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Measurements of 5G Standalone Network

Zdenek VYLEZICH[1]*, Marketa VRSECKA[1], Antonin MAZALEK [1]

[1]Department of Communication Technology, Electronic Warfare and Radiolocation, Faculty of Military Technology, University of Defence, Kounicova 65, 662 10, Brno, Czech Republic

*Correspondence: *zdenek.vylezich@unob.cz*

Abstract

The paper focuses on testing a 5G stand-alone network for the operation of UGVs and UAVs with an emphasis on video transmission. Common key parameters indicators measurements mainly assess lower network layers and do not provide a sufficient insight into the behavior of real services, which are also influenced by higher layers. Therefore, the testing combined the *iperf* tool configured with parameters suitable for video streaming and a *ping* test to indicate congestion. The outdoor results showed that the standard uplink/downlink ratio of 20/80 is not suitable for this scenario. A comparison with indoor measurements using a 45/55 ratio confirmed significantly better performance. Based on the configuration changes, it was verified that the 5G stand-alone network is suitable for video transmission from mobile platforms and allows further expansion of testing.

KEY WORDS: *5G, Stand-alone, cellular networks, network testing*

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1. Introduction

The fifth generation of mobile networks (5G) represents a major step forward in wireless communications, thanks to a combination of high transmission speed, low latency, massive connectivity, high reliability and improved network security [1,2]. These features make 5G a key technology for current and future autonomous systems, including unmanned aerial vehicles (UAVs) [3] as well as unmanned ground vehicles (UGVs) [4]. 5G networks are designed to support three main usage scenarios: Enhanced Mobility Broadband eMBB, Ultra-Reliable Low-Latency Communication URLLC, and Massive Machine-Type Communication mMTC. Together, they cover a wide spectrum of requirements ranging from real-time video transmission to ultra-fast response times for autonomous control systems.

The demanding performance requirements placed on individual network components also translate into increased demands on antenna systems, which are continuously being improved. For example, antennas can be manufactured using 3D printing technologies [5] or integrated into building interiors without disturbing the architectural design [6]. The 5G network employs advanced transmission and access technologies,including Orthogonal Frequency Division Multiplexing (OFDM) and Filter Bank Multicarrier (FBMC) [7], while fiber-optic links are used in the backbone interconnecting network devices [8]. Due to its high reliability, 5G is considered suitable for critical infrastructure and for equipment used by fire and rescue services, and it can also be deployed at airports [9]. With the growing need for high-speed data transmission, it is increasingly used in military applications, particularly for controlling UAVs and UGVs. The technological challenges associated with deployments in land, maritime, and aerial operations are described in [10], while the advantages of the technology at the tactical level are discussed in [11,12].

Mobile networks undergo continuous testing and measurement, not only during their deployment but also throughout operation and during any subsequent technological upgrades. Typically, such measurements are performed as static point-based tests, as presented in [13], where the authors focused primarily on industrial environments and various application scenarios. Using AT commands, they were able to record key performance indicators (KPIs) such as Received Signal Strength Indicator (RSSI), Reference Signal Received Power (RSRP), and Reference Signal Received Quality (RSRQ). Mobile measurements are addressed in [14,15], where the authors collected data from a moving vehicle at various speeds and compared the performance of different mobile network operators. However, these tests were conducted on public

5G networks under full operational load. Another approach is vehicle-to-vehicle (V2V) communication, as described in [16]. The mentioned studies focus mainly on the physical layer of the network model. The combination of iperf and ping enables throughput and latency measurements at higher network layers and is commonly used in standalone (SA) 5G networks [17,18]. This article concentrates on higher-layer network measurements and throughput testing in the context of UGV utilization

2. Method of investigation

For experimental verification, the freely available measurement software iperf3_18_64 was selected and used in combination with a ping test. This methodology builds upon previously published studies that focused primarily on static measurements of mobile network throughput. The main advantage of iperf3 lies in its wide configurability, which enables detailed adjustment of transmission parameters. The ping utility serves as an additional diagnostic tool, as it allows continuous monitoring of the transport layer load through RTT analysis despite the very small packet size. The presented measurement extends previous experiments aimed at mobile network characterization using metrics such as SINR, RSRP, and other radio signal parameters obtained with an unmanned aerial vehicle at multiple altitude levels. The results of those experiments, including simulation models and detailed datasets, are published in [3].

The current experiment was conducted with a permanently running background stress test, whose parameters were fixed and emulated UGV operation—particularly video stream transmission with predefined traffic priority classes. Measurements were performed from a Zebra ET85 end device running Windows 11, placed inside a vehicle moving at speeds of up to 10 km/h. A known limitation of the ping method is the inherent unpredictability of response times, as they depend on the behaviour of the 5G network.

This issue was mitigated through sending ping every second and subsequent statistical post processing using the merge_asof function, which allowed compensation for response delays. Preliminary results confirm the suitability of this methodology for future Standalone (SA) 5G testing in the n78 band, even under conditions without Internet access and with connectivity limited solely to the 5G Core.

Furthermore, the possibility of combining two end devices in a client–server configuration provides sufficient conditions for evaluating traffic prioritization and overall transmission quality. During the experiment, no additional traffic was present on the tested network. The total measurement time was 15 minutes, and the configured uplink/downlink traffic ratio was 20/80 outdoor. Indoor measurements took place with the ratio of 45/55.

3. Investigation Results

For data streaming iperf test was set the parameter -b 50M, and -ToS 0x88 equals to streaming video. The measurement results from iperf and ping are summarized in Table 1:

Table 1.

Measurement results

Experiment	Throughput [Mbps]		Latency RTT [ms]	
	Max	Mean ± stdev	Max	Mean ± stdev
Downlink – TCP	492	49.99 ± 65.75	205	18.14 ± 14.10
Uplink – TCP	63.7	18.05 ± 18.09	823	137.68 ± 99.30
Downlink – UDP	73.1	46.41 ± 11.43	579	67 ± 125.67
Uplink – UDP	73.2	40.66 ± 8.92	492	183 ± 152.60

Subsequently, the measured data transfer is plotted in the time domain. Figure 1a illustrates the TCP downlink behaviour. TCP window scaling mechanisms influenced and compensated for periods of low signal strength. This effect is visible at the end of the measurement, when buffered data were transmitted across the network, exploiting the available bandwidth and resulting in a peak throughput of 492 Mb/s. After this peak, the throughput clearly stepped down to the configured bandwidth limit of 50 Mb/s. This behaviour led to a high value of standard deviation.

Figure 1b shows the TCP uplink performance. In contrast to Figure 1a, the uplink differs due to limited available bandwidth; therefore, no throughput peak was observed. The data transmission reached a maximum of 50 Mb/s, which can be considered the saturation limit under the given conditions. These results are also supported by latency measurements. At the beginning of the measurement, ping values of approximately 100 ms were recorded, indicating a congested network. Although window scaling mitigated the congestion and enabled data transmission, the resulting latency remained high and unacceptable for video streaming applications.

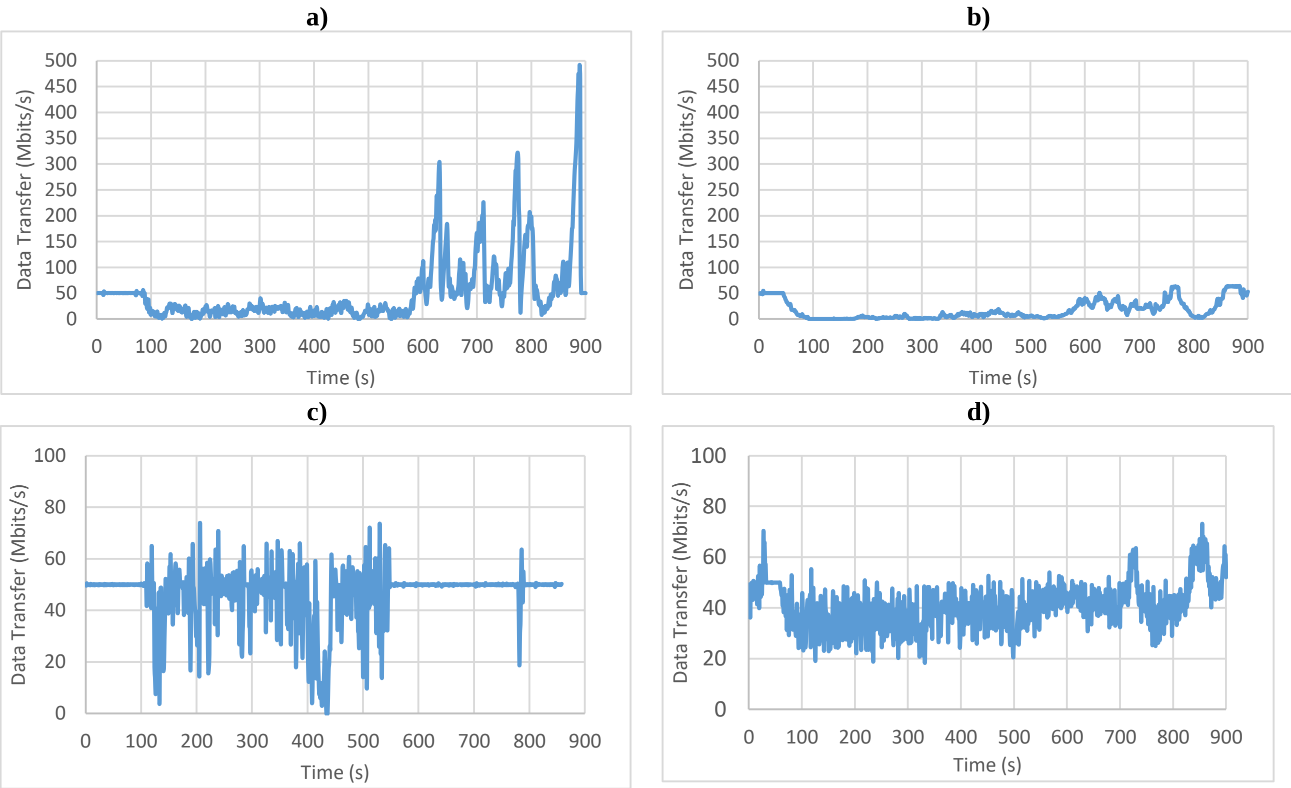

Fig. 1 a) Downlink TCP protocol b) Uplink TCP protocol c) Downlink UDP protocol d) Uplink UDP protocol

The results indicate that UDP performs better; however, these results are burdened by a high error rate, which did not play a significant role in the case of TCP. For Figure 1c, the average packet error rate reaches 6.5%, while the maximum observed value was as high as 81%. Figure 1c depicts UDP downlink transmission, which means that no window scaling or acknowledgment mechanisms are applied. From the network perspective, the configured bandwidth was sufficient; however, due to higher buffering demands, packet loss occurred. The packet error rate for UDP uplink, shown in Figure 1d, reached 57% at the receiver (server) side. Such error rates exceed typical video encoder tolerance and confirm the unsuitability of unprotected UDP streaming in the tested configuration.

Table 2.
Static Results in an Indoor Environment (UL/DL 45/55).

Experiment	Throughput [Mbps]	
	Max	Mean ± stdev
Downlink – TCP	50.5	49.99 ± 0.11
Uplink – TCP	50.6	49.99 ± 0.09
Downlink – UDP	50.6	49.99 ± 0.13
Uplink – UDP	50.3	49.99 ± 0.06

The results indicate that adjusting the UL/DL ratio yields performance suitable for autonomous vehicle applications. RTT values remained in the order of a few milliseconds throughout the measurement. The test was conducted under static indoor conditions. Subsequently the heatmap of latency is added from measurements 1a and 1c.

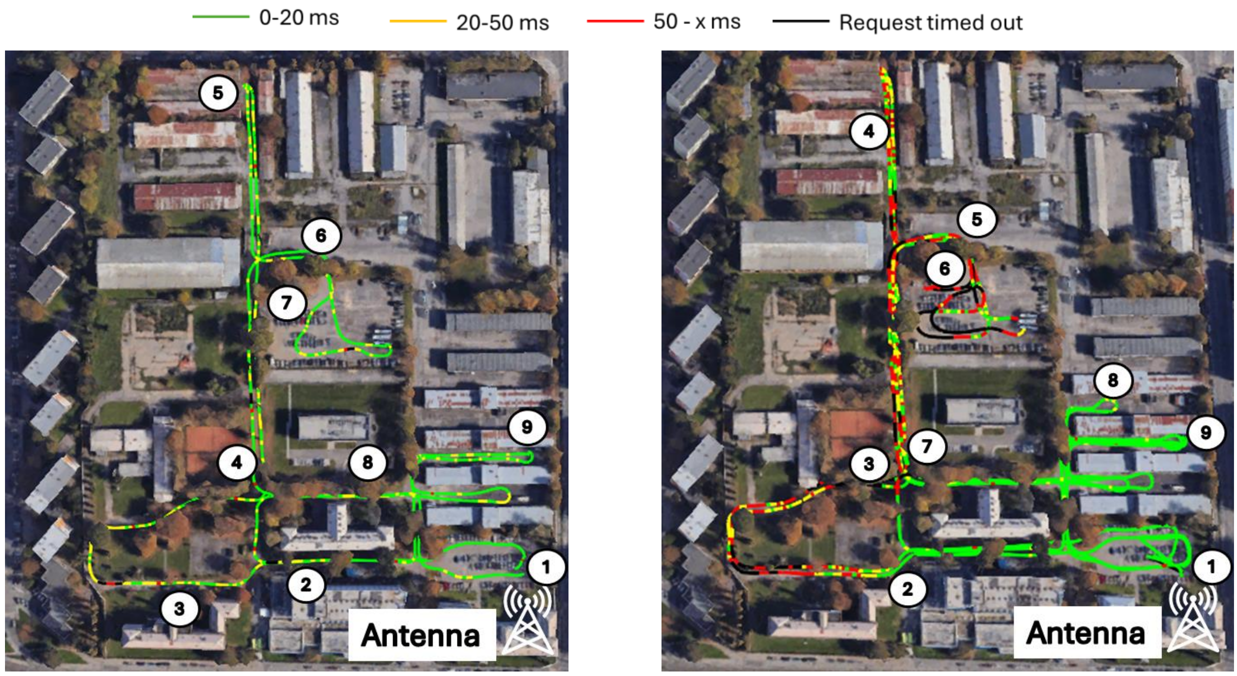

Fig**.** 2 Graphical display of latency using Google Earth a) Downlink TCP c) Downlink UDP

4. Discussion

During the measurement, some weaknesses of the iperf3_18_64 software became apparent again. During testing, a parameter was added for the service type corresponding to real-time video streaming, however, when checked with Wireshark software, it turned out that the service type was not included in the IP packet header. When you run iperf again, the field has already been filled in. This can be a significant limitation, especially when testing network loads. Another limitation is the synchronization of reading data from GPS as well as the random variability of ping responses, which can be problematic for measurements requiring higher device speeds. The results also highlight limitations of the measurement methodology, as standard deviation is not suitable for dynamic measurements with varying parameters. Additionally, TCP proved to be more network-friendly and is a suitable option for environments where streaming devices share network resources with other users.

5. Conclusion

The results demonstrate that under strong signal conditions, even with a slow-moving vehicle (approximately 10 km/h), the response times and error rates do not fully meet the requirements of autonomous systems, given the configured UL/DL ratio of 20/80. Issues in ping responses begin to appear when the RSRP decreases to approximately –90 dBm, at which point the connection was ultimately lost. Nevertheless, the 5G network was able to successfully transmit data with low ping values once the vehicle stopped and movement was reduced to a slow walking pace. Especially in the case of additional static/dynamic measurement in indoor conditions where is UL/DL configured to 45/55. A major advantage of the presented measurement method lies in the use of a connectivity testing script that eliminates the need for external servers by allowing direct access to the 5G Core network through the device's integrated modem. The primary outputs of the measurements can be visualized in Google Earth in the form of a 3D map, enabling a clear spatial definition of the safe and operational workspace for autonomous vehicles.

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References

1. **Mehic M., et al.** Quantum cryptography in 5G networks: A comprehensive overview. *IEEE Communications Surveys & Tutorials*, 2023, **26** (1), p. 302–346.
2. **NEDYALKOV, Ivan.** Methodology for Studying the Level of Network Security of an IP PBX Server. In: *Telecom*. MDPI, 2026. p. 22.
3. **Bajer J., et al.** Assessment of 5G Connectivity for UAV Operations in Urban Environments: An Analysis of Network Performance and UAV Communication Architecture. *IFAC-PapersOnLine*, 2024, **58** (9), p. 103–108.

4. **Kornacki, J., Wójcikowska, A., & Hoeft, M.** (2025). Meeting Industrial 5G Requirements for High Uplink Throughput and Low Control Latency in UGV Scenarios. *Applied Sciences*, *15*(12), 6427.
5. **Vršecká M., et al.** Printed Antenna with Dielectric Lens for 5G Applications. In: *2025 35th International Conference Radioelektronika (RADIOELEKTRONIKA)*. IEEE, 2025, p. 1–5.
6. **Vršecká M., Olivová J., Križan R., Vaněk S.** Glass 5G antenna for indoor coverage. In: *2025 Communication and Information Technologies (KIT)*. Liptovský Mikuláš, Slovakia: Institute of Electrical and Electronics Engineers Inc., 2025, p. 1–4. ISBN 979-8-3315-7339-3. DOI: 10.1109/KIT67756.2025.11205451.
7. **Ledaj R., Babjak M.** OFDM and FBMC Spectral Properties Comparison in Narrow-Band Channels. In: *2025 Communication and Information Technologies (KIT)*. IEEE, 2025, p. 1–6.
8. **Vylezich, Z., Kyselak, M., & Vavra, J.** (2022, July). Signal transmission of multichannel fiber-optic sensors in wavelength-division multiplexing technology. In *2022 International Congress on Advanced Materials Sciences and Engineering (AMSE)* (pp. 1-5). IEEE.
9. **Hoika T., et al.** The impact of the automatic terminal information service on airspace capacity and air traffic controller's workload. *Aviation*, 2025, **29** (4), p. 222–230.
10. **Bajracharya R., et al.** 5G and beyond private military communication: Trend, requirements, challenges and enablers. *IEEE Access*, 2023, **11**, p. 83996–84012.
11. **Vardoulias G., Bartsiokas I.A., Nikopoulos N., Karachalios G., Gardikis G., Alampasis N., Giannoulakis I., Kafetzakis E.** Linking independent 5G Bubbles using tactical IP radios: Part 1, laboratory deployment and testing. *IEEE Access*, 2025.
12. **Gašo Š., Babjak M.** Covert and Secure Military Communications in 5G Networks. In: *2025 Communication and Information Technologies (KIT)*. IEEE, 2025, p. 1–7.
13. **Polák L., et al.** Measurement and analysis of 4G/5G mobile signal coverage in a heavy industry environment. *Sensors*, 2024, **24** (8), Article 2538.
14. **El-Saleh A.A., et al.** Measurement analysis and performance evaluation of mobile broadband cellular networks in a populated city. *Alexandria Engineering Journal*, 2023, **66**, p. 927–946.
15. **Zmysłowski D., Kelner J.M.** Mobile Network Operators' Assessment Based on Drive-Test Campaign in Urban Area for iPerf Scenario. *Applied Sciences*, 2024, **14** (3), Article 1268.
16. **Tahir M.N., Katz M., Pottu A.** Vehicular Communications Testing in 5G Networks. In: *2024 IEEE Vehicular Networking Conference (VNC)*. IEEE, 2024, p. 257–258.
17. **Lackner T., et al.** Measurement and comparison of data rate and time delay of end-devices in licensed sub-6 GHz 5G standalone non-public networks. *Procedia CIRP*, 2022, **107**, p. 1132–1137.
18. **Vyležich Z., Vršecká M., Platenka V.** Extending the capabilities of private 5G networks for VoIP purposes. In: *2025 International Conference on Military Technologies (ICMT)*. IEEE, 2025, p. 1–6.