TECHNICAL UNIVERSITY OF GABROVO

Faculty of Electrical Engineering and Electronics

Department “Communication Equipment and Technologies”

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MANAGEMENT OF THE PERFORMANCE AND QUALITY OF SERVICE IN MOBILE BROADBAND NETWORKS

A U T H O R’s S U M M A R Y

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The dissertation paper was presented and sent for official defense at the session of the Extended Departmental Council of the Department of Communication Equipment and Technologies at the Faculty of Electrical Engineering and Electronics at the Technical University - Gabrovo, held on 24.01.2024.

The dissertation contains 171 pages. The scientific part is presented in: an introduction, five chapters and a conclusion, includes 150 figures and 32 tables. 142 literary sources and 42 internet addresses are listed. The numbering of figures, tables and formulas in the abstract are consistent with that in the dissertation.

The research of the dissertation work was carried out at the Department of "Communication Techniques and Technologies" of the Faculty of Electrical Engineering and Electronics of the Technical University - Gabrovo and on the territory of the city of Gabrovo and Skopje.

The official defense of the dissertation paper will take place on April 26, 2024 at 1:00 p.m. in room 2215, Academic Building 2 (Bajdar) of the Technical University - Gabrovo.

The materials related to the defense of the dissertation are available to those who are interested, in office 3209, building №3, at the Technical University - Gabrovo.

The remarks and opinions from the members of the scientific commision and the abstract are published on the website of the university: www.tugab.bg .

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I. GENERAL CHARACTERISTICS OF THE DOCTORAL DISSERTATION

Relevance of the topic:

The existence and construction of a quality mobile Telekommunications infrastructure and a technologically advanced mobile network must be owned and upgraded by each mobile operator of electronic communications networks, because mobile broadband requires fast and always-on Internet access and connections that support the transmission of innovative contents and services. On the other hand, compared to traditional slower data transfers, mobile broadband can access the Internet instantly and transfer large amounts of data, reducing waiting times and improving efficiency for users.

This doctoral dissertation paper analyze the ways to regulate and implement the main parameters that must be respected by an operator of a public electronic communication network in order to implement the strategy itself and the requirements for broadband Internet, as well as to enable quality services through mobile cellular networks.

The subject of the dissertation paper is the management of efficient and quality services in broadband mobile networks, where the main emphasis is placed on the evaluation of the channel's parameters as well as the dependencies between them, determining the quality of the signals and the efficiency of the network.

Purpose and tasks of the dissertation paper:

The aim of the dissertation paper is to present and research the processes of mobile radio coverage by synthesizing analytical dependencies, simulation models, as well as implementing practical experimental results, which will lead to opportunities to improve routing efficiency and service quality in mobile broadband. networks.

For realization of the formulated goal, it is necessary to answer the following main tasks:

1. Creation and description of an analytical methodology for designing and calculating the parameters of a broadband mobile network.
2. Development and synthesis of a simulation model in Matlab's Simulink graphical environment to study WCDMA (End-to-End Physical Layer) for studing the performance of the broadband mobile network model.
3. Carrying out research on the parameters of a broadband mobile network and possibilities for improving the quality of services in a densely populated urban area and statistical processing of the results.
4. Implementation of practical measurements of coverage and broadcasting of the mobile operators in the Macedonia to make an independent assessment of the quality of the provided radio coverage and to propose methods and measures for its improvement.

Researching methods:

Researching methods are mainly identified in separate chapters, such as analytical, simulation and practical methods, and cover the dependence of parameters that characterize the implementation of individual models.

The research place is an example for the practical research of the communication channel in a certain part of the the coverage area in the wireless network. The software environments Matlab/Simulink, TEMS Investment, Ariesso etc. were used for the simulation studies. Exemplary models of radio coverage in a broadband mobile network, using the wireless channels are presented through the simulation models that demonstrate the mutual correlation and dependence of the parameters in them.

Scientific news:

These are different processes at the physical level related to the communication channel, as well as the factors related to the parameters that determine the efficiency of information transfer in the specific conditions. The created analytical models, the proposed calculations refer to the overall radio stability and ensure the quality of service. Synthesized simulation models, obtained and analyzed results are presented in different communication channel scenarios. The numerous practical measurements of the signal parameters of different mobile cellular technologies in a real environment of urban and non-urban environments, the reported problems and the recommendation to solve them in order to improve the management effects and the quality of services offered on broadband mobile networks, are scientific novelty.

Practical implementation:

The implementation of the dissertation paper is related to the creation of methodologies in order to correct approaches in modeling, selection and implementation of the architecture, the need for equipment and correct configuration, through monitoring and evaluation of signal parameters in broadband mobile networks. As such, it would serve in the training and scientific research of students and doctoral students, in the work of regulatory bodies, legal physical and control over the activities of mobile operators, as well as the employed operators in order to improve the efficiency of communication, management and quality of Telekommunication services in mobile broadband networks.

Approval of the dissertation paper:

The main stages of the development of the dissertation paper are presented in five publications at international conferences and scientific publications, fully covering the minimum requirements in terms of the considered criteria. Two of the papers were presented at the Unitech International Scientific Conference and two at a national conference and TechCo, both of which were independent. The publications were issued in peer-reviewed collections from the international scientific conference "Unitech" and the national conference "TechCo" in the study period 2022-2023, which actually represents almost 2/3 of the content of the dissertation paper. One of the publications was presented at the international scientific conference EEPES 2023 (Greece) and was published in the American Referred Publishing House AIP, which has a Scopus rank. The publications present a large part of the conducted research and present the main conclusions of the dissertation paper.

Structure and scope of the dissertation:

The dissertation paper includes an introduction, five chapters, the conclusion, a list of abbreviations that are used, a list of publications for the dissertation paper, and a list of references. The total volume is 171 pages and was developed based on an analytical review of 142 literary sources and 42 Internet-based sources.

II. CONTENTS OF THE DISSERTATION

CHAPTER I. STATUS AND REGULATION OF SERVICES IN MOBILE BROADBAND NETWORKS

1.1. Broadband Internet access and its importance

The transmission of digital data plays an increasingly important role in the lives of citizens and in the work of public institutions and enterprises. The high availability and speed of the Internet made possible by broadband Internet access is of crucial importance for companies in Europe to maintain their competitiveness in the global society.

1.2. Status of the broadband internet and use of Telekommunication networks in the Balkan region

1.2.1. Status of using the broadband internet and Telekommunications network in the Republic of Serbia

The development of Telekommunications infrastructure and broadband internet is a condition for the development of the concept of "smart cities" in Serbia. Efforts are being made in

Serbia to implement the creation of the basic so-called basic infrastructure not only for smart cities, but also for the concept of smart management.

1.2.2. Status of using the broadband internet and the Telekommunication networks in the Republic of Montenegro

It is common knowledge that broadband Internet access is fundamental to social and economic development of any kind. International examples show that broadband access networks have a strong impact on a country's economic growth and development. Aware of their importance, Montenegro defines national goals in this area in the Strategy for the Development of the Information Society for the period 2012-2020.

1.2.3. Status of using the broadband Internet and Telekommunications network in the Republic of Croatia

High speeds of broadband Internet access are a prerequisite for less developed areas to achieve the same quality of life as those in most larger and urban areas. The Government of Croatia has adopted an extensive national program for the development of broadband infrastructure in areas where there is no adequate commercial interest for investment.

1.2.4. Status of the broadband internet and Telekommunication networks in the Republic of Bulgaria

Until 12/31/2022, the total number of subscribers to retail internet services (fixed and mobile internet access) is 9.360 million, which represents an increase of 4.1%, which is close to the growth of 4.2% recorded in the previous year. The growth trend in the number of subscribers to package services (including fixed and/or mobile Internet access) continues after 2022, with a growth of 5.6% in absolute terms, reaching 6.648 million subscribers to package services last year.

1.2.5. Status of the broadband internet and Telekommunication networks in Macedonia

The European Union's 2020 Digital Agenda asks for all European citizens to be able to access the internet at 30 Mbps or faster by 2020, while 50% of Europe's population will have access to the internet at 100 Mbps or more.

1.3. Analyzes and conclusions in CHAPTER 1

The Mobile networks have an extremely dynamic development, accompanied by the continuous expansion of their capabilities in order to offer the fast broadband services, which requires taking into account the specific conditions of the environment, the number of users and the change in their location. All this is essential in the design of the network and its functioning.

Since the radio spectrum is a limited resource, according to the standards, it is necessary to allocate individual radio channels among operators and to seek effective frequency planning related to better management efficiency and continuous improvement of the quality of the services offered.

Preparing a correct frequency plan is very important for the quality of service in the network, as it largely determines the level of interference. When planning the coverage, the main task is to find a compromise between the size of the radio coverage range of the base stations and the traffic capacity of the network. Traffic and coverage thresholds are considered global parameters because they affect coverage, capacity, and quality simultaneously.

Antenna height greatly affects the coverage limits of a cell, and thus the maximum use of frequencies (ie, capacity), as well as parameters related to the quality of service for subscribers.

1.4. Purpose and tasks of the dissertation

The purpose of a broadband mobile communication system consists not only providing the necessary services to its subscribers by broadcasting digital signals, but also in its ability to detect and correct problems that appear in the communication channel. Therefore, this dissertation paper aims to show what is the extent and possible proper planning and operation to improve the management and quality of service and services offered by mobile operators.

Considering the situation analyzed in the first chapter and the regulation of services in broadband mobile networks, **the aim of this dissertation paper** is to present and research the processes of the mobile radio coverage by synthesizing analytical dependencies, simulation models and implementing practical experimental results that lead to possibilities to improve the efficiency of management and the quality of services in mobile broadband networks.

In order to realize the formulated goal, it is necessary to solve the following assigned tasks:

1. Creation and description of **an analytical methodology for designing and calculating the parameters of a broadband mobile network.**

2. Development and synthesis of a **simulation model** in Matlab's Simulink graphical environment for the study of WCDMA (End-to-End Physical Layer) to study the performance of a broadband mobile network model.

3. Conducting **research on broadband mobile network parameters and opportunities for improving the quality of services** in a densely populated urban area and statistical processing of the results.

4. Implementation of **practical measurements of coverage and broadcasting** of mobile operators in Macedonia, related to the amount of services and diagnostics during exploitation and use of the cellular network in urban and non-urban regions, as well as based on the results to make an independent assessment of the amount of confirmed radio coverage and to **propose methods and measures** for its improvement.

CHAPTER II. ANALYTICAL METHODOLOGY FOR DESIGNING AND CALCULATING THE PARAMETERS OF THE BROADBAND MOBILE NETWORK

2.1. Stages of mobile broadband network design

The following things should be considered:

• Planning the coverage provided by the network - from the point of view of guaranteeing the access of subscribers to the services provided by the network, it is of great importance.

• Capacity planning – it is necessary to ensure the necessary traffic capacity of the network for different types of services with a sufficiently low level of blocking and delays.

• It is also essential to ensure the necessary quality of service, which is given by the connection between coverage and capacity.

The entire planning phase should end with a network cost estimate.

2.2. Types of services provided by the network

With the introduction of mobile systems of the new generation, represented by 5G, different services and information transfer speeds appear.[57] Channel switching and packet switching applications are also provided:

• Voice services - Adaptive Multiple Rate (AMR);

• Video telephony;

• Data stream (video and audio);

• Interactive services such as access to the Internet, transfer of information in file format from one subscriber to another, use of corporate correspondence (e-mail), etc. Given the variety of speeds and services in the system, careful network calculation and planning is required. In fig. 2.1 shows a block diagram of the system planning and sizing process.

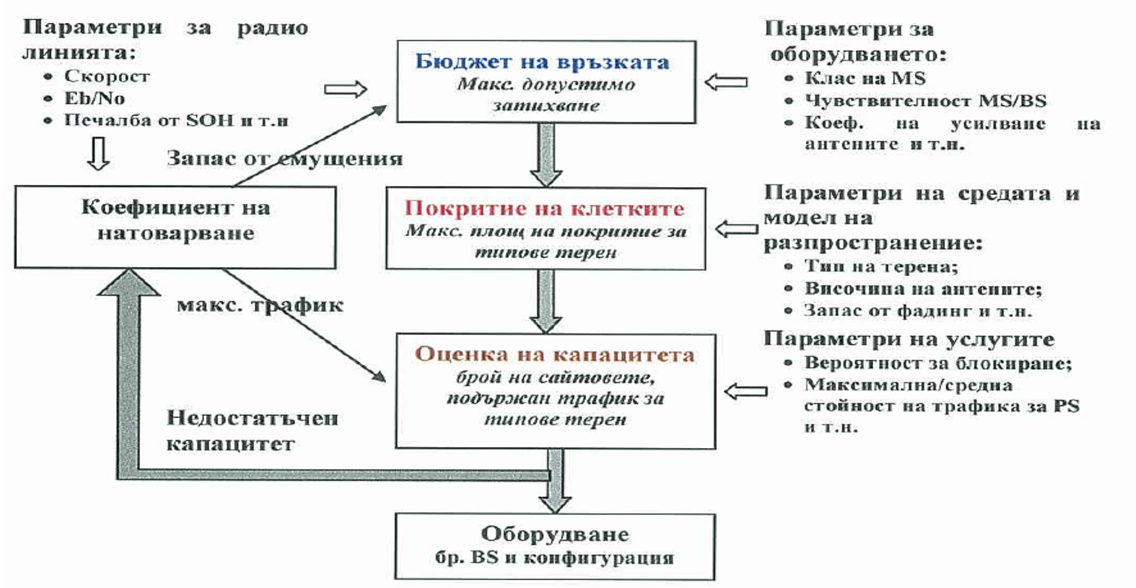


Fig. 2.1. *Steps in planning and sizing a broadband network*

2.3. Determination of capacity

Calculation of the theoretical cell radius is essential for determining coverage. For this purpose, the losses of the propagation medium, the impact of multipath propagation of radio waves, as well as the cell load, i.e. how many subscribers will use a given service or different services at the same time, must be taken in consideration. A characteristic of 5G is that the radius of the cell decreases depending on the number of users in its territory who use the system at the same time. It is necessary to note that the radius of the cell is different for the different speeds provided by the technology.

When planning the coverage, it is necessary to take into account a number of factors, as well as the reduction or, accordingly, the increase of the radius of a given cell, depending on what services it offers and the number of subscribers it serves.

2.3.1. Determination of load

There is no duplication of frequency usage in mobile broadband networks, so this factor is eliminated. The problem arises from the fact that it is necessary to plan the system at maximum load on the network itself or, in particular, on the cell. Hence, an accurate calculation of the load in the WCDMA system is required, both: in one and the other direction.

2.3.2. Determining the capacity of the mobile broadband network

For the broadband system to be operational, it is not necessary to be 100% loaded. Therefore, the maximum allowed values are taken:

- $Q_{MAX\_UL} = 70\ \%$ in the reverse direction
- $Q_{MAX\_DL} = 76\ \%$ in the straight direction

2.4. Methodology for coverage determination

2.4.1. Losses in the middle of the spread

The propagation of electromagnetic waves in free space is associated with many negative effects, as a result of which a large part of the signal energy is lost on the way to the receiver. In mobile communications, for the considered frequencies, the greatest influence is exerted by: reflection, absorption, scattering and diffraction (propagation of the wave with multiple rays).

2.4.2. Defining connection levels

The maximum value of forward and reverse propagation losses must be calculated.

2.4.3. Determining of the recorded levels

At the very beginning of network planning, it is necessary to make predictions related to multipath losses on the connection channel. Distortions created by complementing fast fading with slow fading must be considered. Fading is a phenomenon characterized by fluctuations in the amplitude of the received signal at a certain point. These fluctuations are due to multipath propagation. Recorded levels are defined for this purpose.

2.4.4. Determination of losses

Losses and varying signal attenuation must be taken into account. For this purpose, the system is considered from the generation of the information in the transmitter to its reception in the receiver.

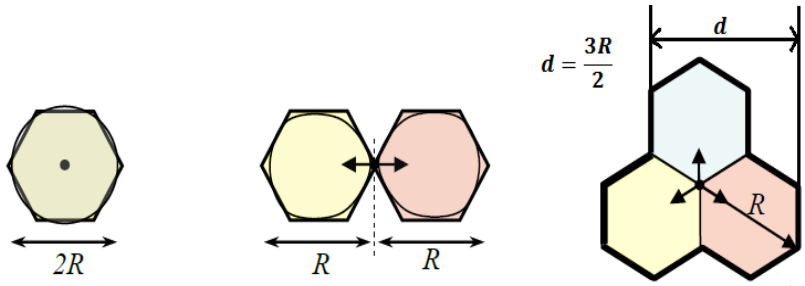
2.4.5. Antenna gain

The gain of the base station and the gain from the mobile station are given by a common parameter, which is the sum of the two gains - Ga.

2.4.6. Determining the coverage area for a single cell

After defining the input parameters and the different types of losses, attenuation and gains, the maximum value of the propagation losses in the environment should be defined.

The area of the covered area depends on the configuration of the site. In fig. 2.5 shows how this area is determined for one-sector, two-sector and three-sector sites.



$$S=\frac{3\sqrt{3}}{2}R^2 \qquad S=\frac{3\sqrt{3}}{4}R^2 \qquad S=\frac{9\sqrt{3}}{8}R^2$$

Fig. 2.5. *Determining the area of the cell depending on the configuration of the location.*

2.4.7. Calculations in the right direction

An important parameter in the right direction is the nominal power of the base station $P_{nom,RBS}$. When determining it, the losses introduced by the amplifier into the antenna system must be taken into account. It is designed to neutralize losses in the feeders.

2.5. Application of the methodology for proper coverage planning in urban areas

Coverage planning is done for example in a city with a total area of about 500 square kilometers and a population of about 1.5 million people.

Coverage planning is the first step of access network planning, which results in a defined area that can be covered by a cell and the number of base stations needed to cover that area.

The coverage that can be provided by a cell is closely related to the maximum permissible signal propagation losses. These losses are calculated separately for both transmission directions, after which the smaller of the two values is taken into account, i.e. the design is made for the critical side to enable communication in both directions of transmission.

2.5.1 Coverage planning for a densely built-up urban environment

The power balance is performed separately for both transmission directions. It reflects losses during signal propagation and, accordingly, reserves for their compensation.

The maximum allowable losses in one direction can be calculated with the formula:

$$Lp_{DL} = Pout_{BTS} - Ldupl_{BTS} - Lf_{BTS} + Ga_{BTS} - MS_{sens} - RF_{m\arg} - IF_{m\arg} - BL - LNF_{m\arg(o+i)} - BPL_{mean} =$$
$$= 45 - 3.5 - 3 + 17 - (-104) - 3 - 2 - 5 - 10 - 25 = 114.5$$

$$Lp_{DL} = 114.5 \text{ dB}$$

The maximum allowable losses in the reverse direction can be calculated using the formula:

$$Lp_{UL} = Pout_{MS} - RF_{m\arg} - IF_{m\arg} - BL - LNF_{m\arg(o+i)} - BPL_{mean} + Gd_{BTS} + Ga_{BTS} - Lf_{BTS} - Ldupl_{BTS} - BTS_{sens} =$$
$$= 33 - 3 - 2 - 5 - 10 - 25 + 3.5 + 17 - 3 - 3.5 - (-111) = 113$$

$$Lp_{UL} = 113 \text{ dB}$$

For the following calculations, we choose the smaller of the two values, i.e. $Lp = 113$dB, and we continue with the calculation of the cell diameter. To determine the parameter, we use the formula:

$$\alpha = \frac{Lp\, lg\, f\, lg\, h_{B_{M_{max}}}}{44.9 - 6.55\, lg\, h_B}$$

$$= \frac{113 - 69.55 - 26.16\, lg\, 9\,00 + 13.82\, lg\, 3\,0 + 0.016 + 0}{44.9 - 6.55\, lg\, 3\,0} = -0.38$$

For the diameter of the cell we get:

$$R = 10^{\alpha} = 10^{-0.38} = 0.416 \text{ km}$$

The area covered by a three-cell base station can be found from:

$$Area = \frac{9}{8}\sqrt{3}R^2 = \frac{9}{8}\sqrt{3}(0.416)^2 = 0.34 \text{km}^2$$

This part of the city that meets the characteristics of a densely built urban environment is about 10 km^2 (the area of the terrain is determined with the help of the **Mapinfo program**, in which a digital map of the city is entered). The number of base stations can be easily found:

$$N_{BTSdense} = \frac{Area_{terr}}{Area_{BTS}} = \frac{10}{0.34} \approx 30 \text{ BTS}$$

2.5.2. Coverage planning for a medium built urban environment

The planning is done in an analogous way, taking into account the differences introduced by the type of environment - the attenuation from buildings, the allowance for fading from shading and the factor involved in the calculation of the cell diameter.

Calculations will be made for the case when we plan coverage inside buildings, which in itself guarantees coverage outside them.

The maximum allowable losses can be calculated using:

$$Lp_{DL} = Pout_{BTS} - Ldupl_{BTS} - Lf_{BTS} + Ga_{BTS} - MS_{sens} - RF_{m\arg} - IF_{m\arg} - BL - LNF_{m\arg(o+i)} - BPL_{mean} =$$
$$= 45 - 3.5 - 3 + 17 - (-104) - 3 - 2 - 5 - 8.4 - 20 = 121.1$$

$$Lp_{DL} = 121.1 \text{ dB}$$

2.5.3. Coverage planning for sparsely built urban environments

The planning is done in a way equivalent to that for the previous two types of environment, taking into account the differences in attenuation introduced by buildings, the allowance for fading from shading and the factor included in the cell diameter calculation.

Calculations will be made for the case when we plan coverage inside buildings, which will ensure coverage outside them as well.

The maximum allowable losses can be calculated using:

$$Lp_{DL} = Pout_{BTS} - Ldupl_{BTS} - Lf_{BTS} + Ga_{BTS} - MS_{sens} - RF_{marg} - IF_{marg} - BL - LNF_{marg(o+i)} - BPL_{mean} =$$
$$= 45 - 3.5 - 3 + 17 - (-104) - 3 - 2 - 5 - 6.8 - 15 = 127.7$$

$$Lp_{DL} = 127.7 \text{ dB}$$

The maximum allowable reverse losses can be calculated using:

$$Lp_{UL} = Pout_{MS} - RF_{marg} - IF_{marg} - BL - LNF_{marg(o+i)} - BPL_{mean} + Gd_{BTS} + Ga_{BTS} - Lf_{BTS} - Ldupl_{BTS} - BTS_{sens} =$$
$$= 33 - 3 - 2 - 5 - 6.8 - 15 + 3.5 + 17 - 3 - 3.5 - (-111) = 126.2$$

$$Lp_{UL} = 126.2 \text{ dB}$$

For the following calculations, we choose the smaller of the two values, i.e. $Lp = 126.2$ dB, and we continue with the calculation of the cell diameter. To determine the parameter we use:

$$\alpha = \frac{Lp\ lg\, f\ lg\, h_{B_{M_{max}}}}{44.9 - 6.55\, lg\, h_B}$$

$$= \frac{126.2 - 69.55 - 26.16\, lg\, 900 + 13.82\, lg\, 30 + 0.016 + 8}{44.9 - 6.55\, lg\, 30} = 0.25$$

For the diameter of the cell we get:

$$R = 10^{\alpha} = 10^{0.25} = 1.78 \text{ km}$$

The area covered by a three-cell base station can be found from:

$$Area = \frac{9}{8}\sqrt{3}R^2 = \frac{9}{8}\sqrt{3}(1.78)^2 = 6.2\text{km}^2$$

The area whose terrain meets the characteristics of a sparsely built urban environment is 80 km^2 (the area of the terrain is determined again with the help of the Mapinfo program, where a digital map of the city is in). The required number of base stations can be easily found from:

$$N_{BTS\,sub} = \frac{Area_{terr}}{Area_{BTS}} = \frac{80}{6.2} \approx 13\text{BTS}$$

The total number of base stations N_{BTS}, needed to cover the entire settlement can be found as follows:

$$N_{BTS} = N_{BTSdense} + N_{BTSurban} + N_{BTSsub} = 30 + 100 + 13 = 143\text{BTS}$$

2.5.4. Air interface capacity planning

The input data on whose baisis the calculations will be made are presented in tabular form. The data in the table. 2.17 refers to a single cell, not the entire site. It shows the number of dedicated service channels, the number of channels reserved for data transmission and free channels that can be used for voice services. Also shown is the traffic that these free channels can serve with a 2% probability of blocking or interference:

$$A_{BTS_{dense}} = 3.29{,}2 = 87{,}6 \text{ Erl}$$
$$A_{BTS_{urban}} = 3.17{,}5 = 52{,}5 \text{ Erl}$$
$$A_{BTS_{sub}} = 3.10{,}7 = 32{,}1 \text{ Erl}$$

Table 2.17. Cellular data in different signal propagation environment

Area	No. of TRX	No. of BCCH channels	No. of SDCCH channels	No. of channels for data	Free channels	Traffic Erl
Densely populated	6	1	3	6	38	29.2
Medium populated	4	1	2	4	25	17.5
Sparsely populated	3	1	2	4	17	10.7

If, for example, the number of subscribers is N_{subs} (400,000 subscribers), which capacity is required, as well as the average traffic per subscriber A_{subs} (25 mErl). From this data we can calculate the total trafficA_{total}, for which we need to provide resources.

$$A_{total} = N_{subs}.A_{subs} = 400000.0{,}025 = 10000 \text{Erl}$$

The population density is not the same throughout the entire territory of the settlement, which also determines the difference in the traffic served by the base stations.

Table 2.18 shows information about the share of traffic that falls on each of the three defined types of environments.

Table 2.18. Traffic distribution

Basic traffic $A_{total} = 10000$Erl		
	Section [%]	Section [Erl]
Densely populated	40	4000
Medium populated	50	5000
Sparsely populated	10	1000

т.е. $A_{dense} = 4000$ Erl, $A_{urban} = 5000$ Erl и $A_{sub} = 1000$Erl

We can determine the number of base stations required for each type of environment:

- $n_{BTSdense} = \frac{A_{dense}}{A_{BTS_{dense}}} = \frac{4000}{3.29{,}2} \approx 46$ BTS densely built urban environment

- $n_{BTSurban} = \frac{A_{urban}}{A_{BTS_{urban}}} = \frac{5000}{3.17{,}5} \approx 95$ BTS medium built urban environment

- $n_{BTSsub} = \frac{A_{sub}}{A_{BTS_{sub}}} = \frac{1000}{3.10{,}5} \approx 32$ BTS sparsely built urban environment

We can find the total number of base stations needed n_{BTS}, using:

$$n_{BTS} = n_{BTSdense} + n_{BTSurban} + n_{BTSsub} = 46 + 95 + 32 = 173 \text{ BTS}$$

$n_{BTS} > N_{BTS}$ will also be the final number of base stations for the city example.

2.6. Conclusions for Chapter 2

This chapter presents an analytical methodology for the design and calculation of mobile broadband network parameters. Design phases, types of services, determination of network capacity related to load, determination of radio coverage and application of the methodology, such as coverage planning in urban conditions and determination of the optimal effective number of base stations, are considered. Based on all this, the following conclusions can be defined:

1. When designing a broadband mobile network, it is necessary to set requirements to be followed, to ensure quality communication in a given area, regardless of environmental limitations, radio wave propagation or interference in the connection channel. Given the variety of speeds and services in the system, careful network calculation and planning is required.

2. The calculation of the theoretical coverage radius of the cell is essential in determining the coverage. For this purpose, the losses of the propagation area, the impact of multipath propagation of radio waves, as well as the cell load, i.e. how many subscribers will use a given service or different services at the same time, must be taken into account.

3. The increase in the number of users and the width of the used frequency band leads to an increase in noise in the connection channel, that is, to problems with the quality of services. It can be seen that high-speed information transmission is limited by the number of users simultaneously transmitting information, and also by the speed with which subscribers move in the coverage area.

4. As the mobile station (mobile device) moves and approaches the limits of cell coverage, it is necessary to transmit the signal with a higher power, to ensure the required quality. The power control algorithm has limitations and when the reserve power regulation resource is used up, it switches to other channels (handover). Broadcasting with very high power leads to a decrease in system sensitivity, therefore the B_{PC} parameter is introduced for power regulation, the value of which is 0.7 at a subscriber movement speed of 3km/h and 0 at a subscriber movement speed of 50km/h.

5. When planning the radio coverage, the power balance is performed separately for both directions of transmission. It reflects losses during signal propagation and, accordingly, reserves for their compensation. Analytical planning uses some parameters that are specific to the equipment manufacturer. Since the balance of capacity depends largely on the type of area being planned for, it is preferable to plan for three different types of environment found in the projected settlement - dense built-up, medium built-up and sparsely built-up to urban areas.

6. The main stages of planning a mobile broadband network start with sizing, taking into account what traffic and area the design is for, as well as threshold values for coverage. The second stage includes detailed planning, where the configuration of the cells and their number are determined. The last part is the monitoring and optimization of the working base stations and is only done when the network already exists in real time.

CHAPTER III. SIMULATION MODELING AND CHARACTERISTICS OF A BROADBAND MOBILE NETWORK MODEL IN MATLAB (SIMULINK)

3.1. Synthesizing a WCDMA End-to-End Physical Layer Simulation Model

This chapter presents the simulation of the full physical layer WCDMA End-to-End, the role of frequency division duplex (FDD) and the downlink models defined by the third generation systems for wireless communication known as broadband network access with coding. Wideband with Code Division Multiple Access (W-CDMA).

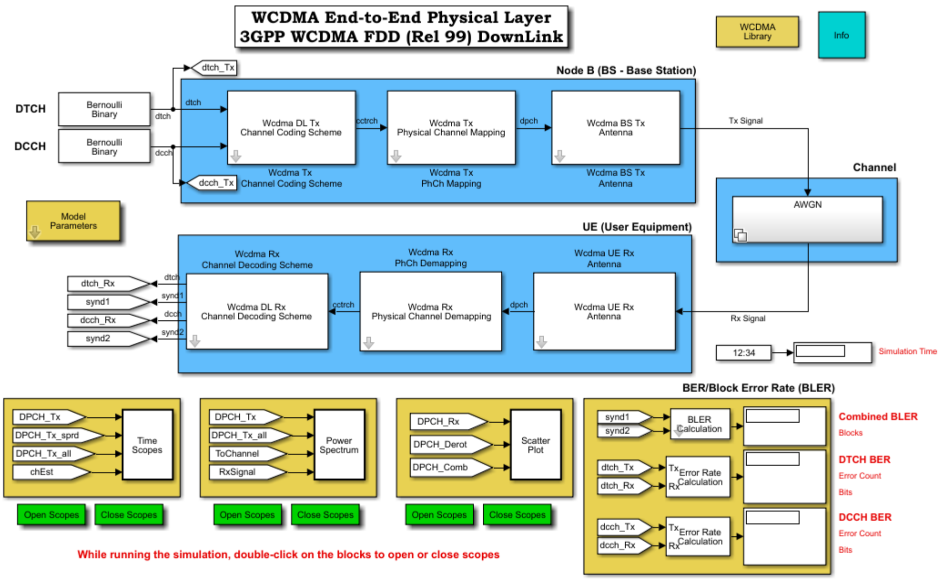


Fig. 3.1. WCDMA End-to-End Physical Layer

3.2. Model setup parameters

Model parameters can be changed or viewed by selecting individual modules. For example, the block labeled "WCDMA: Initial Settings" shows the type of omission for the block's parameters. The power parameters [DPCH, P-CPICH, PICH, PCCPCH, SCH] are represented in decibels and consist of a series of vectors containing the powers in decibels corresponding to the different physical channels.

3.3. Simulation results - oscillograms, spectral characteristics and constellation diagrams

The obtained results shown below are for the simulation model parameters shown in the table. 3.5.

Table 3.5. Parameters of the simulation model

№	Case presented	Transmission channel parameters
1	Static AWGN	SNR= от -9dB до 1dB; Number of enable fingers = 1; Relative delay of Rx signals = 0s; Average Powers of Rx signals = 0dB; Speed of Terminal = 0km/h
2	Multiple Profile - Case 2	SNR= от -9dB до 1dB; Number of enable fingers = 3; Relative delay of Rx signals = 0s, 976e-9s, 20000e-9s; Average Powers of Rx signals = 0dB, 0dB, 0dB; Speed of Terminal = 3km/h
3	Multiple Profile - Case 5	SNR= от -9dB до 1dB; Number of enable fingers = 2; Relative delay of Rx signals = 0s, 976e-9s; Average Powers of Rx signals = 0dB, 10dB; Speed of Terminal = 50km/h

The following blocks calculate various simulation errors:

• The BLER (Block Error Ratio) calculation shows the error ratio of the combined transport channels.

• The BER (Bit Error Ratio) calculation shows the BER calculation results associated with each transport channel separately.

• The following timing oscilloscopes display the signal in different ways. To see the waveforms, double-click the switches when the simulation is running.

• Timing oscilloscopes show the bit stream before equalization to equalize the energy, after reallocation, and after combining with the various physical channels. They show both the real and the imaginary moment in particular. They also show both real and imaginary parts of the channel output.

The results shown below can be divided into two:

− results in the worst case – when setting is on SNR = –9 dB;

- best results in the case - when setting is on SNR = 0 dB.

3.3.1. Results at SNR = –9 dB

• Oscillograms of the output signal in the channel estimator and on the bits after energy equalization (real and imaginary part).

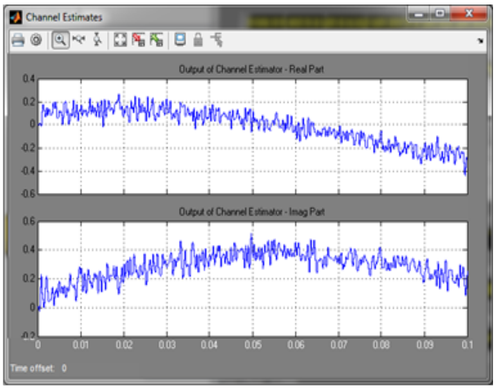


Fig. 3.2 (a) Outputs of the channel estimator – real and imaginary part

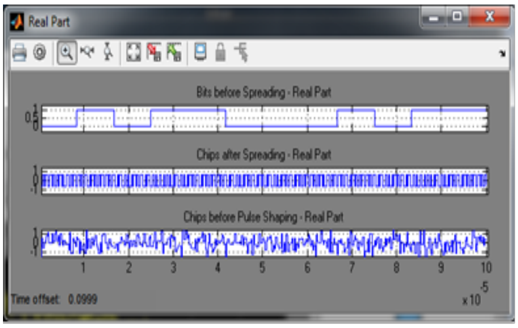


Fig. 3.2 (b) Real part - bits before energy equalization, chip after energy equalization, chip before pulse shaping

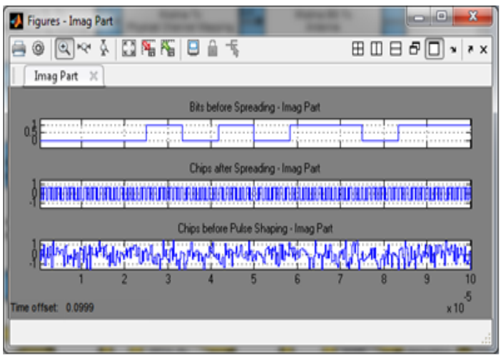


Fig. 3.2 (c) Imaginary part - bits before energy equalization, chip after energy equalization, chip before pulse shaping

• Spectrum of the signal before energy equalization, after energy equalization, after pulse shaping and at the input of the receiver antenna.

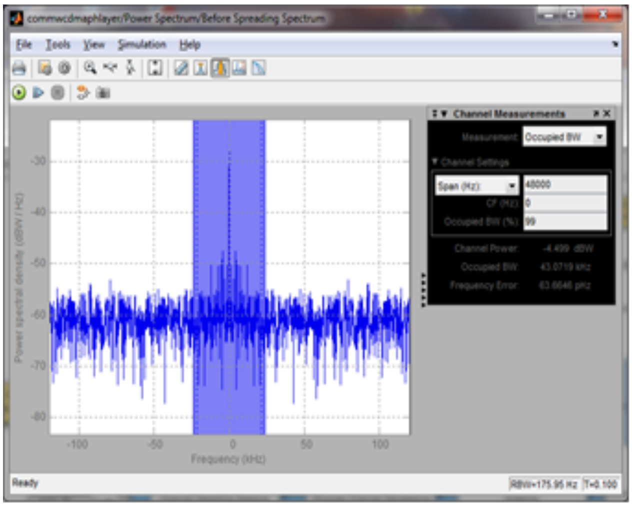


Fig. 3.3 (a) Spectrum of the signal before propagation

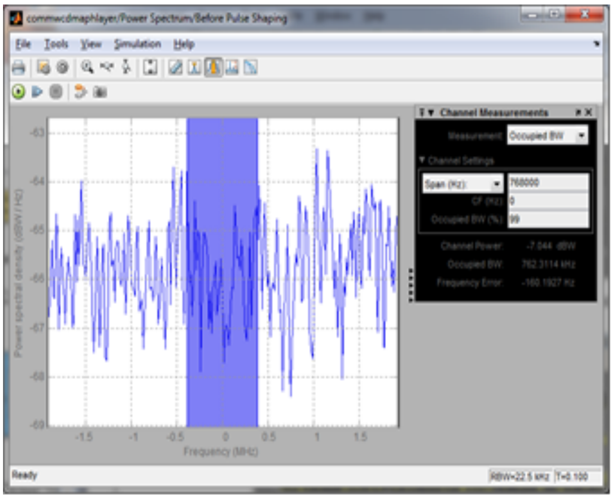


Fig. 3.3 (b) Spectrum of the signal after propagation

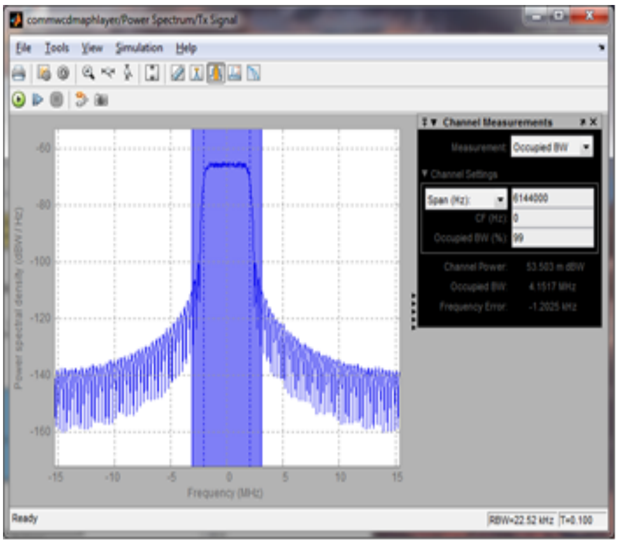


Fig. 3.3 (c) Spectrum of the signal after pulse shaping

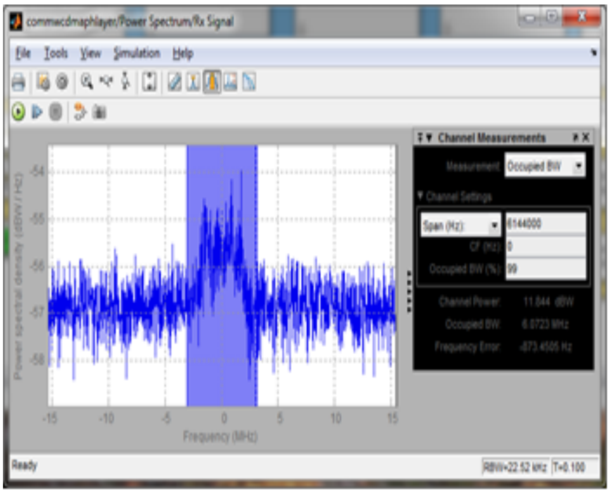


Fig. 3.3 (d) Spectrum of the signal at the input of the receiving antenna

• The signal constellation diagram shows the state of the output information, after phase derotation and amplitude correlation.

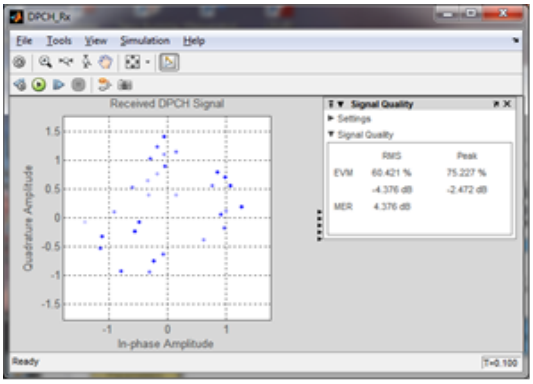


Fig. 3.4 (a) Constellation diagram of the output signal of a data correlator

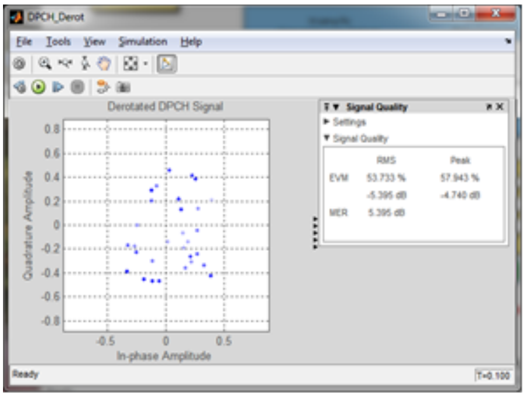


Fig. 3.4 (b) Constellation diagram of the output signal after phase derotation

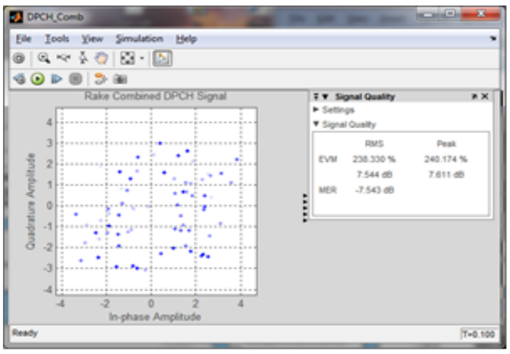


Fig. 3.4 (c) Constellation diagram of the output signal after amplitude correction

3.3.2. Results for SNR = 0 dB

(the results are similar to the previous ones and are presented in the dissertation)

3.4. Simulation results - graphical dependencies

These measurements are based on changing the main parameters in the simulation such as signal-to-noise ratio and transmission rates, but as described above in the text, other transmit- and receive-side-specific parameters, as well as channel parameters, may are changed. The obtained results are presented in three different cases:

1) Static AWGN – is received in the transmission channel to affect only to the addition of white Gaussian noise, ie. ideal transmission channel;

2) Multipath Profile - Case 2 - additive white Gaussian noise is assumed to operate in the transmission channel, there is one line-of-sight signal and one reflected signal attenuated in amplitude and time delay, and the mobile station is moving at walking speed – 3 km/h;

3) Multipath Profile - Case 5 - additive white Gaussian noise is assumed to act in the transmission channel, there is one line-of-sight signal and one reflected signal attenuated in amplitude and time delay, and the mobile station is moving at the speed of a car in populated place - 50 km/h.

• First case: Static AWGN

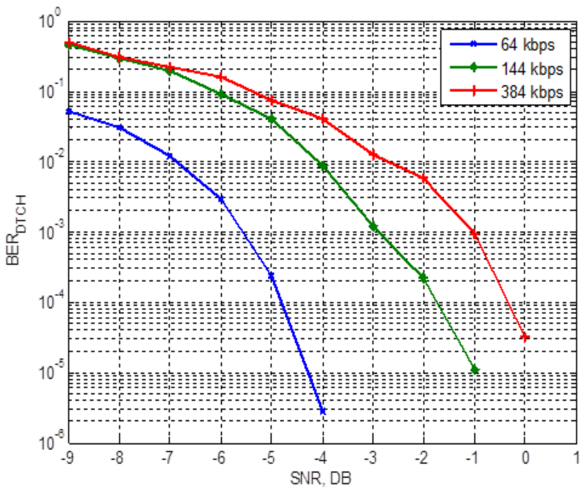


Fig. 3.8. Logarithmic dependence of channel speeds 64kbps, 144kbps and 384kbps in case of AWGN

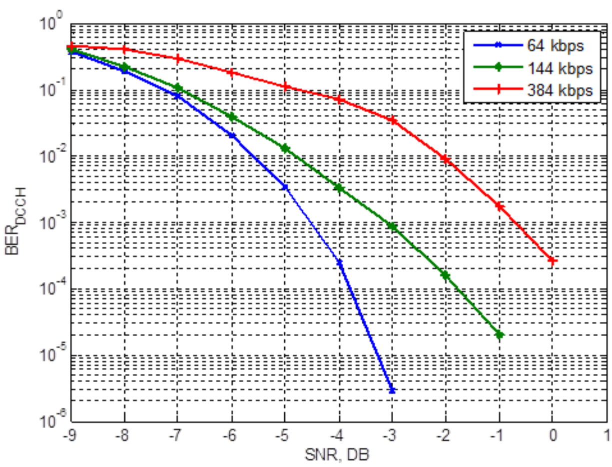


Fig. 3.9. Logarithmic dependence at channel speeds of 64kbps, 144kbps and 384kbps in case of AWGN

• Second case: Multipath Profile - Case 2
• Third case: Multipath Profile - Case 5
(the results are similar to the previous ones and are presented in the dissertation)
• Comparative analysis:

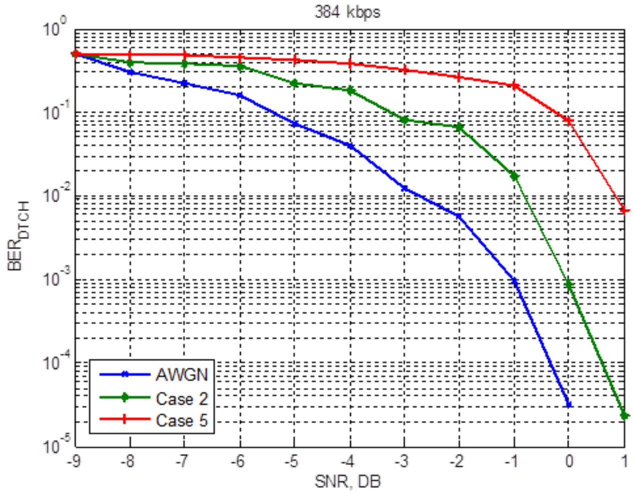


Fig. 3.18. Logarithmic dependence on channel speeds of 384kbps for the three cases

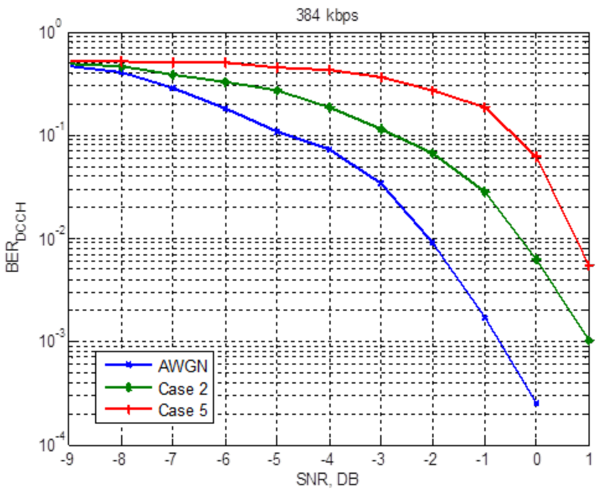


Fig. 3.19. Logarithmic dependence at 384kbps channel speed for the three cases

3.5. Analysis and conclusions from CHAPTER 3

The Researches in the area of simulation of mobile cellular network models is a current and serious task. Regardless of the existing standards in this area, there are a number of factors that affect the quality of the signal, which requires making decisions specific to the given mobile network related to its optimization and improvement of the quality of service.

In this chapter, a simulation model of the WCDMA standard for mobile broadband networks is presented in detail. This model is used to examine the quality of the transmitted signal in different cases: in the presence of only added white Gaussian noise in the transmission channel (i.e. ideal transmission channel), in the mobile station with user movement speed and in mobile car speed station, in an urban environment. The last two cases reflect the impact of multipath signal propagation and model actual results in an urban environment. Most results are obtained at different SNR levels, with different channel rates and for two different channels – traffic channel and control channel.

To make the realization of this task, the simulation of WCDMA (WCDMA End-to-End Physical Layer), the role of frequency division duplex (FDD) and the low link models defined by the third generation of wireless communication systems known as broadband (Widband) code division is presented and multiple access (W-CDMA).

The Basic settings are performed on the WCDMA TH Channel Coding Scheme (Coding Subsystem), WCDMA Th PhCh Mapping and its corresponding subsystems on the receiving side. The obtained results of the simulations - oscillograms, spectral characteristics and the diagrams with the results are based on changing the main parameters in the simulation, such as the signal-to-noise ratio and transmission rates, characteristic of the transmitter, as well as the channel parameters. The obtained results are presented in three different cases:

1) Static AWGN – it is assumed that only added white Gaussian noise affects the transmission channel, i.e. ideal transmission channel;

2) Multipath Profile - Case 2 - it is assumed that added white Gaussian noise is operating in the transmission channel, there is one line-of-sight signal and one reflected signal attenuated in amplitude and time delay, and the mobile station is moving at walking speed – 3 km/h;

3) Multipath Profile - Case 5 - it is assumed that added white Gaussian noise acts in the transmission channel, there is one line-of-sight signal and one reflected signal attenuated in amplitude and time delay, and the mobile station is moving at car speed in populated place – 50 km/h.

As a conclusion, the following answers can be drawn from the experimental results:

1. It is clearly seen that the BLER, BER and bit error rate decrease drastically as the signal-to-noise ratio increases.

2. As the channel speed increases, the probability of receiving an error increases and the BER value deteriorates.

3. Mobile station movement creates more difficult reception conditions in the multipath signal propagation environment. As a result, at higher speeds, the reliable reception capability deteriorates, the receiver can hardly make a decision, and the BER value deteriorates significantly even at a higher value of the SNR ratio.

CHAPTER IV. EXPERIMENTAL RESEARCH OF THE PARAMETERS OF THE MOBILE BROADBAND NETWORK AND POSSIBILITIES FOR IMPROVING THE QUALITY OF SERVICES

4.1. Application of software tools for testing radio coverage through a mobile terminal

In an appropriate way, independent and continuous monitoring of the quality of coverage and services in mobile cellular networks was carried out with the help of independently developed mobile applications for different platforms for mobile devices that allow users to be part of this process. In the presence of many such applications, as well as mobile devices, the results of this monitoring allow the evaluation of the efficiency of the devices themselves, as well as the verification of the results of the planning, design and construction of the network with real ones of the operation of the network by individual users. Through the feedback available in these applications, all information collected from them is often sent to a centralized data collection server, where through a database and additional geographic information, detailed independent information is collected for each mobile operator in each township or geographical area, where often this method of research is applied almost everywhere in the world.

In our case, we will use Android-based applications for monitoring mobile coverage, as it is currently one of the most common software platforms for mobile devices. It is open source and allows many developers to offer different applications with different functionality.

4.1.1. Review of Android-based mobile coverage monitoring applications

After the analysis of each of them, taking into account their advantages and disadvantages and the possibility of obtaining different results, the use of the Network Cell Info application is chosen for the purposes of the dissertation paper.

Description of Network Cell Info application

Network Cell Info is a tool for measuring and diagnosing 5G, 4G+, LTE, CDMA, WCDMA, GSM technologies. Network cell information can help to resolve the connectivity issues while providing the information about the mobile operator's radio frequency situation. The app also includes a mobile internet speed and performance test tool and download, upload and ping test results.

4.1.2. Presentation of the experimental setup

In fig. 4.1. the scheme of the experimental setup used in the implementation of the mobile network monitoring is presented.

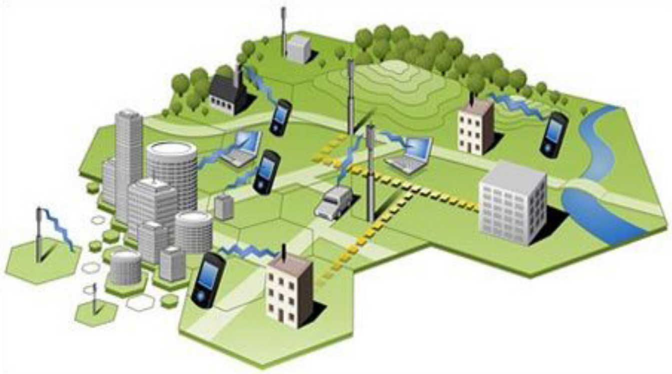


Fig. 4.1. Presentation of the experimental setup for monitoring

In the combination with the signal parameters of the current cell, the mobile device also receives signals from neighboring cells, which makes it possible to gather information about the parameters of the signals as an overall. Various coverage maps are output, parameters such as SNR, signal level, evaluation of different traffic and logical channels, as well as information about neighboring cells and handover performance are read.

In the process of research and measurement of radio coverage parameters, it is possible to choose the type of network – 2G, 3G, 4G/LTE, 5G or combined.

4.1.3. The Route selection in an urban city environment and configuration of the device that is used

The choice of the route for the implementation of the monitoring of the mobile network is in accordance with the geographical characteristics, for the exsample, cities with a population of about 10 inhabitants. Given the location of the city and the attempt to cover both boulevards and smaller streets, two routes were chosen for practical measurements.

The results obtained from the research of the mobile network of Makedonski Telekom AD Skopje will be presented in 3 variants for the 3 different modes of operation of the mobile terminal: 2G - only GSM, 3G - UMTS, 4G - LTE.

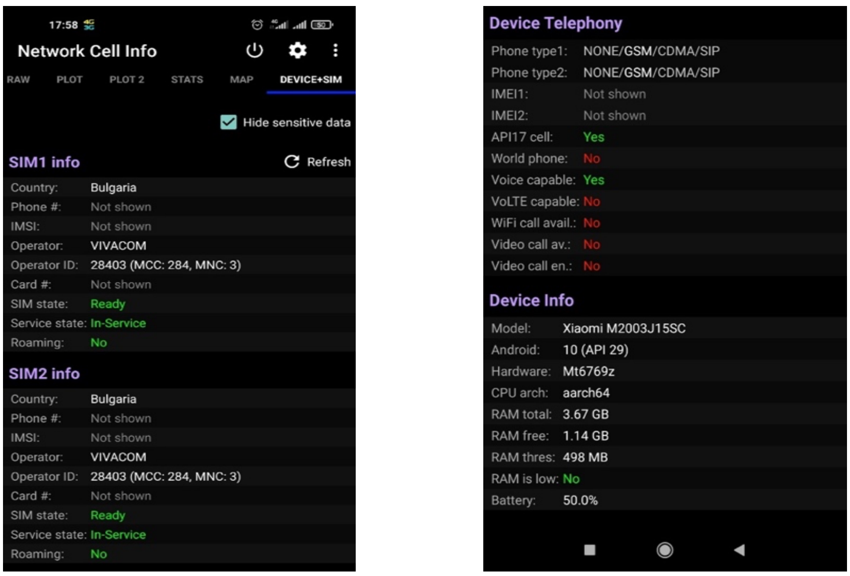


Fig. 4.5. Information on the adjustment and configuration of the smartphone with which the practical measurements will be performed

4.2. Research on the parameters of the mobile operator in an urban environment

4.2.1. Researching of 2G - GSM only coverage

Route 1

The results of the measurements as working screens are shown on fig. 4.6 - fig. 4.12.

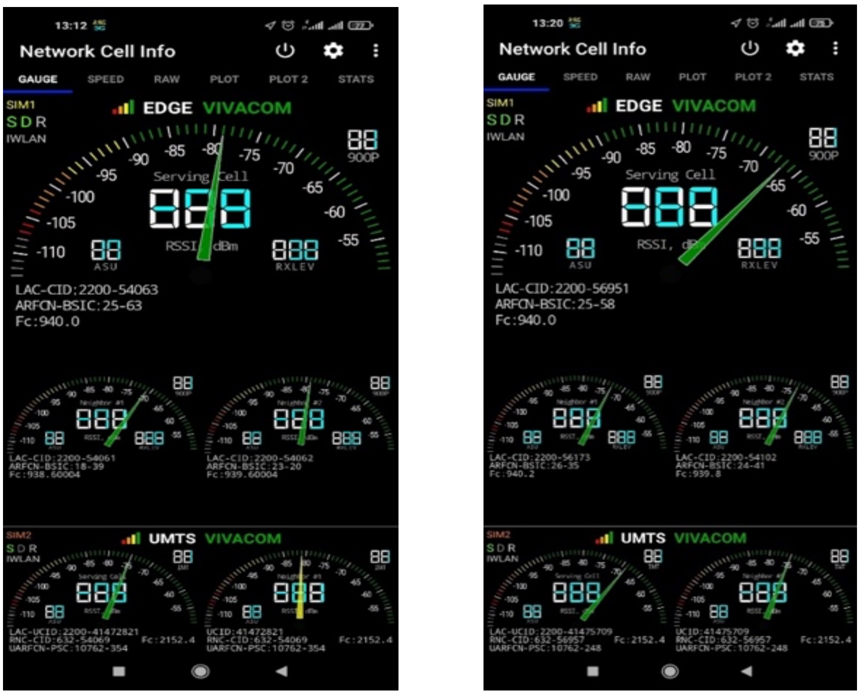


Fig. 4.6. Signal power information about the cell in use, neighboring cells and the second SIM card

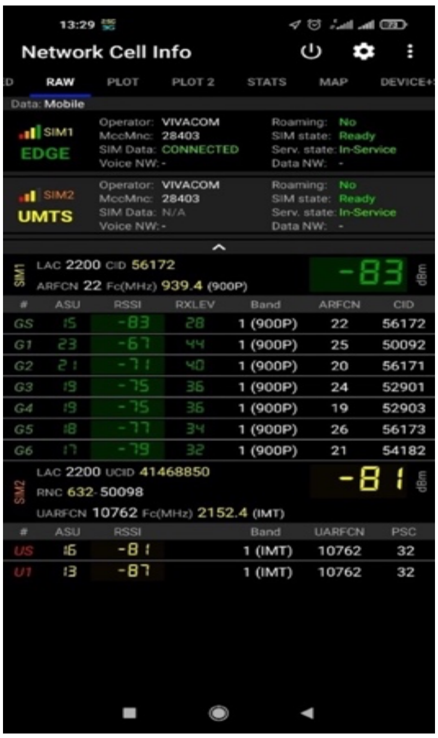


Fig. 4.9. Information about the wireless connection

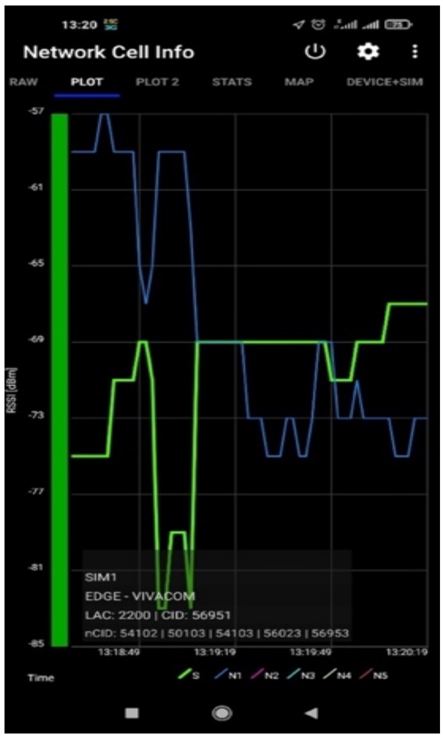


Fig. 4.10. Signal power S, neighboring cells N 1, 2, 3, 4, 5

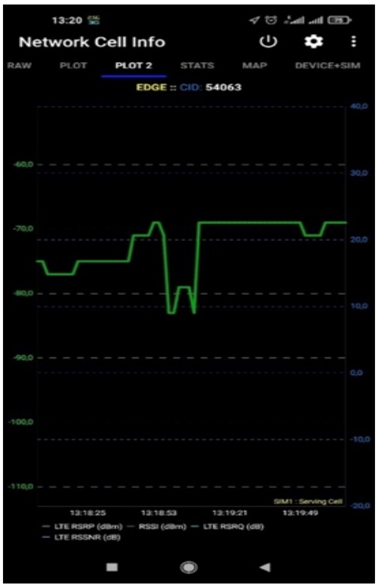


Fig. 4.11. Signal quality over time

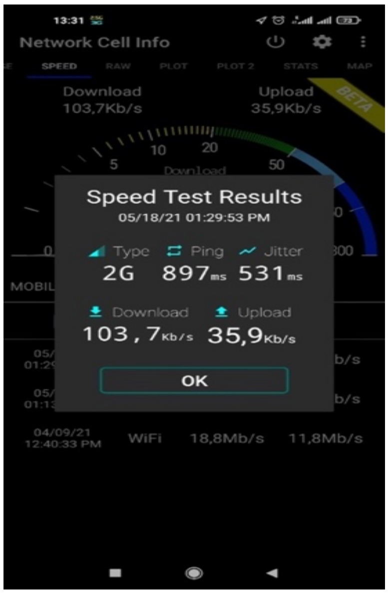


Fig. 4.12. Speed test the connection

From the conducted research in 2G - GSM mode, the following important conclusions can be drawn for route 1:

1) The bypass route signal level is mostly high: –75dB. Only two sections show level degradation and drops down to –79dB/–91dB, which is due to the densely built surface (causing significant multiple reflections).

2) Signal quality can be rated as good - this is reflected by the aRXLEV.

3) When passing the route, 7 cells were detected, and an even and smooth handover between them was reported without significant drops in the signal level and lack of coverage. The service time is also reflected in each of them.

Route 2 (the results are similar to the previous ones and are presented in the dissertation)

4.2.2. 3G - UMTS coverage survey

Route 1

The results from the measurements are shown in Fig. 4.21 - Fig. 4.28.

Fig. 4.21. Signal strength, information about the cell in use, neighboring cells and the second SIM card

Route 2

The results are similar to the previous ones and are presented in the dissertation.

4.2.3. Research of the 4G -LTE coverage survey

Route 1

The results of the measurements are shown in fig. 4.37 - fig. 4.44.

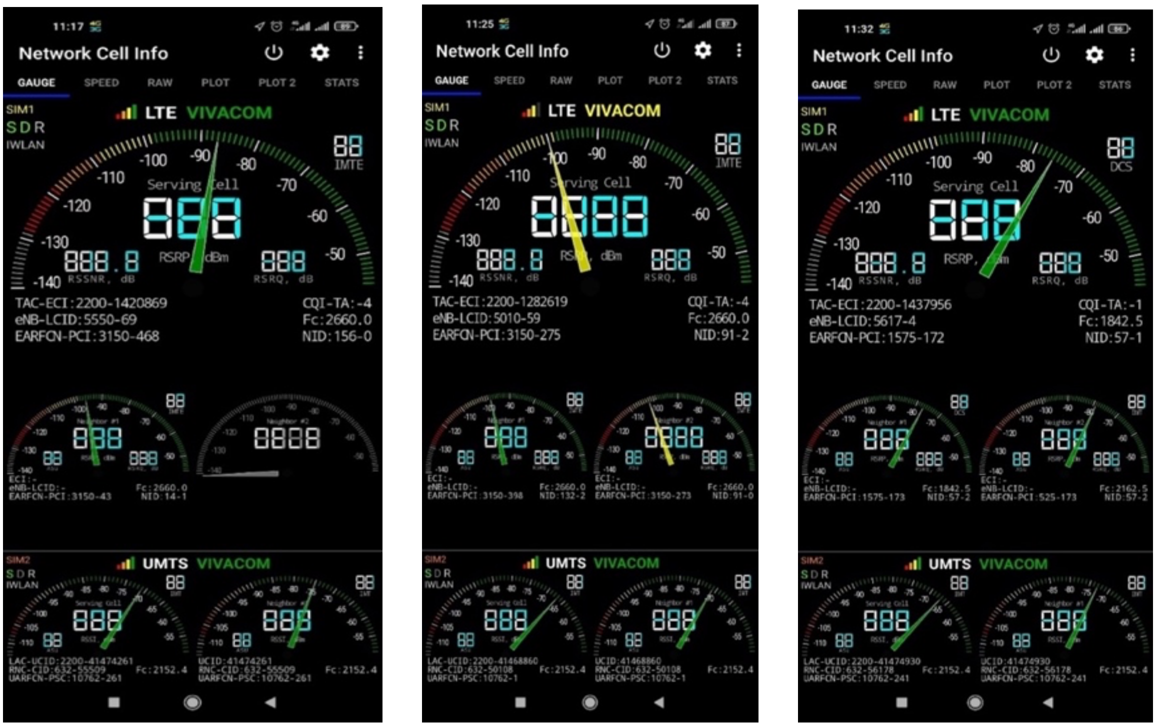


Fig. 4.37. Signal strength, information about the cell in use, neighboring cells and the second SIM card

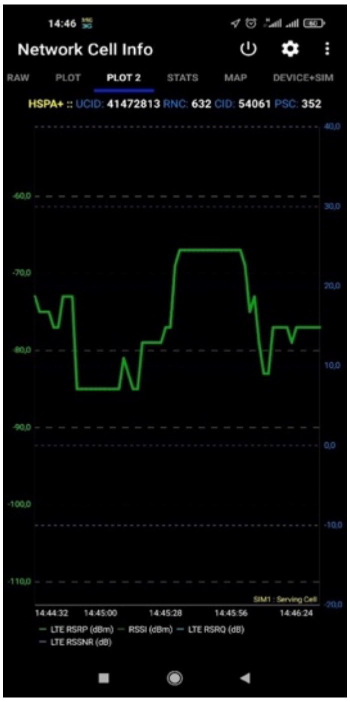


Fig 4.26. Signal quality over time

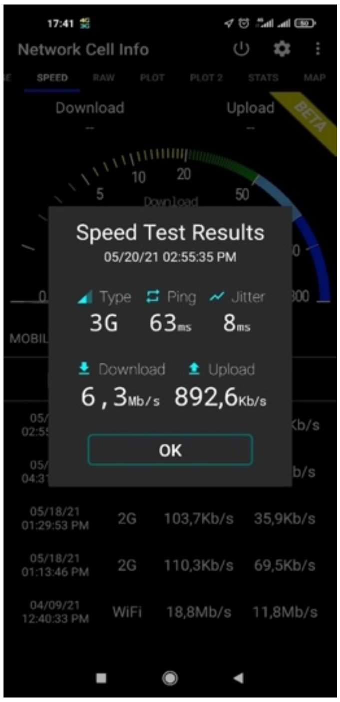


Fig.4.27. Connection speed test

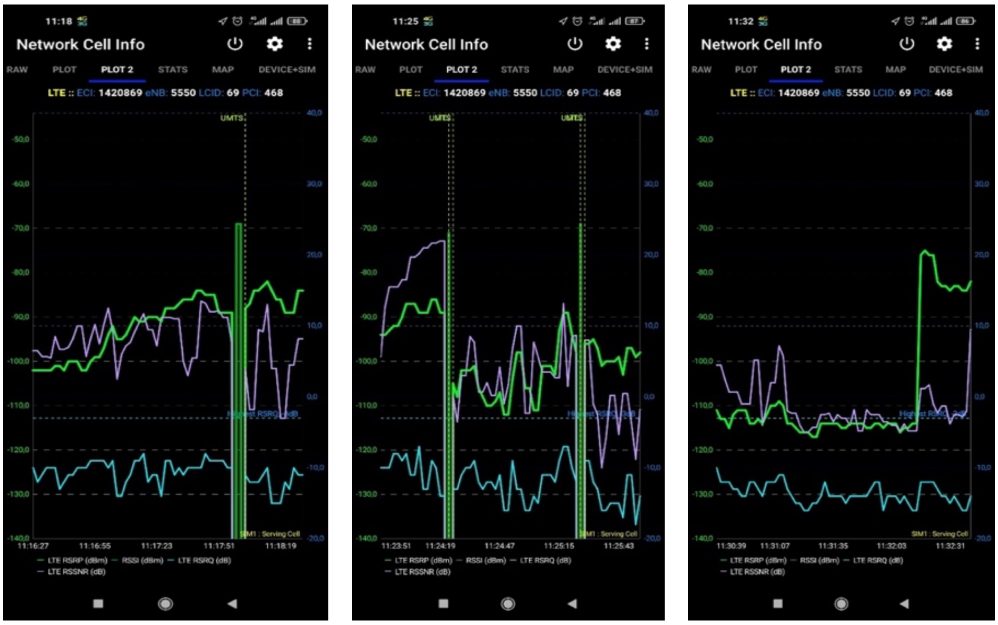


Fig 4.42. Signal quality over time

Fig 4.43. Connection speed test

Route 2

The results are similar to the previous ones and are presented in the dissertation.

4.3. Bandwidth measurement in the network of Makedonski Telekom AD Skopje

When measuring the bandwidth of the operator's network, the speed of downloading (Download) and sending (Upload) are taken into account during data transfer for the 3 operating modes of the mobile device. The results will be presented for six different points - three for each route, examining the start and end sections of the route, and the middle sections closer to the city centre. Measurements are for 3 different operating modes of the mobile device: 2G - GSM only, 3G - UMTS, 4G - LTE. The results of the measurements for route 1 are shown in Fig. 4.53 - Fig. 4.55.

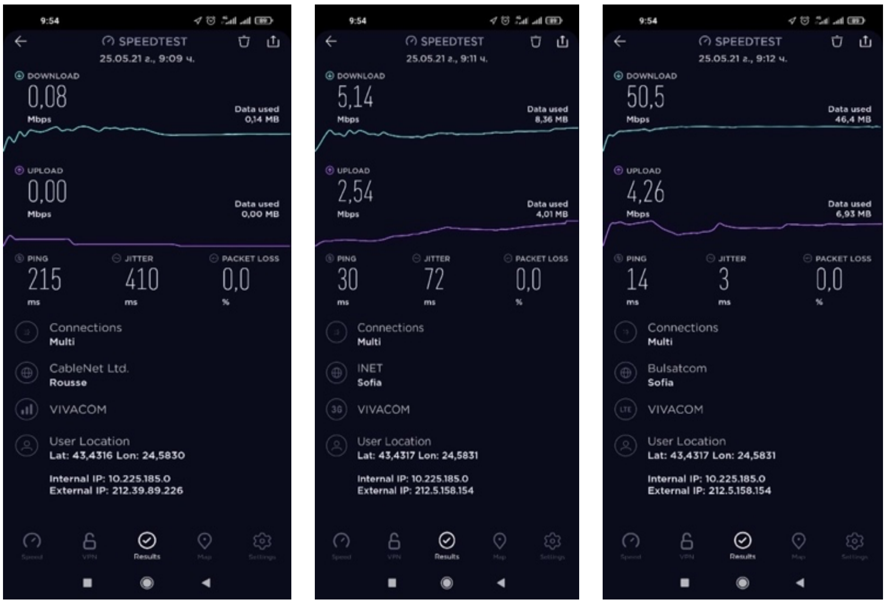


Fig. 4.53. Determination of network throughput for route 1 in a final settlement for 2G - GSM, 3G - UMTS and 4G - LTE

The following conclusions can be drawn from the research conducted on network bandwidth for data traffic through mobile Internet access:

1) The advantage of fast access to 4G compared to slow 2G is clearly visible - the difference in throughput in the forward direction (Download) is on average more than 400 times in favor of 4G, and in the opposite direction (Upload) - more than 500 times.

2) When comparing the bandwidths between 3G and 4G, the values are as follows: in the forward direction, the difference is over 7 times in favor of 4G, and in the opposite direction - over 11 times.

3) A better throughput was observed in the central city and in the western part of the city compared to that reported in the southern and eastern parts. In 2G mode the speed is almost the same in all measured parts, and in 4G mode it varies.

4) The asymmetry of the mobile internet service is clearly expressed – the upload/download ratio is 1/1 in 2G mode, 1/3 in 3G mode and 1/2 in 4G mode.

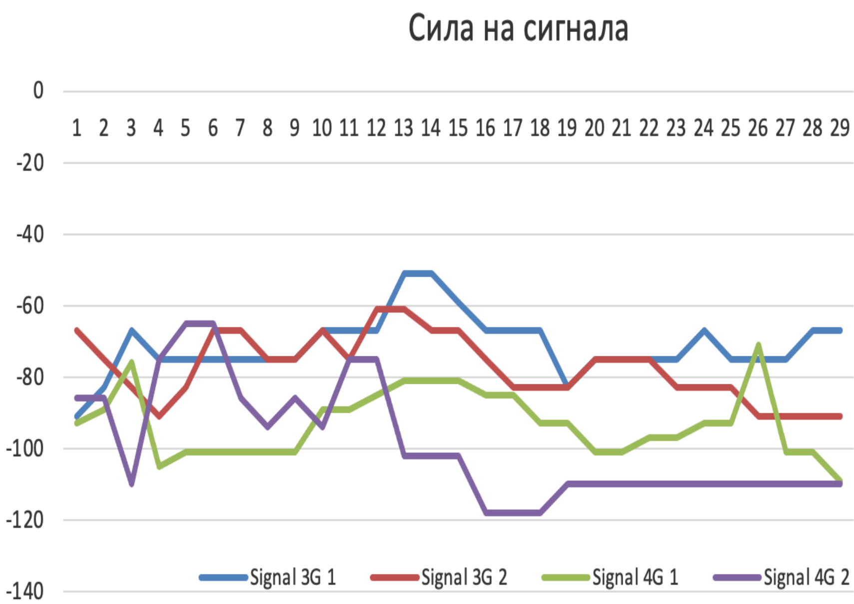


Fig 4.59. 3G and 4G signal strength chart for both directions

4.4. Research of the 4G mobile coverage of the operator A1

Route 1

The results of the measurements are shown in fig. 4.61 - fig. 4.67.

Fig 4.61. Signal strength, information about the cell in use, neighboring cells and the second SIM card

Fig 4.65. Signal power S and neighboring cell N 1

Fig 4.67. Connection speed test

The following important conclusions for route 1 can be drawn from the research in the 4G – LTE mode:

1) The signal level for the traveled route varies significantly within the limits: –92dB/–103dB, with the lowest values observed at the beginning of the route.

2) Signal quality varies, with an average reading of -15 dB shown with the app's RSRQ option and a best reading of -14 dB.

3) The SNR ratio varies a lot – 0dB/13dB, which is not a prerequisite for good signal quality.

4) Had 4G signal 100% of the time.

5) When crossing the route, 7 cells were detected. The dwell time of the mobile device in each of them was reflected, and an even and smooth handover between them was observed without significant drops in the signal level and lack of coverage.

Route 2

The results are similar to the previous ones and are presented in the dissertation.

4.5. Research of the A1 5G Mobile Phone Coverage

Route 1

The results of the measurements are shown in fig. 4.76 - fig. 4.83.

Fig 4.76. Signal power, information about the serving cell, neighboring cells and the second SIM card

Fig. 4.82. Connection speed test

The following important conclusions for route 1 can be drawn from the research in the 5G mode:

1) The bypass route signal level varies significantly within the limits: –77dB/–99dB, with the lowest values being in the central part of the city.

2) Signal quality varies, with an average reading of -12 dB and a peak reading of -10 dB.

3) The SNR ratio varies a lot – -2dB/14dB, which is not a prerequisite for good signal quality.

4) 5G signal was reported 97.8% of the time and 4G signal 2.2% of the time.

5) 10 cells were detected while traversing the route. The time of stay of the mobile device in each of them was reflected, and an even and smooth handover between them was observed without significant drops in the signal level and lack of coverage.

6) The GAUGE section of the application shows that the received signal is 5G (NSA-Non-Standalone), which means that base stations and equipment from 4G technology are used.

Route 2

The results are similar to the previous ones and are presented in the dissertation.

4.6. A1 network throughput measurement

During the measuring of the bandwidth at the operator's network, the speed of downloading (Download) and sending (Upload) are taken into account when transferring data for the second mode of operation of the mobile device. The results will be presented for six different points - three for each route, examining the start and end sections of the route, and the middle sections closer to the city centre. Measurements are for 2 different operating modes of the mobile device: 4G - LTE and 5G - NSA.

The following conclusions can be drawn from the research conducted on network bandwidth for data traffic through mobile Internet access:

1) The advantage of fast access to 5G compared to 4G is clearly visible - the difference in throughput in the forward direction (download) is on average more than 4 times in favor of 5G, and in the opposite direction (upload) - more than 3 times .

2) There is an increase in throughput in 4G, after the upgrade of base stations for access to 5G.

3) A better throughput was observed in the central part of the city and in the western part of the city compared to that reported in the southern and eastern part.

4) The asymmetry of the mobile Internet service is clearly expressed - the upload/download ratio is 1/7 in 4G mode and 1/10 in 5G mode.

4.7. Analysis and conclusions of CHAPTER 4

In this chapter, an the research is carried out on the parameters of the mobile broadband network and the possibilities for improving the quality of services, using software tools for testing the radio coverage through a mobile terminal. For this purpose, the Network Cell Info application installed on a mobile phone was used and the network parameters of 2 examples of mobile operators in an urban environment along 2 established routes were investigated. Equipment configurations and settings were made and radio coverage parameters were measured for the following mobile network technologies - 2G, 3G, 4G/LTE and 5G. After the experiments, the following important conclusions were established:

1. From the research carried out in 2G - GSM, the following important conclusions can be drawn for route 1:

1) The bypass route signal level is mostly high: –75dB. Only two sections show level degradation and dips of –79dB/–91dB, which are due to the densely built surface (causing a significant amount of reflections).

2) Signal quality can be rated as good - this is reflected by the application's RXLEV.

3) When passing the route-route, 7 cells were detected, and an even and uninterrupted handover between them was reported without significant drops in the signal level and lack of coverage. The service time is also reflected in each of them.

2. From the research carried out in 2G - GSM, the following important conclusions can be drawn for route 2:

1) The bypass route signal level is mostly good: –83dB. In just two parts there is an improvement in level to –69dB/–75dB.

2) The quality of the signal can be rated as good.

3) When passing the route, 7 cells were detected, and an even and smooth handover between them was reported without significant drops in the signal level and lack of coverage. The service time is also reflected in each of them.

3. The following important conclusions about route 1 can be drawn from research in 3G – UMTS mode:

1) The bypass route signal level is mostly good: –70dB/–80dB. Only in a few parts there is a deterioration of the level and it drops to -87dB/-95dB, due to reasons already mentioned in the 2G analysis.

2) The signal quality can be rated as average to good, which is shown by the ASU option of the application.

3) It has good coverage of neighboring cells.

4) 12 cells were detected while traversing the route. The primary residence of the mobile device was in 4 of them, reporting smooth and uninterrupted handover between them without significant drops in signal level and lack of coverage.

4. The following important conclusions can be drawn for route 2 from the research in 3G – UMTS mode:

1) The signal level at the beginning and at the end of the traveled route is satisfactory: -85dB, while in some sections it is weak: -107dB. In its larger part, which is closer to the central part of the city, it is good: -67dB/-80dB.

2) The quality of the signal can be rated as good.

3) 6 cells were detected while traversing the route. The primary residence of the mobile device was in 4 of them, reporting smooth and uninterrupted handover between them without significant drops in signal level and lack of coverage.

5. The following important conclusions can be drawn for route 1 from research in the 4G – LTE mode:

1) The signal level for the traveled route varies significantly within the limits: –70dB/–100dB, with the lowest values observed throughout the section.

2) Signal quality varies, with an average showing of -12dB with the app's RSRQ option and a best of -3dB.

3) The SNR ratio varies a lot – 1dB/11dB, which is not a prerequisite for good signal quality.

4) 98.2% of the time there was a 4G signal and the rest UMTS.

5) 15 cells were detected while traversing the route. The dwell time of the mobile device in each of them was reflected, and an even and smooth handover between them was observed without significant drops in the signal level and lack of coverage.

6. The following important conclusions for route 2 can be drawn from the strained research in the 4G – LTE mode:

1) The signal level for the bypass route varies significantly within the limits: –70dB/–117dB, with the lowest values in the outer parts, which are far from the central part of the city.

2) Signal quality varies, with an average reading of -12 dB and a peak reading of -3 dB.

3) The SNR ratio varies a lot – 3dB/27dB, which is not a prerequisite for good signal quality.

4) 98.1% of the time a 4G signal was reported, 0.2% a 3.5G signal and 1.6% a 3G signal.

5) When crossing the route, 9 cells were detected. The dwell time of the mobile device in each of them was reflected, and an even and smooth handover between them was observed without significant drops in the signal level and lack of coverage.

7. The following conclusions can be summarized from research conducted on network throughput during data traffic via mobile Internet access:

1) The advantage of fast access to 4G compared to slow 2G is clearly visible - the difference in throughput in the forward direction (download) is on average more than 400 times in favor of 4G, and in the opposite direction (upload) - more than 500 times.

2) When comparing the bandwidths between 3G and 4G, the values are as follows: in the forward direction, the difference is over 7 times in favor of 4G, and in the opposite direction - over 11 times.

3) A better throughput was observed in the central city and in the western part of the city compared to that reported in the southern and eastern parts. In 2G mode the speed is almost the same in all measured parts, and in 4G mode it varies.

4) The asymmetry of the mobile internet service is clearly expressed – the upload/download ratio is 1/1 in 2G mode, 1/3 in 3G mode and 1/2 in 4G mode.

8. From the intensive research in the 4G – LTE mode of the mobile operator A1, the following more important conclusions can be drawn for route 1:

1) The signal level for the traveled route varies significantly within the limits: –92dB/–103dB, with the lowest values observed at the beginning of the route.

2) Signal quality varies, with an average reading of -15 dB shown with the app's RSRQ option and a best reading of -14 dB.

3) The SNR ratio varies a lot – 0dB/13dB, which is not a prerequisite for good signal quality.

4) Had 4G signal 100% of the time.

5) When crossing the route, 7 cells were detected. The dwell time of the mobile device in each of them was reflected, and an even and smooth handover between them was observed without significant drops in the signal level and lack of coverage.

9. From the intensive research in the 4G – LTE mode of mobile operator A1, the following important conclusions can be drawn for route 2:

1) The bypass route signal level varies significantly within the limits: –90dB/–101dB, with the lower values being in the central and western parts of the city.

2) Signal quality varies, with an average reading of -14dB and a peak reading of -11dB.

3) The SNR ratio varies a lot – -6dB/5dB, which is not a prerequisite for good signal quality.

4) 4G signal reported 100% of the time.

5) When crossing the route, 7 cells were detected. The dwell time of the mobile device in each of them was reflected, and an even and smooth handover between them was observed without significant drops in the signal level and lack of coverage.

10. The following important conclusions about Route 1 can be drawn from the research in the 5G mode:

1) The signal level for the bypass route varies significantly within the limits: –77dB/–99dB, with the lowest values being in the central part of the city.

2) Signal quality varies, with an average reading of -12 dB and a peak reading of -10 dB.

3) The SNR ratio varies a lot – -2dB/14dB, which is not a prerequisite for good signal quality.

4) 5G signal was reported 97.8% of the time and 4G signal 2.2% of the time.

5) 10 cells were detected while traversing the route. The dwell time of the mobile device in each of them was reflected, and an even and smooth handover between them was observed without significant drops in the signal level and lack of coverage.

6) The GAUGE section of the application shows that the received signal is 5G (NSA-Non-Standalone), which means that base stations and equipment from 4G technology are used.

11. The following important conclusions about Route 2 can be drawn from research in the 5G mode:

1) The signal level for the bypass route varies significantly within the limits: –88dB/–102dB, with the lowest values being in the southern and central parts of the city.

2) Signal quality varies, with an average reading of -16dB and a peak reading of -14dB.

3) The SNR ratio varies within large limits – 5dB/4dB, which is a prerequisite for good signal quality.

4) 5G signal was reported 94.8% of the time and 4G 5.2% of the time.

5) When crossing the route, 7 cells were detected. The dwell time of the mobile device in each of them was reflected, and an even and smooth handover between them was observed without significant drops in the signal level and lack of coverage.

6) The GAUGE section of the application shows that the received signal is 5G (NSA-Non-Standalone), which means that base stations and equipment from 4G technology are used.

12. The following conclusions can be summarized from research conducted on network throughput during data traffic via mobile Internet access:

1) The advantage of fast access to 5G compared to 4G is clearly visible - the difference in throughput in the forward direction (download) is on average more than 4 times in favor of 5G, and in the opposite direction (upload) - more than 3 times .

2) There is an increase in throughput in 4G, after the upgrade of base stations for access to 5G.

3) A better throughput was observed in the central city and in the western part of the city compared to that reported in the southern and eastern parts.

4) The asymmetry of the mobile Internet service is clearly expressed - the upload/download ratio is 1/7 in 4G mode and 1/10 in 5G mode.

CHAPTER V. PRACTICAL MEASUREMENTS OF COVERAGE AND RADIATION OF MOBILE OPERATORS IN MACEDONIA RELATED TO THE QUALITY OF SERVICES

5.1. Quality of provided public electronic communication services through public electronic communication networks for settlements and public roads

The regulatory body for Telekommunications in Macedonia is obliged to measure the quality parameters of the services (QoS parametars), provided by mobile operators. The obtained results are compared with the required values. If any of the mandatory QoS parameters does not meet the criteria, then the mobile operator is obliged to take measures to improve it in a certain period of time to ensure quality in accordance with the policy of the Agency for Electronic Communications (AEC) as a Regulatory Body.

The measurements were focused on 3 (three) questions:

• Cities/roads and derived different parameters for city/road area;
• Voice and data services and defined parameters for each service;
• Evaluation of the parameters related to the quality of services.

In conclusion, it can be said that, for voice services, the mobile operator A1 Macedonia meets the quality requirements set by AEC. The mobile operator Makedonski Telekom also provides the voice service according to the quality determined by AEC, except for the call failure rate parameter. Therefore, the mobile operator Makedonski Telekom will have the obligation to improve this parameter according to the mandatory value for full compliance with the defined service quality.

The next parameter related to the quality of services (QoS) is the speed of data transmission through a radio communication network, regardless of the technologies in cities (GPRS, EDGE, UMTS and LTE).

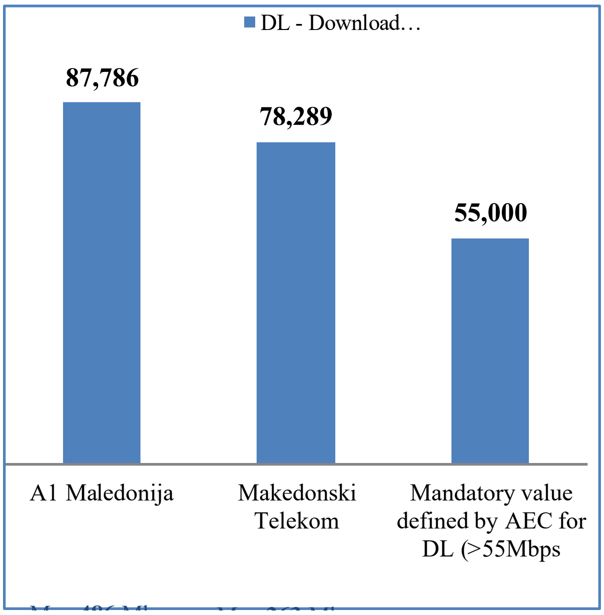


Fig. 5.7. Data transmission speed through a radio communication network in an urban environment in Mbps

Calculations are made on a value size of 10 GB over the HTTP protocol. The mandatory value in cities is 55 Mbps, set by AEC as the regulatory body. In fig. 5.7, the bottom of the figure shows the maximum data rate measured during the analyzes and measurements. The value for the mobile operator A1 Macedonia is 87.8 Mbps, and for the operator Makedonski Telekom it is 78.3 Mbps. Thus, both mobile operators provide a very good speed of data transfer through the radio communication network.

The next QoS parameter is the speed of data transmission through the radio communication network, regardless of access technologies (GPRS, EDGE, UMTS and LTE).

5.2. Examples of experimental measurements and detection of problem zones with a test equipment module in the network of mobile operators

5.2.1. Basic goals in radio interface measurement

The measurement of the radio interface is intended to show the current state of the network, as well as to detect the presence of problems. It also enables the analysis and planning of subsequent optimizations in order to improve the quality of the service. We can divide measurements into the following categories:

• Periodic measurements along a certain route - usually carried out once or several times a year, in order to check the quality of the service, along the important road lines and main streets of the city road network.

• Measurements related to a change in network parameters - performed before and after the change, in the area of the given facilities. They aim to create a benchmarking baseline and provide guidance for further optimizations if needed.

• Measurements related to the integration of a new object in the network or the relocation/dismantling of another – provide the necessary information about the subsequent changes, in order to adapt the network to the new conditions.

• Measuring the service surface of a cell with degraded indicators - The main task in monitoring the network is the analysis of the database, with the key indicators of the objects in the network (Key Performance Indicators). When a deterioration of the indicators of a given cell is detected, a measurement is ordered to determine the cause of the deterioration.

• Measurements related to received signals with reduced quality - performed in areas with reduced quality of service, for which there is prior information from users.

An important stage is the preliminary preparation of the measurement. It consists in choosing the appropriate equipment and measurement method, determining the route and the appropriate time. For example, when measuring a third-generation mobile network, it is practically mandatory to foresee the use of a scanning module. It helps to detect unshared neighboring cells causing interference as well as measure the levels of neighboring WCDMA cells operating on another channel.

5.2.2. Main measurements of a newly built 4G site

Measurements were made with TEMS Investigation 17. Data speed /throughput/ and speech - Voice were measured. This measurement "downloads" /DL/ and "uploads" /UL/ data from a server of precisely defined size. Time is measured and throughput is determined.

During the measuring of the voice services in the phone's 4G mode, a voice call is made to another phone also in 4G mode. Since the network does not yet offer VoLTE /Voice over LTE/ when you try to make a call, the phone switches to 3G or 2G mode to make a call. This procedure is called CSFB /Circuit Switched Fallback/. The network is set to CSFB the phone and the signal first goes to 3G mode, and if there is no or if there is congestion, to 2G mode.

In fig. 5.18 in the "LTE Serving Cell" window, the main parameters obtained from the network for the measured LTE cell are visualized, such as: Cell identity and accordingly, RB /Resource Block/,, frequency band, the channel of the used frequency, etc.

The LTE Serving/Neighbor Cell window displays information about the measured 4G neighboring cells. In the third window, which is located to the left of the mentioned two, the specific measurement is visualized.

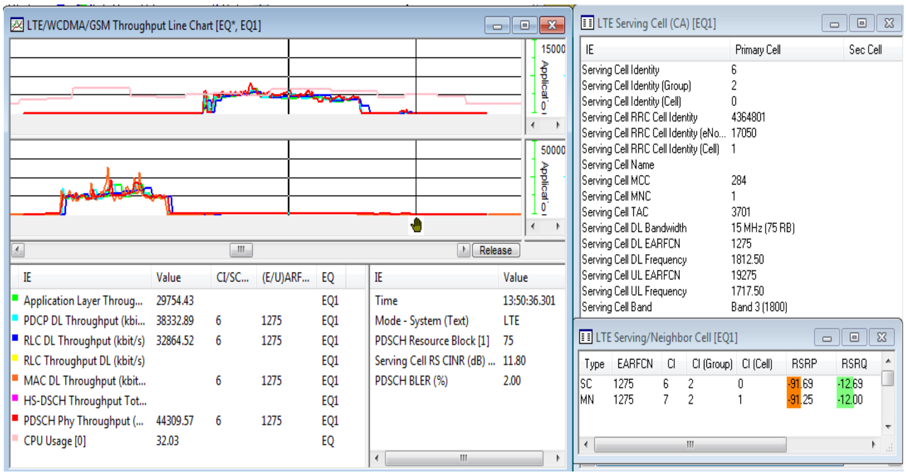


Fig. 5.18. The LTE Serving operating screen displays information about the measured 4G signals

Measurement of data speed and taken activities

When the measurement was made in the service measurement zone of one of the sectors, relatively low speeds were found - fig. 5.9. After analyzing the results, it was found that the signal-to-noise ratio was low and that this was due to the strong signal from the neighboring 4G cell.

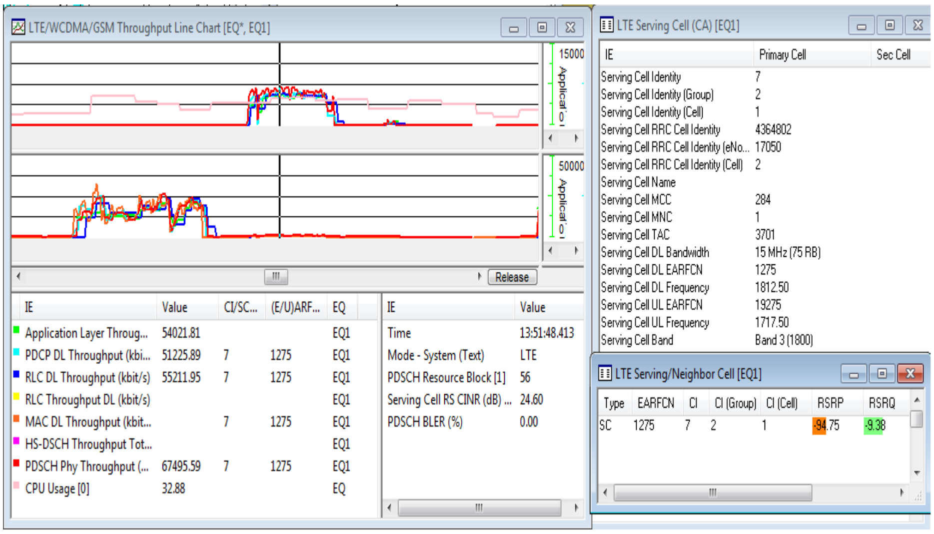


Fig. 5.19. Data speed measurement for 4G –UL / DL after optimization

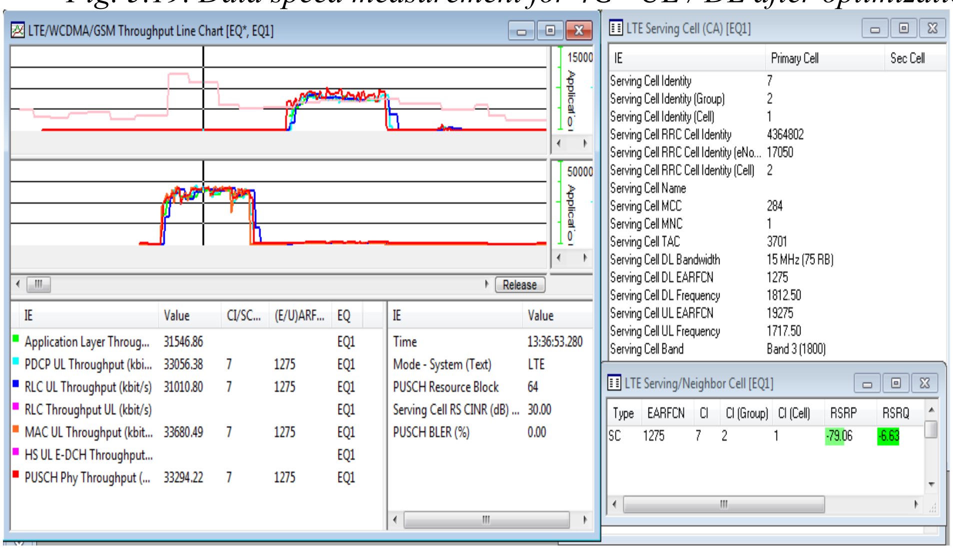


Fig. 5.20. New data rate measurement for 4G –UL / DL after optimization

Optimization of the antennas of the two sectors that interfere with each other has been done. By correcting the slope (vertical slope) the expected result was achieved.

Fig. 5.19 and Fig. 5.20 shows the new measurement after optimization. The speed improvement in both directions (DL and UL) is significantly improved.

Measurement of voice service (Voice) in 4G.

In Fig. 5.21 is showen a successful attempt to establish a conversation. After dialing a call, the signaling indicates that the terminal switches from 4G to 3G.

An additional Layer 3 Messages window is displayed for this procedure, where the entire sequence of network signaling messages can be followed to perform the switchover.

If the switchover fails, these displays can show the reason for the failed switchover.

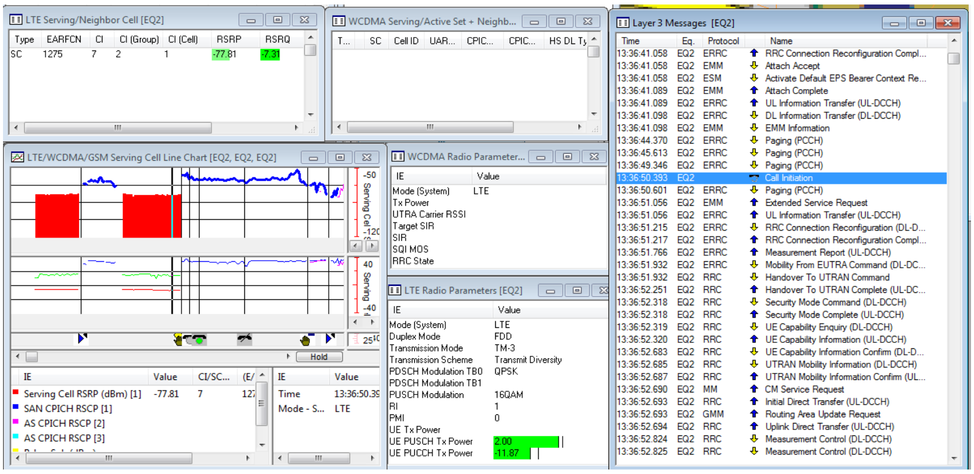


Fig. 5.21. Measurement of voice services during transfering from 4G to 3G

5.2.3. Practical investigations of problem areas

The investigated zone affects an urban environment in a three-sector antenna that uses UMTS technology. Specialized Arieso software was used through a mobile measurement and tracking system. Investigations were carried out on three problem zones, which were solved by additional adjustments of the equipment used by analyzing the obtained results. The marked points are the location of the subscriber. Therefore, CID 42603 is UMTS on 2100 MHz and CID 42609 is UMTS on 900 MHz.

In fig. 5.24 shows that the subscriber was on UMTS 2100 MHz with RSSI -94.5dBm and Ec/No (quality) -4.25dBm.

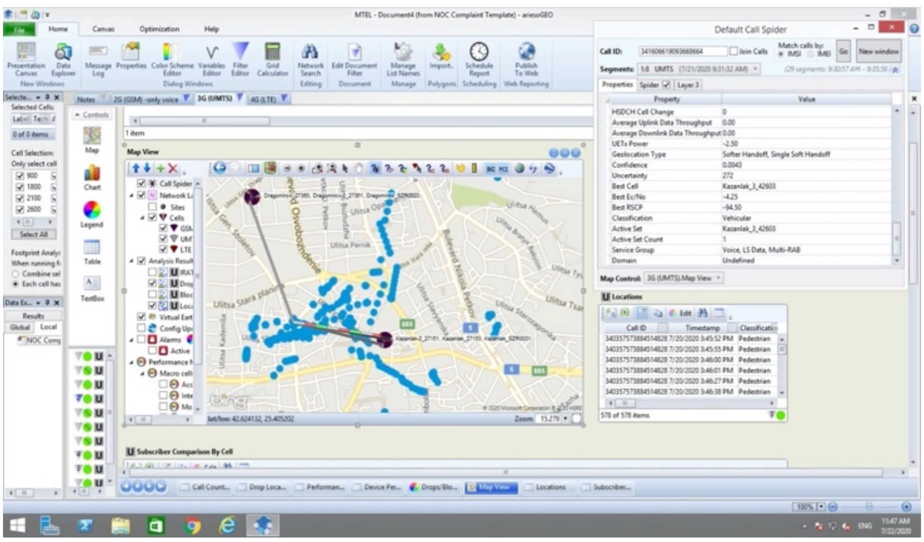


Fig. 5.24. Correlation of quality measurements such as signal levels and signal-to-noise ratio with problem levels in the first zone

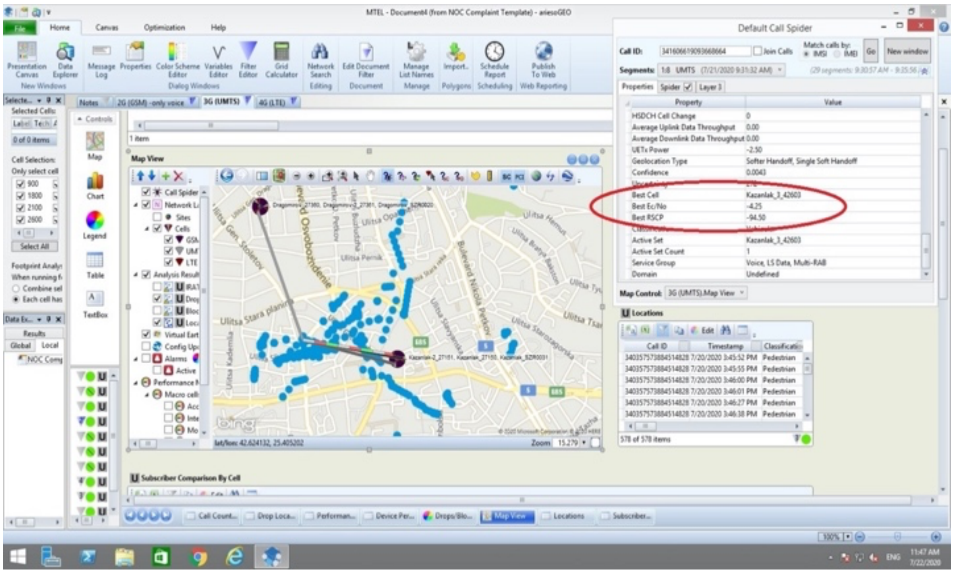


Fig. 5.25. Improvement of connection quality such as signal levels and signal-to-noise ratio after antenna equipment adjustments in the first zone

It turned out that the antennas at 900 MHz have a much larger angle (tilt) and that is 10 degrees down, and those at 2100 MHz are at 4 degrees. For this reason, 900 MHz performs well only when very close to the BS, and at further places an anomaly occurs, with those at 2100 MHz having better characteristics than 900 MHz. By correcting the angle of the antenna (tilt) at 900 MHz from 10 to 6 degrees, the problem is solved.

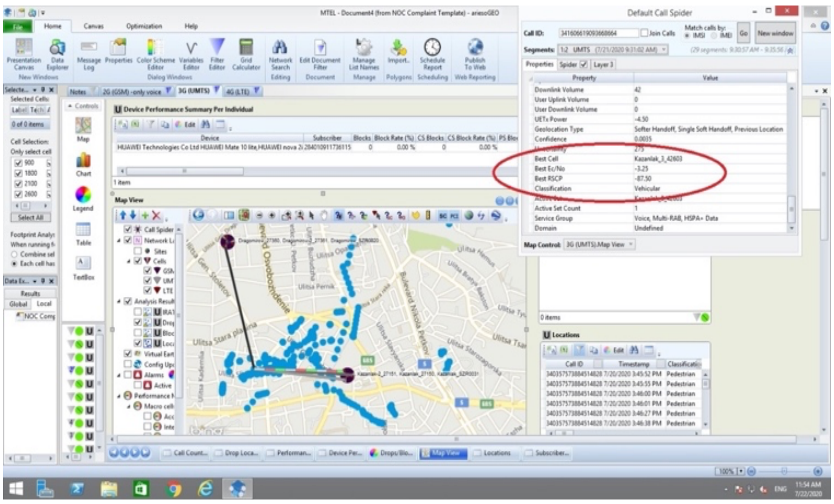


Fig. 5.29. Improvement of connection quality such as signal levels and signal-to-noise ratio after third-zone antenna equipment adjustments

5.3. Research on the emission of non-ionizing radiation from base stations of mobile operators

In the context of the expansion of modern Telekommunication systems based on wireless transmission, it is necessary to comprehensively perceive the biological effects of electromagnetic radiation in the range of radio frequency and microwave frequency and through legislation to provide appropriate protection measures for all categories of the population.

The rapid development of wireless Telekommunications systems and the liberalization of the Telekommunications market have led to the installation of a large number of stations emitting electromagnetic waves from the RF and microwave part of the radio spectrum, such as base stations for mobile communication systems, transceiver stations for microwave links (links for radio relay), broadcast transmitters, etc. A large number of these stations are located in or near populated areas, so all population structures are exposed to radio frequency and microwave radiation.

For the population, the most important information is the energy density with which their space is loaded, and it depends on the characteristics of the antennas, their position (height and placement angle), the dynamics and levels of use of the base stations and the position. of the space (being investigated) in relation to the antennas.

5.3.1. Measurements of non-ionizing radiation at the 5G base station of the mobile operator Makedonski Telekom AD Skopje

Defined parameters and regulation from the European Commission

The current analysis is made of some ordinary and some special parametric of the field power measurements made with professional instruments at a base station owned by Makedonski Telekom AD Skopje as an operator for mobile Telekommunication services to users.

Weather conditions and location for 5G base station measurements

5G base measuring station that research and measures, owned by the company Makedonski Telekom AD Skopje, is placed on the edge of the building, and the measurement is made in front of the building of the Regulatory body Agency for Electronic Communications, located at the address: Kej Dimitar Vlahov number 21, Skopje and approximately 160 m from the first base station and approximately 400 m from the second base station. Measurements are carried out on 05.12.2022 and 13.12.2022 in the time slots 13.45 - 15.20 and 10.00 - 14.10. The weather is cold and cloudy with 7 degrees.

Defined parameters and EU regulation

Dominant sources of electromagnetic radiation: (location description)

The recommendations of the International Commission on Non-Ionizing Radiation Protection - ICNIRP (International Commission on Non-Ionizing Radiation Protection) for limiting exposure to various electromagnetic fields up to 300 GHz and the recommendations introduced by the European Commission given in CEPT, ECC REC recommendation (02) 04 – Measurement of non-ionizing electromagnetic radiation (9KHz-300GHz).

Measuring equipment:

During the measurement, calibrated equipment of the manufacturer NARDA was used, namely: broadband electromagnetic field measuring instrument NBM 550 and frequency selective electromagnetic field measuring instrument SRM 3006 with appropriate isotropic antennas depending on the frequencies of the electromagnetic radiation.

Measurement protocol:

The measurement follows the methodology described in standards EN50492 EN50383, EN50400, EN50413. Since the distance from the sources of non-ionizing radiation to the point of measurement is much greater than the wavelength of the electromagnetic field, it can be said with certainty that the measurements are performed at a certain point and cover an area of a remote field. Therefore, it is enough to measure only the power of the electric field, and the strength of the magnetic field and the energy density can be calculated, since these quantities are closely related to each other.

The measurement is carried out in order to determine the maximum electromagnetic field and the radiation of the population with non-ionizing radiation. It is also necessary to research the impact of the 5G NR test network on non-ionizing radiation.

Dominant sources of electromagnetic radiation: (location description)

Near the measuring point (in front of the AEC building) there are dominant sources of electromagnetic radiation. The nearest base station for mobile telephony is at a distance of about

160 meters (from the Macedonian Telekom building) and about 420 meters (from the TC Centar building). GSM, UMTS, LTE signals are being broadcast from base stations and for the first time a 5G NR signal is being tested. The frequency range of the 5G signal is 100 MHz.

Measurement results:

The following results were obtained from the measurements:

• General electromagnetic field exposure coefficient: 14.90% (% of the maximum allowed, Electric field value);

• Total power density: 185.46mW/m^2;

• Total electric field strength: 8.36V/m.

Сервис	%
FM	0.77
DVB-T	0.73
GSM	4.99
UMTS	4.09
LTE	10.37
5G	8.48
LTE TDD	0.13
Вкупно	14.90

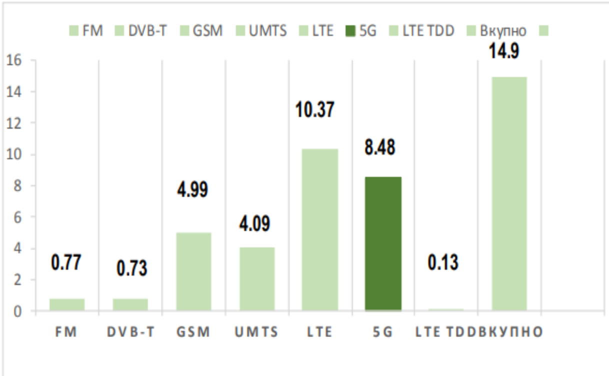


Fig. 5.33. Radiation levels of different services in the measurement location

The results are obtained according to the measured humidity, and the total result is obtained according to the formula for the total electromagnetic field exposure factor: 14.90%:

$$14{,}9 = \sqrt{0{,}77^2 + 0{,}73^2 + 4{,}99^2 + 4{,}09^2 + 10{,}37^2 + 8{,}48^2 + 0{,}13^2}$$

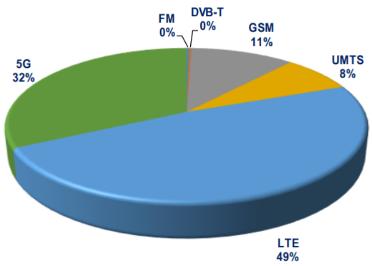


Fig. 5.34. Percentage ratio about the radiation of different types of Telekommunication services

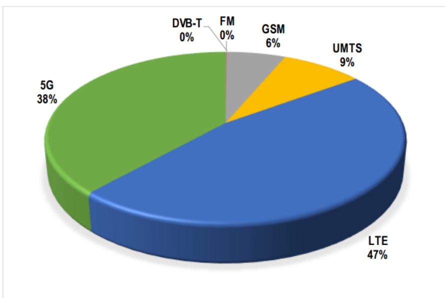


Fig. 5.35. The contribution of technologies to the total density of electromagnetic energy [mW/m^2]

Based the results obtained according the measurements, we may conclude that with the new 5G technology the non-ionizing radiation increases, but with GSM and UMTS technologies it will decrease. However, the result and the total radiation during this measurement, at a distance of 220 m from the mobile base station, is below 11% of the maximum allowed limit value.

The results of the measurements are calculated by interpolation and show what the strength of the electric field would be, i.e. what would be the energy density at the measurement point if the measured base stations were operating at full capacity or operating at full power. Such a case would be, for example, if the user is located in a place where a mass or large gathering (sporting, cultural or political) is held with many users or where the mobile base stations that would be located in the immediate vicinity of the event will work with full capacity.

5.4. Reported problems and strategies in managing performance and quality of service in mobile broadband networks

5.4.1. Financial problems

Information and communication technologies are strategic tools for the business sector that affect productivity and growth at the macroeconomic level. Experience shows the dependence between changing work processes and increasing skills in the business sector, on the one hand, and continuous and proactive investments in information and communication technologies, on the other hand.

5.4.2. Investments and planning in urban and non-urban environments

The benefits of broadband access are particularly important for remote and rural areas, as improved communication systems can overcome many of the problems imposed by distance from urban environments. Broadband Internet allows people to communicate and exchange information regardless of their physical location. Increased interactivity enables more active participation in the social and democratic flows of life. Broadband improves their standard of living by bridging distance, improving health, education and access to public services.

5.4.3. Regulatory activities, obligations and laws

The Agency for Electronic Communications should impose obligations on operators with significant market power in markets for physical access to network infrastructure (including unbundled or fully unbundled access) at a fixed location to provide physical access to their channels, established works and other passive network elements that are necessary to create a competitive optical infrastructure.

5.4.4. Ensuring conditions for transparency

Operators with significant market power must submit a Model Offer for access to physical infrastructure, which will also contain information related to locations, channel capacity and other passive elements, information on access points (topography of the network, possible connections in street cabinets, locations of concentration of access points, lists of already connected buildings, etc.), which should be approved by the agency. The agency must determine in advance the form and degree of detail of the information in the reference offers.

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5.4.5. Policies and regulation of prices and services

Prices for access to existing physical infrastructure should be based on the costs incurred by an operator with significant market power. The agency must create an appropriate methodology for price control in accordance with the recommendations of the European Commission. Prices for access to new channels, construction works and other passive elements must be based on a previously established price control methodology established by AEC and in accordance with the recommendations of the European Commission. The prices may include so-called project-specific "risk premiums", which represent the investment risk to which the operator is exposed during the construction of the infrastructure.

5.4.6. Guaranteeing the principle of non-discrimination

The Agency for Electronic Communications must ensure full compliance with the principle of non-discrimination, i.e. the operator with significant market power to provide access to the passive infrastructure under the same conditions, both for its business units or partners, and for third parties.

5.4.7. Development of broadband internet in municipalities

The construction of electronic communication networks, especially optical networks, requires very large investments in the construction of the infrastructure. Complex administrative procedures, lack of sufficient information for obtaining permits, outdated local administration, etc. can appear as obstacles, which very often discourage investors to invest, especially in the field of Telekommunications, since the sector requires fast and dynamic operation and monitoring of needs at the market.

5.4.8. The benefits of broadband Internet access during a pandemic and emergency

The benefits of quality broadband/internet access in the event of a pandemic and emergency are enormous. The existence of a pandemic such as the recent corona virus (COVID-19), has changed the life of the whole world. Hence the growing need for fast exchange of information, smooth two-way communication between people wherever they are on the globe, through the provision of broadband internet.

5.5. Analysis and conclusions in CHAPTER 5

1. Practical research was carried out by the regulatory body of Macedonia - the Agency for Electronic Communications (AEC). Statistics, processing and analysis of practical results for voice services and data transmission of the most important operators in the country have been carried out. Measurements were made for several routes in urban and non-urban environments.

2. The results show the presence of good network coverage and it can be said that for voice services the mobile operator A1 Macedonia meets the quality requirements defined by AEC. The mobile operator Makedonski Telekom also provides the voice service according to the quality determined by AEC, except for the failure rate parameter of established calls. Therefore, the mobile operator Makedonski Telekom will have the obligation to improve this parameter according to the mandatory value in order to be in full compliance with the defined service quality. With the introduction of the new 5G DSS and LTE technologies, which are in continuous development and improvement, it can be argued that the data speed at this stage is much higher in an urban environment, and time delays are lower, compared to non-urban routes.

3. Basic experimental measurements related to monitoring a core part of a network and detecting problematic coverage areas using specialized equipment and software with TEMS Investigation are presented. After analyzing the results, low levels of the signal-to-noise ratio were detected, and this was due to the strong signal from the neighboring 4G cell. An optimization of the antennas of the two interfering sectors was proposed, and the expected result was achieved by correcting the tilte (tilt).

4. With the help of specialized software Arieso and through a mobile system for measurements and monitoring, a practical study of problem areas and less populated places was

carried out. It was found that the antennas at 900 MHz have a very large tilt angle (tilt) by 10 degrees down, and those at 2100 MHz by 4 degrees. For this reason, 900 MHz has good levels only very close to the BS, and at further places an anomaly occurs, with which it can be concluded that those on 2100 MHz have better levels than 900 MHz. After a suggested correction of the antenna tilt (tilt) of the 900 MHz ones from 10 to 6 degrees, the problem was solved.

5. Research related to the emission of non-ionizing radiation from the base stations of the mobile operators related to the launch of the new 5G technology was done. The obtained results show that the total radiation during this measurement at a distance of 220 m from the mobile base station is below 11% of the maximum allowed limit value. The results of the measurements are by calculated interpolation, and actually show what the strength of the electric field would be, i.e. what would be the energy density at the measurement point if the measured base stations were operating at full capacity or operating at full power.

6. Reported problems and strategies in managing the efficiency and quality of services in broadband mobile networks, analyzing the financial problems related to investments and planning, can be solved by the regulatory laws and projects for the development of broadband Internet in the municipalities of Macedonia.

CONCLUSION

Broadband Internet enables the creation of new and innovative services, applications and content, encourages the development of new services and improves the quality of their delivery to consumers. It enables the reorganization of work and production processes and is the basis for the development of information and communication technologies, which are the main drivers of productivity and economic growth in the country.

In the last 2-3 years, Macedonia has made significant progress in the development of broadband internet. This is also due to the creation and implementation of effective policies to promote liberalization and competition, as well as the efficient implementation of legislation by the Agency for Electronic Communications.

The development of the economy in Macedonia in the last few years has positively influenced the increase in the penetration of broadband internet, but broadband internet services also significantly influence the development in all economic and non-economic sectors in the country. The positive trend in the development of broadband Internet is expected to continue at the same pace in the future.

In order to control the work of the operators, AEC, as an independent regulatory authority for Telekommunications, constantly performs measurements of the quality of services provided by the two network mobile operators throughout the territory of Macedonia and publishes the results of these measurements on the website of AEC: www.komuniciraj.mk .

As a result of the research within the dissertation work, the following **scientific-applied and applied contributions** have been achieved with significance and usefulness in the planning, setting up and functioning of mobile networks which affect the management of the efficiency and quality of services in them:

Scientific and applied contributions:

- An analytical methodology for designing and calculating the parameters of a broadband mobile network is presented;
- Mathematical dependencies related to network load factors in forward and reverse direction, with determination of radio coverage, radio propagation losses and antenna gain are derived;
- WCDMA End-to-End Physical Layer simulation model was synthesized, based on which the research was done and graphical results were shown for three different cases of the environment and the user's movement in it. Based on this, the effective BER values can be determined depending on the SNR, related to ensuring the quality of services under different conditions.

Applied contributions:

- It was determined that the Power Control Algorithm has limitations and when the reserve resource for power regulation is used up, it switches to channel switching (handover). Broadcasting with very high power leads to a decrease in system sensitivity, therefore the BPC parameter is introduced for power regulation, the value of which is 0.7 at a subscriber movement speed of 3 km/h and 0 at a subscriber movement speed of 50 km /h per hour;
- Experimental results of broadband mobile network parameters in urban areas, using specialized software applications installed on a mobile station, are presented. Signals from 2 operators in an urban environment in 2/3/4 and 5G modes of operation along certain routes were investigated by changing the speed of movement of the mobile measuring station. From the statistics and the analysis of the obtained results, 12 specific conclusions related to improving the efficiency of management and ensuring better quality of services in an urban environment were established;
- The experimental setup has been fulfilled and practical research was carried out by the regulatory body of Macedonia - the Agency for Electronic Communications (AEC). Statistics, processing and analysis of the practical results for voice services and data

transmission of the most important operators for the country were performed. A process has been developed that includes network monitoring, measurements of key performance parameters and cell optimization to improve efficiency and quality of service;

- Real measurements related to the emission of non-ionizing radiation from the base stations of the mobile operators related to the launch of the new 5G technology were made. Diagnostics and evaluation of operational characteristics related to ensuring the quality of service in urban areas have been carried out, problem areas have been localized and basic technical-technological solutions for its improvement have been defined.

LIST OF PUBLICATIONS
FOR THE DISSERTATION PAPER

[A.1] **Arsov B.**, Arsova E., Sadinov S., *Measurements of the non-ionizing radiation of 5G base station of Mobile operator Makedonski Telekom AD Skopje and electricity supply with Photovoltaic plant,* International Conference on Electronics, Engineering Physics and Earth Science (EEPES 2023), 2023 in Kavala, Greece. (Indexing and Publishing AIP Conference Proceedings is indexing in: Scopus, CPCI (part of Web of Science), Inspec index, **SJR 0.19**) (in Print)
https://pubs.aip.org/aip/acp

[A.2] **Arsov B.,** *Non-ionizing radiation measurement of 5G mobile base station of A1 operator,* 7th National scientific conference with international participation – TechCo 2023, June 30, 2023 Lovech, ISSN 2535-079X, pg. 89-94.
https://www.tugab.bg/images/tk-lovech/programa_TechCo-2023_n.pdf

[A.3] **Arsov B.,** *Quality of 5G traffic service and implementation of 5G in N.Macedonia*, 7th National Scientific Conference with international participation – TechCo 2023, June 30, 2023 Lovech, ISSN 2535-079X, pg. 95-100.
https://www.tugab.bg/images/tk-lovech/programa_TechCo-2023_n.pdf

[A.4] Sadinov S., M. Tomov, **B. Arsov**, A. Ahmed*, Distributed GSM Signal Quality Improvement Across the Entire 890-960 MHz Band,* International Scientific Conference – Unitech 2023, 17-18 November 2023, Gabrovo, ISSN 1313-230X, pp. I-217-222.
https://unitech.tugab.bg/docs/doc100.pdf

[A.5] Sadinov S., **B. Arsov**, A. Ahmed, E. Ozdikililer, *Comparative Analysis Of Software Tools For Testing Radio Coverage Through A Mobile Terminal,* International Scientific Conference – Unitech 2023, 17-18 November 2023, Gabrovo, ISSN 1313-230X, pp. I-223-227.
https://unitech.tugab.bg/docs/doc100.pdf

TITLE: „MANAGMENT OF THE PERFORMANCE AND QUALITY OF SERVICE IN MOBILE BROADBAND NETWORKS“

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ABSTRACT:

The dissertation presents an analytical methodology for designing and calculating the parameters of a broadband mobile network. Mathematical dependencies related to network load factors in the forward and reverse direction, with determination of radio coverage, radio propagation losses, antenna gain are derived. A simulation model of the WCDMA End-to-End Physical Layer was synthesized, based on which research was done and graphical results were displayed for three different cases of the environment and the user's movement in it. It can be used to determine the effective BER values depending on the SNR, related to ensuring the quality of services under different conditions. Experimental results of the parameters of a broadband mobile network in urban conditions are presented, by using specialized software applications installed on a mobile station. The signals from 2 operators in an urban environment in 2/3/4 and 5G modes of operation along certain routes were investigated by changing the speed of movement of the mobile measuring station. From the statistics and the analysis of the obtained results, specific conclusions have been established, related to improving the efficiency of management and ensuring a better quality of services in an urban environment. Experimental setups were proposed and practical studies were carried out by the Regulatory body for the Republic of N. Macedonia - the Agency of Electronic Communications (AEC). Statistics, processing and analysis of the practical results for voice services and data transfer of the most important operators for the country N. Macedonia have been carried out. A process has been developed that includes network monitoring, measurements of key performance parameters and cell optimization to improve efficiency and quality of service. Real measurements were made related to the emission of non-ionizing radiation from the base stations of the mobile operators related to the commissioning of the new 5G technology. Diagnostics and evaluation of the operating characteristics related to ensuring the quality of service in urban areas have been carried out, problem areas have been localized and basic technical and technological solutions for its improvement have been defined.

Keywords: Mobile (Cellular) communication, Mobile broadband network, GSM(2G), UMTS(3G), LTE (4G) 5G, BER, SNR, BCH, QoS, Simulation Matlab, CDMA (WCDMA).