Comparison of Current Consumption and Data Rates in 5G NSA Over FR2 and FR1 Bands

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***Abstract*—This paper presents a comparison of current consumption in a 5G User Equipment (UE) under Non-Standalone (NSA) deployment when submitted to different scenarios, such as the number of antennas (MIMO), Carrier Aggregation (CA), and modulation schemes. The comparison will occur over the same network parameters but for Frequency Range 1 (FR1) and Frequency Range 2 (FR2) bands. Measurements were taken in the laboratory using a setup with test stations for the simulation of LTE and NR Cells and a Control PC with Rapid Test Design (RTD) for the communication between the UE and the test stations, as well as the measurements itself. The results obtained through laboratory measurements show that FR1 scenarios cause less current consumption than FR2 scenarios. Also, the relationship between the electric current consumption and data rates is presented in both scenarios when the UE is connected over FR1 and FR2 network bands.**

***Index Terms*—5G; NSA; mmWave; current consumption; FR1; FR2.**

I. Introduction

Telecommunications technologies constantly evolve, providing new features and better performance to mobile devices. The transition from the fourth generation (4G) to the fifth generation (5G) of mobile technologies is being conceived in two parts. The first one is known as 5G Non-Standalone (NSA) [1], in which the core of the network, i.e., Evolved Packet Core (EPC), remains the same as in 4G but works in conjunction with the 5G Radio Access Network (RAN), allowing the devices to reach more significant data rates and lower latency. Although this is not the performance level expected for a pure 5G Standalone (SA) technology, it was already considerably higher than the performance in 4G.

These results are possible due to the application of a set of complex techniques, such as network slicing, which enables connectivity for smartphone services with diverse refinements through multiple logical networks [2], higher-order modulations, multiple antennas working simultaneously (MIMO), and exploiting Carrier Aggregation (CA) techniques. In addition, the use of frequency spectrum in the range of millimeter Waves (mmWaves) enabled Bandwidth (BW) in order of hundreds of MHz for each Carrier Component (CC).

For 5G, the relevant spectrum is divided into frequency ranges: Frequency Range 1 (FR1) and Frequency Range 2 (FR2) [3]. The first range varies from 450 MHz to 6000 MHz [4]. The second range extends from 24.25 GHz to 52.6 GHz [4], which has a small wavelength, in order of millimeters (thus why FR2 is known for mmWaves). The 3rd Generation Partnership Project (3GPP) defines technical specifications for the main requirements for FR1 and FR2, which can be found in TS 38.101-1 [5] and TS 38.101-2 documents [6], respectively.

Although these advanced techniques provide the best performance for mobile devices, they can represent a high cost in battery life consumption, which is an essential characteristic of this equipment [7]. The values of data rate reached by mobile phones, the electric current consumption for each different scenario, and the trade-off between these two parameters when the mobile phone is connected in FR2 bands or FR1 bands, will be crucial information for motivating the creation of new techniques to manage the battery life of these devices better.

All these issues bring a scenario where there is a need to test and study the new possibilities and capabilities and the impact of these issues on mobile devices. Unlike the aforementioned studies, this paper analyzes the performance of 5G User Equipment (UE) over millimeter waves (Frequency Range 2 - FR2) through laboratory experiments using common user terminals (smartphones) and compares them with FR1 scenarios. The main contributions can be summarized as:

- Analysis of current consumption in UE over FR1 and FR2 scenarios with MIMO 2x2, different modulation orders and CA with 1 and 2 CCs;
- Analysis of data rate in UE over FR1 and FR2 scenarios with MIMO 2x2, different modulation orders and CA with 1 and 2 CCs;
- The results achieved shall help to measure the difference between data rate and current consumption in FR1 and FR2 scenarios;
- Achieved results will motivate and help direct new research to aim for longer battery duration in UEs, as well as better allocation of the network's resources.

The remainder of this work is structured as follows. Section II covers the related works on 5G scenarios and technology performance. Section III will explain the Analysis Methodology, describing the variables and equations used for

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performance analysis in detail. Section IV will go into the Measurement Setup used to collect power consumption from user devices and data rate. Section V will offer an analysis of the acquired data. Section VI displays the conclusions and summarizes what has been discussed so far, as well as the suggestions for future works.

II. Related Works

New research is being developed to test 5G capabilities and performance, most of them motivated by the characteristics defined by the 3GPP release 15 [1], even before its implementation began, such as enhanced Mobile Broadband (eMBB), Ultra Reliable Low Latency Communications (URLLC) and massive Machine Type Communications (mMTC). CA is used in [8] to improve the network capacity. The Network Simulator 3 (NS3) was used to evaluate the performance of CA for different network scenarios, and they concluded that a higher number of CCs can contribute effectively to increasing the network capacity.

In [9], 5G FR2 scenarios are exploited to analyze the behavior of the TCP protocol for mmWave and evaluate its impact on system-level performance. The study examined handover operations and found blockages in congestion control. Additionally, this work concludes that the performance of the protocols that target a higher throughput decreases when channel quality degrades for long periods.

An analysis of current consumption and data rates over 5G NSA over millimeter waves is presented in [10]. The study showed that 5G may achieve data rates around 8 Gbps using millimeter waves, with 70% extra current consumption compared with a scenario with no CA, concluding that an efficient resource allocation is mandatory for a longer battery life of the UE.

This paper will make its main contribution to evaluating the performance of a 5G UE when comparing FR1 and FR2 bands. The comparison will be made regarding electric current consumption and data rate through laboratory experiments using standard user terminals (smartphones). The main contributions can be summarized as:

- Data rate measurements for FR1 and FR2 complex scenarios.
- Electric current consumption measurements for FR1 and FR2 complex scenarios.
- Evaluation of the gain in data rates over the electric current consumption for FR2 compared to FR1 bands.
- Achieved results may contribute to better network planning, targeting a longer UE battery duration.

III. Analysis Methodology

For this research, a mobile smartphone with a Snapdragon SM8450 CPU and Dynamic AMOLED 2X 6.8-inch display screen was used. Two parameters were measured: electrical current consumption and data rate. Both were measured in different scenarios using complex techniques, such as MIMO, Carrier Aggregation, and different modulation schemes. All of the device's applications and non-essential services were closed for the measurements.

Both parameters will be measured for 5G New Radio (NR) cells operating in FR1 and FR2 so that the results can be compared later in this work. Also, the measurements will be carried out on the same mobile device so that the hardware is maintained during the comparisons made in this work.

For the electrical current consumption, after setting up the communication between the UE and the network, the UE battery is disconnected, and the device is powered directly by power measurement equipment. Therefore, when the UE attaches to the network, the current measurement is started, and data is collected over about 10 seconds, with a sampling interval of 0.2 milliseconds, i.e., a total of about 50,000 samples for each scenario. The electric current consumed in the process of attaching into the network is not relevant, since this takes only a few seconds.

The measured data rates are obtained directly from the Anritsu software (RTD), which has a measurement tool for network parameters. These values consider only NR data rates, not LTE data rates. That is because the LTE cell in NSA networks is explicitly used for the control plane, i.e., to transmit signaling messages between the UE and the network. Also, the theoretical data rates can be calculated for validation purposes using Equation (1) [11].

$$Datarate(Mbps)_{(NR)} = 10^{-6} \times \sum_{j=1}^{J} (v_{layers}^{j} \times Q_m^j \times f^j \times R_{max} \frac{12 \times N_{PRB}^{BW(j),\mu}}{T_S^\mu} \times [1 - OH^j]), \quad (1)$$

where J is the number of aggregated component carriers in a band or band combination, v_{layers}^{j} is the maximum number of layers (number of antennas in the link), Q_m is the maximum modulation order (QPSK, 16-QAM, 64-QAM, 256-QAM and so on), f is the scaling factor (defined per band or band combination as 1, 0.8, 0.75, and 0.4 [11]), R_{max} is the maximum code rate (which can add more redundancy bits in a trade-off for a lower data rate), N_{PRB} is the number of physical resource blocks (PRB) allocated in a specific bandwidth (BW) with numerology μ (which represents the Sub Carrier Spacing of 15, 30, 60, 120, and so on) and OH is the overhead for control channels (0.14/0.08 for FR1 DL/UL and 0.18/0.10 for FR2 DL/UL). Finally, T_S^μ is the average OFDM symbol duration, given by Equation (2).

$$T_S^\mu = \frac{10^{-3}}{14 \times 2^\mu} \quad (2)$$

The measured data is obtained through laboratory experiments and evaluated. These data rate measurements are captured by a Compact Antenna Test Range (CATR), which is the same antenna that radiates the signal of the LTE and NR Cells. The electric current consumption measurements are also performed in the same laboratory, considering the same 5G NSA scenarios used for data rate measurements. The setup parameters are based on [10], presented in Tab. I. The variations made on the network were: Modulation Coding

Scheme (MCS) (5, 10, 19, and 27 as QPSK, 16-QAM, 64-QAM, and 256-QAM, respectively) and the number of carrier aggregation CCs, for 1 and 2 CCs.

TABLE I
NETWORK CELL PARAMETERS

Parameter	Value (FR1/FR2)
Frequency Band	LTE: Band 2 ; NR: Band 78/261
Subcarrier spacing (SCS)	30KHz/120KHz
Scaling factor (f)	1
OH	0.14/0.18
R_{max}	0.58, 0.64, 0.85 and 0.92
Bandwidth (BW)	LTE: 5MHz, NR: 100 MHz per NR CC
Number of NR CCs	1 and 2 CCs intra-band
MCS	5, 10, 19 and 27
Modulation Scheme	QPSK, 16-QAM, 64-QAM and 256-QAM

IV. MEASUREMENT SETUP

The setup used various equipment to simulate the network, control the signaling, and perform the simulation itself. These equipment are listed in Tab. II.

TABLE II
SETUP LIST OF EQUIPMENT

Equipment	Purpose
MD8430B	LTE Test Station
MT8000A	NR Test Station
Control PC	Control of stations and UE
Measurement Equip.	Current and direct powering of the UE
CATR	Signal radiation originated from the network
ShieldBox	Isolation of the UE from external interference

The Anritsu MD8430B generates the LTE anchor cell, which is responsible for the control plane signaling messages between the UE and the network. At the same time, the Anritsu MT8000A emulates the 5G secondary cell groups (SCG), which are responsible for the user plane data. The power measurement equipment is responsible for directly powering the UE and the current consumption measurement. The control PC controls all the test stations and the electrical current measurement equipment through its respective software. Finally, the Compact Antenna Test Range (CATR) and the Shield box are both responsible for providing an Over-The-Air (OTA) environment that will be shielded from outside signals that would represent interference to this setup. An illustration of the setup is presented in Fig. 1.

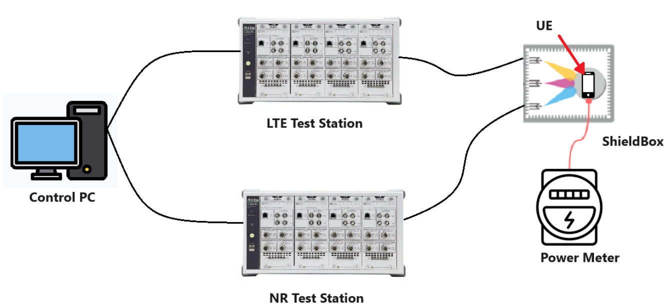

Fig. 1. Setup Equipment

V. RESULTS AND DISCUSSION

Once the data rate of the proposed scenarios is calculated, the measurements are performed in the presented setup. Fig. 2 illustrates the measured Data Rate for different modulation orders in MIMO 2x2 scenarios for 1 and 2 CCs of NR over FR1 and FR2.

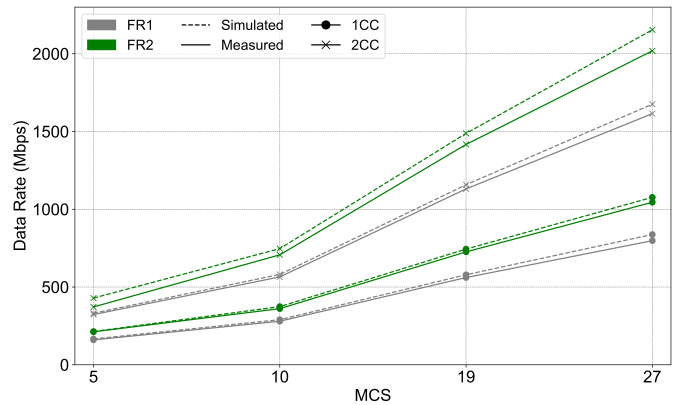

Fig. 2. Data Rate measurement for 5G NSA over FR1 with 1CC and 2CC NR

In addition, electric current consumption measurements are performed for various scenarios, which are presented below. Fig. 4 shows the measured electric current consumption over FR1 for different modulation orders in MIMO 2x2 scenarios for 1 and 2 NR CCs, respectively. Fig. 3 shows the same scenario over FR2.

Fig. 2 shows that the Data Rate increases with the modulation order (from MCS 5 (QPSK) up to MCS 27(256-QAM)) and also with the number of CCs. For FR1 with 1 CC NR, the data rate increases from 161 Mbps to 798 Mbps, while for 2CCs NR, the data rate increases from 323 Mbps to 1615 Mbps. In the FR2 scenario with 1 CC NR, the data rate increases from 212 Mbps to 1054 Mbps, while for 2 CCs NR, the data rate increases from 372 Mbps to 2019 Mbps.

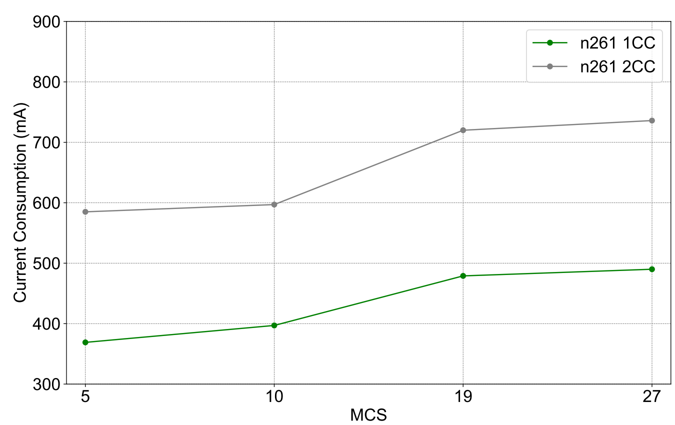

Fig. 3. Current consumption measurement for 5G NSA over FR2 with 1CC and 2CC NR

Figs. 3 show that the electric current consumption over FR2 for 1 CC varies from 369 mA to 490 mA with MCS 5 (QPSK) to 27 (256-QAM). For 2 CCs, the electric current consumption

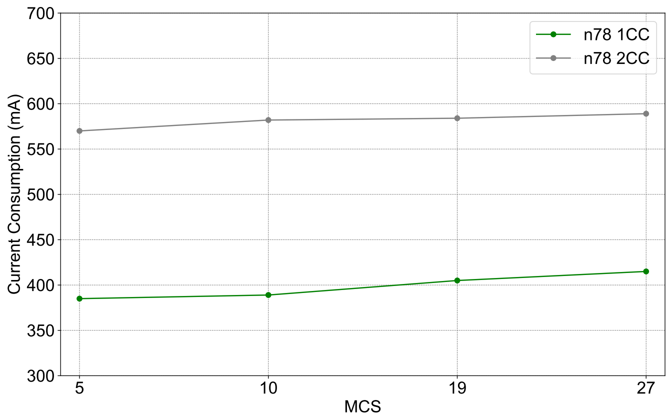

Fig. 4. Current consumption measurement for 5G NSA over FR1 with 1CC and 2CC NR

varies from 585 mA to 736 mA with MCS 5 (QPSK) to 27 (256-QAM).

In the same way, Fig. 4 shows that the electric current consumption over FR1 for 1CC varies from 385 mA to 415 mA with MCS 5 (QPSK) to 27 (256-QAM), and for 2 CCs, it varies from 570 mA to 589 mA with MCS 5 (QPSK) to 27 (256-QAM). Also, because of the quick variation of the electric current, the difference between FR1 and FR2 scenarios will be easier to see in higher MCS. The values in low MCS need to be analyzed with a possible 5 to 10% error criteria. That is why the value captured for FR2/MCS 5/1 CC (369mA) is lower than the value captured for FR1/MCS 5/1 CC (385 mA).

Since the electric current consumption as well as the data rate of both scenarios behaves similarly for the variations in modulation order, a fair comparison would be to take the average value of the results of these parameters, described in Tab. III, and once again the average value between 1 CC and 2 CCs. After this we will have one value of data rate and one value of current consumption representing FR1 (679 Mbps/498.5 mA) and another representing FR2 (865 Mbps/546 mA). When comparing FR1 to FR2 scenarios, it's possible to observe an increase in the current consumption of only 9.6%, while the data rate increases by 27.4%.

TABLE III
CURRENT AND DATA RATE MEASUREMENTS

Scenario	Current consumption	Data Rate
FR1 1CC	398 mA	449.7 Mbps
FR1 2CC	581 mA	908.5 Mbps
FR2 1CC	433 mA	593.0 Mbps
FR2 2CC	659 mA	1138.0 Mbps

VI. CONCLUSIONS AND FUTURE WORK

This paper showed that the performance of a UE, in terms of data rate, can be highly increased by the use of complex techniques such as MIMO, high order modulations, Carrier Aggregation, and especially the use of millimeter waves (FR2 bands). These techniques also represent a considerably higher consumption of electric current, which will lead to a lower battery life. However, this study showed an average gain of 27.4% in data rate (considering average values for different modulation orders and single carrier to 2 CCs with an average cost of only 9.6% more current consumption. This gain in the data rate represents almost 3 times the cost of electric current consumption. This means the costs in battery life can be overcome by techniques of better resource allocation, which can bring up a very high performance without compromising the battery of the mobile device.

Future works can evaluate the same comparison for scenarios with different mobile devices or techniques and look for better energy management techniques for mobile devices.

Also, Algorithms with Artificial intelligence (AI) may be used to implement the best moment to shift between FR1 and FR2 bands to achieve a high data transfer rate and then quickly shift back to FR1 bands when the user no longer needs a high transfer rate.

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