A field study of 5G speed in Sofia city

Iskren Varbanov
NRAIL, Institute of Robotics
Bulgarian Academy of Sciences
iskren@robotics.bg

The fifth generation (5G) of mobile communication networks represents a significant advancement in wireless technology, promising enhanced data throughput, ultra-low latency, and massive device connectivity. This study presents a performance analysis of 5G networks deployed in Sofia, Bulgaria, focusing on real-world measurements of key parameters, including download and upload speeds under TCP and UDP. Field tests were conducted across various urban environments, including residential, commercial, and high-traffic areas, to assess the network's reliability and consistency.

Results for TCP show average download speeds of 60-80 Mbps and average upload speeds of 40-60 Mbps. While results for UDP indicate that average download speeds in Sofia range from 300 to 500 Mbps, upload speeds typically range up to 100 Mbps, depending on the operator and test location. The analysis reveals strong coverage in densely populated districts, with noticeable performance drops in peripheral zones due to low base-station density.

The findings highlight Sofia's rapidly evolving 5G infrastructure and its readiness to support data-intensive applications, including intelligent mobility, telemedicine, and industrial automation. However, further optimization—particularly the transition to a standalone (SA) 5G architecture and the expansion of mid-band spectrum utilization—remains crucial to realizing the full potential of 5G technology in Bulgaria.

Keywords: mobile networks, 5G, TCP, UDP, link speed.

I. Introduction

With growing reliance on mobile communication technologies, assessing network performance has become crucial. Fifth-generation mobile networks (5G) promise high speeds, low latency, and greater reliability. This makes them suitable for applications that require stable transfer of large amounts of data, low latency, and predictable connection quality. In this context, accurate assessment of downlink and uplink speeds is essential for validating network parameters and determining realistic usage limits. According to the specification, the 5G speed requirements are Downlink: 20 Gbit/s, Uplink: 10 Gbit/s [1].

For the analysis, speed measurements were performed in a 5G mobile environment using iPerf3, a well-established tool for measuring throughput [2]. The measurements cover both TCP and UDP traffic. For TCP, the maximum achievable downlink and uplink speeds were recorded. These values provide an upper bound on throughput under conditions of reliable delivery and congestion control, which are characteristic of TCP.

UDP measurements serve a different purpose. They allow the network behavior to be assessed in the absence of retransmission and traffic control mechanisms. This makes UDP suitable for detecting the actual channel resilience under different loads. In the experiment, four different UDP downlink speeds were set: 1000 Mbit/s, 500 Mbit/s, 400 Mbit/s, and 300 Mbit/s. A 100 Mbit/s speed was used for the UDP uplink. For each test, the percentage of lost packets and other indicators were recorded, allowing an assessment of the extent to which the network can maintain stable transmission under the specific configuration.

Lost packets are a key parameter because they directly affect the connection's effective speed and quality. High speeds are of little practical value if losses are significant and cause service instability. Therefore, one of the main objectives of the study is to determine the optimal speed at which minimal losses and acceptable connection quality can be guaranteed. Comparing TCP and UDP results provides a comprehensive picture of the 5G network's ability to support different traffic types and varying load levels.

In the article, a method is described for measuring the connection speeds of 5G mobile networks across different mobile operators in Bulgaria, along with the tools used to implement it. The measurement results are analyzed, and comparative graphs and tables are created.

II. Method of measurement

- Experimental setup

The experimental setup for testing the achievable connection speed parameters across different mobile operators is shown in Fig. 1.

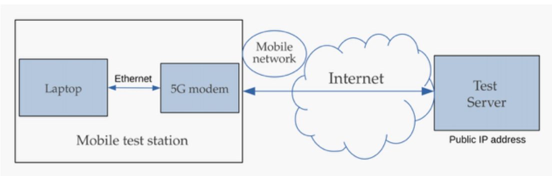

Fig. 1. Testing setup diagram

The experimental setup is designed to provide reliable, reproducible measurements of 5G mobile network throughput. The primary measurement module is a mobile test station that includes a 5G modem with an external antenna mounted on a vehicle and a mobile computer with specialized measurement software installed. This configuration provides direct access to the radio interface and enables real-time recording of parameters, including downlink and uplink speeds, latency, and packet loss percentage. Measurements are performed under real field conditions, without additional stationary infrastructure, which ensures an objective assessment of network performance.

The mobile test station connects to a remote measurement server located in a data center. The server is integrated into the leading national peering network, minimizing the number of intermediate routing nodes and reducing the impact of external network factors. This provides the closest possible connection point to mobile operators, reducing latency and packet loss. This allows for an accurate assessment of mobile network capacity.

The connection between the mobile test station and the test server is used to run iPerf3 tests, which generate TCP and UDP traffic with controlled parameters.

- Communication device

1. Teltonika RUT C50
- 5G Standards: 3GPP Release 15, 5G NR SA/NSA
- Supported frequency ranges (5G/4G): Sub-6 GHz, 617–6000 MHz
- Maximum speed 5G: Downlink 3.4 Gbps / Uplink 900 Mbps.
- Maximum speed 4G(LTE): 1.6 Gbps DL / 200 Mbps UL.
- Maximum speed 3G: 42 Mbps DL, 5.76 Mbps UL.
- SIM cards: 2 SIM cards + up to 7 eSIM.
- Modem: Qualcomm 5G industrial class.
- 3GPP Release: Release 16.
- Ethernet: 10/100/1000 Mbps.
- Wireless: 802.11b/g/n/ac/ax (Wi-Fi 6) / 2402Mbps on 5GHz.
- Antennas: 4 x SMA for Mobile, 3 x RP-SMA for Wi-Fi, 1 x SMA for GNSS.
- Power supply: 9–30 V DC [3].

2. Teltonika 5G COMBO MIMO MOBILE/GNSS/WI-FI ROOF SMA ANTENNA

5G MOBILE MIMO ANTENNA Specifications:
- Frequency range: 617 - 960 / 1710 - 2690 / 2900 - 4200 MHz
- Polarization: Linear.
- Gain: 4.0 dBi.
- V.S.W.R: ⩽3.0.
- Impedance: 50 Ω [4].

Using a router with an external antenna mounted on a vehicle provides more accurate, stable measurements in real-world conditions. The roof antenna has better coverage and is not affected by metal parts in the passenger compartment that would weaken the signal. This not only improves the mobility of the mobile station but also provides a better signal through the antenna at all measurement points. This makes the results more comparable and closer to the actual behavior of the 5G network.

- Software tool

To measure network connection throughput and quality in the experimental environment, the iPerf3 tool was used, one of the most widely used and reliable tools for testing network parameters. iPerf3 enables the generation and analysis of controllable network traffic, supporting both TCP and UDP. This makes it suitable for evaluating the maximum achievable speed and other aspects of network performance.

The tool provides measurements of key indicators, including throughput, packet loss, jitter, latency (for UDP), and actual throughput. iPerf3 allows you to set parameters such as channel width, packet size, number of parallel streams, and test duration. This enables controlled experiments and the evaluation of network behavior across different load levels.

For TCP tests, iPerf3 uses TCP-specific congestion control mechanisms, allowing the measurement of the maximum stable throughput with reliable delivery. UDP mode, on the other hand, allows accurate measurement of losses and delay variations, as no packet retransmissions are performed. This makes the tool particularly effective in determining the optimal speed that the network can sustainably maintain without significant losses.

An additional advantage of the iPerf3 network measurement tool is its platform independence, ease of configuration, and support for client-server architecture. Its widespread use in academic and industrial research makes it a reliable tool for objective and comparable assessment of network performance. [5].

- Method of testing

The measurement method has been developed to provide a reliable, reproducible, and comparable assessment of 5G mobile network throughput under various conditions in a real urban environment. For the study, the iPerf3 tool was used, which allows the generation of artificial network traffic and precise measurement of parameters related to connection performance. The tool operates in a client-server architecture, where the mobile test station acts as the client and the remote server in the data center receives or sends data depending on the scenario. This configuration minimizes the influence of local factors. It ensures consistent server power so that the results reflect the actual performance of the mobile network rather than the limitations of the endpoints.

The measurements were taken at various locations in Sofia, including residential areas and open spaces. This allows for an assessment of network performance under typical user conditions and provides a realistic picture of connection behavior. To ensure comparability across the three mobile operators, measurements were taken only at high signal levels, with RSRP ⩾ –80 dBm. This signal level is considered excellent and guarantees maximum data speeds [6]. Thus, the measured values primarily reflect the network's capacity, the behavior of the core, and the transport infrastructure.

The measurement locations are shown in Fig.2

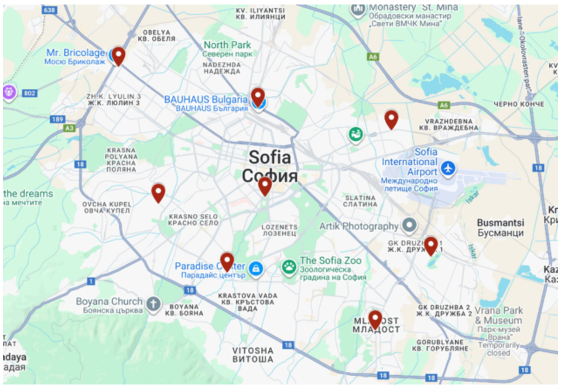

Fig. 2. The measurement locations.

Two types of traffic were used to evaluate network throughput: TCP and UDP, each of which examines a different aspect of the communication environment. TCP traffic provides information about the maximum stable speed achievable with reliable data delivery. Due to the congestion control mechanism and retransmission of lost packets, TCP measurements allow the upper limit of the actual throughput for downlink and uplink to be assessed. This is an important indicator for many applications where stability and transmission accuracy are critical.

UDP tests were conducted to assess channel stability at various preset channel widths (speeds). The channel widths used for UDP downlink were 1000 Mbit/s and 400 Mbit/s, and for UDP uplink, 100 Mbit/s. For each scenario, the tool records the percentage of lost packets and the actual throughput achieved. Loss analysis is fundamental because, in the absence of congestion control, UDP directly shows how well the network can maintain a stable flow at a given speed. This allows determining the optimal speed that can be considered sustainable. Sustainable means data transmission with packet loss below 2%, which is regarded as acceptable for most applications [7]. These channel widths were not chosen at random but rather determined through a series of tests to identify the upper limit of the UDP throughput that mobile operators' networks can support.

In all tests, the iPerf3 transmission duration, packet size, and operating mode are identical across all operators. This ensures statistical comparability of the results and allows direct comparison of the behavior of different networks under similar conditions. This method of field measurement ensures high validity of the results.

III. Results

The results obtained for average speed values, median, standard deviation, minimum, maximum values, and coefficient of variation for TCP Uplink, Downlink, and UDP at channel widths of 1000 Mbits/s and 400 Mbits/s, and percentage of lost datagrams are presented in Tables I, II, and III, respectively, for the three mobile operators.

Table 1. RESULTS FOR MOBILE OPERATOR1

	TCP		UDP Downlink bandwidth 1000Mbits/s		UDP Downlink bandwidth 400Mbits/s	
	Uplink [Mbits/s]	Downlink [Mbits/s]	[Mbits/s]	Lost Datagrams [%]	[Mbits/s]	Lost Datagrams [%]
AVERAGE	39,18	81,87	516,09	22,56%	387,29	2,27%
MEDIAN	36,75	82,35	532,00	23,00%	395,50	0,25%
STD	16,129	20,8682	81,526	13,18%	24,415	3,73%
MIN	10,50	39,90	280,00	0,00%	322,00	0,00%
MAX	86,60	160,00	641,00	57,00%	466,00	18,00%
CV	0,4117	0,2549	0,1579	0,5845	0,0630	1,6433

Table 2. RESULTS FOR MOBILE OPERATOR 2

	TCP		UDP Downlink bandwidth 1000Mbits/s		UDP Downlink bandwidth 400Mbits/s	
	Uplink [Mbits/s]	Downlink [Mbits/s]	[Mbits/s]	Lost Datagrams [%]	[Mbits/s]	Lost Datagrams [%]
AVERAGE	61,42	55,78	530,58	19,29%	395,18	0,98%
MEDIAN	56,05	60,70	541,00	21,00%	399,00	0,19%
STD	26,6215	26,359	96,7043	12,03%	25,4759	2,07%
MIN	16,80	13,60	235,00	0,07%	289,00	0,00%
MAX	155,00	108,00	707,00	57,00%	464,00	12,00%
CV	0,4334	0,4726	0,1823	0,6235	0,06445	2,1027

Table 3. RESULTS FOR MOBILE OPERATOR3

	TCP		UDP Downlink bandwidth 1000Mbits/s		UDP Downlink bandwidth 400Mbits/s	
	Uplink [Mbits/s]	Downlink [Mbits/s]	[Mbits/s]	Lost Datagrams [%]	[Mbits/s]	Lost Datagrams [%]
AVERAGE	43,45	63,52	474,24	25,18%	360,05	9,05%
MEDIAN	34,60	61,90	481,00	27,00%	378,50	3,55%
STD	28,8869	16,4956	101,4192	15,22%	58,1119	14,76%
MIN	0,00	14,60	214,00	0,00%	116,00	0,00%
MAX	141,00	107,00	679,00	64,00%	433,00	74,00%
CV	0,6649	0,2597	0,2139	0,6045	0,1614	1,6305

A graphical representation of the average results for the three mobile operators in TCP Uplink/Downlink is shown in Fig. 3.

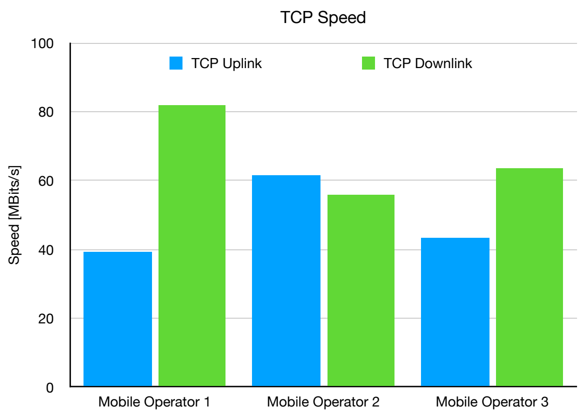

Fig. 3. Graphical representation of the results for TCP

A graphical representation of the average values obtained for the three mobile operators for UDP Downlink at the specified bandwidths of 1000 Mbits/s and 400 Mbits/s is shown in Fig. 4, while Fig. 5 shows the average percentage of lost datagrams.

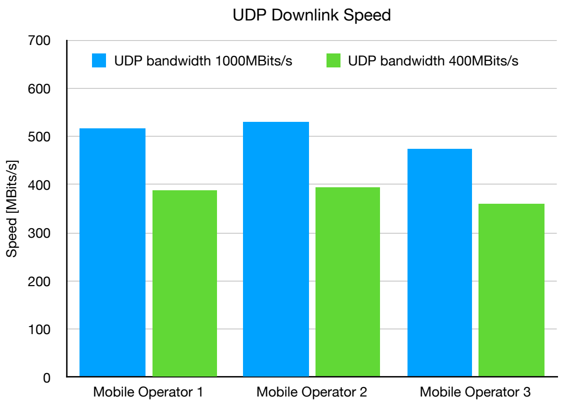

Fig. 4. Graphical representation of the results for UDP

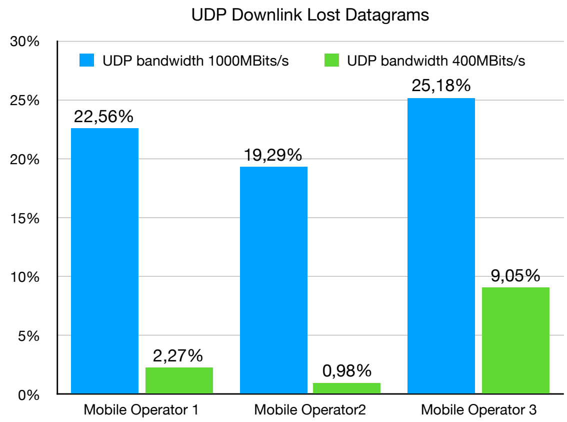

Fig. 5. Graphical representation of the results for UDP lost datagrams

The results of measuring TCP speed are 60-80Mbits/s for the Downlink and 35-40Mbits/s for the Uplink, which is a significant increase from previous studies[8].

The UDP results show that at a given channel width of 1000 Mbits/s, the measured speeds are around 500 Mbits/s, but at the expense of a high packet loss rate (20%–25%), far from the desired 2%. At a given channel width of 400 Mbits/s, the loss percentage decreases significantly, and for two mobile operators, this speed is acceptable for most applications in terms of loss levels.

The transition to 5G SA can deliver higher speeds than NSA because it uses an entirely new 5G core and does not depend on the 4G LTE core. With NSA, part of the management goes through LTE, which creates additional delays in traffic processing. With SA, signaling and data are processed faster, allowing for more efficient use of radio resources. This would help TCP maintain higher and more stable speeds. UDP also benefits from SA because the network can achieve higher throughput and lower packet loss. Thus, SA unlocks the full potential of 5G and enables significantly better performance for both protocols.

IV. Conclusion

As a result of the research process and the experimental measurements performed, several key conclusions were drawn:

- Compared to previous studies, the measured TCP speeds have increased by about 2.5 times.
- The actual achievable speed at UDP Downlink with 2% packet loss is 400Mbits/s, which is attainable by two of the mobile operators.
- All mobile operators passed the UDP Uplink test at 100Mbits/s.
- The experimental results obtained served as an excellent basis for assessing the development of mobile networks in Bulgaria.
- The measurement methodology developed in the course of the work can be used for new research in different coverage areas.

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