 30Mbps in UL, while UE2 and UE3 request maximum traffic load.

Different QoS means that UE1 has ARP priority level 1, UE2 2, and UE3 3, with weights $w_{UE1}=1000$, $w_{UE2}=500$, and $w_{UE3}=200$. From (1), $R_{UE1}=1000/1700=0.59$, $R_{UE2}=500/1700=0.29$ and $R_{UE3}=200/1700=0.12$.

Each UE in scenarios S1-S4 requests maximum traffic load. The [transmission control protocol \(TCP\)](#) traffic load for each UE, in scenario S1-S5, was generated using *iperf3* tool in different time-frames as follows: UE1 (10-25) s, UE2 (5-20) s, UE3

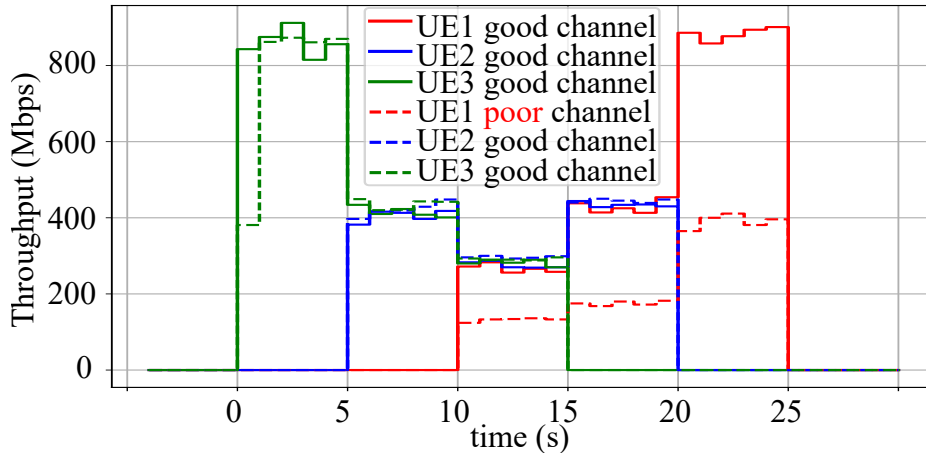


Figure 9: Impact of channel conditions on the DL TP by comparing scenarios S1 (solid lines) and S2 (dashed lines).

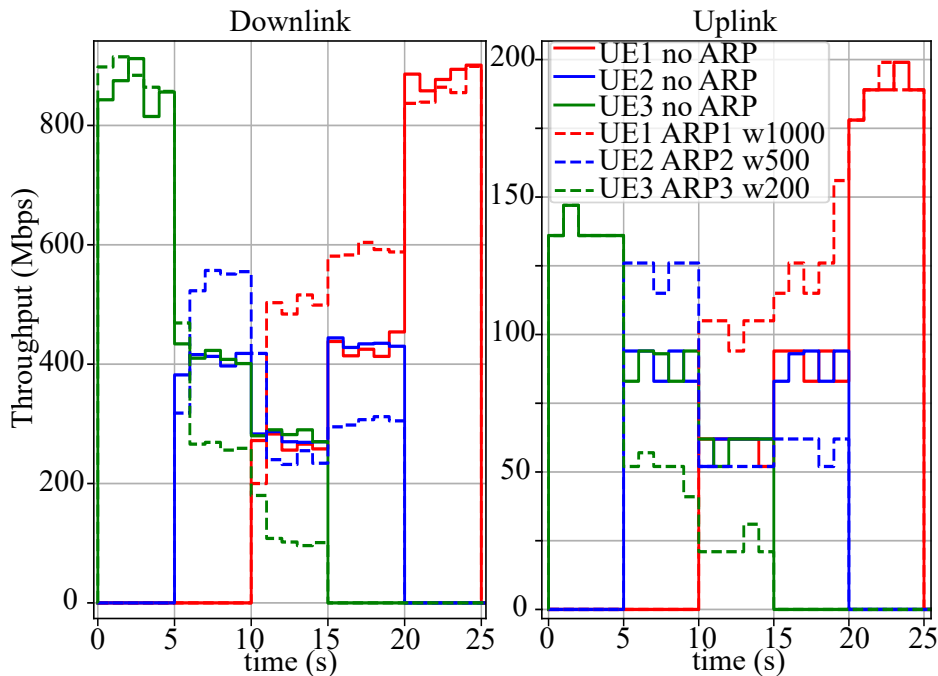


Figure 10: Impact of the QoS ARP level on the DL and UL TP by comparing scenarios S1 (solid lines) and S3 (dashed lines).

(0-15) s. The reason for UEs being active in different time frames is to show the TP capacity distribution among UEs in scenarios when only one UE is active, two UEs are active and all three UEs are active. The TP performance with poor channel conditions was measured at point (2,37) of the factory floor, where measurement points are presented on heatmaps (see Fig.8). Note that the performance among only three UEs has been analyzed. However, each UE can represent a group of UEs with the same channel conditions and QoS flows, which share the same radio resources, in order to estimate the TP performance with a higher number of UEs. In Fig.9, the scenario S1 (solid lines) is compared with the S2 (dashed lines). It can

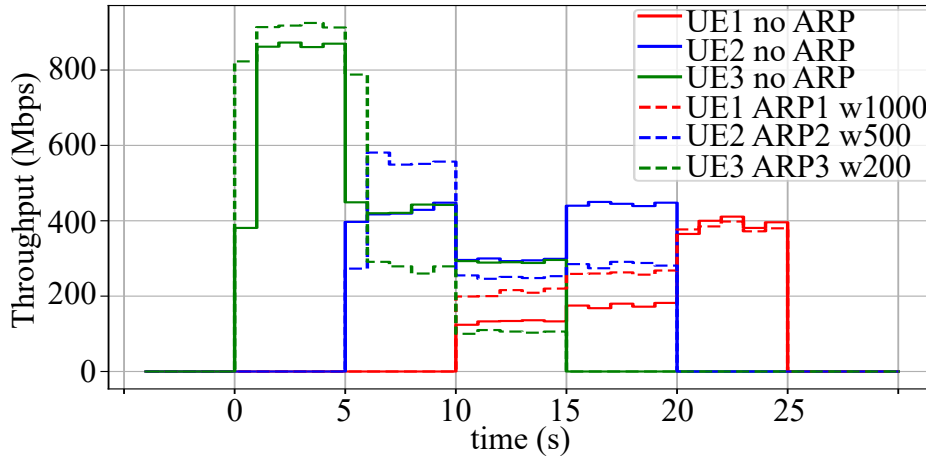


Figure 11: Impact of the QoS ARP level on the DL TP by comparing scenarios S2 (solid lines) and S4 (dashed lines).

be seen that in S1 the available TP capacity is shared equally among active UEs. From time 10 to 25s, it can be seen that the DL TP performance of UE1 has decreased significantly in S2, due to poor channel conditions of UE1. UE1 achieves lower TP with the same amount of resources, due to a lower modulation scheme used.

In Fig. 10, scenarios S1 (solid lines) and S3 (dashed lines) are compared, where the impact of the QoS ARP parameter on the TP performance, with all UEs with good channel conditions, is presented. It can be seen from time 5 to 20s, that both UL and DL TP performance in S3 is shared among active UEs equally to the share of priority weights w since all UEs competing for the same resources have the same channel conditions.

The TP performance of low-priority UEs does not have to be limited in a fixed manner in order to secure the needed resources for higher-priority UEs or QoS flows. Instead, we showed that the resources can be dynamically allocated with prioritization for higher-priority QoS flows for better utilization of the limited resources. Similar to Fig. 10, Fig. 11 compares scenarios S2 (solid lines) and S4 (dashed lines) to show the impact of QoS ARP on the DL TP performance of UEs. Here the UE1 is under poor channel conditions. It can be seen that if the high-priority UE1 has poor channel conditions, the QoS ARP could ensure that it gets more of the available resources (proportional to the ARP weights w) in order to improve the TP performance, which could be critical, especially under poor channel conditions.

However, it is important to control the requested resources of the high-priority UEs or QoS flows to maximize the utilization of resources such that lower-priority UEs can be serviced. The aforementioned scenario S5 (dashed lines) is compared with S3 (solid lines), as presented in Fig. 12. It can be seen that even though the UE1 has the highest priority, by limiting the requested DL or UL TP performance to only a

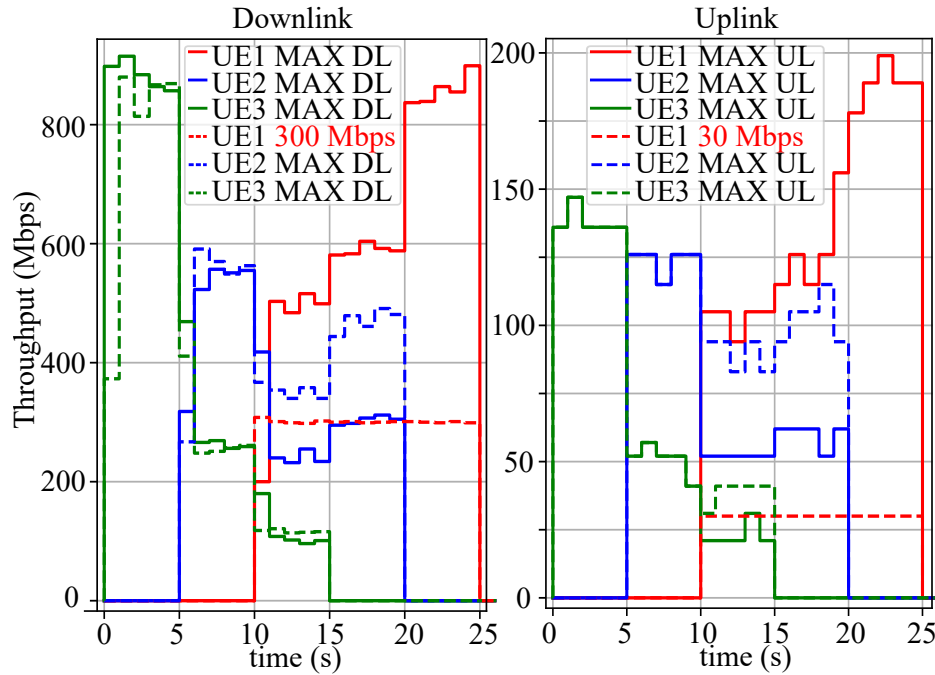


Figure 12: Impact of traffic load on the DL and UL TP by comparing scenarios S3 (solid lines) and S5 (dashed lines).

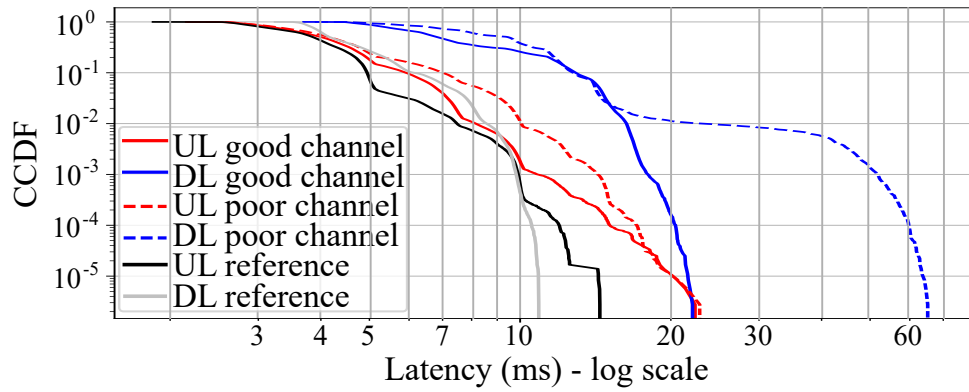
needed level, such as 300Mbps for DL and 30Mbps for UL, low priority UEs can utilize the available resources. We also noticed that UE3 decreased its maximum UL TP performance compared to UE1 even when the channel and QoS conditions were similar (compare time frames 0 to 5s and 20 to 25s in Fig. 10 and Fig. 12 for UL).

Based on the measurement results, it can be concluded that the resource share of a QoS flow can be controlled in a deterministic manner with the QoS ARP level in varying channel conditions and traffic loads. As an example, the TP performance is well suited for an industrial use case ‘Small-scale deployment scenario’, defined by 5G alliance for connected industries and automation (ACIA) in Table 12 [1], where 200 UEs running different applications require a total of 105Mbps for UL and 300Mbps for DL TP.

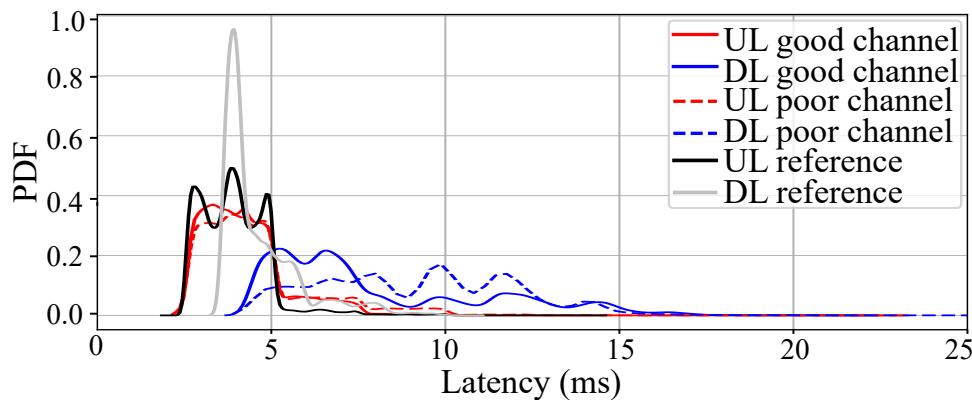
4.3 One-way OTA UL and DL latency measurements with varying channel conditions and QoS priorities

In this section, we provide the E2E latency measurement results with varying channel conditions of a UE, the impact of the QoS ARP prioritization on the UL and DL latency, and the impact of a high traffic load on the latency. In all scenarios, latency is measured with *IRTT* tool, generating random-value packets of 60 Bytes and cyclic interval of 10ms for the duration of an hour (360000 packets).

In the first scenario, the impact of channel conditions on the one-way latency with



(a) CCDF



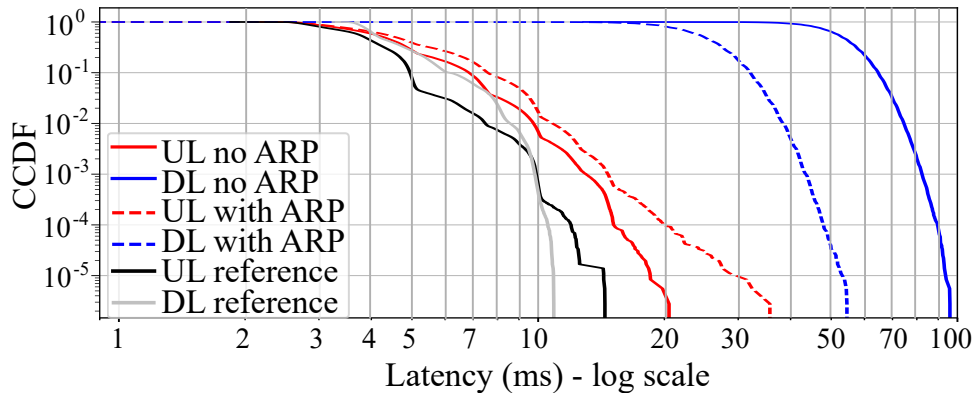
(b) PDF

Figure 13: Impact of the channel conditions on the UL and DL one-way OTA latency performance of a UE with additional DL traffic at 450 Mbps. The reference scenario is the latency measurement of a single UE without additional traffic load.

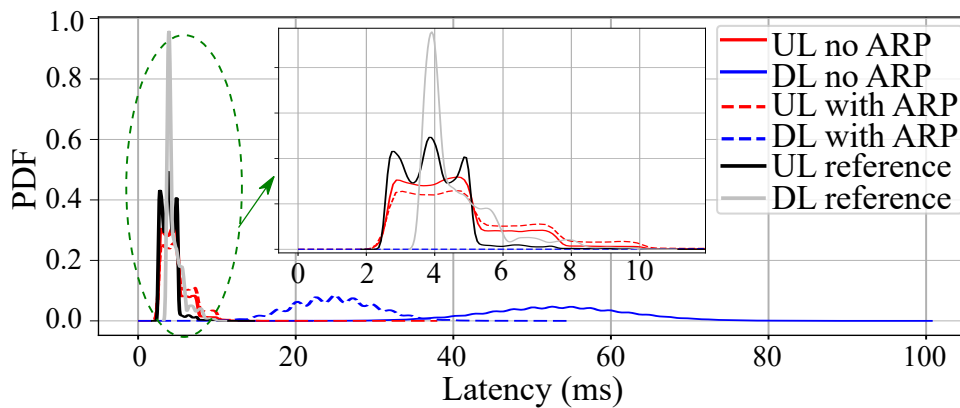
fixed additional DL traffic load (generated using *iperf3* tool) is presented in Fig. 13. It can be seen that the DL latency increases when channel conditions are poor due to higher resource occupation with decreased PDSCH MCS for a fixed DL traffic load of 450 Mbps. On the other hand, the traffic load in DL slightly affects the UL latency, comparing scenarios of good and poor channel conditions.

The second scenario shows the importance of the QoS ARP parameter in terms of latency if the maximum DL traffic load is generated for multiple UEs. The mean value of DL latency decreases from 53 ms to 25 ms when using QoS ARP prioritization whereby the measured DL latency in the reference scenario without additional traffic load is 4.6 ms. Moreover, it can be seen from Fig. 14 that the UL latency also increases slightly when the DL traffic load is high. This behavior is specifically noticeable at the tail of the latency distribution curve compared with the reference scenario. In these scenarios, the latency is measured at the UE with a higher QoS ARP level.

Similar to the previous scenario, we also tested a scenario where the maximum UL traffic load was generated by multiple UEs, utilizing all the available UL resources



(a) CCDF

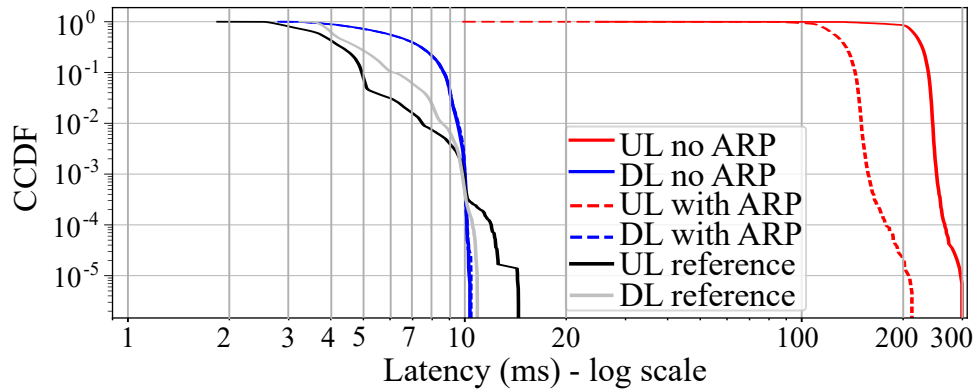


(b) PDF

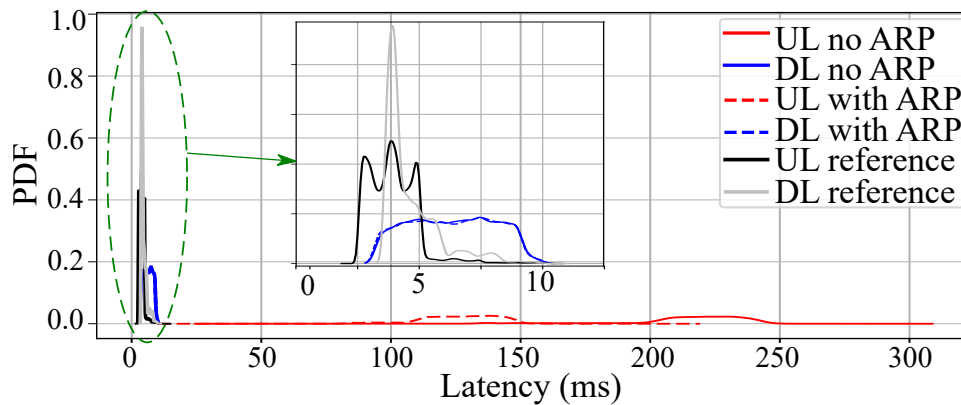
Figure 14: The impact of QoS ARP on the UL and DL one-way OTA latency performance in a scenario with 2 UEs with maximum additional DL traffic load on both UEs.

and therefore causing congestion in the UL traffic. Fig. 15 shows the impact of the QoS ARP parameter on latency performance. The mean value of UL latency decreases from 211 ms to 123 ms, while the mean value measured for the reference scenario without additional traffic load is 3.9 ms. From both Fig. 15a and 15b it can be seen that there is no impact of QoS ARP parameter on the DL latency, in scenarios with maximum UL traffic load. However, compared with the reference scenario without additional traffic load, there is also a noticeable increase in DL latency, in scenarios with maximum UL traffic load. It is important to note that only in scenarios with maximum UL traffic load, a significant packet loss of UL latency-measurement packets was observed, i.e., 29% with QoS ARP and 52% without QoS ARP.

From the measurements results, it can be concluded that the E2E OTA latency with low traffic load, as shown in Fig. 13-15 as ‘UL reference’ and ‘DL reference’ has a mean value of 3.9 ms and 4.6 ms, and a maximum value of 14 ms and 11 ms, respectively, with the reliability of 99.9997%, based on the measurement duration



(a) CCDF.



(b) PDF.

Figure 15: The impact of QoS ARP on the UL and DL one-way OTA latency performance in a scenario with 2 UEs with maximum additional UL traffic on both UEs.

of an hour. This performance could fulfill requirements of several industrial use cases, such as monitoring or remote maintenance, as defined in Table 1 in [2], industrial wireless sensors use cases, and mobile robots (real-time video stream) use case, defined by 3GPP in [16] in Table 5.2-2 and Table 5.4-1, respectively. However, with a very high traffic load, the latency values increase significantly. The QoS ARP level improves the latency performance, however, it is not sufficient to ensure the controlled latency performance. First, 5G QoS parameters such as MFBR or AMBR could be used to prevent traffic congestion which can significantly decrease the maximum latency values. Second, 5G QoS parameters such as 5QI, the ARP-preemption capability option, or URLLC features are necessary in order to control the maximum latency in all channel or traffic load conditions. A part of the work described in this deliverable is published in [8].

Other parameters that can significantly influence the performance of the 5G system, especially the latency, are the TDD configuration patterns and SCS. The TDD configuration directly influences the latency because with a shorter period between the UL and DL slots in a repeated TDD pattern, the packets wait a shorter amount of time to get a scheduled resource and therefore the latency is lower. Similarly,

the *SCS* also directly influences the latency because with higher numerology (wider *SCS*), the slots are shorter in time, and therefore the latency is lower.

Regarding the throughput, the exact radio planning plays a significant role because the number of cells and access points influences the network's capacity, as described in the deliverable D2.1 of this project. Moreover, the BW of the cell scales with the number of cells. With more cells, less BW per cell is available and therefore, less throughput is achievable per a single user.

In addition, configurations such as Distributed MIMO, slicing, and other *QoS* parameters, as mentioned in the Introduction, can also significantly influence the performance of a user, group of users, and/or overall network capacity.

5 Conclusions

The use of 5G for several different vertical applications is highly advocated. In this work, we evaluate the performance of the 5G campus network considering factory floor scenarios. It can be concluded from the coverage heatmaps that the placement of the *RRUs* is suitable for achieving high communication performance in the factory floor area. The TP results show a minimum of 450 Mbps in DL and 120 Mbps in UL is available in the factory area. These results can serve as a guide in planning for the placement of *RRUs* in indoor environments. It can be concluded from the TP measurements that with the *QoS* ARP parameter, the share of available resources among different *QoS* flows can be controlled in a deterministic manner, even in scenarios with extremely high traffic load as well as in various channel conditions. However, the channel conditions have to be taken into account while planning the required resource share for a certain *QoS* flow such that the required TP can be achieved.

On the contrary, from the latency measurement results, it can be concluded that latency increases significantly with high traffic load and cannot be controlled in a deterministic manner using only the *QoS* ARP levels, even though it was observed that the latency is noticeably lower for high-priority *QoS* flows. Moreover, it can be concluded that variations in latency for the same traffic load depend on channel conditions, due to the utilization of a different amount of resources with a varying modulation scheme.

Lastly, the presented measurement results show that this 5G setup could fulfill several industrial use cases, defined by 3GPP or 5G ACIA in terms of TP and latency performance, even without the usage of *URLLC* features. However, latency performance improvements are expected with *URLLC* features.

Acronyms

3GPP 3rd generation partnership project. 3

5GS 5G system. 4, 7

5QI 5G QoS Identifier. 3, 18

ACIA alliance for connected industries and automation. 15

AMBR aggregated maximum bit rate. 3, 18

AMF access and mobility management function. 4

ARP allocation and retention priority. 3, 12

AUSF authentication server function. 5

BBU baseband unit. 5

BW bandwidth. 4

CQI channel quality indicator. 2, 3, 6, 7

CSI channel state information. 7

DL downlink. 2, 3, 6, 7

E2E end to end. 3, 6, 15

GFBR guaranteed flow bit rate. 3

IoT internet-of-things. 3

iperf internet performance working group. 6

IRTT isochronous round-trip tester. 6

JKU Johannes Kepler University, Linz. 7

LIT Linz institute of technology. 7

MCS modulation and coding scheme. 2, 3, 6, 7, 16

MFBR maximum flow bit rate. 3, 18

MIMO multiple-input, multiple-output. 5

NIC network interface card. 6

NRF network repository function. 4

OS operating system. 5

OTA over-the-air. 2, 3, 6, 16–18

PDSCH physical downlink shared channel. 7, 16

PTP precision time protocol. 6

ptp4l PTP for Linux. 6

QAM quadrature amplitude modulation. 7

QoS quality of service. 2–4, 12, 18, 19

RAN radio access network. 4, 5

RB resource block. 4

RHUB RRU HUB. 5

RI rank indicator. 3, 6, 7

RRU remote radio unit. 3, 5, 7, 10, 19, *Glossary: RRU*

RSRP reference signal received power. 2, 3, 6, 7, 10

RSRQ reference signal received quality. 2, 3, 6, 7

RX receive. 5

SA standalone. 4

SCS sub-carrier spacing. 4, 18, 19

SINR signal to interference and noise ratio. 2, 3, 6, 7

SMF session management function. 4

TCP transmission control protocol. 12

TDD time division duplex. 4

TP throughput. 2–4, 6, 7, 10

TX transmit. 5

UDM unified data management. 5, 12

UE user equipment. 4–6

UL uplink. 2, 3, 6, 7

UPF user plane function. 5

URLLC ultra-reliable low-latency communication. 3, 18, 19

Glossary

RRU Commonly referred to as a remote radio head (RRH), is a transceiver that can be found on wireless base stations.. 3

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