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INTELLECTUALIZATION OF DATA FLOW MANAGEMENT IN MOBILE RADIO NETWORKS AT THE NETWORK LEVEL OF THE OSI MODEL

Abstract. Topicality. The rapid development of mobile radio networks of the 5G and 6G standards is accompanied by an increase in the volume of heterogeneous traffic, increased requirements for latency, reliability and adaptability of the network infrastructure. Under conditions of dynamic topology, radio channel instability and limited spectral resources, traditional data flow management mechanisms, developed mainly for wired IP networks, demonstrate limited efficiency. This makes it relevant to study intelligent approaches to data flow management at the network level of the Open Systems Interconnection (OSI) model, which provides logical addressing, routing and inter-node interaction. **The subject of the study** is methods for managing data flows in mobile radio networks at the network level, as well as mechanisms for adapting them to the dynamic conditions of the radio environment. **The purpose of the article** is to analyze existing methods for managing data flows to determine the possibility of their application in mobile radio networks, to substantiate the need for intellectualization of the management process and the formation of an intelligent approach to managing data flows at the network level of the OSI model. **Results obtained.** The analysis of classical approaches to data flow management was carried out, their functions and limitations in the conditions of mobile radio networks were determined. It was substantiated that the use of intelligent algorithms allows to increase the efficiency of radio resource use, reduce transmission delays and ensure the stability of network operation in conditions of variable bandwidth. A generalized model of an intelligent data flow management system at the network level is proposed, which takes into account network state parameters and traffic characteristics in real time. The feasibility of integrating intelligent mechanisms into the processes of routing and data flow management in mobile radio networks is determined, the advantages and disadvantages of routing methods when used in mobile radio networks are outlined. **Conclusion.** Intellectualization of data flow management at the network level of the OSI model is a necessary condition for ensuring the effective operation of new generation mobile radio networks and increasing their adaptability, scalability and resistance to dynamic changes in the data transmission environment.

Keywords: intellectualization of management; mobile radio networks; network layer; OSI model; data flow management.

Introduction

Problem relevance. The rapid development of mobile telecommunications and the introduction of new generation networks is accompanied by a significant increase in the volume of transmitted data, the emergence of new types of services and increased requirements for the quality of service of network traffic. Modern mobile radio networks provide the functioning of a wide range of applications - from mobile Internet and multimedia services to the Internet of Things, autonomous transport and real-time systems. In such conditions, the requirements for effective data flow management, minimizing delays, increasing the reliability of information transmission and optimal use of limited radio resources are significantly increasing.

At the same time, mobile radio networks are characterized by a highly dynamic operating environment, due to user mobility, changes in radio channel parameters, uneven load and limited spectrum bandwidth. Traditional data flow control mechanisms used in IP networks are not always able to respond effectively to rapid changes in the network state. The network layer of the OSI model, which implements the functions of routing, logical addressing, and packet transmission control between network nodes, requires special attention.

In this regard, it is relevant to study and implement intelligent approaches to data flow management, which involve the use of adaptive algorithms, network traffic analysis methods and machine learning technologies to

make effective decisions in conditions of uncertainty and dynamic changes in network parameters. The intellectualization of the data flow management process allows to increase the efficiency of radio resource use, ensure the stability of network operation and improve the quality of user service in new generation mobile radio networks.

Literature review. In scientific research on the functioning of telecommunication and mobile radio networks, considerable attention is paid to the problems of efficient transmission and service of information flows. It is known that several data transmission routes can pass through one node of a mobile radio network, as a result of which network elements must ensure the identification of traffic types and their differentiated service in accordance with the requirements of quality of service. This is due to the fact that different types of traffic (data, voice, video) have different requirements for delay, bandwidth and transmission reliability.

In the scientific literature, a data stream or information flow is defined as a continuous sequence of data united by common features that allow them to be distinguished from the general network traffic. [1] Researchers note that two main groups of statistical characteristics are used to assess network performance and ensure the required quality of service. The first group includes packet delay characteristics, in particular packet delivery delay, average delay value, maximum delay time, delay variation and packet turnover time in the network. The second group includes transmission speed characteristics, such as instantaneous, average and peak

data transfer rates. [1-3] It is these parameters that determine the requirements of different types of traffic for network resources.

Many authors emphasize that the main task of telecommunication and mobile radio networks is the reliable transmission of data streams with specified quality of service parameters. The relevance of this problem increases with the growth of the number of modern application services that impose more stringent requirements on the bandwidth of communication channels, transmission delays and network stability. [4] Multimedia services, streaming video and real-time services are especially sensitive to network parameters.

Given that a significant part of information flows is sensitive to network congestion, delays and packet loss, scientific works emphasize the need to apply special methods of data flow management. Such methods should ensure effective decision-making under conditions of a priori uncertainty arising from high user mobility, changing network topology and instability of radio channel parameters, which are characteristic of mobile radio networks. [5-8]

In general, data flow management in a telecommunication network is considered as a process of matching the characteristics of information flows with the parameters of network resources that provide their service. This is achieved by setting the optimal values of network element parameters, which guarantee data transmission with a given quality of service. [9, 10] In this case, the data flow management mechanism is implemented as a set of rules and traffic processing algorithms that determine packet transmission routes, service strategies and disciplines in network nodes, as well as procedures for preventing overloads and blocking. In addition, an important component of such mechanisms is the regulation of incoming traffic and effective management of buffer resources of network equipment.

In packet-switched networks, data flow control methods are primarily aimed at preventing network overload, optimally distributing resources between users, and matching network performance with the level of incoming load. At the same time, an analysis of modern scientific publications shows that the effectiveness of these mechanisms largely depends on the level of their implementation in the network architecture, as well as on the management methods used.

In this regard, further consideration of the problem should be directed to the study of data flow management levels in telecommunication networks, the definition of the main functions of data flow management methods, as well as the analysis of existing methods used to optimize the transmission of information flows in modern networks. This will allow us to determine their advantages, limitations, and possibilities of use in mobile radio networks.

The purpose of the article is to study and generalize existing methods of data flow management in order to assess the possibility of their use in mobile radio networks, as well as to substantiate the feasibility of implementing intelligent approaches to network traffic management and to determine the conceptual principles

of building an adaptive data flow management system at the network level of the OSI model.

1. Research into approaches to data flow management for their application in mobile radio networks (MRN)

In telecommunication networks, the following levels of data flow control are distinguished [11]:

1) inter-node level - at this level, data flow control is provided between two neighboring switching nodes in order to prevent overflow of local buffers (OSI model link layer);

2) network access level - the incoming flow is limited based on the results of measuring the internal network load. Management is carried out between subscribers and the switching node (OSI model link and network layer);

3) «switching node-source-switching node-destination» level. Prevents overflow of the switching node-destination buffer (OSI model network layer);

4) «process-process» level. Prevents overflow of user buffers at the process level (OSI model transport layer).

Taking into account the above, Fig. 1 shows the main functions that should be implemented by data flow control methods used in MRN, as well as the mechanisms by which these functions can be implemented.

The purpose of collecting information about the network state (the state of the information direction between the sender and the recipient) is to determine the list of controlled network parameters, the values of which will be used by the node control system to make decisions on data flow control, routing, energy resources, etc. [8]

Coordination of transmission and reception speeds, as well as ensuring reliable information transmission at all protocol levels, is based on mechanisms and methods for reducing redundancy in information transmission, detecting congestion, controlling the window size and retransmission timer.

Congestion prevention is achieved by controlling the incoming flow (flow limiting) in the nodes of the data transmission network. In this case, methods of global and local data flow control are distinguished. Global control involves either limiting the total number of packets transmitted in the network (isorhythmic control), or limiting the number in each virtual connection "source-destination" (end-to-end control). In accordance with local control, either the total number of packets in the switching node is limited, or the number of buffers allocated to different classes of packets.

In addition, to prevent congestion, prediction methods can be used, the main task of which is to predict the network zone (section of the information direction) that will be overloaded, using the collected information about the network state. This will allow redirecting data flows to less loaded routes (information about existing routes from the network layer of the OSI model - the routing control subsystem [12]) and avoid a sharp reduction in network throughput.

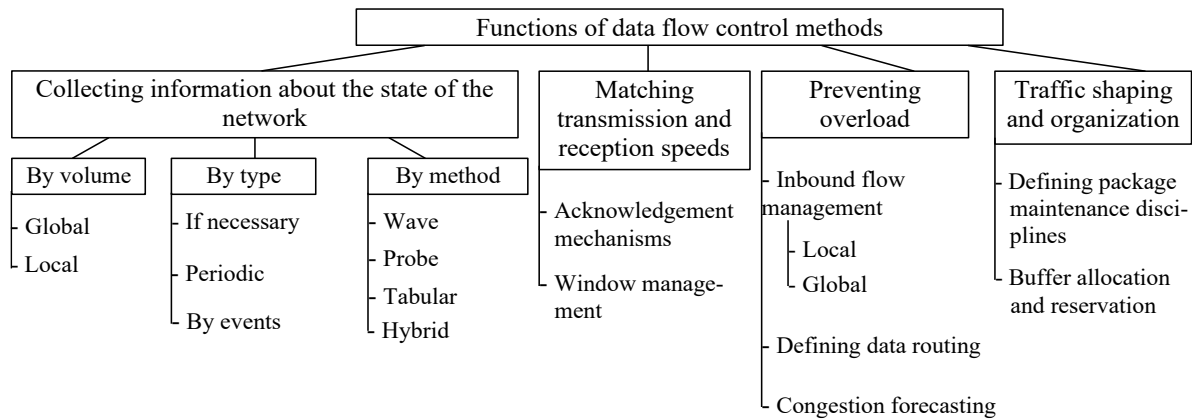


Fig. 1. Functions of data flow control methods in mobile radio networks

Traffic shaping and ordering involves defining packet service disciplines of different priorities (dropping packets when queues are full – Tail Drop, Random Drop, Drop from Front, Random Early Detection; methods that determine the sequence of queue service – First In – First Out, Class-Based Queuing, fair queue, Weighted Fair Queuing, Priority Queuing, etc.; methods for pre-reserving resources – bandwidth, processor performance, buffer memory, etc.) and buffer allocation and reservation (arbitrary allocation of buffer memory between queues, limiting the maximum queue length, partitioning with limiting the maximum queue length and guaranteed minimum queue length).

Let us analyze and classify the methods of data flow control that implement the above functions.

In fixed communication networks, reliable and high-quality data flow transmission is ensured by the functioning of transport layer protocols of the OSI model, in particular TCP and UDP, as well as their modifications.

The transport layer protocol UDP is responsible for the transmission of multimedia information in real time, but it does not have mechanisms for controlling data flows and guaranteeing information delivery. Therefore, the TCP protocol is the main data flow control protocol in fixed communication networks, which ensures the coordination of transmission speeds between all network elements, prevents network congestion, and also ensures reliable information delivery by establishing a virtual connection between the sender and the recipient. At the same time, the control parameters by which the TCP protocol affects the network throughput S (1) are the size of the congestion window W and the amount of time to wait for a receipt confirming the correct reception of data packets by the recipient (retransmission timeout) [4, 12]:

$$S = \frac{W \cdot MSS}{T_R}, \quad (1)$$

where MSS – the maximum size of a transport layer segment that can be sent to the network.

However, as the analysis [12-14] showed, the specifics of the operating conditions of MRNs and the

differences in the tasks they solve make it impossible to use TCP and UDP protocols when building MANET class networks or significantly reduce their efficiency due to the high dynamics of the network topology.

The classic TCP protocol has a number of disadvantages [4, 9-10], which are especially noticeable when used in networks with dynamic topology:

1) TCP cannot distinguish packet loss due to route breakage from loss due to network congestion, so packet loss in the MRN is always regarded by the protocol as occurring due to congestion. This leads to low efficiency of using the congestion window method in wireless networks, where the probability of transmission route breakage is significant due to the high dynamics of the network topology. In this situation, instead of searching and building new transmission routes, the TCP protocol continues to generate retransmissions, filling the MRN with service traffic;

2) «dishonest behavior» of TCP involves competition between nodes for the channel bandwidth. To determine the maximum possible congestion window, a rapid increase in the intensity of sending segments is carried out, which occurs until the packet is lost, after which a more rapid reduction in the window size is carried out to avoid network congestion. This drawback leads to spikes in the network load and, accordingly, to an increase in the probability of segment loss;

3) data flow control is carried out mainly by end nodes without the possibility of intermediate nodes on the route to influence packet transmission.

In order to increase the performance of the TCP protocol, as well as its adaptation to the dynamic environment of MR, a number of data flow control methods have been developed: Tahoe, Vegas, Reno, Newreno, Random Early Detection, etc. However, these methods are focused on static or quasi-static conditions of MR operation and do not eliminate the problem of the TCP protocol associated with the inability to detect the cause of packet loss [12, 14].

Considering the functions of data flow control methods that should be implemented in MANET class networks, as well as existing methods, it is proposed to distinguish the following classification features of data flow control methods (Fig. 2):

by type: active (prevent overloads), reactive (contain mechanisms for dealing with overloads after their detection);

by the number of supported transmission speeds: multi-speed (with the ability to switch to lower transmission speeds in case of overload detection), single-speed (without the ability to switch to other speeds);

by the presence of feedback: with explicit feedback (the router explicitly informs the load source about the network state), without feedback (the sender is informed about the overload through the receiver, thus they are both responsible for determining the network state. Implemented in Leaky Bucket and Token Bucket) [12, 14];

by type of data flows: external flow control (data flows that pass through a node using it as a switch), internal flow control (data flows that enter or exit an end node);

by number of routes: single-path (data is transmitted via one route), multi-path (data is transmitted via several different routes);

by functioning at the OSI model level: single-layer (at the link, network or transport level), inter-layer (provide interaction between several levels of the OSI model);

by the presence of service priority: without priority, with priority;

by the place of control: end-to-end, between two neighboring nodes, between processes of the upper layers of the OSI model [11];

by the class of hardware: used in terminal equipment or in routers;

by the control parameter: congestion window, sender queue size, recipient queue size, retransmission timer [12], route [15], topology [16], channel access method (TDMA, CDMA, FDMA) [17].

Table 1 compares the data flow control methods discussed above, taking into account the main classification features shown in Fig. 2. Thus, it can be concluded that the main attention of researchers engaged in improving the TCP protocol for use in MANET class networks is aimed at ensuring the interaction of the specified protocol with protocols of other layers of the OSI model (in particular, network and link). First of all, this interaction should solve the issue of the inability of TCP to detect the cause of packet loss in MRN. However, to date, the considered methods (protocols) are only at the stage of experimental research [14].

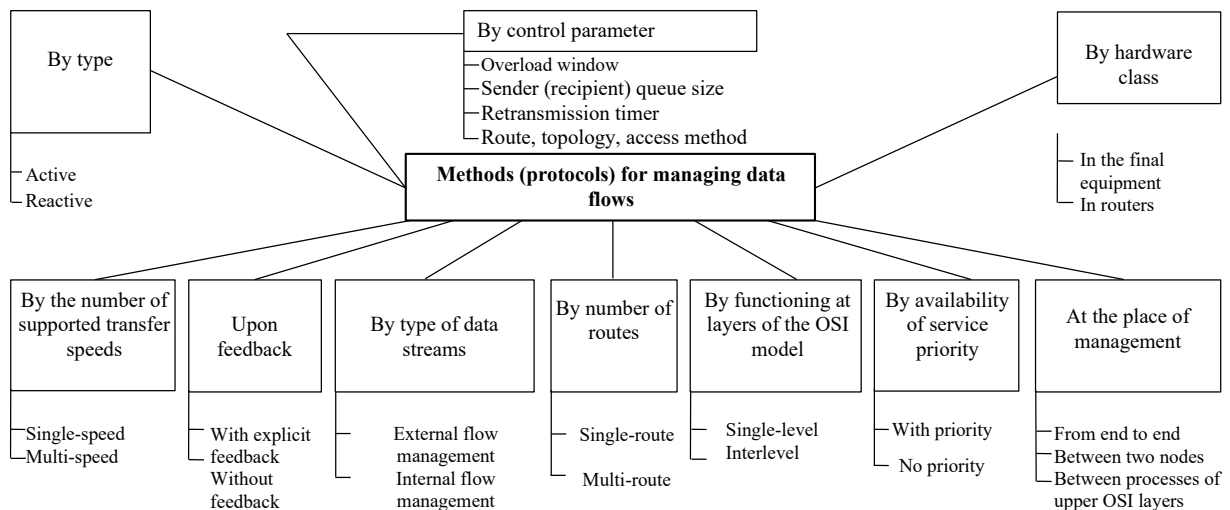


Fig. 2. Classification of data flow management methods (protocols)

Table 1 – Comparison of existing methods (protocols) for data flow management

Method	OSI model layers	Control parameter	Route loss detection/rerouting capability	Control room/equipment	Complexity	Network type
TCP	SL*	OW*, RTO*	No / No	End-to-end / End devices	Low	Wired
TCP-F	IL*	OW, RTO	Yes / No		Medium	MANET
ELFN	IL	OW, RTO	Yes / Yes		Medium	MANET
ATCP	IL	OW, RTO	Yes / Yes		High	MANET
Fixed RTO	SL	OW, RTO	Yes / No	End-to-end / Sender node	Low	MANET
TSR	IL	RT*, PRIT*	Yes / Yes	End-to-end / End devices	High	MANET

Method	OSI model layers	Control parameter	Route loss detection/rerouting capability	Control room/equipment	Complexity	Network type
<i>C³TCP</i>	IL	B*, PRTT	No / No		Medium	Ad-Hoc
<i>C³Reno-2</i>	IL	TP*, OW	No / No		Medium	Ad-Hoc
<i>Fuzzy-RED</i>	SL	OW, message queue	No / No		High	MANET

* Marking: SL – single-level; IL – interlevel; OW – overload window; RTO – retransmission timeout; RT – route table; PRTT – packet round trip time; B – bandwidth; TP – transmitter power.

A common drawback of existing approaches to improving the TCP protocol is that intermediate nodes on the transmission route either do not participate in the process of managing data flows at all, or only measure the network state parameters, without being able to influence their optimization.

Also, the proposed approaches use a limited number of parameters (taking into account only certain features of the wireless environment), which does not allow for a sufficiently accurate assessment of the network state. In addition, most of the considered methods require feedback from the network to assess the situation in it, and are unable to make control decisions under conditions of uncertainty. At the same time, the main sources of uncertainty in MR control problems are [18, 19]:

complexity of the formalized description of MRN and their management tasks, taking into account errors in calculations and measurements;

vagueness of the goals of functioning and management tasks;

non-stationarity of MRN parameters and their management system (high mobility of subscribers, change and unpredictability of the network topology);

a priori uncertainty of the situation and conditions of MRN functioning;

presence of random and intentional influences of the external environment (means of destruction and radio-electronic suppression);

distortion of information during transmission in radio communication channels, etc.

Therefore, for effective data flow management in MANET class networks, in addition to inter-layer interaction, the following directions for improving the TCP protocol and its modifications are proposed:

1. Using a set of heterogeneous parameters for evaluating the state of the MRN to make decisions on data flow management at different levels of the OSI model.

2. Intellectualizing the data flow management process.

3. Predicting the loss of connectivity between mobile nodes.

4. Developing multi-path information transmission methods.

The implementation of these approaches will reduce the time spent on collecting and analyzing service information about the network status, reduce the volume of this information, and minimize errors associated with making the wrong decision on managing the MR, taking

into account the requirements for transmitting certain types of traffic. In addition, the use of knowledge processing technologies will ensure the ability of nodes to self-learn in the process of transmitting information and the ability to self-organize into the network at the stage of its initialization.

2. Developing an intelligent approach to data flow management in MRN

Ensuring effective management of MR in conditions of frequent changes in the situation is possible only with the presence of a nodal control system capable of making management decisions in conditions of uncertainty. In addition, ensuring the ability of MR to self-organize, as well as adapt its nodes to different operating conditions requires the presence of a learning subsystem as part of the nodal control system. The functioning of the learning subsystem is not possible without a knowledge base, the main task of which should be the formation of new rules of "behavior" of the node based on the analysis and generalization of information about the state of MRN [6].

Today, control systems are intensively developing in the direction of their intellectualization, while the technology of making management decisions is significantly changing. Intelligent information systems (IIS) combine the capabilities of database management systems and artificial intelligence technology, thanks to which the storage of management information in them is combined with its processing and preparation for use in decision-making.

For a long time, it was believed that IIS are effective only for solving the so-called non-formalized and poorly formalized tasks associated with the need to include in the algorithm for their solution data on training on real experimental material (for example, pattern recognition tasks). However, recently, IIS have been increasingly used in solving tasks in communication and telecommunications systems: switching control, routing, traffic management, channel allocation in mobile radio communication systems, etc. [20, 21].

Let us give some arguments in favor of the fact that IIS should become the most important component of the management system of a MANET network node:

firstly, the main problem in managing a MANET network is the need to choose from a variety of possible management solutions depending on the situation in the network, as well as the requirements for transmitting a certain type of traffic;

secondly, network management requires processing a large amount of service information about its state,

which is used by management methods of different levels of the OSI model to make appropriate decisions. The problem of obtaining information from objects (network nodes) operating in real time has been solved today (using various methods of network probing) [15]. But this gave rise to another problem: how to reduce the amount of service information to the level that is really necessary for the management system to make a decision? At the same time, it should be noted that the loss of service information coming from network nodes operating in real time can significantly affect the final decision made by the management system;

thirdly, the lack of time for decision-making and the problem of coordinating the interaction of control methods that perform various functions (data flows, routing management, topology, energy consumption, security, etc.).

In this regard, in [19-21] it is proposed to intellectualize the process of managing MRN resources by using various knowledge processing technologies when building a nodal control system.

Fig. 3 shows a generalized model of an intelligent MRN node control system. The control system has a rather complex structure, which includes a number of functionally subordinate subsystems, including the data flow control subsystem. Such a division involves a multi-level organization of the control system, which has

developed intellectual capabilities for analyzing and recognizing the situation in the MRN, forming a strategy for the appropriate behavior of MRN nodes, planning a sequence of actions, as well as synthesizing control influences aimed at meeting the requirements for servicing certain types of traffic.

It is important to note that the main architectural feature that distinguishes an intelligent control system from one built according to the “traditional” scheme (Fig. 3) is connected precisely with the connection of mechanisms for storing and processing knowledge (the “knowledge base” block) to implement the ability to perform the necessary functions in conditions of uncertainty (incomplete information) with the random nature of external influences. The knowledge base contains information about the principles of building a control system and the purpose of its functioning, the specifics of using various control methods, as well as the features of the functioning of the decision-making subsystem and the control object itself. In addition, the control system, if necessary, may include a subsystem for replenishing knowledge and training, which provides generalization of accumulated experience and, thus, replenishes the base with new knowledge.

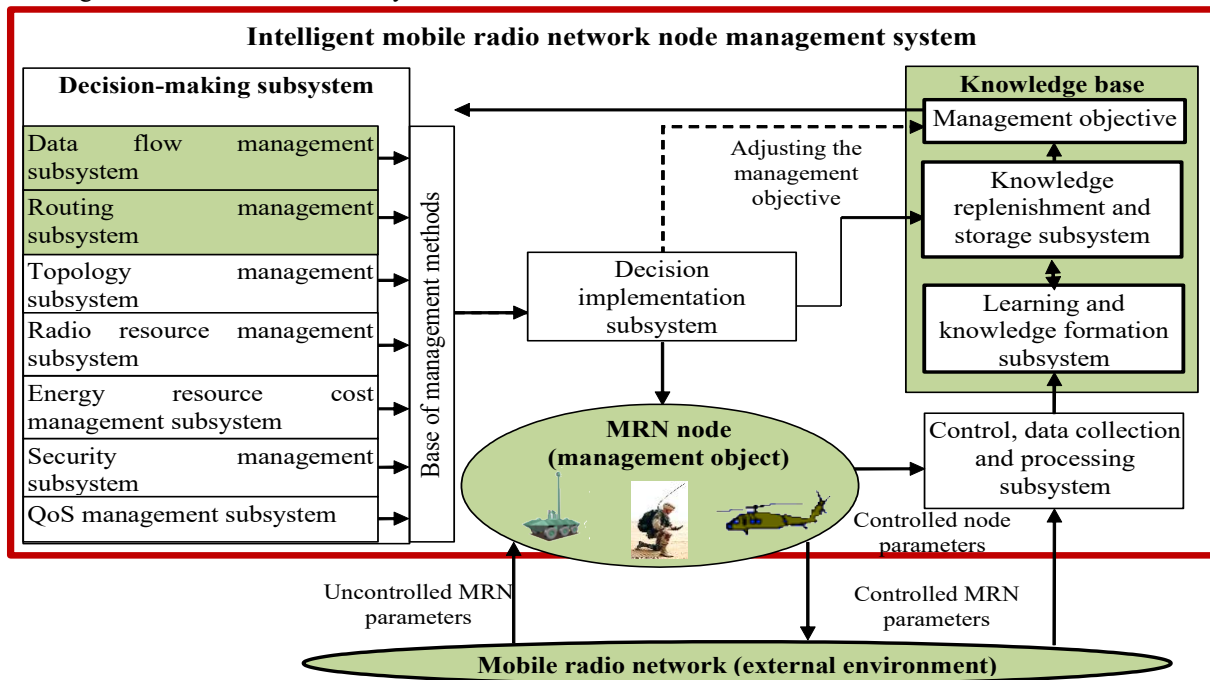


Fig. 3. Generalized model of an intelligent control system for a mobile radio network node

The subsystem of control, collection, processing and storage of data is intended for measurement of the monitored parameters of mobile nodes and the radio network as a whole. Different functions (levels) of control require different volume (number of parameters) and depth of collection of information about the state of the network. The depth of collection by the *i*-th node of the network is usually determined by the distance (area in the presence of a positioning system), which is given

by the number of relay sections from this node. Of course, knowledge of complete information about the network allows to make more informed decisions, but leads to a significant increase in service traffic in the conditions of topology dynamics and input load.

The decision-making subsystem is built on the principle of control functionality, which is presented in [22]. Combining the functions of the control system into relatively independent groups allows for the

decomposition of network control into subsystems, which greatly simplifies the task of developing mathematical support for control.

The organization of elements of an intelligent network control system requires the use of a set of knowledge representation models, information support, description of the controlled object, etc. The main difference in building an intelligent MR control system is the use of artificial intelligence methods and technologies as the main means of combating the uncertainty of the external environment. The practical implementation of this concept assumes the selective use of certain knowledge processing technologies depending on the specifics of the tasks being solved and the characteristics of the control object.

Thus, today, the intellectualization of control systems and their transformation into IIS is taking place. The introduction of IIS into the MRN control system will allow:

to reduce the time spent on collecting and analyzing service information about the network status, to reduce

the volume of this information by taking into account the situation in the network, as well as the requirements for traffic transmission;

to minimize errors associated with making the wrong decision on radio network management, which are caused by the human factor in the process of network initialization.

3. Managing data flow routing at the network layer of the OSI model

Data flow management at the network layer of the OSI model is carried out by routing data flows between the sender and the recipient. Today, there is a large number of studies related to the study of data flow routing processes in both fixed networks and MANET class networks. A detailed classification (Fig. 4) of routing methods (RM), as well as the functions performed by MRN in fixed networks and MANET class networks are given in [15].

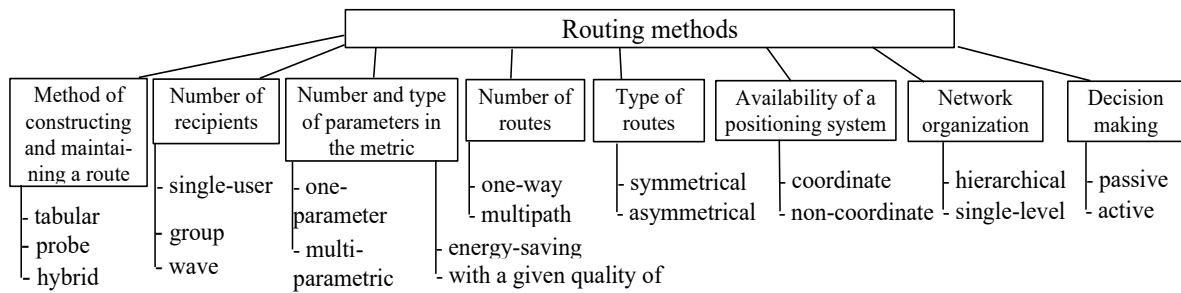


Fig. 4. Classification of routing methods

In the context of data flow management in mobile radio networks, an important role is played by the effective organization of routing, which is implemented at the network layer of the OSI model. It is at this level that the selection of packet transmission routes between network nodes is carried out, which directly affects the data delivery delay, the level of packet loss and the overall network performance. This process becomes particularly complex in mobile radio networks, where the network topology can change dynamically due to the movement of nodes and the instability of the radio channel.

According to the above classification (Fig. 4), routing methods are divided into three main classes according to the method of constructing and maintaining routes: table-oriented, probe and hybrid. Each of these approaches has its own peculiarities of organizing the routing process and a different level of efficiency in dynamic mobile networks.

Table-oriented routing methods involve constant maintenance of up-to-date information about the network topology and available routes to other nodes in the network nodes. To do this, each node generates and periodically updates routing tables containing information about the optimal paths for transmitting packets. The advantage of this approach is the possibility

of fast data transmission without additional route search procedures when the need arises for transmitting packets. However, in mobile radio networks, where the topology often changes, constant updating of routing tables leads to an increase in service traffic and load on network resources.

Probe routing methods are based on a different principle: routes are formed only when there is a need to transfer data between nodes. In this case, the source node initiates the route search procedure by distributing special requests in the network. After the route is established, data transmission is carried out along the found path. This approach allows you to reduce the amount of service information in the network, since there is no need to constantly update routing tables. However, the route search procedure can lead to additional delays before data transmission begins.

Hybrid routing methods combine the advantages of table-based and probe-based approaches. Within such methods, the network is usually divided into certain logical zones or clusters. Within a zone, routes are maintained according to the tabular principle, which provides fast access to local nodes, while for interaction between different zones, a probe route search mechanism is used. This approach allows to reduce the amount of service traffic and at the same time reduce the time for

establishing routes, which is especially important for mobile radio networks with dynamic topology.

Thus, the analysis of existing classes of routing methods shows that each of them has both advantages and limitations when used in mobile radio networks. The high dynamics of the operating environment, the variability of radio channel parameters and the unevenness of the network load complicate the application of traditional routing algorithms. In this regard, the search for new approaches to managing data flow routing is relevant, in particular, using intelligent methods that can adapt to the current state of the network and ensure more efficient use of network resources.

Discussion of results

In the course of the study, approaches to data flow management in mobile radio networks were analyzed and the features of their application in a dynamic network environment were determined. The analysis of the functions of data flow management methods showed that the main tasks of such methods are to regulate traffic intensity, prevent network overload, optimize the use of network resources and ensure the required quality of service for different types of traffic. Based on the study of literature sources, a classification of data flow management methods was carried out and their comparative analysis was conducted. The results obtained indicate that traditional data flow management methods function effectively in relatively stable networks, however, in mobile radio networks their effectiveness is reduced due to the variability of the topology, instability of the radio channel parameters and uneven network load.

The second important aspect of the research was the formation of an intelligent approach to data flow management in mobile radio networks. The article proposes a generalized model of an intelligent control system for a mobile radio network node, in the structure of which special attention is paid to the decision-making subsystem. Within this subsystem, a data flow management subsystem and a routing subsystem are distinguished, which ensure adaptive decision-making regarding the allocation of network resources and the selection of data transmission routes. This approach allows taking into account the current state of the network, traffic characteristics and radio environment parameters, which creates the prerequisites for increasing the efficiency of mobile radio networks.

Special attention is paid to the management of data flow routing at the network level of the OSI model. The article provides a classification of routing methods, which include table-oriented, probe and hybrid methods. For each of these approaches, characteristic features, advantages and limitations when used in mobile radio networks are determined. The analysis showed that table-oriented methods provide fast access to routes, but create significant service traffic, probe methods allow to reduce the amount of service information, but can cause

additional delays in route establishment, while hybrid approaches combine the advantages of both methods, but require more complex management mechanisms.

The results obtained confirm the feasibility of integrating intelligent mechanisms into the processes of data flow management and routing in mobile radio networks. The use of intelligent algorithms within the decision-making subsystem allows adapting the management process to changes in the network state and traffic characteristics, which contributes to increasing the efficiency of network resource use and improving the quality of service indicators. Thus, the results of the study confirm the prospects for further development of intelligent data flow management methods at the network level of the OSI model for new generation mobile radio networks.

Conclusions

The article considers the features of data flow management in new generation mobile radio networks and analyzes the possibilities of applying existing traffic management methods at the network level of the OSI model. The analysis showed that traditional approaches to data flow management, developed mainly for wired IP networks, do not fully take into account the specifics of the functioning of mobile radio networks, in particular, dynamic topology changes, instability of radio channel parameters, and uneven network load.

It has been established that the efficiency of mobile radio networks largely depends on the mechanisms of routing and data flow management, which should ensure rational allocation of network resources, minimize transmission delays and reduce the probability of packet loss. The analysis of routing methods has shown that table-oriented, probe and hybrid approaches have both advantages and certain limitations when used in conditions of high mobility and variable bandwidth of communication channels.

The feasibility of using intelligent approaches to data flow management, which allow adapting the decision-making process to the current state of the network, traffic characteristics and changes in radio environment parameters, is substantiated. The use of intelligent algorithms in routing and traffic management processes creates the prerequisites for increasing the efficiency of radio resource use, improving the quality of service and ensuring the stability of mobile radio networks.

The results obtained indicate the prospects for further research in the direction of developing intelligent methods for managing data flows at the network level, in particular methods for adaptive routing and network load forecasting. The implementation of such approaches can become the basis for building effective traffic management systems in mobile radio networks of 5G standards and promising 6G networks.

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Received (Надійшла) 26.02.2026

Accepted for publication (Прийнята до друку) 16.03.2026

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ІНТЕЛЕКТУАЛІЗАЦІЯ УПРАВЛІННЯ ПОТОКАМИ ДАНИХ У МОБІЛЬНИХ РАДІОМЕРЕЖАХ НА МЕРЕЖЕВОМУ РІВНІ МОДЕЛІ OSI

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Анотація. Актуальність теми. Стрімкий розвиток мобільних радіомереж стандартів 5G та 6G супроводжується зростанням обсягів гетерогенного трафіку, підвищенням вимог до затримки, надійності та адаптивності мережевої інфраструктури. За умов динамічної топології, нестабільності радіоканалу та обмеженості спектральних ресурсів традиційні механізми управління потоками даних, розроблені переважно для дротових IP-мереж, демонструють обмежену ефективність. Це зумовлює актуальність дослідження інтелектуалізованих підходів до управління потоками даних саме на мережевому рівні моделі Open Systems Interconnection (OSI), який забезпечує логічну адресацію, маршрутизацію та міжвузлову взаємодію. **Предметом дослідження** є методи управління потоками даних у мобільних радіомережах на мережевому рівні, а також механізми їх адаптації до динамічних умов функціонування радіосередовища. **Метою** статті є аналіз існуючих методів управління потоками даних для визначення можливості їх застосування в мобільних радіомережах, обґрунтування необхідності інтелектуалізації процесу управління та формування інтелектуального підходу до управління потоками даних на мережевому рівні моделі OSI. **Отримані результати.** Здійснено аналіз класичних підходів до управління потоками даних, визначено їх функції та обмеження в умовах мобільних радіомереж. Обґрунтовано, що використання інтелектуальних алгоритмів дозволяє підвищити ефективність використання радіоресурсів, зменшити затримки передачі та забезпечити стабільність функціонування мережі в умовах змінної пропускну здатності. Запропоновано узагальнену модель інтелектуальної системи управління потоками даних на мережевому рівні, яка враховує параметри стану мережі та характеристики трафіку в реальному часі. Визначено доцільність інтеграції інтелектуальних механізмів у процеси маршрутизації та управління потоками даних у мобільних радіомережах, окреслено переваги та недоліки методів маршрутизації при використанні в мобільних радіомережах. **Висновок.** Інтелектуалізація управління потоками даних на мережевому рівні моделі OSI є необхідною умовою забезпечення ефективного функціонування мобільних радіомереж нового покоління та підвищення їх адаптивності, масштабованості й стійкості до динамічних змін середовища передачі даних.

Ключові слова: інтелектуалізація управління; мобільні радіомережі; мережевий рівень; модель OSI; управління потоками даних.