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CONVERGENCE OF HETEROGENEOUS WIRELESS NETWORKS FOR FUTURE COMMUNICATIONS: ARCHITECTURE, QOS AND RESOURCE MANAGEMENT

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Scientific and theoretical approaches to the implementation of a heterogeneous mobile communication network based on SDN/NFV and SDR technologies are described. The architecture of the future heterogeneous network is proposed, taking into account the evolution of emerging standards and key technologies. An algorithm for dynamic bandwidth allocation and reservation between several logical channels at a certain moment of time to provide QoS for information flows in future networks is created. A simulation model of network traffic service with parameters corresponding to real networks has been made. The study of femtocell SDR load, as the main convergent device at the level of heterogeneous network access by users of different generation mobile communication technologies has been conducted.

Ключові слова: *SDN; SDR; NFV; QoS; Heterogeneous Wireless Networks.*
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1. Introduction

Mobile communications networks have gone through a complex evolutionary development path (Fig. 1), during which they provided users with the ability to exchange information over a distance.

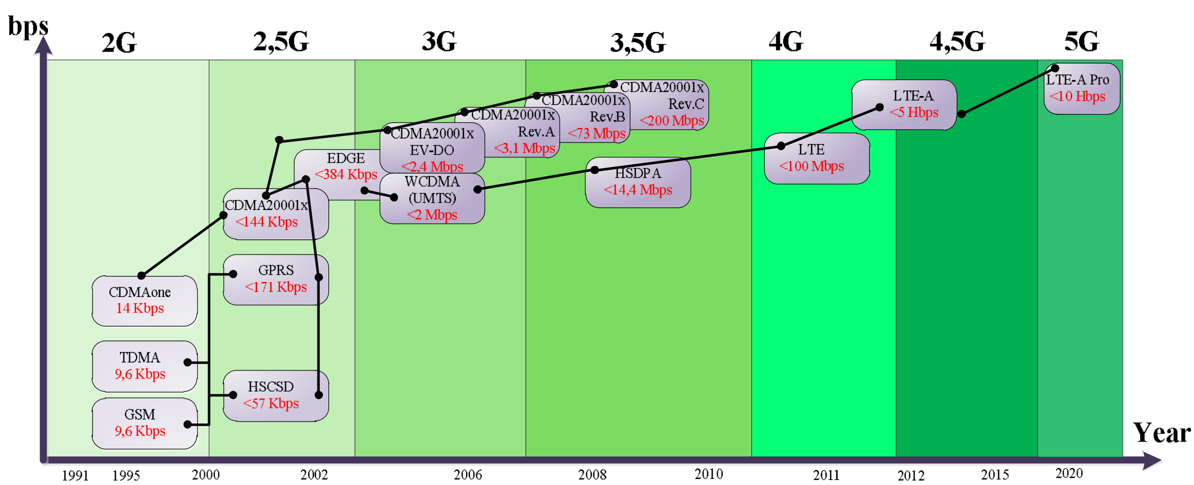

Fig. 1. Evolution of mobile communication technologies

The rapidly growing demands of the mobile broadband market have posed a huge challenge to the traditional architecture of mobile broadband networks. With limited machine room space and insufficient power supply, operators are unable to accommodate the exponentially growing amount of network equipment [1]. Conversely, network heterogeneity caused by different specifications of wireless access equipment leads to costly management and optimization.

The active development of mobile communication technologies presents hardware manufacturers and investors with the problem of technology selection (CDMA2000, UMTS/W-CDMA, EDGE, GPRS, LTE, LTE-A, etc.) for investing funds. The problem is very difficult, because it is not easy to predict the direction in which the market for mobile communication systems equipment will develop in the future. A mistake in this case leads to significant financial losses [2].

"Standard GSM/UMTS/LTE mobile network equipment on the operator side" is a whole rack of equipment (and often more than one) with interfaces, cards. Operation of such equipment is a complicated occupation, requires qualified engineers, and having experience in operating different equipment of different manufacturers.

Therefore, many research laboratories and manufacturers of mobile telephony equipment are already looking towards Software Defined Radio (SDR) and Software-defined Networking (SDN) technology and Network Functions Virtualization (NFV) as alternatives for the development of the future mobile network [3].

This paper proposes a future network infrastructure, which includes various technologies such as NFV, SDR and SDN. In particular, we explore both existing standards and possible extensions for 4G/5G mobile networks, and consider several open questions for future research [4].

2. Emerging wireless communications and networking technologies for advanced heterogeneous networks

The new architecture actually means replacing all types of different mobile network equipment (BSC/RNC/MSC/MSS/SGSN/GGSN/MME, etc.) with a common HW platform, on which all their functions are virtualized. Constructing a network using SDR and SDN/NFV approaches, it is possible to obtain a conceptual architecture in terms of operator equipment (Fig. 2).

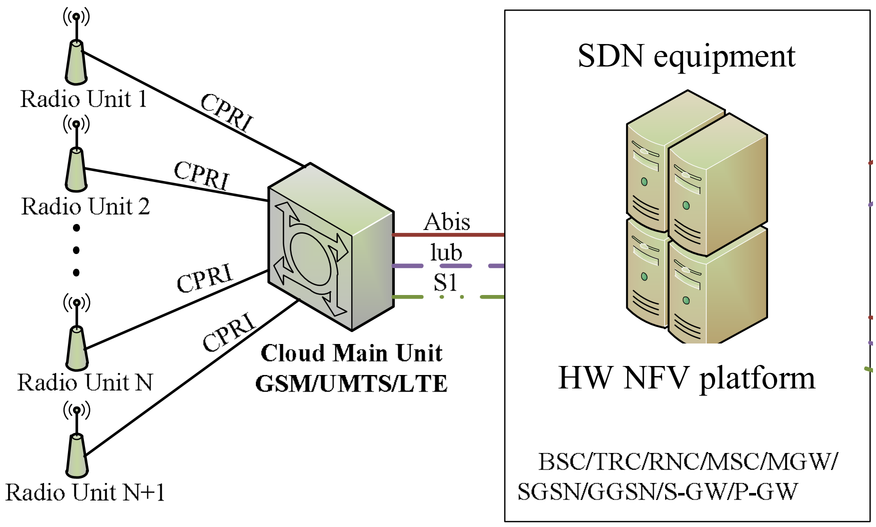

Fig. 2. Architecture of a software-defined heterogeneous mobile network

In the construction of such a network, the feasibility of using SDR, SDN and NFV technology was carried out. For further effective development and modernization of mobile networks, it is advisable to move to the use of software-defined radio subsystems and networks. This approach will solve the problems of modernization, allowing for continuous improvement of equipment by upgrading only the software, with virtually unchanged hardware.In a heterogeneous operator’s network it is proposed to use group access equipment based on SDR technology. The use of SDR can significantly simplify the technical support of international roaming, increase the number of supported services and achieve greater flexibility of communication devices. Secondly, from the point of view of mobile operators SDR is a powerful tool to add additional services and services. And finally, thirdly, manufacturers of terminals and base stations receive many benefits through high scalability and flexibility of solutions, the ability to use the same hardware configuration for the implementation of many different types of devices. This makes it easier to achieve high reliability solutions, as well as provide significant cost savings in both design and manufacturing, as well as in all phases of the device lifecycle. Flexibility refers to the ability to switch between channels and change modulation type. As a result, the existing SDR hardware platform can be easily reprogrammed to support any new wireless communications standards.

Software-defined networking (SDN) refers to a data network in which the network management layer is separated from the data devices and implemented by software, it is a form of virtualization of computing resources.The basic element of the SDN concept is the OpenFlow protocol, which provides interaction between the controller and network devices. On the "north" side, the controller provides software interfaces that allow the network owner or third-party developers to create applications to manage the network. These programs can perform various functions for business purposes (e.g., access control, bandwidth management, etc.), and their developers do not need to know the details of the operation of specific network devices. Thanks to the controller, the entire network, consisting of many different types of devices from different manufacturers, is to the program as one logical switch.That is, in general, the introduction of SDN technology in mobile networks means a revision of the network architecture, separation of management from data transmission and automation of the process of administration of network equipment.

In the transition to software-based network management in addition to SDN technology plays a key role virtualization technology network functions NFV. These technologies complement each other in that they address different elements of the software-managed solution provisioning. SDN increases network flexibility with holistic network management, enables rapid innovation, and lowers operating costs. NFV is designed to enable operators to reduce Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) by lowering equipment costs and reducing energy consumption.In addition, NFV also reduces complexity and makes it easier and faster to manage the network and deploy new capabilities. Network Function Virtualization, a network architecture concept, proposes to use virtualization technologies to virtualize entire classes of functions of network nodes as building blocks that can be connected together or linked in a chain to create telecommunication services (services).

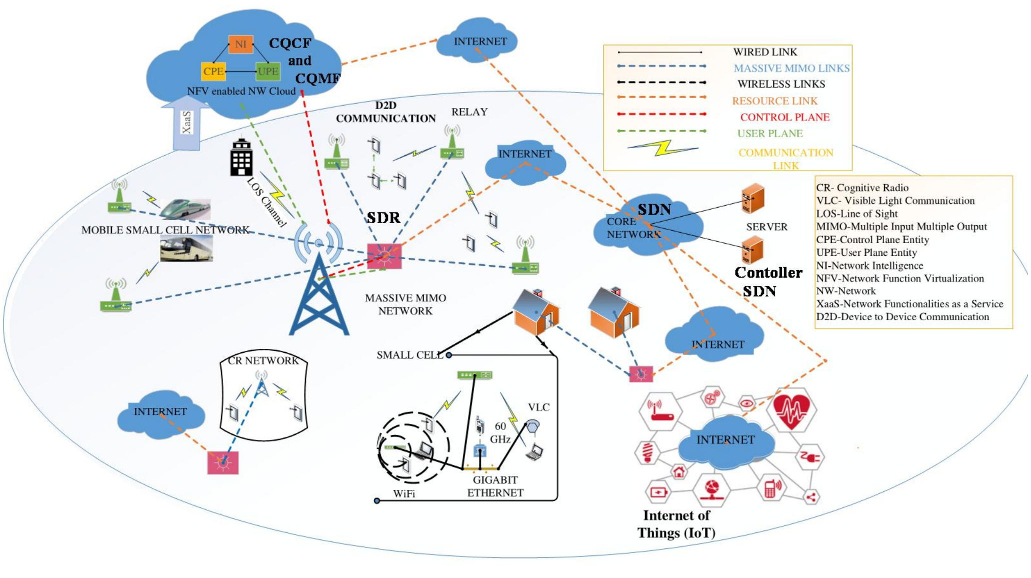

Fig. 3. The architecture of the conceptual future mobile network based on the use of SDN/SDR/NFV technologies

The development of the concept of virtualization of network functions will lead to the virtualization of quality management functions, which can be represented in two main functions: QoS management (Cloud QoS Control Function, CQCF) and QoS management (Cloud QoS Management Function, CQMF). CQCF QoS Control Function will provide real-time control over traffic flows in the 5G network based on the QoS levels agreed at the connection establishment stage. Key controls include QoS traffic profiling, scheduling and flow control. CQMF's QoS management function will ensure that the 5G network supports QoS in accordance with SLA contracts [5]. It will also monitor, support, view and scale quality of service. In this work, the conceptual model of the future mobile communication network based on the use of SDN, SDR and NFV is presented in Fig. 3.

Based on the developed prototype network in the future work is proposed to implement the proposed methods for quality management and resource allocation, which will provide a hypothetical end-to-end quality of service on the criterion of delay in the conceptual model of the software-defined 4G/5G mobile network (Fig. 4).

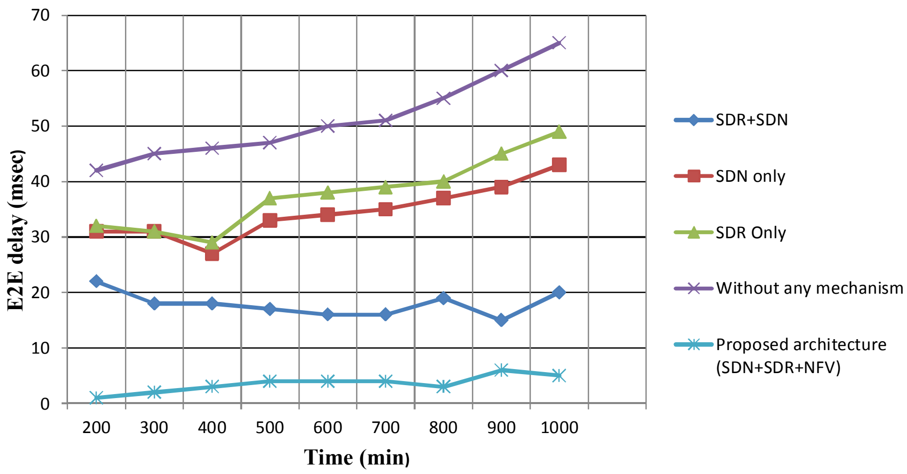

Fig. 4. Average E2E latency in the 5G-SDWN conceptual model (Software Defined Wireless Network)

Integration of the proposed solution in combination with SDN/SDR/NFV operator network technologies will allow:

- significantly improve the coverage of mobile access networks and their throughput by introducing a heterogeneous 5G wireless access network;
- improve the quality of mobile communication services;
- virtualize the network infrastructure;
- introduce load balancing on access networks by means of the handover algorithm.

All of the factors mentioned above will allow a more efficient use of network equipment and network resources, and consequently reduce capital and operating expenses, as well as attract more users due to the introduction of new services, and thus increase the operators' revenues.

Manufacturers and suppliers of hardware and software for networks and user devices will also benefit economically from the implementation of these solutions, since they will be able to develop hardware or software standardized solutions on the basis of the proposed solutions.

3. Resource management in the future mobile network to ensure QoS

Consider the resources of a channel, both wired and wireless with bandwidth C_{Σ} (in our case, for ease of understanding, take 100 Mbps), which are limited. To create new mechanisms for resource and channel bandwidth management, it is necessary to analyze existing distribution methods. Thus, in the physical channel there are several logical (consider three logical (virtual)) channels, selected for certain users with statically specified bandwidths) C_1 and C_n from the total resource C_Σ, where the value of $C_1 = C_2 = C_n = C_{\Sigma/n}$, so with normal access to the Nth number of users, certain traffic is allocated bandwidth

When introducing new telecommunication technologies and launching 4G/5G mobile networks, an important task is to provide the necessary end-to-end bandwidth for certain types of services in order to ensure a guaranteed quality of service [6].

Let us consider channel resources, both master and wireless with bandwidth C_Σ (in our case for simplicity of understanding let us assume 100 Mbit/s), which are limited. To create new mechanisms of the channel bandwidth i resource management it is necessary to analyze the existing methods of distribution. So, in a physical channel there are several logical (consider three logical (virtual)) channels organized, allocated for certain users with statically set carrying capacities C_1 and C_n of the common resource C_Σ, and $C_1 = C_2 = C_n = C_{\Sigma/n}$, consequently the usual access N number of users has a certain carrying capacity

$$C_{1,2,n} = \frac{C_\Sigma}{N}, \tag{1}$$

and $C_\Sigma = C_1 + C_2 + C_n$ (see Fig. 5).

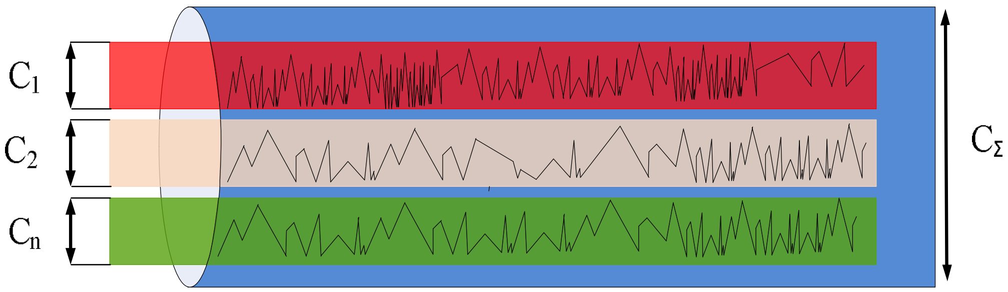

Fig. 5. Static bandwidth allocation of the physical channel between the three logical

The first of these carries real-time, delay- and loss-sensitive information (for videoconferencing systems), while the second and third carry secondary information (data, WEB, FTP and information that is not delay- and loss-sensitive). There is a problem of the most effective way of dividing the total C_Σ bandwidth of the physical channel between the three logical ones. Since the first virtual channel transfers the lossy-sensitive information, it is necessary to increase the throughput C_1 of this channel. However, in this case its effectiveness decreases and so does the available bandwidth for the second channel (Fig. 6). As a result, resources of physical channel are spent inefficiently.

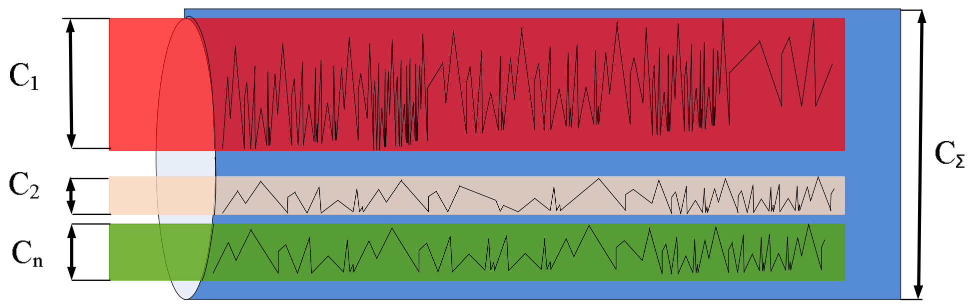

Fig. 6. Dynamic channel bandwidth allocation between three logical

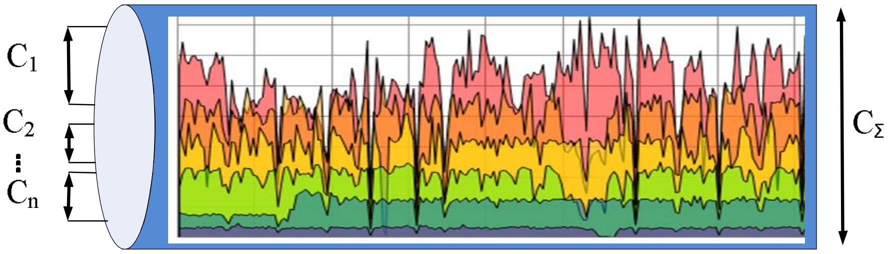

Fig. 7. Dynamic bandwidth allocation of a physical channel between several logical channels at a certain point in time

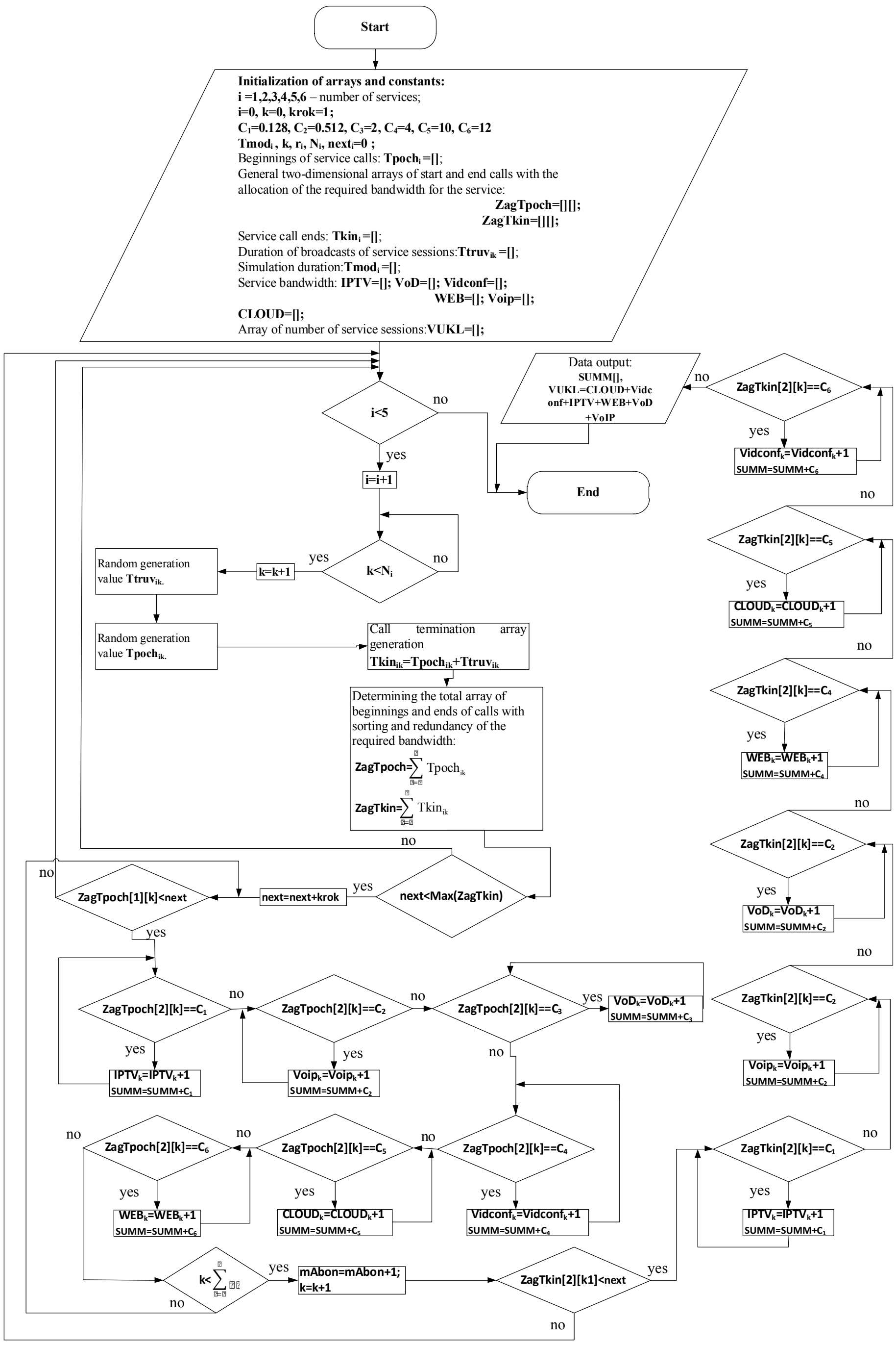

Fig. 8. Block diagram of the dynamic channel capacity allocation simulation model method

$$C_1 = C_\Sigma - C_{n-1} - C_n. \tag{2}$$

$$C_{[1,t]} = C_\Sigma - C_{[n-1,t]} - C_{[n,t]}. \tag{3}$$

Much more opportunities in this case can offer a scheme with dynamic channel bandwidth management with the provision of necessary network resources in order to ensure the quality of service in the mobile networks of new network generation.Therefore, with dynamic bandwidth allocation until the time t, the system allocates the necessary bandwidth resource for the first service to provide QoS, while allocating the second and third channels all the other available bandwidth. As can be seen from Fig. 7, the principle of dynamic bandwidth management in this example increases the bandwidth efficiency in the first channel and provides more resources for the second and third channels.The block diagram of the simulation model algorithm of dynamic bandwidth allocation and reservation of the physical channel between several logical channels at a certain point in time to provide infocommunication services is shown in Fig. 8. As a result of the simulation it is obtained.

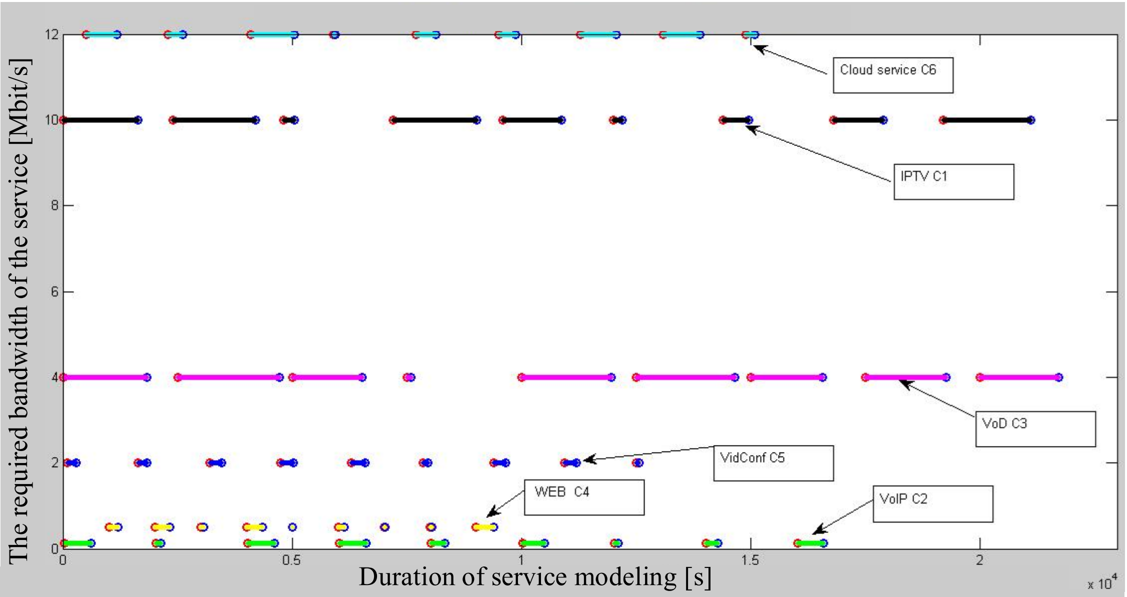

Fig. 9. Time diagram of sessions of using infocommunication services by one user

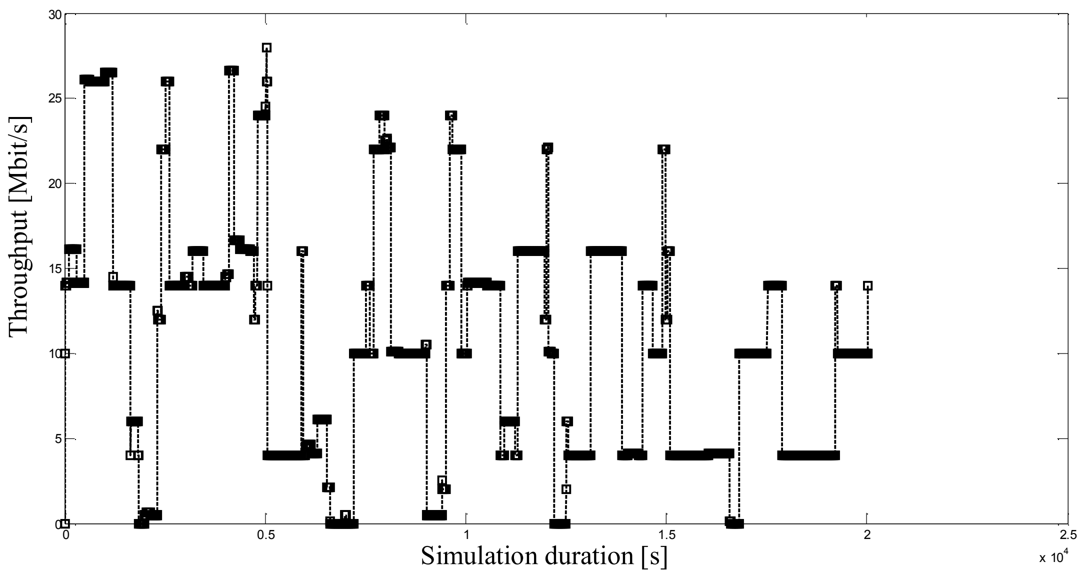

Fig. 10. Dynamic channel bandwidth control

As can be seen from Fig. 10, the duration of infocommunication services sessions in the process of broadcasting services by one user within 6:00 are random values; in this case we consider that for the duration of the session it is necessary to reserve the bandwidth, which is necessary for a particular service to provide QoS in the process of access resources to the network node.

Fig. 11 shows the dynamics of the reserved bandwidth for QoS during the simulation duration when a user accesses a node (router, base station) that uses multiple services. As we can see, in the case of using heterogeneous services, the maximum bandwidth he needs to reserve is 27 Mbit/s, providing the proper level of QoS and not using all the available bandwidth of the channel provided by the network provider. In our case, the maximum bandwidth is 100 Mbit/s, but only 88 Mbit/s are allocated for public use, reserving the remaining 12 Mbit/s for signaling data and control mechanisms.

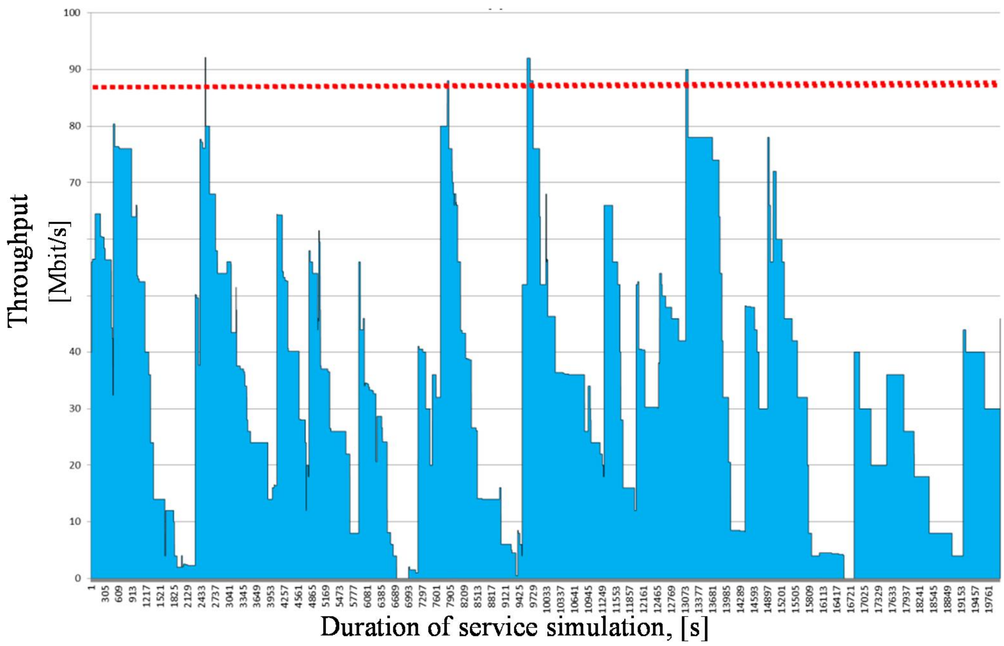

Fig. 11. Reserving the necessary service bandwidth during the simulation duration for 4 users

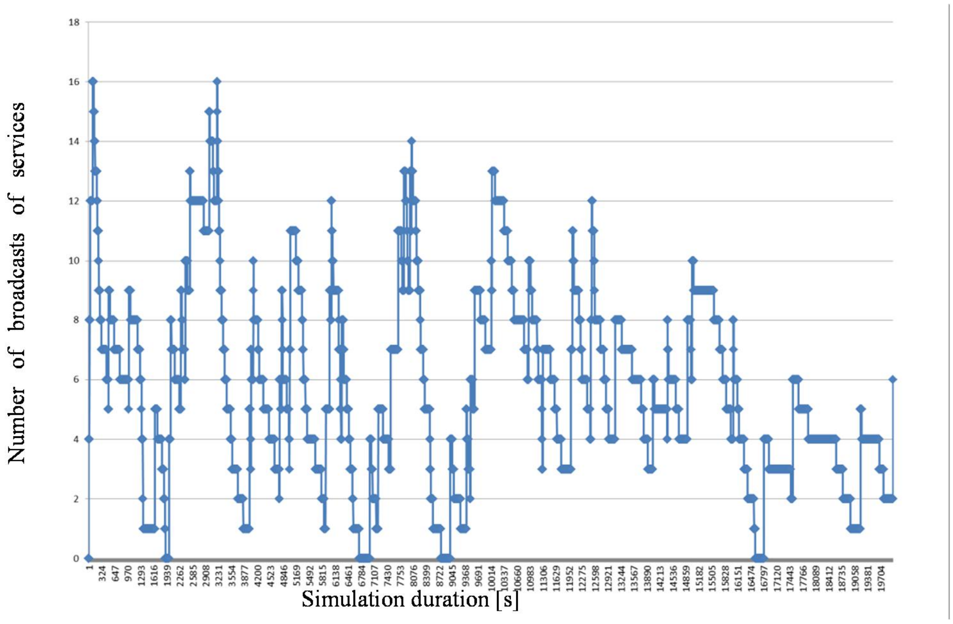

Fig. 12. Number of service broadcasts during the simulation duration for 4 users

Fig. 11 and 12 show the results of bandwidth booking for 4 users and the number of service broadcasts during the simulation duration created by them, who use the selected set of infocommunication services. From Fig. 11 we see that at some points in time is a denial of service. To solve this problem, it is proposed to give high priority to the delay-critical services on the basis of dynamic prioritization of services.

One way to address this shortcoming in the existing IP network is to develop and implement new methods for predicting the load on network elements, as well as the implementation of dynamic management of IP network resources. To develop such methods, it is necessary to take into account the properties of real network traffic, were investigated in the previous chapters.

3. Simulation of femtocell SDR utilization by users of different generations of mobile technology

The main device that is supposed to unify the generations 2-4,5G is SDR femtocells–a miniature base station designed for home or office use [7–9]. According to this device allows coverage of different generations of mobile networks with only access to the Internet. Since each of the technologies has its own characteristics and parameters of functioning, the work proposes an algorithm for radio and physical resource management model to predict the diversity and amount of allocated resources required to ensure the quality provision of multiservice services to mobile users (Fig. 13).

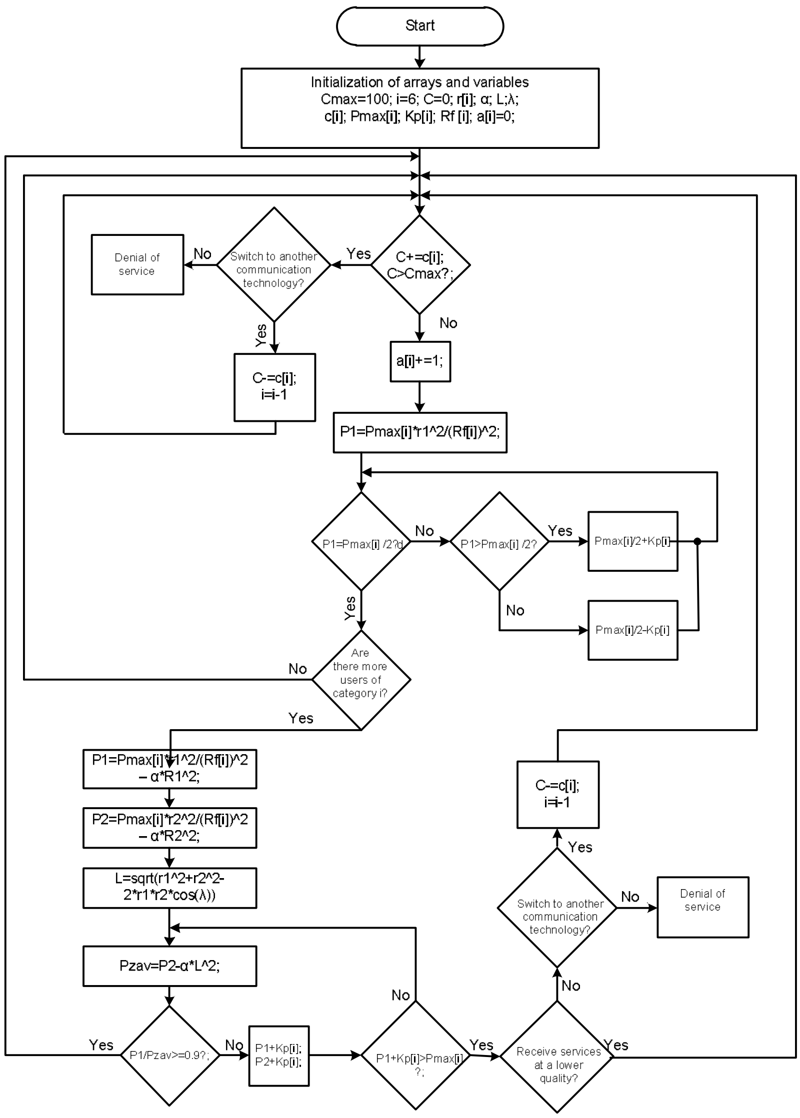

Fig. 13. Algorithm of the model for managing radio interfaces and physical resources of a femtocell

Algorithm description:

The algorithm performs three basic functions: handover between users within the convergent coverage area, controlling the power radiated, and controlling the bandwidth of the femtocell.

Step 1: Variables and arrays are initialized, will be processed in the Radio Controller SDR femtocell.

Where:

$C_{\max}$ is the maximum bandwidth of the femtocell;

C is a variable to find the sum of the bandwidths required to serve the interfaces connected to the femtocell;

with$[i]$ is an array of values of the bandwidths of the technologies required to provide quality service;

$P_{\max}[i]$ is array of maximum capacities of interfaces;

$Rf[i]$ is an array of values of service area radius of different generations of mobile communications;

$a[i]$ is an array that will show how many users of each technology are connected at the moment;

$Kp[i]$ is an array of values of power tuning steps;

$r[i]$ is an array of values of the change in the user's stay distance from the radiation source;

λ – angle between the radii r_1 and r_2 of the users of the same technologies (0 -360)

α is the signal loss in space;

L – distance between users A and B;

Step 2: a check on the permissible bandwidth (it must not exceed 100 Mbit / s). If the condition is met, the transition to Step 3, if not – the user is offered to switch to another mobile technology. If the user agrees to switch the service area, the technology$[i]$ is replaced by a less resource-intensive $[i-1]$, the value of the bandwidth required by the technology $[and]$ is removed from the variable C, the algorithm returns to step 2. If the user does not agree with the transition, he receives a denial of service.

Step 3: the counter of the number of users is incremented by 1 for the mobile category to which it belongs; the calculation of the necessary power that the radio interface must emit to provide quality service to the user is performed.

Step 4: at the beginning of its operation all femtocell interfaces are configured so that they emit only half of their maximum power. The power calculated in step 3 is compared to the initial power. If it is greater than the initial power, the power tuning step value is added to the initial power; if less, the step value is added; the cycle continues until the calculated power is equal to the radiated power.

Step 5: Is there any more users of category $[and]$ present? If so, then:

a) the power that user A receives is calculated, taking into account the attenuation at distance r_1 from the source;

b) the calculation of power, which user B receives, taking into account the attenuation at the distance r_2 from the source;

c) calculation of the distance from user A to user B;

d) calculation of the amount of interference resulting from the impact of B on A.

Step 6: if the signal to noise ratio (in our case, the ratio P_1 / P_{zav}) is greater than 0.9, then the user will receive quality services, but if less than 0.9 there is an increase in the radiated power of the source, respectively increasing the power P_1 and P_2.

Step 7: the power comparison takes place: if the radiated power exceeds $P_{\max}$ – the quality of service decreases, because the power exceeds the maximum allowable for a particular technology. According to the transition to another technology, or, if the user refuses to switch–denial of service.

In this work a simulation statistical model of femtocell as a converged device at the access level to provide multiservice services with the implementation of vertical handover is developed.

Simulation model inputs: femtocell channel capacity *C* = *10Gbp/s*; number of mobile communication technologies supported by station i = 7 (GPRS, EDGE, WCDMA, CDMA20001RevA, HSPA, LTE, LTE-A) technology bandwidth required to provide quality service to mobile users C_i = = [Mbps] (GPRS = 0. 000171, EDGE = 0.000384, WCDMA = 2, CDMA20001RevA = 3.1, HSPA = 14. 4, LTE = 100, LTE-A 1000); probability of i-category users' access to femtocell resources pi (0.15, 0.25, 0.2, 0.1, 0.15, 0.1, 0.05); duration of calls T_{trv} from the i-th user, generated by the Poisson distribution with the mean λ = 600 s; moments of calls T_{poch} generated randomly with a uniform distribution law; the moments of call ends defined as $T_{kin} = T_{poch} + T_{triv}$; the simulation duration $T_{triv} = 1$ hour.

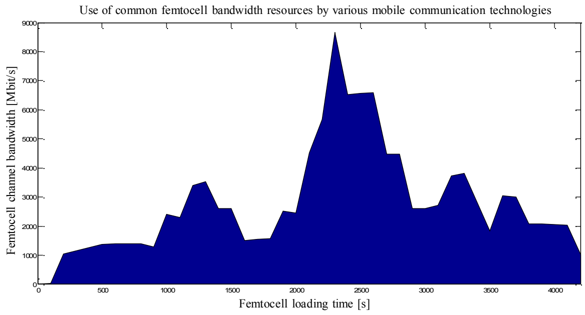

Fig. 14. The amount of bandwidth used by users when sharing a device (N = 250)

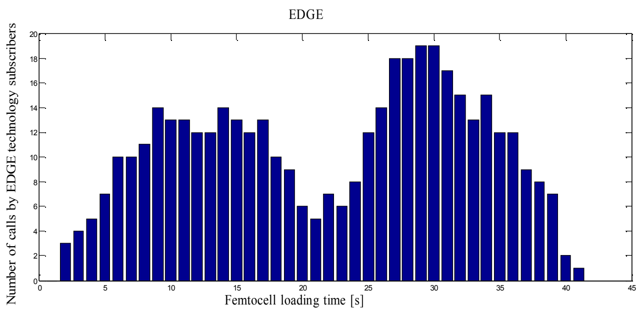

Fig. 15. Number of EDGE users during simulation time

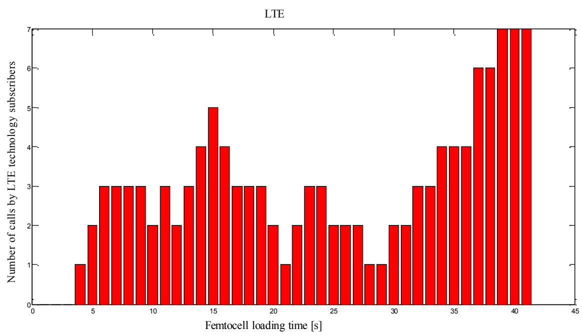

Fig. 16. Number of LTE users during the simulation time

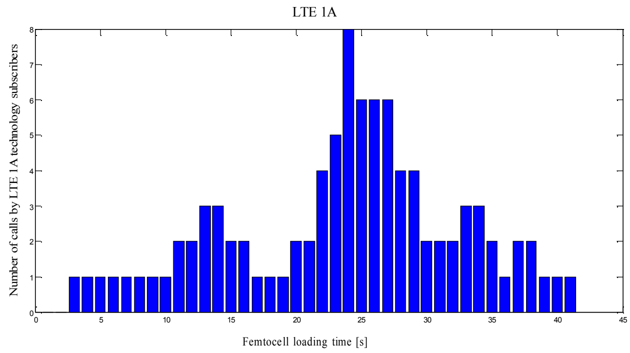

Fig. 17. Number of LTE-A users during the simulation time

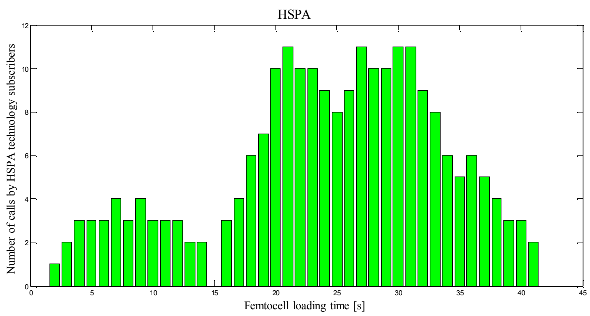

Fig. 18. Number of HSPA users during the simulation time

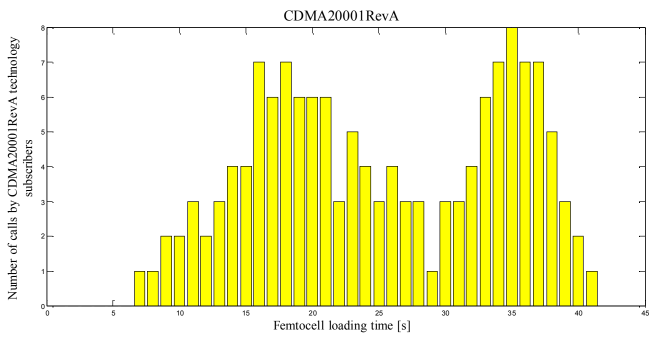

Fig. 19. Number of CDMA20001RevA users during the simulation time

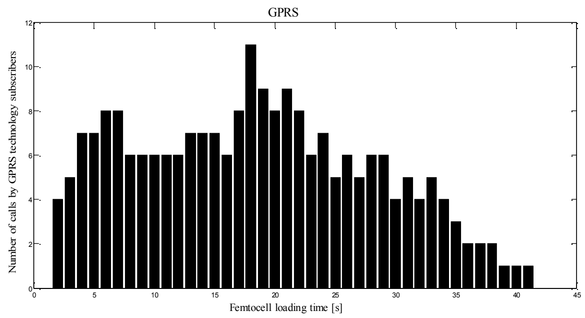

Fig. 20. Number of GPRS users during the simulation time

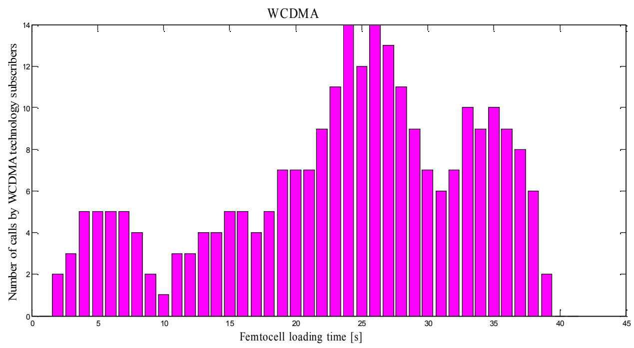

Fig. 21. Number of WCDMA users during the simulation time

As a result of the converged device simulation, it was investigated that the maximum number of calls to femtocells from users is 250. However, in 2350 s bandwidth used by mobile users of different generations is 8.45Gbit/s with 10Gbit/s possible. The results show that the converged device is able to provide quality services to a certain number of users.

Conclusion

This paper proposes the architecture of future heterogeneous network based on the integration of modern technologies NFV, SDR and SDN. The feasibility of using software-defined radio subsystems and networks with virtualization of network functions in a heterogeneous mobile network was carried out. It is established that the mobile network built on the principles of SDN, SDR and NFV, will allow to create modern mobile networks, which can easily move from standard to standard (GSM-UMTS-LTE-LTE Advanced), providing high quality latest services in the shortest possible time. As part of this work, the algorithm was created for dynamic bandwidth allocation and reservation of physical channel bandwidth between several logical channels at a certain point in time to provide QoS information flows. A simulation model of network traffic service with parameters corresponding to the real networks has been conducted.

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КОНВЕРГЕНЦІЯ ГЕТЕРОГЕННИХ БЕЗПРОВІДНИХ МЕРЕЖ ДЛЯ КОМУНІКАЦІЙ МАЙБУТНЬОГО: АРХІТЕКТУРА, QOS ТА УПРАВЛІННЯ РЕСУРСАМИ

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Описано науково-теоретичні підходи до реалізації гетерогенної мережі мобільного зв'язку на основі технологій SDN/NFV та SDR. Пропонується архітектура майбутньої гетерогенної мережі з урахуванням еволюції нових стандартів і ключових технологій. Створено алгоритм динамічного розподілу та резервування пропускної здатності між кількома логічними каналами в певний момент часу для забезпечення QoS для інформаційних потоків у майбутніх мережах. Створено імітаційну модель обслуговування мережевого трафіку з параметрами, що відповідають реальним мережам. Проведено дослідження навантаження фемтостільникового SDR, як основного конвергентного пристрою на рівні неоднорідного доступу до мережі користувачами технологій мобільного зв'язку різного покоління.

Ключові слова:*SDN; SDR; NFV; QoS; гетерогенні безпровідні мережі.*