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Analysis of Construction Principles of Fifth Generation Mobile Communication Networks (5G)

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Abstract

The article provides an overview of a number of scientific publications related to 5G networks in the last five years and analyzes the main technologies used in these networks. The 5G networks themselves have developed a structure that includes two planes, such as software-based implementation of functions and standard commercial equipment, as well as their architecture consisting of control and user planes. In order to expand the structure and architecture of these networks, their vector models have been proposed.

Keywords: 5G networks, 5G network structure, QoS parameters, vector models of 5G network structure, vector models of 5G network architecture.

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Beşinci nəsil mobil rabitə şəbəkələrinin (5G) qurulma prinsiplərinin analizi

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Xülasə

Məqalədə 5G şəbəkələrinə aid son beş ildə olan bir sıra elmi nəşrlər üzrə icmal verilmiş və bu şəbəkələrdə istifadə olunan əsas texnologiyaların təhlili aparılmışdır. 5G şəbəkələrinin özündə funksiyaların proqram təminatı əsasında həyata keçirilməsi və standart kommersiya avadanlığı kimi iki müstəvini ehtiva edən strukturu, eləcə də onların nəzarət və istifadəçi müstəvilərindən ibarət olan arxitekturası işlənmişdir. Bu şəbəkələrin strukturunun və arxitekturasının genişləndirilməsi məqsədilə, onların vektor modelləri təklif olunmuşdur.

Açar sözlər: 5G şəbəkələri, 5G şəbəkələrinin strukturu, QoS parametrləri, 5G şəbəkələrinin strukturunun vektor modelləri, 5G şəbəkələrinin arxitekturasının vektor modelləri.

Анализ принципов построения сетей мобильной связи пятого поколения (5G)

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Аннотация

В статье произведен обзор ряда научных публикаций, касающихся сетей 5G за последние пять лет. Проанализированы основные технологии, используемые в этих сетях. Разработана структура сетей 5G, включающих две плоскости – программную реализацию функций и стандартное коммерческое оборудование, а также разработана их архитектура, состоящая из плоскостей управления и пользователя. С целью расширения структуры и архитектуры этих сетей предложены их векторные модели.

Ключевые слова: сети 5G, структура сети 5G, параметры QoS, векторные модели структуры сети 5G, векторные модели архитектуры сети 5G.

Introduction

The fifth generation mobile communication networks (5G) is a dynamically developing technology that plays an important role in the development of the digital economy, has a high potential for creating new types of services and increasing their number. Unlike previous generation networks, 5G networks have the advantages of transmitting data at a higher speed and with lower latency, being able to connect a large number of users, using energy with high efficiency, having a high degree of transmission capacity, and providing high user mobility [1]. The high productivity, efficiency and low latency of these networks expand the possibilities of users and enable them to connect a large number of industrial objects, including agriculture, energy, and other industrial enterprises. 5G networks also improve the quality of healthcare due to high-speed data transmission [2], i.e. healthcare professionals can exchange patient information in real time, which significantly increases the efficiency of healthcare, as well as the time spent on diagnosis and treatment reduces. 5G network technology also enables the creation and development of new business models such as the smart city, which allows improving the living conditions of city residents and connecting city management systems [3]. This technology also makes it possible to sufficiently improve and develop traffic safety due to the rapid exchange of data in cars [4].

5G networks are widely used in most sectors of the economy, industrial enterprises, and households because of their functional capabilities and high-speed data transmission. These networks, thanks to their integration with digital economy technologies, create wide opportunities for the application of innovative technologies in the industry, significantly increase the level of automation of industrial enterprises and pave the way for the mass use of industrial robots. Thanks to the introduction of 5G networks, "smart home", "smart building", etc. the range of different services for solutions is expanding significantly. These networks contain a wide variety of devices, including smartphones, tablets, "surveillance cameras", weather sensors, "smart sensors" for power grids, and more can operate various devices.

5G network technology is also widely used in the telecommunications industry. This technology makes it possible to create infrastructure for teleproduction and broadcasting in the format of ultra-high-definition display, volumetric video and presence effect, to work in cloud storage, as well as to develop augmented and virtual reality services. Thanks to 5G network technology, viewers have the opportunity to watch 3D TV without glasses and watch the highest speed ultra-high definition online videos by downloading them in seconds.

The fact that 5G networks have high transmission speed and throughput enables them to transmit large amounts of data that will be generated by industrial projects. This feature allows to connect driverless cars, higher-speed video streaming, "smart cities", "smart roads", airplanes, dams, and more to 5G networks.

5G network technologies. A number of qualitatively different advanced technologies are used in the construction of 5G networks, one of which is the "Internet of Things" technology [5]. This technology is not only a large number of transmitters and devices connected to each other by a wireless network, but also a tight integration of the real and virtual world where communication between people and devices takes place. The Internet of Things technology not only connects all household appliances, but also allows connecting all areas of human activity.

However, another technology that may have a greater impact on 5G and next-generation networks than Internet of Things technology is Touch Internet technology, which requires a delay of 1ms [6]. The application of this technology in the network allows not only speech, video and data, but also human and robot touch sensations to be transmitted in real time. The Internet of Touch creates a real-time interactive system between

humans and machines, which realizes human-machine interaction in a massive network. Touch Internet allows you to draw, play musical instruments, and perform remote surgical operations. When using the Touch Internet in e-commerce, users have the opportunity to try out any product by touching it before buying it.

In 5G networks, a MIMO array is used to concentrate the signal with certain parameters and direct them in a certain direction, which provides the transmission of up to 8 data streams to one receiver [7]. This array, consisting of several antenna complexes, creates very sharp beam directions. Thanks to this, the strength of the received signal improves and the interference of other users is eliminated, which has a positive effect on the network's throughput and efficient use of the frequency spectrum. One of the technologies used in building 5G networks is Open Flow technology. This technology is a protocol that implements software-configured network technology based on routers and switches, as well as the management of the data transmission process over the network [8, 9].

One of the important achievements in building 5G networks is virtualization technology, which is considered a revolutionary concept from devices to software solutions. This technology allows to optimize network resources and increase the productivity of networks. 5G networks are implemented on the basis of software-based network PTS and virtualization of network functions. The functions of these networks are implemented by the virtual network functions running in the HFV infrastructure. PTS is an effective technology that allows to reduce the amount of equipment and simplify infrastructure maintenance. This technology implements software-based digital transformation and the transfer of services to cloud technologies.

SFV allows mobile operators to virtualize network functions and at the same time realize "network on demand", as well as separate hardware and computing parts from each other. In this technology, special equipment is used to perform network functions. Thus, while the traditional model requires appropriate hardware for each network function, a single physical foundation is sufficient in the HFV model. At this time, all data is processed and stored in the "Cloud" virtual environment, and the function of transferring user traffic is performed with classic equipment. This approach corresponds to convergence, which integrates separate network objects into a single computing complex, which is very important for "smart" devices for online exchange of information.

Structure of 5G networks. The structure of 5G networks includes two layers, such as software-based implementation of functions FPTR and standard commercial hardware SKA. A simplified structure of the 5G network is given in figure 1.

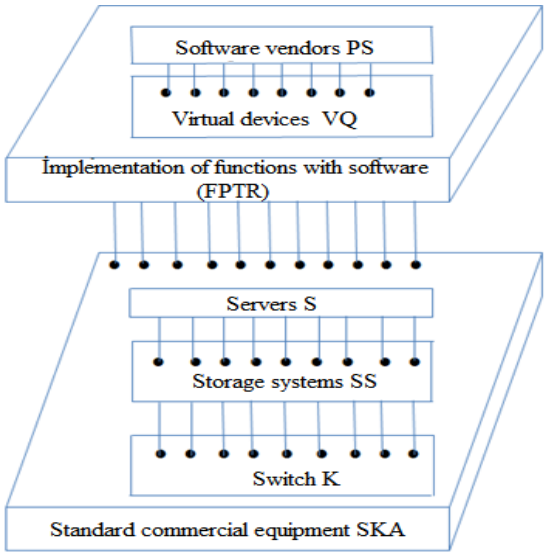

Figure 1 – Simplified structure of a 5G network

The FPTR plane connects software vendors PS and virtual devices VQ to itself. Software vendors PS's function is to sell and promote software under its brands and trademarks. The PS function does not always produce goods independently, its main task is the promotion and sale of programs. Virtual devices perform the function of virtualization in the network. These devices enable operators to facilitate network

expansion, increase the availability of new services, and reduce both capital and operational costs for the network.

Standard commercial hardware The SKA plane includes three types of standard equipment that are relatively inexpensive, including servers, storage systems, and switches. Servers play an important role in the realization of 5G networks. They implement virtualization of network functions and provide the computing power required to host network functions, the volume of standard storage systems, and network connectivity to host virtualized network functions. Servers also provide resource pooling, network scalability, flexibility, productivity and efficiency, as well as reliability.

Storage systems SS itself reflects the evolution of the domain name server. These systems store information about the types of network functions, their names and extents, identifiers of network function instances and network levels, IP-addresses of network functions, exchange points for each service, etc.

The switch performs the processing and management of the flow of packets transmitted over the network, as well as determines the basic functions of forwarding the flow of packets through the table it has, and quickly directs them to the appropriate output interface.

Architecture of 5G networks. The architecture of these networks includes two planes, the control plane and the user plane. A simplified architecture of the 5G network is given in figure 2.

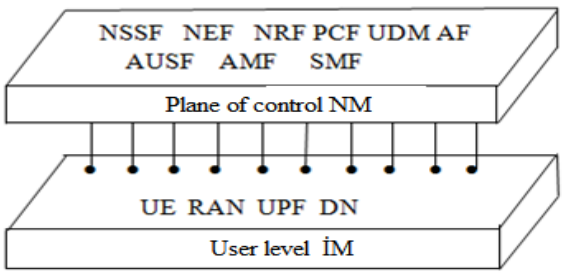

Figure 2 – Simplified architecture of 5G network

The control plane includes the following software modules and network functions [8]: NSSF- network segment selection function. This feature selects the best available segments for the service users want in a 5G network environment with multiple services. NEF - the function of ensuring the interaction of applications with an external platform. This function enables the interaction of external platform and applications with the backbone network (5GC). The NEF function allows platforms, applications to subscribe to specific events generated by various network elements and to receive notifications about such events, transfer data for specific user terminals, manage QoS settings and rate policies (PCC) for these terminals. This function uses subsets of application programming interfaces (APIs) to interact with various elements, platforms, applications, and other functions.

The security of these interactions is ensured by security mechanisms implemented directly by the NEF function, including authentication and authorization of compatible platforms and applications. NRF – function of saving network functions. This function provides for saving copies of network functions deployed in networks and selecting one or more instances of them. Each network function must register its storage status, functionality capabilities, and supported options when enabled.

PCF – policy control function. This function forms certain policies, including quality of service QoS parameters and pricing rules, to user terminals in real time. PCF also determines the service required by the subscriber to transmit any type of traffic, its profile, location, network load level, etc. dynamically creates virtual channels with different characteristics.

UDM – user data management module. This module performs user data management, including the list of services available to users, saving and modifying their corresponding settings. UDM also provides user registration, SMS message delivery, user ID management, as well as service and communication session continuity.

AF – app function. This function performs interaction with the 5GC core network, PCF – policy control function and traffic routing management, as well as provides access to the function of providing interaction with NEF – external applications.

AUSF – function of authentication server. This function stores the key obtained after authentication for reuse during simultaneous registration of user terminals on different network technologies.

AMF - access and mobility management function. This function provides the organization of the interfaces of the control plane and performs the organization of the exchange of signal traffic, its data encryption and integrity protection.

SMF - session management function. This feature provides session creation, modification, and release, including maintaining a tunnel between the access network and the UPF. The SMF function also manages the distribution and management of user equipment IP addresses, the selection of the used UPF gateway, the organization of interaction with the policy control function PCF, etc. realize.

The user plane integrates the following software modules and network functions: UE - express terminal. This terminal detects the first and second synchronization signals in 5G networks, as well as performs the synchronization function with the radio access network RAN. In this case, a specific user terminal can be served by one or more network layers at the same time. Accordingly, throughout the session, the UE is served by a UPF gateway having an IP address.

RAN – radio access network. This network is a set of mobile network elements responsible for the management of radio connections, as well as the distribution of frequency resources among subscribers. That is, it is a part of the system that directly interacts with smartphones and regulates their activity. RAN user terminals are connected wirelessly by the UE to the core network. The backbone network of 5G is 5GS session management SMF, authenticity verification AUSF, policy control PCF, network function storage function NRF, etc. facilitates the operation of various network functions.

UPF – data transmission function. This function provides an interface for connecting to external data networks, including the global Internet, as well as routing and forwarding data packets. Notifies user terminals that packets are buffered and data downlinks are available, as well as marking data packets according to the required QoS parameters.

DN – external networks. These networks include networks that belong to the 3GPP standard and those that do not.

Vector models of the structure and architecture of 5G networks. In order to mathematically expand the structure of these networks given in Figure 1, its vector base model [9] can be written with the following vector:

$$W_s = [F, S],$$

where F and S are subvectors of software-based implementation of functions and standard commercial hardware plane subsystems, respectively.

F – subvector is equal to:

$$F = [V_{PS}, V_{VQ}]$$

where V_{PS} and V_{VQ} indicate subsets of software vendors and virtual devices, respectively.

The S-subvector can be written as follows:

$$S = [V_S, V_{SS}, V_K],$$

where V_S, V_{SS} and V_K are servers, storage systems, and switch subsets, respectively.

In order to mathematically extend the architecture of the 5G network given in Figure 2, the vector base model can be written as follows:

$$W_A = [N, I],$$

where N and I are subsystems representing the corresponding interacting control and user plane subsystems.

The N-subvector is equal to:

$$N = [V_{NSSF}, V_{NEF}, V_{NRF}, V_{PCF}, V_{UDM}, V_{AF}, V_{AUS}, V_{AMF}, V_{SMF}]$$

where

$$V_{NSSF}, V_{NEF}, V_{NRF}, V_{PCF}, V_{UDM}, V_{AF}, V_{AUS}, V_{AMF}$$

and V_{SMF} – according to network segment selection function, external application interoperability function, network function storage function, policy control function, user data management module, the application function, the authentication server function, the access and mobility management function, and the session management function are subsets.

The i-subvector can be written as:

$$I = [V_{UE}, V_{RAN}, V_{UPF}, V_{DN}],$$

where V_{UE}, V_{RAN}, V_{UPF} are V_{DN} subsets of UE - user equipment, radio access network, data transmission function and DN - external networks.

Conclusion

An overview of a number of existing scientific publications related to 5G networks was given, and technologies such as Internet of Things, Touch Internet, MIMO arrays, Open Plow and virtualization used in these networks were analyzed.

The issue of developing the structure and architecture of 5G networks was considered, the structure containing two levels such as software-based implementation of functions and standard commercial equipment, as well as the architecture of these networks consisting of control and user levels, the main software modules of these levels were developed and network functions were analyzed.

The issue of expanding the structure and architecture of 5G networks from a mathematical point of view was considered. For this purpose, vector base models of the structure and architecture of 5G networks, as well as their corresponding subvector models based on these models, have been proposed.

Conflict of Interests

The authors declare there is no conflict of interests related to the publication of this article.

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