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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

RESEARCH AND MODELING OF THE BIOLOGICAL EFFECTS OF ELECTROMAGNETIC RADIATIONS IN MOBILE COMMUNICATION SYSTEMS

Specialty: 3325.01- "Telecommunication technology"

Field of science: Technical sciences

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GENERAL CHARACTERISTICS OF THE WORK

Relevance of the topic and degree of development. The development of modern communication means is due to the introduction of technical means and complexes of various frequency ranges and functional purposes and the increase in their energy potential, the emergence of new information technologies. The rapid development of communication systems and technical means based on the architectural concept of new generation networks, the ever-increasing demand of users in the service sphere and the increase in the volume of data transmitted with the help of perspective information and telecommunication technologies require the study and investigation of the sources of potentially biologically hazardous electromagnetic fields and the sphere of influence of various radio frequencies in a new aspect.

Despite the scientific research conducted so far on the harmful effects of mobile phones on the environment and living organisms, there is still much to be done in this area. Thus, even if the electromagnetic radiation (EMR) of individual communication devices and systems is within the norm, the level of EMR created by them together may exceed the norm. As a result, in densely populated areas, the indicators of electromagnetic field intensities increase, causing electromagnetic pollution in the areas. This is directly related to the chaotic placement of communication devices and systems, transmission and distribution devices. Therefore, studying the impact of various radio frequency electromagnetic fields radiated by communication devices operating in Azerbaijan, regulating the coverage area of antennas, and developing a methodology for their effective placement are not only relevant, but also of great importance from the point of view of the environment and human health and safety.

Considering the above, the study and analysis of aspects of the variable radio frequency electromagnetic field, considering QoS quality of service in prospective information technology networks and mobile telecommunications devices in accordance with the proposals of ITU-T (International Telecommunication Union

Telecommunications Standardization Organization), is of great relevance and practical importance.

Object and subject of the research. The object of the research of the dissertation work is general-service mobile communication systems and high-intensity electromagnetic emitters, and the subject of the work is the proposed methods and mathematical models for increasing the efficiency of electromagnetic radiation sources of mobile communication devices.

Research goals and objectives. The main goal of the dissertation work is to increase the efficiency of transmitting devices of mobile communication systems based on telecommunication technologies and means and to reduce the overall level of the electromagnetic field by effectively using the radiation power, as well as to develop methods for modeling the biological effects of the resulting electromagnetic radiation.

To achieve the set goal, the following issues were raised and resolved in the dissertation:

1. Analysis of electromagnetic radiation and variable radiofrequency electromagnetic fields created by existing mobile communication systems and telecommunications equipment.
2. Preparation of a model with variable structural electrophysical properties using modeling methods to study the aspects of the impact of electromagnetic radiation on biological structures and the development of a method for calculating the absorption of electromagnetic energy in different layers of the model.
3. Construction of a mathematical model of the electromagnetic field based on the study of the direction diagrams and characteristics of various electromagnetic radiating antennas of mobile communication equipment and the development of methods for increasing the efficiency of mobile communication base stations by adjusting the coverage area based on this model.
4. Development of a method for effective placement of base stations to effectively use the radiation power of mobile communication equipment transmitters and reduce the overall level of electromagnetic fields.
5. Monitoring of field intensities and spheres of influence of

mobile communication devices and studying their normative indicators based on experimental results conducted to assess the performance of mobile communication systems operating in Baku.

Research methods. To solve the problems posed, electromagnetic field theory, computer modeling method, least squares method, auxiliary sources method, Green's tensor function methods were used.

Main provisions submitted for defense. The set of main provisions submitted for defense is as follows:

1. Results of theoretical and experimental research on the biological effects of electromagnetic radiation generated by mobile communication systems using a model with multilayer variable electrophysical properties to study the effects of electromagnetic radiation of various radio frequencies in mobile communication systems.
2. Method for calculating the specific absorption coefficient in different layers of a multilayer model created for the purpose of systematic research of electromagnetic energy absorption and its effects on biological structures.
3. Geometric correction algorithm serving to increase the efficiency of mobile communication networks and control the coverage areas of base stations, created because of systematic research of high-intensity electromagnetic fields.
4. Method for effective placement of base stations and transmitter systems designed to reduce the intensities of electromagnetic radiation of various radio frequencies in mobile communication networks.
5. Study of the intensity of electromagnetic radiation of communication networks for the city of Baku during peak hours and report on safety, sanitary and hygienic standards of electromagnetic radiation.

Scientific novelty of the research.

1. Modeling of aspects of absorption and impact of various radiofrequency electromagnetic radiation of mobile communication systems in biological structures with multilayered variable electrophysical properties.
2. Application of a geometric correction algorithm for adjusting

the coverage areas of mobile communication networks according to real terrain indicators and load levels.

3. Application of a method for effective placement of base stations of mobile communication networks, ensuring the minimization of various radiofrequency electromagnetic radiation levels and efficient use of the power of radiating devices.

Theoretical and practical significance of the research. In the dissertation work, the systematic study of high-intensity electromagnetic radiation from mobile communication devices not only explains the aspects of the biological effects of the electromagnetic field created by these devices but also allows for the efficient use of the radiation power of communication systems to reduce their radiation intensities, increase their efficiency, and thus significantly improve their quality, efficiency and safety indicators. The new mathematical models obtained in the dissertation work and the algorithms developed for solving these models can also be successfully applied in the process of designing modern communication devices operating in other frequency ranges.

Approval and implementation. The main provisions of the dissertation work were discussed in detail at the following conferences: Materials of the 7th International Scientific and Technical Conference on “Microelectronic Converters and Devices Based on Them” (Baku-Sumqait, November 27-29, 2013); Materials of the Scientific and Technical Conference dedicated to the Year of Industry (Baku, December 15-16, 2014); Materials of the International ETC on the Modern State and Development Prospects of Information and Communication Technologies (Baku, October 27-28, 2014); Materials of the 19th Republican Scientific Conference of Doctoral Students and Young Researchers (2015); Materials of the Republican Scientific and Technical Conference of Students and Young Researchers on the Theme “Youth and Scientific Innovations” dedicated to the 94th Anniversary of the Birth of the National Leader of the Azerbaijani People, Heydar Aliyev (Baku, May 3-5, 2017); "Bulletin of the Russian New University", International conference on "Fundamental problems of biomedical radio electronics: inter-disciplinary approaches and modern challenges" (Moscow, November

26-27, 2020); "НИЦ Вестник науки ", " Current issues of modern science and practice " VI - International scientific-practical conference (Ufa September 14, 2021); Belarusian State Academy of Communications, "Современные средства связи" XXVI international scientific and technical conference (Minsk, Republic of Belarus October 21-22, 2021); "Infocommunication systems and artificial intelligence technology" II International scientific and technical conference (Baku, December 4-5, 2024).

After the application of the results of the dissertation, it is expected that appropriate measures will be taken in the service sphere and in the manner prescribed by the legislation to strengthen control in the field of electromagnetic safety in the republic and prevent excessive electromagnetic pollution.

At the same time, the results of the dissertation were applied as a visual aid in the educational process of the Azerbaijan Technical University.

Publication of the results of the work. 16 scientific works were published in various scientific and technical publications, 8 of which were foreign, reflecting the content of the dissertation work and their results, 7 of which were scientific articles and 9 conference materials. Of these, 8 scientific works were published in periodicals recommended for scientific publications in the Republic of Azerbaijan and included in international summarization and indexing systems.

Name of the organization where the dissertation work was performed. The dissertation was completed at Azerbaijan Technical University.

Personal contribution of the author. The main scientific and experimental results of the dissertation work were obtained by performing it directly by the author. The proposed method for studying the effective use of the radiation power of mobile communication devices, effective placement of base stations, antenna characteristics, absorption and interaction of electromagnetic radiation, mathematical models and algorithms for the application of these models were performed by the author independently or with his participation as a responsible executor.

Total volume of the dissertation in characters, indicating the volume of the structural sections of the dissertation separately. The dissertation work consists of an introduction, four chapters, a list of used literature and an appendix. The dissertation consists of 191 printed pages (computer text) and 220273 characters (excluding figures, tables, graphs, appendices and a list of literature). The main part includes 60 figures, 23 graphs, 15 tables, a list of 173 references and an appendix.

MAIN CONTENT OF THE WORK

In the introduction, the relevance of the dissertation topic is justified, the purpose and main tasks of the research are explained. The scientific novelty of the work and the practical significance of the results obtained are presented. Information on the application of important conclusions, proposals and recommendations in the educational process and in production is given.

In the first chapter, an analysis of mobile communication devices from the aspect of their interaction with the environment and biological objects is carried out, and electromagnetic safety issues are studied. For this purpose, first, the modern state of mobile communication devices is examined, as well as research conducted in foreign sources in the field is analyzed [7]. The role of the specific absorption coefficient (SAR), which is considered the main parameter in the study of the impact of electromagnetic radiation of telecommunications devices on the environment, is clarified [5, 6], and its internationally accepted norms are given.

The chapter also models the biological impact of electromagnetic radiation of mobile communication devices. Since it is impossible to study the impact of electromagnetic radiation experimentally on humans, modeling methods are mainly used here.

In order to study the biological effects of electromagnetic radiation on tissues, a multilayer model consisting of layers analogous to their electrophysical properties was designed. The geometric dimensions of the model were selected based on the anatomical structure of the human body (Fig. 1).

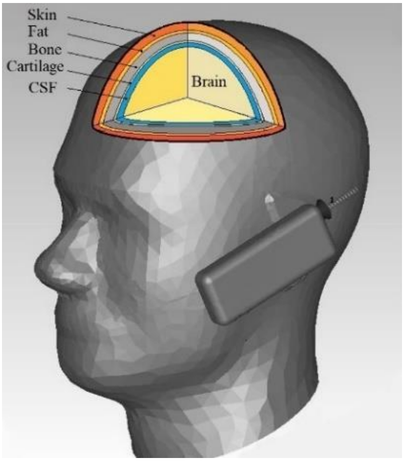

Figure 1. Selection of layers of a multilayer model with variable electrophysical parameters according to anatomical features.

The layers were selected according to their electrophysical properties, density, dielectric permeability, and geometric dimensions of the tissues to which they belong and were named accordingly: brain, cerebrospinal fluid, cartilage layer, bone, fat layer, skin [15].

Due to the rather high frequency range of current mobile communication standards the anatomical features of the organs were not considered in the structure of the model (Fig. 2).

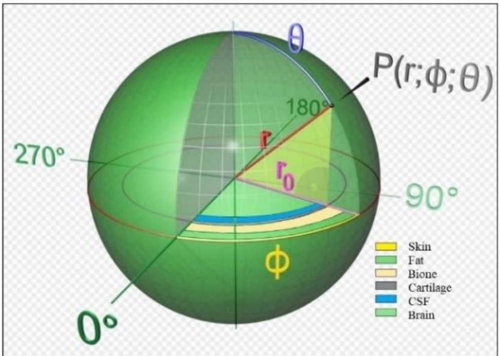

Figure 2. 6-layer model with variable electrophysical parameters.

The layers of the developed model consist of 6 layers, which are equivalent to the electrophysical and dielectric properties of biological tissues. The parameters of particular importance for the 6-layer model are shown in Table 1.

Table 1. Electrophysical properties of the six-layer model.

Layer name	Boundary radius *mm.*	Thickness *mm.*	At a frequency of 1800 MHz		
			Relative dielectric permittivity, ε_r, *F/m*	Density of matter, ρ, g/sm^3	Specific electrical conductivity σ, *Sm/m*
Skin	90	3	41.11	1.100	0.45
Fat	87	3	79.1	0.950	0.59
Bone	84	6	40.7	1.800	0.12
Cartilage	78	1	20.9	1.600	0.25
CSF	77	5	10	1.050	1.8
Brain	72	144	40.7	1.030	1.5

Comparative assessment of the absorption of radiation power of telecommunications devices is carried out using the specific absorption rate (SAR). SAR is considered the most important parameter characterizing the absorption of electromagnetic radiation and is characterized as a local property of absorption [16]. It is this parameter that carries the value of the electric field strength at any point and, therefore, is used to study the long-term effects of radiation and electromagnetic radiation on the tissues of living organisms[1]. For this reason, this parameter was referred to in the study. SAR is regulated by various telecommunications standards and should not exceed certain standards. Thus, in Western European countries, the European Committee for Electrotechnical Standards has adopted a maximum SAR indicator of 2 W/kg.

$$SAR = \frac{\sigma|E|^2}{\rho}, \tag{1}$$

$|E|$- is the electric field strength modulus, σ is the specific electrical conductivity, ρ is the density of the substance.

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1. Ahmad N.A., Shaharun P.F. SAR measurement from mobile phone and its effect to human body // Elektrika- Journal of Electrical Engineering. – 2023. T. 22. № 1. – p. 63-69.

The parameters σ, ρ are taken separately for each layer of the model depending on the frequency.

As can be seen from (1), if the value of the electric field strength E-is known, the value of SAR can be calculated for any point in the model.

In order to study the effects of various radiofrequency electromagnetic radiations in mobile communication systems, mathematical expressions of the electromagnetic field were written for each layer of the model created using the modeling method, and the amount of electromagnetic energy absorbed in layers with electrophysical properties varying according to their structure was calculated [4, 8, 10, 11, 14].

Based on the numerical results obtained, the distribution of SAR across different layers of the model was shown, and graphs of the dependence of SAR across layers on frequency and the angles φ and θ of the radiation source on different planes were constructed. Table 2 shows the results of the calculations.

Table 2. SAR values in the layers of the spherical model in the range of θ and φ angles within 0°-180°.

SAR 1st layer								SAR 2nd layer						
ϕ\θ	180	140	100	60	20	0		ϕ\θ	180	140	100	60	20	0
0	1.6	1.2	2.4	2.1	2.5	2.3		0	0	0,2	0,6	0,1	0,5	0,1
60	1.8	2.1	2.6	2.5	1.1	1.2		60	0,1	0,3	0,8	0,2	0,6	0,3
120	1.2	1.9	2.5	1.8	1.6	1.3		120	0,2	0,4	0,5	0,5	0,3	0,3
180	1.3	1.2	2.1	1.3	1.2	1.1		180	0,3	0,2	0,8	0,2	0,4	0,1
SAR 3rd layer								SAR 4th layer						
ϕ\θ	180	140	100	60	20	0		ϕ\θ	180	140	100	60	20	0
0	0	0,2	0,6	0,1	1,2	0,1		0	0	0,2	0,6	0,1	1,3	0,1
60	0,1	0,3	0,5	0,2	0,9	0,2		60	0,1	0,3	0,5	0,2	1,1	0,2
120	0,2	0,4	0,5	0,5	0,7	0,3		120	0,2	0,4	0,3	0,5	0,9	0,3
180	0,3	0,2	0,8	0,2	1,1	0,1		180	0,3	0,2	0,8	0,2	1,4	0,1
SAR 5th layer								SAR 6th layer						
ϕ\θ	180	140	100	60	20	0		ϕ\θ	180	140	100	60	20	0
0	1.1	1.2	1.8	1.2	1.5	1.3		0	0	0,2	0,6	0,1	1,9	0,1
60	1.4	1.1	1.9	1.6	1.1	1.2		60	0,1	0,8	0,3	0,2	1,7	0,2
120	1.2	1.5	1.5	1.8	1.6	1.3		120	0,2	0,8	0,2	0,5	1,6	0,3
180	1.3	1.2	1.4	1.3	1.2	1.2		180	0,3	0,2	0,8	0,2	1,8	0,1

As can be seen from the table, the maximum value of the SAR - specific absorption coefficient - for the layers of the model was 2.6

W/kg. This is 0.6 W/kg higher than the SAR standard adopted by the European Committee for Electrotechnical Standards [12].

The distribution of SAR at different frequencies across the layers of the model based on the numerical results obtained is shown in Chart 1. The difference in the amount of absorption in the layers of the model is explained by the fact that its first layer is closer to the radiation source, and the CSF layer contains a greater amount of fluid.

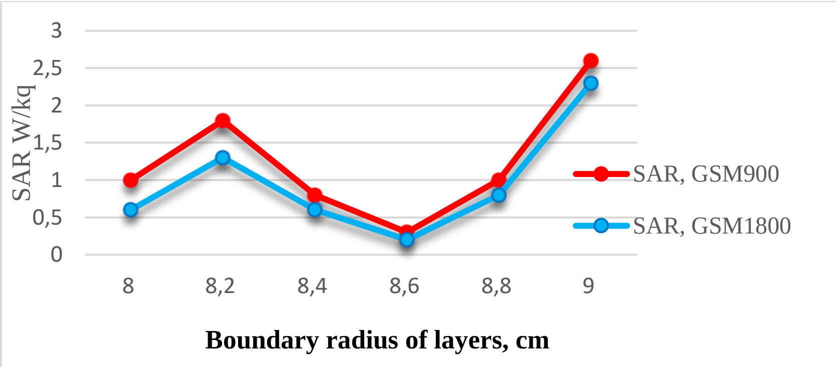

Chart 1. Distribution of SAR across layers of the model.

Chart 2 shows the dependence of SAR on the angles φ and θ in the first layer of the model.

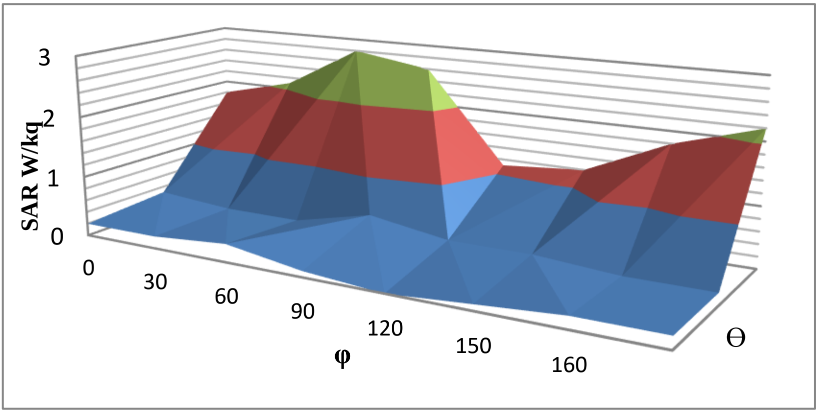

Chart 2. Distribution of SAR in the first layer of the spherical model in the range of angles θ and φ from 0° to 180°.

There are two types of influence factors of electromagnetic waves on biological organisms. One of them is thermal and the other is non-thermal factor[2]. In the dissertation work, thermal effects arising in tissues as a result of absorption were also studied.

The SAR specific absorption coefficient was used to calculate the temperature change resulting from the absorption of electromagnetic field energy. To assess the dependence of temperature on SAR, many factors, such as the mass of tissues, tissue density, their heat capacity, the intensity of electromagnetic radiation and other parameters, should be considered.For this purpose, using the principle of energy balance, we can write the formula for the relationship between absorbed energy and temperature as follows:

$$\frac{dT}{dt} = \frac{SAR \cdot m}{m \cdot c} - \frac{hA(T - T_a)}{m \cdot c} \qquad (2)$$

where, *dT/dt* - rate of change of body temperature;

SAR- specific absorption coefficient, Wt/kg;

m - mass of the affected object, kq;

c- specific heat capacity of the tissue, J/kq;

h- heat transfer coefficient, Vt/m^2;

A- surface area of the object, m^2;

T_a- ambient temperature, $C°$.

Based on the calculations, the thermal effects arising in the tissue at the values of energy flow density of 100 mkW/sm^2 and 150 mkW/sm^2 were determined.

Chart 3 shows the time dependence of the temperature increase inside the model. As can be seen from the chart, as a result of 3 hours of continuous exposure to electromagnetic radiation, the temperature increase continues for100 mkW/sm^2 and reaches 37,26 °C. This is 0.66°C higher than the norm.

Figure 3 provides a visual representation of the temperature indicators along the depth of the model. As can be seen from the figure, temperature changes continued up to a depth of 760mm of the model

2. Бондарева Л. А. Исследование теплового воздействия излучения мобильного телефона на организм человека по изменению температуры барабанной перепонки // Фундаментальные и прикладные проблемы техники и технологии, – 2018. № 5 (331). – с. 115-122.

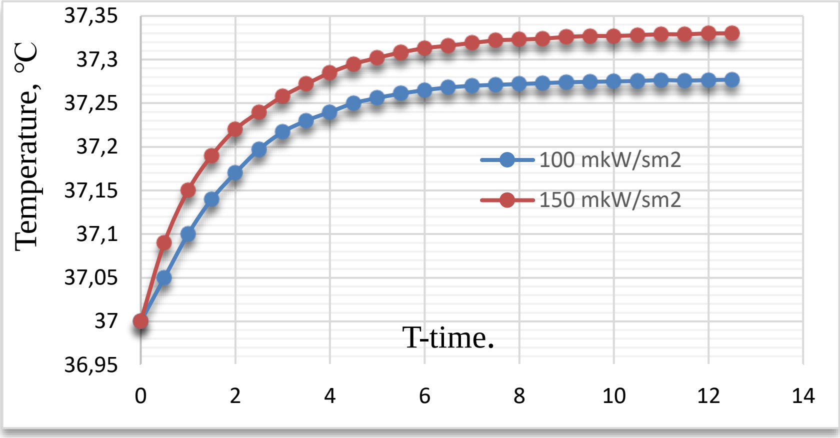

Chart 3. Time dependence of the temperature inside the model under the influence of the electromagnetic field.

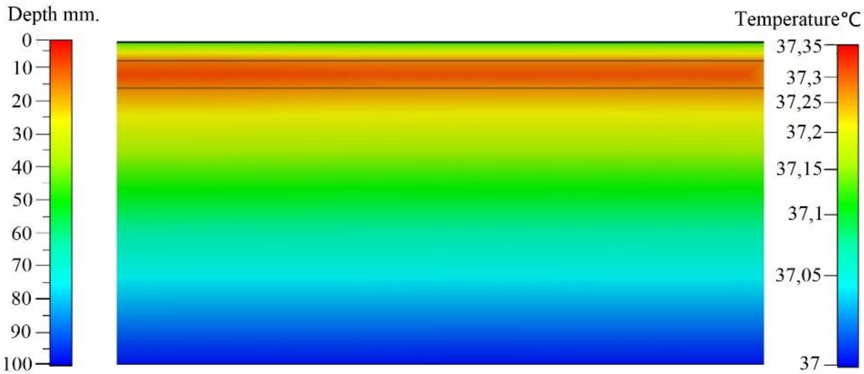

Figure 3. Temperature changes within the model.

In the second chapter, based on the results obtained as a result of studying the influence of the radio frequency electromagnetic field of mobile communication devices, research work was continued to reduce this influence. For this purpose, a geometric correction method of the coverage area of base stations (BS) of mobile communication devices was developed, and through this method, it was achieved to effectively use the radiation power of the BS, thereby increasing its effectiveness. Using the capabilities of the geometric correction method of the coverage area, it is possible to increase the placement efficiency of BS of mobile communication devices. For this purpose, a method of effective placement of mobile communication BS was developed in the dissertation work, and through this method, it was achieved to reduce the number of BS in densely populated areas, thereby reducing the overall electromagnetic radiation intensity.

During the mathematical calculations of the geometric correction method of mobile communication base stations, a mathematical model was developed using the least squares (LS) method. With the application of the LS method, the coverage area of BSs was improved, both the overlap zones were minimized, and the empty zones were covered. Coverage of empty zones in the coverage area can be achieved at any time either by increasing the radiation power of individual stations, or by using the reserve radiation power coefficient when constructing the elasticity matrix.

As is known, in cellular mobile communication networks with a cellular structure, network management is carried out in the form of a cluster group. Each cluster group is controlled by a communication center. In general, the working principle of the geometric correction method is based on ensuring maximum coverage by dynamically controlling the radiation power of individual BSs within the cluster[3].

Experimental calculations were carried out for a cluster group of five base stations located symmetrically to each other at the outer corners and in the center. The distances between the stations are - $d_{12} = d_{25} = d_{45} = d_{14} = 10$km, $d_{13} = d_{23} = d_{35} = d_{34} = 7{,}071$km, the base station reserve radiation power factor k=2, and the BS loading intensity levels are assumed to be equal for each station $y_{1-5} = 1$ Erl, (Fig. 4).

Here Erl- is a quantity expressing the loading level. Using the capabilities of the proposed algorithm, the BS coverage area was corrected on the cluster q=5 As can be seen, based on the given data, we calculate the coverage area of the stations and find their exact size: $r_1 = r_2 = r_4 = r_5 = 5\ (km), r_3 = 2.071\ (km)$.

3. Isabona J. Accurate base station placement in 4G LTE networks using multiobjective genetic algorithm optimization / J. Isabona, A.L. Imoize, S. Ojo, [et al] // Wireless Communications and Mobile Computing. – 2023. T. 2023 – p.

7476736.

However, open zones are observed at the edges of the coverage area. We obtain a new result by changing the value of the reserve radiation power coefficient of all BS to k=1.8. In this case, we obtain new radius values of the coverage zones, including the gaps: $r_1 = r_2 = r_4 = r_5 \approx 5{,}556\ (km)$, $r_3 \approx 2{,}301\ (km)$. Thus, by changing the BS reserve radiation power coefficient, it is possible to eliminate the gaps (Fig. 5). In the example considered, the coverage radius of BS5 has changed at most 1,703 times.

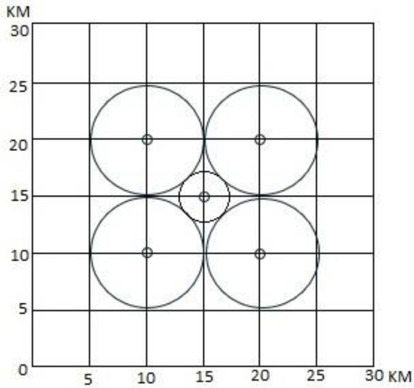

Figure 4. Coverage area of a BS with cluster q=5. Backup radiation power factor k=2. Loading intensity $y_{1-5} = 1Erl$

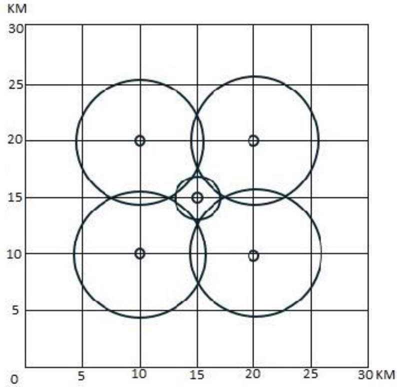

Figure 5. Coverage area of a BS with cluster q=5. Backup radiation power factor k=1.8. Loading intensity $y_{1-5} = 1Erl$

The results of calculations carried out using mathematical methods used in the solution of the proposed algorithm show that the distribution of BS loading intensities by cluster is effective and is carried out with adequate consideration of the geometric configuration. The solutions obtained create wide opportunities not only in terms of efficiency, but also in terms of practical conditions in areas with difficult terrain and location.

Thus, the LS method creates an optimal solution for calculating the coverage area by changing the values of individual BS loading intensities and reserve radiation power. The block diagram of the proposed algorithm is shown in Figure 6.

Based on the geometric correction method of BS coverage area described above, a method for effective placement of base stations in mobile networks has been developed. Experiments have been conducted to reduce the number of stations by applying the geometric correction method to base stations located over a $10km^2$ area and adjusting the coverage area [1,2,9].

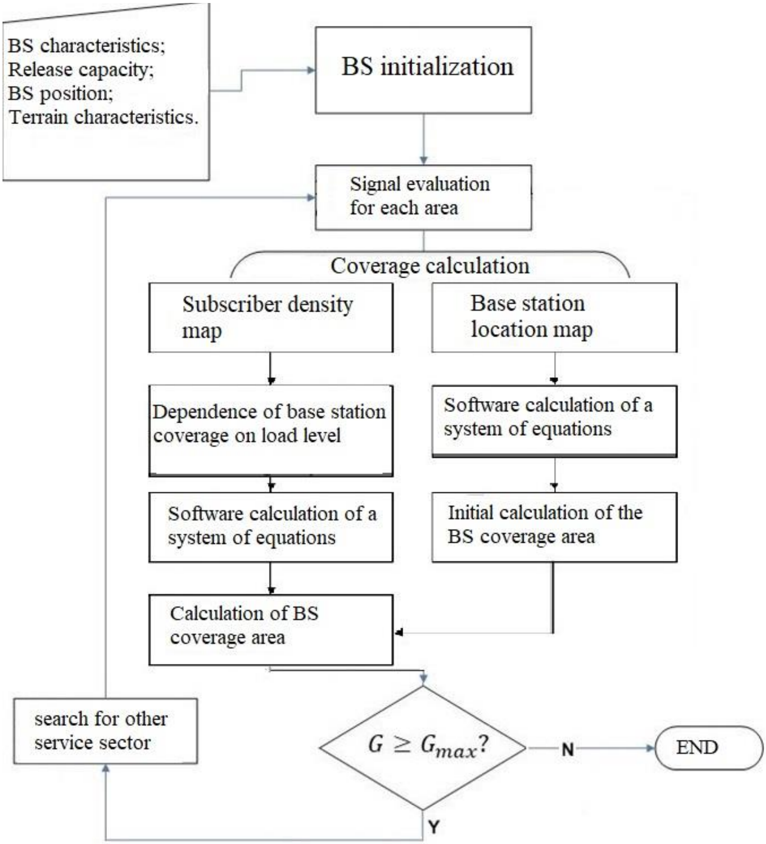

Figure 6. Block diagram of the coverage geometric correction algorithm.

When a communication network is established, a maximum of one base station should be placed in the location of candidate base stations, considering the need to ensure electromagnetic compatibility in the area. This condition is as follows:

$$\forall m \ \sum_{n=1}^{N} Y_{km} \leq X_{nm}^{bb} \tag{3}$$

where, m- number of potential base stations, $m = \overline{1, M}$; n- antenna type of base station, $n = \overline{1, N}$; k - number of subscribers at given coordinates, $k = \overline{1, K}$; XX_{nm}^{bb}- permissible number of base stations, $Y = \|Y_{km}\|$ - subscriber distribution matrix over base stations.

According to the accepted constraint, each subscriber should connect to only one base station. This condition is written as follows:

$$\forall k \quad \sum_{m=1}^{M} Y_{km} = 1 \tag{4}$$

Based on the above statements, we can express the issue of effective placement and minimizing the number of base stations as follows:

$$\varphi = \sum_{knm} X_{nm}^{bb} Y_{kn} + \sum_{mn} c_n X_{nm}^{bb} + \sum_{km} \frac{1}{g_{km}} Y_{km} \rightarrow min \tag{5}$$

During the calculations, the Δ- criterion, which is the mean square error indicator, was applied to evaluate the effective placement of the BS (Fig. 7).

Let us assume that there are overlapping and, conversely, empty zones of the coverage areas of two neighboring BSs. It is clear from Figure 4 that the dependence of the radius of the coverage areas of two base stations on the distance between these stations is proportional to the overlap and empty zones of the coverage area.

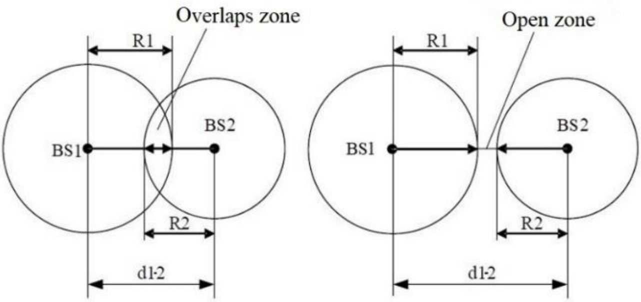

Figure 7. Coverage errors during base station setup.

$$\Delta = \sqrt{\sum((r_i + r_j) - d_{ij})^2}, \qquad |\Delta| \rightarrow min \tag{6}$$

Δ- root means square error;

r_i və r_j –coverage radius of base stations BS_i and BS_j;

d_{ij}- the gap between the coverage areas of stations BS1 and BS2.

Although |Δ|=0 is considered the most effective case for the coverage of communication devices during the maximum effective deployment of BS, in real practice, the minimum mean square error value Δ=0,6096 was determined in a cluster of q=5 base stations [13].

Based on the mathematical model of effective placement of BS of mobile communication devices, location options were developed using the LINGO modeling software and visual results were obtained. For this, potential candidate base station locations were determined in a relative area of 10 km^2. The locations of subscribers and survey types were arbitrarily selected to ensure comprehensiveness of the results obtained and divided into 3 time periods T1, T2, T3 (Fig. 8).

Thus, the most optimal options among the 12 potential candidate stations must be calculated and determined. Based on the minimization condition, we can write as follows:

$$\sum_{j\in S} \sum_{i\in T}(c_{ij}\, z_{ij} + d_{ij}\, y_{ij}) \tag{7}$$

where, C_{ij}- overlapping areas of coverage of base stations i and j.

d_{ij}- area of the empty zone not covered by stations i and j.

z_{ij}, y_{ij}- are variables that depend on the time of receipt of the request and the number of subscribers.

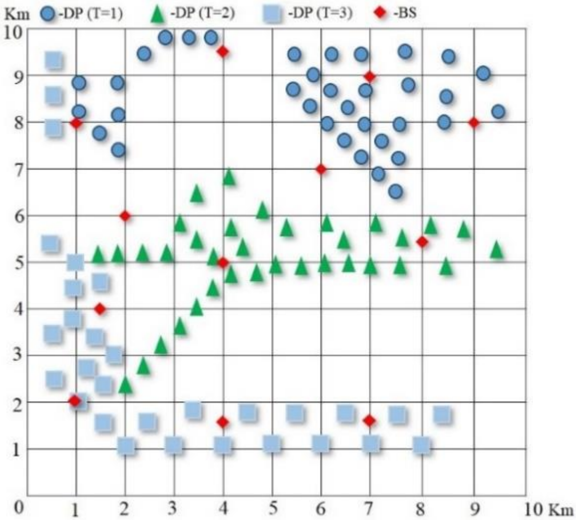

Figure 8. BS deployment over a 10km^2 area.

Thus, based on the mathematical model for the effective placement of mobile communication base stations, 10 base stations were identified to cover all subscriber requests in the experimental area (Fig. 9).

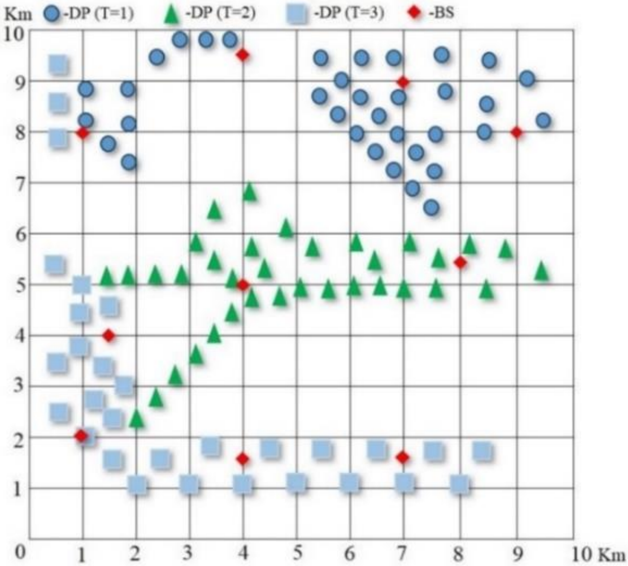

Figure 9. BS placement based on geometric correction method over an area of 10km^2.

The proposed method creates more solutions than symmetrical placement in terms of calculating the most effective placement of base stations. It was determined that the placement of base stations based on the results obtained does not contradict physical, technical, and economic aspects and is consistent with their cluster configuration structure. This proves the adequacy of the results obtained.

In the third chapter, the modeling of the electromagnetic field created by antennas of various designs was carried out. Here, the issue of modeling the electromagnetic field created by antennas of various designs was solved, considering the radiation, energy, and polarization characteristics of antennas of various designs. Direction diagrams of various designs were constructed based on the intensities of electric and magnetic fields in remote areas, the gain characteristics, radiation resistance, and useful work coefficient were calculated, and the polarization characteristics were clarified.

One of the important parameters of antenna devices is polarization characteristics and energy properties. In the chapter, verification calculations were carried out to verify the results presented in the previous chapter and these were compared with the results shown in the literature[4], and graphs of the dependence of the active part of the mutual resistance of antennas in free space on the distance between them were shown. The dependences of the electric field components E_Θ and E_φ of the electric vibrator on the angle θ- near the conductive model were found. In order to check the correspondence and adequacy of the obtained expressions of the radiation characteristics of the antenna in the conditions of interaction with the model, the obtained results were visualized and compared using a computer program. For this purpose, the orientation diagrams of the vibrator antenna near the model were constructed using a modeling program.

Considering the multilayer structure and the highly complex dielectric permittivity properties of the individual layers, the model has high shielding properties, as shown in Figure 10. As can be seen from the figure, the location of the six-layer model near the antenna significantly changes its directional diagram.

According to the obtained result, it can be concluded that the orientation diagram of the electric vibrator located near the dielectric model is significantly distorted compared to the orientation diagram of the vibrator located in free space.

One of the problems set in the dissertation is determining the dependence of the intensity of high-frequency electromagnetic radiation on the distance from the radiation source to the object, as well as on the angle of the antenna of the radiating device relative to the object.

During the experiments, a simulation was carried out in the nearby zone. In each case, the model was placed between two antennas.

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4. Krasuk V.N., Udrov M.A. Technique of calculation dimension conducting surface for forming antenna pattern an open ended waveguide // Fifth International Kharkov Symposium on Physics and Engineering of Microwaves, Millimeter, and Submillimeter Waves. –Ukraine, – Kharkov: National Academy of Sciences of Ukraine, – 2004. – p. 653-655.

One of the antennas played the role of a transmitter, and the other played the role of a receiver [9]. The distance between the model and the antenna surfaces is 180 millimeters, which corresponds to the near zone. Thus, the distance from the antenna to the model is 0mm on each side (180 mm model thickness). During the simulation, the model placement scheme was carried out in the form of “emitter - model - receiver”.

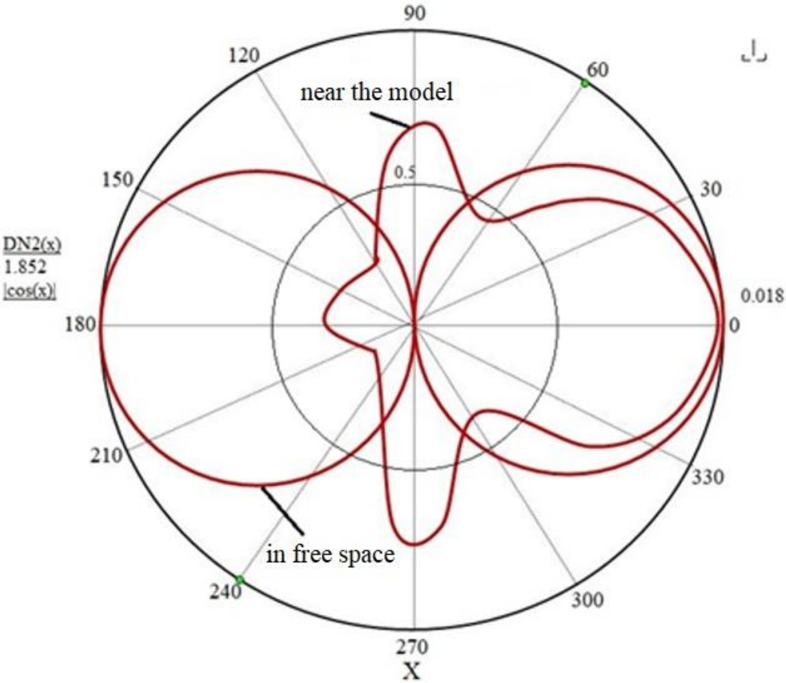

Figure 10. Diagram of the dependence of the E_Θ -component of the electric field voltage on θ.

Then, the experiments were continued with the distance between the antennas being 200, 240, and 250mm. As the distance between the antenna and the model changed, a change in the intensity of the electromagnetic field was observed. Thus, when in direct contact with the model, the SAR value in the first layer was 2.8W/kg, at a distance of 10m. it was 2W/kg, at 20mm it was 1.5W/kg, and at 50mm it was 0.9W/kg. The results obtained show that the SAR value decreases to

2.2W/kg at 50mm from the object. The dependence of the distance between *K*-antennas on the ΔG - gain coefficient is shown in chart 4.

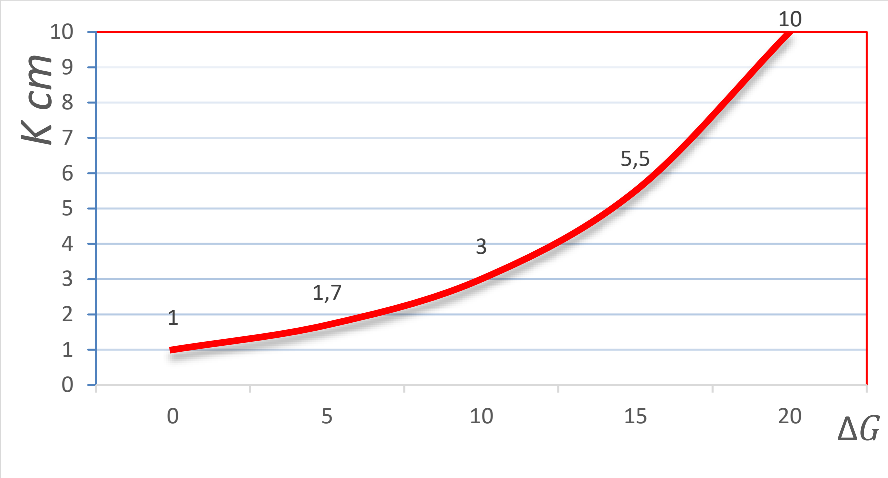

Chart 4. Dependence between the distance between antennas and the ΔG-gain coefficient.

In the conducted studies, a six-layer model was considered, and it was determined that it had significantly more shielding properties than other simplified structures. This was explained by the presence of a substance with a high complex dielectric permittivity, such as CSF, inside it.

The fourth chapter is devoted to the standards and experimental measurements of ensuring the electromagnetic safety of telecommunications equipment. The types and norms of permissible levels of sanitary-hygienic electromagnetic radiation for the population are indicated.

To assess the impact of electromagnetic radiation, the *E*- electric field voltage (V/m) and *H*- magnetic field voltage (A/m) are used, which characterize the radiation intensity. The absolute permissible levels (E_{APL}, H_{APL}) of the electric and magnetic components of the electromagnetic field (EMS) vary depending on the duration of exposure and frequency.

At frequencies of 300MHz-300GHz, the intensity of the EMF is determined by the energy flow density ($EFD, Vt/m^2, mkVt/sm^2$).

$$\overrightarrow{EFD} = \vec{E} * \vec{H} \quad (8)$$

where, *E*- electric component of the electromagnetic wave, *V/m*; *H*- magnetic component of the electromagnetic wave, *A/m*.

The maximum allowable value of the ESS at high frequencies is determined as follows:

$$EFD_{APL} = \frac{EE_{EFD}}{T} \quad (9)$$

where, *T*- is the exposure time.

Based on the above, the temporary permissible level of electromagnetic radiation generated by mobile radiocommunication systems is determined as EFD = 100 mkW/sm^2 for radiotelephone users, and the EFD-level for the population in the base station area is EFD = 10 mkW/sm^2. It should be noted that the given permissible levels of electromagnetic radiation coincide with the internationally accepted normative indicators in this area.

In the dissertation work, in order to assess the compliance of the electromagnetic radiation intensity in Baku with the appropriate permissible norms of sanitary and hygienic electromagnetic radiation for the population, adopted in the classification of radio frequencies according to the international radiocommunication rules, and also to compare the results obtained in the calculations carried out in the study, the electromagnetic field of telecommunications equipment was monitored in different areas of the city, and experimental results were obtained. In Baku city, in areas with dense population and business centers and compact location of radio transmitters of communication networks, the electromagnetic field strengths (EFS) created by them were measured and the experimental results were presented [3]. Electromagnetic field intensities were measured using an electric field strength measuring device of the type "ИПМ-101М".

The main reason for electromagnetic pollution in large densely populated cities is the simultaneous operation of numerous telecommunications devices with different frequency ranges and purposes in the same area and at different radiation intensities.

It should be noted that the level of electromagnetic field voltage can be high even inside business and residential buildings located in the immediate vicinity of the area where the transmitting devices of mobile communication devices are installed together. Therefore, only through measurements can we gain an idea of the safety of the electromagnetic field created by communication devices operating together in densely populated areas.

In the experimental part, the electromagnetic field voltages generated around radio transmitters operating at frequencies above 300 MHz were measured in the areas mentioned, based on the principle of superposition of the electromagnetic field, and the results were given. Since the electromagnetic field consists of electric and magnetic components, the results are given in the form of electric field voltage - *E, V/m* and magnetic induction - *H, mkTl* units.

The areas where the measurements were taken are shown below:

Area №1- “Teleradio” Production Association.

Area №2 - Narimanov metro station.

Area №3 – Elmlar akademiyasi metro station.

Area №4 - 20 Yanvar metro station.

The change in the value of the ESS in different areas and measurement points is clearly shown in chart 5.

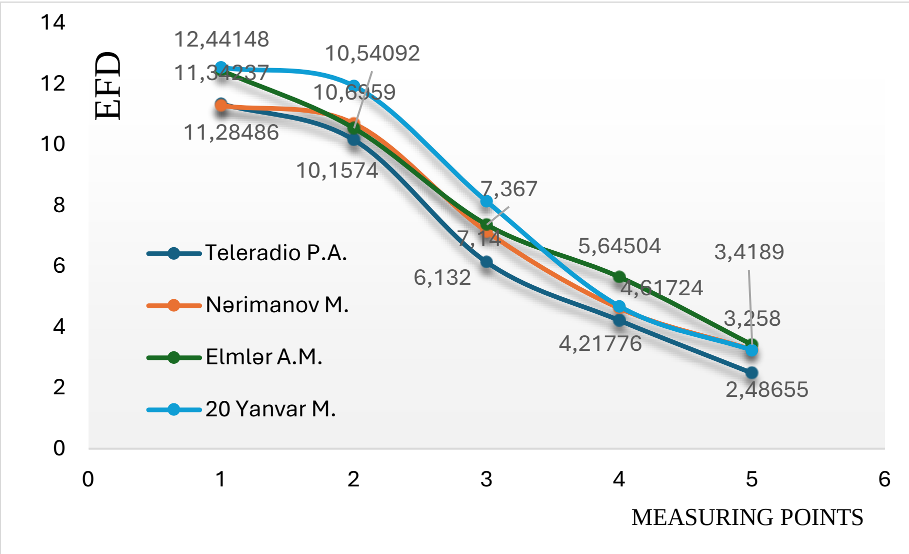

Chart 5. Dynamic indicator of ESS price at different measurement locations.

As can be seen from the graph, the results obtained in the areas where the measurements were taken exceeded the norm:

$$EFD_{max} = \frac{11{,}34+11{,}28+12{,}44+12{,}53}{4} = 11{,}89\,\frac{mkW}{sm^2}$$

In other words, in the indicated areas, the maximum EFD values in the zone near the BS were 1.89mkW/cm^2 higher than the normative level. It should be noted that because of measurements conducted in areas with dense mobile communication systems, the highest intensities of electromagnetic radiation were observed at distances of 5-10 meters close to the location of the radiating antenna group. It was observed that the level of radiation intensity was within the norm as the distance increased.

Indeed, the EFD value usually tends to decrease with distance from the base station. This can be expressed by the inverse square law of distance, which can explain many physical phenomena and is also used in the propagation of radio waves. We can write the expression for the distance dependence coefficient to the BS as follows:

$$EFD(r) = EFD_0 \cdot \frac{1}{r^2} \tag{10}$$

where, $E(r)$ – dependence of the energy flow density on the distance r – to the base station; EFD_0 – alue of EFD- at the initial r_0 – point; r – distance to the base station, r_0 – initial distance to the BS.

From the results of the measurements, it is known that $E_0 = 11.89\,mkVt/sm^2$, the distance from the measurement point to the base station $r = 5 \ldots 1000m$ and the initial minimum distance of the measurement $r_0 = 1m$.

Then, the value of the EFD distance dependence coefficient will decrease proportionally to the square of the distance and take the following form.

$$EFD(r) = EFD_0 \cdot \frac{r_0^2}{r^2} = 11.89 \cdot \frac{1^2}{1000^2} = 11.89 \cdot 10^{-6}\,mkW/sm^2 \tag{11}$$

Thus, let us calculate the ESS value according to the result we obtained by applying the method of effective placement of base stations presented in Chapter 2. As mentioned, during the study, it was possible to reduce the number of BS to 10 with the proposed method in a 10 km^2 area where 12 BS were located.

Taking this into account, we can write how the maximum ESS value will change in the following expression:

$$EFD_{max} = EFD_0 \cdot \frac{BS_0}{BS_Y} + ESS(r) \qquad (12)$$

here, BS_0- the number of initial base stations, BS_Y- is the new number of BS obtained based on the effective placement method.

Thus, considering the distance dependence coefficient, if we substitute the quantities specified in the above expressions, we get:

$$ESS_{max} = 11.89 \cdot \frac{10}{12} + 0.04 = 9.95\, mkW/sm^2 \qquad (13)$$

As can be seen from the expression, the maximum value of the EFD even in the closest zone is $9.95\, mkW/sm^2$. Calculations give grounds to say that with the application of the algorithm for correcting the coverage areas of antennas of mobile communication systems and the methods of effective placement of base stations presented in the dissertation, the value of the energy flow density parameter characterizing electromagnetic radiation in densely populated areas will decrease by 1,94mkW/sm^2.

As can be seen by applying the method of effective placement of base stations, it is possible to limit the number of stations by effectively using the power of the transmitting devices of mobile communication systems. In addition, the geometric correction method proposed for BS placement and working based on the LS method is promising in terms of finding optimal solutions and can serve to improve the technical and economic indicators of the network. As a result of the studies conducted for this purpose, the economic efficiency of increasing the efficiency of mobile communication networks was calculated. As is known, to properly organize the service, mobile communication networks are installed more often in densely populated areas. However, to assess the use of mobile communication devices by the population, the number of populations in the country and the density of that population by place of residence, as well as whether the area is a city, town or village, should be considered. Chart 6 shows the ratio of the number of BSs to the share of territorial units of the country.

As can be seen from the graph, the main share here falls on Baku city, due to its denser population.

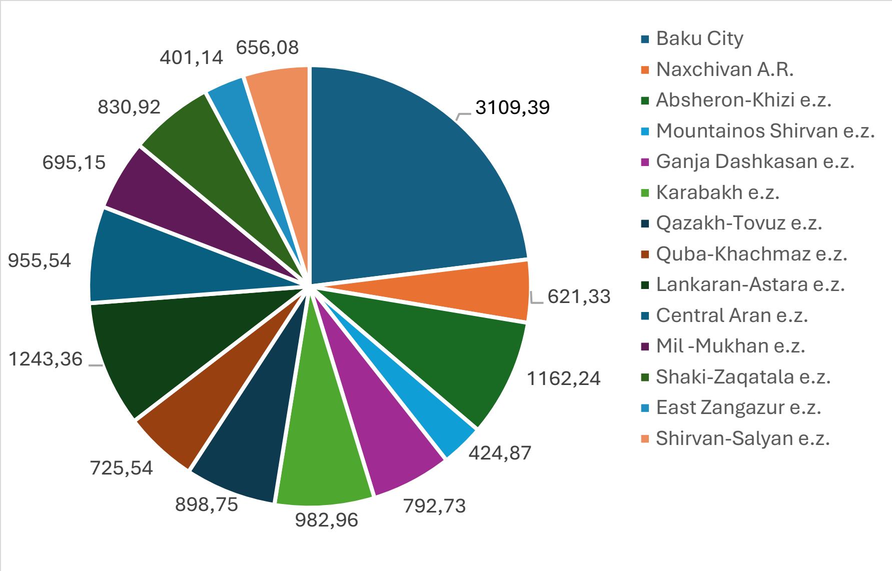

Chart 6. Coverage of administrative territories in economic regions with mobile communication operators.

Thus, we can write for base stations of mobile communication networks by administrative territorial units.

$$BS_{AT} = \frac{MO_{BS}}{R_{AT}} * 10km^2 \qquad (14)$$

where, BS_{AT}- number of BSs in the administrative territory, R_{AT}- administrative territory of the republic, MO_{BS}- BS-number of base stations of mobile operators. From the formula, it is possible to determine the average number of mobile communication devices BS for 10 km^2 of the total territory of the republic. However, considering that the area and population ratios of cities, settlements and villages are different, it is not correct to evaluate them under the same conditions. Therefore, it is necessary to include an additional coefficient characterizing the administrative territory and population density in the formula. In addition, it should be considered that cities, settlements and villages in administrative territories do not have the same conditions in terms of the propagation of electromagnetic waves. In this regard, the population density in the indicated territorial units was also considered in the evaluation of the general distribution of mobile communication base stations in the territory in the dissertation work. Taking this into account, a coefficient characterizing population density should be included in formula (14). To determine population density, the ratio of the population number to the size of the territory in each administrative territory should be found:

$$P_{den} = \frac{P_{AT}}{T_{AT}} \tag{15}$$

where, P_{den}- dense-population density coefficient, P_{AT}- population number by administrative area, T_{AT}- administrative area size.

Thus, considering population density, we can write formula (15) as follows:

$$BS_N = \frac{\left(\frac{MO_{BS}}{P_{AT}} * 10km^2\right)P_{den}}{100} \tag{16}$$

where, BS_N- is the number of base stations.

Then, based on the number obtained as a result of applying the geometric correction method, let's calculate the number of BSs that can be reduced in the area for each of the 12 stations.

$$BS_{red} = \frac{BS_{NAT}}{12} * 2 \tag{17}$$

where, BS_{red}- reduced number of BS, BS_{NAT}- is the number of BSs per administrative area.

As can be seen, the presented method allows determining the number and areas of BSs whose number can be reduced. According to calculations, by applying the algorithm, it is possible to reduce 194 BSs in 15 areas. Based on this, the economic benefit that can be achieved as a result of the effective placement of base stations has been determined. This, in turn, is expected to provide the republic with an economic benefit of 36 278 000 AZN.

RESULT

1. The electromagnetic radiation and the variable radiofrequency electromagnetic field generated by existing mobile communication systems and telecommunications devices were analyzed and the interaction of these radiations with biological objects was modeled for the first time [14, p. 28-33].

2. The maximum value of the SAR-specific absorption coefficient for the layers of the multilayer model with variable electrophysical properties created through modeling was 2.8 W/kg. This indicator decreased to 0.9 W/kg when the radiation source was located at a distance of 50 mm [10, p. 32-39; 12, p. 49-52].
3. As a result of the study of the thermal effects of electromagnetic energy on biological structures, it was found that the continuous effect of an electromagnetic field at a power flux density of 100 mkW/sm^2 for 3 hours causes a temperature increase of 0.66°C in biological structures. Based on the results obtained because of mathematical analysis, the relationship between tissue depth and temperature changes was analyzed and it was determined that temperature changes were observed up to a depth of 760mm in the model [11, p.718-723; 16 p.365-369].
4. To reduce the impact of mobile communication network transmitters and efficiently use the radiation power, a geometric correction algorithm for the coverage areas of base stations has been developed. It has been proven that the obtained solutions do not conflict with the physical placement of base stations, are compatible with their cluster configuration structure, and create broad opportunities not only in terms of efficiency, but also in terms of practical conditions. By applying the geometric correction algorithm, it was possible to achieve a maximum change of the coverage radius of the BS5-cluster group in the positive and negative ranges by 1.7 times [4, p.201-203].
5. To increase the efficiency of mobile communication base stations and reduce the intensity of electromagnetic radiation in densely populated areas, the effective placement of base stations was modeled. By applying the effective placement method, it was possible to reduce the number of base stations to 10 stations while maintaining communication quality in a conventional area of 10 km^2 with 12 BS [9, p.35-40].
6. The effective placement of mobile communication base stations in the territory of the republic by applying the geometric correction method of the coverage area is considered effective in terms of optimizing technical and economic parameters in the construction

of networks, and an economic benefit of 36 278 000 AZN is expected from the application of the method.

7. As a result of monitoring the electromagnetic field intensities of existing mobile communication systems in Baku, it was determined that in areas with dense population and workplaces where communication devices are compactly installed, the maximum energy flux density value in the immediate vicinity of the antenna devices of radio transmitters operating at mobile communication frequencies was $EFD_{max} = 11{,}89\, mkW/\text{см}^2$. The final values of the electromagnetic radiation intensity generated in the mentioned places are 1.89 $mkW/\text{см}^2$ higher than the standard applied to the levels of permissible intensity of electromagnetic radiation [3, p. 158-160].
8. By applying the algorithm for correcting the coverage area of mobile communication antennas and effective placement methods of base stations, it was calculated that the maximum value of the ESS in the zone closest to the source of electromagnetic radiation in densely populated areas will be 9.95 mkW/sm^2, lower than the current value [6, p. 181-186; 1, p. 137-139].

The main content of the dissertation work has been published in the following scientific works:

1. Salahov A.Z. The effect of electromagnetic radiation of modern mobile phones on the human body // Materials of the 19th Republican Scientific Conference of Doctoral Students and Young Researchers. – Baku: – 2015. – №1, – p. 137-139.
2. Salahov A.Z. Mobile phone antennas // Materials of the Republican Scientific and Technical Conference of Students and Young Researchers on the theme “Youth and Scientific Innovations” dedicated to the 94th anniversary of the birth of the national leader of the Azerbaijani people Heydar Aliyev, – Baku: AzTU, – May 3-5, 2017. – p. 244-246.
3. Salahov A.Z. Calculation of the electric field strength of mobile phones and base stations / A.Z. Salahov R.Sh. Abdullayev X.Kh. Hashimov // Scientific works, – Baku: AzTU, – 2018. – №1, – p.

158-160.
4. Salahov A.Z. Green's tensor function method in electromagnetic excitation problems in communication systems. // Scientific works, – Baku: AzTU, – 2018. – No. 2, – p. 201-203.
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The author's personal participation in scientific articles published with co-authors:

[3] – Solving the obtained differential equations, preparing

reports and analyzing the results

[8] – Formulation of the problem, experimental research work, preparation of conference materials,

[9] Solving mathematical expressions, designing the antenna frame, issuing reports.

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