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ANALYSIS OF ROUTING PROTOCOLS CHARACTERISTICS IN AD-HOC NETWORK

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Background. Wireless ad-hoc networks are becoming increasingly prevalence in remote areas, in extreme environments, even in military operations, and in scenarios where setting up infrastructure networks is not possible. Research of ad-hoc routing protocols problems allows improving the efficiency of their operation in conditions of high variability in packet loss or instability of network operation when the speed of users changes.

Objective. The purpose of the paper is analysis of packet loss dependency from a network operation time, study of a user speed influence on a network efficiency, and research of network operation efficiency with different routing protocols.

Methods. The method of routing protocols efficiency evaluation is the simulation of their operation in an ad-hoc network on a test data set and research of a network indicators dependency in time under different loads and changing mobility of users.

Results. The conducted research demonstrated that user’s mobility at different speeds significantly affects the network operation as a whole. The instability of users' positions leads to a significant increase in route search time and packet transmission time. Among researched GPSR, DSDV, and AODV protocols, the latter proved to be the best because it has the lowest percentage of data loss and the lowest average time of message send and receive operations.

Conclusions. The work is dedicated to the actual problem of developing and setting parameters of ad-hoc network. Received research results indicate the need to choose the optimal routing protocol depending on specific application conditions, such as user movement speed and network stability. The proposed solutions can be the first stage of complex processing of packets in the mobile network and justify the choice of AODV protocol as a basis for further improvement.

Keywords: *ad-hoc network; routing protocol; 5G; AODV; DSDV; GPSR; user mobility; network topology; data loss; network simulation.*

Introduction

The analysis of the characteristics of routing protocols in an ad-hoc network is an extremely relevant task in the field of telecommunications. Wireless ad-hoc networks are becoming increasingly common in remote regions, in extreme conditions, even in military operations, and in scenarios where it is not possible to install infrastructure networks Routing protocols are an important component of ad-hoc networks to ensure efficient and reliable data exchange among network nodes. However, due to the dynamism and unpredictability of such networks, choosing the optimal routing protocol becomes a challenging task. Up-to-date research in this area is necessary to optimise the performance of ad-hoc networks and ensure their best functioning. Analysing the characteristics of different protocols allows telecommunications engineers to understand their advantages and limitations, which in turn helps to develop optimal solutions to improve the functionality and efficiency of ad-hoc networks in various application environments.

The current problems include high variability in packet loss, instability of the network when user speeds change, and insufficient efficiency of routing protocols in ad-hoc networks.

The purpose of the work is to analyse the network efficiency of different routing protocols and check the impact of user speed on packet loss rate.

1. Existing approaches to traffic classification in 5G ad-hoc network

The introduction of 5G has led to the revival of ad-hoc networks, and accordingly, the number of publications devoted to covering the current problems of routing in these networks has increased significantly. The problem of efficient routing in such networks is their dynamism and unpredictability, which complicates the data transmission process. For example, in [1], a general approach to the classification of routing protocols in ad-hoc wireless networks was described, with an emphasis on table-based protocols. The problems of resource allocation, dynamic topology, optimal resource utilisation, local route maintenance, quality of service (QoS) and storage of information about the network topology are considered. A classification of protocols by route update mechanism (proactive, reactive, hybrid), use of time information (current or predicted), routing topology (flat or hierarchical) and use of specific resources (e.g., GPS) is proposed. Showed that table-based protocols (DSDV, WRP, CGSR, STAR) provide stable route updates but have a high network load. Reactive protocols (DSR, AODV, TORA) are effective in networks with high mobility, reducing the load on the network. Hybrid protocols (ZRTP) combine the advantages of both approaches.

In [2], an approach to solving the problem of energy saving in ad-hoc networks was proposed. The authors considered the problem of dynamic changes in node positions and its impact on energy consumption. To this end, the paper proposed a new protocol that uses a combination of a reactive approach and a state vector protocol. This approach is aimed at reducing the load on nodes by selecting the least loaded routes for data transmission. The result is an effective reduction in energy consumption while maintaining network stability.

In the paper [3] AODV routing protocol for ad-hoc networks was investigated. AODV protocol has shown some drawbacks, in particular, the route discovery and route recovery time can be a significant obstacle to network performance. In this paper, an improved version of the protocol known as B-AODV was proposed. This protocol includes a number of innovative approaches to address these problems, including reducing route discovery time by using BRREQ instead of RREP and improving route recovery by including the IP addresses of the two nodes ahead in control messages and route tables.

In [4], an approach to solving the problem of routing in mobile ad-hoc networks using AODV protocol was considered. The essence of the problem lies in the need for efficient route determination in a network with a dynamic topology where there is no fixed infrastructure. The advantages of the approach include efficient use of bandwidth, adaptability to topology changes, and minimal storage costs.

The paper [5] describes a solution to the problem of packet loss in the GPSR routing protocol for wireless networks of mobile vehicles. In this paper proposed to add the ability to use several routes simultaneously to transmit one packet in order to reduce the probability of loss. The effectiveness of this approach has been tested in the Omnet++, Veins and SUMO environments, where the advantages of the proposed solution in comparison with GPSR in terms of packet delivery ratio have been revealed.

Based on the analysis of the described sources, the following protocols were selected to analyze their effectiveness: AODV, DSDV, GPSR.

2. Research pre-condition and brief protocol overview

The analysis of the characteristics of routing protocols in an ad-hoc network is aimed at analysing the effectiveness of AODV, DSDV and GPSR protocols. For this purpose, a training dataset in the form (x_i, y_i) is used, where $x_i \in R_n$ represents information about a particular routing protocol, and $y_i \in \{1,...,K\}$ is a class label indicating the level of packet loss. The main goal is to find the optimal routing protocol for different user traffic conditions.

Let us consider in detail the main routing protocols used in this paper:

1. The AODV protocol works on a demand basis, creating routes only when they are needed for data transmission. The main feature is the speed of route finding and recovery when the network topology changes.

2. The DSDV protocol uses constantly updated routing tables for each node. The main feature is resistance to changes in network topology due to regular updates of routing tables.

3. The GPSR protocol works on the principle of selecting the best route using local information about neighbours. The main feature is the high

speed of packet transmission due to minimal information exchange.

Each of these protocols has its own advantages and disadvantages, which were identified through the analysis of literature sources.

To compare the effectiveness of different routing protocols in an ad-hoc network, a network dataset is used, which contains information on the packet loss rate, average round trip time, and standard deviation for each protocol. The input data also includes the effect on traffic of the user's speed, which can be absent, moderate or average.

For the study, the Omnet++ software was used to create simulations, which allowed us to analyse in detail the characteristics under consideration and their impact on the performance of various routing protocols.

Based on the results obtained, recommendations can be formulated for choosing the optimal routing protocol depending on the conditions of user traffic and network characteristics.

3. Approaches and metrics for evaluating the effectiveness of algorithms

To evaluate the effectiveness of routing protocols, it is necessary to select metrics. To evaluate the quality of the built models, the following metrics are used in this paper (Table 1).

Table 1. Metrics for assessing the quality of the network and routing protocols.

Metrics	Equation
Packet loss rate	$\text{Loss Rate} = \left(\frac{N_{lost}}{N_{sent}}\right) * 100\%$
Average round-trip time	$RTT_{avg} = \frac{\sum_{i=1}^{N} RTT_i}{N}$
Standard deviation	$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(RTT_i - \overline{RTT_{avg}})^2}{N}}$

where: RTT_i – round trip time for each measurement i; N – total number of RTT measurements; N_{lost} – the number of lost packets; N_{sent} – total number of transmitted packets; N – total number of measurements; σ – standard deviation.

4. Experiment preparation and modelling results

To conduct the experiment in the Omnet++ environment, where the operation of an ad-hoc network using the AODV, DSDV and GPSR protocols was modelled, a certain part of the test data was taken. All data manipulations, as well as the analysis of the experimental results, were performed using the C++ programming language.

To determine the level of packet loss, average round trip time and standard deviation, we used the built-in tools for analysing the results in the Omnet++ environment. Before conducting the experiment, it was necessary to prepare the data for further processing. For example, to analyse the level of packet loss, C++ scripts were created to collect data from the results of simulations in the Omnet++ environment, and then the data was processed and analysed.

As a result of the data analysis, we obtained the packet loss rate, average round trip time and standard deviation for each of the routing protocols that were studied. These metrics allowed us to draw conclusions about the efficiency and performance of each protocol in the simulated ad-hoc network conditions.

To conduct the test in the Omnet++ environment, where the operation of the ad-hoc network and the AODV, DSDV and GPSR routing protocols were modelled, a corresponding network scheme was built and the prerequisites for the experiment were created.

The network scheme was built taking into account the main characteristics of an ad-hoc network, such as the wireless nature of communication, random location of nodes, and limited resources of each node. The network consisted of a certain number of nodes that are able to communicate with each other via a wireless channel.

The prerequisites for the test included setting up the parameters of each routing protocol (AODV, DSDV, and GPSR) in accordance with the requirements of the experiment. For example, for each protocol, parameters such as the maximum waiting time for route establishment, the maximum distance for data transmission, sensitivity to changes in network topology, and others were defined.

In addition, prior to the test, initial conditions were created for each node in the network, such as the initial location of the nodes, initial energy reserves, and other parameters that determine the state of the node at the beginning of the simulation.

At the first stage of the study, the stability of the network performance and its self-adjustment time were assessed. For this purpose, the dependence of the studied network indicators on time under different loads and varying subscriber mobility was assessed. At the same time, subscriber mobility was considered in four scenarios: from a static position to fast movement. As can be seen from Fig. 1, at the initial stage of network operation (initialisation stage), there is an exponential increase in traffic, which leads to unstable system operation. This period insignificantly depends on the degree of user mobility and on average takes from 1 to 3 seconds. Accordingly, it can be concluded that it is advisable to perform a comparative analysis of network performance after the initialisation period.

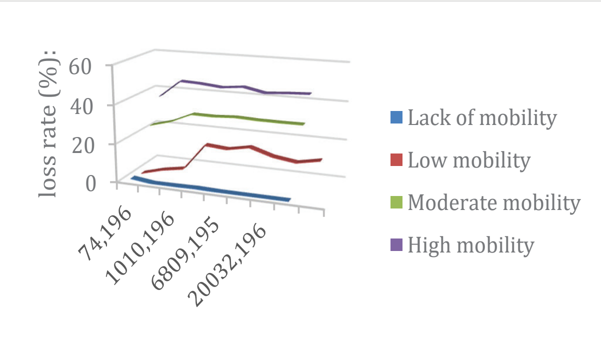

Fig. 1. Dependence of packet loss on operating time

Let's evaluate the impact of user speed on network efficiency in an ad-hoc network using the AODV protocol. A network structure will build with two fixed communication nodes and a set of 20 mobile nodes that interact with the fixed nodes and each other (Fig. 2). The results of the study are shown in Table 2.

According to the results, with the growth of user speed in the AD-HOC network, an increase in data loss (up to 43%) is observed when routing using the AODV protocol, which indicates problems with data transmission and reception in the network. At the same time, the average values of the delay time (787.03 ms) and large values of the standard deviation (1521.98 ms) indicate significant fluctuations in the data delivery time.

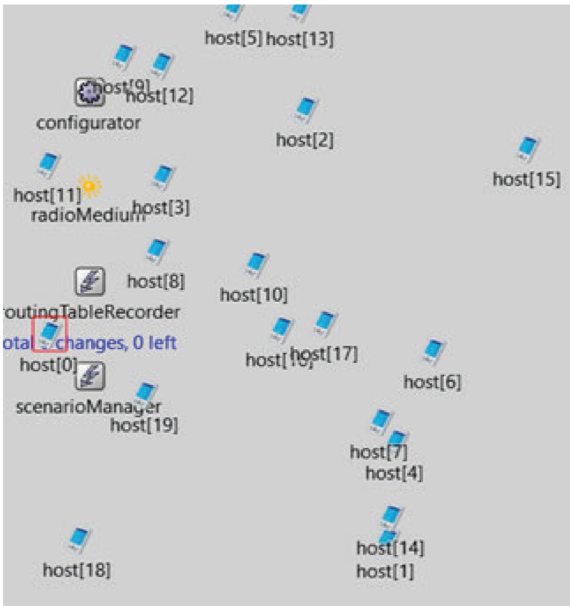

Fig. 2. Scheme of the analyzed ad-hoc network

Table 2. Analysing the impact of user's speed on network performance.

User's speed	Packet loss rate (%):	RTT average (ms)	Std deviation (ms):
Lack of mobility	0.003	1.92	0.1
Low mobility	16.03	177.60	857.77
Moderate mobility	30.75	460.75	1255.67
High mobility	43.67	787.03	1521.98

These indicators point to the challenges posed by high user mobility. In today's Internet of Things (IoT) networks devices are able to move from one location to another. This lead to problems with communication reliability and data transfer efficiency. In cases where user mobility is low or non-existent, network efficiency is quite high, as evidenced by low data loss and low average connection times. Such conditions can be typical for stationary or small mobile objects, such as sensors in monitoring systems. However, in cases where the speed of users is moderate or high, the network performance deteriorates significantly, which can lead to data loss and increased connection times. Such conditions can arise, for example, when using mobile applications.

Thus, an ad-hoc network using the AODV protocol can be effective in cases of low or no mobility, when a fast and reliable connection between nodes is required. However, in cases of high mobility, problems with network stability and efficiency may arise, which may require additional optimisation measures or the choice of another type of network.

The study also evaluated the network performance when using different routing protocols, including AODV, DSDV, and GPSR (Table 3).

Table 3. Comparative analysis of network characteristics using different routing protocols

Routing protocol	Packet loss rate (%):	Average delay time (ms)	Number of transmitted packets
AODV-1	0.006	3.16	33571
AODV-M	0.006	4.81	33540
DSDV	7.99	13.92	33559
GPSR-1	0.15	14.26	33530
GPSR-M	0.15	14.23	33527

According to the results, the AODV and GPSR protocols demonstrated low data loss and low average delay time, which emphasises their high efficiency in route discovery and data exchange in the network. On the other hand, the DSDV protocol showed significant data loss and a high average delay time, which indicates its lower efficiency compared to other protocols.

As a result of the research, it can be stated that the indicators are almost independent of time, and that the mobility of users at different speeds significantly affects the operation of the network as a whole. The tables above show how the instability of the users' position leads to a significant increase in the route search time and packet transmission time. Among the protocols studied, AODV is the best, as it has the lowest percentage of data loss and the lowest average time to send and receive a message. Based on the data provided, it can be seen that for AODV-1, the percentage of data loss is only 0.006% and the average round trip time is 3.16 ms. Thus, the results obtained show the potential advantage of AODV over other studied protocols and the possibility of its selection as a basis for further improvement.

Conclusion

The emergence of new services and the introduction of new technologies complicate the operation of existing traffic routing protocols. This is primarily due to the fact that 5G technology allows direct connections between devices. Accordingly, classical computer network routing protocols do not take this into account. In addition, the change in the location of subscriber devices and other network elements forces to abandon proactive protocols in favour of reactive ones, so the study of the effectiveness of routing protocols in different conditions is relevant.

The results of the study indicate the need to select the optimal routing protocol depending on specific application conditions, such as user speed and network stability. In particular, high user traffic speeds can lead to significant data loss and degradation of network efficiency, which requires careful selection of the protocol and possible optimisation strategies.

The proposed solutions can be the first stage of complex packet processing in a mobile network and justify the choice of the AODV protocol as the basis for further improvement. Together with clustering and distributed data processing, the proposed approach will help to improve the efficiency of the mobile communication system as a whole.

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Аналіз характеристик протоколів маршрутизації в ad-hoc мережі

Проблематика. Бездротові ad-hoc мережі стають все більш поширеними у віддалених регіонах, в екстремальних умовах навіть у військових операціях та в сценаріях, де немає можливості встановлення інфраструктурних мереж. Дослідження проблем протоколів маршрутизації ad-hoc мереж дозволяє покращити ефективність їх функціонування в умовах високої варіабельності у втратах пакетів або нестабільності роботи мережі при зміні швидкості користувачів.

Мета досліджень. Аналіз залежності втрат пакетів від часу роботи мережі, вивчення впливу швидкості користувачів на ефективність мережі та дослідження ефективності роботи мережі при різних протоколах маршрутизації.

Методика реалізації. Методом оцінки ефективності протоколів маршрутизації є симуляція їх роботи в ad-hoc мережі на тестовому наборі даних та дослідження залежністі показників досліджуваної мережі від часу при різному навантаженні і змінюваної мобільності абонентів.

Результати досліджень. Проведені дослідження показали, що мобільність користувачів на різних швидкостях суттєво впливає на роботу мережі вцілому. Нестабільність положення користувачів призводить до суттєвого збільшення часу пошуку маршруту та часу передачі пакетів. Серед досліджуваних проколів GPSR, DSDV та AODV останній виявився найкращим, оскільки він має найнижчий відсоток втрат даних і найнижчий середній час відправки та отримання повідомлення.

Висновки. Робота присвячена актуальному питанню розробки та налаштування параметрів роботи ad-hoc мережі. Отримані результати дослідження вказують на необхідність вибору оптимального протоколу маршрутизації в залежності від конкретних умов застосування, таких як швидкість руху користувачів та стабільність мережі. Запропоновані рішення можуть бути першим етапом комплексної обробки пакетів в мобільній мережі і обґрунтовують вибір протоколу AODV в якості основи для подальшого вдосконалення.

***Ключові слова**: ad-hoc мережа; протокол маршрутизації; 5G; AODV; DSDV; GPSR; мобільність користувача; топологія мережі; втрата даних; симуляція мережі.*