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RESEARCH ARTICLE

Real-Time Data Measurement Methodology to Evaluate the 5G Network Performance Indicators

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ABSTRACT The 5G technology offers a higher complexity than earlier generations, introducing a new type of network designed to connect virtually everyone and everything together, including vehicles, smart devices, and road infrastructure, while ensuring security, coverage, and increased performance. Therefore, following all these aspects introduced by 5G technology, different reliability assessments are necessary for optimal operation. This paper presents a practical method of real-time data measurement, which aims to obtain the necessary information to thoroughly evaluate the 5G network. The used hardware setup is based on the SIM8200EA-M2 platform for connecting to different mobile terminals. Moreover, different types of measurements are illustrated, as well as the validation of various 5G network parameters. To evaluate the 5G network performance, several performance indicators resulting from data measurement were analyzed, such as 5G network coverage, signal strength and quality, signal-to-noise ratio, throughput, communication channel quality, and transmission power. The obtained results deal with different aspects of cellular communication and can be used to analyze the 5G networks performance.

INDEX TERMS 5G technology, network performance indicators, real-time measurement, cellular communications, SIM8200EA-M2 platform.

I. INTRODUCTION

The wireless technology has evolved due to the large data consumption, extension of urban areas and, as well as a demand for real-time response capabilities. There are a number of benefits that the fifth-generation (5G) technology can bring over the previous generations, including increased spectral capacity, higher data rate, ultra-low latency, massive connectivity, availability, and robustness [1], [2].

A major milestone in the 3rd Generation Partnership Project (3GPP)'s development is the introduction of 5G technology with Release 14 [3], [4] in response to increasing demands in terms of smart devices usage and connected vehicles. The 5G New Radio (NR) standard continued to be developed for Release 15, which included the full version of the first stage of 5G standards. There are several features addressing enhanced Mobile Broadband (eMBB) requirements, related to a low latency, a higher data rate, and high mobility [5]. Next, Release 16 established a series of use-cases, key performance indicators (KPIs), and technologies specific to the 5G NR [6]. Release 17 reaches the stage 3 of the standard [7], extending capabilities for new 5G devices and applications further enhanced by massive MIMO, device power savings, spectrum expansion, coverage enhancement, sidelink expansion, slicing, and more [8], [9]. The 5G KPIs specified ultra-reliable low latency communications (uRLLC) requirements of no more than 0.001% of 20 bytes packets can fail to be delivered by 1 ms. This

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is a packet and latency service level commonly provided by telcos. This is about 99.999% reliability and 99.999% availability. The reliability performance indicator fails if too many packets are lost, too many arrive too late, or the packets have errors. Mission-critical services such as remote surgery, connected robotic factories, autonomous cars require permanent connectivity to the network. Any 5G network issue could be life threatening, thus the operators need to design the 5G architecture to be available with redundancy integrated into every component.

However, the 5G network is anticipated to cover 40% of the population and have 1.9 billion subscribers by 2024, which is equivalent to 20% of all mobile subscriptions [10]. One of the areas of activity of 5G technology with the strictest requirements in terms of KPIs are vehicular services, incorporated in Cellular Vehicle-to-Everything (C-V2X) communications, that refers to high-bandwidth, low latency, and highly reliable communication [11]. The 5G NR standard comes with some new use cases for C-V2X, such as: vehicle platooning, support for remote driving, and advanced driver assistance functionalities [12]. Therefore, in the implementation of these functionalities, certain network requirements must be satisfied, considering that it must ensure human safety. In order to confirm that the network can satisfy the necessary requirements, different real-time measurements must be carried out, with the aim of validating specific performance indicators. Thus, different methods of real-time measurements have been developed, which involve evaluating the 5G network performance.

The work from [13] presents the development of a flexible measurement test-bed to evaluate the private 5G campus network, from the point of view of data packets communication. In [14] an end-to-end (E2E) measurement study is described using three 5G phone models, focusing on network coverage, E2E throughput and delay, and energy consumption. A massive 5G measurement exposure in a town is presented in [15], in which different aspects of coverage are analyzed and specific quality of service (QoS) is evaluated.

This paper describes another practical method of acquiring data relevant to the 5G network. The method proposed in this paper consists in creating a hardware setup, based on the SIM8200EA-M2 module, and a software implementation for module control and various parameters measurement. Furthermore, some real-time measurements made in the city of Iasi, Romania, are illustrated. The tests were performed in motion, where the setup was installed in a car and a certain route was travelled, the result considering the verification of the 5G coverage, the connection with the base stations, but also the data collection for the related parameters of the 5G network in order to evaluate its performance. Another type of performed test, involved connecting to a single base station, the setup being fixed in the same position. For these static measurements, the cellular network provider, Orange Romania, also contributed, thus was possible to evaluate the performance of the proposed method by comparing the results obtained locally with the ones supplied by Orange.

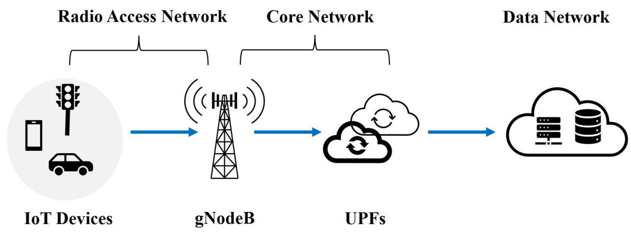

FIGURE 1. Cellular network architecture.

The rest of the paper is organized as follows. Section II deals with a general presentation of 5G technology, by describing the architectures, characteristics, and operating modes. The third section presents the data collection procedure, by exemplifying the hardware setup and the developed measurement script. In Section IV, real-time measurements are illustrated, by describing the proposed scenarios and analyzing the values of different performance indicators. Section V presents the conclusions and future research directions.

II. 5G NR TECHNOLOGY

The evolution of wireless technology is examined in this section, with an emphasis on the introduction of 5G networks. In addition, the use cases and the most important characteristics of 5G technology are presented. Along with these, the architecture of a cellular network is described as well as 5G standalone and non-standalone deployments. The last subsection presents the operating modes available for the transmission of information between the component elements of the 5G network.

A. 5G BASIC ARCHITECTURE

The evolution of cellular networks intended to improve the capabilities of the network in terms of flexibility and efficiency as the number of users had increased year by year. A general architecture of the 5G network is presented in Fig. 1 and is composed by 2 parts: a Radio Access Network (RAN) and a Core Network (CN) [16]. The RAN component makes the link between the user equipment (UE), illustrated as Internet-of-Things (IoT) devices in Fig. 1 and the base station, which in case of 5G network is called Next Generation Node Base (gNodeB or gNB). It is responsible of the radio resources management, mobility management, and control radio bearer of the network plane [17]. In consequence of the challenges that high mobility requires, in [18] are presented various RAN architectures toward 5G. Cloud-RAN, heterogeneous cloud-RAN, virtualized cloud-RAN, and fog-RAN are also discussed in [19]. Moreover, the scalability of the architecture for the NR is analyzed in [20].

The CN component is responsible of the interconnection of the RAN part with the Data Network (DN) and it is basically composed by one or more User Plane Functions (UPFs) [21], [22]. The CN has a protocol stack which includes three planes: the user plane, the control plane, and the management plane. The user plane protocol stack between the gNB and UE consists of the following sub-layers: Packet Data Convergence Protocol (PDCP), Radio Link Control (RLC), and Medium Access Control (MAC). The control plane includes the Radio Resource Control layer (RRC) which is responsible for configuring the lower layers [23]. The management plane of a networking device is the element within a system that configures, monitors, and provides management, monitoring and configuration services to all layers of the network stack and other parts of the system [24].

B. 5G USE CASES AND CHARACTERISTICS

As a result of the widespread use of wireless connections in many areas, the 3GPP classified a number of use cases in Release 16 [6]. There are a variety of industries and verticals with specific use cases that could benefit from ubiquitous 5G cellular connectivity:

Regulatory and Mission Critical:

- emergency call;
- first responder;
- alerting service of nearby emergency responders;
- emergency equipment outside hospitals;

Location-Based Services:

- bike sharing;
- augmented reality;
- wearable devices;
- advertisement push;
- flow management;

Industry and eHealth:

- persons and medical equipment in hospitals;
- patients outside hospitals;
- waste collection and management;

Transport (Road, Railway, Maritime, and Aerials):

- traffic monitoring, management, and control;
- road-user charging (RUC);
- asset and freights;
- unmanned aerial vehicle (UAV).

A large number of the above-presented applications require precise location determination and real-time responsiveness, which are particular characteristics of 5G networks. In Release 16, the KPIs for the applications based on the 5G are illustrated, mentioning the accuracy, timing, power consumption, security and privacy, reliability, and so on. Besides this, the requirements targeted for applications where the number of users is huge and the speed of the vehicles can be around 200 km/h supposes a horizontal positioning error $<= 50$ m, a vertical positioning error < 3 m, and an E2E latency < 1 ms. Thus, due to the ever-increasing demand for network capacity, more frequencies should become available, such as the millimeter wave band (30 to 300 GHz). For extended frequency range, 5G uses FR1 (4.1 GHz to 7.125 GHz) and FR2 (24.25 GHz to 52.6 GHz). SoftBox [25] and TurboEPC [26] are methods to reduce the latency based on the improvement of the Evolved Packet Core (EPC). The

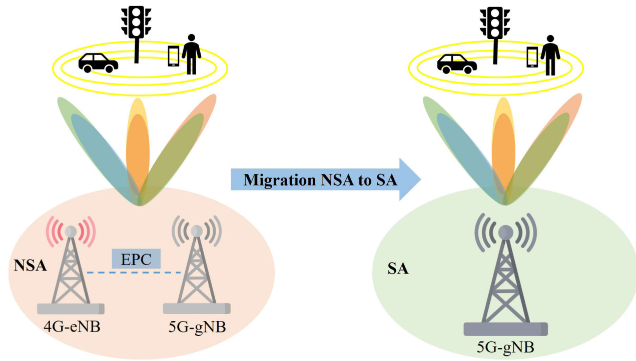

FIGURE 2. The SA and NSA architectures.

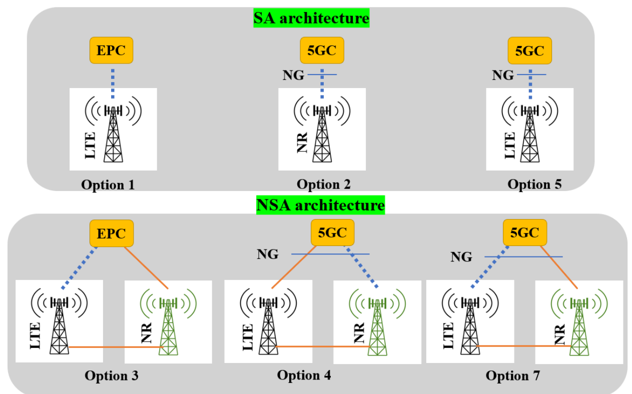

FIGURE 3. The SA and NSA architecture options.

power-saving feature is also an ubiquitous characteristic for the 5G already mentioned use cases and more others [27].

C. 5G ARCHITECTURE DEPLOYMENT OPTIONS

The evolution of the network has to satisfy the exigent requirements that 5G users encounter, but this process is a step-by-step one which involves upgrades to the new network, while still maintaining performances for 4G users. In consequence, 3GPP established two architecture deployments for the 5G network: Standalone (SA) and Non-Standalone (NSA), represented in Fig. 2. The SA option refers to a full enhancement 5G NR architecture running into a single Radio Access Technology (RAT). On the other hand, the NSA architecture is based on the existing LTE infrastructures deployment. In this case, the 4G base station (eNB) and the Evolved Packet Core (EPC) are reused in connection with the 5G network. Thus, the advantages of the LTE consisting in connection stability, availability on a higher area coverage, and robustness, are still available. These are combined with higher data transmission and ultra-low latency of the 5G NR [28]. The NSA option is a cost effective solution for any operator, but this architecture implementation is limited and cannot support all 5G NR features for example, network slicing, eMBB, massive Machine Type Communications (mMTC), and even does not reach the uRLLC. The

SA and NSA architectures include 7 options for the NR architecture based on 3GPP as represented in Fig. 3.

The SA is an independent 5G network which includes: a 5G NR and a 5G Core Network (5GC). For the SA, there are 4 options available:

- Option 1: it is a typical 4G LTE SA system where an E-UTRA NodeB (eNB) is connected to a EPC.
- Option 2: is a pure 5G architecture; the system contains a new 5G base station and a 5GC.
- Option 5: combines the 4G with 5G. The 4G base station (eNB) is upgraded to next generation gNodeB (gNB) to fit with the 5GC. This option allows the elimination of the EPC, but does not ensure proper results in terms of latency, peak rate, and capacity.
- Option 6: is not a standardized 3GPP option; moreover, it is unpractical because the EPC which is specific to LTE still remains the core, even with the full migration to 5G [29].

The most common used architecture nowadays is the NSA, as it can be implemented at a lower cost and provide dual-connectivity (DC), which brings a combined radio access connection to both 4G and 5G networks for the UE. In this manner, the control plane is connected to the CN that can be either the 5GC or the EPC [28]. A number of additional options are also defined, similar to the SA architecture:

- Option 3: is based on the 4G core (EPC) connected to the eNB, while the gNB is connected to the eNB through an Xn interface. The traffic data split to the UE is done directly at the level of eNB, or to the 5G network.
  - Option 3a: the traffic split is done as in the Option 3, but the user plane (data split) is distributed from EPC to the 4G and 5G network.
  - Option 3x: combines the 3 and 3a Options, meaning that the data split from the EPC can be transmitted to both networks. Further, the gNB can redirect the signal to the UE over the air interface, or it can be transmitted to the eNB via the Xn interface.
- Option 4: supposes the 5G to be the 5GC. Thus, the data traffic split is done on the gNB which is connected to the 5GC directly, and the connection between gNB and eNB goes through the Xn interface. The user plane can be transmitted directly to the UE or indirectly via the Xn interface through eNB.
  - Option 4a: the traffic split is at the level of 5GC which can transmit or reveice the traffic to the eNB and gNB.

  Option 7 is similar with Option 3, with the difference of an upgrade of the 4G core network in order to allow the connection with the 5GC.
- Option 7: is based on a direct connection between eNB and gNB, and also a connection of the eNB with the 5GC. The 4G network is responsible for anchoring the control plane [29], [30].

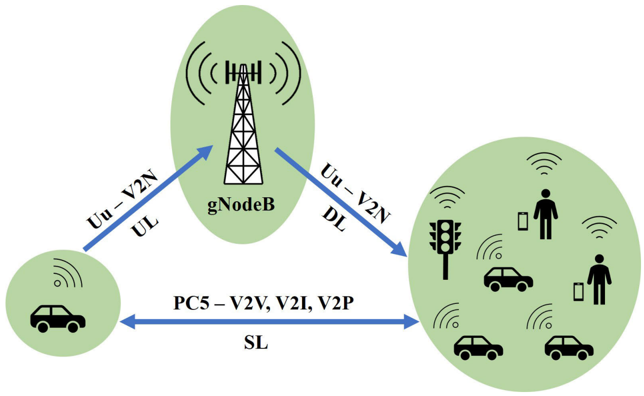

FIGURE 4. C-V2X radio access interfaces.

  - Option 7a: the data split is done on the 5G core network and the connection between gNB and 5GC is granted via the NG-u interface.
  - Option 7x: combines the characteristics of Option 7 with Option 7a, where both networks receive signal from 5GC, and after that is forwarded to the UE via the air interface. The UE receives the data from the 5GC directly from the gNB, or indirectly from the 5GC via Xn interface.

The 5G networks are gradually evolving from Option 1, which consists of a 4G typical architecture, to NSA, with options 3x, 7x, 4 and all the way to SA architecture, a pure 5G network. A 5G NR spectrum can have a value of up to 30 GHz, whereas a 4G spectrum can have a value of up to 6 GHz. According to [31], more tests performed to compare the performances of SA and NSA architecture proved the higher ranking of the pure 5G setup in terms of uplink (UL) and downlink (DL) data rates.

D. 5G OPERATING MODES

The new communication technology brings ubiquitous connectivity, guaranteed QoS through the Cooperative Intelligent Traffic System (C-ITS), where the C-V2X communication technology is a key element. The performance of the C-V2X is studied in [32] through the effects of shadowing on system performance, and the three different channel models. The authors of [33] present the modeling and analysis of success probability in multi-relay cooperative C-V2X networks.

In [34] are described the massive multiple-input multiple-output (MIMO) systems, small cells, millimeter-wave (mmWave), and cognitive radios, which will be used to considerably elevate capacity, resource, speed, and reliability constraints as key elements of the 5G technologies. Thus, having all these features available, the C-V2X allows an efficient communication between the end user and technology resources. Technology resources are brought closer to the user by multi-access edge computing (MEC). Rather than storing data in a distant data center, data is processed at the edge of a network, significantly reducing latency. As a real-time enterprise enabler, MEC offers both IT ser-

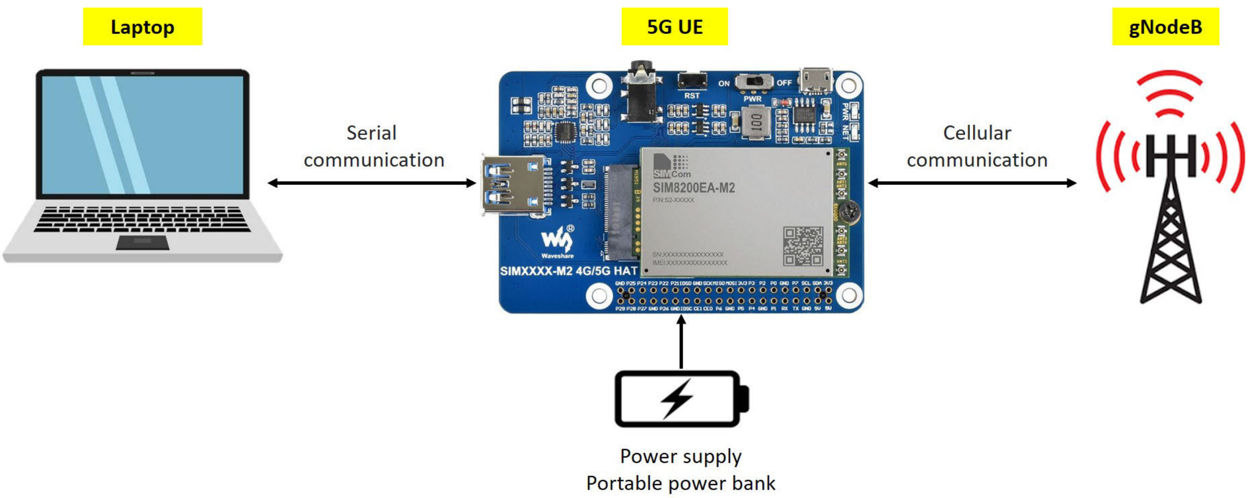

FIGURE 5. An overview of the measurement setup.

vice environments and cloud computing capabilities [35]. Moreover, C-V2X depends on two radio access air interfaces, Uu interface and PC5 interface, as can be observed in Fig. 4. While the Uu interface is the interface used for traditional UL and DL transmissions, the PC5 interface allows direct communications among V2X nodes using sidelink (SL) transmissions. Furthermore, the 5G Uu interface is used for interconnecting the end user with a cloud/edge server, specific to the Vehicle-to-Network (V2N) communication, while the 5G PC5 interface simplifies the cellular infrastructure along a direct communication among users in proximity [36], using Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), and Vehicle-to-Pedestrian (V2P) communication modes. Thus, the collaborative interaction between vehicles and network is possible via PC5 and Uu interfaces which grants the information (vehicle location, speed, etc.) transmission to the edge computing platform by Road-Side Unit (RSU) or gNB. Moreover, in paper [32] is described the SL connection over PC5 air interface which facilitates the SL communication.

Besides high rate connectivity, another key feature of the 5G network is the capacity to provide uRLLC. It is expected that a transmission of a 32 bytes packet will have a 99,999% reliability and a latency at most 1 ms [37]. As a way to reduce communication latency, the 5G defines a new radio interface with a new mechanism at the Physical (PHY) and Medium Access Control (MAC) layers. The PHY and MAC layers, together with RLC, are the lower layers which are responsible to support the high increasing data rate. The PHY layer facilitates transmission, security, authentication, and so on. The MAC layer allows access and resources to logical layers, prioritizes data, performs scheduling information reporting, error correction via hybrid ARQ retransmissions (HARQ), dynamic scheduling across UEs (DL only), and handling the priority between the UEs. In addition, the MAC layer provides a connection to the RLC layer through various logical channels (Broadcast Control Channel (BCCH), Common Control Channel (CCCH), Paging Control Channel (PCCH), Dedicated Control Channel (DCCH)) [37].

III. DATA COLLECTION METHODOLOGY

This section presents the data collection methodology. More precisely, the hardware setup based on the SIM8200EA-M2 device and the script developed for the communication between the device and the gNBs will be detailed.

A. HARDWARE SETUP

The data collection was performed using the hardware setup shown in Fig. 5. The SIMCom SIM8200-M2-EVB development board, based on the SIM8200EAM̂2 module, was used to connect to the 5G cellular network and to measure the various relevant parameters. The SIM8200EAM̂2 module is connected to a laptop for sending various commands, using the serial communication. Moreover, for mobility tests, the module is powered by an external battery, which manages to satisfy the requirements related to the voltage supply.

The SIM8200EA-M2 device is used as 5G UE in the described cellular architecture, and it is dedicated to applications that require high throughput data communications for a variety of radio propagation conditions. Therefore, it is designed for multiple bands in 5G NR, Frequency-Division Duplexing LTE (LTE-FDD), and Time-Division Duplexing LTE (LTE-TDD) technologies. At the same time, the SIM8200EA-M2 module supports NSA/SA implementations for 5G Release 15, as well as data transfer up to 4 Gbps for DL and 500 Mbps for UL. The module provides interfaces for six antennas, which are shown in Fig. 6. The description and frequency range for each antenna are illustrated in detail in Table 1. Antennas ANT0-ANT4 are used to transmit and receive signals, and ANT5 is used for GPS information [38].

Programming the SIM8200EA-M2 module is done by using a specific set of AT commands, these being a dedicated

FIGURE 6. SIM8200EA-M2 antenna interfaces.

TABLE 1. SIM8200EA-M2 antennas description.

Name	Frequency range	Description
ANT 0	617 MHz - 960 MHz 1710 MHz - 2690 MHz	3G/4G/5G signal transmission and reception
ANT 1	3300 MHz - 5000 MHz 2496 MHz - 2690 MHz	4G/5G signal transmission and reception
ANT 2	617 MHz - 960 MHz 1710 MHz - 2690 MHz	3G/4G/5G signal reception
ANT 3	1710 MHz - 2690 MHz 3300 MHz - 5000 MHz	3G/4G/5G signal reception
ANT 4	1710 MHz - 2690 MHz 3300 MHz - 5000 MHz	3G/4G/5G signal reception
ANT 5	3300 MHz - 5000 MHz 1166 MHz - 1610 MHz	4G/5G/GNSS signal reception

set of alphanumeric commands intended for controlling mobile terminals [38]. Besides that, in order to communicate with gNBs, the SIMCom SIM8200-M2-EVB development board must have a connected phone card with active 5G services.

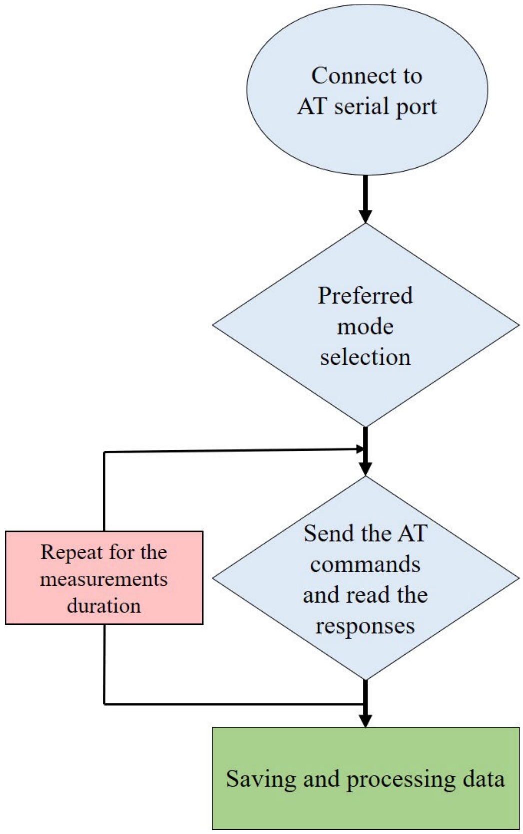

FIGURE 7. Main steps of the data collection script.

B. DATA COLLECTION SCRIPT

This section presents the developed script for data collection. It was made using the Python programming language, with the aim of making various measurements in an automatic manner. As can be seen in Fig. 5, the SIMCom SIM8200-M2-EVB development board is connected to a laptop using serial communication, to be able to program SIM8200EA-M2 module using AT commands. In order for the serial connection to be established and, at the same time, for sending the AT commands, it is necessary to install specific drivers for the module, which allow the use of the module's ports, more precisely the serial port intended for AT commands. Moreover, these drivers offer the possibility of using a specific network adapter to connect the laptop to the cellular network.

Considering the purpose of the work, a series of AT commands were chosen for the created script, all of which can be found in the AT command manual for the module. The AT commands used for data acquisition and the role of each of them are as follows:

1) **AT+CNMP** (Preferred mode selection) - this command is used to select or set the state of the mode preference (GSM, WCDMA, LTE, 5G NR, or combinations between them);
2) **AT+CSQ** (Query signal quality) - this command is used to return Received Signal Strength Indication (RSSI) and Channel Bit Error Rate (BER);
3) **AT+CPSI** - this command is used to return UE system information. Following the execution of the command, information is obtained related to UE operation mode, Mobile Country Code (MCC), Mobile Network Code (MNC), Location Area Code (LAC), Service-cell Identify (Cell ID), Frequency Band, Physical Cell ID (PCellID), Reference Signal Receive Power (RSRP), Reference Signal Receive Quality (RSRQ), and Signal-Noise Ratio (SNR);
4) **AT+CGPSINFO** - this command is used to obtain GPS position information, such as latitude, longitude, N/S indicator, E/S indicator, altitude, speed over ground, date, and time;
5) **AT+CNWINFO** - this command is used to return extra network information, which refers to System mode, eNodeB ID (eNBID), Modulation and Coding Scheme (MCS), UL/DL Modulation Type, Channel Quality Indication (CQI), and UE TX Power.

The steps of the developed script are illustrated in Fig. 7. In the following, each of these steps will be detailed by exemplifying the actions carried out:

1) **Connect to AT serial port** - configure the AT serial port (port name, baudrate, and timeout) and open the AT serial port;
2) **Preferred mode selection** - set the AT+CNMP command with value 109 (LTE + 5G NR), this value is

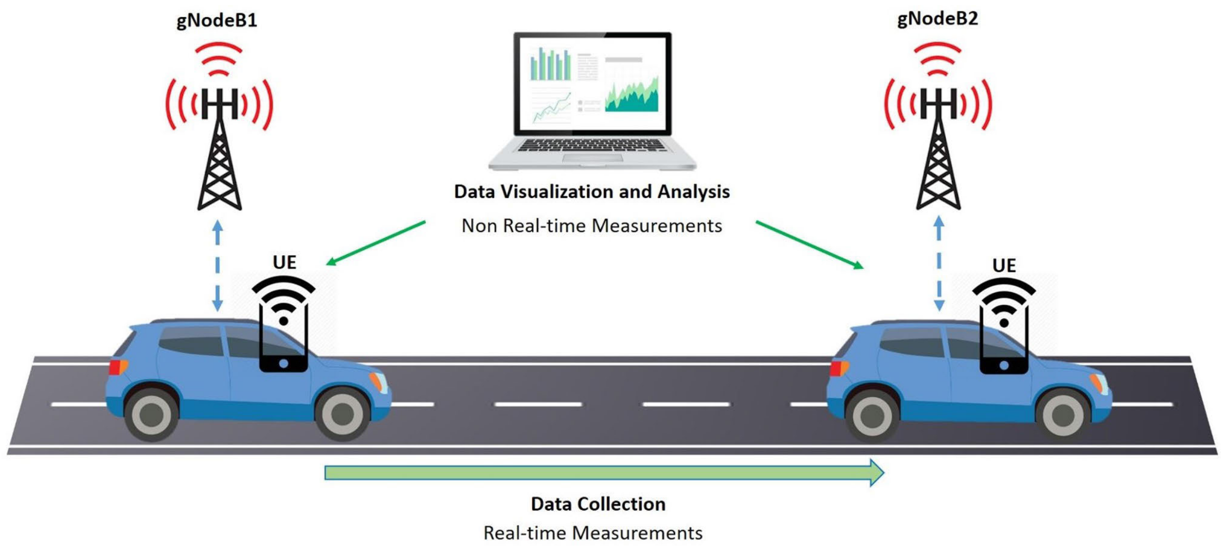

FIGURE 8. Real-time measurement scenario.

used for 5G NSA architecture, which is available in the location where the measurements were performed, i.e., Iasi, Romania.

3) **Send the AT commands and read the responses** - write the AT command and read the response on the AT serial port. This is valid for each command (AT+CSQ, AT+CPSI, AT+CGPSINFO, and AT+CNWINFO). After sending the AT command, read the response from the module on the serial port, then move on to the next command until all four are executed. All four commands are executed at a period of one second, considering that this is the minimum time for obtaining data from the GPS. Moreover, these steps are included in a while loop, which is executed every second as long as it takes to complete the measurements;
4) **Saving and processing data** - the responses following the execution of the AT commands are saved in an Excel format, the data from the GPS and the parameters of the cellular network being saved. After that, the Excel files are used in data processing and visualization.

These steps are performed after the module is connected to a gNB, hence in the first phase there must be a cellular connection between the SIM8200EA-M2 and the gNB before running the script.

Remark 1: The main contributions for the data collection methodology are the following: *i)* development of an algorithm for the real-time acquisition methodology, it was made using the Python environment, and is addressed to the SIM8200EA-M2 commercial module; *ii)* configuration of the module for the various tests; *iii)* processing and evaluating the measured data and data visualization using Leaflet.

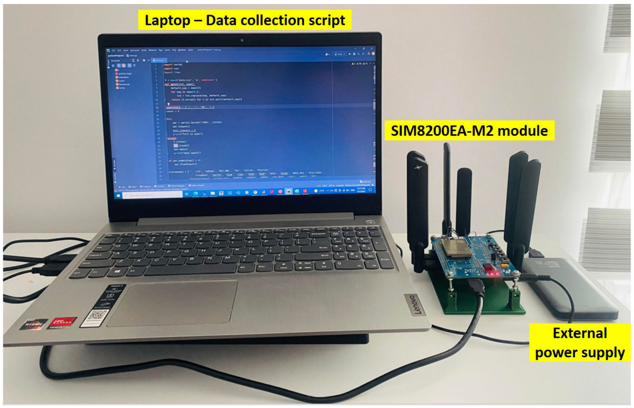

FIGURE 9. Real-time measurement setup.

IV. REAL-TIME MEASUREMENTS

This section refers to the real-time measurements, which aim to validate the previously presented collection method and evaluate the various parameters of the 5G network. Furthermore, in order to better exemplify the data measurement process and their analysis, the following types of measurements were chosen: *i)* performing measurements in mobility conditions, by traveling a route by car and connecting to the various base stations along this route; *ii)* the execution of static measurements, the setup being fixed in the same position, with the connection only to one base station.

A. DYNAMIC MEASUREMENTS

The measurements made in mobility conditions will be presented in this subsection. Fig. 8 shows the way of performing the measurements for this case. More exactly, the SIM8200EA-M2 module (5G UE) is connecting to different gNBs along the route, using the 5G cellular technology

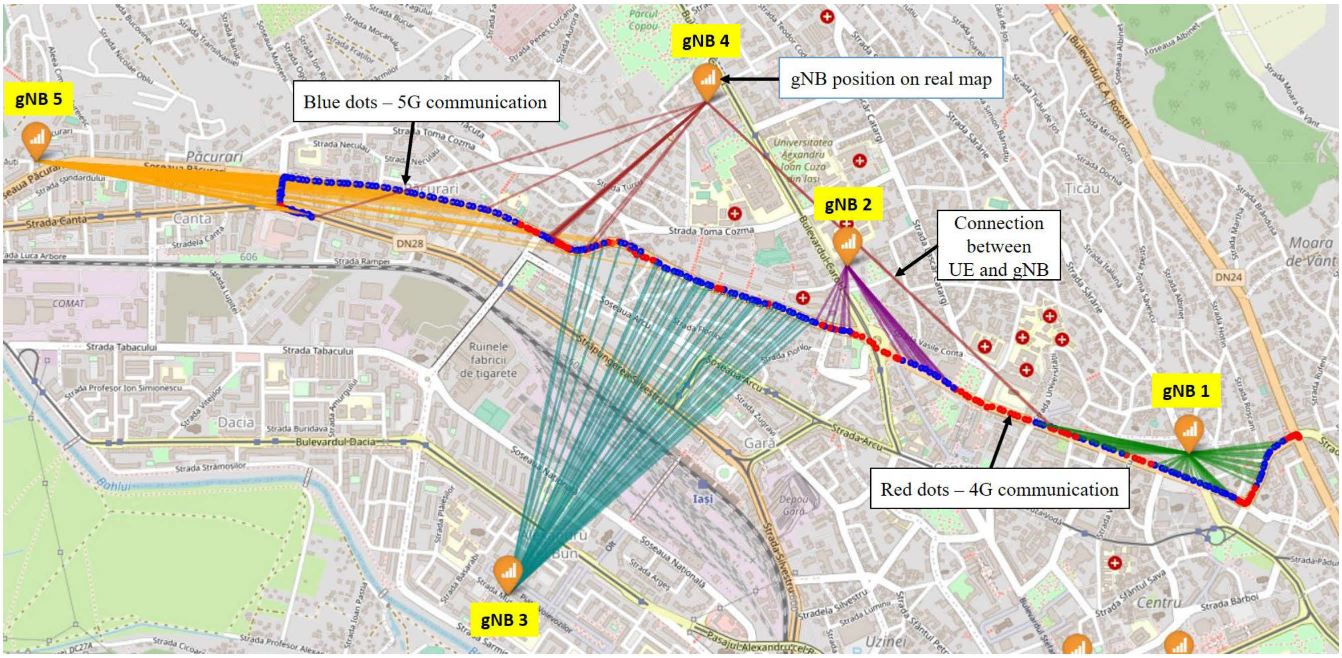

FIGURE 10. Dynamic measurements - cellular communication coverage.

offered by the Orange Romania provider. Therefore, the setup presented in Fig. 9 was mounted in a car and a route was traveled. The exchange of information between the UE and gNBs is monitored, collecting various relevant data for 5G communication between them. The collection of this data helps to draw some conclusions regarding 5G communication, by highlighting some relevant performance indicators for different crossed areas, outlined through GPS information. This type of measurement aims to highlight the coverage of 5G technology, the way to connect to gNBs depending on the GPS position, and to illustrate the values for relevant parameters of the 5G network.

The route chosen for this type of measurements was a main boulevard in the city of Iasi, Romania, this area being a congested area with a high density of gNBs, with different building heights. Regarding to the approach presented in the previous section, the setup from Fig. 9 was installed in a car, following the crossing of the previously mentioned route. The measurements were performed under the 5G NSA architecture, where 5G NR is anchored in the 4G CN, some indicators of 4G network also being evaluated. At the moment, in the city of Iasi, only the 5G NSA architecture is available, based on 3GPP Release 15. Moreover, only the eMBB use case is available for the commercial network, which supports services with high data rates, high mobility radio access, complemented by moderate latency improvements for both 5G NR and 4G LTE. Throughout the measurements, the SIM8200EA-M2 module operated in frequency band n78 for 5G communication, this being part of Frequency range 1 for 5G NR band. Using TDD, the 5G NR band n78 has a frequency range from 3300 - 3800 MHz, with a bandwidth of 500 MHz for both UL and DL. Regarding 4G communication bands, it operated in the 4G E-UTRAN 3 (1710 - 1780 MHz for UL and 1805 - 1880 MHz for DL) and 4G E-UTRAN 7 (2500 - 2570 MHz for UL and 2620 - 2690 MHz for DL), both of which are of the FDD type.

The results obtained in the presented measurement setup are illustrated in Fig. 10, from the point of view of highlighting the route taken, the type of cellular communication, and the connections with gNBs. The measurements were made for 600 seconds, the related AT commands being sent every second, as presented in the previous section. The method of data plotting shown in Fig. 10 was made using Leaflet [39], which is an open-source JavaScript library for mobile-friendly interactive maps. Therefore, the following steps were used to obtain this representation on a real map: *i)* the representation on the map of gNBs, using the orange signal icons, with the help of the received information from the Orange Romania provider about gNBs (latitude, longitude, and the physical identifier of each cell); *ii)* placing the points according to the GPS information (latitude and longitude), illustrating the type of communication, the 4G communication is marked with red dots and 5G communication with blue dots; *iii)* making for 5G communication the connections between the gNBs and the points where the measurements were made, this being achieved by associating the physical identifier of the cell to which the module was connected with that of the gNBs. Therefore, Fig. 10 illustrates the coverage of the cellular network for the chosen test route. Depending on the GPS information, the areas with 4G and 5G coverage were represented. Furthermore, for each measurement it is possible to see to which gNB the SIM8200EA-M2 module was connected. For

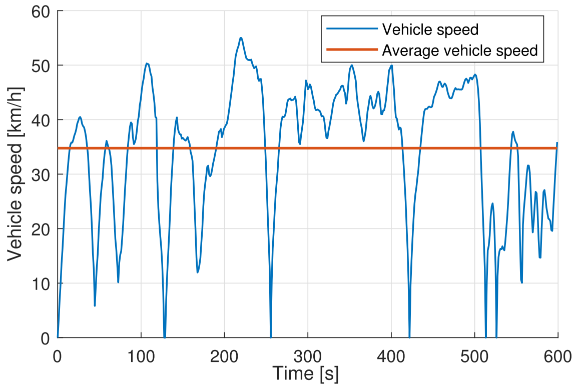

FIGURE 11. **Dynamic measurements - vehicle speed.**

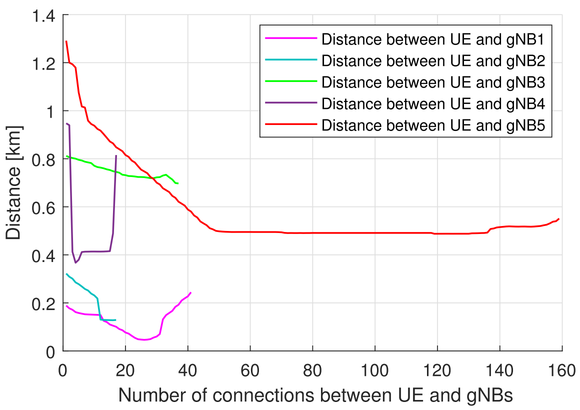

FIGURE 12. **Dynamic measurements - distances between UE and gNBs.**

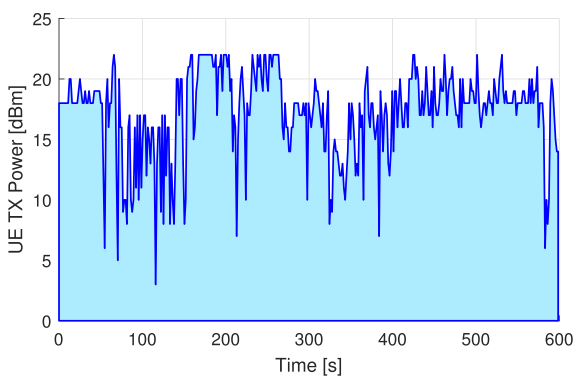

FIGURE 13. **Dynamic measurements - SIM8200EA-M2 TX power.**

a more consistent analysis, in Fig. 11 is illustrated the vehicle speed for the entire duration of the measurements, where it can be seen that the average speed with which the vehicle moved was 35 km/h. Fig. 12 shows the distance between the UE and each gNB to which it was connected during the measurement. More precisely, the distance is illustrated only for the moment when there was a cellular connection between the UE and the respective gNB. Also, the distribution of transmission power of the module over the measurements can be seen in Fig. 13.

The network performance indicators are associated differently for 4G compared to 5G. In 4G, they are associated with Cell Specific Reference Signal (CRS), and in the case of 5G communication, CRS is not used. In contrast, the Channel State Information (CSI) and Synchronization Signal (SS) are used for performance indicators, which are defined for FR1 and FR2. The performance indicators chosen to evaluate the cellular communication for the route from Fig. 10 are presented in detail in the following [40], [41]:

1) **RSRP** - reports the average power over the received signal from the base station. Besides this, this indicator can be used for DL positioning measurements, cell selection for UE, reselection, and handover. The RSRP value is measured in dBm, and a too low value for this indicator may represent an unstable connection or not at all installed.
2) **RSRQ** - is a cell-specific metric that indicates the quality of the received reference signal. Similar to RSRP, this indicator is used to provide a differentiation between cells, depending on their signal quality. Moreover, it comes as a complement to the RSRP measurements, in terms of making decisions for cell reselection and handover.
3) **RSSI** - measures the total power of the signal received by the UE on the entire frequency band, and its measurement unit is dBm. RSSI measures main signals, co-channel non-serving signals, and even thermal noise on the specified frequency band. Moreover, for the LTE system, it can be used in the measurement calculation for the RSRQ indicator.
4) **SNR** - indicates the quality of the signal; it is the ratio between the power of the received signal compared to the sum of interference and noise. It is measured in dB and used only at the UE level, especially for the deduction of the throughput value depending on the radio conditions. Moreover, SNR can be used to calculate the channel quality, more precisely the value of the CQI indicator.
5) **CQI** - is used to measure the quality of the communication channel. CQI messages are periodically sent between the UE and gNB; with their help, the current quality of the channel can be reported and validated. Moreover, the value of this indicator can take scalar values between 0 and 15, the highest value describing a high quality of the channel. Furthermore, this value can indicate the level of modulation and coding that the UE could operate on.

The indicators for 4G communication are illustrated in Fig. 14, where the values for RSRP, RSRQ, and RSSI can be observed. Being a NSA architecture, the module measures these parameters for both 4G and 5G. Therefore, according to the SIM8200EA-M2 module specifications, the range of reported values for RSRP is between −44 dBm and −140 dBm, between −20 dB and −3 dB for RSRQ, and between −120 dBm and 0 dBm for RSSI.

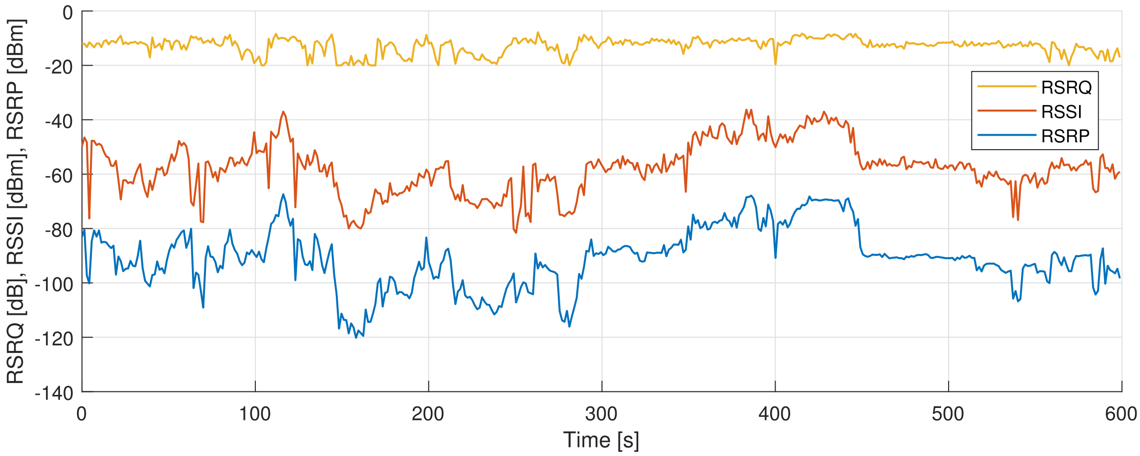

FIGURE 14. Dynamic measurements - RSRP, RSRQ, and RSSI values for 4G communication.

Comparing the values for RSRP, RSRQ, and RSSI from Fig. 14, it can be observed that RSRP and RSSI follow a similar trend in terms of behavior over time. Thus, the difference between the two indicators can give us the relationship with RSRQ, a smaller difference between RSRP and RSSI guarantees a better RSRQ. Moreover, even if RSRP is always lower than RSSI, a smaller difference between the two guarantees less interference, which implies a better quality of the received signal. According to Fig. 14, for 4G, the measured values for RSRP have values between −120 dBm and −67.4 dBm, with an average value of −90.99 dBm. The RSRP level varies depending on the proximity to the LTE cell, the signal has a value of approximately −75 dBm near a cell to −120 dBm at the edge of the LTE coverage. Moreover, values higher than −80 dBm mean an excellent signal strength, while for values lower than −100 dBm the signal is very poor, performance will decrease significantly and when the value is close to −124 dBm there are possible disconnections. Considering that the average value obtained for this indicator is −90.99 dBm, safe data speeds can be discussed, but data with drop-outs are possible. The measured values for RSSI are between −81.6 dBm and −36.3 dBm, with an average value of −57.71 dBm. As previously mentioned, higher values are obtained for RSSI than in the case of RSRP. Thus, a value greater than −65 dBm for this indicator means a very good signal strength. The RSSI being formed by the sum of all the strengths reported by the other indicators, this indicates the possibility that the RSSI has promising values, even if another indicator is weaker, because the other indicators can compensate for this. Furthermore, for RSRQ, values between −20 dB and −7.8 dB were obtained, with an average value of −12.83 dB. It can be observed that the values of this indicator were directly proportional to the difference between RSRP and RSSI, the best quality of the channel being obtained for the smallest differences. The measurement of this indicator is quite important when it comes to the transfer between cells. Thus, for a value greater than −10 dB it means a very good quality of the signal, once this value drops to −20 dB the quality decreases, and for a value equal to or lower than −20 dB one can discussed about disconnection and signal loss.

Related to 5G communication, in Fig. 15, the values for the RSRP and RSRQ indicators are presented. Another important performance indicator for 5G communication is represented in Fig. 16, i.e., the SNR indicator. The distribution of values for RSRP is between −124 dBm and −96 dBm, the average value for the entire duration being −108.64 dBm. Moreover, for the RSRQ indicator, values between −18 dB and −11 dB were obtained, with an average value of −12.74 dB. In the case of the performed measurement shown in Fig. 10, the measured values for SNR indicator are between −1 dB and 31 dB, with an average value of 9.75 dB.

According to [42], for 5G NR FR1, the range of possible values for RSRP are between −31 dBm and −156 dBm with 1 dB resolution, for RSRQ is from −43 dB to 20 dB with 0.5 dB resolution, and reporting range for SNR is defined from −23 dB to 40 dB with 0.5 dB resolution. A minimum SNR of −20 dB is needed to detect RSRP or RSRQ. Comparing Figs. 15 and 16, a relationship between RSRP and SNR can be deduced. Thus, they are directly proportional on average, showing similar variations in certain measurement points. A higher value for SNR, means less interference, which implies a better quality of the signal and also better values for RSRP. Also, the SNR values can indicate an increase in the channel's data throughput, with a lower noise rate.

Analyzing the distances between UE and gNBs, from Fig. 12, it can be highlighted that the RSRP and RSRQ indicators are directly impacted by this distance. For the connection between UE and gNB1, where the distance was around 200 m, the best values for RSRP, RSRQ, and SNR can be observed. As this distance increases, reaching the range of 800 - 1000 m, one can see that the performance decrease, indicators having the lowest values. This can be validated with the help of Figs. 12 and 15, more precisely for communications with gNB3, gNB4, and gNB5. By analyzing the performance

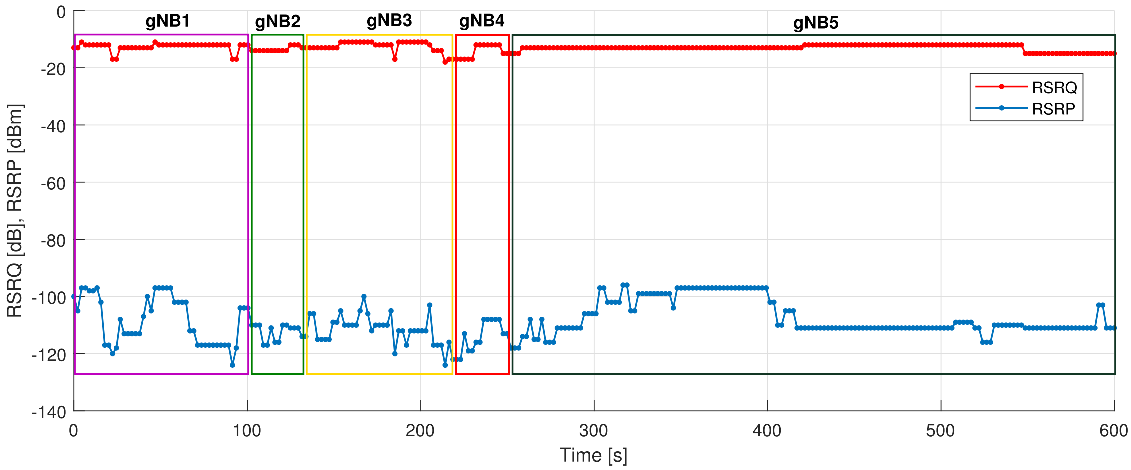

FIGURE 15. Dynamic measurements - RSRP and RSRQ values for 5G communication.

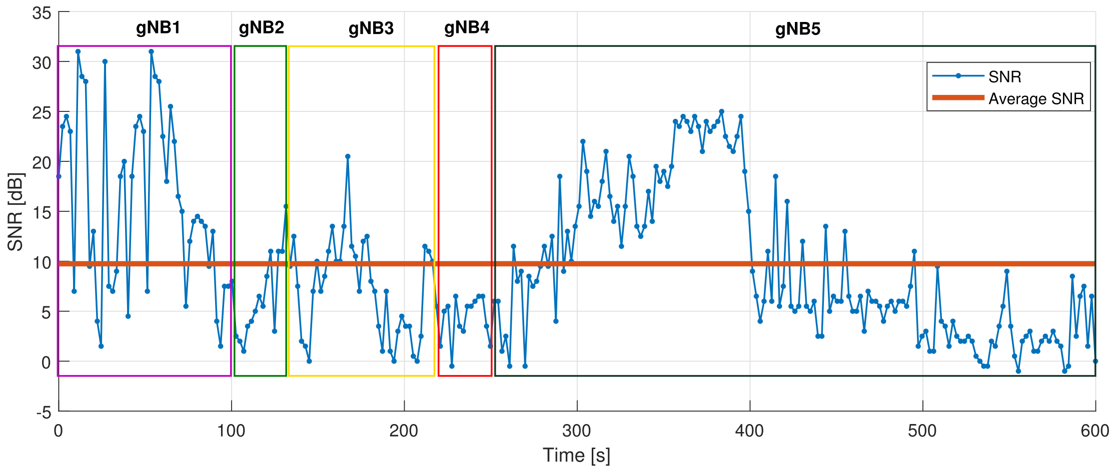

FIGURE 16. Dynamic measurements - SNR values for 5G communication.

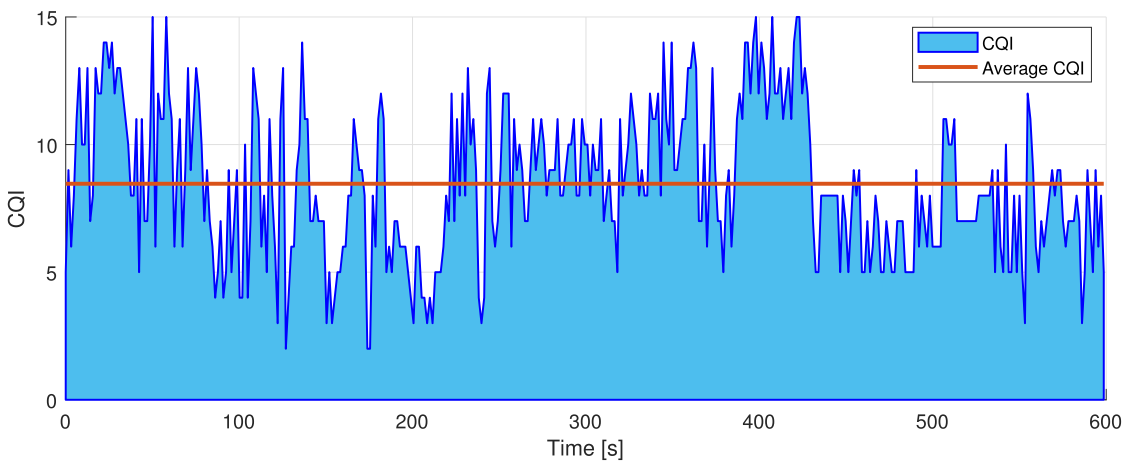

FIGURE 17. Dynamic measurements - CQI values for cellular communication.

indicators at the beginning of the communication with them, marked in the figures by borders, it can be observed that for distances greater than 800 m the lowest performances are obtained. Moreover, in addition to the distance, the size of the buildings can intervene on the indicators values, which can be negatively influenced by certain heights.

The quality of the channel for cellular communication between the module and the gNBs, for the entire measurement period, is illustrated by the CQI indicator and can be seen in Fig. 17. The module returns a decimal value between 0 and 15, the higher value meaning the better quality of the channel. The average value measured for this indicator was 8.46. Observing the waveforms from Fig. 16 and 17, it can be seen that the CQI is calculated based on the SNR value. Thus, where the SNR values fall below the average of 9.75 dB, the channel quality also drops significantly. Considering that it is about dynamic measurements, where the module is not in the same position, the vehicle moving at different speeds, and there are several handover processes, it is normal for performance indicators to have less good values than in the case of some static measurements.

B. STATIC MEASUREMENTS AND CONFIRMATION WITH THE 5G NETWORK PROVIDER - ORANGE ROMANIA

This subsection presents an example of static measurements, carried out with the help of the 5G cellular network provider Orange Romania, which aim to validate the presented methodology of real-time data measurement, through a double check of the values for the most relevant performance indicators. The purpose of these measurements was to evaluate the performance of 5G communication, being connected to a single gNB, the UE remaining in the same position throughout the tests. Moreover, the communication between the UE and gNB was monitored, at the same time, by Orange Romania, by tracking the traffic reported to the cell to which the UE was connected. The network performance measurement method, implemented by Orange Romania, involves using of Operations Support Systems (OSS). These are a collection of hardware and software tools designed to help telcos monitor, analyze and manage telecom networks. Any UE camping on the cells of a gNB communicates with it a Temporary Mobile Subscriber Identity (TMSI). For the measurement method, this TMSI is used to identify the UE on a gNB, following the UE monitoring. Fig. 19 shows a capture from the OSS interface, where one can see all the information about the connection between the UE and gNB, but also about different performance indicators relevant for the communication between them.

In the same way as for the dynamic measurements, the static ones were also carried out in a dense urban area in the city of Iasi, Romania. The positioning of the hardware setup, noted as UE, but also that of the gNB can be seen in Fig. 18, the distance between the two being 300 m. The data was collected for a duration of 35 minutes, from 16:55 PM to 17:30 PM. For the communication between the UE and the gNB, from the point of view of the used spectrum, the same frequency bands were used as in the case of the dynamic measurements. During all this period, the UE was connected to one of the three cells of gNB, to the cell with the physical identifier 145. The number of 5G users served by cell 145 is

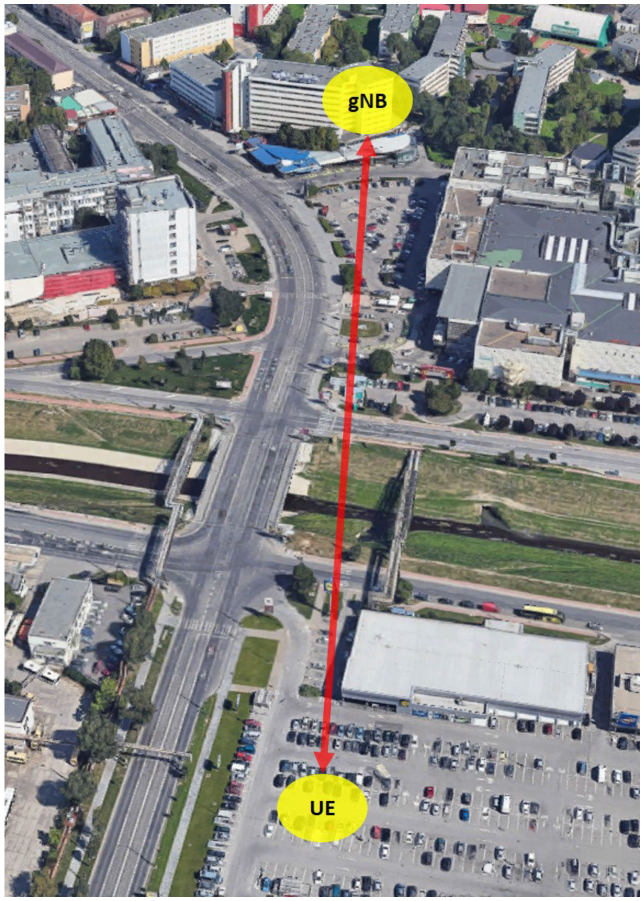

FIGURE 18. Measurement map.

illustrated in Fig. 20. Thus, the number of users is monitored for each hour, starting with 6:00 AM until 11:00 PM. Therefore, in Fig. 20, with a blue line are the number of users who have accessed cell 145 and with those red bars their service percentage is illustrated. Moreover, the time zone in which the static experiments were carried out was marked with green color, where it can be seen that the number of users served by the cell was between 8000 and 8500, with a service percentage between 99.75% and 99.95%.

Remark 2: Static measurements are used as functional testing of real-time data measurement methodology, thus the validation is done by comparing the measured values of SIM8200EA-M2 with the values measured by the 5G cellular network provider, Orange Romania.

A more detailed analysis can be seen in Figs. 21 and 22, where one can observe the results obtained by the measurement method presented in comparison with the results measured by Orange Romania. The two figures illustrate some of the most important performance indicators, in Fig. 21 values for RSRP can be observed, and in Fig. 22 values for SNR. Related to the two figures, it can be seen that the values obtained with the SIM8200EA-M2 module are quite close to the measurements made by the cellular network provider, which indicates that the data collection method, presented in

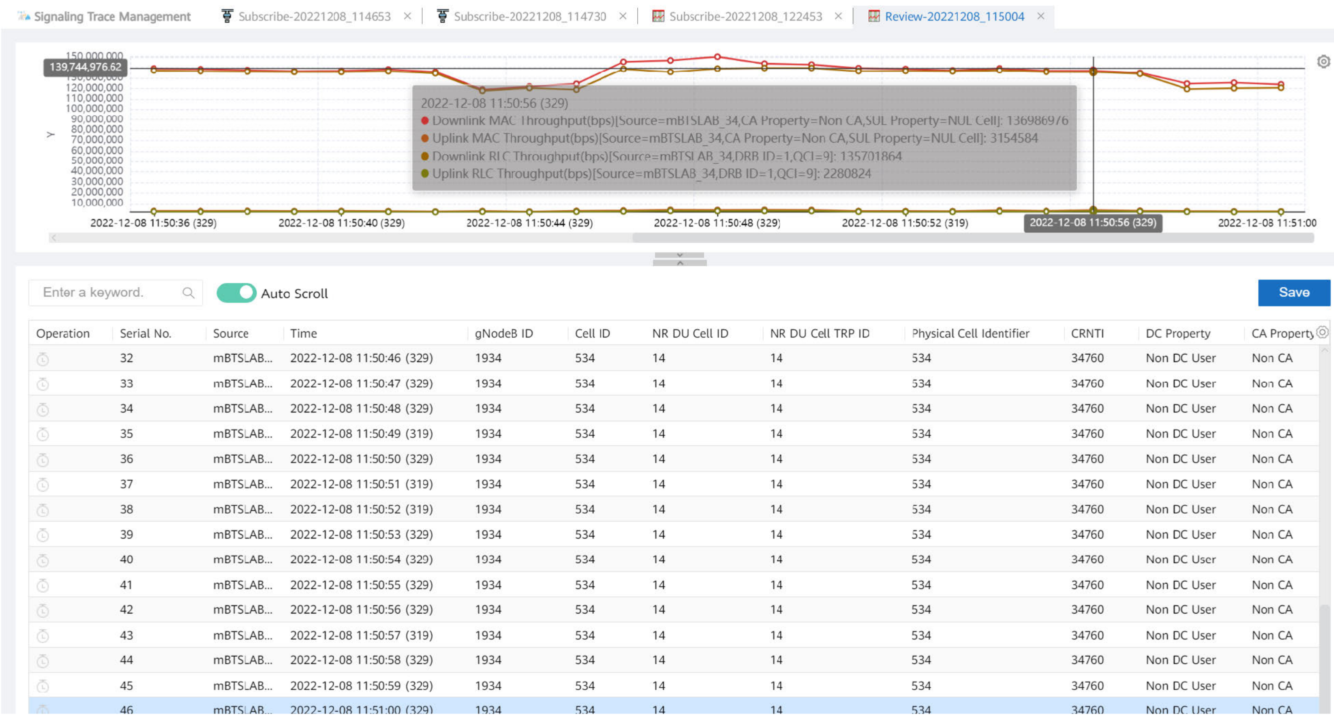

FIGURE 19. Operations support systems interface.

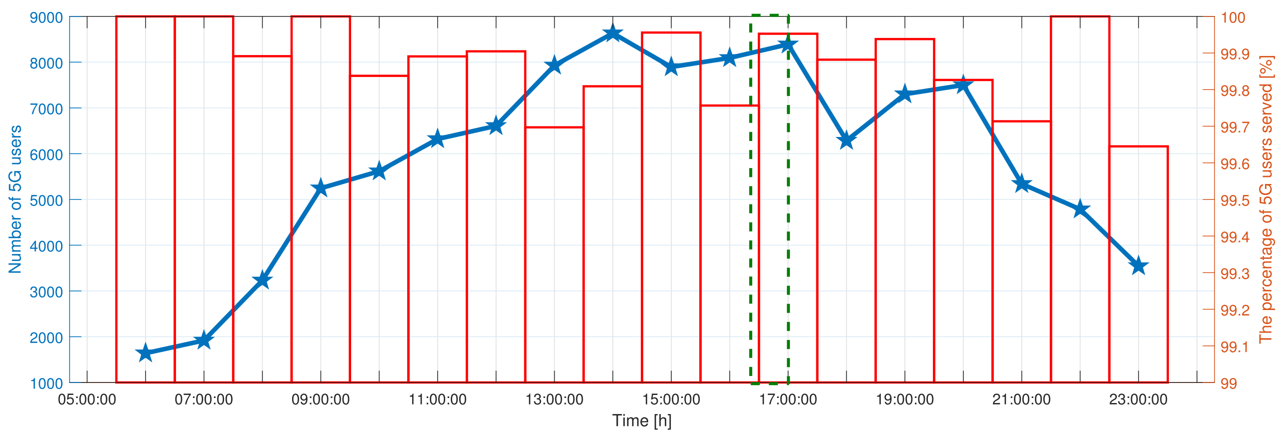

FIGURE 20. Number of 5G users served by cell 145.

this paper, is stable and offers a safety regarding the values of the measured parameters. Moreover, in addition to the similarities presented, in relation to the values for the two performance indicators, it can be observed that in the case of static measurements, their values are better than in the case of dynamic measurements. These values are expected to be better, considering that the same position of the UE is used, the constant distance from the gNB, and the connection to a single cell, without the existence of handover procedures.

In this type of measurement, in addition to RSRP and SNR, the throughput value for the two MAC and RLC layers for 5G NR protocol was also measured. Therefore, in Figs. 23 and 24, one can see the throughput values for the MAC layer for both UL and DL. Also, the values for the throughput of the RLC layer can be seen in Figs. 25 and 26. These values represent ratio of data transmitted within the static measurements, expressing the number of bits per second exchanged between the UE and gNB for both UL and DL. The transmitted packets have several headers attached to them that contain information about their content and destination. Maximum segment size (MSS) measures the non-header portion or payload and limits the size of packets that travel across a network. According to user plane protocol stack between UE and gNB, the small throughput difference between RLC and MAC can also be explained, considering that the RLC layer

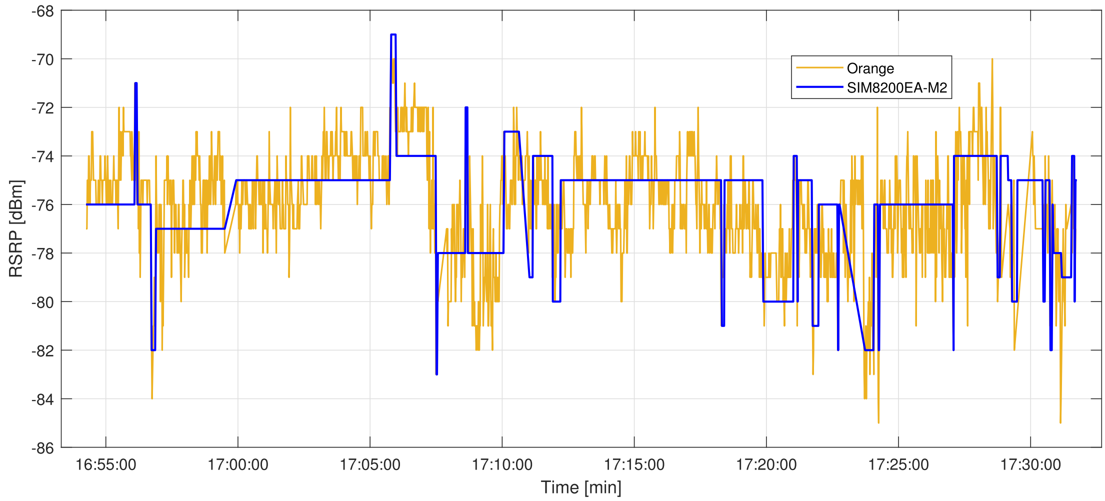

FIGURE 21. Static measurements - RSRP measurement for 5G.

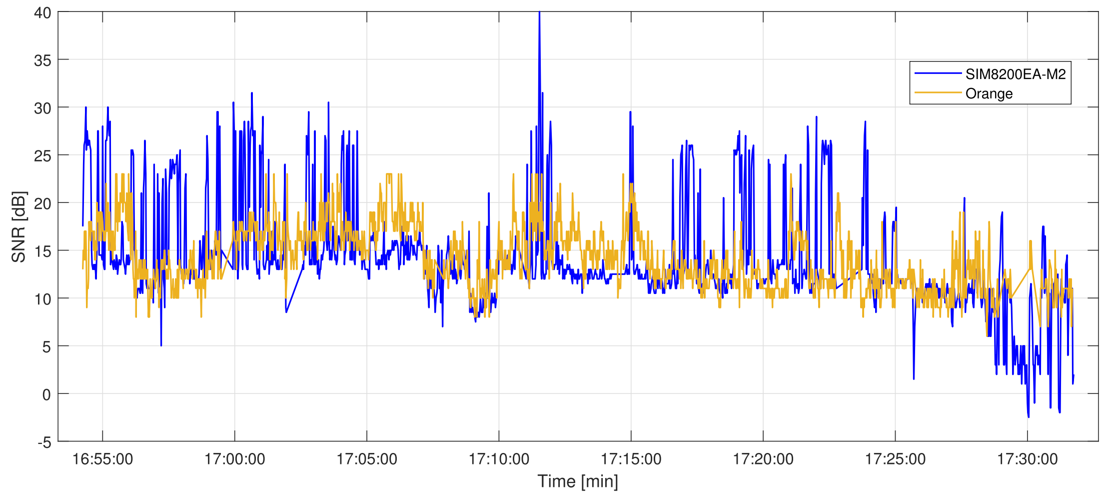

FIGURE 22. Static measurements - SNR measurement for 5G.

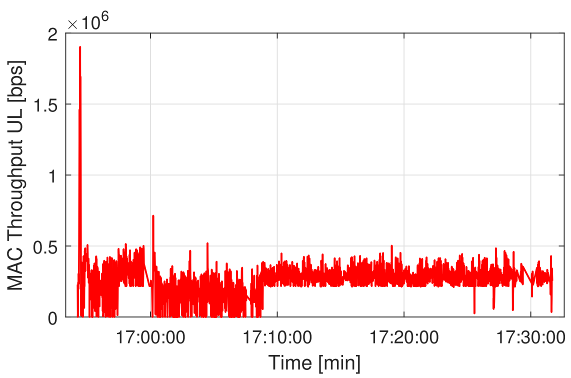

FIGURE 23. Static measurements - MAC throughput UL.

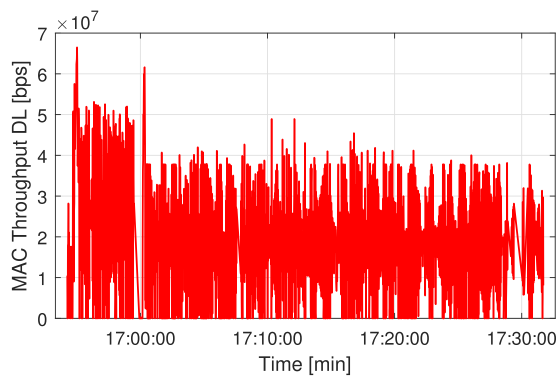

FIGURE 24. Static measurements - MAC throughput DL.

is just above the MAC layer, the overhead of 2 bytes per PDU influences this throughput difference. Moreover, packets are generally not sent with the maximum MSS size, hence the differences can be larger. At the application level, the real speed seen on mobile is even higher compared to RLC or MAC layers.

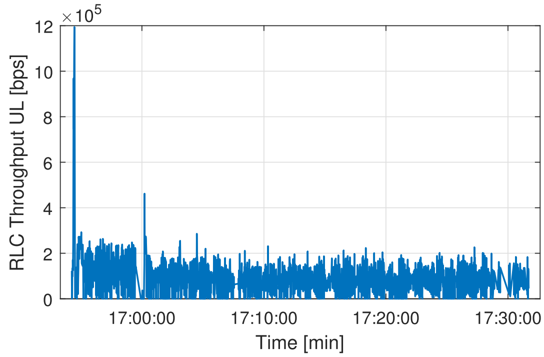

FIGURE 25. Static measurements - RLC throughput UL.

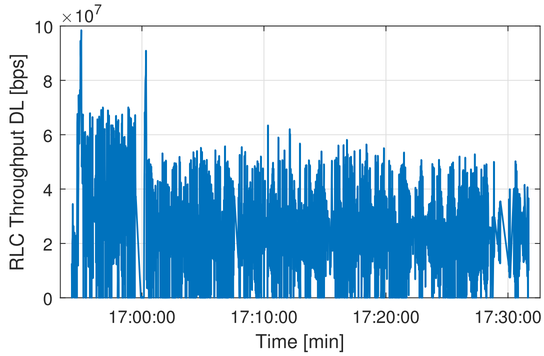

FIGURE 26. Static measurements - RLC throughput DL.

V. CONCLUSION

This paper presents a practical method of real-time data measurement for the 5G network, using the SIM8200EA-M2 module. Moreover, different measurement methods were presented, by illustrating the dynamic and static tests carried out, which aimed to validate the relevant network parameters for 5G communication. Besides these, a series of functional tests were carried out, together with the cellular network provider, Orange Romania. These tests demonstrated the fact that the method presented in this work ensures a certain safety from the point of view of the values of the measured parameters. In conclusion, the described setup can be useful for different specific tests, using different scenarios, to validate the relevant aspects of the 5G network.

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