Optimization of the Radio Access to Provide Vehicular Communications Based on Drive Tests

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***Abstract*—Cellular radio access networks provide a great flexibility in terms of the number of possible transmission modes and signal formats. This flexibility is increased for 5G, whose field test trails and deployment are forthcoming, with several numerologies, new frequencies and higher bandwidth. With the aim of providing some understanding about the best options to provide a certain coverage and quality of service, we have carried out real environment measurements through drive tests performed in a 4G network. After validating and adjusting the channel model, some of the new features of the 5G New Radio have been included for comparison purposes. In this paper we present the measurements, validation process and results that offer some insights on how this new technology will perform.**

***Index Terms*—Drive tests, LTE-A, 5G NR, path loss, RSSI, throughput**

I. Introduction

The first commercial deployments of the fifth generation (5G) of mobile networks are being announced. Those deployments are based on the Non-Stand-Alone (NSA) new radio (NR) specifications for 5G, provided by the 3rd Generation Partnership Project (3GPP) in late 2017, integrated in previous-generation Long Term Evolution Advanced (LTE-A) core networks. However, the NSA version of 5G NR is just the first milestone of a stepwise approach to expand 5G standards to the standalone (SA) 5G scenario [1]. The new radio system, complemented with enhancements for LTE-A and several intermediate scenarios, will be capable of fully achieving IMT-2020 compliant 5G networks [2], [3].

Radio tests for analyzing waveform and multi-antenna performance were carried out [4], [5], though most of mobile operators are currently deploying new radio equipment to perform 5G NR field test trials in city environments [6]. The objective of those measuring campaigns is to improve the performance of the radio system. In order to have a deeper knowledge of the network performance before massive deployments begin, new simulation tools that represent the behavior of those systems are essential, resulting on a better understanding for network planning and optimization ultimately leading to improved performance.

This paper combines these two approaches, while being an extended work of [7]. On the one hand, we present a measurements campaign at fixed locations and a drive test, both based on the latest release of LTE-A Pro. On the other hand, we reproduce the measuring results through simulations. While measurements are done with a professional network testing software, simulations are loosely based on the Vienna Cellular Communications Simulators (VCCS) LTE-A Downlink System Level Simulator [8]. Proper adjustments have been made in the simulator to represent these results most faithfully. In addition, we show some comparison between the peak data rate for a LTE-A and 5G NR with the aim of giving some insights for network optimization. With first hand information from network providers and operators, different configurations of 5G NR in terms of channel bandwidth and carrier frequency are shown.

The reminder of this paper is organized as follows. Section II details the measurements campaign and the drive test carried out in a real environment under a LTE-A network. Section III briefly shows the mathematical formulation for calculating path losses corresponding to a verified channel model and the results from simulations. In Section IV we introduce some aspects of 5G NR to simulate its behavior in the drive test scenario and comparison between different configurations. Final thoughts and conclusion are presented in Section V.

II. LTE-A Pro Measurements Campaign

Two settings are presented in this section. On the one side, we carried out fixed locations test trails with the aim of verifying the channel model and its macroscopic path loss formulation used in [7], which will be the basis of our simulation. On the other side, drive testing is done. The measurements campaign takes place within a medium size European city[1]. This scenario supposes a mixed situation of urban and suburban line-of-sight (LOS) and non-line-of-sight (NLOS) conditions. All measurements are carried out with a LTE Cat.18 Samsung Galaxy S9 terminal as user equipment (UE), which is capable of 4x4 multiple-input multiple-output (MIMO) communications in closed-loop spatial multiplexing (CLSP) transmission mode. For LTE data monitoring and recording we employ TEMS Investigation – a computer-based mobile network testing software. The connection between the terminal and the computer is via universal serial bus (USB).

TEMS Investigation provides the user with plenty of recorded information and measured parameters. Only those parameters that we consider essential for this work are presented. These are as follows:

- Received Signal Strength Indicator (RSSI): Wideband received power from serving and non-serving cells at UE.
- Reference Signal Received Power (RSRP): Average power from resource elements (RE) carrying cell-specific reference signals.
- Signal-to-Interference-plus-Noise-Ratio (SINR): Relation between useful received power and average interference power and background noise.

[1]Due to confidentiality reasons we cannot specify the place in which tests have taken place.

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TABLE I
FREQUENCY BANDS AND CHANNEL BANDWIDTHS

LTE Band	Channel Bandwidth
L800	10 MHz
L1800	20 MHz
L2100	15 MHz
L2600	20 MHz

A. *Fixed Locations Tests*

All four LTE frequency bands, shown in Table I, are measured in fixed locations, though not every emplacement provides all of them. Seven different locations have been chosen for preliminary testing. For identifying a concrete cell, sector and LTE band, we compare the enhanced-UTRA absolute radio frequency channel number (EARFCN) and the physical cell identity (PCI) shown by TEMS Investigation and those provided by the network operator. More details of this procedure can be found in [7]. Testing is performed by locking the UE at a specific frequency band. All measured parameters for every location and LTE band, shown in Table II, are averaged values from a continuous measuring in the same place. These results will help verifying the channel model.

The first measuring (Location 1) takes place in a outdoor parking lot with LOS suburban conditions being close to the serving cell and far away from the only interfering one. This first testing aims to verify everything is working as expected. Every measurement is done with the terminal in horizontal position, so up to 8 dB of additional losses are expected.

The second measuring (Location 2) takes place within a car (still considered and outdoor scenario with additional penetration losses of 7 dB) in a LOS suburban situation with serving cell being further away to the terminal than the interfering one. In this particular location, terrain is not flat between the interfering cell and the UE, which causes additional losses and most probably forces the terminal to attach itself to the furthest eNodeB (eNB). This time, longer distances between the UE and base stations and interference are key while evaluating measured parameters.

Now, for the third measuring (Location 3), the UE is equidistant to both previous eNBs. Again, we have a LOS suburban measuring from inside a car. Better channel conditions are expected since we are closer to the serving cell.

Forth measuring (Location 4) takes place in a NLOS urban scenario. While evaluating this type of measurement buildings mean height and streets mean width must be considered. Serving cell is near the terminal and has a much higher emplacement than the rest of base stations, so interference is not a limiting factor.

Fifth measuring (Location 5) represents an outdoor-to-indoor (O2I) urban situation since the terminal is situated at the first-floor of a building. The indoor scenario is pretty much isolated the UE from interference.

For comparison purposes, sixth measuring (Location 6) is similar to the previous one being the UE at the second-floor of the same building instead. RSSI measured values are roughly similar, nevertheless.

Lastly, the seventh measuring (Location 7) aims to reproduce a NLOS urban outdoor scenario. Similar to second and third measurements, there are two eNBs fairly close to the terminal. No matter an outdoor or indoor situation are given, NLOS urban scenarios show that interference is not a limiting factor thanks to the isolation of the UE.

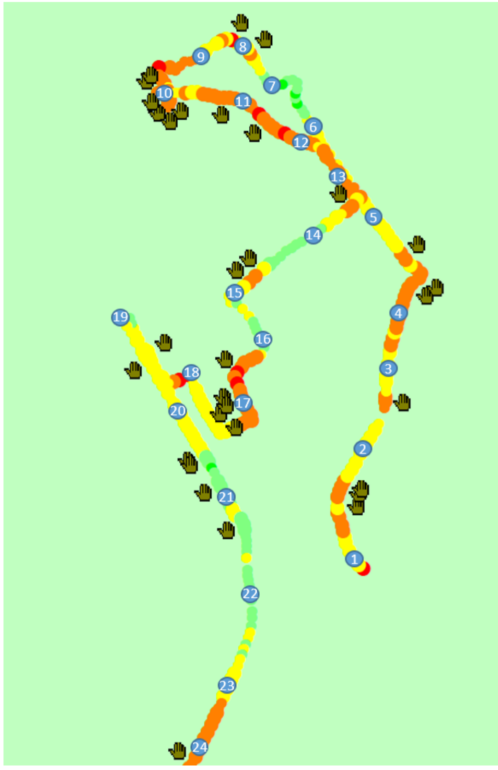

Fig. 1. Drive test route with with data recorded positions.

B. *Drive Test*

The drive test is performed driving around the city downtown streets with the UE locked at the L1800 band only. The route followed is shown in Figure 1, where a hand represents the handover operation and color variations ranging from green to red represent high or low RSSI level, respectively. Since the number of recorded positions is considerably high, only the measurement for 24 positions are shown in Table III, marked by blue numbered bubbles in Figure 1. We chose equidistant positions for having representative results. TEMS Investigation reports the GPS position of the terminal, so we can calculate the distance to each base stations in those position, which is needed for running the simulations shown in Section III.

III. CHANNEL MODEL VERIFICATION

The RSSI level is the parameter used for comparison between measured date and simulation results. It is defined as

$$\text{RSSI [dB]} = 10\log_{10}(P_{s,r} + \sum_{i=1}^{N_i} P_{i,r}) + G_{\text{UE}}, \quad (1)$$

where N_i is the total number of interfering eNBs, $P_{s,r}$ is the received power from serving cell and $P_{i,r}$ is the received power from i-th interfering cell, both in linear units, and G_{UE} is the UE antenna gain in dBi. We define $P_{s,r}$ as

$$P_{s,r} = 10^{\frac{P_{s,t}+G_s-L_t-L}{10}}, \quad (2)$$

TABLE II
FIXED LOCATIONS TESTING RESULTS

	LTE Band	RSSI	RSRP	SINR
Location 1 (suburban, outdoor)	L800	-25 dBm	-59 dBm	24 dB
	L1800	-35 dBm	-41 dBm	20 dB
	L2100	-37 dBm	-69 dBm	22 dB
	L2600	-41 dBm	-73 dBm	27 dB
Location 2 (suburban, outdoor)	L800	-58 dBm	-85 dBm	3 dB
	L1800	-64 dBm	-85 dBm	17 dB
	L2100	-64 dBm	-90 dBm	3 dB
	L2600*	-	-	-
Location 3 (suburban, outdoor)	L800	-45 dBm	-71 dBm	13 dB
	L1800	-61 dBm	-89 dBm	12 dB
	L2100	-57 dBm	-83 dBm	17 dB
	L2600*	-	-	-
Location 4 (urban, outdoor)	L800	-45 dBm	-75 dBm	12 dB
	L1800	-49 dBm	-78 dBm	17 dB
	L2100	-57 dBm	-88 dBm	20 dB
	L2600	-58 dBm	-90 dBm	16 dB
Location 5 (urban, indoor)	L800	-54 dBm	-79 dBm	16 dB
	L1800	-55 dBm	-83 dBm	20 dB
	L2100	-62 dBm	-88 dBm	19 dB
	L2600	-63 dBm	-91 dBm	25 dB
Location 6 (urban, indoor)	L800	-53 dBm	-78 dBm	14 dB
	L1800	-57 dBm	-85 dBm	16 dB
	L2100	-58 dBm	-87 dBm	20 dB
	L2600	-59 dBm	-90 dBm	13 dB
Location 7 (urban, outdoor)	L800	-55 dBm	-80 dBm	15 dB
	L1800	-60 dBm	-87 dBm	12 dB
	L2100	-61 dBm	-86 dBm	14 dB
	L2600*	-	-	-

*Serving cell is not capable of transmitting at the L2600 band.

where $P_{s,t}$ is the base station transmission power in dBm, G_s is the eNB antenna gain in dBi, L_t are the insertion losses and L is the path loss. Except for L, all these parameters are known and/or given by the operator. One base station may have a different transmission power for each frequency band. L is calculated using the path loss formulation including in the channel model [9] evaluated in [7]. Some additional losses are needed to be considered in some particular situations, e.g. a concrete terrain orography or measurements done from inside a car. Now, for LOS situation we have

$$\text{PL}_{\text{LOS}}\ [\text{dB}] = 22\log_{10}(d_{\text{3D}}) + 28 + 20\log_{10}(f_c) \tag{3}$$

where f_c is the carrier frequency and d_{3D} is the 3D distance between the corresponding eNB and the UE expressed in meters. It is defined as

$$d_{\text{3D}} = \sqrt{d_{\text{2D}}^2 + (h_{\text{eNB}} - h_{\text{UE}})^2}, \tag{4}$$

being d_{2D} the linear distance between the eNB and the terminal and h_{eNB} and h_{UE} the eNB and UE heights, respectively. All these variables are expressed in meters as well.

On the other hand, for the NLOS scenario the path loss is defined as

$$\begin{aligned}\text{PL}_{\text{NLOS}}\ [\text{dB}] = {} & 161.04 - 7.1\log_{10}(W) + 7.5\log_{10}(h) \\ & - \left[24.37 - 3.7\left(\frac{h}{h_{eNB}}\right)^2\right]\log_{10}(h_{\text{eNB}}) \\ & + \big(43.42 - 3.1\log_{10}(h_{\text{eNB}})\big)\big(\log_{10}(d_{\text{3D}}) - 3\big) \\ & + 20\log_{10}(f_c) - \big(3.2(\log_{10}(17.625))^2 - 4.97\big) \\ & - 0.6(h_{\text{UE}} - 1.5),\end{aligned} \tag{5}$$

TABLE III
DRIVE TEST RESULTS

	RSSI	RSRP	SINR
Position 1	-54 dBm	-87 dBm	-5 dB
Position 2	-59 dBm	-88 dBm	2 dB
Position 3	-58 dBm	-87 dBm	11 dB
Position 4	-61 dBm	-98 dBm	-4 dB
Position 5	-58 dBm	-90 dBm	-1 dB
Position 6	-60 dBm	-87 dBm	15 dB
Position 7	-50 dBm	-76 dBm	27 dB
Position 8	-60 dBm	-94 dBm	1 dB
Position 9	-63 dBm	-91 dBm	13 dB
Position 10	-68 dBm	-98 dBm	0 dB
Position 11	-62 dBm	-93 dBm	-5 dB
Position 12	-63 dBm	-92 dBm	10 dB
Position 13	-66 dBm	-94 dBm	9 dB
Position 14	-51 dBm	-80 dBm	11 dB
Position 15	-57 dBm	-84 dBm	12 dB
Position 16	-52 dBm	-79 dBm	20 dB
Position 17	-66 dBm	-98 dBm	0 dB
Position 18	-57 dBm	-90 dBm	10 dB
Position 19	-53 dBm	-82 dBm	8 dB
Position 20	-54 dBm	-87 dBm	11 dB
Position 21	-50 dBm	-79 dBm	9 dB
Position 22	-44 dBm	-75 dBm	24 dB
Position 23	-55 dBm	-86 dBm	12 dB
Position 24	-61 dBm	-94 dBm	10 dB

where W is the streets mean width and h is the buildings mean height, both expressed in meters.

Finally, for the O2I scenario we have

$$\text{PL}_{\text{O2I}}\ [\text{dB}] = \text{PL}_{\text{LOS}}\ [\text{dB}]\Big|_{d_{\text{3D}}^{\text{in}} + d_{\text{3D}}^{\text{out}}} + 20 + 0.5 d_{\text{2D}}^{\text{in}}, \tag{6}$$

where $d_{\text{3D}}^{\text{in}}$ and $d_{\text{3D}}^{\text{out}}$ are the 3D distances for the indoor and outdoor segments, respectively, and $d_{\text{2D}}^{\text{in}}$ is the linear distance for the indoor segment.

For accounting for the error that might exist between the measured values and the simulation output, we set the metric

$$\Delta[\text{dB}] = \big|\text{RSSI}_{\text{measured}}[\text{dBm}] - \text{RSSI}_{\text{simulated}}[\text{dBm}]\big|. \tag{7}$$

In Figure 2 this error metric is shown for every fixed location and frequency band. Since the path loss formulation cannot replicate every situation a mean UE may experienced and it is much more intended for generic scenarios, we consider an error up to 6 dB to be reasonable. In addition, this channel model is focused on transmission whose carrier frequency is between 2 and 6 GHz, so inaccuracy in the L800 and probably L1800 is expected. In most situations the results are fair enough, except for location 7 where we have a combination of mixed height buildings hard to replicate.

Figure 3 shows the evolution of the RSSI level throughout the 24 positions of the drive test. We can see that simulation hardly matches the measured values in some positions. The drive test represents a NLOS outdoor situation similar to fixed locations 4 and 7, however less information about the environment and obstacles in the surroundings are at hand, making it difficult to adjust the model. Note that doppler shift is not considered since the speed of the terminal while drive testing is considerably low.

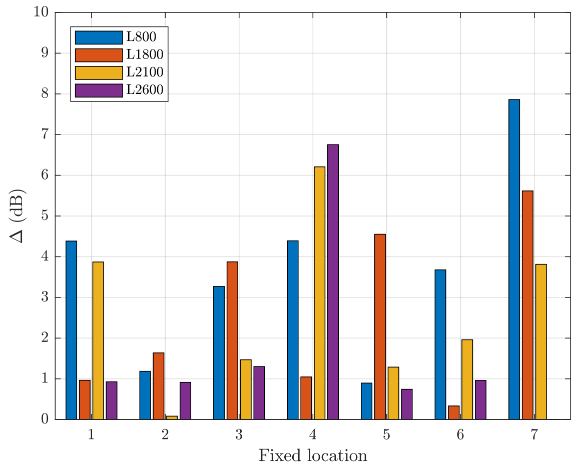

Fig. 2. Error measured for the fixed locations testing.

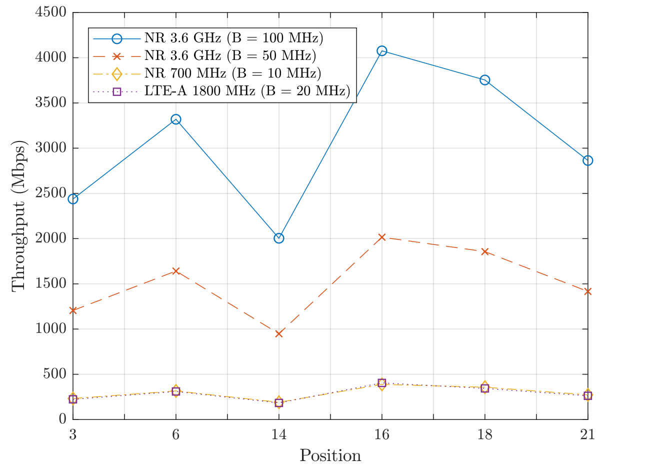

Fig. 4. Comparison between peak throughout for LTE-A and different configurations of 5G NR.

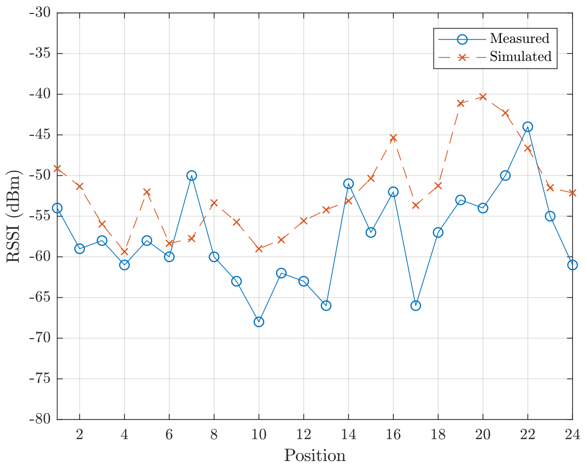

Fig. 3. Comparison between measured and simulated RSSI for the drive test.

IV. 5G NR Simulation

5G NR brings a much more flexible environment when talking about bandwidth adapting to different scenarios and services. First, numerologies are introduced which make subcarrier spacing (SCS) no longer fixed and vary the number of slots per frame [10]. Total transmission bandwidth with no carrier aggregation (CA) goes further ahead as well. Depending on the SCS and the frequency range, bandwidth goes up to 100 MHz for the traditional sub-6 GHz band and up to 400 MHz for the millimeter wave (mmWave) band [11], though higher values can be achieved with CA. In the end, higher bandwidth means more available physical resource blocks (PRBs) for resource allocation and thus, higher per user throughput. It worth noting that the latest releases of LTE-A brought a higher modulation order and an updated CQI reporting table [12], [13] that remains the same in 5G NR [14].

In this section we compare the simulated SINR level, CQI reporting value and user throughput in LTE-A and 5G NR for 6 of the 24 positions of the drive test, having the previous verified channel model as a basis. 3GPP introduced a new channel model intended for 5G NR communications [15], but the macroscopic path loss modeling is the same as in the channel model we used for LTE-A. CQI is derived from the estimated SINR value [16], which we defined as

$$\text{SINR} = \frac{P_{s,r}}{\sum_{i=1}^{N_i} P_{i,r} + N_0}, \quad (8)$$

where N_0 is the thermal noise power.

Thanks to the information provided by network suppliers, we know that 5G NR first deployments are set to work in the 3.6 GHz frequency band with SCS set to 30 KHz and up to 100 MHz of channel bandwidth. In addition, gNodeBs (gNBs), i.e. 5G NR base stations, will employ 64 elements antennas with the capability of performing 8x8 MIMO communications. For comparing with LTE-A, we set 5G NR SCS to 15 KHz with the maximum bandwidth of 50 MHz. Results are shown in Table IV. As expected, RSSI values for 5G NR are slightly lower than in LTE-A since the 3.6 GHz band suffers from higher path loss. SINR remains nearly the same nevertheless. The additional macroscopic losses affect the same way both the serving cell and the surrounding interferers, so these SINR values seem reasonable. The almost imperceptible difference between both technologies SINRs is because the thermal noise term ramps up a little bit due to the higher bandwidth that 5G NR uses. Bear in mind that modern cellular networks are interference limited systems.

Now, a much more realistic scenario supposes a SCS of 30 KHz for the 3.6 GHz 5G NR frequency band with a maximum bandwidth of 100 MHz. A part from the 3.6 GHz band, both a new 700 MHz and the 26 GHz band will be available in the future. Table V shows a comparison between the 700 MHz and the 3.6 GHz frequency bands. THe 26 GHz band is not considered in this work. For the 700 MHz band SCS is set to 15 KHz with a 10 MHz channel bandwidth, though this parameters are not official yet. The RSSI values at 700 MHz improve due to the higher penetration capacity of this band, though the SINR remains almost the same as at the 3.6 GHz band. The slight differences between them is again due to lower bandwidth and reduced thermal noise term.

User data rate not only depends on the signal quality, but also on the total number of users being served and

TABLE IV
LTE-A PRO AND 5G NR COMPARISON

	LTE-A Pro				**5G NR 3.6 GHz** (SCS = 15KHz)			
	RSSI	**SINR**	**CQI**	**Throughput**	**RSSI**	**SINR**	**CQI**	**Throughput**
Position 3	-55.9645 dBm	9.1123 dB	8	223.2562 Mbps	-61.9851 dBm	9.1119 dB	8	1.2056 Gbps
Position 6	-58.3404 dBm	13.3182 dB	10	303.9750 Mbps	-64.3610 dBm	13.3179 dB	10	1.6415 Gbps
Position 14	-54.2185 dBm	7.0019 dB	7	183.4875 Mbps	-60.2391 dBm	7.0017 dB	7	0.9483 Gbps
Position 16	-50.3487 dBm	17.3968 dB	12	404.7750 Mbps	-56.3693 dBm	17.3957 dB	12	2.0157 Gbps
Position 18	-51.2478 dBm	14.7715 dB	11	343.7437 Mbps	-57.2684 dBm	14.7710 dB	11	1.8562 Gbps
Position 21	-42.3012 dBm	11.2014 dB	9	262.2375 Mbps	-48.3218 dBm	11.2011 dB	9	1.4161 Gbps

TABLE V
5G NR COMPARISON

	5G NR 700 MHz (SCS = 15KHz)				**5G NR 3.6 GHz** (SCS = 30KHz)			
	RSSI	**SINR**	**CQI**	**Throughput**	**RSSI**	**SINR**	**CQI**	**Throughput**
Position 3	-47.7610 dBm	9.1121 dB	8	232.1865 Mbps	-61.9851 dBm	9.1119 dB	8	2.4380 Gbps
Position 6	-50.1369 dBm	13.3192 dB	10	316.1340 Mbps	-64.3610 dBm	13.3179 dB	10	3.3194 Gbps
Position 14	-46.0150 dBm	7.0020 dB	7	190.8270 Mbps	-60.2391 dBm	7.0017 dB	7	2.0037 Gbps
Position 16	-42.1452 dBm	17.3961 dB	12	388.2060 Mbps	-56.3693 dBm	17.3957 dB	12	4.0762 Gbps
Position 18	-43.0443 dBm	14.7719 dB	11	357.4935 Mbps	-57.2684 dBm	14.7710 dB	11	3.7537 Gbps
Position 21	-34.0977 dBm	11.2015 dB	9	272.7270 Mbps	-48.3218 dBm	11.2011 dB	9	2.8636 Gbps

the resource allocation strategy carried out by the network scheduler. Operators use highly complex machine learning-based schedulers whose PBR assignment to users cannot be predicted or simulated easily. All throughput values shown in both tables are peak values, i.e. all available PRBs are assigned to a single user. Nevertheless, these results give some insights about the improvement that 5G NR supposes in terms of user data rate over LTE-A. An overall comparison between simulated throughput is shown in Figure 4.

V. CONCLUSION

In this paper we have presented real LTE-A Pro measurements in a mean size city at fixed locations and performing a drive test. The 3GPP LTE channel model has been verified with simulations having an error that we consider low enough. Less optimistic results are obtained when simulating the results from the drive test, since reproducing each positions is tougher due to the lack of information for adjusting the path loss model. It is clear that a generic path loss model can hardly match real environment measurements in anyway. Field test trials will remain essential for network planning.

With simulated values, the SINR has been obtained derivating from it the corresponding CQI value and user throughput. Comparison between LTE-A and 5G NR with basic SCS has been presented, as well as comparison between two different 5G NR bands. Flexible numerologies give 5G NR the capacity to adapt to different use cases.

As future work, 5G NR measurement campaign should be carry out. This could give insights about the real performance of this technology and would help in adjusting channel models.

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