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Analysis of the Impact of Network Architecture on Signal Quality in LTE Technology

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Abstract: In this paper, the impact of the network architecture on signal quality in the fourth generation of the public mobile network is analyzed. The analysis was performed using RSRP (Reference Signal Received Power), RSRQ (Reference Signal Received Quality), SINR (Signal to Interference plus Noise Ratio) and throughput parameters in indoor environment. The signal quality parameters were collected by measurement using TEMS Investigation and TEMS Pocket software. The measurements were carried out at the School of Electrical Engineering on the ground floor of the Technical Faculty building for the macro and micro cell scenario. It has been found that better signal quality is ensured in micro cells. Quality of the signal is also considered by the various services provided to the users.

Keywords: LTE, Macro cell, Micro cell, RSRP, RSRQ, SINR, Throughput.

1 Introduction

Mobile radio communications have become a part of everyday life. In the last two decades, mobile communication systems have evolved from an expensive technology that only individuals could afford, to this day when they have become ubiquitous systems used by the majority of the world's population. LTE (Long Term Evolution) technology represents the fourth generation of mobile telecommunication systems. Compared to previous generation's technologies, LTE offers several benefits to operators and users. Improvements in system performance and capacity, better utilization of radio resources and reduced energy consumption are some of the main benefits.

One of the main challenges in radio communications is radio network optimization. In the first step, operators plan radio network deploying the base

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station [1]. After that, network optimization is performed, which requires testing the features on an active mobile network. For this reason, manufacturers of the telecommunication measurement equipment are tasked with finding the simplest way to measure the parameters which are needed for analysis of network performance.

In this paper, an experimental analysis of the performance of LTE technology was performed using an active mobile network on the ground floor building of the School of Electrical Engineering in Belgrade. Services such as web browsing, 32 B packet size ping, media streaming, 800 B packet size ping, file download and file upload were tested. These services represent typical services of LTE technology. In addition, considered services are the most commonly used services by students who spend time in the building of the School of Electrical Engineering. To analyze LTE network performances RSRP (Reference Signal Received Power), RSRQ (Reference Signal Received Quality), SINR (Signal to Interference plus Noise Ratio) and throughput, were used. Macro and micro cells scenarios were considered during measurements. A macro cell scenario is a case when end user equipment is serviced by a macro cell base station, and a micro cell scenario is when a micro cell base station does it. A comparative analysis of the results obtained in macro and micro cells scenarios was performed. All measurements were performed in the indoor environment.

Similar research has been performed within UMTS (Universal Mobile Telecommunication Systems) technology (third generation of public mobile network). In [2] it was shown that by installing the micro cells at appropriate distances from macro cells, it is possible to improve the functionality of the network. Network enhancement is shown through the achieved throughput, SNR (Signal to Noise Ratio) and the level of the receiving signal as parameter of signal quality in the UMTS network.

The rest of the paper is organized as follows. The second chapter discusses LTE technology, its basics, features and parameters of interest. Chapter three contains a description of used measurement procedure. In chapter four are presented the results of the measurements and a comparative analysis of the obtained results. Discussions on relationship between QoS (Quality of Service) and QoE (Quality of Experience) are given in chapter five. Finally, chapter six concludes the paper.

2 Long Term Evolution

2.1 Basic concepts of LTE technology

LTE is designated as fourth generation of radio technology. The goals of switching to LTE network technology are: providing higher data rate transmission to the end users, improving spectral efficiency, realizing significantly more efficient packet switching, improving and increasing the number of services and their implementation, translating the mobile network to a only packet network and better integration with existing standards of signal processing and transmission [3].

On the downlink, LTE uses an OFDMA (Orthogonal Frequency Division Multiple Access) multiple access system, which gives system that is more robust with increased capacity. Increasing the capacity of a telecommunication channel is achieved by multiplexing users' low rate data across channel with wide bandwidth, while robustness is achieved by allocating user traffic by frequency to avoid narrowband interference and multiple propagation fading. On the uplink it is used the SC-FDMA (Single Carrier - Frequency Division Multiple Access) multiple access system, which is the most important factor energy efficiency, to increase coverage and reduce user equipment cost and energy consumption. SC-FDMA has a low PAPR (Peak to Average Power Ratio) which is the main reason for using this technique on the upload communication side [4].

This approach, which is based on using two different systems on the downlink and uplink, ensures orthogonality among users, reducing interference and improving network capacity [4]. Depending on the available spectrum, the bandwidth can be selected in the interval from 1.4 MHz to 20 MHz. The 20 MHz bandwidth provides up to 150 Mb/s throughput on the downlink when is used 2x2 MIMO (Multiple Input Multiple Output) and up to 300 Mb/s when is used 4x4 MIMO system. Uplink data rates transmissions can reach up to 75 Mb/s.

2.2 Signal quality parameters of LTE technology

BER (Bit Error Rate) is the most commonly used parameter for evaluation of the performance of digital telecommunication systems. Some other parameters are used for assessing signal quality in some specific telecommunication systems to provide the best possible service to users. RSRP, RSRQ and SINR are signal quality indicators that are often used in optimization of the public mobile network of LTE technology.

RSRP represents the level of signal strength at the receiving side but does not show signal quality but it is an indicator of cell coverage [5]. The RSRP values are expressed in dBm and it is used as a metric for reselection and handover decision.

RSRQ is the parameter that indicates the quality of the received signal [5]. To get the final value of RSRQ, in the first, total signal (useful signal, interference and noise), which is received in one OFDM (Orthogonal Frequency Division Multiplex) symbol is measured, thereby is obtained the RSSI (Received Strength Signal Indicator) value. In parallel, the RSRP parameter value is also measured. The relation of these two parameters multiplied by the number of resource blocks gives a final value of RSRQ, which can be represented by the equation:

$$RSRQ = \frac{RSRP}{RSSI} N_{RB}, \tag{1}$$

where N_{RB} represents the number of resource blocks that depend on the bandwidth used in LTE technology.

SINR is the quality parameter that is measured by the user equipment, allowing the choice of the most appropriate modulation and coding scheme for the data transmission. Each resource block calculates SINR and user equipment converts obtained values to CQI (Channel Quality Indicator). After conversion, CQI values are being sent to the base station [6].

If the user is located in a rural area, only the RSRP level of signal is observed due to the small number of base stations, which are covering the area. However, if the user is in an urban area with a good level of RSRP, but there is a high interference due to the existence of several base stations in that area, a decision when is necessary that the user terminal served by another base station (make handover) or remain connected on the one that currently serving it, can be made based on level of RSRQ [7].

Throughput represents the bit rate per unit of time in digital telecommunication systems. Data rate transmission directly affects the performance of the public mobile network, and especially on the QoS based on packet switching [8].

3 Measurements

Measuring equipment consisted of laptop computer with TEMS Investigation software installed on it and mobile device Sony Xperia Z3 D6603 with TEMS Pocket software installed on user equipment. TEMS Investigation is a powerful software tool for optimization, verification, solving problems and maintaining public mobile networks. It collects and processes data from which performs real-time analysis. Software tool supports technologies like LTE (Frequency Division Duplex, FDD and Time Division Duplex, TDD), WCDMA (Wideband Code Division Multiple Access) / HSPA (High Speed Packet Access) / HSPA+, GSM (Global System for Mobile Communication) / GPRS (General Packet Radio Services, Wi-Fi (Wireless-Fidelity), etc.

The measurement procedure was performed at the ground floor of building of School of Electrical Engineering, University of Belgrade, for the macro and micro cell scenarios. Measurements were made during the working day due to the highest network load during that period. Telekom Srbija’s mobile network was used to test LTE technology services. All measurements were made in an indoor environment.

For testing purpose, a script was prepared within the TEMS software. The script consisted of several services running in the following order: 32 B packet size ping of google.com, blic.rs web browsing, 32 B packet size ping of private IP address, data download for 10 seconds, data upload for 10 seconds, google.rs web browsing, 3 MB size of data download, 1 MB size of data upload, YouTube web browsing, 800 B packet size ping of private IP address and streaming media from the YouTube. These services are usually used during the network drive test. As soon as one service was completed and the measurement of it was finished, another service was automatically started. It was taken a little more than three minutes to measure all of the parameters and services. In order to cover the entire hallway of the ground floor of the School of Electrical Engineering, it was necessary to repeat the script three times, so the measurement time was about nine and a half minutes.

Looking at Fig. 1, the starting point of the measurement was the right bottom corner of the hall (red circle). The measurement was continued by moving along the longer part of the hall to the left, then up and right to the middle of the up part of the hall (red arrows). In the central part of the hall was made a circle (blue arrows). After that circle, and returning to the middle of the upper part of the hall, the movement continued to the right up corner and finally, the movement was completed at the starting point (orange arrows). This way, the entire hall was covered.

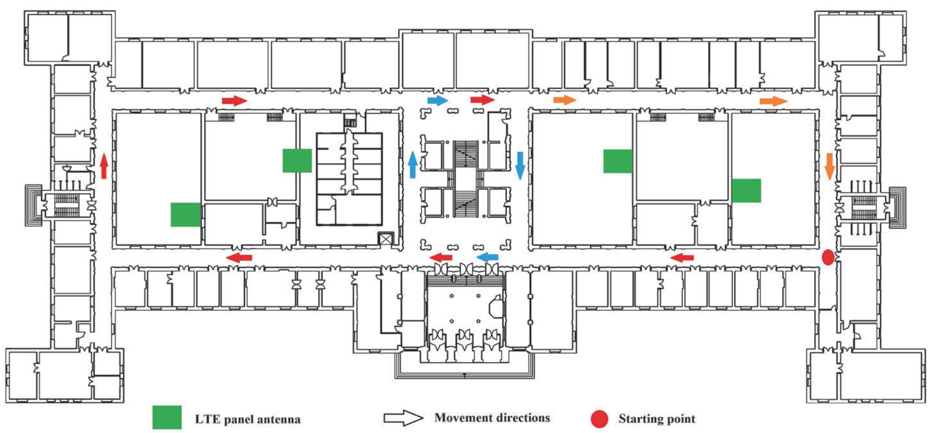


Fig. 1 – *Ground floor scheme of the School of Electrical Engineering with LTE technology base stations antenna layout.*

The location of the base stations antenna and the layout of the ground floor where measurements were performed are shown in Fig. 1. The positions of the LTE panel antennas are marked with green color.

4 Results

Obtained results are presented graphically, calculating CDF (Cumulative Distribution Function), similar as in [9], where the measurement was performed in outdoor environment. The range of referent values of RSRP, RSRQ and SINR parameters are shown in the **Table 1**. These parameters determine level of signal quality, that is, QoS provided to the user.

Table 1
Signal level values versus signal quality.

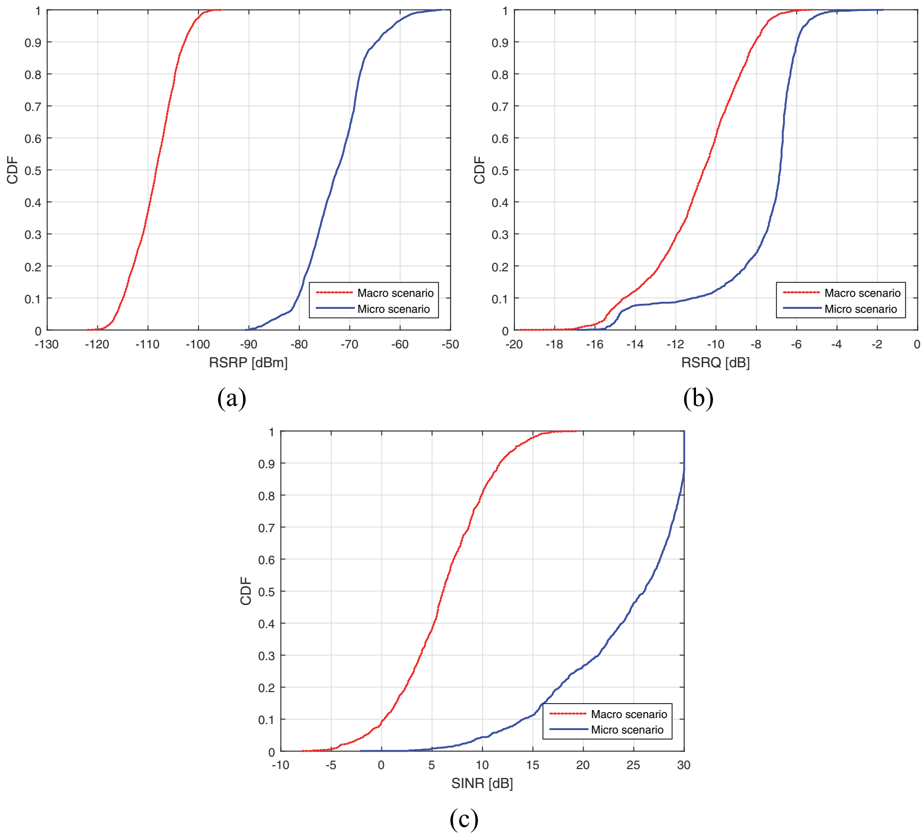
	Parameters	RSRP [dBm]	RSRQ [dB]	SINR [dB]
Signal quality	Excellent	> –84	> –5	> 12.5
	Good	–102 to -85	–11 to –6	10 to 12.5
	Fair	–111 to -103		7 to 10
	Poor	< –112	< –12	< 7

Level of RSRP for macro and micro cell scenarios is shown on Fig. 2a. Values of RSRP are in range from -120 dBm to -95 dBm for a macro cell scenario, so the values of signal include three levels from the **Table 1**, with poorer signal quality. About 25% of the measured signal values have poor quality, 70% have fair quality, while the remaining 5% have satisfactory signal quality. RSRP signal values are in range from –90 dBm to –55 dBm for micro cell scenario, which is excellent level of the signal based on data from **Table 1**. It can be concluded that the signal level is significantly better in the case of a micro cell scenario, which is expected, since the micro base station is located on the wall of the School of Electrical Engineering, so it provides better signal coverage.

Values in range from -11 dB to -6 dB represent good signal quality for RSRQ parameter. For the macro cell scenario, RSRQ has values from –20 dB to –5 dB, while for the micro scenario the RSRQ values are in range from –16 dB to –2 dB, which is shown on Fig. 2b. It can be seen that the level of RSRQ is better in the micro cell scenario as it expected due to the proximity of the micro base station to the user. In addition, both scenarios include all three signal quality levels presented in **Table 1**, with very few values of excellent signal quality.

Obtained results of SINR parameter are illustrated in Fig. 2c. As RSRP and RSRQ, SINR also has much better values of signal in micro cell scenario.

About 60% of all measured SINR values in macro cell scenario and only 2% in micro cell scenario have poor signal quality. A very high signal quality in micro cell scenario is shown with the 92% of all measured signals with values over 12.5 dB. In addition, in macro cell scenario, only the 6% of all measured values have signal with excellent quality.

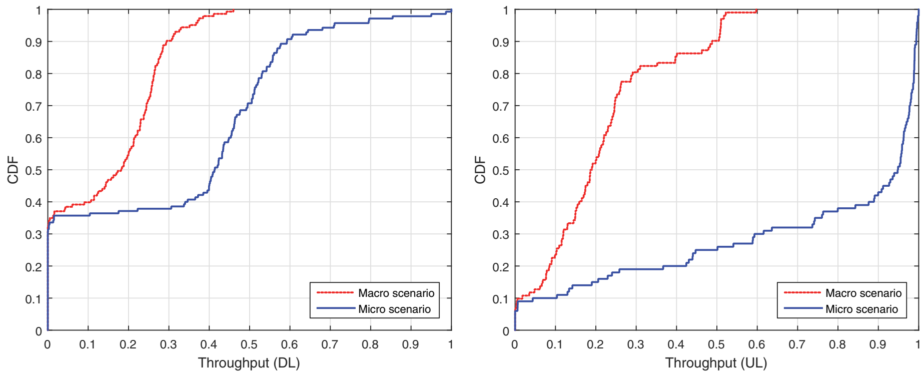


(a) (b) (c)

Fig. 2 – *Comparison of the CDF for the macro and micro cell scenario of* (a) *RSRP values;* (b) *RSRQ values;* (c) *SINR values.*

Results of throughput comparison for the two analyzed scenarios are shown on Fig. 3, where are illustrated downlink and uplink data transmissions using CDF. Fig. 3a presents normalized downlink throughput for the 10 seconds of data download service. Normalization is performed by dividing each throughput values by maximum measured value for the 10 seconds download service when the user equipment was served by micro cell. Higher throughput is achieved in the case of micro cell scenario compared to the macro cell scenario by about twice the value.

In the case of uplink data transmission for the 10 seconds duration data upload service, higher throughput values were achieved in micro cell scenario. The difference in the transmission rates between macro cell and micro cell scenarios is slightly smaller than in the case of downlink transmission. In this case, also, the values of throughput are normalized by maximum value of uplink throughput during 10 seconds data upload in the micro cell scenario. Fig. 3b shows the uplink throughput in macro cell and micro cell scenarios.

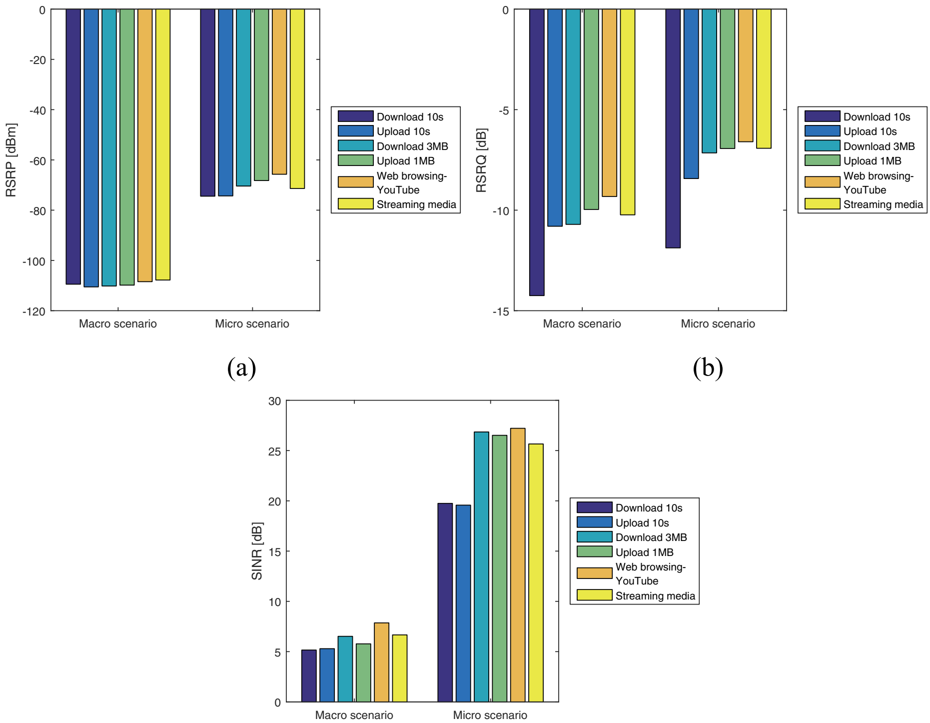


(a) (b)

Fig. 3 – *Throughput during 10 seconds for macro and micro cell scenario in case of* (a) *Download;* (b) *Upload.*

Fig. 4 presents signal quality in the form of RSRQ, RSRP and SINR in relation to the most common services provided to the users. The results are obtained after averaging the signal level after each of the three repetitions of the script during the measurement and the three new obtained values are averaged again. This is repeated for each service separately. Analyses are performed for data download for 10 seconds, data upload for 10 seconds, download 3 MB data, upload 1 MB data, loading YouTube and streaming media from YouTube. These services are selected because they are the most commonly used of all the measured services during the research. Required time to download 3 MB of data is significantly shorter than data download for 10 seconds because LTE technology provides very high rate of data transmission. The same goes for upload service.

The RSRP values in macro cell scenario indicate that for all services, the signal is at the border of fair quality, which significantly affects the communication performance. In addition, in the macro scenario, for most tested services, the RSRQ parameter has values around the boundary between fair (good) and poor. Poor signal quality occurs during 10 seconds data download, while for loading YouTube the signal was slightly better quality than the level of signals of other services. Similar results were obtained with the SINR parameter. All tested services have a poor level of signal quality except YouTube browsing where signal has a fair quality.

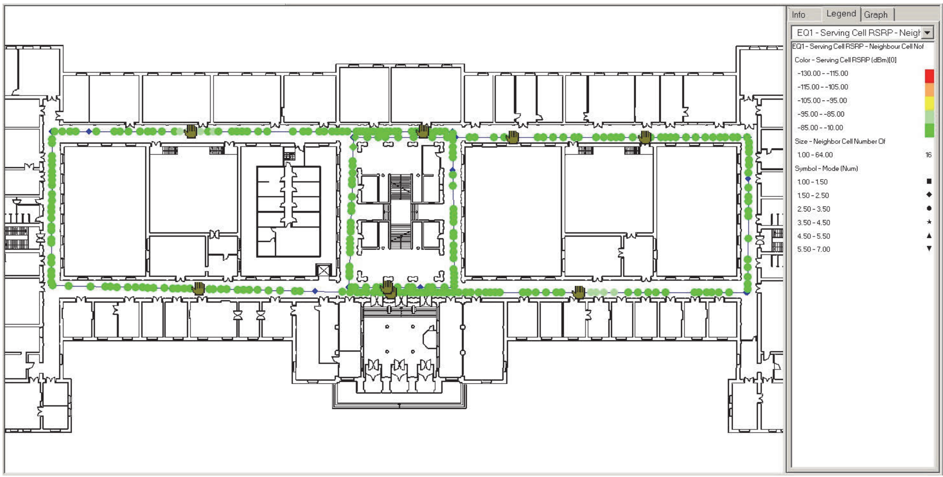


(c)

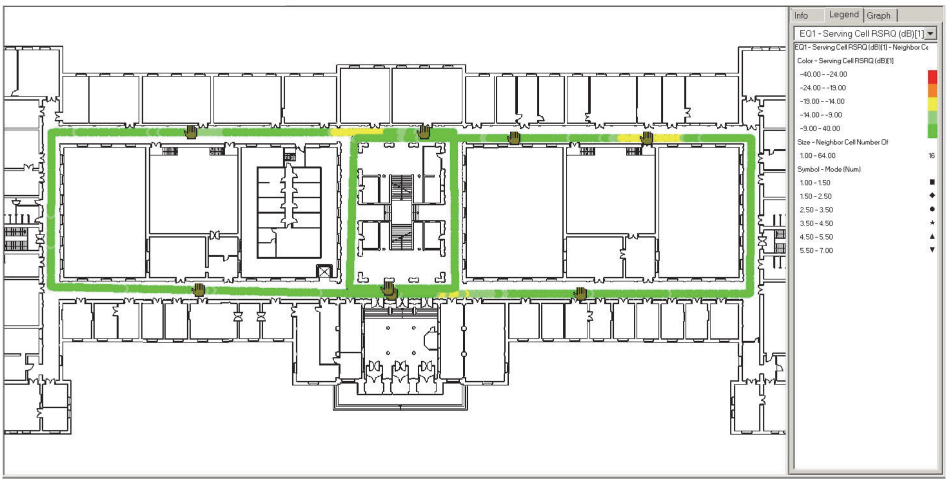
Fig. 4 – *Average values for the macro and micro cell scenario for different services in case of* (a) *RSRP; (b) RSRQ;* (c) *SINR.*

Different results were obtained in micro scenario. Observation of the RSRP parameter revealed a very high level of signal quality for all tested services. All values of RSRP parameter showed that is achieved an excellent level of signal when the micro cell base station serves the user equipment. The RSRQ parameter also gives slightly different results in scenario of micro cell. The data download during 10 seconds has poor level of signal, while all other services can be classified as signal with good quality when the values obtained from the measurement are compared with the values in **Table 1**. Values of SINR for all tested services are very high, so all have the excellent signal quality. Two services, data download and data upload during 10 seconds, have lower values than the other four, but still are about 7 dB higher than the border value of 12.5 dB.

Fig. 5 shows the RSRP and RSRQ levels of signal measured along the hallways of the School of Electrical Engineering in the micro cell scenario. Fig. 5a shows values of RSRP parameter. Based on the obtained results, it can be observed that the signal quality was extremely high all the time, so, it can be said that there is not any signal degradation occur.



(a)

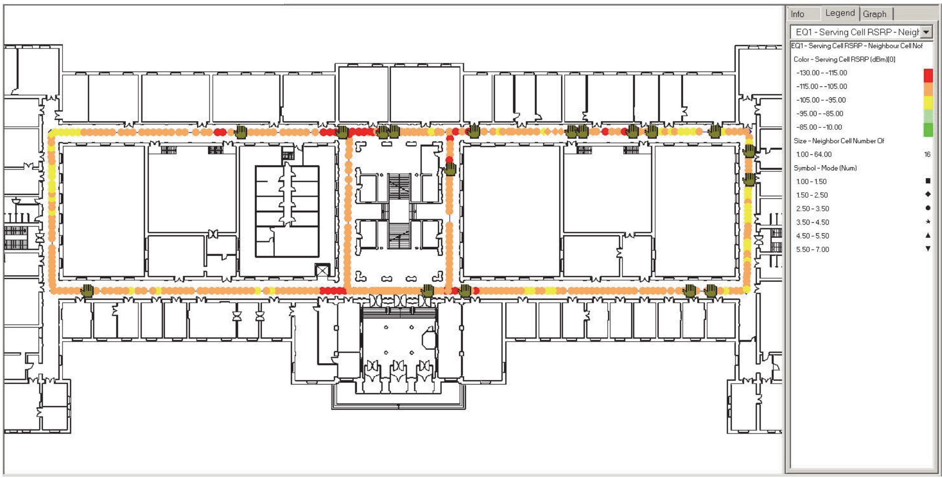


(b)

Fig. 5 – (a) *Level of RSRP;* (b) *Level of RSRQ; in micro cell scenario during the movement through the hall of School of Electrical Engineering.*

Values of RSRQ parameter are shown on the Fig. 5b. In this case, in some spots, there was some degradation of the signal to the poor level, according to **Table 1**. These points are colored in yellow and represent range values from

–19 dB to –14 dB. It is important to emphasize here that during the movement through the hallway and the measurements, eight handovers occurred between the four cells of micro base stations whose locations are shown in Fig. 1 and marked with the small hands.

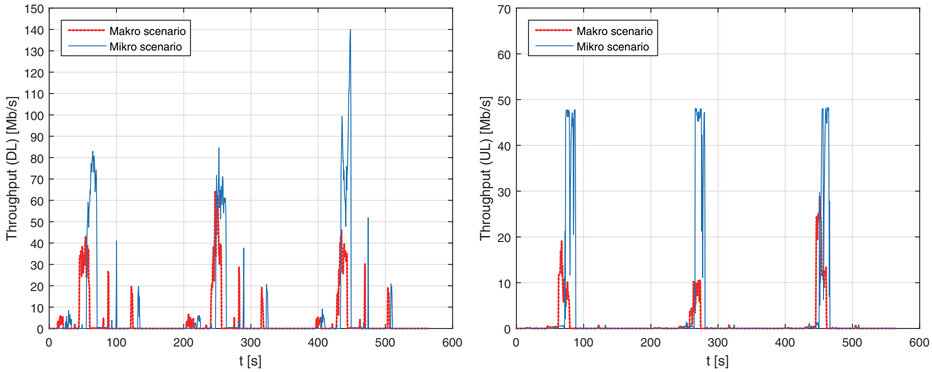


(a)

(b)

Fig. 6 – (a) *Level of RSRP;* (b) *Level of RSRQ; in macro cell scenario during the movement through the hall of School of Electrical Engineering.*

Fig. 6 illustrates the RSRP and RSRQ levels of signal in the macro cell scenario. Fig. 6a shows values of RSRP in the hall of the School of Electrical Engineering. There can be seen that there are not the values of signal with excellent quality. It can be said that most of measured signals have fair signal quality (orange points). There are, on some spots, signals with good (yellow points) and poor (red points) quality. The RSRQ parameter shows, on the Fig. 6b, that the most signal values have good (fair) quality (light green points). Some spots have better or worse signal, but same as RSRP, and RSRQ parameter gave the worse results in relation to micro cell scenario. In this case, it came to 18 handovers. It can be explained by the fact that the some macro base stations have the same coverage area. Also, micro base stations have better indoor environment coverage, so provide better service.



(a) (b)

Fig. 7 – (a) *Downlink;* (b) *Uplink; throughput values during the measurement.*

The values of throughput during the measurement on downlink and uplink in micro cell and macro cell scenarios are shown on Fig. 7. From the graphics, intervals in which three scripts were repeated can be seen. Fig. 7a shows the measurements obtained on the downlink, where can be seen that the data rate transmissions were significantly higher in micro cell scenario. That difference is greatest with the third repetition of the script, for 90 Mbps, within the data download service during 10 seconds. For other services, the differences in data rate transmissions for macro and micro scenarios are minimal. The maximum data rate transmission is achieved in micro cell scenario and it value is 140 Mbps.

The similar results are obtained on the uplink. The data rate transmissions were significantly higher within micro cell scenario when running all three scripts and the biggest difference was in the second repetition, where difference was about 40 Mbps. The maximum achieved data rate transmission was about 50 Mbps in the micro cell scenario. In the macro cell scenario, a maximum data rate transmission of 30 Mbps was achieved. Based on the obtained results, it can be concluded that 2×2 MIMO systems are used at the measuring location. In order to meet the needs of the users, it is necessary to ensure consistency at high data rates, especially at downlink (over 100 Mbps at any time).

5 QoE in radio network optimisation

The main goal of all operators is to provide the best possible service to the users. For this reason, during optimisation of public mobile network, it is necessary to take into account subjective quality assessments by users for different kinds of services. However, collecting subjective quality assessments can be long, tiredness and expensive. As a consequence, operators are changing legacy network management approaches, focused on network performance and QoS to a more modern approach focused on user opinion and quality of experience QoE [10]. Good network QoS parameters do not necessarily mean that the end user is satisfied with the provided service, since his satisfaction depends and on other factors. Thus, in order to measure the user satisfaction, it needs to define the QoE, which takes into account factors like expectation, requirements and perception of the user, content type provided by the service, user's device features, network QoS and the context in which the user is using the service, like the access type, movement and location [11].

Different models have been developed so far to map QoS to QoE. For example, mapping models for web browsing [11] and video transmission in wireless communications [12] are presented. The QoE data for the web browsing model was determined by applying a model that predicts the perceived quality for this type of service through the web page download time. The model was developed using machine learning techniques, more specifically the SVR (Support Vectors Regression) algorithm. The models take as input QoS metrics that can be measured, for instance, in drive tests. The models map these metrics in a single metric of QoE, the MOS (Mean Opinion Score) [11]. In [12], video dataset with network QoS parameters such as packet loss rate, jitter, delay and bandwidth are presented. The video dataset contain subjective assessments that can be helpful to create QoS to QoE mapping model for special radio network service - video transmission. Nowadays, radio network services such as live streaming video using YouTube or Facebook depends a lot on subjective perception [10]. The great challenge for all researcher is to create optimal and universal model for QoS to QoE mapping for all services which operators provide. After creation and testing, implementation of mapping models will significantly improve the network performance.

In addition, some QoS to QoE mapping models can be used to define decision to perform handover and improve it [13]. Existing handover algorithms consider radio (signal strength...) or QoS as context parameters for handover decisions, so there is plenty of space for improvement.

6 Conclusion

The impact of network architecture on the signal quality of the LTE communication system is presented in this paper. Through measured values of

RSRP, RSRQ and SINR parameters, it is shown that better signal quality is obtained for the micro cell scenario. In throughput analysis, it has been shown that even during download and upload communication, higher throughput is achieved within micro cell scenario, where the data rate transmissions are significantly higher than in the macro cell scenario. In the case of observing the tested services, the worst signal quality occurs during the 10 s data download, while the best quality is achieved loading YouTube. Due to the different coverage areas in the micro cell and macro cell scenario, the number of handovers in the macro cell scenario was more than twice as high as in the micro cell scenario.

Based on obtained results, further implementation of micro cell can improve the area coverage, signal quality. Different radio range and network characteristics in micro cells increase the transmission rate, while decrease traffic on the macro cells. Implementation of femto cell and pico cell can further improve the signal quality, transmission capacity and area coverage in urban environment, especially in indoor environment.

In the further work, it is possible to observe other services as well as other locations where measurements would be made. Also, measurements can be taken over several days to identify some regularities according to the number of users located at the observed location. Traffic in LTE technology is expected to increase in the Republic of Serbia, as implementation of this technology is still ongoing, so it is expected that different results may be obtained. It should be noted that preparations for the implementation of VoLTE (Voice over LTE) technology that will provide voice service, and this service, which is the least resistant to any interference with the wireless telecommunication channel, should be considered by some further analysis. Finally, it would expect more frequent implementation of QoE in the optimization of the public mobile network.

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