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Designing and Calculating Bandwidth of the LTE Network for Rural Areas

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***Abstract*— The standard of broadband mobile communication LTE can be used to build a mobile communication network in remote populations and provide the population with modern mobile communication services, such as video calls, data transmission, high-speed mobile Internet, Internet TV, etc. In this work, a LTE network has been designed, and the network capacity has been calculated for a certain area. Muynak of the Republic of Karakalpakstan, located in the northwest of the Republic of Uzbekistan, was taken as the territory. The paper presents the characteristics of the selected equipment required for the construction of the mobile network, calculations of network bandwidth, number of potential and active network subscribers, the number of base stations, the average bandwidth of the projected network, the average traffic per subscriber in the busy hour, the radio frequency plan, the geographical location of the base stations, and the LTE network design scheme has been developed. In addition, the characteristics of the number of potential subscribers are described in tabular form, as well as graphs of the number of base stations, the average bandwidth of the designed network, the total traffic of the designed network depending on the number of potential subscribers. The LTE network frequency plan has been developed for the city of Muynak. The designed network will increase the number of subscribers to 12,000 without reducing bandwidth.**

***Keywords*—Base station; bandwidth; equipment; LTE; mobile communication; network.**

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I. INTRODUCTION

In recent years, mobile broadband has become more common. They are directly related to the provision of operator services to subscribers. Therefore they quickly pay off even in an unfavorable economic situation. Technologies are constantly being improved here to meet new user needs. New technical solutions appear that are characteristic only of these networks. The emergence of new software and services has contributed to the advancement in information and communication technology (ICTs), particularly the rapid mobile technologies developments [1]. Currently, there is a growing trend in mobile services. At the same time, mobile operators are experiencing the need to develop their networks towards increasing channel capacity, data transmission speed, reducing transmission time delays, and improving the quality of service in general. New services, such as mobile television, online games, etc. appear and are increasingly being introduced. These facts raise the question of the further technological development path for mobile operators and providers since the usual solutions do not fully satisfy the organization of services in full. Of all the technologies available for building mobile networks, the most common is Long-Term Evolution (LTE) technology [2].

LTE is a wireless high-speed data transmission standard for mobile phones and other data terminals. [3]. It is based on network technology such as GSM/EDGE and UMTS/HSPA, increasing bandwidth and speed by using a separate radio interface along with strengthening the core of the network. The standard was set by 3GPP (a consortium that develops specifications for mobile telephony) and is defined in a series of Release 8 documents, with minor enhancements described in Release 9 [2].

The LTE network architecture as seen in Figure 1: The E-UTRAN (Evolved Universal Terrestrial Radio Access Network) control network and the central network of SAE (System Architecture Evolution). The LTE network consists of two main components: The Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) and the System Architecture Evolution (SAE) core network [4].

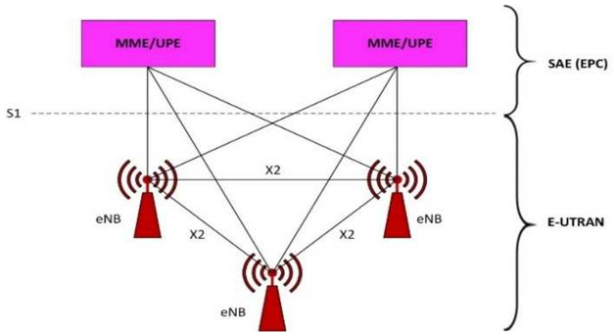

Fig. 1 LTE network architecture: E-UTRAN access network and SAE core network

The technical characteristics of the E-UTRAN radio network are only compatible with eNBs (evolved Node B), this includes the air interface between the terminations of the control plane protocol and the user plane against the user equipment (UE) [5]. The eNBs are elements of the complete E-UTRAN and are interconnected using the X2 interface on a "one to one" basis. The X2 interface in E-UTRAN is responsible for sharing messages between handover process nodes [6]. The X2 interface supports handover in the mobile terminal in LTE_ACTIVE. Each base station has an S1 interface built on the principle of packet switching with the SAE core network. Radio resource control and routing of user plane data to SAE Gateway are the eNB's key functions [7].

The SAE core network, sometimes called the Evolved Packet Core (EPC) network, is composed of MME / UPE nodes composed of MME and UPE gates. The logical element Mobility Management Entity (MME) is responsible for solving the mobility problems of the client terminal, and the E-UTRAN network works with the eNB base stations using the C-plane control plane protocol (S1 C interface). The User Plane Entity (UPE) responds to the U-plane protocol mapping data and works with the eNB through the S1-U interface [8], [9].

The base stations are connected to multiple MME/UPE nodes that allow the sharing of network resources using the S1 interface. This interface is called S1-flex. As a result of the deployment of the LTE network, the possibility of providing a wide range of low-cost services increases, and the cost of data transmission is reduced. Therefore, from these points of view, the design and calculation of the coverage area of the LTE network for a certain territory are relevant. This research aims to solve the problem of providing mobile broadband access services to rural residents based on the LTE network. Development is based on real data.

The tasks of the project development are:

- the choice of a specific territory located in the countryside,
- the choice of equipment and the necessary tools to create an LTE network,
- performing the necessary calculations (calculating the throughput and the number of potential LTE network subscribers, etc.),
- designing an LTE network for rural areas.

We also reviewed some research studies by several scholars on designing the LTE network.

In 2010, Lima *et al*. [10] reviewed Scheduling for Increased System Capacity in Multiservice 3GPP LTE. In this paper, the authors had studied the effect of scheduling algorithms on the delivery of multiple services in the LTE framework. In 2011, You and Lu [11] reviewed the New Dual-Band Planar Dipole Array Configuration for 4G LTE/WiMAX Access Points. This work suggests a new 1x4 dipole array with dual-band service for LTE/WiMAX access points. In 2013, Mun *et al*. [12] reviewed Present MIMO Handset Antenna Setup for LTE 700 Band Applications. This paper suggests a lightweight MIMO antenna for LTE 700 band (746~787 MHz) implementations.

In 2014, Hong *et al*. [13] Planned a multiband antenna to operate the LTE/GSM/UMTS band. This paper suggested a multiband antenna to apply the LTE/GSM/UMTS band. The planned antenna consists of a meandered flat Inverted-F antenna with an extra branch line for broad bandwidth and a folded-loop antenna. Lai and Jiang [14] reviewed Assets pricing in LTE networks by multi-objective optimization. LTE technology provides flexible mobile networks that use a range of tools. This allows providers to offer a differentiated level of operation to customers or consumers in order to maximize their satisfaction. Wong *et al.* [15] Optimized and designed MIMO Antenna of LTE 1800. This work proposes a MIMO antenna consisting of a printed microstrip patch antenna and a printed double-l sleeve monopoly antenna for mobile LTE 1800 applications.

In 2016, Perez *et al.* [16] analyzed Characterizing radio and networking capacity in LTE networks. According to this work, power usage is a crucial factor in how end consumers rate the level of service on mobile networks; however, its characterization is a difficult problem owing to the multiple criteria involved and the sophistication of their dependencies. In 2018, Rahmatia *et al.* [17] reviewed LTE Network Architecture Frequency Division Duplex of 1800 MHz Based on Subscriber Growth Prediction in 2025 at Denpasar, Indonesia. According to this work, due to the constraints of the network development operated by the operator, optimal planning must be carried out before adopting LTE network technologies. The planning carried out involves coverage planning by selecting the right method, frequency, and bandwidth. In 2019, Choi and Noh [18] reviewed Propagation Paradigm in Indoor and Outdoor for LTE Networks.

II. Materials and Method

It is necessary to build an LTE network in Muinak of the Republic of Karakalpakstan. Figure 2 depicts the location of the city of Muynak [19]. Muynak is the administrative center of the Muynak region. Muynak district is located in the north of the Republic of Karakalpakstan and was created on

September 1, 1931. Figure 2 shows the territory of the city of Muynak [19]. The region borders the Kungrad, Chimbay, Takhtakupyr, Kegeilin regions of Karakalpakstan, Kyzylarda, and Mangistau regions of Kazakhstan. Muynak has received city status since 1963. The total area is 37.5 thousand sq. m. As of 2018, 13,500 people live in the city [19].

Fig. 2 The location of Muynak City

Fig. 3 The territory of Muynak City

The equipment of the transport network should be selected primarily considering the specifications of the LTE technology, that is, taking into account the efficiency, flexibility, and compactness of vehicles with a wide range of functions and prices. The main reason for choosing the transport network equipment is the reliable transmission of user data of the LTE network [20], [21]. The equipment of the transport network for data transmission using LTE technology is divided into:

- transport facilities of intelligent aggregates,
- a radio communication network of transport equipment.

As a transport device for the radio access network, we choose the Cisco ME 3600X-24CX switch, shown in Figure 4. This switch features hardware acceleration, good performance, and low latency [22].

Fig. 4 External view of the switch "Cisco ME 3600X-24CX" [23]

We choose the Cisco 7603 OSR (Optical Service Router) for intelligent transport aggregation, which is shown in Figure 5.

Fig. 5 Exterior view of the Cisco 7603 OSR router [23]

Optical router Cisco 7603 OSR is designed for building geographically distributed (WAN) and metropolitan (MAN) networks [24], [25]. The main task of this router is to provide the operation of critical IP applications at the speeds of optical communication channels [26].

A. The choice of LTE network management equipment

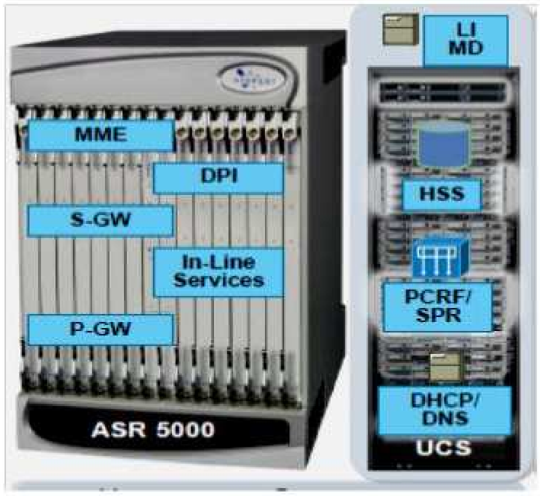

Fig. 6 Exterior view of the Cisco 7603 OSR router [23]

The regulation of subscriber sessions and services in LTE networks is carried out with the support of the core packet network EPC (Evolved Packet Core) [27], [28]. The Cisco ASR 5000 Router Type is designed specifically for broadband networks. This router is distinguished by integrated intelligent functions, durability, distributed architecture, and scalability [29], [30]. With a distributed architecture, all tasks and services can be distributed across the platform. This unique approach enables the deployment of more efficient mobile networks that can support more concurrent calls, optimize resource utilization, and provide enhanced services and easy scalability [31].

In Figure 6, Cisco Systems' solution for integrating EPC network functions is based on a single platform CiscoASR 5000 PCS3. The foundation of the implementation idea was the combination of the Mobility Management Entity (MME), Serving Gateway (SGW), and Public Data Network Gateway (PGW) functions in one chassis of the Cisco ASR 5000 PCS3 multiservice platform [32], [33].

B. The choice of LTE network base station equipment

Before choosing an eNB LTE base station, you need to consider whether other equipment supports other mobile communication standards [34], [35]. We also need to remember the planned output power of the TRX transceiver and other technical properties [36]. It is supposed to use the Flexi Multiradio base station as radio access equipment. The multi-standard base station Flexi Multiradio offers original abilities according to the construction of sites [37], [38]. Low power consumption is ensured when using this base station, compliance with capacity conditions with regularly increasing mobile traffic, and high spectral efficiency [39]. Figure 7 shows the base station Flexi Multiradio, consisting of two main components: a radio module with three transceivers and a system module for digital signal processing.

Fig. 7 Base station Flexi Multiradio from Nokia Siemens Networks [26]

In mobile networks, the radio module assumes an element of the base station, which guarantees the increase of any individual radio signal before it is transmitted from the antenna. Due to the higher output power, this module improves the property of the signal used to transmit voice or data to users of mobile telephones. This factor directly influences how much useful information a signal can carry or how many connections established by subscribers can be served by a base station [40]. The module's full name is "Flexi RF Module Triple 90 W". The radio module is responsible for processing radio frequency signals. We can use the Flexi Multiradio multifunctional radio module for any type of installation, in particular for indoor and outdoor installation, for distribution installation, and for mounting on mast supports [41], [42], [43]. Figure 8 depicts the "Flexi RF Module Triple 90W" RF module. The output power of the radio module for 1 sector is capable of reaching 240 watts. Likewise, the radio module can guarantee an 80 W output signal to any of the 3 sectors.

Fig. 8 RF module "Flexi RF Module Triple 90W" [23]

The radio module supports any combination of technologies: GSM, 3G, LTE, and LTE +. The device is capable of distributing carriers in the 60 MHz bands.

III. Result and Discussion

C. Network Bandwidth Calculation

There are several differences between designing an LTE radio network and designing other radio access technologies. The main difference is using a new type of multiple access based on OFDM technology. As a result, new concepts appear, and design methods change [44], [45]. The LTE radio network project is being developed for rural areas, which means that subscriber density is low, and base stations need to be installed as far apart as possible. Moreover, each eNB can cover the maximum possible area. Depending on this, the appropriate radio frequency spectrum must be selected [46], [47]. In this case, the lower the frequency, the farther the radio signal passes. The 791-862 MHz radio frequency spectrum fully complies with this requirement. We call the frequency of the duplex type – FDD [48], [49].

Bandwidth or network capacity is estimated based on average cell spectral efficiency for a specific situation. Spectral efficiency determines the data rate in a given frequency range. It is also a sign of efficient use of frequency resources. In mobile communication systems, spectral efficiency requires a coefficient (bit/s/Hz) calculated as the ratio of the data rate to the frequency band used at 1 Hz [50]. For FDD duplex frequencies based on 3GPP version 9, the bandwidth is 20 MHz for various MIMO configurations. The average spectral efficiency for an LTE network is shown in Table 1.

TABLE I
AVERAGE SPECTRAL EFFICIENCY FOR LTE NETWORK

Line Average	MIMO Diagram	Spectral Efficiency (bit/s/Hz)
UL	1X2	1.252
	2X2	1.829
DL	2X2	2.93
	4X2	3.43
	4X4	4.48

For FDD systems, the average throughput of one sector of the base station can be obtained by directly multiplying the channel width by the spectral efficiency of the channel [50]:

$$R = S \cdot W, \quad (1)$$

where: S – average spectral efficiency (bit/s/Hz); W – channel width (MHz). W = 10 MHz.

For DL line:

$$R_{DL} = 4{,}48 \cdot 10 = 44{,}8\ Mbps$$

For UL line:

$$R_{UL} = 1{,}829 \cdot 10 = 18{,}29\ Mbps.$$

To calculate the bandwidth of the base station ReNB, we need to multiply the number of base station sectors by the bandwidth of one sector. In one base station eNB, there are three sectors from which we can write the following formula [50]:

$$R_{eNB} = R_{DL/UL} \cdot 3 \quad (2)$$

For DL line:

$$R_{eNB.DL} = 44{,}8 \cdot 3 = 134{,}4\ Mbps.$$

For UL line:

$$R_{eNB.UL} = 18{,}29 \cdot 3 = 54{,}87\ Mbps.$$

The next task is to calculate the number of cells for the designed LTE network. This requires calculating the total number of channels allocated for the construction of the projected LTE network. The total number of channels N_{ch} is calculated by the following formula [50]:

$$N_k = \left[\frac{\Delta f}{\Delta f_k}\right] \quad (3)$$

here: Δf – the frequency band allocated for network operation is 71 MHz; Δf_{ch} – frequency band of one radio channel.

In LTE networks, the radio channel is a resource block with a bandwidth of 180 kHz. That is, Δf_{ch} = 180kHz.

$$N_{ch} = \left[\frac{71000}{180}\right] = 395 \text{ channels.}$$

Then we set the number of channels $N_{ch.sec}$ needed to serve subscribers in one sector of the cell:

$$N_{ch.sec} = \left[\frac{N_{ch}}{N_{cl} \cdot M_{sec}}\right] \quad (4)$$

here: N_{ch} – total number of channels; N_{cl} – cluster size; M_{sec} - the number of eNB sectors is 3 channels.

We calculate the number of $N_{tch.sec}$ traffic channels in one sector of one cell. It is calculated using the following formula:

$$N_{ch.sec} = \left[\frac{395}{3 \cdot 3}\right] = 43 \text{ channels.}$$

here: N_{tch1} - the number of traffic channels per radio channel, set in accordance with the radio access standard (for OFDMA N_{tch1} = 1 ... 3); for the LTE network, we take N_{tch1} = 1.

$$N_{tch.sec} = N_{tch1} \cdot N_{ch.sec} \quad (5)$$

In accordance with the Erlang model, we set the rated load A_{sec} for one cell sector. As calculated above, the blocking probability is 1%, and Ntch.sec is 43. Hence, A_{sec} = 50 Erl.

D. Calculation of the Number of Potential Network Subscribers

The number of subscribers served from one base station is calculated using the following formula [50]:

$$N_{sub.eNB} = M_{sec}\left[\frac{A_{sec}}{A_1}\right], \quad (6)$$

here: A_1 - average subscriber traffic load from one subscriber; the value can be 0.04...0.2 Erl. Since the planned network is planned to be used for high-speed data exchange, we assume that the value A_1 is 0.1 Erl; M_{sec} - the number of sectors of one base station; A_{sec} - rated load of one sector of the cell.

So:

$$N_{sub.eNB} = 3 \cdot \left[\frac{50}{0{,}1}\right] \approx 1500 \text{ subscribers.}$$

The number of eNB base stations in the designed LTE network is calculated using the following formula:

$$N_{eNB} = \left[\frac{N_{sub}}{N_{sub.eNB}}\right] + 1, \quad (7)$$

here: N_{sub} - the number of potential subscribers. We define the number of potential subscribers as 30% of the total population. The total population of the city of Muynak is 13.5 thousand people [19]. Thus, the number of potential subscribers is 4050 people, including:

$$N_{eNB} = \left[\frac{4050}{1500}\right] + 1 = 4\ eNB$$

The average bandwidth of the designed network R_N is calculated by multiplying the number of base stations eNB by the average bandwidth. This can be written as a formula [50]:

$$R_N = (R_{eNB.DL} + R_{eNB.UL}) \cdot N_{eNB} \quad (8)$$

$$R_N = (134{,}4 + 54{,}87) \cdot 4 \approx 757{,}08\ Mbps.$$

Then we compare the calculated value and give a control estimate for the capacity of the designed network. Moreover, we find the average traffic per subscriber per hour of maximum load (HML):

$$R_{T.HML} = \frac{2 \cdot T_t}{N_{HML} \cdot N_d} \quad (9)$$

here: Tt - average monthly traffic per subscriber, T_t = 15 GB per month; N_{HML} - the number of HML per day, N_{HML} = 7; N_d - the number of days in the month, N_d = 30.

$$R_{T.HML} = \frac{2 \cdot 15}{7 \cdot 30} = 0{,}143\ Mbps.$$

We determine the total traffic of the designed network in HML $R_{tot/HML}$ according to the following formula:

$$R_{tot/HML} = R_{T.HML} \cdot N_{act.sub.} \quad (10)$$

here: $N_{act.sub}$ is the number of active subscribers in the network; We define the number of active subscribers in the network as 80% of the total number of potential subscribers N_{sub}, that is, $N_{act.sub}$ = 3240 subscribers.

$$R_{tot/HML} = 0.143 \cdot 3240 = 463{,}32\ Mbps.$$

TABLE II
CHARACTERISTICS DEPENDING ON THE NUMBER OF POTENTIAL SUBSCRIBERS

Number of potential subscribers	Number of base stations	R_N, Mbps	$R_{tot/HML}$, Mbps
4050	4	757,08	463,32
6000	5	946,35	686,40
7500	6	1135,62	858,00
9000	7	1324,89	1029,60
10500	8	1514,16	1201,20
12000	9	1703,43	1372,80

Based on the above calculations, we can determine the number of base stations with an increase in the number of potential subscribers and the values of R_N and $R_{tot/HML}$. The characteristics depending on the number of potential subscribers are given in Table 2 and Figure 9, Figure 10, and Figure 11:

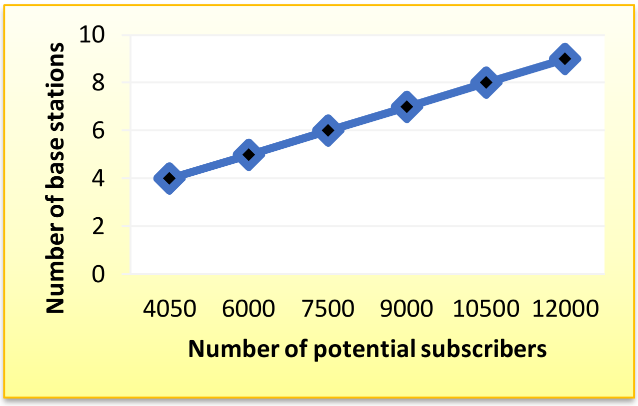

Fig. 9 The graph of the dependence of the number of base stations on the number of potential subscribers.

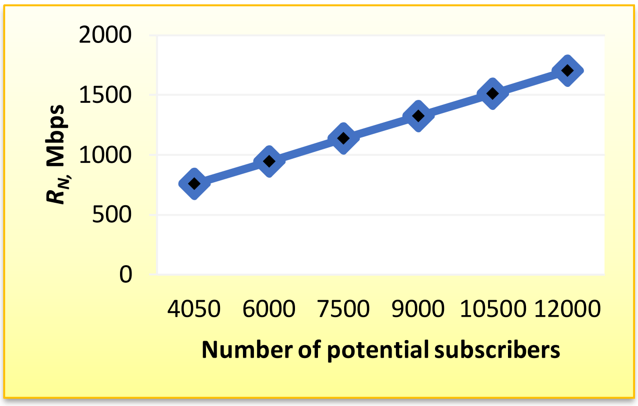

Fig. 10 The graph of the dependence of R_N on the number of potential subscribers

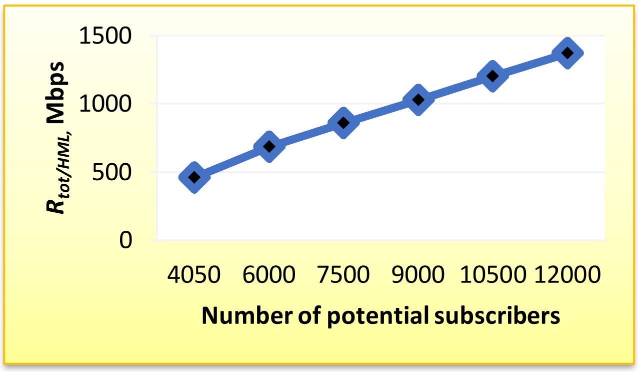

Fig. 11 The graph of the dependence of $R_{tot/HML}$ on the number of potential subscribers

Thus, $R_N > R_{tot/HML}$, this shows that the network we are designing will not be overloaded in HML.

E. Radiofrequency Plan

The frequency band 791-862 MHz is assigned to the designed network, the width of the frequency spectrum is 71 MHz. The eNB bandwidth should be up to 20 MHz per sector. Then the available spectral frequency band is divided into 3 bands from 20 MHz plus the protective frequency band (for separation of different sectors and re-coating with a signal). Table 3 shows the results of constructing the frequency obtained by assigning conditional numbers to each of the three parts of the sector.

TABLE III
LTE NETWORK FREQUENCY PLANNING FOR MUYNAK

Number of eNB	Sector	Azimuth	The radius of the coverage area, km	Conditional part number of the frequency spectrum
1	1.1	0	9	1
	1.2	120	9	2
	1.3	240	9	3
2	2.1	0	9	1
	2.2	120	9	2
	2.3	240	9	3
3	3.1	0	9	1
	3.2	120	9	2
	3.3	240	9	3
4	4.1	0	9	1
	4.2	120	9	2
	4.3	240	9	3

After launching the designed LTE network, it is necessary to go through the stage of network optimization, where it is necessary to adjust the initial planning, that is: if necessary, increase the network bandwidth, change the height of the radio modules, reduce or increase the radiation power. We have provided an LTE network organization table showing the base stations on the maps to provide more detailed information about our network, refer to Figure 12.

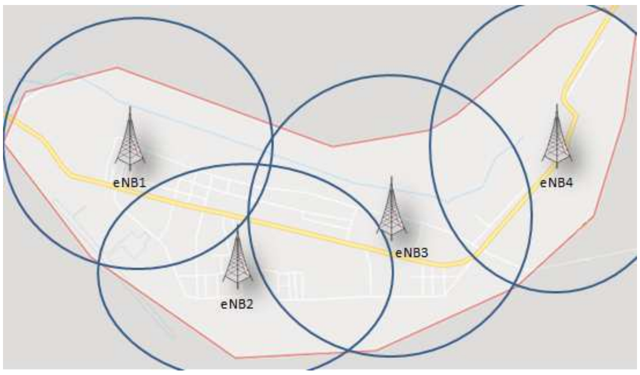

Fig. 12 The scheme of the LTE network in Muynak (with the geographical location of base stations)

F. Development of LTE network design scheme

According to the calculated network bandwidth, to provide a radio coverage area in Muynak, 4 base stations will be required to create a broadband connection using LTE technology. At the optimization stage, the capabilities of base stations can be expanded by deploying additional Flaxi Multi radio modules from Nokia Siemens Network. The design scheme of the LTE network in the city of Muynak is shown in Figure 13.

Each base station provides transmission to the Cisco ME 3600X24CX switching station using a fiber optic transmission line in accordance with the Gigabit Ethernet 1000 BASE-LX standard. The Cisco ME 3600X24CX station is located inside the room to house base station equipment. Through Cisco ME 3600X24CX switches, network traffic is routed to the Cisco 7603 OSR Router.

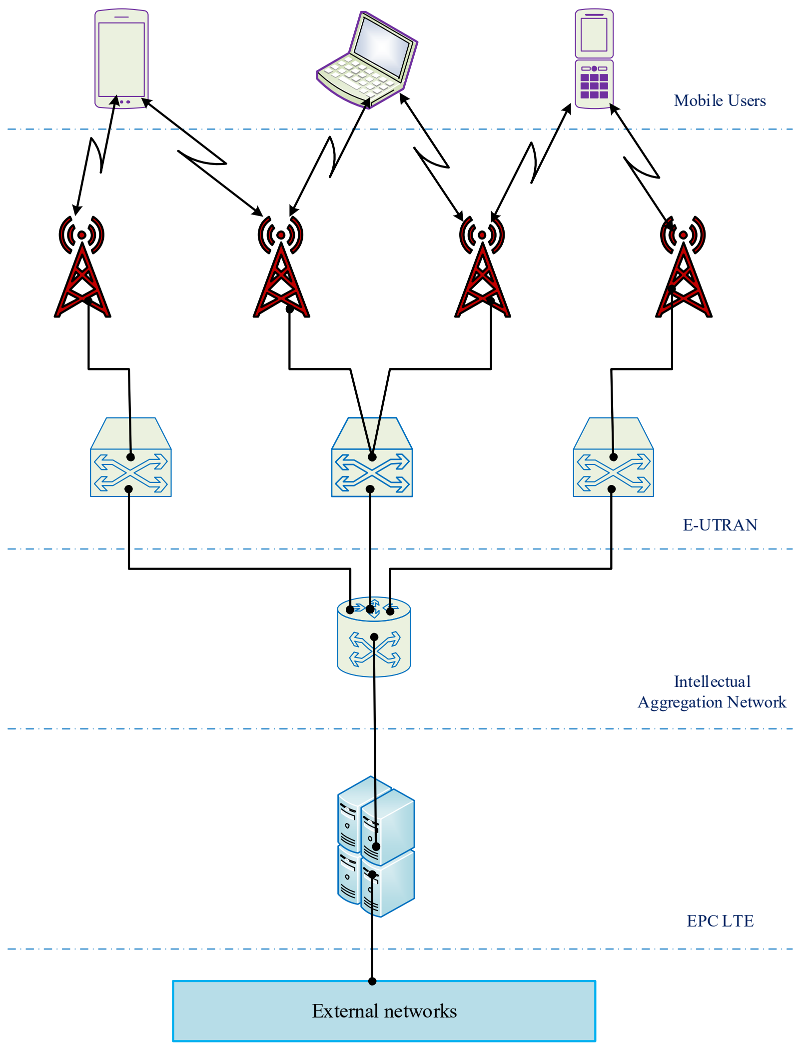

Fig. 13 The scheme of the LTE network in Muynak (with the geographical location of base stations)

The communication between the Cisco ME 3600X24CX and the Cisco 7603 OSR is based on fiber optic transmission lines based on the Gigabit Ethernet 1000 BASE-LX standard. Network traffic will then be forwarded to the LTE network supported by the Cisco ASR 5000 PCS3 Multi-Service Platform. Integration between the Cisco 7603 OSR Router and the Cisco ASR 5000 PCS3 platform is supported by 10 Gigabit Ethernet 10 BASE-ER fiber optic link. The EPC (Evolved Packet Core) LTE line manages the network, forms connection sessions, manages applications, bills, and connects to external networks: Internet, 2G, IMT, not 3GPP, ISDN, 3G, and some interfaces and switches.

IV. Conclusion

Today, in many countries around the world, the mobile Internet is becoming more and more popular in line with global trends and in some cases is replacing the global Internet connection over a wire. The emergence of new technologies, such as the introduction of LTE technology, the widespread use of mobile phones, which include standards and technologies that provide access to the global network, contributes to the development of the Internet, and today such services are provided by mobile operators. The constant growth in the number of mobile Internet users makes ever higher demands on the quality and speed of data transmission to mobile operators' networks. Thus, using the fourth-generation network, mobile operators provide high-speed Internet access, multimedia services, video communication, mobile television, etc. As a result of the globalization of the mobile Internet and the emergence of new cellular technologies, mobile operators are improving Internet access and data transmission services. Subscribers have access to a variety of web resources no matter where and when they are. This is a great contribution to the development of the Internet in regions and rural areas. At the moment, improvements to the LTE system will be introduced in the following directions: improving the functionality of the radio interface; introduction of new types of services; development of long-term plans for the development of the communication network; expansion of the coverage area by radio signals and smoothing of "dead, shadow" zones in them; use of several paths of radio signal propagation to combat fading; an increase in the capacity of communication channels due to the development of new methods of generating and processing signals (spatial diversity of signals, code diversity using orthogonal codes, frequencies, polarization diversity, etc.); the use of MIMO technology to increase the quality of transmission and reception of signals (OFDM signals), emission and reception of signals using several polarized antennas.

In this work, the LTE equipment used on the projected territory is selected and described, the necessary calculations are made, and a scheme for designing an LTE network for Muynak is developed. For the integration of EPC network functions, the CiscoASR 5000 PCS3 platform was chosen, the Cisco 7603 OSR router was chosen for intelligent transport aggregation, the Cisco ME 3600X-24CX switch was selected for the transport device in the amount of 3 pieces and 4 Flexi Multiradio base station was chosen as radio access equipment. The radius of the base station service area is 9 km. The designed network can serve up to 4050 subscribers and can be expanded to 12000 subscribers. The results of the work can be used in the design and operation of LTE networks and further used as an example of the design of mobile communication networks.

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