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IMPLEMENTATION OF 3G, 4G MOBILE CONNECTIONS TECHNOLOGIES IN URBAN AND RURAL REGIONS

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Abstract**—***Currently in Ukraine, taking into account the development of the latest mobile Internet standards (3G/4G), it is possible to access the Internet even in remote places. There are no wired Internet due to the high cost of installation and maintenance. At the same time, a huge amount of equipment appeared on the market, which allows you to assemble systems for obtaining high-quality Internet over a wireless communication line. This refers to various types of antennas in the 900–2700MHz range, modems and routers with 3G/4G support. The locations of 3G/4G Internet base stations are in district centers predominantly. So, there is a situation that remote villages, settlements do not have the opportunity to get access to high-speed Internet. This especially harms the work of biological stations and rural medical clinics, which are spread over the territory of Ukraine and are often connected in a network. The purpose of the work is to describe briefly some practical results of our own development of providing high-quality mobile communication in some remote places of the territory of the state. To provide this service in remote areas of Ukraine, signal amplification is necessary. In addition, there is a problem with the propagation of radio waves over the rough terrains for the ultra short wave and microwave ranges. To solve this problem, it is proposed to use an external antenna with a high amplification factor, which will be installed at a height of at least 6 meters above the ground to reduce the impact of interference on the path of radio waves.*

Index Terms—Analysis and modeling of panel and wave channel antennas; MIMO; SISO; wave channel; TDD; UMTS; FDD; LTE.

I. INTRODUCTION

Fourth-generation 4G LTE communications has been operating in Ukraine for enough long time. During this time, operators have significantly expanded the coverage area of their LTE networks; they are available now not only to residents of large cities, but also to small settlements located in rural areas. Despite the fact that coverage is constantly expanding and improving, many users in both large cities and remote settlements have communication problems still and often they need to strengthen a weak signal and install an external antenna. This can happen due to the density of urban buildings, construction of the rooms in them, and the materials from which they are made (for cities, towns). Or, in other cases, significant distances of many settlements from the base stations (hereinafter - BS) of these communication operators, the presence of various obstacles in the form of dense high forests, terrain relief, etc. which interfere with the propagation of radio waves (in rural areas, in country houses, cottages, etc.). With the help of an additional external antenna, you can strengthen a weak signal several times and increase the speed of reception and transmission of mobile data. The author experience of implementation of 3G, 4G connections technologies at the territory of Ukraine is given briefly in the article.

The ***purpose of the work*** is to describe briefly some practical results of our own development of providing high-quality mobile communications in some remote locations at the territory of Ukraine.

II. PROBLEM STATEMENT

The antenna is actually the interface in which the conversion takes place – the conversion of high-frequency electromagnetic energy in the transmitter system into the electromagnetic wave, capable for propagating in space [1] – [4]. Or in the case of reception, it performs the reverse transformation - an electromagnetic wave into high-frequency

http://jrnl.nau.edu.ua/index.php/ESU, http://ecs.in.ua

oscillations. The completed set of works was carried out using the 3G/4G MIMO Yagi antenna with 20 dBi amplification and operating frequency range 1700–2170 MHz. For a system with such antenna, the following regularity was valid. We have registered that the lower the frequency, the longer the wavelength and the further it can spread from the source-antenna (from BS). Accordingly, with higher frequency the wavelength is shorter, consequently shorter the range of propagation of such waves; and the lower the ability of such a signal to overcome obstacles. For example, at the frequencies of 800 MHz and 900 MHz, the wavelength is approximately 33–34 cm, but at the frequency of 1800 MHz – about 16 cm. The maximum range of radio waves depends on the power of the transmitter, topography of the area, and presence or absence of various obstacles.

For example, at a frequency of 800 MHz the distance is 35–37 km from the base station, but at a frequency of 1800 MHz it is 10–12 km. At the frequency of 2600 MHz it is even less – about 7 km. The lower the frequency, the longer the wavelength, the easier the waves go around / overcome various obstacles; but the smaller the BS capacity and the lower the theoretical data transfer rate. Conversely, for the higher frequency the wavelength is shorter, the worse it overcomes the obstacles and the shorter the distance of radio waves propagation; but in this case the capacity of BS is greater, and the higher the theoretical transmission speed. Therefore, 4G LTE base stations at the frequency of 2600 MHz are installed mainly in the large cities in places with high concentration of active users. In such locations, it is theoretically possible to get a mobile Internet speed higher than in places where towers operate at a frequency of 1800 MHz. Base stations operating at frequency of 1800 MHz are installed in small towns, in rural areas, between cities, where the population concentration is lower (and, accordingly, less active users). They have less capacity and lower theoretical data transfer rate; but they cover more territory.

But what kind of antenna should be used to strengthen 3G and 4G LTE communication in certain conditions? How to choose the right 4G antenna for modem or router? At which distances from the BS one can fight for high quality signal and good data transfer speed? Which antenna is better for the city, which one for a house in the village, in the country, or at remote biostation or rural dispensary? We tried to answer these questions in our work below. These results can be seen from other point of view too – the results of such works are rather important for some works in science (biology) and practice (agriculture). In our previous works we had described the experience of networked organization structures implementation for nature protection measures and domestic agriculture [5], [6]. Numerous biological stations, united in networks, were organized in Ukraine at the second half of XX c. They operated perfectly well, providing economy by necessary biological information. Having great experience in the development of information systems for such networks of biostations [6] – [12], as well as in usage of modern mathematical methods for such structures organization and functioning [9] – [11], we see the necessity to provide them by good communication possibilities, especially telecommunication possibilities, as we mentioned about this earlier [12]. The subject of present publication – is the first attempt to provide our developed networked system by 3G, 4G mobile connections. The main attention is focused on the rural regions, and conditions of urban settlements are given in comparison. Below are the results we had obtained. In our results written below we would like to describe briefly some practical results of our own development of providing high-quality mobile communication in some places of the territory of Ukraine.

III. Problem Solution

Methods. In our work we used analytical approaches for equipment selection to provide high-quality mobile communications in urban and rural areas. Characteristics of 3G/4G MIMO antenna [1], [2] in the operating frequency range (1700–2170 MHz) were investigated and analyzed.

Grounding of applied methods. For making a base for the used methods, the set of the works has to be performed, they are described below [1] – [4]. Any slowing structures based on resonant elements (director elements) that form spreading wave (slowed relatively to the speed of propagation of the spherical wave front from the radiating element) have the following 2 properties in a wide frequency band [1] – [4]. These techniques were described too in [13] – [29]. Some data of these works are put in base of present work; brief basic data are in 1, 2.

1) At a certain wavelength, for this period of the structure, maximum deceleration occurs and maximum radiation directivity (amplification, aperture) is achieved. As the frequency increases above this maximum, the directivity decreases sharply. This happens when the effective length of the elements approach $\lambda/2$. So, the delay they introduce turns from leading to retardation and the spreading wave turns in the opposite direction (directors begin to behave like reflectors). Wave channel calculation is recommended to do in such a way – the maximum of antennas characteristics has to be close or slightly higher than the highest frequency of operating range (so that the cut-off does not begin within the calculated band).

2) Lower than the frequency of maximal amplification – the directivity decreases evenly together with frequency decreases far enough (by about an octave). But the directivity (amplification) decreases faster than the square of the frequency, in other words, the aperture (in m^2) decreases too. Wave channel of antenna do not have a uniform aperture; they are more effective at the top of the wave range and less effective at the bottom (for panel antennas the opposite is true usually – coefficient of antenna aperture usage (CAAU) is usually higher at lower frequencies than at higher ones).

To evaluate the directional properties (amplification, aperture) of wave channels of an unknown design, the first thing you need to do is to measure the frequency at which the designer chose the maximum of amplification and aperture and to see how this frequency correlates with the declared operating range. The R-net company chose the maximum directivity point at 2030 MHz (18.36 dBi). As a result, above this frequency the directivity begins to decrease sharply and to 2170 MHz it falls down to 13.63 dBi. Powerful (up to +7 dBi) side lobes begin to form in the front hemisphere (at angles of ± 28 degrees to the main direction). The maximum aperture is at the frequency of 2000 MHz and it reaches 1204 cm^2. Above this frequency, the aperture decreases sharply and at 2170 MHz it is only 368 cm^2 (i.e., if you place the antenna in an incident flow with the fixed density of W/m^2, then at 2170 MHz the antenna will receive only 30% of the power at 2000 MHz). The choice of such a low cut-off frequency is obviously due to the desire to sacrifice performance at 3G frequencies and add couple of dB at the 1710 MHz uplink frequency in the 1800 band. Results of the work done for such techniques implementations are on Figs 1–5.

The Yagi antenna used in 3G/4G MIMO with a gain of 20 dBi and an operating frequency range of 1700–2170 MHz is shown in Fig. 1.

The graph of the dependence of the amplification factor on the frequency is shown in Fig. 2. The gain factor of the used 3G/4G MIMO Yagi antenna is presented for the operating frequency range of 1700 – 2170 MHz.

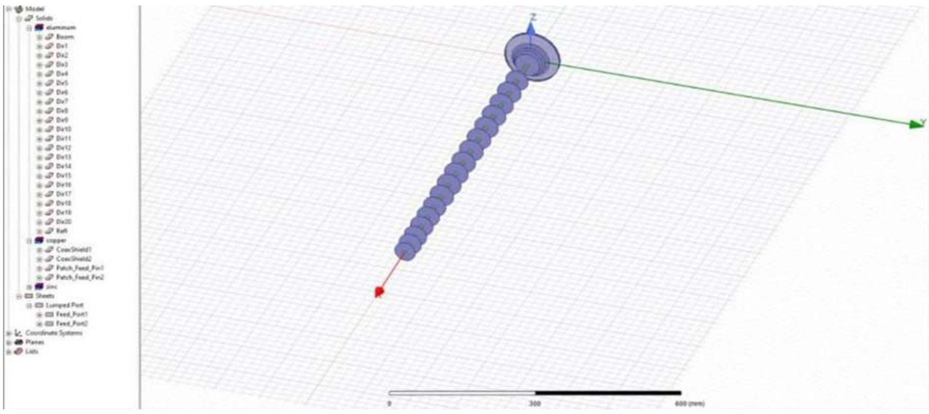

Fig. 1. Antenna design appearance

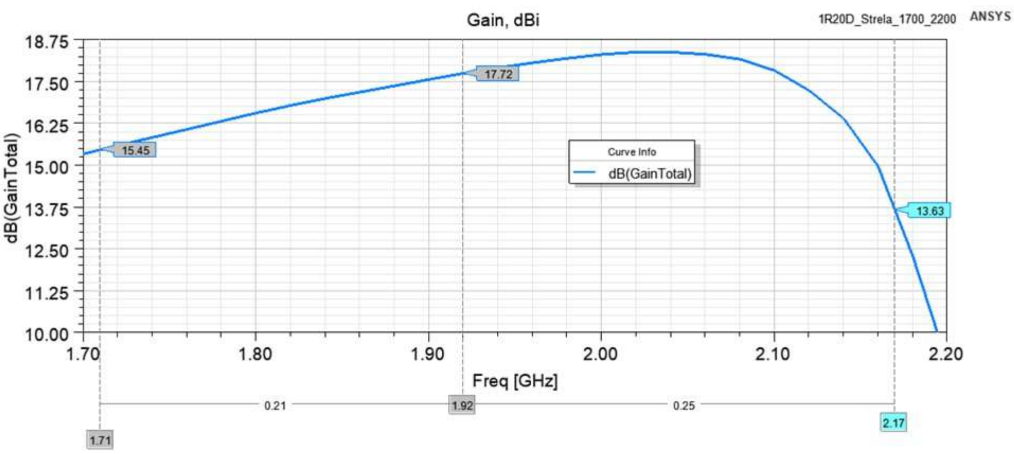

Fig. 2. Graph of the dependence of the gain coefficient on the frequency

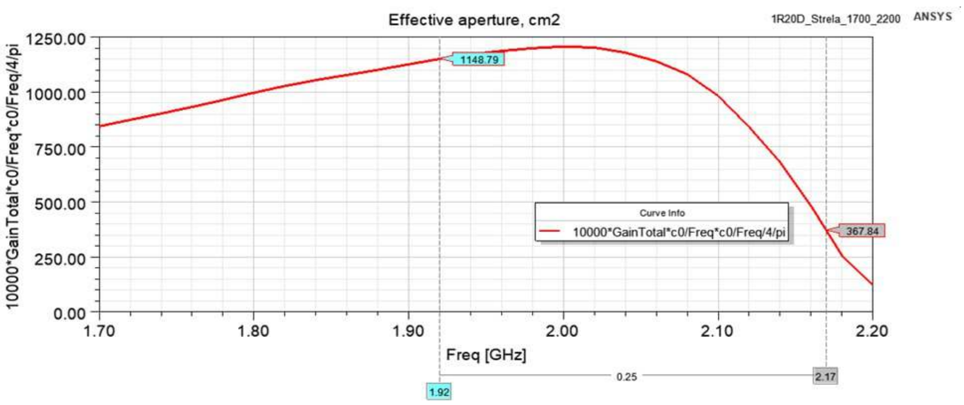

Fig. 3. Aperture of 3G/4G MIMO Yagi antenna with 20 dBi amplification and operating frequency range 1700–2170 MHz

Fig. 4. The graph of dependence frequency – VSWR (Voltage Standing Wave Ratio) (Port1)

Fig. 5. The graph of dependence frequency – VSWR (Voltage Standing Wave Ratio) (Port2)

Description of completed works and measurements. Antennas for 3G and 4G LTE networks have significant differences, caused primarily by the spread of radio waves in the specified communication standards. Thus, in the 3G UMTS standard, radio waves propagate in vertical polarization, and therefore antennas for such networks also have vertical polarization. In the 4G LTE standard, the transmitting base station relays waves in both vertical and horizontal polarization, and special antennas are used to receive the signal, which support MIMO technology (MIMO means Multiple Input Multiple Output) – method of spatial coding of the signal, which allows to increase the bandwidth transmission of a channel in which data transmission and data reception are carried out by multi-antenna systems.

MIMO antennas used for signal amplification in 4G LTE networks are, as a rule, panel antennas of various types and coefficients of amplification. They have two antennas in their design, one of which has vertical polarization, and the second one has horizontal polarization. Due to this, such antennas better amplify and stabilize the signal, thereby increasing the speed of data transmission. MIMO antennas have two outputs, to which you can connect two antenna connectors in a modem or router via a coaxial cable. For full operation in 4G LTE networks with an antenna, the modem or router subscriber device has to support MIMO technology and have to have two antenna connectors).

Also, for 4G networks, the ordinary antennas of the "Wave channel" type without MIMO support are used. Such antennas have fairly large amplification factors (up to 15–16 dB on average) and narrow directional patterns; they can register a signal at distances of up to 20 km (and in some cases even more) from the base station. But due to the fact that in directional antennas "Wave channel" does not support MIMO (and this is important for LTE networks), they amplify the signal well, but do not give a significant increase in the data transfer rate. In other words, if somebody installs directional antenna of the "Wave channel" type and connect it to the modem, then in some cases one can get the full scale of the signal level on the device, but the Internet speed will not be very high.

Recently, the use of MIMO antennas of the "Wave channel" type with the design of reflector and directors in the form of round disks ("Strila-5") or two SISO "Wave channel" antennas placed apart in space (mounted in the same direction in an orthogonal projection) has become widespread.

This allows combining the high coefficient of amplification and MIMO technology. Residents of rural areas can obtain particularly powerful effect of using such antennas. For example, in places where a ordinary SISO "Wave Channel" antenna does not connect to the base station, or the signal SINR is negative, using a "Wave Channel" MIMO antenna can achieve a signal SINR greater than 0 and average quality of data transmission. As example from our practice, in one of rural locations of Ukraine, at a distance of 30 km from the Lifecell base station in the 1800 LTE range, the reception speed was up to 8 mBt/s, and the SINR of the signal was about 2.

The greater the amplification of the antenna, the smaller the deviation angle from the base station. An antenna with a amplification of 9 dBi has a deflection angle of about 40 degrees, and antenna with a amplification of 20 dBi is already less than 20 degrees. So, for example, panel antennas with a amplification of 9 dBi work not only within the direct line of sight of the BS, but also catch the reflected signal well. Therefore, they can be used in conditions of urban development, when it is impossible to register direct signal from the transmitting tower. Such antenna will be able to pick up the reflected signal from buildings or other nearby objects.

IV. CONCLUSIONS

1) For providing of the settlements in rural territories of Ukraine by mobile connections the 3G/4G MIMO Yagi antenna with 20 dBi amplification and operating frequency range 1700–2170 MHz was suggested and used. Obtained results were given on Figs 1–5. It was proposed to use an external antenna with a high amplification factor, which will be installed at a height of at least 6 meters above the ground to reduce the impact of interference on the path of radio waves.

2) In urban conditions, where the concentration of operators' base stations is quite high and it is not always possible to register direct signal from the tower, panel MIMO antennas of small amplification (from 9 to 15 dBi) can be used to amplify the signal in the 4G LTE standard. Such antenna has to be installed outside the building and directed towards the BS or towards the object (building) from which the reflected signal will be registered.

3) In rural areas, in country houses, cottages, at remote biostations or rural dispensaries, industrial or warehouse buildings located outside the cities at long distances from transmission stations of cellular operators, antennas with a higher amplification should be used – from 15 to 24 dBi. Such antennas have narrower directional patterns, but allow to strengthen the signal and improve the speed of mobile Internet over long distances, especially the latest modifications of MIMO "Wave Channel" antennas. In addition, in rugged terrain and poor conditions of reception-transmission of signals, it is possible to get the Internet using a 900 MHz MIMO antenna as a last possibility in conditions, when the data transfer rate is low.

4) The results of the work done complete in significant degree our works for networked structures organization for domestic science (biology, nature protection measures), and agriculture; for information systems for them [5], [6]. The type of antenna was suggested that should be used to strengthen 3G and 4G LTE communication in such conditions, as well as suitable 4G antenna for modem or router. These findings are perfect for providing of information systems in biology, agriculture by necessary information along with good communication possibilities for their functioning.

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В. М. Шутко. Н. С. Фоменко, О. М. Ключко. Впровадження технологій 3G, 4G мобільного зв'язку в міських та сільських регіонах
В даний час в Україні з урахуванням розвитку новітніх стандартів мобільного зв'язку Інтернету (3G/4G) з'явилася можливість отримувати доступ до Інтернету навіть у віддалених місцях, де провідний Інтернет відсутній через високу вартість прокладки та обслуговування. У той же час на ринку з'явилася величезна кількість апаратури, яке дозволяє збирати системи для отримання якісного Інтернету за бездротовою лінією зв'язку. Мається на увазі різні види антен діапазонів 900–2700МГц, модемів і роутерів з підтримкою 3G/4G. З урахуванням, як правило, розташування базових станцій 3G/4G Інтернету в районних центрах ми маємо ситуацію, що віддалені села, поселення не мають можливості отримати доступ до швидкісного Інтернету. Особливо це шкодить роботі біологічних станцій та сільських медичних амбулаторій, які розповсюджені по території України та часто поєднані у мережі. Метою роботи було – описати коротко деякі практичні результати власних робіт із забезпечення якісного мобільного зв'язку в окремих віддалених локаціях території України. Для забезпечення цієї послуги у віддалених місцях країни необхідно підсилення сигналу. Крім того існує проблема на розповсюдження радіохвиль пересіченою місцевістю для ультракоротких і надвисоко-частотних діапазонів. Для вирішення цієї проблеми пропонується використання зовнішньої антени з високим коефіцієнтом підсилення, яка буде встановлена на висоті не нижче 6 метрів над землею для зменшення впливу перешкод на шляху поширення радіохвиль.
Ключові слова: аналіз і моделювання панельних антен та антен типу «хвилевий канал»; MIMO; SISO; хвильовий канал; TDD; UMTS; FDD; LTE.

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