

Metadata of the chapter that will be visualized online

Chapter Title	Basic Stations Work Optimization in Cellular Communication Network	
Copyright Year	2021	
Copyright Holder	The Author(s), under exclusive license to Springer Nature Switzerland AG	
Corresponding Author	Family Name	Tkachuk
	Particle	
	Given Name	Anatolii
	Suffix	
	Division	Technological Faculty
	Organization	Lutsk National Technical University
	Address	Lutsk, Ukraine
	Email	a.tkachuk@lntu.edu.ua
Author	Family Name	Zablotskyi
	Particle	
	Given Name	Valentyn
	Suffix	
	Division	Technological Faculty
	Organization	Lutsk National Technical University
	Address	Lutsk, Ukraine
	Email	v.zablotsky@lntu.edu.ua
Author	Family Name	Zabolotnyi
	Particle	
	Given Name	Oleg
	Suffix	
	Division	Technological Faculty
	Organization	Lutsk National Technical University
	Address	Lutsk, Ukraine
	Author	Family Name
Particle		
Given Name		Dagmar
Suffix		
Division		Faculty of Materials Science and Technology
Organization		Slovak University of Technology, Bratislava
Address		Bratislava, Slovakia
Email		dagmar.caganova@stuba.sk

Author	Family Name	Yakymchuk
	Particle	
	Given Name	Nataliia
	Suffix	
	Division	Technological Faculty
	Organization	Lutsk National Technical University
	Address	Lutsk, Ukraine
	Email	m.yakymchuk@lntu.edu.ua

Abstract The paper proposes an algorithm that automatically determines the test data amount, depending on the bandwidth of the network channel, so the measurement procedure eliminates operator error. This is especially true during daily measurements, which are carried out on different days of the week. Daily measurements allow to estimate the base station single sector workload, a small area or the entire network as a whole. It is necessary to analyse the network operation and to optimize its problem areas. According to the results of the research, the authors of the paper revealed the hours of maximum and minimum load and load extrema, which is characterized by the fact that the number of subscribers using the cellular network for voice calls or data transmission is the maximum. The regularity of cases when the subscriber terminal is registered in the network but it is impossible to make a voice call or transmit data is revealed. If such a case is isolated, there is no need to change the network or perform optimization. However, if the network overload occurs at certain intervals, it is recommended to optimize the problem area of the network by dynamic power control or installation of an additional transmitter. This method of adjusting base station receivers is suitable for use in 4G and 5G networks.

Keywords (separated by “-”) Monitoring - Connection - Loading - Subscriber terminal - Base cellular station

Basic Stations Work Optimization in Cellular Communication Network

Anatolii Tkachuk , Valentyn Zablotskyi , Oleg Zabolotnyi ,
Dagmar Cagaňová , and Nataliia Yakymchuk 

1 Introduction

Now, mainly such companies as Kyivstar, Vodafone Ukraine, Lifecell and Intertelecom provide 3G and 4G cellular services in Ukraine.

The launch of 1.8 GHz 4G networks in Ukraine has allowed Vodafone to significantly increase the coverage of high-speed Internet. In comparison with the previous period of operation, mobile Internet in the 2.6 GHz was available only in places with the largest concentration of Internet users. According to the operator, 4G service from Vodafone is available for 11.7 million Ukrainians. The geography of coverage of the fourth-generation network includes the entire territory of Ukraine (Fig. 1).

After the launch of 4G, Vodafone subscribers have the opportunity to actively use mobile Internet and 4G-based services (HD TV streaming, online games), actively use cloud services. Thanks to the introduction of new communication technologies, new directions have also become possible for use: telemedicine, smart-management of energy and agriculture, and electronic mobile wallets.

Because Kyivstar is one of the oldest operators in the mobile market of Ukraine, the company was able to increase the largest base of subscribers (approximately 27 million), as well as create a wide map of mobile Internet coverage (Fig. 2). Today it is a leader in the growth rate of new subscribers, as well as in the amount of traffic

A. Tkachuk (✉) · V. Zablotskyi · O. Zabolotnyi · N. Yakymchuk
Technological Faculty, Lutsk National Technical University, Lutsk, Ukraine
e-mail: a.tkachuk@lntu.edu.ua; v.zablotsky@lntu.edu.ua; m.yakymchuk@lntu.edu.ua

D. Cagaňová
Faculty of Materials Science and Technology, Slovak University of Technology, Bratislava,
Bratislava, Slovakia
e-mail: dagmar.caganova@stuba.sk

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2021
D. Cagaňová et al. (eds.), *Advances in Industrial Internet of Things, Engineering and Management*, EAI/Springer Innovations in Communication and Computing,
https://doi.org/10.1007/978-3-030-69705-1_1

AQ4

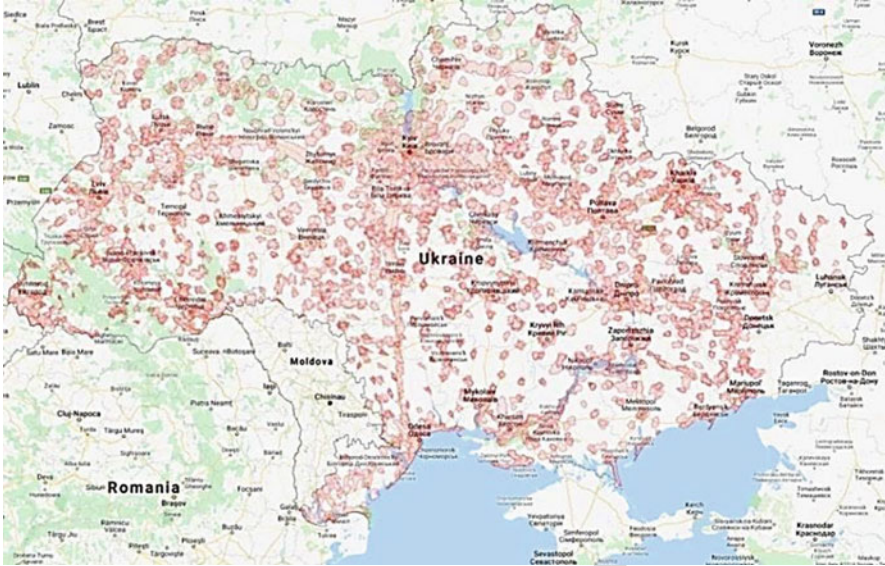


Fig. 1 4G zone coverage of the territory of Ukraine by “Vodafone”. (Source: [1])

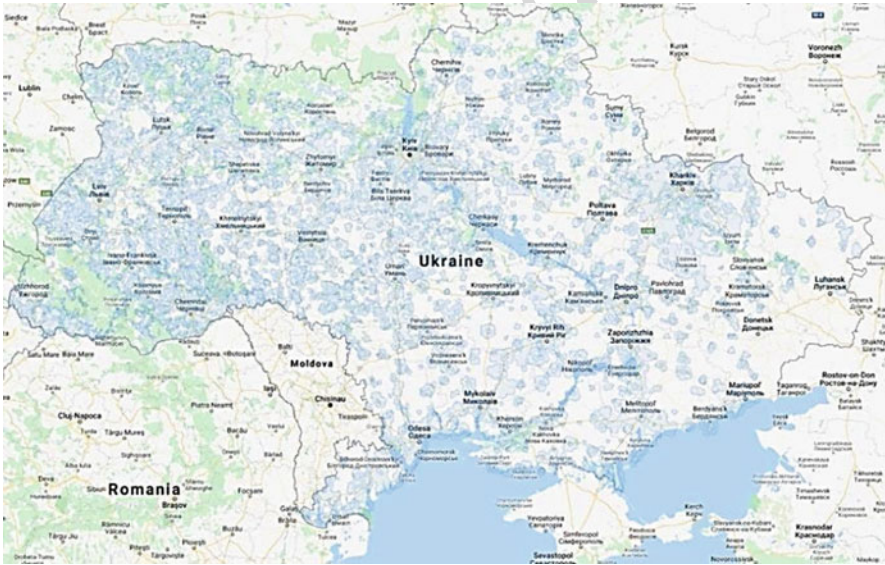


Fig. 2 4G zone coverage of the territory of Ukraine by “Kyivstar”. (Source: [1])

consumed. The operator Kyivstar 4G coverage is developing very rapidly. At the auction of the fourth-generation frequencies, Kyivstar was able to get 30 MHz in the 2600 range and 70 MHz in the 1800 range, which is the highest indicator among competitors.

The main advantages of the new standard are a multiple increase in Internet speed (more than 15 times), improved ping, and no drop in speed while driving.

A very important indicator when choosing an operator is the quality of reception not only in large cities, but also outside them. The most common in this case is 3G Internet.

One of the operators providing wireless Internet services in Ukraine is the company Intertelecom. 3G Internet of this operator covers a significant part of the country. This company is the only one in the country, which, thanks to EV-DO technology, gives the opportunity to take advantage of the connection with a unique Speed B+ capable of transmitting data at a speed of about 14.7 Mbps.

On the territory of Ukraine, Intertelecom is a leader in providing 3G Internet connection; the coverage map covers at least 14,000 settlements and all regional centres (Fig. 3). Over 16 years of operation, the map of the location of Intertelecom base stations has become the most extensive and dense thanks to the use of fibre-optic lines and SDH multiplexer nodes. The base stations are located in such a way that high-speed wireless communication is provided to all major roads and railways, also in the area of action falls and most of the countryside. The coverage area is more than 85% of the country.

The Lifecell mobile operator uses a 4G network in the 1800 MHz band. Today, the third- and fourth-generation technology from Lifecell covers 2252 settlements of the country and is available to more than 22 million users (Fig. 4).

As seen in Figs. 1, 2, 3 and 4, mobile operators provide communication services in the territory of the majority of settlements of Ukraine. It is also seen that there

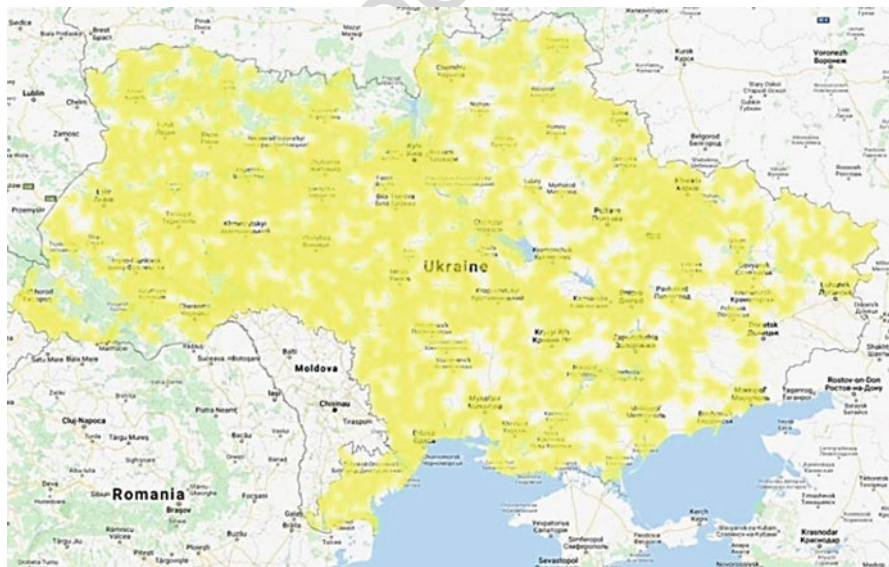


Fig. 3 Zone 3G and 4G coverage of the territory of Ukraine by “Intertelecom”. (Source: [1])

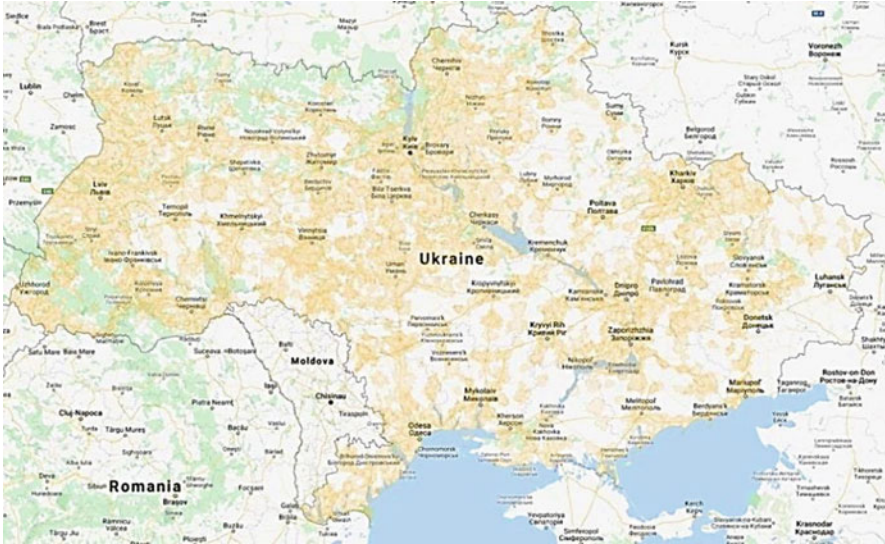


Fig. 4 3G and 4G zone coverage of Ukraine by “Lifecell”. (Source: [1])

is a trend of transition of subscribers from active use of voice data to active use of Internet services. In this regard, the requirements to the criteria of information transmission quality, such as high bit rates, stability of channel bandwidth, and network capacity, are increased.

Currently, two generations of cellular communication coexist and function simultaneously. The third generation of WCDMA is the most common, as its development and implementation began much earlier than the fourth generation of LTE. WCDMA is used to transmit voice calls because third-generation subscriber terminals are the most common. Since such subscriber terminals are cheaper to manufacture and easier to maintain, the third generation of subscriber terminals will exist in the market of communication services for a certain period. In addition, the re-equipment of communication systems, as well as the replacement of subscriber terminals, will be an economically difficult task.

Simultaneously with WCDMA, the fourth-generation LTE system is deployed. These systems can work simultaneously without interfering with each other, because they have a different frequency range. The fourth generation of cellular communication systems has a much larger bandwidth of the radio channel, and therefore has a much higher data rate. The fourth generation of LTE communication is mainly used for broadband Internet access, as well as for video calls and viewing a wide range of multimedia information in streaming mode.

Thus, two generations of communication systems complement each other, simultaneously operating on the same section of the network.

Quality control of all services provided, both voice and the mobile operator should perform data transmission for both generations.

Operators need to maintain the quality of services at a high level, so there is a need to test periodically cellular networks.

One of the important parameters that affect the quality of communication is the bit rate of the Internet connection. The problem of providing high-speed Internet connection is exacerbated by the growth of data transmitted through the Internet, which is now very actively used to view multimedia information in streaming mode (TV movies, online channels, mobile TV, etc.), as well as to visit social networks, where information pages are overloaded with graphic information. For comfortable work on the Internet now you need speed 1.5–2 Mbps. Therefore, the requirements to the quality of the data transmission channel, as well as to the stability of technical and operational characteristics of cellular networks, are increased.

Therefore, an important task is to monitor the speed of your Internet connection, which currently uses a variety of Internet resources that allows you to quickly determine the connection speed, but have several significant limitations such as: the limited number of queries per day, the impossibility of testing the speed of your Internet connection without user interaction (automated testing), and the inability to arbitrarily change the size of the test package. In this regard, there is a need to develop a test system independent of any external services.

The procedure for testing the communication channel is as follows. A test file of a certain size is generated on the remote server and then the generated file is transferred to the device under test. The data rate is defined as the amount of data transferred over a period. Typically, this interval is 1 s, but sometimes it is necessary to determine the average data rate per hour or per day. During testing, the operator selects a broadband connection, and the speed test server generates a large test file, which is necessary to determine accurately the data rate [2–4]. However, for the low speed, testing takes longer than planned, which can lead to errors in determining the speed of the Internet connection or “hang” service [5–7].

2 Analysis of Recent Research and Publications

In order to avoid such situations, it is proposed to use an adaptive algorithm for measuring the speed by changing the size of the downloaded file. Speed measurements will be performed in the following way: first, a small file is transferred and the bit rate is determined relative to the control time interval. If the test file is transferred immediately, the second step is to repeat the procedure with a larger file, and so on until the results of two consecutive measurements are of the same order, then the results are averaged and displayed to the operator as the results of the measurement [8–10]. In order to improve the accuracy of measuring the bit rate of the Internet connection, as well as reducing the total testing time, the following volumes of test files are proposed (Table 1).

The authors of the paper recommend to use a 10 kB test file size to test the efficiency of the communication channel. With any quality of communication channel, such a small amount of information should be transmitted to the test server.

AQ5

Table 1 Recommended file sizes for Internet connection speed testing (own measurements)

Test file size	Purpose of this test	
10 kB	Test line check	t3.1
200 kB	Testing EDGE (GPRS) connections	t3.2
800 kB	Testing EDGE (GPRS) connections (improved accuracy)	t3.3
1.6 MB	Testing HSDPA/HSUPA connection up to 3.6 Mbps	t3.4
8 MB	Testing HSDPA/HSUPA connection up to 14.4 Mbps	t3.5
16 MB	Testing HSDPA/HSUPA connection up to 14.4 MBps (increased accuracy)	t3.6

Then it can be estimated the time for which the data were transferred. If the time interval equals to 2 is exceeded to 4, it can be considered a test of a complete channel, as studied the data channel is the low speed.

A data volume of 200 kB is used to test the data link that is generated when 2G networks are used at 384 kbps EDGE (GPRS) speeds. This file size allows to get an upper estimation of the Internet connection speed. To determine the speed of an Internet connection more accurately, a larger amount of data is required in order to measure the speed of multiple passes. To do this, the authors of the paper recommend to use a test file with 800 kB of data. Testing the third-generation networks requires much more data to determine adequately the bit rate. It is recommended to start testing in WCDMA networks with a test file with 1.6 MB of information. At an initial data transmission speed is 3.8 Mbps file will be passed through 8–10 s. For later versions of the HSDPA standard, up to 14.4 Mbps data transfer rates are achieved using 15 channel gate codes and 16-QAM modulation. At these high data rates, it is recommended to use 8 MB of data and 16 MB of data to determine the data rate more accurately. After carrying out a test study of the first file, to select the second file, then if the file is transferred in the same short time, in several stages can be skipped and immediately selected a larger file, which will more accurately determine the bit rate of the Internet connection.

3 Material and Method

To ensure the high quality of services provided by the operator, it is necessary to constantly diagnose and monitor various parameters of cellular communication systems. According to ISO 9000-2001, the quality of services should be ensured at all stages of customer service. Let us consider the main parameters of indicators for voice calls:

- Ensuring the normative level of quality indicators.
- Restore communication in case of failures.
- Carrying out preventive measures for the operation of the operator's equipment.

One of the most important factors is the provision of access to the network in the zone of confident reception and ensuring the normative level of service quality

indicators in the zone of confident reception; therefore, it is proposed to use the following methodology: when assessing the continuity of communication, calls that meet the requirements for three main parameters are evaluated.

1. Availability of communication is the share of successful calls from the total number of calls for the established connection with the subscriber, both mobile and fixed network. The share of successful P_y calls is estimated by measuring the number of successful and non-successful calls made by network subscribers in the direction of network subscribers and fixed network subscribers:

$$P_y = Q/N \quad (1)$$

where N —total number of control calls for all measurement sessions, Q —total number of successful control calls for all measurement sessions.

2. Continuity of communication—the proportion of calls that ended in disconnection of the established connection at the initiative of the subscriber. The proportion of calls with planned disconnection P_n is estimated by measuring the number of successful calls and calls with premature disconnection:

$$P_n = R/N \quad (2)$$

where R —the total number of control calls that ended with disconnection of the established connection at the initiative of the subscriber.

3. The share of calls that meet the standards for the quality of speech. The proportion of calls that meet the standards for the quality of speech is estimated by measuring the number of calls with satisfactory and unsatisfactory quality of speech.

$$R_y = N_{np}/N \quad (3)$$

where N_{np} —the total number of control calls that meet the standards for the quality of speech for all measurement sessions.

Thus, in order to determine the listed quality indicators, a sufficiently large number of voice calls must be made on the network segment. During the testing of the entire network coverage area, the total number of voice calls will be very large. An additional parameter to which high requirements are imposed is the speed of data transmission when using the Internet by the subscriber. For comfortable work on the Internet currently enough speed is 1.5–2 Mbps.

Consequently, the requirements to the quality of the data channel of cellular networks, as well as to the stability of the characteristics of the declared services, are becoming stricter. Therefore, regular testing and monitoring is necessary to ensure high quality of services.

The minimum load hours are the period in which the number of subscribers on the investigated site is minimal. Based on the daily bit rate monitoring data, it is possible to detect such clocks and reallocate resources to other sectors where

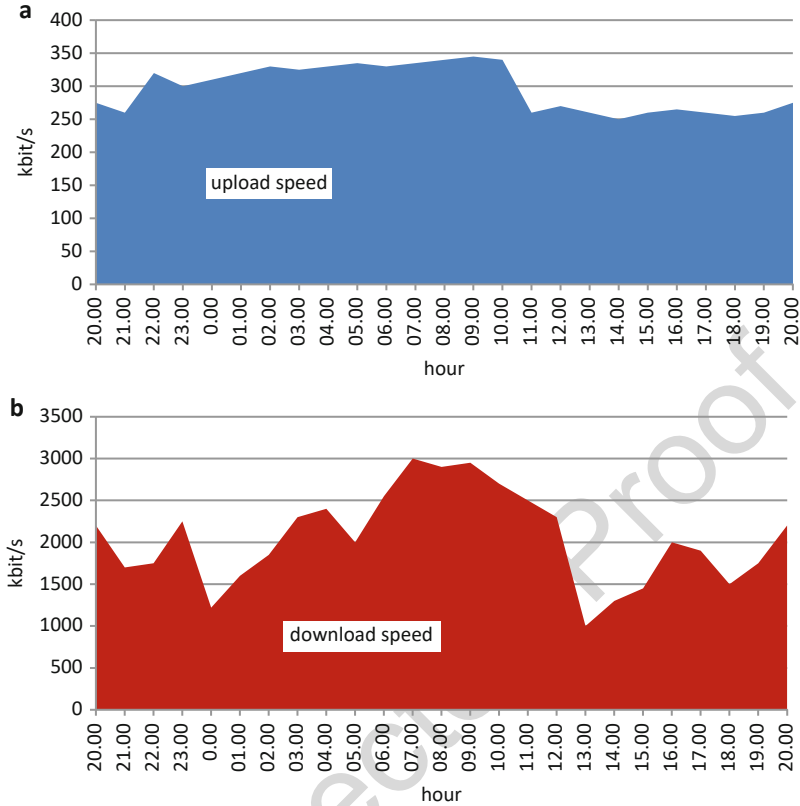


Fig. 5 Diagram of the daily change in the speed of the Internet connection for unloading (a) and loading data (b). (Source: Own measurements)

necessary. The diagram of daily change of Internet connection speed for data 181
unloading (a) and loading (b) is presented in Fig. 5. 182

The graphs show that the minimum download speed (Fig. 5b) observed at about 183
one o'clock in the day, it follows that this point corresponds to the maximum load 184
on the network. 185

The minimum load on the network was recorded at seven in the morning; 186
this experimentally determined maximum speed coincides with the data from the 187
LAC controller. Data from the controller on the load factor of the base station in 188
conventional units for the control period are shown in Fig. 6. 189

The operator to 300 kbps artificially limits the data upload speed. This is done to 190
free up network resources. For daily monitoring of Internet connection speed in the 191
cellular network, the described method is quite expensive, because a large amount 192
of traffic is spent. In this example, about 22 GB of traffic was spent during testing. 193
The average daily rate can be calculated as: 194

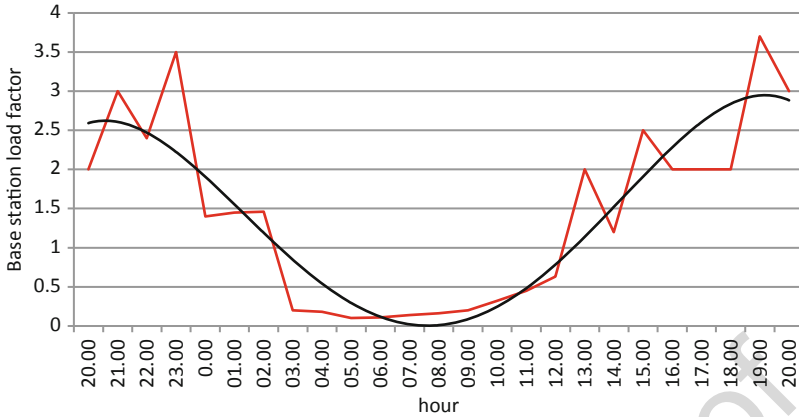


Fig. 6 Changing the load factor of the base station per day. (Source: Own measurements)

$$S_{CP} = \sum_{k=1}^n \frac{S_k}{n} \tag{4}$$

where S_{CP} —average daily bit rate, bit/s, S_k —bit rate of a single measurement bit/s, 195
 and n —number of measurements. 196

In the example shown in Fig. 5b, the average daily download speed when using 197
 an Internet connection is 1283 kbps. For daily network monitoring, the described 198
 method is ineffective, since a large flow of traffic occurs through continuous data 199
 exchange, which will take resources from users, and, accordingly, in the hours of 200
 maximum load will cause failures in different communication services. 201

4 Results 202

An alternative, passive method for determining the hours of maximum and mini- 203
 mum load, as well as the maximum and minimum speeds of the Internet connection, 204
 is proposed. When using the passive method to control the bit rate of the Internet 205
 connection, the minimum amount of traffic is consumed, and the bit rate can be 206
 monitored constantly. 207

To explain the principle of determining the speed in a passive way, consider the 208
 principles of operation of the dedicated data link at the physical level (DPDCH). 209
 A dedicated data link at the physical layer carries high-level information, including 210
 user data, while a dedicated physical layer control channel (DPCCH) carries the 211
 necessary control information at the physical layer. The data rate of DPCCH is 212
 constant, while the data rate of DPDCH between frames can vary [5, 11]. To separate 213
 the signals of one cell from another, scrambling codes and truncated gold sequences 214

are used. All subscriber terminals located in the area of one cell operate at the same frequency, and to separate the transmitted information from the subscriber terminals to the base station and back, Walshcodes are used, with an orthogonality coefficient α [3, 6]. Scrambling codes are superimposed on sewer codes so that they do not change the signal bandwidth, but simply allow signals from different sources to separate from each other. If there is a large delay in the radio channel, the subscriber terminal will perceive part of the transmitter signal of the base station as an obstacle to multiple uses. Therefore, in practice, it is very difficult to obtain an ideal orthogonal signal (typical value). The signal output power of the base station antenna is equal to:

$$P_{\text{TX}} = \frac{N_{\text{rf}} \bar{L} \sum_{j=1}^N \nu_j \frac{(E_b/N_0)}{W/R_j}}{1 - \bar{\eta}_{\text{DL}}} \quad (5)$$

where W —chip transfer rate, bit/s; R_j —bit rate of the j th subscriber terminal (ST), bit/s; ν_j —the activity coefficient of the j th user at the physical level, for the language—0.67, for data transmission—1; \bar{L} —average attenuation of the information signal between the cell transmitter and ST; N —number of ST serviced by a cell; E_b/N_0 —the energy of the information bit divided by the spectral power density of the noise; N_{rf} —noise power at the input stage of the receiver ST:

$$N_{\text{rf}} = N_m + \text{NF}$$

where N_m —thermal noise level. At a bit rate of 3.84 MChip/s; $N_m = 108.2$ dB— noise ratio of the receiver ST. Typical values = 5–9 dBm; $\bar{\eta}_{\text{DL}}$ —average load factor in the downlink, which can be found as:

$$\bar{\eta}_{\text{DL}} = \sum_{j=1}^N \nu_j \frac{(E_b/N_0)_j}{W/R_j} [(1 - \bar{\alpha}) + \bar{i}] \quad (6)$$

where $\bar{\alpha}$ —the average coefficient of the base station transmitter signal orthogonality for the j th ST; \bar{i} —the ratio of the level of interference from another cell to interference in its own cell. The ratio E_b/N_0 defines the minimum requirements for the radio link to be able to receive/transmit data. For speech transmission $E_b/N_0 = 5$ dB is sufficient, and for data transmission at a speed of 384 kbps the ratio $E_b/N_0 = 1$ dB is necessary [8]. With the help of (5) and (6), a ratio is obtained to estimate the bit rate of the k th terminal R_k :

$$R_k = \frac{W \cdot P_{\text{TX}} - W \cdot P_{\text{TX}} \cdot \sum_{j=2}^N \nu_j \frac{(E_b/N_0)_j}{G_j} [(1 - \bar{\alpha}) + \bar{i}] - W \cdot N_{\text{rf}} \cdot \bar{L} \cdot \sum_{j=2}^N \nu_j \frac{(E_b/N_0)}{G_j}}{\nu_k \cdot (E_b/N_0)_k \cdot [N_{\text{rf}} \cdot \bar{L} + P_{\text{TX}} \cdot ((1 - \alpha_k) + \bar{i})]} \quad (7)$$

where R_k —the bit rate of the terminal understudy, bit/s; v_k —the coefficient of user activity at the physical level; α_k —the coefficient of orthogonality of the base station transmitter signal for the at understudy; $(E_b/N_0)_j$ —the energy of the information bit divided by the spectral noise power density for the j th AT, times; G_j —gain in signal/noise ratio when processing signals of the j th ST.

In formula (7), the k th subscriber terminal is included in the total number of N terminals serviced by one transmitter. In this case, the k th ST is investigated, and the j th ST is served by the same transmitter, but the k th ST is excluded from their number, that is, k —corresponds to $j = 1$. If the base station is serviced by one and stored ST the ideal orthogonality of codes, the expression (7) is simplified as it eliminates the influence of all ST in addition to researched:

$$R_k = \frac{W \cdot P_{TX}}{v_k \cdot (E_b/N_0) \cdot [N_{rf} \cdot \bar{L} + P_{TX} \cdot ((1 - \alpha_k) + i)]} \quad (8)$$

Let us calculate the value of the bit rate for the typical network parameters. Let the power of the base station P_{TX} is 16 W (42 dBm), the signal power in the receiver is -80 dBm, the average attenuation on the track is $(L = 42 + 80) \cdot 122$ dB, the spectral noise density in the input stage of the receiver of the subscriber terminal $N_{rf} = -101$ dBm, it is used for data transmission, then $i = 0.55$, which corresponds to the macrocomirci with non-directional antennas. For such parameter values, the bit rate is equal to:

$$R_k = \frac{3.84 \cdot 10^6 \cdot 16}{1 \cdot 10^{1/10} \cdot \left[10^{-101/10} \cdot 10^{122/10} + 16 \cdot ((1 - 1) + 0.55) \right]} \approx 3.649 \cdot 10^5 \approx 364 \text{ kbps}$$

From the expressions (7) and (8) it can be concluded that the bit rate is directly proportional to the signal power, as well as inversely proportional to the losses on the radio and interference signals arising from violations of the channel codes orthogonality.

$$R_k \approx \frac{W \cdot P_{TX}}{[N_{rf} \cdot \bar{L} + P_{TX} \cdot ((1 - \alpha_k) + i)]} \quad (9)$$

Violation of orthogonality occurs not only from the repeated use of frequency, but also due to the multipath propagation of the signal. When the base station serves one ST, it is still possible to break the orthogonality of the codes. For Fig. 3 the dependences of the bit rate R_j on the orthogonality coefficient of the signal α at different power of the received signal α obtained by mathematical modelling are presented.

From Fig. 7, it can be seen that the bit rate depends on the violation of orthogonality of the channel codes. The higher the level of the received signal, the more clearly this dependence is expressed. For example, at the signal level of -75 dBm, there is a change in the bit rate by 20%, when the orthogonality coefficient $\bar{\alpha} = 0.3 \dots 0.9$ changes. From the ratio (7) it can find the bit rate R_j as:

$$R_j = \frac{(1 - \overline{\eta_{DL}}) \cdot P_{TX} \cdot W}{N_{rf} \cdot \bar{L}_j \cdot \nu_j \cdot (E_b/N_0)} \tag{10}$$

From the expression (10) it follows that the bit rate of j th AD will tend to 0 when η_{DL} approaching 1 (Fig. 8).

According to the ratio (9), the average load factor in the downlink increases with the number of subscribers, as shown in Fig. 7. It is seen that as the load factor

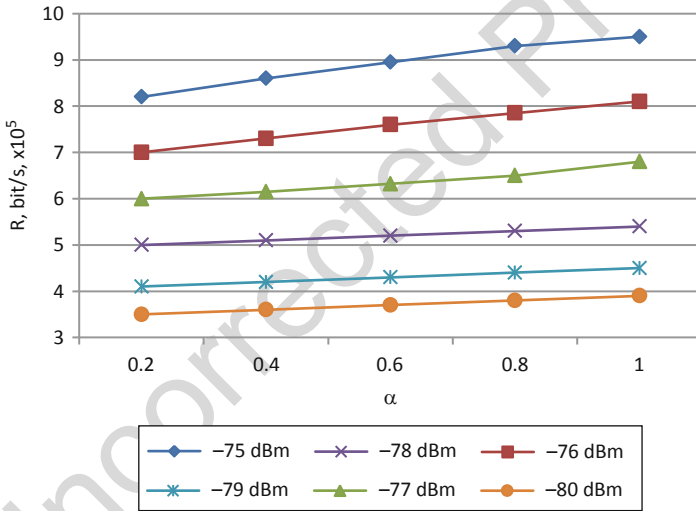


Fig. 7 The dependence of the bit rate on the orthogonality coefficient of the terminal understudy. (Source: [5])

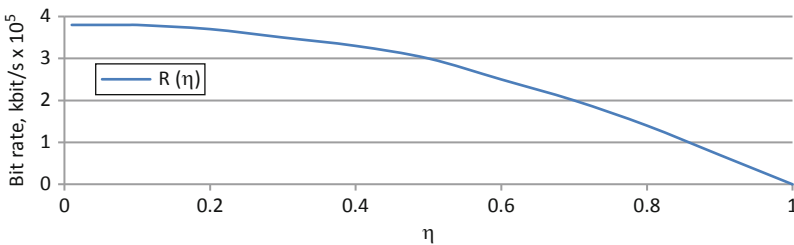


Fig. 8 Dependence of bit rate on load factor. (Source: [5])

increases, the bit rate decreases, orthogonal interference increases. In accordance with the growth of the total number of subscribers, the bit rate of the j th ST decreases.

Let assume that the code orthogonality violation through multipath propagation for the studied subscriber is equal, and the code orthogonality violation through multiple frequency use will vary from 0.1 to 0.8. In this case, it can be taken a typical case of using the network, when the terminal understudy is in data transfer mode, and the other ST is used to transmit voice messages. Using the ratio (7) obtained by the author, the authors of the paper will simulate the change in bit rate from the number of subscribers. The results are shown in Fig. 9.

Figure 9 shows that when the number of active subscriber terminals increases, the bit rate of the investigated terminal decreases. This effect is because the load factor increases. At the same time, with the increase in the number of subscribers, the effect of violating orthogonality of codes increases and leads to an increase in the level of interference.

In this regard, the change in the coefficient of orthogonality of sewage ST codes serviced by one transmitter of the base station leads to deterioration of the air condition, and in accordance with the decrease of bit rate. The simulation results are presented in Fig. 10.

The bit rate of the terminal understudy depends on the violation of the terminal codes orthogonality of the understudy caused by the multipath propagation of the signal, as well as the violation of the other subscriber terminals codes orthogonality caused by the numerous use of frequency. Thus violations of subscriber terminals codes orthogonality bring a hindrances additional component in the general air situation of the base station studied sector. Accordingly, if you carry out once in a given period of time monitoring the speed of the file transfer method to the ftp server, set the maximum possible speed for a given location, and then conduct passive speed monitoring with normalization of the results with the maximum value, it can be obtained a daily distribution of the Internet connection speed changes without spending a huge amount of traffic. In addition, this method will not occupy the resources of the radio line and the controller, as well as not to

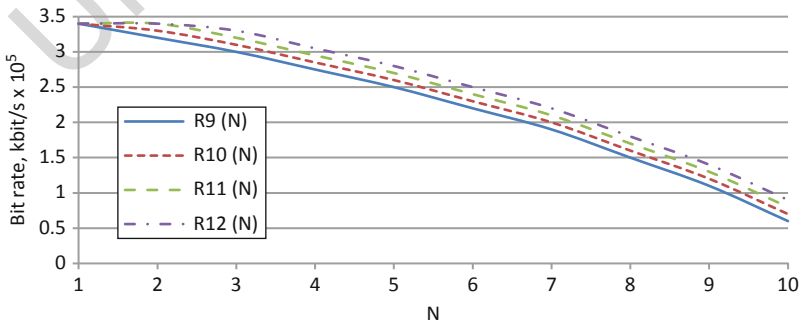


Fig. 9 Bit rate dependence on the number of subscribers. (Source: [8])

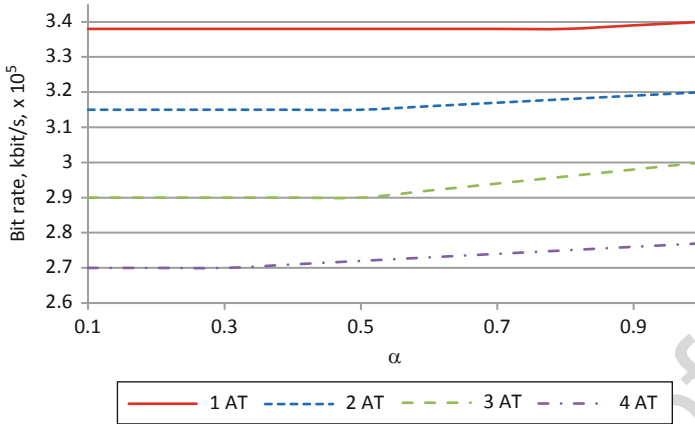


Fig. 10 The dependence of the bit rate of ST on the orthogonality of codes. (Source: [5])

make noise interference in the studied sector, which in long-term measurements will significantly relieve the cellular network.

Let compare the results obtained by active and passive methods of measuring the speed of the Internet connection. In Fig. 11, the diagram shows the results of daily measurements of the bit rate and the calculated values of the bit rate. Figure 11 shows that the maximum load hours are determined in an active and passive way at the same time. The same can be declared about the minimum load hours, they are also determined at the same time. It can be seen that the behaviour of the dependencies is the same, the inflexion points of the decreasing and growing areas are the same in the diagrams obtained in different ways.

It is also worth noting that this method is mainly intended for cellular communication systems continuous monitoring in terms of monitoring the bit rate of the Internet connection.

At the beginning of the system, its launch should begin with the launch of the FTP server, since it stores the general information available for both components of the information and measurement system. Further, when operating the system, the synchronization mode may not be observed, but the FTP server must always be available, otherwise the mobile terminal will not be able to test the parameters of the cellular network. Also, the mobile terminal will not be able to remotely transmit reports with measurement information. In case of unavailability of the FTP server, the information processing module will not be able to send control commands to the mobile terminal and the mobile terminal will function according to the tasks laid down in it at system startup. After the measurement data collection is completed, the mobile terminals transmit the reports to the FTP server.

Since multiple terminals are expected to be used, there may be a situation where two or more mobile terminals will simultaneously transfer encrypted data to an FTP server. A collision may occur during the data transfer process. This problem is solved in several ways. The first of them is at system start it is necessary to

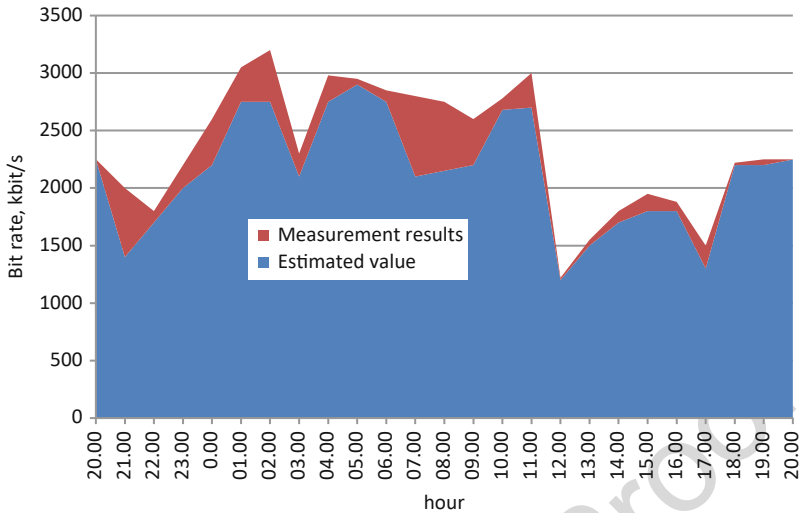


Fig. 11 The calculated and experimental value of bit rate. (Source: Own measurements)

set different time of measurement to all terminals under the condition of their 339
 synchronous start. The second is to set different start times for the same time before 340
 transferring data to the FTP server. The third is to extend the allowable maximum 341
 number of simultaneous FTP server users so that multiple mobile terminals can 342
 simultaneously transmit measured data to the server. The best result of solving this 343
 problem is the use of a combination of several options, for example, increasing 344
 the number of simultaneous FTP server users and setting different data collection 345
 times. Thus, even with a very large number of simultaneously operating terminals, 346
 the probability that one of the terminals will not be able to quickly transfer the 347
 accumulated information is quite small. A block diagram of the algorithm of the 348
 system is presented in Fig. 12. 349

After the data are transferred to the server, the mobile terminals update the 350
 configurations and control files. Thus, it is possible to manage each terminal 351
 separately, updating configuration files individually for each, and all at the same 352
 time, updating one file common to all. The use of the first method is advisable 353
 during the commissioning of a small number of mobile terminals or at the same type 354
 of study of the entire network. The use of this method is justified when using a large 355
 number of active mobile terminals, through which a large number of configuration 356
 files appear. 357

Therefore, the best way to configure and manage mobile terminals is the third, 358
 hybrid way. It is a way to manage specialized groups of mobile terminals divided 359
 into functionally independent clusters. Clusters are designed in such a way that 360
 each of them performs certain highly specialized tasks. For example, two clusters of 361
 terminals are created, one of which is configured to measure the parameters of the 362
 coverage area of cellular networks of the third and fourth generation in rural areas 363

AQ9

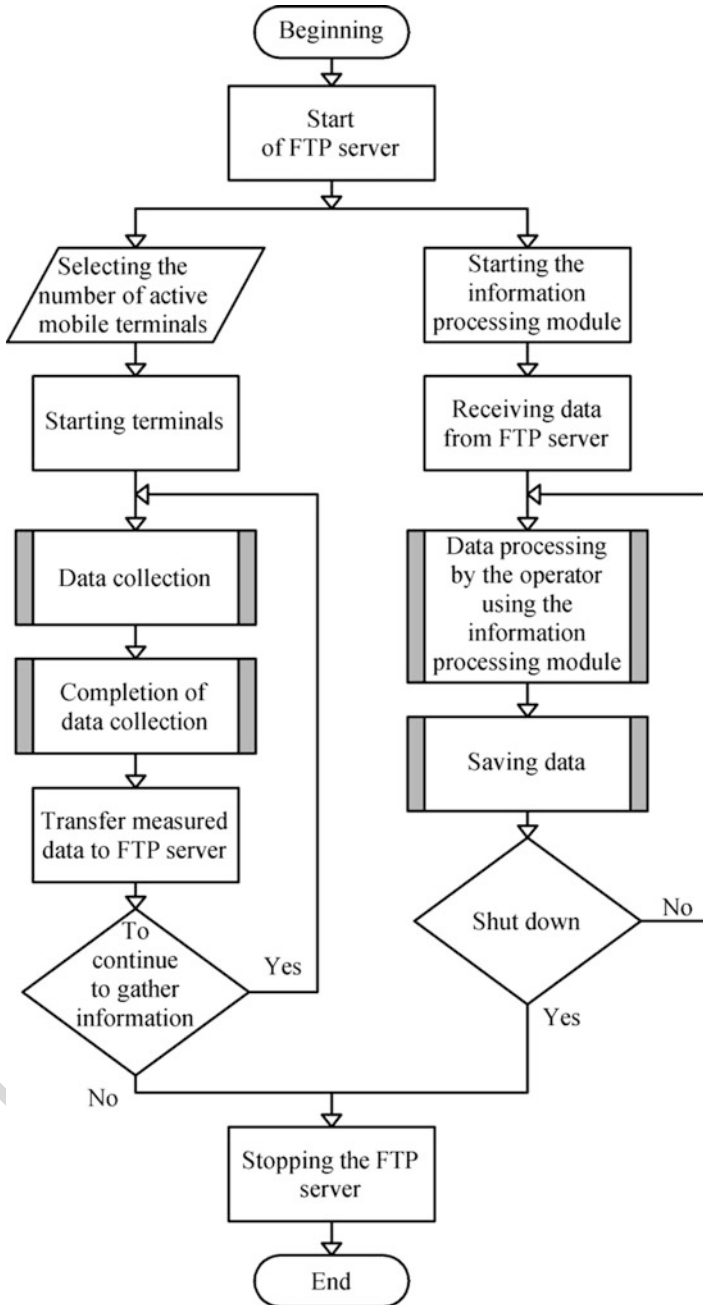


Fig. 12 Block diagram of the algorithm of distributed information and measurement system. (Source: Own measurements)

or on roads of regional importance. The second cluster is configured to measure the bit rate of the Internet connection in the residential and business areas of the city. Settings from the server will be updated separately for the first and second cluster, if necessary, change the number of mobile terminals belonging to one cluster and to another, directly in the process of operation of the system.

The information-processing module is equipped with a graphical interface. It runs an operating system. Configuration files for working with the module are stored locally on the same personal computer where the module is installed. However, it is possible to save configuration files to an FTP server. The latter allows you to use the information-processing module with the same settings on different personal computers.

This is quite convenient when you need to process volumes of information in one place, such as the workplace of the operator conducting the measurements, and provide the results to another place, such as the organization for the report to the lead specialist. In this case, you can process all the measured material in the workplace, then make a report, and save the configuration files on a remote server. The information-processing module is capable of simultaneously processing information from all active mobile terminals.

To deliver all measured data to the local file storage, it is enough to synchronize the data with an FTP server. Synchronization is performed by checking the existing files in the storage and on the local computer. Files that are missing from the local computer will be copied from the remote FTP server. Thus, the data prepared for processing will be automatically transferred to the local computer for processing. A group of files is processed in the same way as a single file.

When the system is shut down, the FTP server should be the last to shut down, because without it the system will function only in fragments.

5 Conclusions

The main objective of the bit rate study in a passive way is to identify trends in user behaviour, namely the hour's identification of maximum and minimum load on the base station.

When carrying out daily measurements in cellular networks, the dynamics of the studied process is more important than the accuracy of measurements. It is important to identify the moments when the bit rate starts to decrease, or to grow, it is important to make the correction in the operation of the network, thus maintaining the quality of services at a high level. Based on data on dynamics of bit rate change, it could be received the ability to reallocate dynamically network resources. For example, during the day in the hours of minimum load can reduce the power of the transmitter, thereby saving electricity. When using the dynamic mode at one base station, the effect of energy-saving is unobtrusive, but when using the dynamic mode of the network as a whole gives a significant economic effect. For example, the power consumption of the base station is 500 W h. Let the total power consumption of the

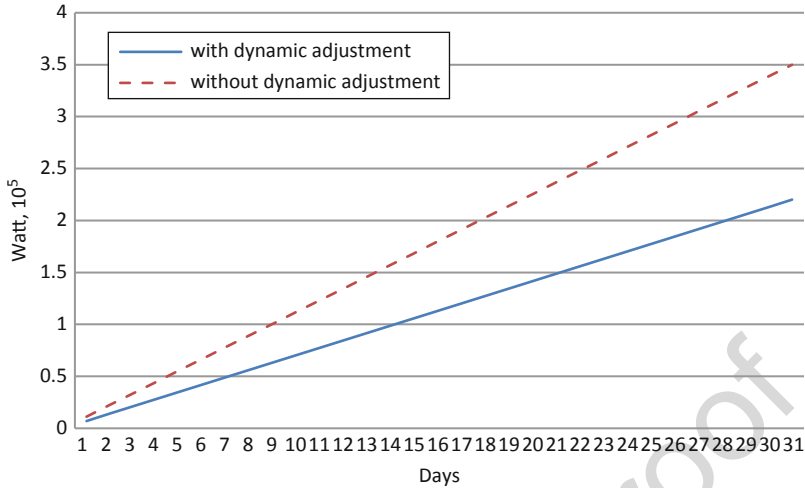


Fig. 13 Total power consumption of the base station. (Source: Own measurements)

control and cooling systems be 300 W h when the transmitter power is reduced by two times. Calculate the total amount of electricity consumed per month by day, the simulation results will be presented in the form of graphs in Fig. 13.

Figure 13 shows that the total energy consumption of one base station without dynamic power control is 0.35 MW per day, and with dynamic control is 0.2 MW per day. Energy savings from one base station can be up to 150 kW per day. One mobile operator in the region has about 150–200 base stations. Thus, the total energy savings range from 22.5 to 30 MW per month. Thus, the use of dynamic power control can reduce energy consumption, thereby reducing heat generation and improving the operating conditions of base stations of mobile operators. This technique has been tested on 2G and 3G networks, but it is suitable for use in modern cellular networks such as 4G and 5G.

Acknowledgements This paper has been written within VEGA project Nr. 2/0077/19: Work competencies in the context of Industry 4.0 development and KEGA project Nr. 030STU-4/2018: E-platform for improving collaboration among universities and industrial enterprises in the area of education.

References

1. MobUA Homepage, <https://www.mobua.net/maps/?pos=48,31,6>. Last accessed 18 Dec 2019
2. D. Caľaňová, M. Bawa, J. Šujanová, A. Saniuk, *Innovation in Industrial Enterprises and Intercultural Management*, 1st edn. (University of Zielona Góra, Zielona Góra, 2015), 126 p. ISBN: 978-83-933843-4-1

3. P. Bakhovsky, M. Yevsyuk, Some aspects of mobile telecommunication development. *Adv. Technol. Dev.* **13** (2018) 426-427
4. Y. Toroshanko, Y. Selepyna, N. Yakymchuk, V. Cherevyk, Control of traffic streams with the multi-rate token bucket, in *International Conference on Advanced Information and Communications Technologies, AICT 2019*, 2019, pp. 352–355. <https://doi.org/10.1109/AIACT.2019.8847860> 428-431
5. H. Holma, *W-CDMA for UMTS* (John Wiley & Sons Ltd., Chichester, 2004) 432
6. M. Naworocki, M. Dohler, A. Aghvami, *Understanding UMTS Radio Network. Modelling, Planning and Automated Optimization* (John Wiley & Sons Ltd., Hoboken, NJ, 2006) 433-434
7. N. Yakymchuk, P. Stanko, Correlation-regression analysis of information networks with non-stationary traffic, in *Conference "Actual Problems of Information Technologies: ARIT-2018"*, Kyiv, 2018, pp. 128–130 435-437
8. R. Röhrle, I. Ehriel, I. Danilov, GPRS protocols and testing. *Commun. Networks Syst.* **12** (2002) 438-439
9. M. Bawa, D. Cagáňová, Selecting network protocols for internet of things based upon innovation and knowledge management. *J. Telecommun. Syst. Manag.* **7**(2), 1–4 (2018). <https://doi.org/10.4172/2167-0919.1000169>. ISSN: 2167-0919. V databáze 440-442
10. V. Saiko, T. Naritnik, P. Bakhovsky, Ultra-fast terahertz radio access channel for 4th and 5th generation mobile networks. *Technical news. Sci. J.* **1**(47), 2(48) (2018) 443-444
11. N. Yakimchuk, V. Olianskii, Characteristic of the system of clock network synchronization to estimate the delay time of the network, in *Conference "Problems of Telecommunications"*, Kyiv, 2018, pp. 107–110 445-447

AQ10

Uncorrected Proof

AUTHOR QUERIES

- AQ1. Please check and confirm if the affiliations are presented correctly.
- AQ2. Please check the hierarchy of the section headings and confirm if correct.
- AQ3. Please note that we could not able to improve the image quality in the artwork of Figs. 1 to 4. Kindly check and confirm.
- AQ4. References have been sorted to maintain sequential order. Please confirm if correct.
- AQ5. Please note that the symbol “...” has been changed to “n-dash (–)”. Kindly check if it is appropriate.
- AQ6. Please check if the sentence “If the time interval equals to...” is presented correctly.
- AQ7. Please check the word for correctness: “macrocomirci “
- AQ8. Please check if presentation of below equation is appropriate.
- AQ9. Please check and approve the edits made in the sentence: “The best result of solving this problem ...“
- AQ10. Please provide page range for Refs. [3, 8, 10].