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THE LATEST MEANS OF COMMUNICATIONS BASED ON LTE AND MIMO TECHNOLOGIES IN 3G, 4G NETWORKS: APPLICATION FOR CONTEMPORARY BIOMEDICAL PRACTICE IN RURAL UKRAINE

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Abstract**—***The network organization of the systems of economic entities, which are distributed remotely over large territories, require the creation of high-quality communications for them. The purpose of present work was to demonstrate the possibility of using the latest means of communication based on Long-Term Evolution and Multiple-Input Multiple-Output technologies (LTE- and MIMO- technologies) in 3G and 4G networks to solve contemporary tasks of organizing of high-quality mobile communication in some places of the territory of Ukraine for the works that need biological and medical information in rarely settled, remote regions. The publication provides the author's data on the practical organization of communication in rural areas and considers the following issues. 1- Determination of spatial parameters of the LTE standard network. 2- Preparation of a map of the area. 3- Choosing an LTE network planning option. 4- Principles of construction and operation of LTE networks. 5- P-GW (Packet Data Network Gateway) functions. 6- MME (Mobility Management Entity) functions. 7- Functions of PCRF. MME (Mobility Management Entity) functions. 8- Functions of PCRF. 9- Peculiarities of using upper and lower frequencies for LTE. 10- Application of MIMO technology in LTE. 11- Application of MIMO technology in 3G and 4G networks. The results of the performed works can be applied for the networked structures development for the use in domestic economy, agriculture, for the science branches like biology, nature protection, and for information systems for such branches. In the result of the work done the type of antenna, other equipment were suggested; they should be used to strengthen 3G and 4G Long-Term Evolution communication in such conditions, as well as suitable 4G antenna for modem or router. Obtained results are suitable for providing of the work of information systems in agriculture, ecological monitoring, other areas of activities, based on biological and medical information; they all need quick data exchange as well as for scientific centers, other settlements, for which such communication possibilities primarily were developed.*

Index Terms—Analysis and modeling of panel and wave channel antennas; long-term evolution; MIMO-technology; wave channel; 3G, 4G networks.

I. INTRODUCTION

The network principles of system organization in engineering and economy have reliably taken the leading positions today. This was facilitated by the rapid development of information and computer technologies (ICT) and contemporary communication systems [1] – [4]. This trend arose at the beginning of the creation and improvement of computer systems, but it became aware and widely used only from about the end of the 1980s. As it always happens, the dominance of such systemic approaches began in the field of technical disciplines and solution of related technical problems in industry and economy. Tested with success in these areas, the network principles of system organization have attracted the attention of those who are engaged in the organization of works and are solving topical problems in biology and medicine. However, in contemporary world, it is impossible to solve the problems of the successful functioning of network systems, if reliable communication between system elements, correlation and coordination of their performance of functions is not ensured, which is a guarantee of effective control of system elements and itself as a whole. Information systems with databases of biological and medical information were in focus of the authors' attention during the last years; some of their samples had been already constructed [5] – [7] and supplemented with telecommunication possibilities [5], [8] – [10].

The author's experience of implementation of 3G, 4G connection technologies on the territory of Ukraine that could be used for the purpose of agriculture will be given briefly in the proposed article in continuation of the previous one [10]. Such technologies of communications are rather useful for agriculture modernization in Ukraine, many spheres of modern life, linked with biological and medical information exchange. For example, core entities in spheres of activities linked with biology (remote scientific centers of ecological monitoring for ecology protection, nature preservation, other ones like these) as well as agricultural industry were developed in rural regions of Ukraine. The situation is similar with rural dispensaries and small remote medical centers in many villages of Ukraine. They can be characterized by *a)* great squares of remote territories; *b)* limited communication capabilities – absence of all communications, as well as good modern types of communications.

The materials in this article were presented in following order. At the beginning, the importance of using the described communication technologies in the branches of Ukraine related to medicine and biology is substantiated. Further, numbers of issues of technical implementation of such communication were given in the next order. Determinations of spatial network parameters of the Long-Term Evolution (LTE) standard were given. Preparation of a map of the area was described. Choosing an LTE network planning option was done. Principles of building and functioning of LTE networks (examples of the structure of LTE network for solving this problem were shown at figures). Packet Data Network Gateway (P-GW) functions. Mobility Management Entity (MME) functions. Functions of PCRF – in fact, a management server that provides centralized management of network resources, etc. Peculiarities of using upper and lower frequencies for LTE were given. Applications of Multiple-Input Multiple-Output (MIMO) technology in LTE, as well as application of this MIMO technology in 3G and 4G networks were described.

The ***purpose*** of this publication was to demonstrate the possibility of using the latest means of communications based on LTE and MIMO technologies in 3G and 4G networks to solve contemporary tasks of organizing of high-quality mobile communication in some places of the territory of Ukraine for the works that need biological and medical information in rarely settled, remote regions.

II. Problem Statement

In our previous works, we have already demonstrated the possibilities of network creating for information systems in area of biology [5], [6], [8], [9] in order to monitor the state of the environment by observing biodiversity (Fig. 1a, b), and medicine [7]. The successful implementation of the idea of monitoring the state of the environment in Ukraine is also ensured by the fact that since the middle of the 20th century, there was organized a powerful network of biostations in Ukraine [5]. Using such a network, even at the then level of technical development, the relevant tasks of accounting of bioindicators were solved, as well as monitoring of their reproduction and movement. Obtained information was generally used for the science-intensive development of agriculture, increasing yields, solving environmental problems of preserving flora, fauna of Ukraine [5], [6].

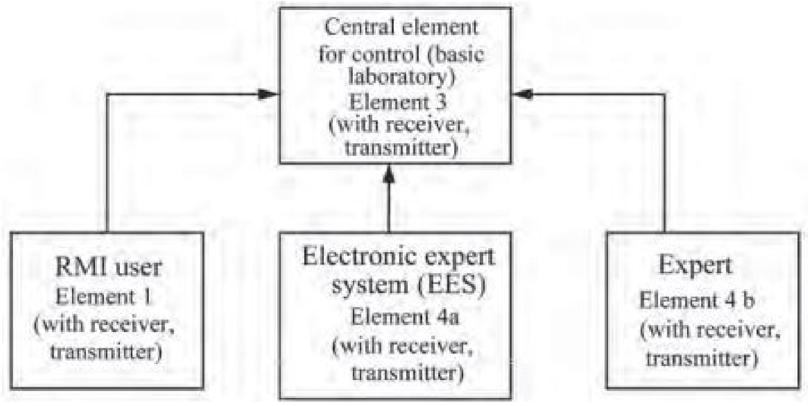
At the same time, similar methods were implemented in medicine and the sphere of health care of Ukraine. During the 20th century, wide networks of dispensaries, dispensary centers, clinics, etc., were created throughout the territory of Ukraine, which provided monitoring of the state of the health of population [5], [7]. Thanks to this, epidemics of deadly infectious diseases were stopped and overcome, and later, in the post-Chernobyl years, all measures were taken to prevent the mass development and progression of cancer throughout Ukraine, primarily in Polissia.

For a number of years, the authors contributed to solving similar problems [5] – [16]. Having their many-year experience in the elaboration of information systems for such networks of biological centers [5] – [10], in linked developments [11], [12], we see the necessity to provide them by communication possibilities of high quality, especially telecommunication possibilities. The subject of this publication – is the attempt to provide our networked system by contemporary 3G, 4G mobile connections [15] – [31].

In our previous publication [5] we had already described the example of information system, one of functional sectors (subsystem) of our developed information system "EcoIS". Such system was supposed by Dr. Klyuchko O.M. for bioindicators accounting for the purposes of monitoring of the state of insect fauna in Ukraine; it was developed primarily for the accounting of the moths – Noctuidae (Lepidoptera) [5], [8], [9].

However, the existence and successful functioning of such large-scale systems are impossible without ensuring of reliable communication between systems' elements. In our example this "EcoIS" subsystem (Fig. 1) was supposed to be developed on the base of the set of biological stations, field biolaboratories, and other biological entities [5]; their well- developed networked system was organized in Ukraine in 20th century but without the use of modern communications. Similar situation has now arisen with the network of rural dispensaries and small remote medical centers in villages located over the far distances throughout Ukraine – they all need reliable, good communications too. At the current stage, the latest means of communications based on LTE and MIMO technologies in 3G and 4G networks could be used for these problems solutions. The results of the work described below are a way to solve such problems – development of the high-quality mobile communication in some places of the territory of Ukraine [10].

a)



b)

Fig. 1. The system for ecological monitoring of fauna in Ukraine "EcoIS": sector for bioindicators accounting [5]: a) is the Fragment 1 of the structural diagram of the "EkoIS" information system for ecomonitoring and tracking changes in the number of bioindicators is drawn; b) is the Fragment 2 of the structural diagram of the "EcoIS" information system for ecomonitoring and tracking of changes in the numbers of bioindicators. *Indications*: PC is the personal computer; LDB are local databases; NC is the node computer; CDB are central databases; EES is the electronic expert system; RMI is the information from the radars for insects monitoring [5], (see the text for other explanations)

III. Problem Solution

A. Determination of spatial parameters of the LTE standard network. Preparation of a map of the area

Solving the problems of providing reliable communication of functional networks of medical and biological centers connected by communication networks, at the first stage, consists in the preparation of an electronic map of the area on which the LTE network should be developed. The map should contain the data describing the relief of the area, the development of the territory, forest and water parts of a territory. As a result, we have to collect and take into account the following detailed information:

- terrain heights;
- land use;
- population distribution, traffic flows and other factors affecting traffic density;
- forecast of the number of subscribers;
- requirements for operating characteristics to ensure the appropriate quality of radio communication;
- blocking probabilities;
- losses of a budget;

- recommended areas for placement of base stations that meet the requirements of availability of connection lines to the public networks, power supplies, the possibility of placing equipment, installation of antennas, etc.;
- available frequency bands;
- compatibility with other systems.

B. Choosing an LTE network planning option

There are two main options for planning networks: with the aim of forming the maximum coverage area or with the aim of ensuring the necessary capacity. These tasks sometimes contradict each other. For example, in urban conditions with a high density of subscribers, the area of service areas of base stations (BS) is much smaller than the maximum possible, but they are optimized in terms of throughput. In rural areas, the situation is often the opposite, the density of subscribers is low, and base stations are installed at the maximal distance from each other so as to cover the maximum territory for each BS. But in both cases, radio coverage and network capacity were evaluated in order to identify factors limiting its characteristics in network project.

In Ukraine, the fourth generation 4G LTE communication standard was launched in 2018, and it is used by the big three mobile operators – Kyivstar, Vodafone Ukraine and Lifecell. During the introduction of 4G in Ukraine, operators received licenses for the LTE standard at frequencies of 1800 MHz and 2600 MHz, and in 2020 also for the frequency of 900 MHz. Thus, since the second half of 2020, LTE in Ukraine has been operating at frequencies of 900, 1800 and 2600 MHz. 4G in our country works in duplex mode – FDD (Frequency-division duplexing).

Base stations at the frequency of 900 MHz (LTE-900) have a range of about 26 km and can cover enough large areas with a relatively low density of users. Therefore, such stations were installed in rural areas, along the routes of national and local importance, where large areas need to be covered, but where the number of users is much smaller than in large cities.

Base stations operating at frequency of 1800 MHz (LTE-1800) were installed both in rural areas and in small and large towns. Such a base station has a coverage area of 13.5 km and sufficiently large capacity to simultaneously connect a large number of users both in small settlement and in a city with billions of population.

Base stations at the frequency of 2600 MHz (LTE-2600) have a short range (up to 2.5–3 km) and the largest capacity. Therefore, they are installed in large cities with a large concentration of users.

C. Principles of construction and operation of LTE networks

In present publication LTE-technology includes a radio access network (Evolved Universal Terrestrial Radio Access Network, E-UTRAN) and improved packet core (Evolved Packet Core, EPC) (see Figs. 2 and 3). The LTE network is built as a set of new base stations eNB (Evolved NodeB, or eNodeB), where neighboring eNBs are connected to each other by the X2 interface. The eNB is connected to the EPC via the S1 interface. Interactions of new elements in the network architecture: S-GW (Serving Gateway) – serving gateways containing management software based on the MM protocol (MME – Mobility Management Entity) was represented at Fig. 2.

The structure of the LTE network was shown at Fig. 3, where the abbreviation "GW" means "Gateway". The core of the EPC network (Evolved Packet Core) consists of serving gateway S-GW (Serving Gateway), gateway for accessing packet networks P-GW (Packet Data Network Gateway), as well as management structure of the Mobility Management protocol MME (Mobility Management Entity), connected to S-GW and eNodeB signaling interfaces.

Functions of eNodeB (Evolved NodeB):

- eNodeB combines the functions of base stations and 3rd generation network controllers;
- provides transmission of traffic and signaling over the radio channel;
- manages the distribution of radio resources;
- provides end-to-end traffic channel to S-GW;
- supports transmission synchronization and controls the level of interference in the cell;
- ensures encryption and integrity of transmission over the radio channel, selects MME and organizes signal exchange with it;
- compresses IP packet headers;
- supports multimedia broadcasting services;
- when using a structure with gain of power on the antenna mast, it organizes the management of antennas using a special Iuant interface.

The S1 interface, as shown in Fig. 3, supports the transmission of the data from the S-GW and signaling through the MME. Note that an eNB may have connections with several S-GWs.

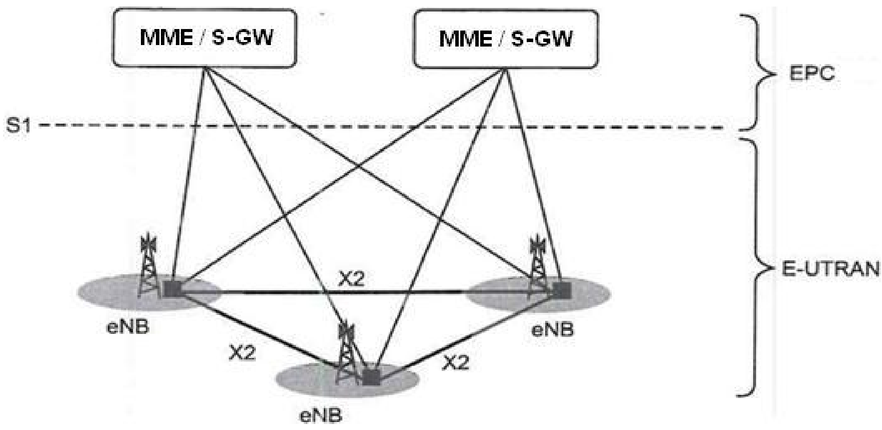


Fig. 2. Simplified LTE network architecture (abbreviations are given in the text)

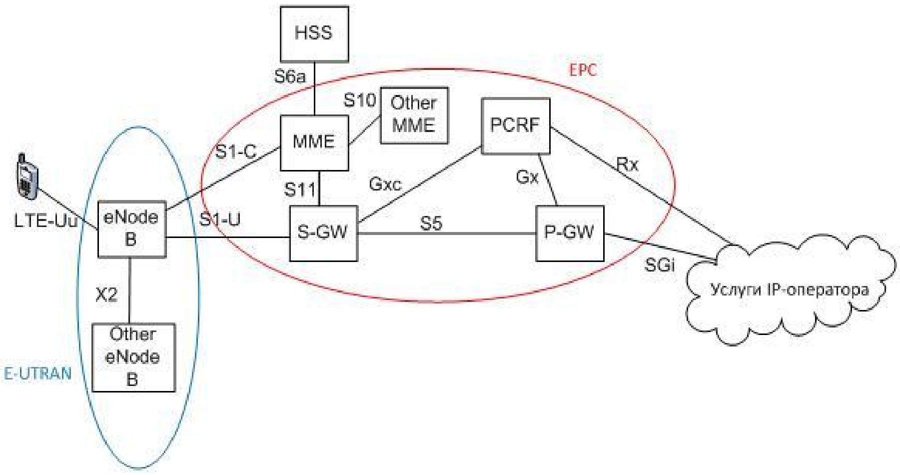


Fig. 3. Aperture of 3G/4G MIMO Yagi antenna with 20 dBi amplification and operating frequency range 1700–2170 MHz

Functions of the S-GW service gateway:

- routing of transmitted data packets;
- setting quality indicators (Quality of Service, QoS) of services provided;
- buffering of packets for UEs that are in Idle Mode;
- provision of accounting data for tariffication and payment for performed services.

S-GW is an anchor structure that ensures subscriber mobility. Each active UE is served by a specific S-GW. Theoretically, a UE can be connected to several packet networks; then it will be served by a few S-GW servers.

D. P-GW (Packet Data Network Gateway) functions

The P-GW packet gateway provides an access point to external IP networks. Accordingly, the P-GW gateway is the anchor gateway to provide traffic. If the subscriber has a static IP address, the P-GW activates it. If the subscriber needs to receive a dynamic IP address during the communication session, the P-GW requests it from the DHCP (Dynamic Host Configuration Protocol) server or performs the necessary DHCP functions itself, after which it delivers the IP address to the subscriber. The P-GW includes PCEF (Policy and Charging Enforcement Function), which provides quality characteristics of services on the external connection through the Sgi interface and filtering of data packets. When serving a subscriber in the home network, the P-GW and S-GW functions can be performed by two different devices or by one device. The S5 interface is a GPRS or Proxy Mobile Ipv6 tunnel connection. If the P-GW and S-GW are in different networks (for example, when serving a roaming subscriber), the S5 interface is replaced by the S8 interface [8].

E. MME (Mobility Management Entity) functions

The MME control unit primarily supports the implementation of Mobility Management protocol procedures: ensuring network security during UE connection and S-GW, P-GW selection. MMEs are connected to the HSS of their network in the form of an S6a interface. The S10 interface, which connects different MMEs, allows you to serve the UE when the subscriber moves, as well as when he has roaming.

F. Functions of PCRF

Policy and Charging Resource Function (PCRF) is essentially a management server that provides centralized management of network resources, accounting and tarification of services provided. As soon as there is a request for a new active connection, this information is sent to the PCRF. It evaluates the network resources at its disposal and sends commands to the PCEF of the P-GW gateway that establish requirements for the quality of services and their ratifications.

G. Peculiarities of using upper and lower frequencies for LTE

The development of LTE at the frequency of 1800 MHz is on average 60% more economical than the construction of networks in high frequency bands. The use of this range allows reducing the time to market of LTE technology and accelerating its development. Those companies that can carry out reforms for the lower frequencies of 800–900 MHz, where the deployment of LTE networks is several times cheaper than in the bands above 2 GHz, will be in a more favorable position. The deployment of networks in the low-frequency region of the spectrum is more attractive from the point of view of costs and is optimally suited to cover areas with low population density (suburbs and rural areas). Low frequencies, compared to high ones, provide much better penetration inside buildings and a larger area of coverage, which, on the one hand, allows providing communication to large areas, and on the other hand, seriously limits the density of base stations and exacerbates the problem of intra-system interference. High frequencies are excellent for building LTE systems in densely populated areas where high transmission speeds are required. However, if you work only in the high-frequency range, the problems with radio coverage arise. The ability to use a combination of two ranges (high and low) is a guarantee of volume coverage and provision of the necessary capacity in places where traffic is especially demanded. To improve coverage inside buildings, it is recommended to use femtocells [1], [4].

H. Application of MIMO technology in LTE

In modern cellular communication systems, the requirements for their bandwidth and capacity are constantly increasing. This can be achieved by increasing of the number of base stations, the bandwidth of radio channels or the number of radio channels, as well as increasing of the spectral efficiency.

The most extensive and expensive way to increase the capacity of the cellular network is to increase the number of base stations in the serviced territory. In many large cities it is not implemented today: the density of the arrangement of macro base stations has already reached its limit. The next step in this direction will be the transition to micro- and pico-base stations with simplified requirements for installation and operation locations. The most economically justified way is to increase the efficiency of the use of the radio frequency spectrum, that is, the measures of the throughput of the system in one cell of the network, per unit of the radio frequency range.

MIMO technology can be realized as the use of several antennas on the transmitting side and several antennas on the receiving side and allows to significantly increase the bandwidth and/or resistance to interference of the communication system in comparison with a traditional system with one transmitting and one receiving antennas (SISO – Single Input Single Output).

In MIMO systems, both spatial diversity on reception and spatial diversity on transmission can be implemented. In addition, there are multiuser MIMO systems (MU-MIMO – Multiuser MIMO), in which a base station with several transceiver antennas interacts with several subscriber stations, each of which can have one or more transceiver antennas.

MIMO systems obviously use multi-element antennas or antenna arrays on both the transmitting side and the receiving side. Multi-element antennas can be used in such a way as to concentrate energy in the direction of a certain subscriber and to form a corresponding pattern (beamforming). In addition, multi-element antennas can be used to form of several parallel data streams (spatial multiplexing mode).

The joint use of the effects of spatial diversity, spatial multiplexing and beamforming of the directional pattern allows:

- increase the system's resistance to interference (reduce the probability of error);
- increase the transmission speed in the system;
- increase the coverage area;
- reduce the required transmitter power.

These four positive properties of MIMO systems, unfortunately, cannot be realized at the same time. For example, an increase in the speed of information transmission leads to an increase in the probability of error or to increase in the radiated power of the transmitter [1], [4].

I. Application of MIMO technology in 3G and 4G networks

The first MIMO schemes for UMTS were specified in past in Release 99 of 3GPP as optional. However, they did not find application in UMTS networks, as they did not provide a benefit in the conditions of multi-beam propagation of radio waves when using RAKE receivers in subscriber stations. 3GPP Release 7 introduced a feedback spatial multiplexing scheme for High Speed Downlink Packet Access (HSDPA) for base stations with two transmitting antennas. MIMO technology in UMTS was further developed in Release 11, which specified: MIMO schemes with feedback on the "down" line for base stations with four transmitting antennas; as well as uplink MIMO schemes for subscriber stations with two transmitting antennas; schemes of multipoint communication (Multiflow Data Transmission).

3GPP Release 7 includes the following MIMO schemes for base stations with two transmitting antennas:

- space-time transmitted diversity (STTD – Space Time Transmit Diversity), specified in Release 99;
- Time Switched Transmit Diversity (TSTD – Time Switched Transmit Diversity), also specified in Release 99;
- distributed transmission with feedback (TxAA – Transmit Antenna Array), also specified in Release 99;
- spatial multiplexing scheme with feedback (D-TxAA – Double Transmit Antenna Array), specified in Release7.

STTD and TSTD schemes are optional for base stations. But support for these schemes is mandatory for subscriber stations.

IV. CONCLUSIONS

The author experience of implementation of 3G, 4G connections technologies at the territory of Ukraine that could be used for the purpose of agriculture, other spheres of economy were given briefly in present article. Such technologies of communications have to be rather useful for modernization not only of agriculture in Ukraine, as well as numerous spheres of modern life, linked with biological and medical knowledge exchange. Core centers in spheres of activities linked with biology (nature preservation, ecology protection, other ones like these) as well as agricultural industry – they all are located in rural regions of Ukraine. They can be characterized by the great squares of remote territories with the absence of all communications, including good modern types of communications. Taking into account these specific characteristics, our first works in these directions were done. So, this publication demonstrated the possibility of using the latest communication tools based on LTE and MIMO technologies in 3G and 4G networks to solve contemporary tasks for organizing of the works in spheres, linked with transmission of medical and/or biological information in Ukraine.

1) To achieve this goal, the authors first substantiated the importance of using the described communication technologies in the branches of Ukraine related to the medicine and biology.

2) A number of issues of technical implementation of communication means and technologies in such systems were considered above in detail in the following order. Determination of spatial parameters of the LTE standard network. Preparation of a map of the area. Choosing an LTE network planning option. Principles of building and functioning of LTE networks An example of the structure of LTE network for solving of appeared problems is shown in the Figs 1–3. P-GW (Packet Data Network Gateway) functions. MME (Mobility Management Entity) functions. Functions of PCRF – management server that provides centralized management of network resources, etc. were described. Features of using upper and lower frequencies for LTE were given and discussed briefly.

3) The applications of MIMO technology in LTE, as well as application of MIMO technology in 3G and 4G networks were suggested to use for organization of the works in rural regions of Ukraine, including medical and biological data transmission between research and monitoring rural centers.

4) We had proposed external antenna with high gain factor, which has to be installed at a height not less than 6 meters above the ground to reduce the influence of interference on the path of radio waves.

5) Results of presented work can be applied for the networked structures organization for domestic science use where the quick exchange of biological and medical information is necessary. In Ukraine there are the spheres like agriculture, nature protection measures providing, monitoring of population health in rural regions, and etc. need such communications.

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В. М. Шутко. Н. С. Фоменко, О. М. Ключко, О. О. Колганова. Новітні засоби зв'язку на основі технологій LTE та MIMO в 3G, 4G мережах: застосування в сучасній біомедичній практиці в сільській місцевості України

Мережева організація систем суб'єктів господарювання, які розподілені віддалено по великим територіям, вимагають створення якісного зв'язку для них. Метою роботи було продемонструвати можливість застосування новітніх засобів зв'язку на основі технологій LTE та MIMO в 3G та 4G мережах для вирішення сучасних завдань організації робіт, для яких потрібна медична, біологічна інформація у малоурбанізованих, віддалених регіонах України. У публікації наводяться авторські дані щодо практичної організації зв'язку в сільській місцевості та розглядаються такі питання. Визначення просторових параметрів мережі стандарту LTE. Підготовка карти місцевості. Вибір варіанту планування мережі LTE. Принципи побудови та роботи мереж LTE. Функції P-GW (Packet Data Network Gateway). Функції MME (Mobility Management Entity). Функції ПЦРФ. Функції MME (Mobility Management Entity). Функції ПЦРФ. Особливості використання верхніх і нижніх частот для LTE. Застосування технології MIMO в LTE. Застосування технології MIMO в мережах 3G і 4G. Результати

виконаних робіт можуть бути застосовані для розробки мережевих структур для використання в народному господарстві, сільському господарстві, для таких галузей науки, як біологія, охорона природи, а також для інформаційних систем для таких галузей. В результаті виконаної роботи запропоновано тип антени, інше обладнання; їх слід використовувати для посилення зв'язку 3G і 4G LTE в таких умовах, а також відповідну 4G-антену для модему або маршрутизатора. Отримані результати придатні для забезпечення роботи інформаційних систем у сільському господарстві, екологічному моніторингу, інших сферах діяльності, що базуються на біологічній та медичній інформації; вони всі потребують швидкого обміну даними – а отже, у т.ч. для наукових центрів, інших поселень, для яких такі комунікаційні можливості в першу чергу й розроблялися.
Ключові слова: аналіз і моделювання панельних антен та антен типу «хвилевий канал»; LTE-технологія; MIMO-технологія; хвильовий канал; 3G, 4G мережі.

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