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MJERENJE I ANALIZA ZRAČNOG SUČELJA 4G I 5G MOBILNIH MREŽA NA ICT ZELENIM RUTAMA ZA REKREACIJU U GRADU ZAGREBU

MEASUREMENT AND ANALYSIS OF THE AIR INTERFACE OF 4G AND 5G MOBILE NETWORKS ON ICT GREEN ROUTES FOR RECREATION IN ZAGREB

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SAŽETAK

Dolazak 5G mreže u Hrvatsku potiče sve veću upotrebu mobilnih mreža u svim područjima ljudskog života pa tako i u sportu. Kako bi se vidjela mogućnost upotrebe mobilnih mreža u svrhu rekreacije, provedena su mjerenja zračnih sučelja 4G i 5G mobilnih mreža na 3 rute za rekreaciju u gradu Zagrebu. Napravljena je detaljna analiza važnih radijskih parametara koji su bitni za kvalitetan prijenos podataka između bazne postaje i korisnika te analiza kvalitete korisničkog iskustva (eng. *Quality of Experience* – QoE) kroz dva glavna parametra po kojima se promatra: brzina prijenosa korisničkih podataka u silaznoj vezi i kašnjenje (latencija, odziv) mreže. Dana je usporedba rezultata mjerenja za 4G i 5G mobilnu mrežu. Navedeni su mogući načini iskorištenja mobilnih mreža na izmjerenim rutama s obzirom na rezultate mjerenja.

Ključne riječi: *mjerenje, mobilne mreže, rekreacija, kvaliteta korisničkog iskustva, 5G*

ABSTRACT

The arrival of the 5G network in Croatia encourages the increasing use of mobile networks in all areas of human life, including sports. To see the possibility of using mobile networks for recreation purposes, measurements of air interfaces of 4G and 5G mobile networks on 3 routes for recreation in the city of Zagreb were carried out. A detailed analysis of important radio parameters that are essential for high-quality data transmission between the base station and the user was made, as well as an analysis of the quality of the user experience (QoE) through two main parameters that are observed: the speed of user data transmission in the downlink (downlink bit rate) and the delay (latency, response) of the network. The measurement results for 4G and 5G mobile networks are compared. The possible ways of using mobile networks on the measured routes are listed considering the measurement results.

Keywords: *measurements, mobile networks, recreation, quality of user experience, 5G*

1. UVOD

1. INTRODUCTION

Mobile networks are entering more and more areas of human life. One of these areas is sports and recreation. Mobile networks in sports can be used in different ways, especially with the arrival of 5G mobile networks: tracking athletes, results and sport match statistics using different sensors, broadcasting sports events in augmented reality, broadcasting from multiple cameras so that the viewer can choose which one he wants to watch, etc. For recreational athletes, it can make it easier to track results using smartphones, wearables (such as smart watches for example) and similar IoT (*Internet of Things*) solutions.

With the increasing number of smartphones and other wearables that have the ability to connect to the mobile network, there is also a greater possibility of impaired user experience. For user experience analysis, measurements were made on 3 recreational routes in the city of Zagreb as part of Zagreb University of Applied Sciences project *ICT green routes for recreation in the city of Zagreb*. The basic radio parameters and the quality of the user experience were analyzed to see whether users on the measured routes can use their devices for monitoring activities, streaming music, etc. The analysis is also necessary to see if there is potential for deploying IoT devices (for example, devices for measuring lap times, devices for monitoring the user's health condition, heart rate, blood oxygen saturation, etc.) that communicate via mobile networks. The analysis was made for 4G and 5G mobile networks, and the results were compared.

2. ALATI I PROGRAMI ZA MJERENJA

2. MEASUREMENT TOOLS AND SOFTWARE

Measurements were made with Nemo Handy [1] Android application. It can measure the air interface, quality of service and quality of user experience. The application supports all mainstream mobile technologies from GSM (*Global System for Mobile Communications*) to 5G NR (5G *New Radio*) in newer versions and other wireless technologies such as Wi-Fi, TETRA, etc. It was installed on the Huawei P40 Pro smartphone with which the measurements were made. This device belongs to the LTE Cat 21 category, which means that it can achieve a maximum bit rate of 1400 Mbps in the downlink and 300 Mbps in the uplink for the LTE technology.

The application measures the essential radio parameters of the air interface:

- strength of the received signal
- the quality of the received signal,
- signal to interference and noise ratio
- CQI (Channel Quality Indicator) and similar.

These are the parameters that are required for good signal transmission from the base station to the user's device (mobile phone, smart watch or other device connected to the mobile network). The application supports the *Forcing* option, which can lock the device only to a certain technology and/or frequency band we want to measure. This enables us to measure 4G and 5G technology separately. For the entire time of measurement, in addition to the measured parameters, GPS data about the route is saved.

Measurements in the application can be manual, scripted or automatic. Measurement results obtained from Nemo Handy A in a form of separated files for each route were thoroughly analyzed in *Nemo Outdoor* [2] program package.

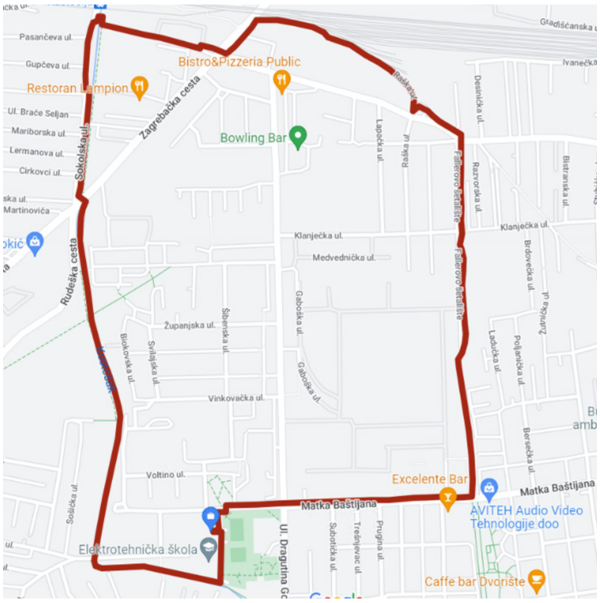
Nemo Outdoor is a *Windows* program that, in addition to measuring the air interface, enables the reproduction of measurements in real time and the analysis of measured results. Measurement results can be displayed graphically, tabularly, statistically or on a map along the GPS measurement route. Through *Nemo Outdoor*, it is possible to export measurement results to a .csv file for detailed analysis in *Microsoft Excel*.

3. RUTE I OPIS MJERENJA

3. MEASUREMENT ROUTES AND DESCRIPTION

Measurements were made on 3 recreational routes in the city of Zagreb, and the routes are named according to their locations: *Streams around the Voltino, Grmoščica viewpoints, All faces of the Dubravica stream.*

The Streams around the Voltino route (Figure 1) start at the Polytechnic of Zagreb in Konavoska Street, go along Matka Baštijana Street to Faller's Promenade, follow Faller's Promenade to Tomislavova Street, pass by the railway line to the Western Station, then along Zagrebačka Road to the Kustošak Stream, which is followed all the way back to the Polytechnic of Zagreb.

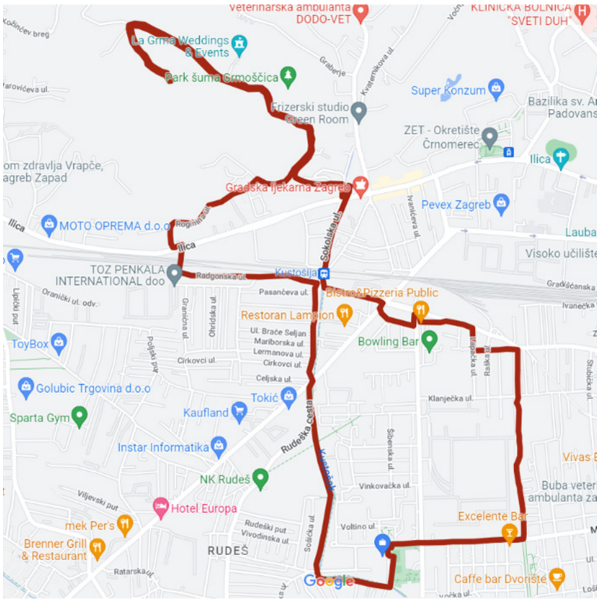


Slika 1 *Ruta mjerenja Potoci oko Voltinog*

Figure 1 *Streams around the Voltino measurement route*

Source: Author's work

Grmoščica viewpoints route (Figure 2) mostly coincides in the lower part with the route *Streams around the Voltino*, with some minor deviations, but it also includes a climb to the viewpoint Grmoščica.

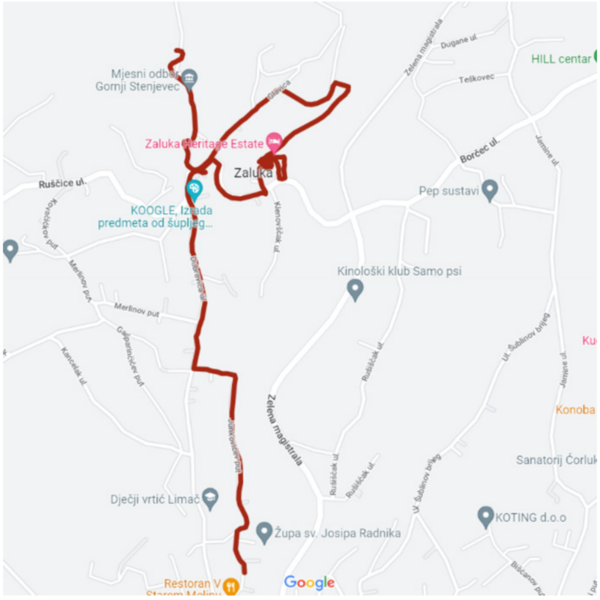


Slika 2 *Ruta mjerenja Vidikovci Grmoščice*

Figure 2 *Grmoščica viewpoints measurement route*

Source: Author's work

The route *All faces of the Dubravica stream* (Figure 3) starts next to the parish of St. Josip Radnik and the manor house of the Junković estate and continues to the north along the promenade along the Dubravica stream towards the retention of the Mačkovec stream. After that, the route leads to Zaluka and continues along Dubravica Street past the old mill to the northernmost point on the route.



Slika 3 *Ruta mjerenja Sva lica potoka Dubravica*

Figure 3 *All faces of the Dubravica stream measurement route*

Source: Author's work

Mladen Sokele Ph.D., project leader of the *ICT green route for recreation in the city of Zagreb*, carried out Route mapping within the Jane's walk initiative - Mapping Trešnjevka [3].

The Streams around the Voltino route is in the urban area, the Grmoščica viewpoints route passes through both urban and rural areas in the part of the ascent to the viewpoint, and the *All faces of the Dubravica stream* route is located on the urban/rural border.

All measurements were made with a Huawei P40 Pro device with the Nemo Handy application installed. As mentioned before, scripted measurements were used. This means that a script with predetermined steps is continuously executed in the measurement application. The script ends after a predetermined time or can be stopped manually when the desired route has been measured. The script with which the measurements were made consists of the following steps:

- 5 seconds of pause
- 15 seconds of downloading the test file
- 10 seconds of pause

- 10 seconds of pinging Google's DNS server
- 10 seconds of pause.

Two measurements were made on each of the 3 routes, one for the 4G network and one for the 5G NR NSA (*New Radio Non-standalone*) network. The measurements were made one after the other to achieve approximately the same conditions for both measurements, i.e., to reduce the influence of the network load on the measurement results. The goal was to achieve conditions that are as close as possible to those as if we were measuring 4G and 5G networks in parallel. Measurements were made while walking.

The 4G measurement on the route was performed while the measuring device was locked to the LTE (*Long Term Evolution*) air interface and measured only the 4G network. In 5G measurements, the device was locked to the LTE + NR air interface. The reason for this is that the current 5G networks in Croatia are so-called non-standalone networks and still use the core networks of the 4G system.

5G NR NSA brings improvements only in the radio part of the network, and in the transport domain it has performance similar to the 4G network. It brings improvements in only one of the 3 main use-cases of 5G networks - eMBB (*enhanced Mobile Broadband*). To achieve improvements in the remaining 2 usage scenarios mMTC (*massive Machine Type Communications*) and URLLC (*Ultra Reliable Low Latency Communications*), it will be necessary to wait for the arrival of a standalone 5G network. In 5G measurement, the device switches between 4G and 5G networks depending on signal availability as it would do in normal use.

The date and time of measurement of certain technologies on certain routes can be seen in Table 1.

4. MJERENI PARAMETRI
4. MEASURED PARAMETERS

For both measurements (4G and 5G), two main QoE were measured: Application Throughput (bit rate) and ping RTT (*Round Trip Time*). In addition to these 2 parameters, the radio parameters of cellular measurements were also measured:

- RSRP (*Reference Signal Received Power*),
- RSRQ (*Reference Signal Received Quality*) and
- SINR (*Signal to Interference plus Noise Ratio*).

When measuring the 5G NR NSA network using the *Packet technology* parameter, we can monitor which technology is used for data transmission between the base station and the user's device, in other words, at what moments the 5G NR NSA network is used. The *Packet Technology* parameter for our measurement settings can achieve the values LTE DL CA (*Long-Term Evolution Downlink Carrier Aggregation*), LTE FDD (*Long-Term Evolution Frequency Division Duplex*) and EN-DC (*E-UTRAN New Radio Dual Connectivity*). EN-DC is a dual connection mode in which the user device is simultaneously connected to the LTE and NR networks, i.e., to the LTE network for the control plane and the NR network for the user plane. When the parameter achieves the value EN-DC, the device is connected to the 5G NR NSA network. In this way, we can see what percentage of the time the measuring device is connected to the 5G network.

Route	Date	4G / 5G measurement	Start of the measurement	End of the measurement
Streams around the Voltino	13.10.2022.	4G	16:00:13	16:44:30
		5G	15:13:42	15:59:04
Grmoščica viewpoints	14.10.2022.	4G	18:58:07	20:19:48
		5G	15:10:46	16:53:40
All faces of the Dubravica stream	14.10.2022.	4G	21:26:56	21:59:57
		5G	21:00:18	21:26:17

Tablica 1 *Vrijeme mjerenja na pojedinim rutama*

Table 1 *Measurement time on individual routes*

Source: Author's work

Ideal RF conditions	Excellent	Good	Mid Cell	Bad Cell
RSRP [dBm]	>= -80	-80 do -90	-90 do – 100	<= -100
RSRQ [dB]	>= -10	-10 do -15	-15 do -20	< -20
SINR [dB]	>=20	13 do 20	0 do 13	<= 0
RTT [ms]	0 do 10	10 do 50	50 do 100	>= 100

Tablica 2 *Referentne vrijednosti mjerenih parametara*

Table 2 *Measured parameters reference values*

Source: Author's work

Table 2 lists the reference values of the parameters that were used to analyze the measurement results and assess the quality of the network based on the comparison of the measured values of the parameters in comparison with the reference values. The values listed in the table were obtained from experience with previous measurements [4], and correspond to the reference values set by Nemo Outdoor. It should be noted that 5G eMBB brings only small improvements in terms of 5G latency. Therefore, the RTT limit values in the table are valid for both 4G and 5G, with the note that for 5G we expect most of the measured values to be excellent (less than 10 ms).

5. REZULTATI MJERENJA RADIJSKIH PARAMETARA

5. RADIO PARAMETERS MEASUREMENT RESULTS

The results of the measurement of the radio parameters are presented in tables containing the average values of the measured parameters and the distribution of the parameters in percentages by ranges from Table 2. For the LTE measurement, the radio parameters of the LTE air interface are shown, and for the 5G NR NSA measurement, the radio parameters of the NR and LTE air interface are shown because the radio LTE air interface parameters can affect the overall quality of user

Route	**Streams around the Voltino**				
	4G measurement (LTE only)				
Parameter	**Average**	**Excellent**	**Good**	**Mid Cell**	**Bad Cell**
RSRP (dBm)	-72,8	26,28 %	36,82 %	30,61 %	6,29 %
RSRQ (dB)	-9,5	40,92 %	54,40 %	4,66 %	0,02 %
SINR (dB)	5,78	0,00 %	3,59 %	88,77 %	7,64 %
	5G NR NSA measurement (LTE 7,7 %; EN-DC 92,3 %)				
	NR radio parameters				
RSRP (dBm)	-70,5	28,45 %	37,26 %	29,12 %	5,17 %
RSRQ (dB)	-11,3	0,26 %	96,26 %	3,40 %	0,08 %
SINR (dB)	10,56	10,50 %	23,93 %	59,05 %	6,52 %
	LTE radio parameters				
RSRP (dBm)	-72,7	23,15 %	33,34 %	35,34 %	8,18 %
RSRQ (dB)	-8,3	62,43 %	34,54 %	3,02 %	0,01 %
SINR (dB)	6,12	0,00 %	4,48 %	89,49 %	6,03 %

Tablica 3 *Rezultati mjerenja na ruti Potoci oko Voltinog*

Table 3 *Measurement results for the Streams around the Voltino route*

Source: Author's work

experience results in 5G measurement. For the 5G measurement, the percentage of connection time with the 5G network is also shown.

Measurement results for *Streams around the Voltino* route are shown in Table 3.

On the *Streams around the Voltino* route, LTE RSRP parameter values are mostly in the Good and Mid-cell ranges, the RSRQ parameter is over 90% in the excellent and good ranges. The measured values of the SINR parameter are somewhat worse, but still, over 88% of them are in the mid-cell range.

For the 5G measurement, we can see that the device is connected to the 5G network 92,3% of the time. LTE radio parameters keep approximately equal average values and range distributions. For the values of NR radio parameters, we can notice that we have a better average value of the SINR parameter even with a worse received signal power (RSRP) and signal quality (RSRQ). We can attribute that to the fact that the 5G network operates in a different frequency band than the LTE network, the number of users is still relatively small, so the interference is also low.

The measured operator's LTE network operates on frequency bands around 800 MHz (LTE band 700, LTE band 800) and 2 GHz (LTE band 1800, LTE band 2100). The 5G network of the measured operator operates in the frequency range of around 3,5 GHz (NR n78 TDD).

Measurement results for *Grmoščica viewpoints* route are shown in Table 4.

On the *Grmoščica viewpoints* route, we can notice that the device was connected to the 5G network only 14.7% of the time. These are unexpected results because almost half of the *Grmoščica viewpoints* route coincides with the *Streams around the Voltino* route where the device was connected to the 5G network over 90% of the time. A more detailed analysis of the *Packet Technology* parameter, which tells us how much time the measuring device was connected to the 5G network, will be given in Chapter 6.

All average values of measured radio parameters (for both measurements) are worse than the measured values on the route *Streams around the Voltino*. In contrast to the measurements on the *Streams around the Voltino* route, a higher percentage of the measured parameter values are in the Mid-cell and Edge-cell ranges, which confirms the fact that the average values are worse. Nevertheless, the value of the 5G SINR

Route	**Grmoščica viewpoints**				
	4G measurement (LTE only)				
Parameter	**Average**	**Excellent**	**Good**	**Mid Cell**	**Bad Cell**
RSRP (dBm)	-72,7	26,26 %	19,29 %	23,69 %	30,75 %
RSRQ (dB)	-10	33,06 %	51,51 %	15,36 %	0,07 %
SINR (dB)	4,20	0,00 %	3,97 %	73,49 %	22,54 %
	5G NR NSA measurement (LTE 85,3 %; EN-DC 14,7 %)				
	NR radio parameters				
RSRP (dBm)	-78,9	19,00 %	36,29 %	26,57 %	18,14 %
RSRQ (dB)	-11,6	0,43 %	94,24 %	5,16 %	0,17 %
SINR (dB)	8,96	5,50 %	29,75 %	52,79 %	11,95 %
	LTE radio parameters				
RSRP (dBm)	-73,5	22,45 %	21,84 %	29,61 %	26,10 %
RSRQ (dB)	-9,7	38,55 %	49,07 %	12,28 %	0,10 %
SINR (dB)	4,16	0,00 %	2,65 %	78,12 %	19,24 %

Tablica 4 *Rezultati mjerenja na ruti Vidikovci Grmoščice*

Table 4 *Measurement results for the Grmoščica viewpoints route*

Source: Author's work

Route	All faces of Dubravica stream				
	4G measurement (LTE only)				
Parameter	**Average**	**Excellent**	**Good**	**Mid Cell**	**Bad Cell**
RSRP (dBm)	-88,3	4,67 %	10,11 %	35,32 %	49,90 %
RSRQ (dB)	-8,6	68,47 %	30,29 %	1,24 %	0,00 %
SINR (dB)	6,84	0,00 %	6,77 %	89,47 %	3,76 %
	5G NR NSA measurement (LTE 89,8 %; EN-DC 10,2 %)				
	NR radio parameters				
RSRP (dBm)	-99,8	0,00 %	0,00 %	33,90 %	66,10 %
RSRQ (dB)	-10,8	0,00 %	100,00 %	0,00 %	0,00 %
SINR (dB)	14,67	6,78 %	59,89 %	33,33 %	0,00 %
	LTE radio parameters				
RSRP (dBm)	-89,9	1,48 %	17,65 %	40,92 %	39,96 %
RSRQ (dB)	-9,5	38,16 %	57,34 %	4,49 %	0,01 %
SINR (dB)	4,89	0,00 %	1,44 %	90,89 %	7,67 %

Tablica 5 *Rezultati mjerenja na ruti Sva lica potoka Dubravica*

Table 5 *Measurement results for the All faces of Dubravica stream route*

Source: Author's work

parameter is again better (about 5 dB higher) compared to the LTE SINR.

Measurement results for *All faces of Dubravica stream* route are shown in Table 5.

On the *All faces of Dubravica stream* route, the device was connected to the 5G network only 10,2 % of the time. This was expected considering the location of the route, which is on the urban/rural border.

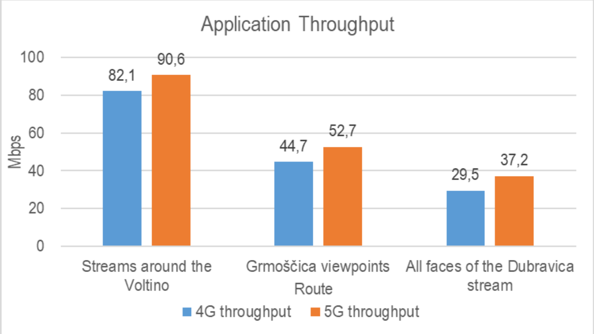
Nevertheless, thanks to its position and assumed lower network load and interference, better LTE SINR parameter values were achieved compared to the measurement on the *Grmoščica viewpoints* route, even with a worse received signal power (RSRP about 16 dB lower) of the received LTE signal. The quality of the received LTE signal is slightly better compared to the *Grmoščica viewpoints* route (1,4 dB in LTE measurement and 0,2 dB in 5G measurement).

The value of the 5G SINR parameter is again much better (7 to 10 dB higher) compared to the LTE SINR even with the worse 5G RSRP (about 10 dB lower compared to the LTE RSRP). With coverage of only 10,2 % in the measurement that lasted 26 minutes, we conclude that the device was connected to the 5G network for less than 3 minutes and that the 5G network in this case will have minimal or no impact on the quality of the user experience in the 5G measurement.

6. QOE I PACKET TECHNOLOGY ANALIZA

6. QOE AND PACKET TECHNOLOGY ANALYSIS

Figure 4 contains measurement results of the Application Throughput average values on all routes.



Slika 4 *Prosječne brzine prijenosa podataka na mjerenim rutama*

Figure 4 *Average data throughput on measured routes*

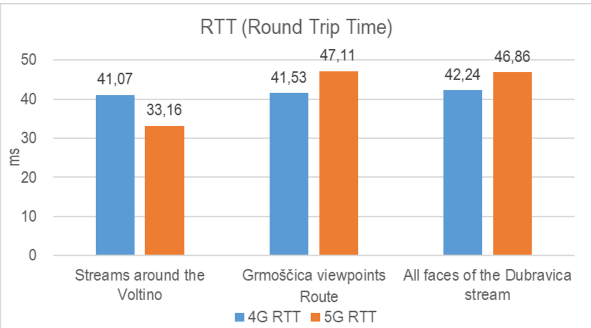
Source: Author's work

From the graph, we can conclude that the transmission bit rates follow the radio conditions on the routes and the percentage of time the device is connected to the 5G network. The better the radio conditions and the percentage of the device's connection to the 5G network, the better bit rates the user will be able to achieve. The highest average bit rates for both measurements were measured on the *Streams around the Voltino* route, which is expected given that the route is located entirely in the city.

On the *Grmoščica viewpoints* route, the average data transfer rate is approximately two times lower because the route also passes through the forest outside the city to the viewpoint Grmoščica. It is precisely on this part of the route that the radio conditions are worse than the urban part of the route, which contributes to the overall worse values of the parameters of the quality of the user experience.

On *All faces of the Dubravica stream* route, the worst values of bit rates were measured for both measurements. This also corresponds to the radio conditions on the route, as the measured values of the radio parameters on this route were the worst, as well as the percentage of time the device was connected to the 5G network.

Figure 5 shows a graphic representation of the results of the measurement of the RTT parameter on the measured routes.



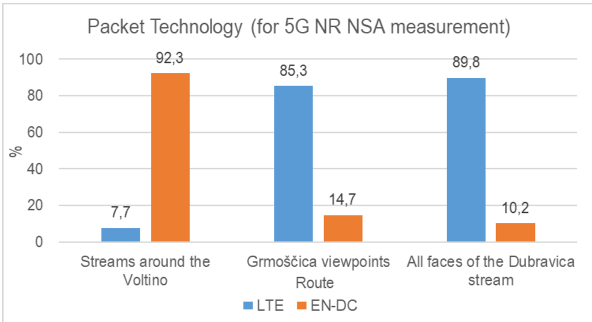
Slika 5 *Prosječne vrijednosti parametra RTT na mjerenim rutama*

Figure 5 *Average Round Trip Time on measured routes*

Source: Author's work

On all routes, the average values of the RTT parameter below 50 ms were measured for both measurements. We can consider these as good values for a 4G network and the user will have a good experience of using mobile devices on routes for common needs (audio streaming, video streaming, applications for monitoring sports activities, social networks, etc.). Nevertheless, these RTT values are too high even for 4G for some advanced use cases like for example online gaming. On all three routes, the average measured values of 4G RTT differ by only about 1 ms. On the route *Streams around the Voltino*, the 5G RTT value is almost 10 ms better than the 4G measurement, while on the remaining two routes, the 5G RTT is worse than the 4G RTT, but not significantly. These are bad values for 5G measurements considering that the 5G network wants to achieve an RTT of 1ms or less in some applications. 5G RTT represents the RTT for the entire 5G measurement, not just for the moments when the device was connected to the 5G network. The time the device was connected to the 5G network on a particular measurement route will be shown below.

Another parameter that is interesting to observe for this measurement is *Packet Technology*. As mentioned before, it is a parameter that shows which technology is used for data transmission between the base station and the user device. The graphical representation of measurement results for the *Packet Technology* parameter is shown in Figure 6.



Slika 6 *Packet Technology - vrijeme povezanosti s 5G mrežom*

Figure 6 *Packet Technology - connection time to 5G network*

Source: Author's work

While the parameter value is EN-DC, the device is connected to the 5G NR NSA network. On the *Grmoščica viewpoints* route, device is connested to 5G NR NSA network for only 14,7 % of the time while on the *Streams around the Voltino* route, this value is much higher, 92,3%. Since these are routes that overlap in almost half of their length, the result for the *Grmoščica viewpoints*

***Slika** 7 Packet Technology na rutama Potoci oko Voltinog i Vidikovci Grmoščice*

***Figure** 7 Packet Technology on the Streams around the Voltino and Grmoščica viewpoints routes*

Source: Author's work

route is very bad. Figure 7 shows the detailed results and the distribution of values along the route for measurement of *Packet Technology* parameter on these two routes on the map.

From the map view, it is evident that the device is not connected to the 5G NR NSA network in the same places in the overlapping parts of the routes. The measurement was made with only one day of difference (both on a working day after 3 p.m.). Unfortunately, we cannot conclude what caused this behavior of the network. The operator uses DSS (*Dynamic Spectrum Sharing*) technology with which it can dynamically allocate network resources between 4G and 5G networks that can use the same spectrum in this way. We can assume that the network load while the *Grmoščica viewpoints* route was being measured was higher compared to the day before, so the operator allocated resources in such a way as to serve a larger number of 4G users. Also, one of the possible reasons is that on that day the operator was carrying out maintenance or upgrading the 5G network, so it was not fully available. The third reason could be the larger number of 5G users at that time on the measured route who required high data transfer speeds, so more spectral resources were allocated to them. We see that it is not only the coverage of the 5G signal that is important but also the way in which the operator allocates 5G resources to users.

7. ZAKLJUČAK
7. CONCLUSION

Detailed measurements and analysis of the results for three recreational routes in the city of Zagreb were made with Nemo tools.

The quality of the mobile network on measured routes will meet the needs of the average user of a mobile device. However, the further we move away from the city center towards forest and rural areas, the radio conditions become worse, and thus the quality of the user experience. This is evident from the large difference in measured bit rates on the *Streams around the Voltino* route, which runs entirely through the city, and the *All faces of the Dubravica stream* route, which is located on the border between the urban and rural areas. At no time was there a complete interruption of service, which can be essential in the need to call emergency services in the case of an injury or accident on recreational routes.

The measured network performance and capacity it offers can support the deployment of IoT devices for simpler applications such as results tracking and user registration via NFC (*Near Field Communication*) or QR code. More demanding applications that require a larger amount of data transmission, such as video monitoring of routes, live video monitoring of athletes by drones, etc., could only be realized on the route *Streams around the Voltino* but would also need lower RTT values at this route for such applications. None of the measured RTT values in both measurements were excellent (less than 10ms), and real-time remote control of drones or other devices requires a latency of 1ms or even less.

The difference in user experience between 4G and 5G networks is not significant, and in some cases the 5G network is even worse than 4G. We also saw from the measurement results that the 5G NR NSA network is not consistent and that its availability depends on the network load and user requirements.

The situation is likely to get better when operators launch stand-alone 5G networks that will bring improvements to all 5G network use cases and enable new applications. After the implementation of a stand-alone 5G network by the operator, measurements can be repeated to investigate the QoE improvements when 5G network is upgraded.

8. REFERENCE

8. REFERENCES

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