Performance Analysis of a Private 5G SA Campus Network

Conference Paper · February 2023


Sachinkumar Bavikatti Mallikarjun
RPTU - Rheinland-Pfälzische Technische Universität Kaiserslautern Landau


Christian Schellenberger
RPTU - Rheinland-Pfälzische Technische Universität Kaiserslautern Landau

Performance Analysis of a Private 5G SA Campus Network

Sachinkumar Bavikatti Mallikarjun, Christian Schellenberger, Christopher Hobelsberger and Hans D. Schotten
Institute for Wireless Communications and Navigation
University of Kaiserslautern, Germany
Email: {mallikarjun, schellenberger, hobelsberger, schotten}@eit.uni-kl.de

***Abstract*—5G has become a reality and there is a strong momentum in the global market as it is growing rapidly. Mobile network operators (MNOs) around the world have already upgraded parts of their networks to 5G stand-alone (SA) operation. 5G subscriptions are projected to exceed 4.39 billion by end of 2027 [1]. Private campus networks (PCN) are also being built to trial new applications that were not possible before. These networks are limited to specific areas such as company premises and optimized for different applications like autonomous driving. Applications have to be adapted to appropriately reflect changing user experiences and network speeds in order to fully exploit 5G's potential. Measuring the performance is crucial for the assessments of the networks, as they can influence anything from investment decisions to legislative measures. Currently, the measurement technologies are not well adapted for private 5G campus networks. This paper presents the results of the performance analysis of the private 5G SA campus network deployed on the campus of the Technische Universität Kaiserslautern. The 5G SA PCN is operating in band n78 with 100 MHz bandwidth (3.7-3.8 GHz) adhering to the Release 15 3GPP standards. For the measurements, an internal speed test server and external speed test application are used to measure parameters like download and upload speeds,latency and jitter. Additionally, measurement tools from Rohde and Schwarz are used to measure signal strength parameters like RSS, SS-RSRP and SS-SINR of the different Radio Heads at the same time. The measurements are recorded in indoor and outdoor environments running different services on the internal and external server.**

I. Introduction

There are a large number of factors that influence measurement accuracy, like user-related considerations, such as chipset feature integration and firmware release. Other factors are test-infrastructure, e.g. test server capacity, test design, e.g. single or multi-link connections, and other user equipment active in the same network cell. This paper presents the results of the performance analysis of the private 5G SA campus network deployed on the campus of the Technische Universität Kaiserslautern. The 5G campus network is operating with 100 MHz bandwidth in band N78 (3.7-3.8 GHz) adhering to the Release 15 3GPP standards. The network is based on Nokia digital automation cloud (NDAC) technology.

The performance is measured in indoor and outdoor environments based on different services like TCP, and web applications (Speedtest Servers) running on internal and external servers. Measurements of the 5G Campus Network show that the advertised data rates of 20 Gbps [2] [3] are not yet being achieved. The dependency of the throughput on the factors such as cell load, network software version, type of user equipment and others can be clearly seen from the measurement data.

For the measurements, an internal speed test server based on the open source lightweight Librespeed [4] and as the external speed test application Speedtest by Ookla[5] are used. The parameters measured are download and upload speeds, latency and jitter (only available with Librespeed). Additionally, measurement tools from Rohde and Schwarz, i.e. ROMES with TSME6 and TSMA6 ultracompact drive test scanner, are used. Measurement data includes RSS, SS-RSRP and SS-SNR of the different RRHs(Cells). For 5G User Equipment, Qualcomm X55 based Quectel RM500Q-GL and Telit FN980 are used for this paper , as well as the Huawei P40 mobile phone based on the Balong 5000 5g module.

The remainder of this paper is organized as follows: Section II discusses the Campus Site and the deployed 5G SA network as well as the user equipment used to analyze the network performance. Section III deals with the measurement tools used to test the network performance. In Section IV the performance of the indoor and outdoor portions of the network are discussed. The measurement data is discussed in section V. Lastly, the conclusion and future work are discussed in section VI.

II. Network and User Equipment

A. 5G SA Network Overview

1) Topography and Radio Environment: The campus of the TU Kaiserslautern represents an average urban environment with a rather flat but dense development. The campus is located on the outskirts of the city directly on the edge of the forest, so that interference factors of various frequency bands are low. These conditions provide an ideal test environment to investigate the 5G SA network in the best possible way.

2) 5G SA Network: In Germany the frequency range between 3.7 and 3.8 GHz with a maximum bandwidth of 100 MHz is reserved for local campus networks. It can be reserved for at the Federal Network Agency (BNetzA) through a simple form. The 5G SA campus network of the TU Kaiserslautern was awarded through a public tender to Smart Mobile Labs AG. The 5G hardware used was supplied by Nokia. It consists of a local core and a cloud core hosted by Nokia. The core is connected to the base band unit (BBU) which in turn is connected to the different remote radio heads (RRH). The outdoor RRHs are directly connected to the BBU. They are

ISBN 978-3-8007-5873-9

capable of 4x4 MIMO, but each split in two 2x2 MIMO sectors. The indoor RRHs (4x4 MIMO) are connected to the BBU via a Hub. We have full control over the network RAN parameters and functions. The cells can thus be activated or deactivated as needed or reconfigured to ensure optimal data throughput as per the user's requirements. The construction of the SA network started in 2020 and was completed in mid-2021. The network hardware and software evaluated in this paper implement 3GPP Release 15 Version. The core is on software release 7.2022.11.3727 and the RAN on 21B. The coverage of the outdoor area of the main campus is achieved through 3 RRHs as shown in figure 1. This is extended with two further RRHs covering additional areas in the direction of neighboring research facilities. The antennas have a beam angle of 65 degrees and are mounted at a height of between 20 and 35 meters, depending on the location.

In addition to the outdoor networks, four indoor networks in different buildings were installed, which are used in various laboratories, e.g. for the practical demonstration of industry-related applications.

3) RAN parameters: For the measurements, an upload to download ratio of 3:7 and a maximum transmit power of 40 dBm per channel were used. This ensures maximum upload required for most industrial applications. For future investigations a variation of the network parameters is possible.

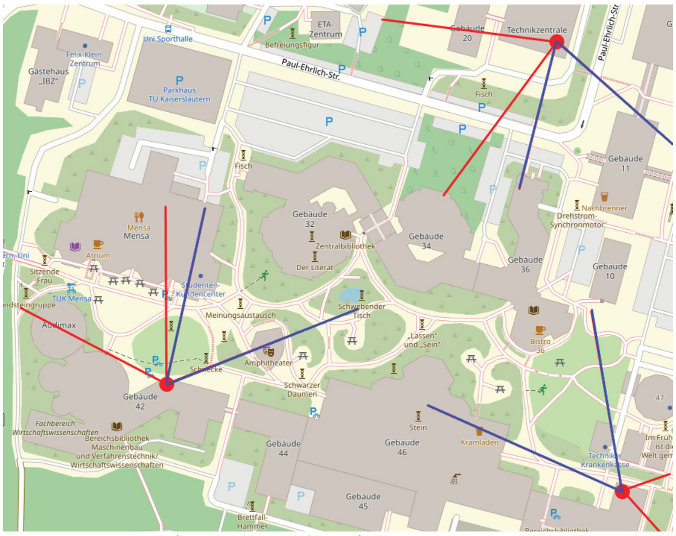

Fig. 1: RRH location on campus

B. User Equipment

5G device availability has been a limiting factor for initial 5G use cases. There are very few devices available in market which support Standalone 5G, especially for campus networks using. Device manufacturers the block public land mobile network (PLMN) IDs assigned for private networks, i.e. mobile country code (MCC) 999. User equipment for 5G are significantly more complicated than the current 4G or LTE User equipment in terms of the design of antennas, modem, frequencies and Physical layer to MAC layer co-design [6]. In this Subsection the user equipment used for this work are discussed.

1) Commercial Mobiles: Quality of Experience and Quality of Service have played a tremendous role for the Cellular phones. The design of Cellular phones have undergone huge changes in antenna design, modem design, and radio frequency design from generation to generation to match up with high-end user applications like Machine learning, High quality Video streaming, Virtual Reality and more. Cellular phones also have to coexist with different technologies apart from Cellular technologies. Cellular communication is tightly integrated into smart phones and therefore can achieve high performance. They are however not well suited for industrial applications where 5G modules have to be directly integrated into other devices like sensors and actuators. For this paper the Huawei P40 Pro based on the Balong 5000 is used to show the performance of smart phones in 5G.

2) 5G Modules: For the paper two different 5G modules were used. The Quectel RM500Q-GL (firmware version: RM500QGLABR11A06M4G01.001.01.001) and Telit FN980 (firmware version: M0H.000201-B005) Figure 2. Both of these are 5G modules with m.2 form factor. The antennas used for this measurement campaign are MIMO supported to get the best results possible. Both devices are Qualcomm X55 based chips but from different integrators with different firmware. So the measurement results may differ between the two devices.

Fig. 2: 5G modules from Quectel (RM500Q-GL) and Telit (FN980)

III. 5G Measurements Tools and KPI

In this Section, the tools used to measure the network are discussed as well as the parameters that can be used to describe the performance of the cellular network. To make the measurements, a self hosted internal speed test server and an external speedtest application are used. Additionally Rohde and Schwarz's ROMES measurement application along with TSME6 and TSMA6 ultracompact drive test scanner are used to measure important radio parameters.

A. Performance Metrics

5G will enable a new set of services, not only for human users, but also for industrial and automotive purposes. Key factors for acceptance and use are the ultra high reliability and the ability for real-time interaction. For these future applications, it is key to measure and rate the interactivity of a network and to efficiently identify bottlenecks in the transmission. The fundamental concept of quality of experience (QoE) and its basic dimensions remain the same, even if the importance for the user and the acceptability thresholds change, like quality, waiting time to access the service and accessibility. Throughput alone cannot define the QOE of the cellular, so we have considered below technical KPI's.

1) Throughput: The amount of data that can be transferred between two network endpoints in a given time span is known as throughput. For instance, throughput can be evaluated between two places in a certain ISP's network or for an end-to-end link, such as between a client device and a server located somewhere on the Internet. A speed test often analyses both downstream (download) and upstream (upload) throughput from client to server[2].Throughput is not continuous; it varies depending on a variety of things, including what other users are doing in the network.

2) Latency: The time it takes for a single data packet to travel to its destination is known as latency. Because measuring one-way latency would necessitate tight temporal synchronization and the capacity to instrument both sides of the channel, latency is typically assessed in terms of round trip latency(ping). Latency generally increases with distance, due to factors such as the speed of light for optical network segments; other factors can influence latency, including the amount of queuing or buffering along an end-to-end path, as well as the actual network path that traffic takes from one endpoint to another. TCP throughput is inversely proportional to end-to-end latency, all things being equal, then, a client will see a higher throughput to a nearby server than it will to a distant one.

3) Jitter: is the variation between two latency measurements, lower the jitter value then the latency of the network will be stable.

4) Radio parameters: The linear average of the received secondary synchronization signals level is called Synchronization Signal reference signal received power (SS-RSRP).SS-SINR stands for Synchronization Signal signal-to-noise and interference ratio, within the same frequency spectrum, SS-SINR is defined as the linear average of the power contribution (in Watt) of resource elements carrying Secondary Synchronization Signal (SSS) divided by the linear average of the noise and interference power contribution (in Watt) of resource elements carrying SSS and Received Signal Strength (RSS) is the total received wide-band power measured by the user equipment over the full bandwidth.

B. Measurement Applications and Tools

1) Speedtest Servers: Since public speedtest applications are not reliable the best way to measure the network speed is to self host the speed test application in our internal network and measuring the network speed within the infrastructure. In this work, the open source speedtest server LibreSpeed [4] is used. LibreSpeed is implemented in JavaScript and it is based on Web Workers and XMLHttpRequest. It is running on a Notebook directly connected to the local breakout of the 5G SA PCN. The application is to measure download and upload speeds, ping(latency/2) duration. Apart from the internal servers, an external speedtest server is used (speedtest.net). For both internal and external speedtest TCP connection have been used and link type for internal speedtest server is single link and for external speedtest server is multi link type.

2) Rohde and Schwarz: To measure the radio parameters the ROMES drive test software from Rohde and Schwarz is used. In combination with the drive test scanner TSME6 and TSMA6 it can be used for network analysis and optimization.

ROMES is the universal software platform, ROMES is used in combination with scanners or test mobile phones, and it supports 5G NR and 5G Qualcomm and Samsung modem based UE measurements. Rohde and Schwarz's measurement tool is used to measure signal strength parameters like RSS, SS-RSRP and SS-SINR of the different Radio Heads at the same time.

C. Measurement Locations

When carrying out the outdoor measurements, care was taken to ensure that the choice of measurement points was balanced. This means that there is at least one measuring point per RRH as serving cell and that the handover areas between two RRHs are also considered. Figure 3 shows the five outdoor locations and the indoor location where the measurements were taken.

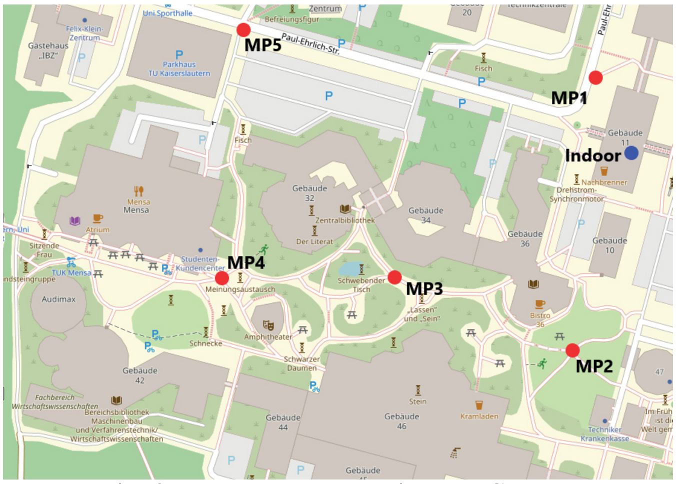

Fig. 3: Measurement Locations on Campus

IV. NETWORK PERFORMANCE

With IoT, industrial automation, and communication services, 5G opens up new opportunities for customers and operational efficiency in indoor networks.

The measurements of the indoor network with respect to the internal server (librespeed server) is shown in Table I and for the outdoor network is mentioned in Table II. The Measurements are displayed with respect to the different User Equipment's. The best throughput performance recorded for the internal network is 749 Mbps download, 233 Mbps upload with 6 ms latency and for the external server (Speedtest.net)

Table I: Indoor 5G Performance with internal server

User Equipment		Download [Mbps]	Upload [Mbps]	Latency [ms]	Jitter [ms]
Quectel RM500Q-GL	*Best*	749	97	11,4	1,6
	Avg.	741,2	40,9	14,4	3,4
Huawei P40 Pro	*Best*	732,58	232,6	6,4	1,2
	Avg.	679,7	228,8	7,9	1,5
Telit FN980	*Best*	376	221	9	3,5
	Avg.	372,8	68,8	9,4	4,4

Table II: Indoor 5G Performance with external server

User Equipment		Download [Mbps]	Upload [Mbps]	Latency [ms]
Quectel RM500Q-GL	*Best*	812,9	58,8	8,5
	Avg.	786,4	41,9	10,5
Huawei P40 Pro	*Best*	650	230	7,5
	Avg.	593,6	205,8	8,7
Telit FN980	*Best*	354,3	36,7	10,5
	Avg.	353,5	29,3	12,2

is 813 Mbps download speed, 230 Mbps upload speed with 7.5 ms latency.

The measurements of the outdoor network with respect to the internal server (librespeed server) is shown in Table III and for the outdoor network is mentioned in Table IV. The measurements are displayed with respect to the different user equipment's. The best throughput performance recorded for the internal network is 750 Mbps download, 127 Mbps upload with 8 ms latency and for the external server (Speedtest.net) is 870 Mbps download speed, 110 Mbps upload speed with 7 ms latency.

V. Evaluation

At every measurement point five measurements were made to avoid outliers in the data due to small changes in radio propagation. More points were tested before the measurements for this paper started to decide on points of interest. For the indoor network the five measurements were made from one point. Table I and Table II represent the measurements of the indoor network with the internal and the external server respectively. Tables III and IV show the measurements of the outdoor area with the internal and external server respectively.

A maximum indoor data throughput of 813 Mbit/s (Quectel chip with external server) in the downlink and 232 Mbit/s (Huawei P40 with internal server) in the uplink were achieved. For outdoor measurements a peak download rate of 870 Mbit/s (Huawei MP4 external server) and peak upload rate of 126 Mbit/s (Huawei MP4 internal server) was achieved. The antenna configuration of the outdoor RRHs is 2x2 MIMO and the indoor antenna configuration is 4x4 MIMO. Apart from the maximum throughput, average values are also determined for the five measurement points. The data shows that the average values differ between the different user equipment. The two chips from Quectel and Telit stand out particularly here since they are both based on the same modem. Overall their average upload data rate is lower than the Huawei smartphone especially in the indoor network.

The values described here are only valid for the current firmware version of the UEs as performance can change with different firmware version. Software updates in core and RAN also influence the measured performance. There are also other factors that influence measurement accuracy, like user-related considerations, such as chip set feature integration and firmware release. Other factors like test-infrastructure, e.g. test server capacity, test design, e.g. single or multi-link connections, or other user equipment active in the same network cell can also impact the measured performance.

Table V shows the reference signal receive power (RSRP)

Table III: Outdoor 5G Performance with internal server

User Equipment			Download [Mbps]	Upload [Mbps]	Latency [ms]	Jitter [ms]
Quectel RM500Q-GL	**MP1**	*Best*	739	115	9,1	3,3
		Avg.	727,6	74,7	10,8	4,9
	MP2	*Best*	98,2	84,5	13,4	1,3
		Avg.	92,2	76,6	14,9	2,7
	MP3	*Best*	731	59,2	13,4	2,3
		Avg.	718,6	53,9	13,6	3,5
	MP4	*Best*	747	104	10,4	1,6
		Avg.	738,4	82	11,4	3,7
	MP5	*Best*	543	68,8	11,2	1,9
		Avg.	526,4	62,7	11,5	3,2
Huawei P40 Pro	**MP1**	*Best*	738,2	90,1	9,1	3,4
		Avg.	731,3	83,7	10,1	5,3
	MP2	*Best*	296,1	102,6	9,1	1,3
		Avg.	293,9	90,6	9,7	2,1
	MP3	*Best*	602,4	79	8,7	1,8
		Avg.	517,8	59	9,5	3,4
	MP4	*Best*	746,3	126,6	9,1	2,6
		Avg.	740,2	111,1	9,2	3,3
	MP5	*Best*	513,2	39	8,5	4,7
		Avg.	473	28,6	10,4	28,4
Telit FN980	**MP1**	*Best*	375	74,2	9	3
		Avg.	373,8	69,5	9,5	6
	MP2	*Best*	177	57,4	12,5	1,2
		Avg.	170	50,3	13,8	3,7
	MP3	*Best*	376	62,7	9,4	0,5
		Avg.	372,8	57	11,8	2
	MP4	*Best*	375	74,1	8	4,4
		Avg.	372,8	65,4	9	5,7
	MP5	*Best*	374	37,5	11,3	1,7
		Avg.	371,6	36	12,3	2,7

Table IV: Outdoor 5G Performance with external server

Outdoor 5G Network Performance with external Server					
User Equipments			Download [Mbps]	Upload [Mbps]	Latency [ms]
Quectel RM500Q-GL	**MP1**	*Best*	718,1	78,3	7,5
		Avg.	708,1	68,3	9,1
	MP2	*Best*	102,2	73,4	8
		Avg.	78,6	58,7	9,6
	MP3	*Best*	693,2	53,9	7
		Avg.	671,1	52,2	8,9
	MP4	*Best*	726,8	75,4	8
		Avg.	707,4	70,3	9,3
	MP5	*Best*	501,2	57,7	8
		Avg.	487,3	55,3	10,5
Huawei P40 Pro	**MP1**	*Best*	707	83,8	8,5
		Avg.	697,4	77,1	10
	MP2	*Best*	283	70,2	7
		Avg.	279,2	65,8	8,6
	MP3	*Best*	474	51,6	9,5
		Avg.	320,2	47,9	10,1
	MP4	*Best*	870	110	8
		Avg.	850,6	102,8	9
	MP5	*Best*	456	36,4	9
		Avg.	413,4	30,4	9,8
Telit FN980	**MP1**	*Best*	353,1	75,8	11
		Avg.	350,6	66	13,6
	MP2	*Best*	169,6	67,5	10
		Avg.	161,4	64,4	11,6
	MP3	*Best*	357,8	60,5	9,5
		Avg.	353,3	53,4	11,3
	MP4	*Best*	353,8	64,7	9
		Avg.	347,7	61,3	11,5
	MP5	*Best*	354,9	43	10
		Avg.	330	34,7	11,6

Table V: Radio parameters for MP1 - MP5

	SS-RSRP [dBm]			**SS-SINR [dB]**			**RSS [dBm]**
	RRH (Serving Cell)	**RRH (Neighbor Cell 1)**	**RRH (Neighbor Cell 2)**	**RRH (Serving Cell)**	**RRH (Neigbor Cell 1)**	**RRH (Neighbor Cell 2)**	**RRH**
MP1	-72,37	-85,3	-97,57	15,1	-15,8	-27,4	-66,6
MP2	-69,4	-88,56	-91,22	10,9	-20,3	-25,9	-65,7
MP3	-76,07	-92	-100,5	14,5	-16,1	-24,7	-50,33
MP4	-64,6	-95,9	-97,4	31,1	-35,4	-35,3	-61,24
MP5	-79,16	-83,89	-102,3	8,3	-9,4	-23,2	-54,32
Indoor	-90,15	-110,42	-112,99	16,15	-20,31	-23,31	-62,2

and signal to interference noise ratio (SINR) of the Synchronization Signal (SS-RSRP and SS-SINR) and received signal strength (RSS) of the serving cell and neighboring cell (indoor and outdoor) for each measurement points. The linear average of the received secondary synchronization signals (SSS) level is called SS-RSRP. Within the same frequency spectrum, SS-SINR is defined as the linear average of the power contribution (in Watt) of resource elements carrying SSS divided by the linear average of the noise and interference power contribution (in Watt) of resource elements carrying SSS. RSS is the total received wide-band power measured by the user equipment over the full bandwidth.

As can clearly be seen in the data some values stand out. For example, the average jitter value of the Huawei smartphone on MP5. The average value in table III is very high because two of the five measurements yielded disproportionately high results. The reason for this is unclear. However, the influence of the outliers can be minimized by a higher number of measurements. It can also be seen that the data throughput at MP2 is the worst despite good SS-RSPR and SINR. In addition, MP2 is without obstacles in the direct line of sight of the RRH. Since this observation was made for all devices, the cause is likely to be found in the RRH. At the time of writing, no cause for the bad performance at MP2 could be found and has to be further investigated. MP5 has the worst signal strength and MP4 has the best signal strength when compared to the other MPs and the throughput is not reflected accordingly for MP5 but throughput is reflected accordingly for MP4. In our case latency is depending on the user equipment rather than MP. The Huawei phone and the Telit FN980 have lower latency with external server. The latency to the internal server higher than to external server, the reason for this could be link load to internal server. 8 virtual Machines supporting different ongoing use cases are running on the internal server along with the speedtest server in one of the virtual machines and all the virtual machine share a single link to the backend of our 5G network. Further investigation has to be done with a dedicated link for virtual machines running in internal server.

VI. Conclusion and future work

In the measurements a maximum indoor data throughput of 870 Mbit/s in the downlink and 232 Mbit/s in the uplink were achieved. The measured values are highly dependent on the measurement location and the user equipment. Apart from the maximum throughput achieved, average values are also determined for different locations of the campus ranging from 850 Mbit/s for the best measurement point with the best performing device to 160 Mbit/s for the worst measurement point and the least performant device. The same holds true for upload speeds ranging from 229 Mbit/s to just about 30 Mbit/s. This highlights the importance of network planning to ensure an optimal coverage of the target area. The data also shows the difference in performance depending on the device used for the measurement. Since the performance depends so much on device choice more devices should be tested, which we plan to do. Furthermore, we plan to run stress tests on the network by connecting multiple devices to the same cell and stream high definition videos. We also plan to run throughput test for different download and upload ratios available (currently 4:1 and 7:3, but 6:4 will be possible in the future). Apart from throughput test the network will also be tested with respect to different ongoing use cases at TU Kaiserslautern (Video Streaming, low latency communication for automated guided vehicles and autonomous unmanned aerial vehicles).

VII. Acknowledgment

The authors acknowledge the financial support by the Federal Ministry for Digital and Transport of Germany in the program 5x5G-Strategie (project number VB5GFKAISE). Further financial support was given by the European Union through the european regional development fund and the Ministry for Industry, Traffic, Agriculture and Winegrowing of the Rhineland-Palatinate (84008296).

References

[1] S. O'Dea. *5G mobile subscriptions forecast worldwide 2020-2027* Statista. Retrieved April 19, 2022, from https://www.statista.com/statistics/521598/5g-mobile-subscriptions-worldwide/

[2] Ericsson. *5G wireless access: an overview* Retrived April 2022,19, from https://www.ericsson.com/en/reports-and-papers/white-papers/5g-wireless-access-an-overview

[3] Samsung. *3GPP Release 16 - Shifting Gears to Increase 5G Speeds on Multiple Network Highways* Retrived April 19,2022, from https://images.samsung.com/is/content/samsung/p5/global/business /networks/insights/white-papers/3gpp-release-16-shifting-gears -to-increase-5g-speeds-on-multiple-network-highways/Samsung- 3GPP-Release-16-Whitepaper.pdf

[4] Librespeed. (n.d.). *Librespeed/speedtest: Self-hosted Speedtest for HTML5 and more* Retrieved April 19, 2022, from https://github.com/librespeed/speedtest

[5] Speedtest.net *Speedtest by Ookla - The Global Broadband Speed Test* Retrieved April 19, 2022, from https://speedtest.net

[6] Huo Y, Dong X, Xu W *5G cellular user equipment: From theory to practical hardware design* IEEE Access. 2017 Jul 18;5:13992-4010.

[7] Feamster, N., Livingood, J. *Measuring internet speed: current challenges and future recommendations.* Communications of the ACM 2020, 63(12), 72-80.