Розглянуто питання організації опорної мережі backhaul з використанням технології LTE. Проаналізовано транспортні backhaul з'єднання для різних сегментів мережі. Запропоновано модель backhaul мережі з використанням технології багатопротокольної комутації за допомогою міток для формування транспортної основи існуючих мереж. Проведено оцінку пропускної здатності і транспортної продуктивності мережі

Ключові слова: опорна мережа, безпровідна технологія, контролер, топологія, пакетна архітектура, пропускна здатність

Рассмотрены вопросы организации опорной сети backhaul с использованием технологии LTE. Проанализированы транспортные backhaul соединения для различных сегментов сети. Предложена модель backhaul сети с использованием технологии многопротокольной коммутации по меткам для формирования транспортной основы существующих сетей. Проведена оценка пропускной способности и транспортной производительности сети

Ключевые слова: опорная сеть, беспроводная технология, контроллер, топология, пакетная архитектура, пропускная способность

UDC 621.38.001:006.354
DOI: 10.15587/1729-4061.2017.96040

DEVELOPMENT OF THE MODEL FOR A BACKHAUL NETWORK BASED ON THE LONG TERM EVOLUTION TECHNOLOGY

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1. Introduction

Further development of telecommunication sector requires new principles for the construction of systems and new technologies for the transmission of data. This is caused by increased requirements to the high-speed data transmission networks due to the rapid implementation of broadband wireless services and fast growth in the number of mobile users.

Big opportunities appear when applying the technologies of wireless access that use an infrastructure of the packet data transfer such as WiMAX and LTE. They are based on the Internet protocol (IP) as a unified protocol for the distribution of services, and on Ethernet as a universal transport level.

The LTE technology is the most promising technology for the broadband mobile communication from the point of view of productivity. For the operators of mobile communication, an increase in the productivity offers a possibility to enhance the network capacity and throughput in conjunction with the high speed of traffic transmission and less delays in data transmission.

This allows the rapidly developing wireless means of telecommunication to support multimedia applications and to provide for the maximum expansion of employing the IP protocol in the network.

A transition to the IP-platform makes it possible for the communication operator to increase the throughput without any problems and to offer new services.

At the same time, due to scalability and flexibility of the network, mobile communication operators encounter economic problems since their backbone networks experience difficulties, related to the reduction in expenditures. That is why at present many communication operators transfer their backhaul networks to IP, based on supporting 3G-traffic, as well as the provision of quality and duration of connection to the Internet or a 4G-network.

A backhaul network plays an important role in the provision of mobile services and it relates to that part of the hierarchical network, which is a connecting link between the Internet and any core network. A backhaul takes over main load in the organization of communication between the elements of mobile access network and the backbone network of operator. This means that its role is to transport data from the mobile subscriber to the commutation capacity of the mobile communication operator and, through it, to other operators. In other words, a backhaul is the binding component between the backbone network and PSTN (Public Switched Telephone Network) or the data transmission networks.

The concept of mobile networks with a simplified architecture is preferable at the present stage of telecommunication market development. Such a concept of the network should possess technical and economic effectiveness, increased connectedness, flexibility, and simplicity to roll out and operate. The organization of network for the traffic aggregation and provision of interaction at the backhaul level is the main task when constructing the new generation of telecommunication networks. The essence of present study is to organize a backhaul network to support the entire spectrum of technologies and services with the use of the LTE technology. This defines the relevance of present article.

2. Literature review and problem statement

Under conditions of offering new high-speed user services, mobile operators encounter technical and economic difficulties. It is necessary to improve the throughput of transportation network, especially at the level of a backhaul network. At the same time, mobile communication operators have to decrease expenditures for the creation and operation of a backhaul network, which is linked to the competitive situation in the telecommunications market.

Article [1] analyzed the standards of mobile communication Wi-Fi IEEE 802.11n and cable networks DOCSIS 3.0, which are proposed to employ not only in the access networks but also in the backhaul networks. By using this approach, it is possible to obtain sufficiently high throughput in the direct and reverse channels, which will improve the backhaul network efficiency. However, such a network is capable of successfully serving the areas with a relatively low population density and a small radius of action only.

In order to organize transportation backhaul connections and implementation of highly reliable communication, it is proposed to use optical systems FSO (Free Space Optical), based on the cellular architecture. Paper [2] notes that this architecture possesses high ratio between price/productivity and it is fault-tolerant. The advantage of these systems is in the fact that their use does not require obtaining a permission to utilize the frequencies, which would substantially lower the expenditures of communication operators.

However, from the other hand, the cost of equipment for such systems will be quite expensive.

In paper [3], it is argued that at present the backhaul of 2G and 3G transport networks, based on time-division multiplexing (TDM) such as SONET/SDH, is actively used. This is caused by stability, predictability and reliability. The high reliability of such networks for the voice traffic and video traffic is noted. However, such technologies can be expensive in the operation and have limited capacities when offering broadband mobile services.

Article [4] highlights one of the promising directions for constructing the heterogeneous backhaul network HetNet. It is proposed to use wireless solutions for the backhaul networks that operate under the NLOS and LOS modes. However, applying the NLOS systems for the non-licensed frequency bands is considered too vulnerable to interferences, which can limit their use in the backhaul networks. At the same time, the lower ranges are limited in their capacity, which leads to low reliability of communication or its loss. That is why such solution is acceptable only when there is no possibility in the technical and economic prerequisites for the realization of backhaul networks based on optical fiber or other technologies.

As an alternative for the backhaul mobile transport networks, article [5] examines the infrastructure of data packet transmission over PDH – Ethernet over PDH. This solution will allow mobile operators to maximally expand the channel bands for their effective use in comparison with the existing approach based on TDM.

However, in order to reach the operator's level in the application of the Ethernet technology, it is necessary to solve issues about the differentiation and prioritization of traffic with the assigned mechanisms to provide for the quality of service.

Paper [6] addresses three strategies for the organization of a backhaul network. The first strategy is a hybrid system that supports separate TDM flows and the Ethernet traffic. This system cannot be attractive for the communication operators because of insufficient throughput and low scalability caused by insufficient support of embedded applications for the emulation of TDM traffic. The second strategy is an approach based on the Ethernet technology where combinations of any types of traffic (TDM or ATM) are possible, as well as obtaining transport flows on their basis. The basic functions and functions of the services aggregation are carried out within the limits of one and the same system. This is the next step in the evolution toward All-IP infrastructure. And the third strategy is a solution, designed only for the Ethernet connection at the level of aggregation. A peripheral device converts other types of traffic into a packet form for the displacement into an aggregation layer.

An analysis revealed that the hybrid system can be deployed as the replacement for the existing systems in the transition stage to the All-IP infrastructure. The second strategy can be used as the reserve solution for improving the overall reliability of a network in the transfer from the TDM networks to IP. And, finally, a transport network with the application of the Ethernet technology in combination with subsequent evolution of the network core will prove to be a solution in the transition to the reliable and economically efficient small networks with the IP technology.

An increase of capacity in a backhaul network is the consequence of high speeds in data transfer, which is explored in [7]. The existing networks, based on the obsolete technologies, cannot maintain higher speeds with the required service quality. That is why a migration of mobile transport network is necessary with maintaining the quality of service (QoS), synchronization by time, insignificant loss of packets and high level of accessibility along with keeping the operating costs low. An analysis of different scripts for the migration demonstrates that there is no a universal way for all types of networks.

Article [8] examined the issues encountered by the contemporary telecommunication society: bandwidth deficit and a variety of high-speed mobile technologies. It is proposed to use an optical access platform for the mobile backhauling with the aim of considerable reduction in capital and operating costs.

It is known that the LTE technology has substantial improvements in the network architecture in comparison with the 3G networks. [9] reflects the basic nodes in the LTE technology with safety functions – a protected access, network domain, user's domain, the domain of application, 3GPP domain. This will ensure overall protection for a network, which, in combination with the minimum delay and flexible channel bandwidth, especially in the backbone part of the network, will attract user. Under conditions of the integration of networks, the issues on protecting the users and applications acquire fundamental importance.

3. The aim and tasks of the study

The aim of present work is to create a model of the backhaul network based on the Unified MPLS Mobile Transport concept. This model will make it possible to realize the interaction between several generations of mobile communication in a unified network architecture, which is required by communication operators at the stage of sequential transition from obsolete technologies to the IP-platform.

To achieve the set aim, the following tasks are to be solved:

– taking into account contemporary tendencies, to select a topology for the fully connected backhaul network based on IP;

– to propose a model of the network to the level core/aggregation in line with the Unified MPLS Mobile Transport concept that uses the MPLS protocol at all levels of the network, based on the flat packet-oriented architecture;

– to receive expressions for assessing the throughput and transport productivity of the network depending on the channel band, the kind of modulation and the type of morphology.

4. Model of network to the level core/aggregation using the MPLS technology

It is known that the organization of 2G, 3G networks is based on the hierarchical structure of construction. The interconnection between base stations and the main elements of packet cores (SGSN, MSC and GGSN), which are the nodes of a backbone network, is carried out through the controllers of transport network (BSC or RNC). There is no direct connection between base stations and the core of the network.

In contrast to the networks of mobile communication of previous generations, the 4G networks are fully based on IP, which is related to the development of telecommunication industry.

The main earnings of mobile communication operators are formed as a result of providing the Ethernet services, IP VPN, VoIP, IP-video conferences to business clients, as well as from providing the services of Triple Play, IPTV to private users. Important share of the mobile communication operators' income is formed by leasing their resources such as mobile aggregation and relaying with the provision of interaction at the reference level on the network.

The architecture of such networks is determined by the basic elements: IP-mobile terminals and applied systems. In addition, the necessary components between the terminals and the application server are: base stations, the level of the traffic aggregation and the packet core as it is (Evolved Packet Core – EPC).

The use of LTE technology with the application of protocol IP only simplifies the operation of network, which is extremely important for the mobile operators. The creation of flat packet architecture excludes from the network such particular devices as transport segment controllers, which makes it possible to connect directly to the packet core using the appropriate interfaces.

Constraints for the 2G and 3G networks, related to the ineffectiveness of obsolete transport technologies based on TDM/ATM, inhibit the development of networks that support growing volumes of broadband mobile services. Thus, according to the estimates by Cisco, global mobile data traffic will grow by 53 % on average from 2015 to 2020, which will amount to 30.6 exabytes per month to 2020 as an eightfold increase in comparison to 2015 [10], which is shown in Fig. 1.

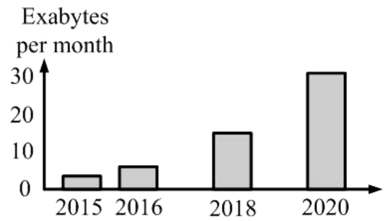

Fig. 1. Forecast of mobile data traffic by Cisco company

Based on the given data (Fig. 1), an increase in the traffic of packet data is observed; that is why the need to deploy the packet transport infrastructure of a network is obvious.

An adequate selection of topology is required for the optimum construction of a backhaul network.

Let us examine known topologies of the backhaul networks. The topology Hub and Spoke is a traditional star-shaped topology for the 2G and 3G networks with a limited number of users and it is a construction structure where all elements of the core are located in the central node. In contrast to it, the Full Mesh topology can be used for a variety of services and an increase in the number of users [11]. Thus, the analysis of the given topologies of backhaul networks reveals that such topologies have become obsolete by now for the backbone networks.

In the transition to the high-speed HSPA+ and 4G/LTE technologies towards meeting the increasing market demands for the telecommunication services, it is expedient to apply the star-shaped configuration of a backhaul network through the Hub (Fig. 2) being a service router for the network backbone core.

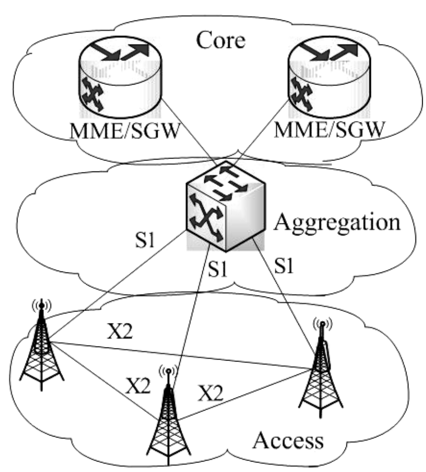

Fig. 2. Architecture of a backhaul network

This architecture is a connection to the central node by means of the aggregation level, which implies the creation of dynamic fully connected backhaul network based on IP. The network space is split into three levels: the access level, the aggregation level and the core level. The entire traffic is transmitted by the IP protocol with the help of interfaces X2 and S1. Interface X2 is the means for messaging exchange directly between base stations, excluding the transfer of traffic to the controller. When the data reach a network's backbone part, mobile communication operators determine the volume and priorities of the Internet-traffic or server content. Such architecture allows processing several types of traffic. The distribution of traffic is necessary to protect the data of different users in the shared network.

When deploying backhaul networks based on the technology LTE, the operators must reach some compromises. On one hand, the network must be scalable and provide quality, while from the other hand, realities of present network equipment require investing into new IP-oriented networks. That is why when developing a transport strategy, the choice between the Layer 2 and Layer levels 3 is connected to the expenditures of operators.

The architecture of a backhaul network shown in Fig. 2 ensures effective combination of Layer 2 (L2) and Layer 3 (L3) according to the OSI model in the transport network; in this case, L2 – in terms of access, L3 – in the segment of aggregation where traffic is aggregated into the core simultaneously with the work of the X2 interfaces.

An interaction, roaming and handover of the LTE and 2G/3G networks are possible to carry out at the initial stage considering the use of IP protocol as the basic protocol that ensures support for the operation of different mobile nodes, which is also represented in the project 3GPP [12]. Recommendations for the project 3GPP consider the use for L2 of virtual private networks VPN, for L3 – VPN and a gateway with the use of the MPLS technology based on VPN. Such a system of control will provide for the economic support of scalable services in the IP network.

The MPLS technology is called a network convergence technology, which enables supporting the transport applications, better support for services and is scaled in the access networks. This opens up a number of attractive possibilities: high productivity and throughput, traffic modeling, simplicity in the construction of networks and their operation.

Using the MPLS technology at all levels of a network, which is a uniform MPLS space, is schematically shown in Fig. 3.

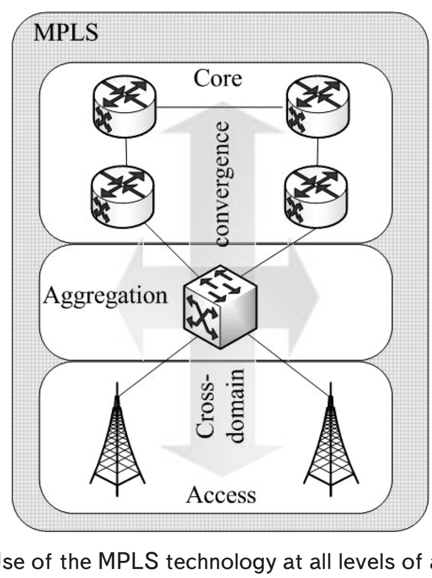

Fig. 3. Use of the MPLS technology at all levels of a network

In the traditional technology of MPLS there are certain difficulties, related to the complexity in the realization of services in big networks. This is, for example, the need to apply complex mechanisms of the L3 level when conjugating with the level L2 protocols.

The Unified MPLS lacks the enumerated deficiencies at the same obvious advantages, connected to the high productivity and throughput, as well as the operational simplicity of networks. Furthermore, by integrating with the help of MPLS the segments of access, aggregation and core, it is possible to decrease the number of administration nodes [13].

Taking into account the indicated requirements to the construction of network, as well as the requirements for scalability, flexibility, manageability and security, we propose a model of the network to the level core/aggregation, in line with the UMMT concept [14] – Unified MPLS Mobile Transport (Fig. 4).

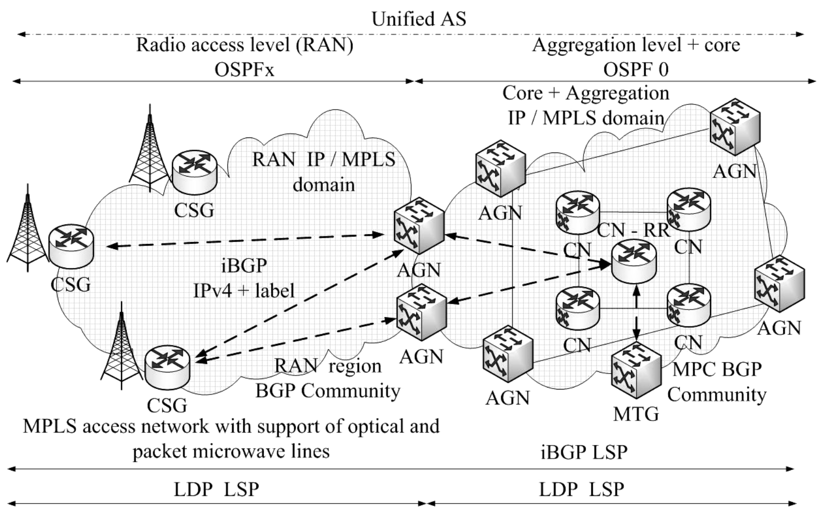

Fig. 4. Model of network to the level core/aggregation

The unified MPLS technology forms a transport basis for supporting the LTE, 2G GSM and 3G networks in the UMTS standard.

Construction of a transport network is possible with the use of different technologies. Operator network can be built with the use of the MPLS technology in the segment of aggregation and backhaul segment; Ethernet – in the access segment [15]. The proposed model of network with the use of the unified MPLS standard for a mobile transport will provide operators with a comprehensive solution, optimized by cost, which supports the users' traffic and traffic of business-services with high parameters in the quality of service (QoS) in comparison with the analogous standards.

The backhaul network of an operator consists of three levels. At the access level are the CSG nodes, the so-called modes for pre-aggregation, which work in the RAN domain. The levels of aggregation and core are combined into one level – aggregation + core. Its corresponding nodes are the nodes of aggregation (AGN) and the nodes of core (CN, CN-RR and MTG). Several adjacent base stations will be switched on to one access node. The MPLS protocol is employed at all levels of network.

The system is configured for a simultaneous support of several generations of mobile communication in the uniform convergent network architecture. The implementation of LTE that supports Pseudowire Emulation (PWE) for transmitting 2G GSM, L2VPN for 3G UMTS/IP and L3VPN for 3G UMTS/IP and LTE is provided in accordance with [16, 17]. The following are supported: synchronization, high parameters in the quality of service (QoS), OAM protocols (in operation, administration and service), rapid convergence and control over productivity. The system is optimized to support such requirements of the 4G standard as IPSec and authentication, direct connection between eNodeB by the X2 interface, multicast, virtualization, possibility to allocate gateways ERS and traffic balancing.

The combined levels of aggregation and core into one level (Core+Aggregation) are integrated into a unified IGP/LDP domain. The access level, the so-called node of preliminary aggregation (RAN), consists of separate IGP domain. The nodes of aggregation unite mobile networks at the access level by the MPLS protocol and render them a part of one autonomous system (AC) with the network of aggregation/core.

The access nodes are included with the aid of different interfaces into L3VPN that correspond to them. The same L3VPN are present in the nodes, to which MSS/RNC and others are connected. Thus, a communication between a base station and the indicated network elements is performed in isolation inside L3VPN by means of the MPS-BGP protocol.

5. Estimation of the throughput of a network

It is known that the quality of LTE voice traffic depends on the magnitude of a radio channel. Thus, the 3GPP standard defined the 5 MHz, 10 MHz and 20 MHz bands for LTE, as well as assigned spectral effectiveness for descending (5 bits/Hz) and ascending (2.5 bits/Hz) channels. In order to obtain a peak speed of the LTE channel, it is necessary to use maximum capacities of the radio channel.

Quality of voice signal is an important parameter of estimation. In the LTE technology, to evaluate the IP-telephony service quality, the following indicators are essential: delay in packet delivery (less than 150 ms), probability for the loss of packets, the jitter (less than 30 ms). And for the broadband services, in connection to the transition to the “all through IP” concept, an important factor is the network throughput at wide bandwidth (larger than 200 kbit/s).

LTE can employ the following modulation methods: QPSK, 16QAM and 64QAM with different quality indicators. The choice of the modulation method follows from the provision of the required coverage area with maintaining the corresponding transfer speeds. The best results are achieved when using the modulation at 64QAM. In this case, it is possible to attain maximum 100 % peak speed in the center of the coverage area. When using the modulation methods at 16QAM and QPSK, it is possible to gain 66 % and 33 % peak speeds of the maximum, but over a larger coverage area.

In order to evaluate the throughput, it is proposed to calculate the transfer speed depending on the utilized band and the modulation method, which is possible to describe by expression (1):

$$R_{DL/UL} = Rt \times M_{mod} \times N_{L1/L2}, \tag{1}$$

where R_t is the theoretical peak speed of data transfer; M_{mod} is the modulation method; $N_{L1/L2}$ is the management of control signal titles of levels L1/L2 (correction of errors, MAC control). The calculation was performed for the descending and ascending channels taking into account the maximum speed of data transfer, passband and different distance from the base station. Table 1 gives the obtained peak speeds for data transfer.

Table 1

Peak speeds in data transfer of the LTE networks users

No. of segment	Channel band		
Distance from BS	5 MHz	10 MHz	20 MHz
Near segment	17/5.6 (Mbit/s)	43/14.4 (Mbit/s)	85/28 (Mbit/s)
Middle segment	11/3.7 (Mbit/s)	28/9.5 (Mbit/s)	56/18 (Mbit/s)
Far segment	5,6/1.8 (Mbit/s)	14/4.8 (Mbit/s)	28/9.5 (Mbit/s)

All peak speed indicators in LTE imply maximum coverage area; however, the resources of cell are used partially, which leads to the decrease in peak speed and average throughput.

However, in view of the fact that mobile terminals are not statistically distributed within the limits of segments, and in this case the peak speeds differ from maximum, then the transport load can be used not to the full within the limits of sectors.

In order to analyze the throughput with a probability of finding the user in the active mode, we used the OBF factor – the so-called “overbooking factor”, which depends on Statistical Multiplexing Gain (SMG) [18].

The existing 3G, CDMA and WiMAX data transfer transport networks have the OBF factor in the range of 2–5.

The estimation of transport productivity was conducted in accordance with the type of morphology, depending on the utilized band and the OBF factor according to expression (2):

$$R[T] = Rt \times S(OBF) \times N_{QCI}. \tag{2}$$

The calculation was performed taking into account the maximum speed of data transfer and by the introduction of identifier of service quality QCI (QoS Class Identifier). A function of QoS guarantees that the transport buffers of the Internet transfer operate with a high priority of data packets without the loss of frames. Table 2 gives results of the network transport efficiency.

Table 2

LTE network transport efficiency

No. of region	Channel band		
Type of morphology	5 MHz	10 MHz	20 MHz
Dense urban construction	20 (Mbit/s)	50 (Mbit/s)	100 (Mbit/s)
Urban construction	13 (Mbit/s)	33 (Mbit/s)	65 (Mbit/s)
Rural area	8 (Mbit/s)	20 (Mbit/s)	40 (Mbit/s)

Thus, densely populated urban areas have the higher needs for speeds than the rural regions, which have the larger size of cell. That is why OBF will be lower in the densely populated cell than in the segments with a small number of users.

The passband, accessible to user, and the coverage area are limited by the size of cell. This determines the overall number of users that can be provided with service in a particular territory. In order to increase capacity in the densely populated areas, operators may resort to "small honeycombs" (micro- and pico-honeycombs). They are territorially located in the same region as macro cells, thus increasing capacity, attending to a larger number of users that are within their coverage area.

This variety of architecture requires additional economical aggregation on the macro cells interacting with each other. In certain cases, an operator may even require an external transport node in addition to the existing node on the small honeycombs. Thus, the aggregation is created between the domains of radio access and transport network.

6. Discussing the results of examining a model of the network with a unified access to the level core/aggregation

Thus, based on the Unified MPLS Mobile Transport concept, we received a model of the network with a unified access to the level core/aggregation.

It should be noted that using the MPLS protocol at all levels of the network makes it possible to employ both the dynamic and static levels of network management. MPLS possesses flexibility to support all types of NGN and traditional services. This does not disagree with practical data, obtained in article [19], the author of which gives a matrix for supporting the MPLS technology with the technologies of Ethernet, Traditional and IP by the key technical characteristics and basic categories of network services.

In the classical transport networks, the configuration of services is conducted at each transit device, which is why a network management system must know information about the topology of network. With the help of the Unified MPLS architecture, the End-to-End services are created by tuning the terminal devices only, which solves the task on reducing the number of administration points.

Present work shows the need in the integration of the combined levels of aggregation and core into a unified IGP/LDP domain. This solution in combination with the BGP protocol is used for the services of the network scale, while iBGP is applied for obtaining IPv4+label remote service administration points. In further studies, we plan to examine issues on the BGP application to all services (IPv4, IPv6, VPNv4, VPNv6) to provide for the high stability and rapid convergence of network.

The model of network proposed is characterized by the most complete operating functional and operating parameters; it makes it possible to realize the interaction between several generations of mobile communication in the uniform network architecture. The communication operators require this at the stage of sequential transition from the obsolete technologies to the IP-platform. Note that the MPLS technology is commonly applied and supported by the equipment, installed in the networks of operators.

Results of the study might prove useful for creating a convergent network script based on Fixed/Mobile Infrastructure (FMI). In order to improve network effectiveness, mobile operators add services on the Unified RAN network, while fixed-line operators add services on the Carrier Ethernet network.

Results of present work indicate a number of controversial issues that concern expediency of applying the MPLS technology at all levels of network. They relate to the problems on the application of mechanisms to improve the convergence of IGP protocols: IP/MPLS Loop Free Alternate Fast ReRoute (LFA FRR) and MPLS TE Fast ReRoute (TE FRR). The choice of given mechanisms should be predetermined by the shortest network recovery time and by operational simplicity, which must contribute to the rapid convergence of network without a complex configuration.

An increase in traffic predetermines a transition to the new version of the IPv6 protocol with a fold increase in the address space. That is why service providers and operators are forced to replace the outdated equipment.

Furthermore, a question that remains open for the provider is a reduction in the cost of data transfer based on the calculation per bit of the transmitted information. The process of network transformation to improve the throughput depends on the situation if a provider creates its own level of aggregation and traffic relaying or it uses services provided by third parties.

7. Conclusions

1. We selected the topology of a backhaul network. It is demonstrated that the adequate topology, the most relevant one in the transition to the high-speed LTE technology, as well as with a large increase in the number of users and services, is a star-shaped configuration through Hub. This choice allows creating a dynamic fully connected backhaul network based on IP.

2. The MPLS technology is determined for constructing a backhaul network for a communication operator. The concept selected is the Unified MPLS Mobile Transport. We designed a model of network, which is a comprehensive solution, at all levels of which the MPLS protocol is tuned for a simultaneous support of several generations of mobile communication in the unified network architecture.

3. The throughput of network is analyzed with the use of standard frequency bands, defined in the LTE technology. It is demonstrated that with the use of maximum capacities of the radio channel, the transport load is maximum in the near segment. However, approximately one third of resources are used to protect user's information from damage during transfer and for control information.

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