5G Testbed Implementation and Measurement Campaign for Ground and Aerial Coverage

Aleksei Fjodorov, Ali Masood, Muhammad Mahtab Alam and Sven Pärand

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Aleksei Fjodorov, Ali Masood, Muhammad Mahtab Alam
Tallinn University of Technology. Email: (aleksei.fjodorov1; ali.masood; muhammad.alam)@taltech.ee
Sven Pärand
Telia Estonia Ltd. E-mail: sven.parand@telia.ee

***Abstract*—5G networks promise high data rates, low latency and extreme reliability. Existing literature is saturated with simulation and numerical investigations on 5G. However, a limited number of studies are available on the evaluation of 5G networks in real-time heterogeneous environments. As 5G networks are being deployed worldwide. Therefore, it is significant to analyse the performance of 5G network in real life, which can be helpful for planning future deployments. This study provides the implementation of a portable 5G testbed and presents the experimental results of ground and aerial measurement campaign in order to evaluate the performance of 5G network operating at 3.5 GHz in terms of coverage, throughput and latency.**

***Index Terms*—5G, real-time, ground and aerial measurements.**

I. Introduction

The deployment of the 5G commercial networks is ongoing across the globe. In 2018 a number of countries started launching limited 5G networks in selected locations. Amongst the first ones are Qatar, China, the United States and South Korea. The first countrywide commercial 5G network was deployed in 2019 in South Korea. By the June of 2021, according to the GSA (Global mobile Supplier Association) report, [1], already 58 countries have 5G networks and a dozen more have partially deployed 5G technology. As technology is still relatively young in the deployment phase. However, the deployment of 5G networks is expanding massively worldwide to provide 5G services. It is envisioned that approximately 3 billion 5G users will connect with the 5G network by 2025. Therefore, it is important to analyse the performance of the 5G network in real-time heterogeneous environments, which will support in future 5G deployments.

A. Related Work

Nokia research team [2] analysed the coverage of the 5G network at the sub-6 GHz frequencies. 5G at 3.5 GHz with the additional use of massive MIMO technology significantly improves the coverage compared to 2x2 MIMO at the same frequency and shows slightly better results compared to 4G LTE at 2.6 GHz for both uplink and downlink. In [3], the authors present the coverage and throughput results of 5G at frequencies of mid and high-bands (3.5 GHz and 28 GHz respectively) in the real urban environment in the city of Calgary, Canada. Along with this, the performance of 4G LTE connectivity at 2.5 GHz has been compared with the 5G. Results show that when a distance between the base station and the user equipment is between the range of 160-900m, the throughput of 5G decreases nonlinearly from 320 Mbps to 125 Mbps. The RSRP (Reference Signal Received Power) tests have been performed for both 5G and 4G LTE. The average RSRP decreases with the increasing distance in both 4G LTE and 5G cases, roughly five dBm higher in 4G LTE case. The authors evaluate the performance of the 5G testbed at sub-6 GHz band in [4] and compare it with 4G LTE at 2.1 GHz. The testbed explores massive MIMO and beamforming technologies at 3.5 GHz. Downlink measurements have been performed in a dense urban area, in line of sight (LoS) scenarios and in both indoor and outdoor conditions. The results show that the 5G without using the beamforming technology has shown a higher signal gain decrease of 5.1 dB in outside and 7.1 dB in indoor. Although, enabling the beamforming technology fully compensates the gain-loss caused by the higher frequency with an additional extra gain increase. It makes 5G at sub-6 GHz band a solid potential replacement for the existing 4G LTE. However, these studies provide ground measurements, however, do not consider the use of UAVs to evaluate the performance of 5G network.

Several UAV-based 5G testbeds have been implemented for different applications. One of the drone-based testbeds was implemented by Ericsson to manage interference in 5G with drones. The Hepta Airborne Group is working on a drone-based solution for massive mobile communications capacity during different crowded events [5]. 5G!Drones [6] aims to test, evaluate, and validate the use of unmanned aerial vehicles in three main use cases of 5G – eMBB (enhanced Mobile Broadband), URLLC (Ultra Reliable Low Latency Communications) and mMTC (massive Machine Type Communications). Stratosphere 5G nodes Project [7] is aiming to provide the 5G network connection directly from the stratosphere using a High-Altitude Platform (HAP). HAP will fly at an altitude of 20 km for up to nine days carrying the required 5G networking equipment.These projects use UAVs as a portable base station, whereas the performance analysis of the developed testbeds is either missing or not comprehensive. Though, authors in [8], [9] comprehensively analyse the ground and aerial measurements in real-time heterogeneous environments. However, they consider out-of-coverage scenarios where base stations are unavailable or destroyed.

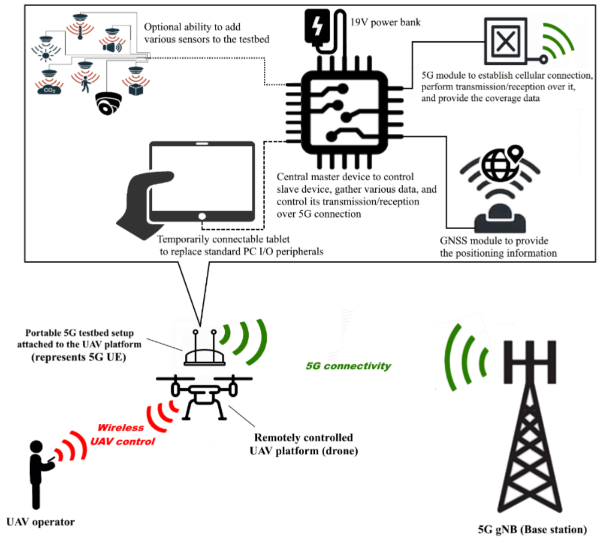

Fig. 1: Components and architecture of the used testbed.

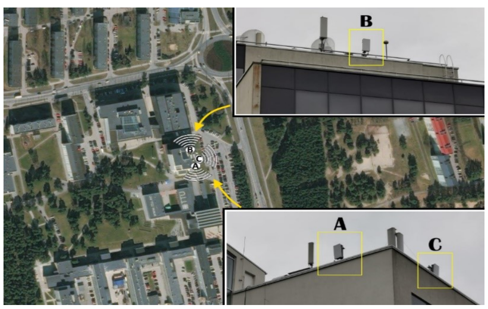

Fig. 2: Locations of 5G NR antennas deployed at university campus.

B. Contribution

To the best of our knowledge, this is the first experimental study that presents the implementation of a portable 5G testbed, which is suitable for both ground and aerial applications. A comprehensive campaign has been carried out to collect real-life data in LOS and NLOS scenarios at 3.5 GHz. The experimental data is presented to analyse the performance of the 5G network in terms of coverage, latency, and both uplink and downlink data rates.

II. 5G Testbed Implementation

This section presents the implementation of a drone-based 5G testbed to measure the coverage and evaluate the performance of the 5G network across the Tallinn University of Technology campus area in heterogeneous environments.

A. Experimental Setup

As shown in Fig. 1, the experimental setup has following components and architecture:

1) 5G NR gNB: 5G NR (New Radio) base station, also known as gNB (gNodeB), has been deployed at university by using the widely utilized non-standalone Option 3x deployment configuration. 5G NR base station has used 60 MHz bandwidth at 3.5 GHz central frequency, and the 4:1 TDD (Time-Division Duplex) configuration. There are three active 5G antennas, deployed around the campus area on the top of the building with an approximate height of 25 m. Locations and images of used antennas are shown in Fig. 2.

2) 5G modules: The key equipment of the 5G testbed is modern 5G supported cellular module. Two 5G modules have been tested, RM500Q-GL module manufactured by Quectel, and SIM8202G-M2 by SIMCom. Both modules have the same core chip set: Snapdragon X55 5G Modem-RF System by Qualcomm,supporting 3GPP Release 15, including all the main cellular technologies up to standalone 5GNR, 256QAM (Quadrature Amplitude Modulation) for both downlink and uplink, 4x4 MIMO layers for downlink and 2x2MIMO for uplink. In this paper, we present the results using the RM500Q-GL module, more details can be found in [10].

3) GNSS receiver module: The GU-902MGG-USB portable GNSS dongle is used for continuous positioning tracking in order to create proper heatmaps of experimental data.

4) Tablet: A Samsung GT-P5100 tablet is used as a wired I/O peripheral for the processing device. TwomonUSB software is used that allows getting a highly mobile and portable touchscreen monitor for processing devices.

5) Power bank: The processing unit is powered by Sandberg 420-23 power bank that has 20000 mAh/74 Wh battery capacity.

6) DJI drone: DJI MATRICE 600 Pro commercial drone is used for the experiments. A portable 5G testbed has been developed that can be easily carried by the drone, as Fig. 3 shows the assembled testbed. After, it is placed inside the

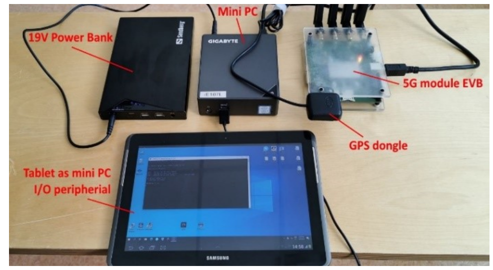

Fig. 3: Hardware used in the implemented testbed setup.

Fig. 4: DJI MATRICE 600 Pro drone with the attached testbed setup.

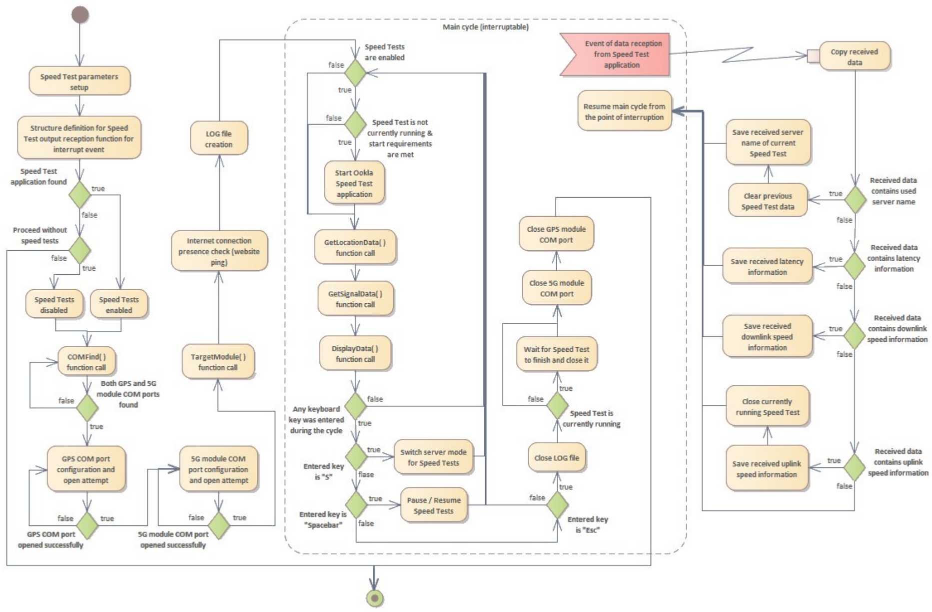

Fig. 5: Flowchart of the implemented software.

plastic box to install the testbed on the drone. , as shown in Fig. 4.

7) Processing unit: It runs the implemented programs and applications to evaluate the performance of the 5G testbed on the Windows 10 operating system. The main program is implemented in C programming language and .NET framework. Fig. 5 shows the flow diagram of the implemented testbed program.

The first part of the program is to check that the peripheral devices are found, and serial communications are established and validated. The next part is defining and detecting the Ookla Speedtest® CLI application, which performs the measurements continuously. It also defines the interruption sub-function which can immediately execute the Speedtest® application every time. Which works independently in parallel with the implemented program and sends measured throughput results with an interruption. The interruption sub-function is quite short and performs a line reading option from the buffer of received data from the active Ookla Speedtest® application. The received data includes the corresponding information about the used server and measured latency, downlink, and uplink speed results in a known order format. The obtained data is saved separately for further logging. More details can be found in [10].

B. Measurement campaign

For this work, the experimental campaign has been carried out to evaluate the performance of implemented testbed at Tallinn University of Technology. All the required permissions have been obtained to carry out measurements campaign.

Four signals have been used for coverage analysis of 5G network: i) synchronization signal-based reference signal received power (SS-RSRP), ii) SS-based reference signal received quality (SS-RSRQ),iii) SS-based signal to noise and interference ratio (SS-SINR) and iv) numerical quality of downlink channel (QoDC). These four parameters are measured based on channel state information (CSI) reference signal and they are a part of a 5G NR CSI information set. Measured reference signal values have been used for both to evaluate the performance of 5G connectivity and to estimate LOS/NLOSs tate of the available channel.

In addition, experiments have been carried out to measure the latency and uplink and downlink throughput of the 5G network deployed at Tallinn University of Technology. The developed testbed uses 5G module and the Ookla Speedtest CLI application for latency, and throughput measurements. Throughput tests have been performed in a static position. Five measurements have been carried out at each spot to increase the precision. The seven different spots have been considered for the throughput experiments. The same approach is followed for the throughput measurements at different altitudes (10, 20 and 30 meters above the ground level).

To evaluate a possible interference on the obtained measurement results due to drone, we have performed all the experiments with and without drone at an altitude of 1 m.

All the measurement points and the positions of 5G gNB antennas are shown in Fig. 6. The positions of all three 5G gNB antennas are marked with letters “A”, “B”, “C”.Key areas for measurements are highlighted with different colours such as green, yellow, red and orange. The green region shows an open piece of land that has no buildings or any other obstacles. The yellow region is a slightly less open area that has obstacles on just one side of receiver. The red region is a completely enclosed area that has many obstacles all around the measurement equipment. The orange region has slightly less obstacles compared to the red region. The exact locations for the experiments are marked with three different colours:

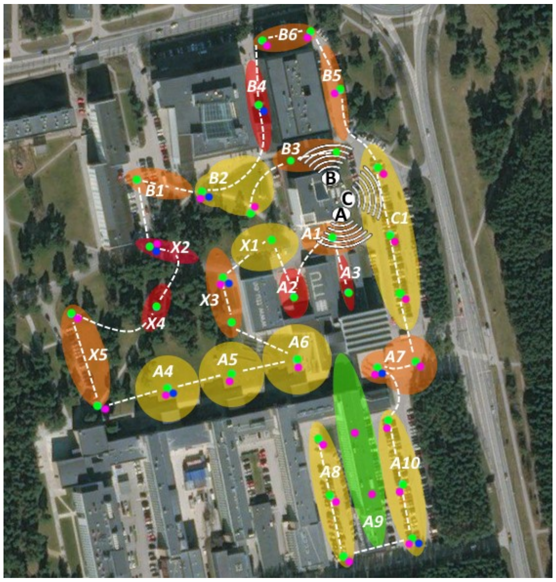

Fig. 6: Area of experimental measurement campaign to evaluate implemented 5G testbed.

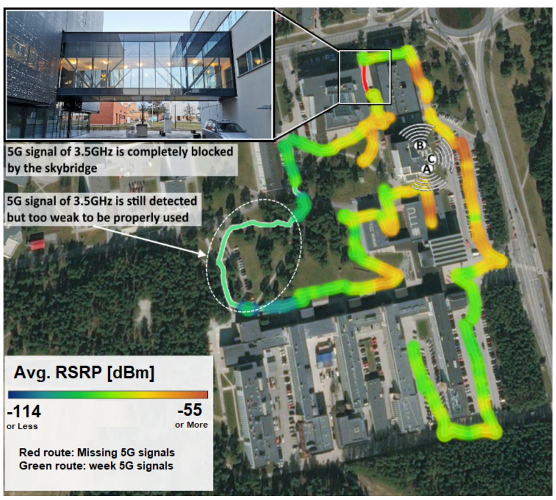

Fig. 7: 5G coverage heatmap based on the measured SS-RSRP signal.

green, blue, and purple. The green spots show the experiments for throughput tests at ground level. The blue spots show both signal quality and throughput measurements at different conditions. The purple spots show the measurements at different altitudes.

III. Empirical Measurement Results

A. 5G coverage without drone

To evaluate the coverage of the 5G network deployed at the university, the SS-RSRP, SS-RSRQ and SS-SINR signals are measured continuously after very one second at ground level while walking. Measured SS-RSRP results are used to create a heatmap of the overall coverage of the 5G network across the campus as shown in Fig. 7. The Burnt orange route

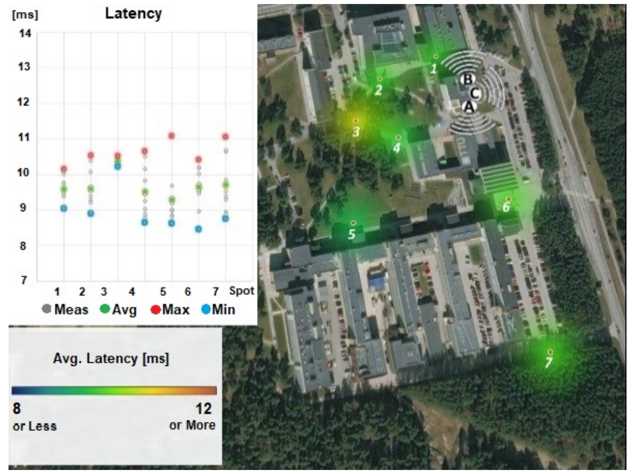

Fig. 8: Measured latency in campus area without drone.

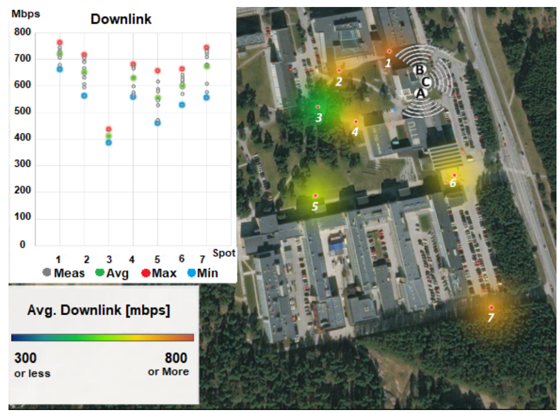

Fig. 9: Measured downlink speed without drone.

represents the excellent signal strength (more than -60 dBm). The light orange route represents a very good signal strength of SS-RSRP signals and reliable network connectivity. While blue colour shows a very poor signal strength (-114 dBm) and network connectivity. Whereas, the green colour shows a weak signal strength (-84 dBm). As it can be seen that the 5G band at 3.5 GHz is quite sensitive to various environmental obstacles and losing a significant amount of power near buildings and other structures. The red solid line shows a very interesting situation in Fig. 7. There is a glass corridor between two buildings, and it totally blocks all the 5G signals transmitted by a nearby gNB antenna. In this area, 5G signals are not able to reach but LTE signals are still present.

B. Latency and throughput measurements without drone

The Ookla application provides several measurement configurations regarding the server selection. For this work, we selected the server manually detected by the application. The highest downlink speed is observed with the "CompicOU" server, therefore for this work, we just present the results using the "CompicOU" server for all the measurements.

Fig. 8 shows the measured latency at different locations. The experiments are performed at seven different spots across

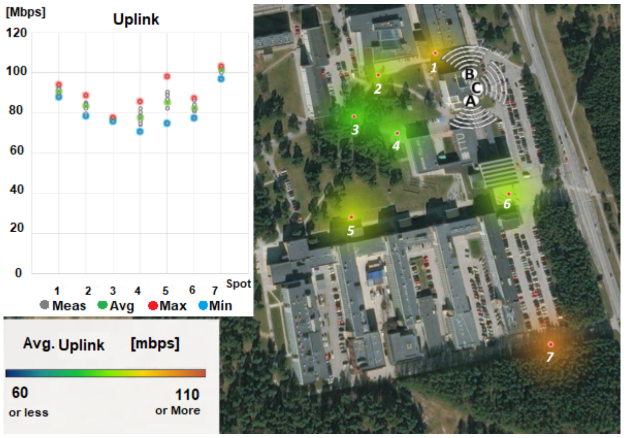

Fig. 10: Measured uplink speed without drone.

the campus. A total of 10 measurements are carried out at each position. Measurement spots are marked on the map with dots. All the measurements are plotted highlighting the lowest, highest and average values against each spot. The average latency values are considered for the heatmap. It can be seen that the average latency value is approximately 9.5 ms regardless of the UE position except at the third spot. The third sport is an enclosed area in woods. The testbed was not able to receive any signal using the 5G band and we used LTE band. Consequently, the LTE band leads to increase latency time. In addition, due to poor network connectivity, just three experiments have been performed successfully out of ten.

Fig. 9 shows the measured downlink results in a heatmap format with a corresponding scatter diagram of the measurements. It can be observed that downlink speed decreases with increasing the distance between the base station and UE for spots that are in non-line of sight (1-5). Whereas the spots numbers 6 and 7 are facing the antenna of a base station, therefore having higher downlink speed. Downlink speed at the 6th spot is smaller compared to 7th one. This is due to infrastructure conditions. Spot number six is just next to a building while spot number seven is in an open area near the trees. Whereas, the low data rate at the third spot is due to the LTE band. Likewise, the same behaviour can be observed in uplinks measurements as shown in Fig. 10.

C. 5G coverage and Throughput measurements at different altitudes using drones

To investigate the 5G connectivity at different heights, the measurements were also performed at different altitudes using a commercial drone DJI MATRICE 600 Pro carrying the implemented testbed. For the signal quality performance and both uplink and downlink throughput measurements, we have been considered three altitudes: 10, 20 and 30 meters above the ground level. The same measurements are performed at the ground level (1m). For all experiments, five measurements are performed. Both signal quality and throughput measurements are performed at the same time. Heatmaps are used to illustrate the experimental result.

Fig. 11: The 5G network coverage at different altitudes across the campus.

Fig. 11 shows the 5G network coverage measuring the SS-RSRP signals at different altitudes across the university campus. Measurement spots are marked with dots. The encircled dots show the spots which are out of coverage of the base station. It can be seen that the signal strength is excellent when a UE is in line of sight with the base station, while signal strength decreases in non-line of sight scenarios and with increasing distance between the base station and UE. It can also be observed that the overall signal strength across the campus improves with the increasing altitude of a drone. The quality of signal strength also depends on the movement of the UE. When a UE is in a static position (see Fig. 11), the overall signal strength is better if we compare it to the scenario when a UE is moving (see Fig. 7).

Fig. 12 shows a heatmap of downlink measurements carried out at different altitudes across the university campus. It can be seen that the environmental conditions and movement of the UE significantly impact the downlink speed. A very slow downlink speed is observed on spots, which are behind the buildings and in the woods. The downlink speed also drops with increasing the distance between the base station and a UE. The downlink speed is also affected by the altitude of a drone. The downlink speed is slow at high altitudes. While a high downlink speed is observed at ground level.

Similar behaviour can be noticed in uplink measurements as seen in downlink measurements. A higher uplink speed is observed on spots, which are near to base station. The uplink speed is fast at ground level compared to it at different altitudes. However, the uplink speed is slow at far away spots at ground level, as shown in Fig. 13.

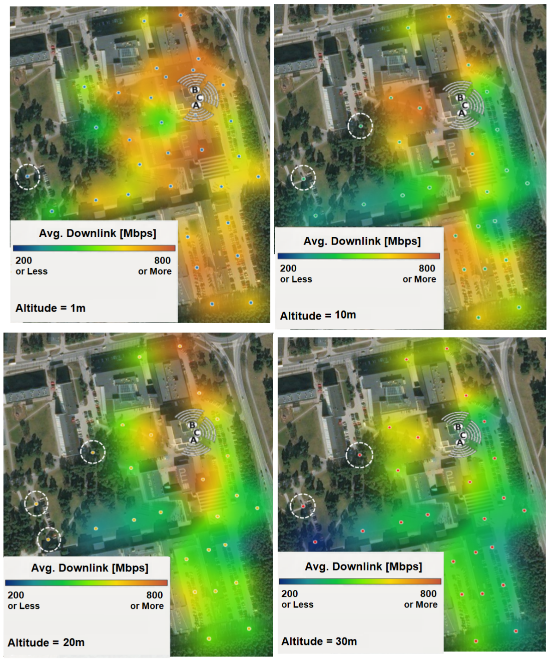

Fig. 12: Downlink speeds at different altitudes across the campus.

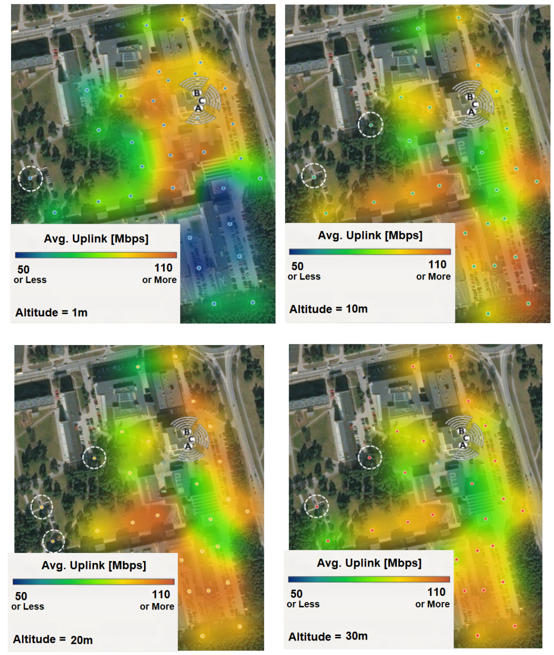

Fig. 13: Uplink speeds at different altitudes across the campus.

In order to investigate the influence of a drone on aerial measurements, some additional measurements have been carried out with and without using a drone. Measurements are carried out at the exact same position and height (at 1 m). Five experiments are performed for the signal quality performance and both uplink and downlink throughput measurements. As it can be seen that, the used drone has a barely noticeable influence on the performed experiments of RSRP, RSRQ, SINR and throughput values. The impact of a drone on latency is approximately 0.5ms. The downlink and uplink speed drop 0.5 Mbps and 1.5 Mbps respectively due to the usage of a drone. Thus, the influence on the performed aerial measurements is barely noticeable and can be neglected.

IV. Conclusion

This experimental study presents the empirical results of both ground and aerial measurements campaign using implemented portable 5G testbed operating at 3.5 GHz to analyse the performance of 5G network in heterogeneous environments. The measurement results are essential for planning the 5G deployment.

Acknowledgment

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References

[1] GSA, "LTE to 5G: June 2021 – Global Update, Global mobile Suppliers Association", 2016, [Online]. Available: https://gsacom.com/paper/lte-to-5g-june-2021-global-update/ , [Accessed 03-03-2022].

[2] Nokia, "5G deployment below 6 GHz. Ubiquitous coverage for critical communication and massive IoT", Espoo, [Online]. Available: https://www.rrt.lt/wp-content/uploads/2018/10/Nokia_5G_Deployment_below_6GHz_White_Paper_EN.pdf, [Accessed 03-03-2022].

[3] M. Dave, "Real-World Performance of 5G", Calgary, Alberta, Canada, 2019 [Online]. Available: https://www.nctatechnicalpapers.com/Paper/2019/2019-real-world-performance-of-5g, [Accessed 03-03-2022].

[4] B. Halvarsson, A. Simonsson, A. Elgcrona, R. Chana, P. Machado, and H. Asplund, "5G NR testbed 3.5 GHz coverage results," in *2018 IEEE 87th Vehicular Technology Conference (VTC Spring)*. IEEE, 2018, pp. 1–5.

[5] Innoenergy, "Hepta Drones and 5G will solve poor network connection during crowded events", 2020 [Online]. Available: https://www.innoenergy.com/news-events/hepta-drones-and-5g-will-solve-poor-network-connection-during-crowded-events/, [Accessed 03-03-2022].

[6] "5G!Drones", 2019 [Online]. Available: https://5gdrones.eu/consortium/, [Accessed 03-03-2022].

[7] Cambridge Consultants, "Cambridge Consultants building the world's largest commercial airborne antenna", 2020 [Online]. Available: https://5gdrones.eu/use-case-scenarios/, [Accessed 03-03-2022].

[8] A. Masood, M. M. Alam, Y. Le Moullec, L. Reggiani, D. Scazzoli, M. Magarini, and R. Ahmad, "Prose direct discovery: experimental characterization and context-aware heuristic approach to extend public safety networks lifetime," *IEEE Access*, vol. 9, pp. 130 055–130 071, 2021.

[9] A. Masood, M. M. Alam, and Y. Le Moullec, "Direct discovery-based cooperative device-to-device communication for emergency scenarios in 6g," *2022 European Conference on Networks and Communications (EuCNC) 6G Summit*, 2022.

[10] F. Alexei, "5G Testbed Implementation and Measurement Campaign for Ground and Aerial Coverage at 3.5 GHz Band", Tallinn University of Technology, Tallinn, 2021.