Agile 5G Network Measurements: Operator Benefits of Employing Aerial Mobility

Joonas Säe, Perttu Kurvi, Sergey Andreev, and Mikko Valkama

***Abstract*—This article discusses a flexible method of assessing 5G networks in connection to aerial mobility and for the benefits of mobile network operators. Two scenarios are considered where the first one features a commercial-grade 5G test network. Here, agile antenna pattern measurements are performed over known configurations with a smart phone attached to an unmanned aerial vehicle (UAV) having different flying speeds. The second scenario presents agile measurements for all mobile network operators in Finland to quickly estimate 5G network availability with respect to a particular area and altitude. The results collected in Scenario 1 indicate that aerial measurements are a prompt method to estimate 5G network antenna patterns, which is important for the operators to validate their new 5G antenna equipment. The results of Scenario 2 show how the existing operator-owned 5G networks perform, which is essential to evaluate the suitability of different services related to aerial mobility. Therefore, agile aerial network measurements are beneficial for the operators to assess the maintenance and optimization needs across their 5G deployments and thus complement traditional drive tests, and as the means to ensure that the deployments are UAV-ready.**

***Index Terms*—Agile measurements, 5G test network, UAV, drone, antenna pattern, mobile network**

I. INTRODUCTION

As 5G networks are becoming increasingly available worldwide, their commercial launches have already reached 200 5G deployments, which includes different mobile network operator (MNO) systems in 78 countries or territories [1]. Moreover, the global market has already announced over 1250 5G device types by the end of 2021 [1].

The commercialization of 5G networks, fueled by the availability of 5G networks and devices, underpinned industrial boost in utilizing 5G systems. Many industries demonstrate growing interest in leveraging these new mobile networks to enable a transition toward truly wireless operation. This has been driven by initial 5G visions with features like ultra-reliable low-latency communications (URLLC) for mission-critical use cases and enhanced mobile broadband (eMBB) for capacity-demanding scenarios, with an emphasis on improved uplink transfer for industry-driven applications.

One of the growing fields that employ 5G connectivity is unmanned aerial systems (UASs), where unmanned aerial vehicles (UAVs), or drones, are utilized. From the mobile network standardization perspective, a comprehensive study performed by the 3GPP is the technical report (TR) 36.777 titled Enhanced LTE Support for Aerial Vehicles [2]. Hence, enhancements to support UAVs over the 3GPP systems were included in the specifications for 3GPP Release-15. Continued in 3GPP Release-16, the focus was set on the identification of UAVs with the 3GPP technical specification (TS) 22.215 titled Unmanned Aerial System Support in 3GPP.

In the latest Release-17 version of TS 22.215 [3], further enhancements for facilitating specifically 5G communications aspects have been introduced. These are focused on the command and control (C2) requirements and their handling at the 5G network side. Additional motivation to consider aerial usage for mobile networks is to offer support for different UAV applications, including their use in, for example, search and delivery missions during disasters, forest fire fighting, agriculture, and logistics.

Improved aerial mobile network utilization may however be insufficient to adequately prepare 5G deployments for UAV communications. Dedicated efforts during network planning may thus be required. Today, radio network design is based on provisioning the system configuration to primarily serve ground-level user equipment (UE). However, drone utilization should be considered during network planning to take into account, for example, how mobility related aspects or interference in the aerial use cases are being handled. Moreover, aerial measurements are required to confirm that these networks are suitable for serving the UAVs.

Conventionally, coverage and capacity as well as interference measurements were performed by walking or driving to collect real-world deployment-specific data. The challenges with conventional drive tests are the limitations related to both area and time in difficult environments. Also, these may not be suitable for evaluating the antenna patterns to verify that the antennas operate as intended. Importantly, third parties may have no information about the actual configuration of the deployed setup as MNOs do not typically disclose this knowledge due to security risks.

Being advanced communications technology, modern cellular systems underpin a transition to setups where each antenna provides a dedicated cell over a particular geographical area. In 5G, this thinking shifts to a more user-centric approach with no-cell (cell-less) paradigm. It is implemented in practice with the aid of multiple beams produced by a 5G antenna instead of having a sole beam [4]. Hence, a UE may be connected to the strongest beam in the area where it uses network services. These so-called cell dominance areas for each beam are more fractured as compared to traditional one-beam antennas, especially in the air.

The goal of this article is to outline an agile UAV-aided

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method to promptly conduct 5G mobile network measurements. In what follows, this process is detailed to demonstrate how to perform such measurements in practice. Two scenarios are presented to offer dedicated examples of how the operators can benefit from such aerial measurements. Further, this article introduces the capabilities of our commercial-grade 5G test network to illustrate how different research angles pertaining to 5G systems can be addressed with a flexible, self-maintained deployment.

II. STATE-OF-THE-ART REVIEW

The authors in [5] assessed the readiness of 5G standardization for aerial usage. In addition to indicating that UAV support in cellular networks is a complicated matter, they noted powerful inbuilt mechanisms to enable drone applications. However, they concluded that a number of issues remain to be solved in utilizing 5G for aerial operations from the standardization perspective.

An extensive overview of drone-centric communications in 5G and beyond was presented by the authors in [6]. Emphasis was set on integrating UAVs with 5G cellular systems, and the main challenges were addressed. The most notable ones are the need for 3D cellular coverage for high-altitude UAVs, severe aerial–terrestrial interference with a high probability of line-of-sight links, as well as handover management and wireless backhaul for high 3D mobility UAVs.

Another crucial aspect of aerial services is their dissimilarity with ground usage in the network functions related to mobility. Mobility in cellular networks is supported via handover mechanisms. Conventionally, when UE moves over ground, it switches from cell to cell as the signal strength of the serving base station changes. Hence, handovers occur at the cell edges, which are typically well-defined for ground-level users. However, as the authors in [7] second, in dense 5G networks with advanced beamforming, the strategies to switch cells should be improved for better mobility handling.

Mobility management in the context of UAVs over cellular is a notable challenge. The authors in [8] illustrated with simulations how fragmented the dominating cell areas are in the air. Mobility-specific issues were also considered by the authors of [9]. They argued that mm-wave radios, massive numbers of devices, increased network diversity, and ultra-dense layouts pose further challenges for mobility related to connected drones. An essential aspect of aerial 5G utilization is the possibility of conducting 5G-centric studies in self-maintained networks. Commercial 5G systems are expected to accommodate various UAV applications and services.

Today's 5G technology can support the so-called private networks, which includes non-public LTE and 5G deployments for industrial utilization that commercial MNOs may offer. The challenge that the companies face with private networks is that these are typically more costly and require further adjustments to meet the desired industrial requirements. Here, a viable option is that the companies would operate their own 5G layouts, that is, deploy a local micro 5G network as studied by the authors in [10]. The questions in this case are the business model behind such an operation as well as the spectrum licensing regime to enable it.

An alternative to having a local private 5G network is to utilize test networks that are operated by, for example, universities. This approach may be preferred as the costs of employing such networks are much lower than those when the companies run their own private networks. Arguably, the test networks in question may not guarantee the same levels of quality of experience as the private networks do. However, the capability of having more experimental features and collaboration with university researchers offer the companies insights into the possibilities that new technologies can provide, especially for the latest features that are not available in the commercial networks. An example of this mode of cooperation is presented in [11], where different test-beds are utilized.

Aside from the standardization-related and other noted challenges, practical use cases and measurements are one of the ways to demonstrate how well 5G networks are suited for aerial UEs. The authors in [12] presented a practical coverage evaluation method for a 5G-related assessment with a drone. Their approach of utilizing a commercial UAV with additional sensors is more suitable for the drone measurements when repeatable experiments are required and the inbuilt functionalities of stock drones are insufficient. Moreover, the authors developed an automatic way-point creation script, such that the measurement drone is able to follow a preset route while only being given simple input on the desired measurement route properties.

The authors in [13] performed extensive 5G drone measurements. While not focusing on direct coverage assessment, interference analysis was conducted for capturing outdoor emissions from indoor private 5G deployments. The latter is increasingly important to capture as 5G markets envision denser deployments. Furthermore, with the emergence of private indoor networks, measures are needed to keep the interference levels within the regulatory limits.

A common aspect in the past drone-centric studies is that they were performed with relatively large drones that carry sufficiently heavy loads. Not only does this mean that they are relatively cumbersome to set up, but they also require careful design of the actual flight plans. Hence, these approaches may not be suitable for agile measurements to be performed spontaneously in the field. To offer a prompt method for conducting on-demand measurements that do not require complex preparations, we first present a means for achieving quick and easy validation of correctness for the deployed mobile network antennas via the measured radiation patterns.

III. COMMERCIAL-GRADE 5G TEST NETWORK AND UAV MEASUREMENT CAPABILITIES

Tampere University, Hervanta campus manages its own commercial-grade 5G test network operating at the frequency band n78 with a dedicated licence for testing, research, and teaching purposes. The system supports non-standalone (NSA) and standalone (SA) 5G connectivity, and the core network services are co-located. The vendor equipment utilized in our deployment is Nokia's evolved Node B (eNB) for LTE and next-generation Node B (gNB) for 5G NR with Nokia's digital automation cloud core network services.

In addition, this system utilizes radio access network (RAN) sharing with another core network called Cumucore, which enables the SA 5G core network functionalities. Moreover, Cumucore core network is connected to 5G Test Network Finland (5GTNF) innovation ecosystem. To orchestrate all of this, network slicing is utilized together with software-defined networking (SDN) to enable flexible utilization of virtualized resource distribution. Further, the test network is maintained up to date with the latest features coming from the vendor to enable timely testing of new capabilities that are implemented according to the latest 3GPP specifications.

Such deployments are preferred for research purposes as one then has full control over the test network licences to operate it. This results in a holistic understanding of the system operations. Furthermore, this permits the testing of functionalities that may remain unavailable in commercial systems. The latter is attractive for the third parties, for example, small and medium enterprises, which are willing to test their own products in a controlled environment. It also benefits the university in the form of research collaboration with companies.

As the focus of this article is to present a method for prompt 5G network measurements, we outline the capabilities of our drone-specific measurement equipment that can be utilized to assess 5G mobile systems. To enable fast UAV-based measurements, we employ a commercially available stock drone, Inspire 2 from DJI, with the weight of under 4 kg. Cellular network measurements further require a measurement device, which in our case is a lightweight smart phone with 5G connectivity capabilities. The latter is crucial to reduce the added payload weight of the drone. This device is attached to the bottom of the drone and is fixed to a single orientation.

All-inclusive smart phones with 5G-capable applications for detailed cellular network measurements still remain limited due to the early phases of 5G roll-outs, while professional tools are only available for selected chipsets. Hence, our measurements were performed with a smart phone having a MediaTek chipset and in collaboration with MediaTek to record the needed values of antenna pattern measurements for our Scenario 1, and OnePlus 8 5G smart phone with Rohde & Schwarz QualiPoc software for our Scenario 2. All the measurement data related to this article is made openly available in [14].

For the flight route design and automation, commercial software named Litchi was utilized. It enables the repeatability of our experiments since pre-planned flight routes can be readily provisioned as desired across the measurement location. The flights were configured such that the UAV altitude remained as close to the antenna height as possible and that a fixed distance from the antenna was used as a radius for the antenna pattern measurements in Scenario 1. The drone was also set to align at all times toward the antenna to keep the phone oriented as much as possible in the same manner throughout the measurement route. This is to minimize the errors originating from the antenna pattern differences of the measurement phone orientation.

TABLE I
HERVANTA CAMPUS COMMERCIAL-GRADE 5G NETWORK CONFIGURATION PARAMETERS.

Parameter	**Value**
Environment	Campus area
Network	5GTNF
Frequency band (4G anchor)	Band 1 (2.1 GHz)
Frequency band (5G)	Band n78 (3.5 GHz)
Drone flight speeds	4 km/h, 18 km/h, 30 km/h
Drone flight mode	Sweep (no stops)
Antenna height above ground (4G and 5G)	33 m
Measurement flight route radius	130 m
Measurement flight route length	195 m
Antenna model and gain (4G)	Kathrein 80010681, 16 dBi
Antenna model and gain (5G)	Nokia AEQA, 23 dBi
Antenna direction (4G and 5G)	East-northeast (60°)
Antenna mechanical tilt (4G and 5G)	-3° (below horizon)
Number of beams (5G)	6
Horizontal beamwidth (4G)	63°
Horizontal steering angle (5G)	90°
Horizontal beamwidth (5G)	15°

For Scenario 1, as the measured antennas reside in our own test network, their configuration was known. Both the 5G antenna and the supporting 4G antenna are co-located and point in the same direction. The essential information on the system configuration is presented in Table I. For Scenario 2, the exact configuration of the commercial network was not available entirely as operators do not share such information publicly.

IV. AERIAL TESTING: SUPPLEMENT TO DRIVE TESTING FOR MOBILE NETWORK OPERATORS

As the name implies, drive testing is typically performed on the ground with the aid of a car and a mobile network measurement device. This enables operators to assess larger areas relatively quickly. The downside is as follows: the regions that can be considered require roads. This is usually not an issue if the goal is to assess large enough areas to form an overall picture of the network performance. However, one of the major challenges with drive tests is that deeper analysis of individual network cells is somewhat limited due to having access solely to areas with roads.

Hence, to adequately address special cases, for example, problematic regions suffering from a drop in network performance, measurements are typically done by walking over that specific area. This is time-consuming and therefore expensive. Moreover, such measurements aim to study, for example, whether the deployed network provides the coverage that was expected. To verify this, accurate measurements are required. However, there may remain certain areas access whereto is limited or remains cumbersome with walking. A feasible alternative would be to measure different areas with the aid of a drone that is quick and easy to set up – to complement drive tests with aerial tests.

The considered method for assessing 5G networks is generally as follows:

1. Record the coordinates of the antenna to be measured and the expected antenna height (e.g., by flying a drone at a safe distance from it in case of unknown antenna configuration) and take note of possible restrictions regarding the flight routes.
2. Design the measurement route and implement it with suitable tools and software at the same height above ground as the antenna (with a fixed radius from the antenna location in case of the antenna pattern measurements).
3. Perform the measurements with a drone that has suitable equipment (e.g., smart phone attached to it) and record the data.
4. Analyze and visualize the measurement data.

Drone measurements are not limited to hard-to-reach places given that there is sufficient free space above ground in the intended area. Occasionally, even that may not be needed as an effective means to evaluate the individual cells is to assess the space next to the serving cell antenna. For example, if the radiation pattern of the antenna for a given frequency band and the desired cell is evaluated in close proximity to the antenna, correctness of antenna implementation can be verified. This, in turn, helps identify whether there might be hardware issues or implementation errors in the desired mobile network area configuration.

Typically, mobile network coverage and capacity assessment is conducted with measurements that target system performance with suitable key performance indicators (KPIs). Examples of these are basic radio access network parameters related to, for example, signal strength and quality. These are assessed with reference signal received power (RSRP) and reference signal received quality (RSRQ) in LTE and, correspondingly, synchronization signal RSRP (SS-RSRP) and synchronization signal RSRQ (SS-RSRQ) in 5G NR. The respective values are collected from the resource elements of the received signals that contain pilot signal information. These signals are transmitted at a fixed power.

A. Scenario 1: Antenna Radiation Patterns

We performed four different sets of 5G measurements with a drone in our commercial-grade 5G test network to offer a method for conducting agile antenna pattern studies. Figure 1 offers a 3D visualization of the area wherein the measurements were collected: one 2D case to demonstrate the antenna beam indexes for the 5G antenna having six beams in the measured sector and three 1D sweep cases under different flight speeds for the horizontal beam patterns (4 km/h, 18 km/h, and 30 km/h) at the flight height of 33 m (i.e., the same height as the antenna has) above the ground level.

The measured 5G NR beam indexes are shown in Fig. 2 for the entire measurement route seen in Fig. 1. It outlines the measurement sector with multiple heights starting from 50 m and down to 24 m above ground to remain over the buildings within the area. A beam index is displayed once every two seconds, as this offers a distinct overall picture of how the beams are distributed in the air across the measurement region. Certain dominance areas can be seen in Fig. 2, as well as the fragmentation of beams caused by the environment. This is essential information for the MNOs who observe the most suitable flight altitudes and possible trajectories for drone operations, for example, from the network mobility point of view.

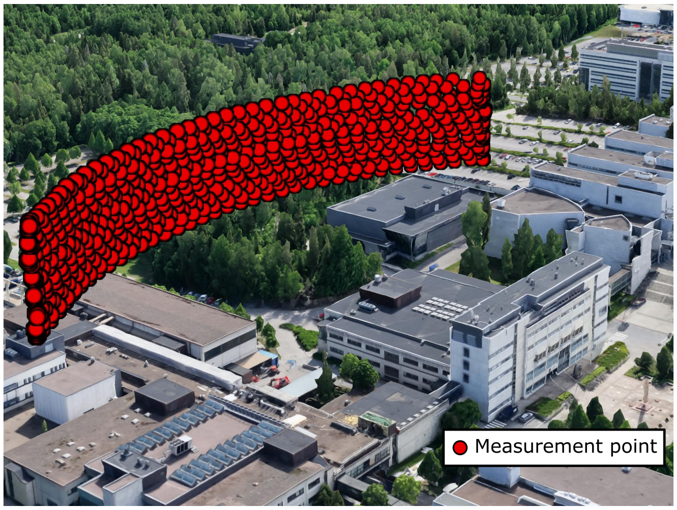

Fig. 1. Scenario 1: 3D visualization of actual measurement points in the air. Background map data: Google, Image Landsat / Copernicus ©2022.

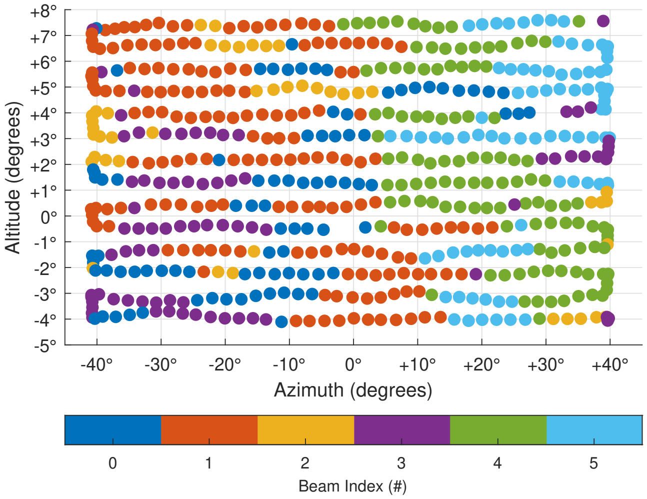

Fig. 2. Scenario 1: 2D representation of 5G NR beam indexes according to the measurement points shown in Fig. 1, with respect to the targeted antenna altitude and azimuth directions.

An example radiation pattern is visualized in Fig. 3 for our 1D results with the drone flight speed of 18 km/h. Antenna radiation patterns are conventionally represented as a function of gain/loss in a specific direction, such that the maximum gain

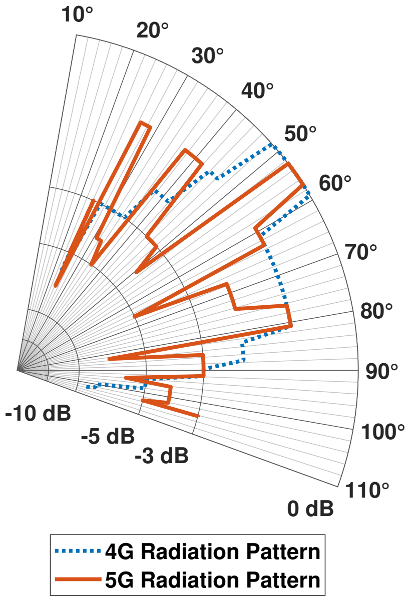

Fig. 3. Scenario 1: 4G and 5G horizontal radiation pattern examples from drone measurements at the height of 33 m above ground (i.e., the same height as the antenna). Maximum RSRP and SS-RSRP values are set as the reference (0 dB).

direction is normalized to 0 dB. Our setup operates actively throughout the measurement route by having the smart phone play a live video stream with a constant sampling rate of 10 samples per second.

Accordingly, the most accurate radiation pattern can be produced at the lowest flight speed of 4 km/h. However, to save the measurement time and drone batteries, the radiation patterns reported at higher drone speeds are also usable to provide distinct beams at the 5G side, as shown in Fig. 3. Furthermore, a clear presentation of the beams offers a reasonable indication of the directions with the highest antenna gains.

We also note the angular resolution [15] of these horizontal radiation pattern measurements. It is affected by the sampling rate of the measurement device, the speed of the drone, and the flight trajectory for an evenly sampled use case. Further, the measurement trajectory needs to follow a spherical path around the antenna for more accurate results. Indeed, if the radius around the measured antenna is not constant, the path loss difference between the base station antenna and the measuring UAV also varies. In the latter case, path loss changes have to be taken into account in the antenna radiation pattern measurements.

Here, the angular resolution is reduced from 20.4 samples per degree for the 4 km/h case down to 2.72 samples per degree for the 30 km/h case with the radius of 130 m from the antenna. Therefore, the radiation pattern accuracy due to the sampling rate and the UAV flight speed is 0.05 degrees for 4 km/h, 0.22 degrees for 18 km/h, and 0.37 degrees for 30 km/h flight speed at the 130 m radius from the measured antenna.

It should be emphasized that these results are based on utilizing the location data directly from the UAV. The latter is more accurate than the location data of the smart phone mainly because in addition to the global navigation satellite system (GNSS) positioning information, the drone adds input from other on-board sensors, such as its inertial measurement unit (IMU). The IMU combines, for example, acceleration values along different axes to improve the positioning accuracy, especially in the vertical direction.

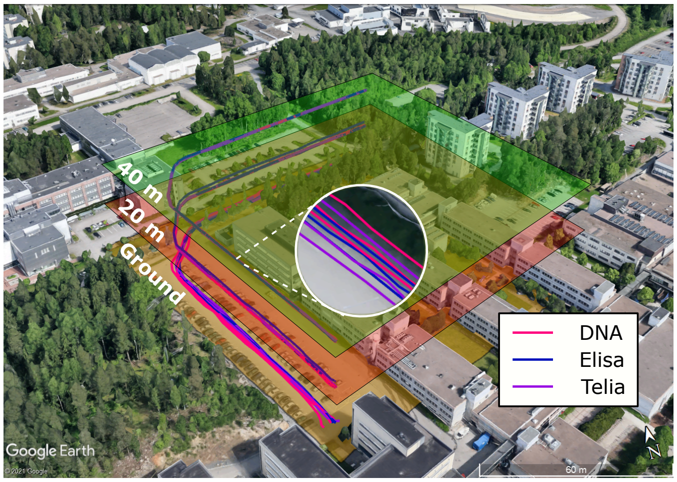

Fig. 4. Scenario 2: Commercial network measurement trajectories for layered 2D maps: ground level, 20 m, and 40 m at Tampere University premises. Background map data: Google, Image Landsat / Copernicus ©2022.

B. *Scenario 2: Commercial 5G Network Measurements*

For Scenario 2, three different routes were considered under the constant speed of 18 km/h to assess three commercial mobile networks in Finland: DNA, Elisa, and Telia. The selected routes were at the ground level (measured with a bicycle) as a reference case as well as at the heights of 20 m and 40 m above ground for the UAV routes, set according to the International Telecommunication Union (ITU) Radiocommunication Sector (ITU-R) M.2135-1 guidelines for evaluating radio interference technologies in different deployment scenarios. These routes can be observed in Fig. 4.

For each MNO deployment, three measurement sets per each route were performed, that is, a total of nine sets of measurements per an operator were conducted. The commercial MNO antenna height in Scenario 2 was estimated to be at 20 m (rooftop level) and the antennas were located approximately at the same position. Similar to Scenario 1, the smart phone was made to reside in its active mode, but these tests utilized parallel data transfers, both in uplink and in downlink, to a commercial speed test server throughout the route. This increased the sampling rate to the order of 30 samples per second. If the phone resided in idle mode, the samples were too scarce from the 5G network side due to advanced energy saving functions both in the mobile network and in the UE.

The results for different KPIs in these commercial 5G networks for all the operators are collected in Table II, which highlights the most notable percentiles, that is, 5th, 50th, and

TABLE II
SCENARIO 2 MEASUREMENT RESULTS.

		DNA			**Elisa**			**Telia**		
	Height above ground level	1 m	20 m	40 m	1 m	20 m	40 m	1 m	20 m	40 m
DL	5th percentile (Mbps)	24	143	168	197	105	66	1	44	61
	50th percentile (Mbps)	397	316	293	430	327	290	257	282	258
	95th percentile (Mbps)	445	383	352	466	388	357	284	354	361
	std. (Mbps)	141	72	64	85	90	89	94	93	83
UL	5th percentile (Mbps)	17	74	65	30	30	9	1	20	0
	50th percentile (Mbps)	96	105	100	92	61	68	78	57	71
	95th percentile (Mbps)	145	124	120	111	80	85	103	93	109
	std. (Mbps)	34	16	16	26	15	21	30	21	34
BLER	5th percentile (%)	1	7	7	3	8	7	0	4	3
	50th percentile (%)	8	10	11	7	11	13	6	8	8
	95th percentile (%)	13	16	15	10	23	18	12	30	16
	std. (%)	3	3	3	2	10	5	7	9	7
SS-RSRP	5th percentile (dBm)	-84	-85	-87	-84	-82	-81	-94	-87	-83
	50th percentile (dBm)	-73	-80	-83	-73	-74	-77	-84	-78	-74
	95th percentile (dBm)	-67	-73	-80	-63	-67	-74	-68	-69	-66
	std. (dB)	5	4	2	6	4	2	8	7	5
SS-RSRQ	5th percentile (dB)	-12	-14	-15	-14	-15	-15	-16	-18	-17
	50th percentile (dB)	-11	-12	-13	-12	-12	-13	-12	-13	-12
	95th percentile (dB)	-11	-11	-12	-11	-11	-12	-11	-11	-11
	std. (dB)	1	1	1	1	1	1	2	3	2
	5G beams utilized (pcs.)	5	9	4	5	10	6	10	9	11

95th percentiles of the measured values. The median values can be utilized to compare the various heights per MNO, while 5th and 95th percentiles offer insights into the worst/best values across the measurements. These are important for the MNOs since the top values (i.e., the 95th percentiles) characterize the best achievable performance. The bottom values (i.e., the 5th percentiles) are typically utilized to assess the network operation in cell-edge areas. It should also be noted that the 5th percentile values can be connected to performance degradation due to blockage or incoherent radio beam combining in 3D space.

Since there are technical differences between the commercial networks, the results in Table II are meant to be utilized only for evaluating the performance of each MNO individually. Further, Table II demonstrates how the network performance varies across altitudes to provide information for the MNOs on how well their networks can serve UAVs at those heights above the ground level and whether any challenges thereto remain. This may include such questions as (i) how error rates behave depending on height in a given environment and (ii) how many beams are utilized at a particular altitude.

Interestingly, the results suggest that while DNA and Elisa have higher signal power levels (SS-RSRP) at lower heights, Telia has stronger signal at higher altitudes. This is because DNA and Elisa have their 5G antennas closer to the measurement route, while Telia's antennas are located farther away from it. This is also confirmed by the downlink throughput, which displays the same effect as the signal strength across the MNOs. These results have a connection to the error rates: due to lower signal strength and higher SS-RSRQ values at higher altitudes, the error rates are also slightly higher. By contrast, the number of beams is the highest at the rooftop level (20 m) for DNA and Elisa, while Telia only has minor differences across heights.

Not limited to the above, MNOs may also be interested in building detailed radio maps to complement the summary of KPIs collected in Table II. These can be constructed based on the discussed aerial measurements by combining the UAV location information with the parameter of interest, such as SS-RSRP for the corresponding radio map. Moreover, when the aerial measurements are performed at different altitudes (as shown in Fig. 4), a 3D radio map can also be formed by combining several 2D radio maps together.

V. CONCLUSIONS AND FUTURE WORK

This article discussed an agile 5G network measurement method based on aerial testing. The considered approach of employing a drone and a smart phone offers an efficient means for the mobile operators to assess, for example, whether the 5G antennas deployed across their networks function as intended. Further, the information about the beam specific areas in the air helps understand how fragmented the network dominance areas are.

With the aid of aerial measurements, MNOs can readily assess the condition of their 5G deployments in the field to reveal problematic regions and/or identify those that might require optimization, especially where the conventional drive tests are not feasible. Aerial testing can also help verify the outcomes of the radio network planning process. Moreover, the possibility to supplement 2D drive tests with 3D aerial tests may improve the understanding of the expected network performance, for example, with the help of layered 2D radio maps at different altitudes.

A commercial-grade 5G test network was also presented in this article to conduct radiation pattern measurements in a system with known configuration. This enabled a more detailed assessment based on concrete examples, such as the evaluation of antenna patterns and the visualization of antenna beams. This may be particularly useful for industry as it enables agile and customized research and development setups.

As UAV-based services continue to proliferate and employ mobile networks for their specific needs, MNOs are increasingly focused on drone-friendly system design. This poses an important issue: radio networks have historically been designed for ground-level UEs and the key system parameters are also optimized for these. Furthermore, interference patterns across the deployment are assumed to originate from such ground-level UEs. As a result, the following key challenges still remain:

- How to design the radio networks such that aerial UEs are adequately taken into account?
- How to prepare and separate the mobility-specific network configurations to better differentiate between the UEs on the ground and in the air?
- How to evaluate and control the radio interference that emerges from the aerial UEs?

To answer these essential questions, further studies in the field are required. These can eventually enable enhanced mobile systems that are better capable of accommodating the various aerial use cases.

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