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Routing protocols in Mobile Ad-hoc Networks

Abstract. *There were more than 8.6 billion mobile devices in the world in the 2019. To be available is imperative in modern society, both in business and in private life. There are mobile networks available on airports, hotels, restaurants, libraries but sometimes we have to make a quick, mobile network on open area for educational campus or military purposes, where there are no mobile operators and public networks such as GSM. A different model of mobile networks is created and called Mobile Ad-hoc Network. The problem of routing is basically the problem of finding the shortest path between nodes. This paper deals with various routing protocols in MANET and shows how to choose the best one for specific purpose.*

Streszczenie. *Na świecie jest ponad 8.6 miliardów bezprzewodowych urządzeń mobilnych I olbrzymia lic\ba sieci. Żeby rozwiązać problemy komunikacyjne trzeba korzystać z metod jak najszybszego I najkrótszego połączenia miedzy węzłami. W artykule analizowano najlepsze sposoby routingu.* ***Protokoły routingu w mobilnych ad-hoc sieciach bezprzewodowych***

Keywords: MANET - mobile ad-hoc networks, wireless communications, routing, protocols.
Słowa kluczowe: sieci bezprzewodowe, protokoły routingu.

Introduction

The field mobile devices have become increasingly popular over the last two decades. Mobile communication devices are getting smaller, more powerful, and there are more and more of them, ranging from laptops, notebooks, tablets, PDAs, to mobile smartphones.

The paper will describe the principle of operation of MANET networks, their topology, fields of application, as well as the importance in emergencies, natural disasters, fires, earthquakes, military industry, as well as application in education outside the headquarters of institutions, e.g. in educational camps or in nature classes.

About MANET

The Mobile Ad-Hoc Network is a dynamic mobile network that enables wireless networking on the go without the need for a pre-built network infrastructure, and consists of mobile nodes, where the node can be a man with a handheld computer (equipped with an appropriate wireless communication device), also laptop, unmanned robots, i.e. anyone can be a node who is equipped with appropriate wireless communication equipment**.**

Nodes in such a network can be very mobile and cause a very rapid change in the position of the nodes, and thus create and close connections between them. As nodes are constantly moving, the network topology is variable. This requires that the network must be capable of leaving a node or more of them, the sent information not to collapse but to find a new path to the destination node on its own. The purpose of MANET is to provide a network that can be set up immediately in an arbitrary communication environment and to quickly adapt to topological changes in the network. Possible situations where this type of communication could be used: in joint action to rescue police, firefighters and ambulances, in military operations, meetings and conferences where data is exchanged without the need for a dedicated network infrastructure, sensor network - in communication between intelligent sensors.

The MANET network can operate as a standalone network, or it can be integrated with external networks, such as a global gateway network.

MANET networks provide network connectivity that can be set up relatively quickly in an arbitrary communication environment. The use of mobile ad-hoc wireless networks can be found in areas where standard network infrastructure is difficult to develop, such as military battlefields, disaster scenarios, and rescue operations. As wireless technologies are constantly evolving, the deployment of mobile ad-hoc networks is also becoming possible in the civilian environment of communicating with personal devices such as PDAs, mobile phones and laptops.

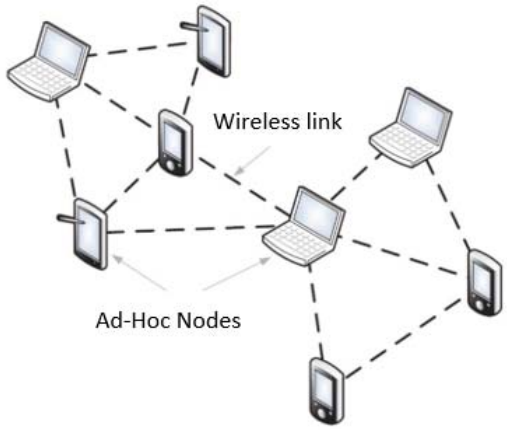


Fig.1. A mobile ad-hoc network made up of devices connected wirelessly [2]

State of the art

In a study [7], point-to-point (unicast), point-to-multipoint (multicast) and broadcast (broadcast) routing protocols for use in MANET networks are presented.

Through comparative analysis of different routing protocols, the authors assume that different routing protocols have different advantages and disadvantages. Therefore, no routing protocol can be adequate for implementation in all possible scenarios and types of transmitted traffic in MANET networks.

In [9], the authors demonstrated that the mobile Ad-hoc network architecture enables cheap and easy delivery of network services almost anywhere, anytime. In addition to internet access, end users are most often searching for and using multimedia applications. However, they impose strict service quality restrictions in the form of bandwidth, delays and packet loss.

A comparative analysis of various point-to-point routing protocols is given in [5]. The authors conducted experimental measurements that presented the advantages and disadvantages of different approaches.

It has been shown that the field of routing protocol research in mobile Ad-hoc networks is a current topic of many scientific papers, and that new contributions can be expected in this field.

MANET model and communication environment

Here are some assumptions regarding communication parameters, network architecture, and network traffic:

• The nodes are equipped with portable communication devices powered by batteries, and the battery life imposes restrictions on the range of the signal, and thus in the communication activity (sending and receiving data) and in the computing power of such devices

• The connection between nodes is not transient, i.e. If node A can communicate directly with node B, and node B communicates directly with node C, this does not mean that node A can communicate directly with node C. This is so-called hidden terminal problem

• We will assume that nodes use permanent identifiers (such as IP addresses)

• each node has the same capabilities, that is, each node is capable of performing one of the functions from the same group of network services, and yet not all nodes necessarily need to perform the same function at the same time.

Also, if a node has a given function in the network, this does not mean that its function is immutable, but changes with time and needs.

MANET is a peer-to-peer network that allows direct communication with any two nodes when conditions exist for sending signals and when the nodes have sufficient power to transmit signals. If there is no direct connection between the start node and the destination node then a multihop connection method is used.

Thus, all communication between the entities of this network is accomplished by sending radio signals, but propagation of such a signal is very sensitive to various deteriorations in the communication channel, so the interconnection of nodes in the network is not guaranteed, moreover intermittent interruptions and occasional interconnections are almost normal occurrences. Most portable devices have limited power sources (batteries), so the power to transmit the signal should be reduced as much as possible. In addition, the signal range of each device is limited, and the channel used by each mobile device is also spatially limited, as multiple devices can use the same communication channel only if they are sufficiently far from each other. This has the consequence that since the range of each device is much smaller than the range of the network, communication between two nodes depends on the nodes located between them, i.e. without them communication between the two outermost nodes would not be possible. Due to the possible fast movements of nodes and the changing conditions of signal propagation (propagation), network information such as routing tables becomes very useless very quickly. Frequent reconfiguration of the network can cause frequent changes of control information among nodes, which serve to restore routing tables and allow each node to know the shape and current state of the network. However, as this information has a short duration, which means that a large number of control messages are exchanged, most of this information will not be used. This means that bandwidth used to send control information is wasted, which can lead to connection congestion.

MANET requirements

Therefore, based on the model previously presented, MANET is expected to:

• Robust routing and algorithms for monitoring the change in network topology to increase reliability and availability - to reduce the possibility of keeping part of the network isolated from the rest of the network

• adaptive algorithms and protocols that nodes can adapt to frequent changes in signal propagation, changes in network topology, and network traffic conditions

• Protocols and algorithms that will send as few control messages as possible to save communication resources (channels)

• Multiple (different) routes between the source and destination nodes - that no traffic flows only between certain nodes, i.e. to avoid congestion on that route and to increase reliability

• Robust network architecture to avoid susceptibility to network faults, congestion at nodes that have a large number of nodes attached to them.

The principle of the MANET network operation

If we identify two nodes that want to communicate with each other (in the picture blue), and will be able to communicate directly if they are in a signal range, and this method of communication between nodes is called Singlehop.

While Multihop mode of communication takes place when the nodes that want to communicate are not within range, but can only make a connection if there is a sufficient number of nodes such that direct communication (Singlehop) is made between each two adjacent nodes.

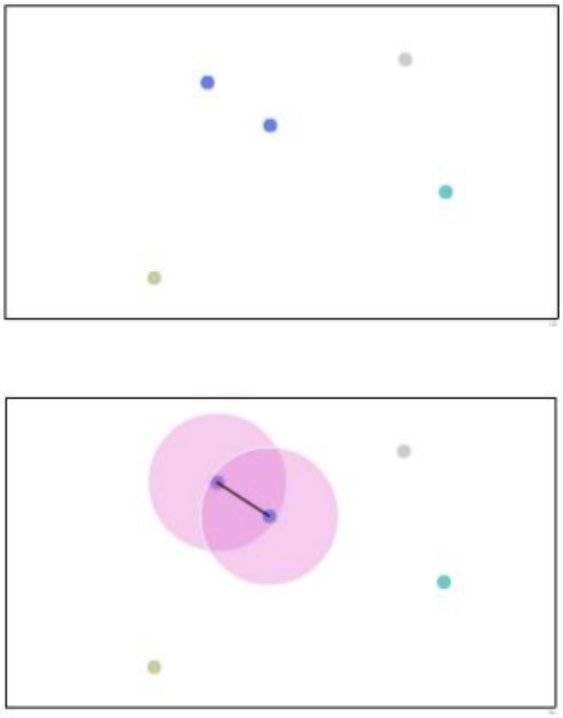


Fig.2. Communication of two nodes in the MANET network – Singlehop

Each node in such a network except is a destination information packet and also performs the function of a router for packets that have other destination nodes. So, the nodes depend on each other for the connection in the network to exist.

Since there is no central element in such a network, it is necessary to use special protocols, which in addition to ensuring packet forwarding from node to node, must find the appropriate path from source to destination node and check whether the connection still exists or if it is broken and in case of interruption specific routes to find a new one and make a connection.

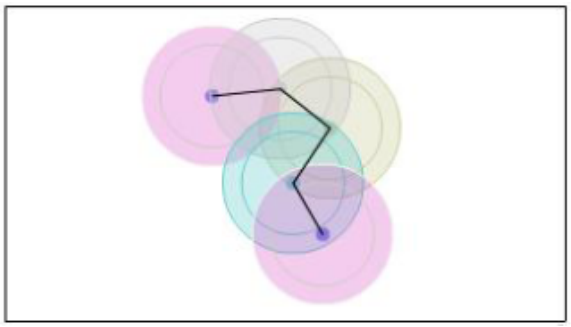


Fig.3. Multihop mode of communication in the MANET network

Protocols

Unlike standard and wireless networks, ad-hoc networks do not have the infrastructure in place or any central unit to monitor and manage the operation of the network. Due to this network architecture and the nature of the ad-hoc network (frequent changes to the network topology), standard routing protocols and other standard protocols cannot be used, so the so-called distribution protocols. That is why the development of protocols that will be able to adapt to the network and the requirements stated earlier plays the most important role in the development of MANET.

The absence of dedicated routers makes it difficult to secure on Ad-hoc wireless networks. This task is even more difficult due to node mobility, limited processing power, and limited availability of resources such as power and bandwidth. Routing protocols intended for use in traditional cable networks cannot be used on MANET networks. The specific features of these networks require special routing protocols that address the identified challenges in these networks [8]. Such routing protocols should have the characteristics listed in Figure 4

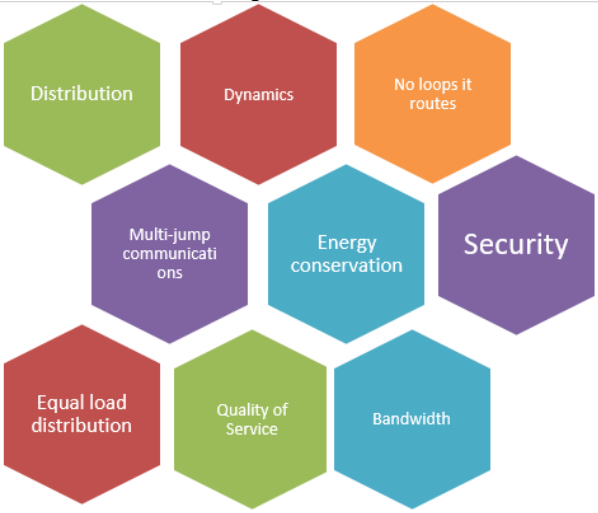


Fig.4.: Characteristics of routing protocols in mobile Ad-hoc networks [Authors]

Usability of any of the existing MAC layer protocols, such as CSMA (Carrier Sense Multiple Access) in the radio signal area is restricted due to the "Hidden Node" and "Exposed Node" issues.

Hidden node problem

The problem arises because networks that operate with radio signals are completely different from networks like e.g. LANs, for example, do not guarantee such good connectivity as LANs. As we said before, the connection between nodes is not transient. So while node A communicates with node B, node C also wants to communicate with node B, but since the connection is intransitive, he cannot use standard CSMA protocol to hear that A is currently in the communication channel due to an "obstacle", node B, so he concludes that the medium is free and able to communicate with node B. This results in a collision at node B, as shown in Figure 5.

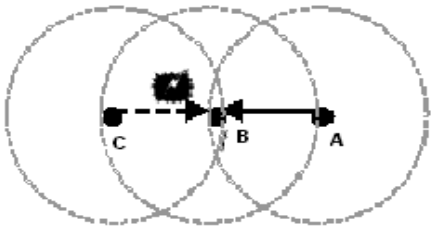


Fig.5. Hidden node problem

Exposed node problem

In this case, node A communicates with node B, while node C wants to communicate with node D. Using the CSMA protocol, node C listens to whether someone is using the medium, and then hears node A to use the medium at the moment, so he does not attempt to communicate with node D. Although there is no reason why node C would not be able to communicate with node D while A was in communication with B, because node B was not within signal range of node C and would not collide as D would not be within range of node A.

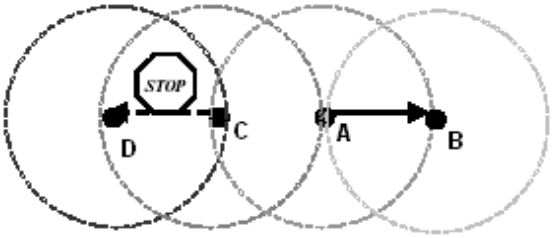


Fig.6. Exposed node problem

Problems were solved using the Medium Access Collision Avoidance (MASA) protocol [12]. In the MASA protocol, before sending data, the so-called RTS / CTS communication. Node A wants to communicate and the first thing it does is send a Request To Send (RTS) control packet, heard by all nodes, and will not access the communication channel until the RTS / CTS dialog is complete. The destination node, after receiving the RTS packet, responds with a second short CTS (Clear To Send) control packet. This packet is also heard by all nodes, so they will not attempt to access the channel for as long as it sends the packet of data. Whereas for node A receiving the CTS packet that RTS / CTS communication has completed successfully and can start sending packets with data.

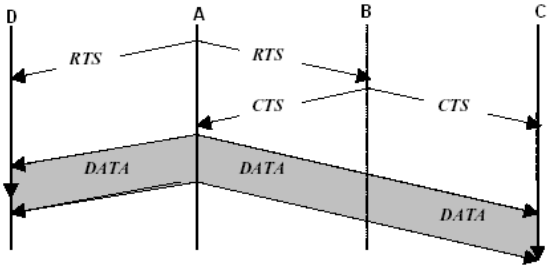


Fig.7. Medium Access Collision Avoidance (MASA) protocol

Routing protocols in MANET

Routing is the process of selecting a path for traffic in a network or between or across multiple networks.

Basic requirements for nodes in the process of routing packets and finding the route to the destination node:

• Each node must have information about its neighboring nodes, i.e. where they can forward packets

• Each data packet contains information about the destination node in its header

• each node has its own routing table that lists the nodes in the network that the node currently knows exist, or does not know because of the frequent change of the network topology, on the basis of which it forwards packets

• when a node receives a data packet, it forwards it to the neighboring node. This forwarding is done by every node on the route to the destination until the packet arrives at its destination

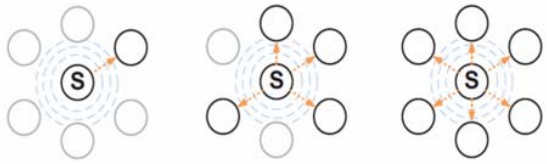
Classification of existing MANET routing protocols

The main goals of the routing protocol are to find and maintain routes between nodes in dynamic topology using minimal resources. A protocol is a set of standards or rules for exchanging data between two devices. Routing protocols are categorized by how packets are forwarded to:

• point - point,

• point - multiple points and

• routing emission protocols (Figures 8 and 9).



a) Point - point b) Point - multiple points c) Emissions

Fig.8. Classification of MANET routing protocols based on packet forwarding method [2]

Point - multicast routing protocols are used when a single node needs to send the same message, or data stream, to multiple destinations. Point - multiple points is the transmission of data from one node to n receivers, which means that only one copy of the message will be delivered to all receivers. This will reduce communication costs compared to the case where a single point-to-point message should be delivered to multiple receivers. Due to its characteristics, point-to-multipoint is often a more convenient mechanism of communication []. However, the best results are achieved by applying the appropriate class of routing protocols to their respective purposes.

Broadcasting is the broadcast from one to all other nodes in the network. Broadcasting is the basic mode of operation on a wireless channel. Namely, every message transmitted on a wireless channel is received at all neighbors within a hop of the sender.

In addition, routing protocols can be classified according to whether the address topology is flat or hierarchical, or based on the use of specific resources. These categories are not mutually exclusive, as individual routing protocols can be grouped into multiple groups.

Point-to-point routing protocols

Routing is the most basic function in networks for packet communication and transmission. For the MANET network to be practically usable, a functional and efficient point-to-point routing protocol is necessary [9].

Point-to-point routing protocols created for use on mobile Ad-hoc wireless networks can be classified according to a mechanism for updating route information in three categories:

• Proactive (periodic),

• Reactive (on demand) and

• Hybrid.

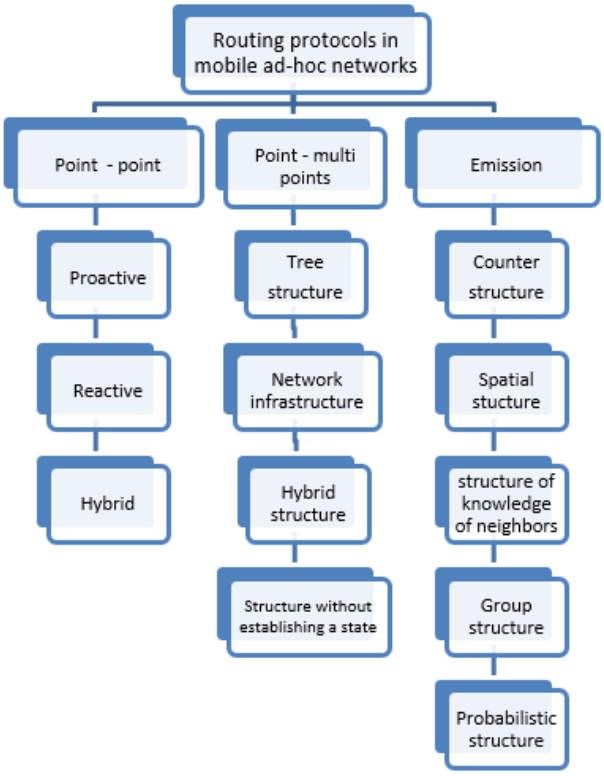


Fig.9. Classification of the MANET routing protocol [2]

Proactive routing protocols

With proactive routing protocols, each node maintains one or more tables to preserve network topology and route information. These tables are often updated periodically by exchanging route information, which is generally broadcast throughout the network. Proactive routing protocols differ in the way they detect and update routing information, as well as the types of information stored in routing tables.

Proactive routing protocols keep routing tables current through periodic control messages or on demand. Each node maintains one or more tables for storing route information. Nodes respond to changes in the network topology by propagating updates through the network to maintain consistency. Areas where different routing protocols differ are the number of required routing tables and the techniques by which nodes emit changes to the network structure.

This type of protocol maintains fresh lists of destinations and their routes by periodically distributing routing tables across the network. The major disadvantages of these algorithms are the large amount of active maintenance routes and slow responses to restructuring and failures.

Reactive routing protocols

The basic feature of mobile Ad-hoc wireless networks is their dynamic topology. As routing protocols track the change in topology, regular updating of the global topology is necessary at every node. Sometimes the route information obtained may expire before the need arises, further complicating matters and affecting bandwidth dissipation. The concept of reactive routing protocols is designed to reduce the amount of unnecessary route updates and therefore the utilization of link capacity.

Reactive routing protocols, unlike proactive ones, do not maintain information about the network topology and route to every node within the network. Routes are found when

the need arises (on request) using the route discovery process. Generally, when a route is required from Source A, a request is propagated within the network to find the route to the desired destination B. When Node B receives a Route Request (RREQ) it sends a Route Response (RREP) back to node A. When a RREQ request is sent via a two-way link, RREP is sent back through the same link. Reactive routing protocols use basic methods for route detection and maintenance. The once discovered route is maintained as long as the destination is accessible along each route from the source or as long as the route is required

Reactive routing protocols can be categorized by route transfer method as:

- stating the correct route and
- Point to point.

In routing protocols with source routing, all data packets carry complete addresses along the route from the source node to the destination node. So, based on its header, the data packet is sent to the destination along the previously established route. The advantages of using this type of protocol are the absence of the need to maintain an active route to the destination at the nodes located along the given route.

For hop-by-hop routing protocols, only the destination and address of the next hop should be specified in the data packet. Nodes are thus used to forward packets to a destination along the route. Using a routing table at each node in the network provides an advantage of the jump-by-hop routing protocol, as dynamic updating of the network topology ensures that the nodes receive the latest topology information and thus can forward data packets along the best routes.

Reactive routing protocols can quickly adapt to changes in routes. They also do not require overuse of resources due to periodic control messages if routes are stored within the routing table or if the network is idle. However, discovering new routes on demand creates an overflow of the network that can lead to congestion, and often bad routes are detected. As a result, packet loss during transmission and long delays in establishing new routes occur.

Hybrid routing protocols

Hybrid routing protocols try to combine the best characteristics of proactive and reactive routing protocols. They often consist of two classic routing protocols:

- proactive (periodic), and
- reactive (on request).

Hybrid routing protocols divide the network into areas called zones, which may be overlapping or non-overlapping, depending on the algorithm used in a particular hybrid routing protocol. The routing zone of a particular node can be defined as the distance from that node or as part of a specific geographical area. The proactive routing protocol operates within zones and is responsible for establishing and maintaining routes to destinations within the zones. The reactive routing protocol, on the other hand, is responsible for establishing and maintaining routes to out-of-zone destinations.

Point - multiple point routing protocols

Point - Point Multiple routing protocols can be classified according to the way routes are created in four categories [4]:

- tree structure,
- network structure,
- hybrid structure and
- structure without conditionality.

Routing Emission Protocols

Routing emission protocols can be classified into the following categories [11]:

- counter structure,
- spatial structure,
- structure of knowledge of neighbors,
- group structure and
- Probabilistic structure.

Point-to-point comparison of routing protocols

Proactive routing protocols rely on a routing table update mechanism that involves the constant propagation of route information, regardless of whether and how often these routes are used. On the other hand, with proactive routing protocols, all route information is always available in each node's routing table. This feature, while useful, generates a significant amount of control traffic within the network and considerable energy consumption. Since bandwidth and battery power are limited resources within the MANET network, this becomes a serious limitation [10].

The advantage of proactive routing protocols is reflected in the fact that the route to the destination can be determined immediately, without delay. The disadvantages are the generation of more control traffic and thus greater bandwidth usage, even when the network is idle, which can cause network congestion. In addition, proactive routing protocols respond more slowly to topological changes within the network. Therefore, proactive routing protocols are recommended for use in moderate-dynamic mobile ad-hoc networks.

In contrast, for reactive routing protocols, a much lower bandwidth value is used to maintain the routing table. They are also more energy efficient. However, for reactive routing protocols, a node that wants to communicate with a remote node that does not know the route will have to wait until such a route is detected, resulting in a much longer delay in establishing communication. Reactive routing protocols are recommended for use on mobile Ad-hoc networks where nodes have a high degree of mobility.

Reactive routing protocols face the problem of scaling, when there are a large number of nodes in the network. The extent of this problem depends on which reactive routing protocol is used and the scenario being observed.

Hybrid routing protocols are theoretically more advanced than purely proactive and reactive routing protocols. However, the over-complexity in their practical implementation, as well as the fact that their efficiency is highly dependent on the number of nodes that initiate traffic to the destination nodes, as well as the zones within which they are located, make hybrid routing protocols less prevalent.

Choice of point-to-point routing protocols in the MANET network

When it comes to choosing routing protocols within the MANET network, the reactive approach performs better when node mobility is high and the amount of traffic transmitted between nodes is small [13]. On the other hand, proactive routing protocols are recommended when the network is generally static and when the amount of traffic generated between nodes is high. If it is necessary to strike a balance between different models of node mobility and different amounts of traffic generated between nodes within a single network, it is recommended to use hybrid routing protocols that combine both classes of protocols - proactive and reactive.

Summary characteristics of the proactive, reactive, and hybrid point-to-point routing protocols are shown in Table 1 [3].

Table 1 - Summary of proactive, reactive, and hybrid point-to-point protocols

Characteristic	*Proactive (periodic)*	*Reactive (on request)*	*Hybrid*
Network organization	Flat / Hierarchical	Flat	Hierarchical
Dissemination of topological information	Periodically	Upon request	Both methods
Route availability and delay	Always available, without delay	Available when needed	Both methods
Node mobility	Periodic updates	Maintaining routes	Both methods
Amount of generated control messages	High	Low	Medium

Conclusion

In the age of modern mobile wireless communication systems, when the number of mobile devices exceeds the number of people living on the planet by a billion, the unpredictable mobile networks in the field - the so-called Ad-hoc mobile networks - MANET take an important place.

The topology of mobile Ad-hoc networks can be dynamic and unpredictable. The traditional routing protocols used with cable networks cannot be directly applied to mobile Ad-hoc wireless networks, since many of the adopted assumptions are not valid in a mobile wireless environment.

So, for example, one assumption is that a node can receive any broadcast message from other nodes within the same subnet. However, this is not the case for nodes in the wireless MANET network, due to the fact that bandwidth is limited in this type of network. Thus, the MANET network model introduces a number of challenges to routing protocols.

Each routing protocol model behaves individually in a particular environment. None of these are perfect for application in all ranges of node mobility, amount of traffic generated, number of nodes, etc. Due to their characteristics, traditional routing protocols used for cable networks are not recommended for use on MANET networks.

The three main groups of point-to-point routing protocols are proactive, reactive and hybrid routing protocols.

A basic feature of proactive routing protocols is the fact that each node maintains routes to all other nodes in the network. Nodes update this information from time to time, regardless of whether routes are used.

On the other hand, with reactive routing protocols, nodes only find routes between those nodes that want to communicate. This type of routing protocol makes more efficient use of wireless bandwidth and limited mobile node resources.

With a proactive approach, the main problem is the high utilization of resources and flow when not necessary. With reactive access, the main problem is the delay in establishing new routes. In both proactive and reactive approaches, the problem of scalability arises.

To mitigate these problems, a new hybrid type of point-to-point routing protocol has been created. Hybrid routing protocols combine a proactive and reactive approach to achieve better performance.

However, none of the existing routing protocols is suitable for mobile ad-hoc networks with a large number of nodes, if each of the nodes has a different speed of movement and the amount of traffic generated.

The fact that the nature of routing protocols is proactive or reactive has far-reaching consequences on the performance of routing protocols in different scenarios.
The main differences are reflected primarily in the way routes are detected and maintained, which dictates further behaviour of the routing protocol. Generally, proactive routing protocols are suitable for deployment in high-capacity networks, while reactive routing protocols perform better in low-capacity networks [13].
Certainly, the application of modern MANET networks is exceptional and it is necessary to continuously monitor, study and improve the protocols in mobile ad-hoc networks as they are becoming more and more prevalent every day.

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