Multicast Routing in Wireless Mesh Networks

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***Abstract*—Wireless networks have recently gained on significance. In environments where it is impossible to build traditional infrastructure wireless networks, ad hoc and wireless mesh networks are used. The purpose of this paper is to evaluate certain multicast routing algorithms used in ad hoc and wireless mesh networks. The first part of the paper addresses the subject of ad hoc and wireless mesh networks, as well as the issue of multicasting in these networks. Furthermore, the paper contains a review of routing algorithms. In the last part of the paper the conducted research is presented and a multicast algorithms with the best performance in WMNs is chosen.**

***Keywords*-WMN; multicast routing algorithms**

I. INTRODUCTION

The growing need for unlimited Internet access and the constant progress in terms of developing new technologies (e.g., smartphones, tablets) caused a considerable development of wireless computer networks. Thanks to this method, access to the Internet has become less expensive, which, in turn, has been followed by a rapid growth in the number of people using it.

Until recently, there have been two basic approaches to creating wireless computer networks: infrastructure and ad hoc. Infrastructure mode requires the use of wireless access points that act as a go-between in conveying information and provide control over the process of communication. In contrast, wireless network operating in ad hoc mode does not require any superior or control devices - every device connected to this network may fulfill the same functions. However, in ad hoc networks, all devices have limited resources - not only energy, but also bandwidth.

The purpose of this research is to examine and compare algorithms and protocols being used in Wireless Mesh Networks in homogeneous conditions and the same parameters. The motivation for this study is the lack of such a comparison in subject literature.

The paper is organized as follows. Section II describes wireless mesh networks (WMN). The next section presents multicast algorithms and algorithms used in WMN. The following section shows simulation parameters whereas the results are discussed in Section V. Finally, Section VI concludes the paper.

II. WIRELESS MESH NETWORKS

There are three main types of ad hoc networks (Fig. 1).

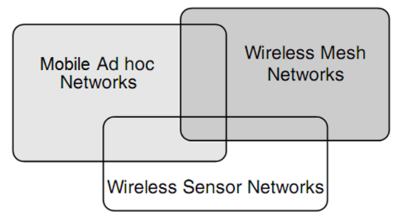

Figure 1. Types of ad hoc networks

A. Mobile ad hoc Networks (MANETs)

One of the most popular applications of ad hoc networks is using them as mobile networks. Mobile ad hoc network is created dynamically by a group of mobile devices without any assistance of the existing infrastructure. In such a network, devices communicate between one another by pursuing one or more hops (Fig. 2).

Main advantages of MANETs are their flexibility deriving from their dynamic structure and independence of any fixed infrastructure. Unfortunately, it comes with a price, because mobility of devices connected to such a network influences the way of designing routing algorithms and algorithms for these networks - mainly because such networks are less stable and prone to disconnect. In the case of proactive algorithms, the status of the network has to be refreshed quickly enough to keep up with changes in the structure of the network. If this requirement is not met, the packet loss may increase on the one hand, but on the other, refreshing topology information too often may influence the links load and reduce effectiveness of network resources usage. Thus, on-demand (reactive) routing algorithms are much more efficient and give better results in such networks.

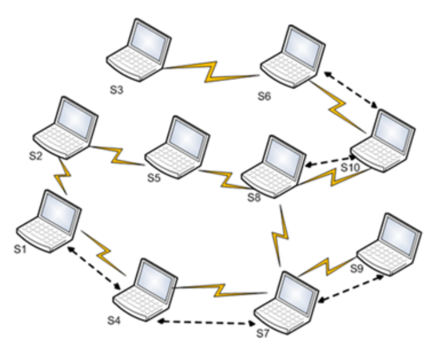

Figure 2. Example of MANET

B. Wireless Sensor Networks - WSNs

A network that consists of spatially distributed autonomous sensors that perform common tasks is called a *sensor network*. Usually, these types of networks are used to monitor environmental conditions, such as temperature, humidity, pressure, etc. Every single sensor has the ability to process data and send them wirelessly to other sensors in range. The development of WSNs was motivated by military applications - for intelligence, battlefield monitoring, etc. Nowadays they are also used in consumer applications, such as security monitoring, monitoring weather conditions or even traffic.

C. Wireless Mesh Networks -WMNs

Wireless Mesh Network is a very specific ad hoc network, which consists of two basic elements: *mesh backbone* and *customers* (Fig. 3). WMNs are the most static ad hoc networks when it comes to topology and structure. The backbone is created between wireless, but static, *mesh routers* (MRs), which have neither bandwidth nor energy limits. Some of MRs, which have a cable connection to the Internet, are called *Internet gateways* (IGWs) - which resembles access points in a traditional infrastructure mode. In addition, reliability of the network is improved by transmitting data between nodes in a *mesh* way, which, when combined with being independent from the local infrastructure, makes WMNs perfect to be applied in places where building a traditional cable network infrastructure would be too expensive or impossible (e.g., desert).

Due to the fact that nodes creating a backbone of the network are mostly stationary, routing methods that establish a permanent connection between multiple nodes, may be applied. In the majority of cases, there is no direct connection between each node in WMN, but they are able to communicate using neighboring nodes. What is more, WMNs have the ability of self-configuration and repair in case the position of a node changed or nodes were added or removed.

As WMNs, similarly to ad hoc networks, do not depend on the available telecommunications infrastructure, they are a very good choice whenever a decentralization is required. Moreover, they may be used wherever it is necessary to quickly restore communication, e.g., in natural disaster areas, where telecommunications infrastructure has been damaged or destroyed.

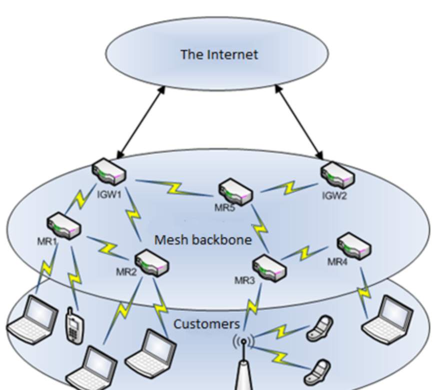

Figure 3. Wireless Mesh Network architecture

III. Multicast routing

A. Types of transmission in packet networks

In packet networks using Internet Protocol we can distinguish four main types of transmission as far as the way of delivering information is concerned: unicast, broadcast, anycast, and multicast.

Multicast transmission is based on sending the same data stream to multiple receivers. Its main advantage is that even though the information is sent to a group of receivers, it is transmitted by each network link only once, which saves considerable amount of bandwidth and energy and eliminates the need for sending multiple copies of the data. To be able to use multicast in WMNs it is necessary to implement algorithms generating a structure of the network as well as ones choosing optimal routes between devices.

In subject literature, 'algorithm' and 'protocol' definitions are often used in an ambiguous way. In this article, authors assume that only such a solution should be referred to as 'protocol', for which a least state machine is defined.

B. Multicast routing in MANETs

Multicast routing algorithms are divided into the three following groups: *mesh-based*, *tree-based* and *hybrid*.

Mesh-based algorithms are recognized as the most reliable, because they create a structure in which more than only one path can connect the sender with the receiver. In tree-based algorithms only one path from sender to receiver exists, but it makes the routing much more effective and eliminates the possibility of loops occurring in the network. Moreover, both - the sender (*sender-initiated*) and the receiver (*receiver-initiated*) may initiate creation of the *multicast tree*.

Typical *tree-based* algorithms are: MAODV [1] and AMRIS [2], whereas typical *mesh-based* algorithms are: ODMPR [3] and CAMP [4]. The existing research [5] shows that in MANET environments, where changes in topology are common, *mesh-based* algorithms show better results than *tree-based* algorithms, which is due to the existence of redundant links in the mesh structure.

As this paper presents only the initial stage of this research, only mesh- and tree-based protocols are analyzed.

C. Multicast routing in WMNs

Wireless Mesh Networks are a relatively new wireless technology and that is why the available literature does not show any recent research studies that would compare the existing multicast routing algorithms. One of the first studies on the topic is [8], in which Ruiz states that the *shortest path tree* (SPT) algorithm does not work well for WMNs and proposes minimum number of transitions (MNT) algorithm that focuses on using properties of multicast transmission to reduce the number of transmissions necessary to reach all nodes in a tree.

In [6], Nguyen and Xu present their analysis on effectiveness of *Minimal Coverability Tree* (MCT) and SPT algorithms. The research shows that SPT algorithms are much more efficient than MCT algorithms.

Moreover, two multicast algorithms for WMNs, i.e., *Level Channel Assignment* (LCA) and *Multi-Channel Multicast* (MCM) are introduced in [7]. These algorithms aim not only to increase throughput in WMNs, but also to minimize the number of hops in a tree. Multicast *mesh tree* is created by dividing routers to different levels using *Breadth First Search* (BFS) algorithm as well as heuristic channel allocation to different radio interfaces.

Zhao, et al. [8] proposes *Gateway Associated Multicast Protocol* (GAMP), which was created to improve *Quality of Service (QoS)* in Wireless Mesh Networks. GAMP is

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a hybrid algorithm, because the sender broadcasts *Hello* messages to all active access nodes and when a receiver wants to join a group, it sends a connection message to the access node (*on-demand*).

D. Algorithms chosen for the simulation

Several factors were taken into consideration while choosing specific multicast routing algorithms for the research: clarity and granularity of the description of an algorithm, comparability to other algorithms and complexity of the implementation. Basing on the aforementioned criteria, the following algorithms were chosen: MAODV (MANETs), ODMPR (MANETs), MNT (WMNs), MCM (WMNs), LCA (WMNs). However, the LCA algorithm was omitted because its comparison with the MCM algorithm is available [7] and shows that the MCM algorithm gives better results than LCA.

E. Description of the algorithms and protocols

Multicast Ad hoc On-Demand Distance Vector (MAODV)
MAODV [1] is a reactive (on-demand) *tree-based* algorithm. It enables fully dynamic and multi-hop routing between mobile nodes willing to join a multicast group in ad hoc networks. What makes this algorithm different from the other ad hoc multicast routing algorithms is that each multicast group has its own sequence number assigned by a group leader (root of the tree). This number increases in time, what guarantees choosing always the most up-to-date paths, because nodes choose paths with the highest sequence. What is more, the group leader sends *Group Hello* messages to all members of the group to update its status.

Because MAODV is a reactive (on-demand) algorithm, as long as the connection between members of a multicast group is preserved, no actions are taken. Each node monitors the state of next-hop links, which is why in the case any path fails, it may be quickly restored.

On-Demand Multicast Routing Protocol (ODMRP)
ODMRP [3] is an *mesh-based* algorithm which implements forwarding group concept for multicast routing. It means that only some nodes of the multicast group may forward and transmit packets. The topology of the whole network is never stored anywhere, which means that user management is dynamic and *on-demand*. For managing routing activities, it requires storing some data structures, such as: *routing table*, *forwarding group table*, *group members table* and *message cache* in different types of nodes.

To keep the mesh structure in the most up-to-date state, soft state approach is used. This means that in the case a source wants to leave the multicast group, it just stops broadcasting *Join Query* messages and, if a receiver wants to leave a group, it stops broadcasting *Join Reply* messages. After some time, a timeout occurs.

Minimum number of transmissions (MNT)
MNT algorithm is described in [9]. According to Ruiz, the general assumption that Steiners tree is a tree of minimal cost, is not necessarily true in WMNs. Ruiz redefines the issue of multicast tree minimization in ad hoc networks to reduce the amount of data transmission. Existing calculations explicitly assume that, given node v, it is necessary to send multicast data k-times to reach k-neighbors of the node v. However, using multicast transmission, it is enough to send multicast transmission *only once* to reach any number of nodes v neighbors. Thus, the minimal cost tree is *not* the one which stores the lowest cost of each edge, but the one connecting senders and receivers in the least number of transmissions needed. This type of structure has been defined by Ruiz as *minimal data overhead tree*.

Multi-Channel Multicast (MCM)
MCM first builds a multicast structure by minimizing the number of relay nodes and hop count distances between the source and destinations, and then uses dedicated channel assignment strategies to improve the network capacity by reducing interference [7]. The authors of the algorithm have made an observation that when all the nodes have multiple radio interfaces, the multicast problem becomes, in fact, a special case of broadcast.

The first step of MCM is realized by *breadth first search* (BFS) algorithm. Then, all edges between any two nodes of the same level are deleted and a *tree mesh* is built.

In the second step of the algorithm, the minimal number of relay nodes forming a broadcast tree is identified. In the tree mesh one node may have more than one parent. The purpose of this step is to identify the only parent for each node, so that the number of relay nodes stays minimal.

After creating a multicast structure thanks to which each multi-receiver may connect with the gateway through minimal hop count distance, the algorithm assigns channels to the interfaces of the tree nodes using two allocation algorithms: *ascending channel allocation* and *heuristic channel allocation* [7].

IV. Simulation parameters

The quality of the simulation is directly related to a simulation model. In the case of WMNs, this model is complicated and consists of five sub-models:

- **node** - defining its hardware and software,
- **arrangement and mobility** (of the topology) - it ensures proper arrangement of nodes,
- **radio** - describing characteristics of the radio interface of a node,
- **propagational** - describing attenuation and radio channel characteristics,
- **traffic** - defining traffic in the network.

Some of the sub-models are based on actual measurements, e.g., propagational and traffic. The rest is synthetic and arbitrary, like the topology generator.

A. Network topology generator

In this study, as a topology generator, we use the algorithm called *Node Placement Algorithm for Realistic Topologies* (NPART) [10] to preserve reality of the generated topology.

The NPART algorithm was created on the basis of the measurements conducted on actual active WMNs in Berlin and Leipzig. The authors of NPART proposed this algorithm because they made an observation that it is difficult to find an algorithm with output similar to real networks.

B. Network topology used in simulations

It is assumed that nodes are allocated on a plane 1000 x 1000 units and that the communication radius is 100. The cost of each connection varies between 10 and 100 and the delay metrics is the Euclidean distance between nodes. For the simulation to be as realistic as possible, 1000 topologies have been generated.

C. Parameters of the simulation

Node count. The total number of nodes in the network is a very important parameter in the process of building structures by multicast routing algorithms. In the study, networks of 50, 100, 150 and 200 nodes were analyzed.

The number of multicast groups. In real WMNs, any number of multicast groups may exist. However, to simplify the analysis of the results, only one multicast group will exist in a simulated network.

The size of a multicast group. As the multicast group grows, finding the optimal structure becomes more time-consuming and requires more hardware resources. Groups of 5, 10, 15 and 20 nodes were examined in the research.

D. Parameters of multicast routing examined in the research study

The mean path length between the sender and a multicast group. Multicast routing algorithms create a structure that enables the most efficient transmission between sending and receiving nodes in WMNs. It is expected that the paths will be as short as possible, which means as few relaying nodes as possible. Each relaying node increases the risk of path breakdown and introduces additional delay and cost. In this research, the mean path length parameter is calculated by adding up all path lengths between sender and each separate node of a multicast group and dividing the result by the number of nodes in the particular multicast group. The path length is expressed in the number of edges (NE) between the sender and the receiver.

The mean path cost between the sender and a multicast group. The value of this attribute reflects the whole set of parameters describing a cost of creating an edge between two nodes. As such a parameter we could assume, for example, bandwidth required for the transmission to be successful. In simulations conducted in this research, the cost of each connection varies between 10 and 100 and is chosen in a random way. Thus, the mean path cost parameter is calculated by adding up all path costs between sender and each separate node of a multicast group and dividing the result by the number of nodes in the particular multicast group. The cost of the path is expressed in Cost Unit (CU).

The mean path delay between the sender and a multicast group. It is desirable for delays in a transmission between the sender and the receiver to be minimal in most cases of modern multicast connections applications. Delay is a time necessary to transmit data from one node to the other. In this paper, delay metrics is assumed to be the Euclidean distance between two nodes and is expressed in Delay Units (DU). Thus, the mean path delay parameter is calculated by adding up all path delays between sender and each separate node of a multicast group and dividing the result by the number of nodes in the particular multicast group.

V. Results

A. The influence of network size on the performance of multicast algorithms

The influence of the number of nodes on the performance of multicast algorithms was examined first. The results are shown below – Figs. 4-6.

The results clearly show that MNT algorithm stands out as compared to other algorithms. This is due to the specific way the algorithm decides to create a path. MNT chooses nodes which cover as many receivers as possible and takes into consideration the rest of the parameters afterwards.

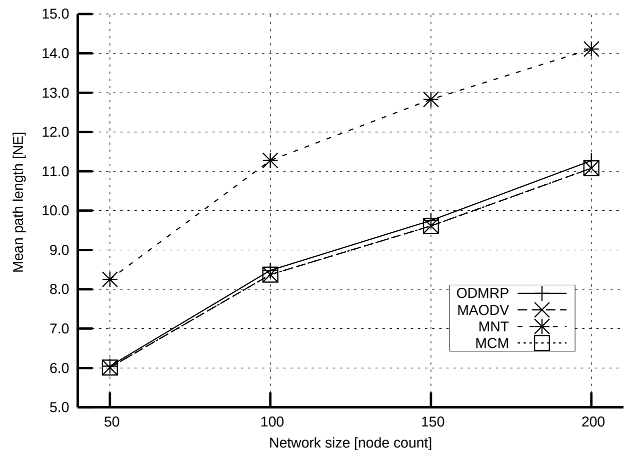

Figure 4. Mean path length in function of network size

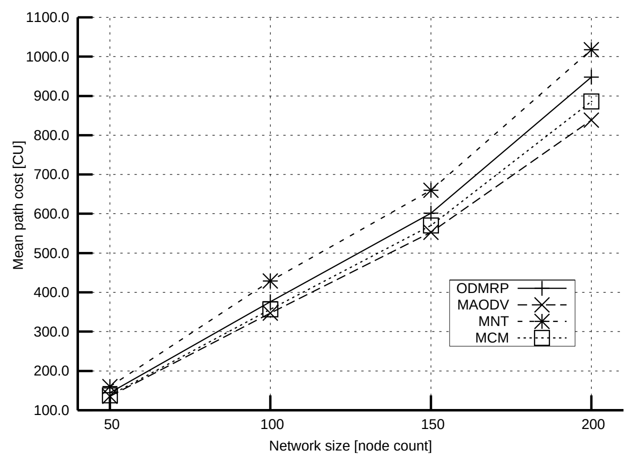

Figure 5. Mean path cost in function of network size

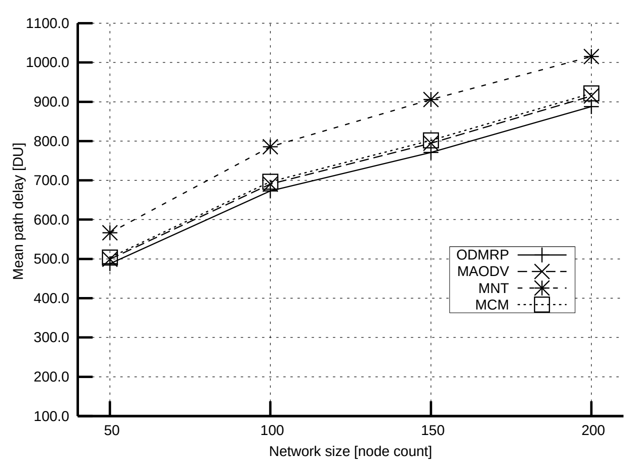

Figure 6. Mean path delay in function of network size

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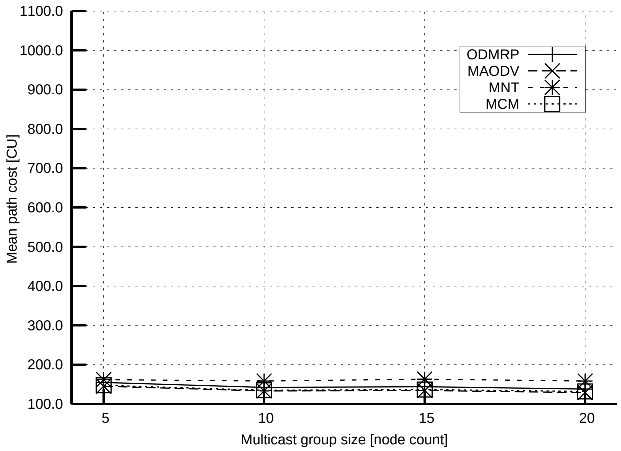

Figure 7. The influence of the number of receiving nodes on the mean path cost (50 nodes)

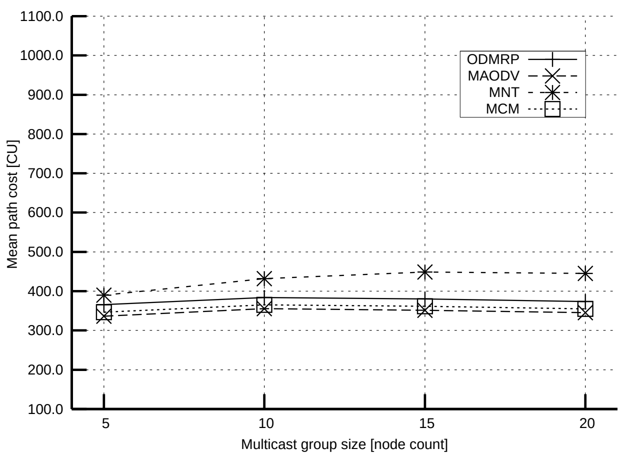

Figure 8. The influence of the number of receiving nodes on the mean path cost (100 nodes)

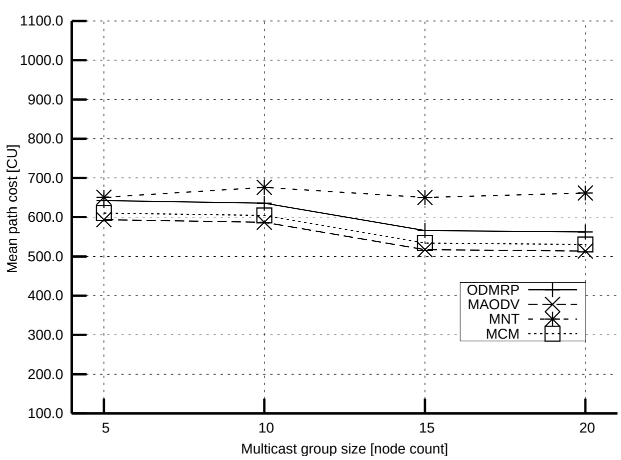

Figure 9. The influence of the number of receiving nodes on the mean path cost (150 nodes)

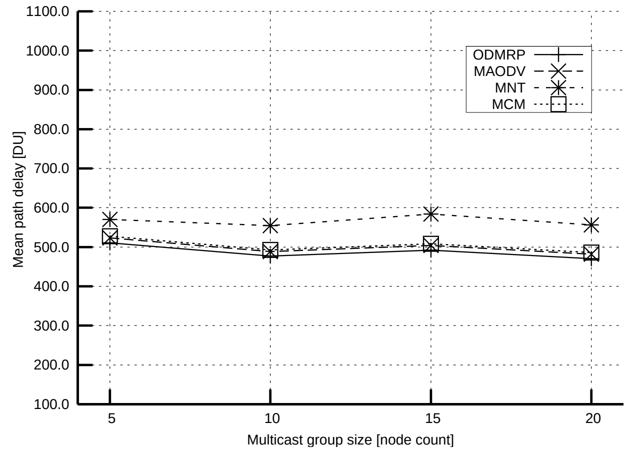

Figure 10. The influence of the number of receiving nodes on the mean path delay (50 nodes)

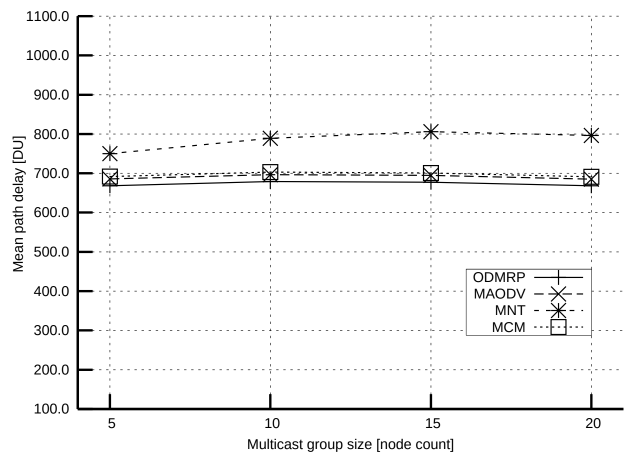

Figure 11. The influence of the number of receiving nodes on the mean path delay (100 nodes)

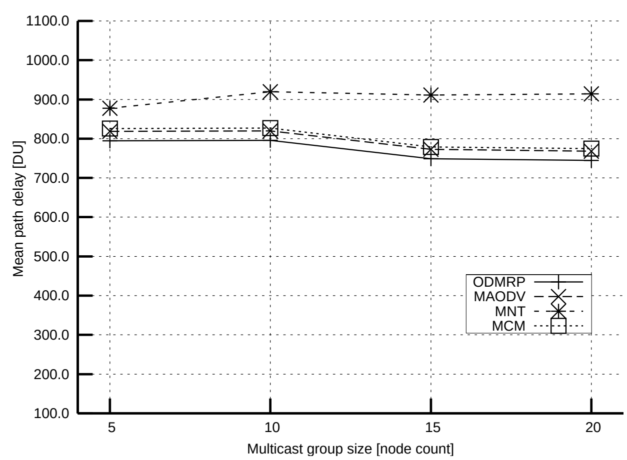

Figure 12. The influence of the number of receiving nodes on the mean path delay (150 nodes)

Surprisingly, despite the fact that ODMRP, MAODV and MCM have different criteria of choosing nodes to join a path, *mean length of the path* is very similar in each case.

This is probably because of the way the cost of the path

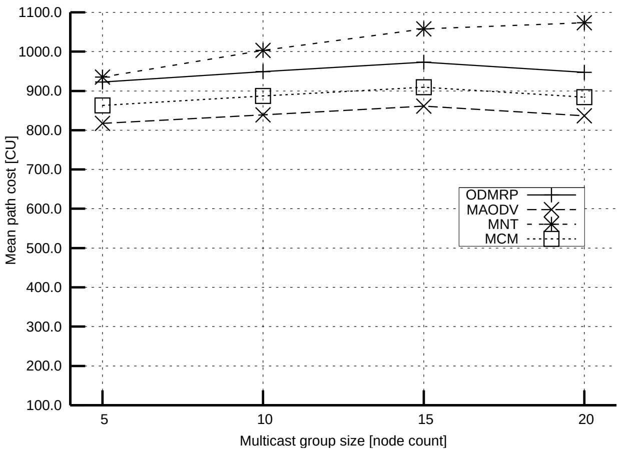

Figure 13. The influence of the number of receiving nodes on the mean path cost (200 nodes)

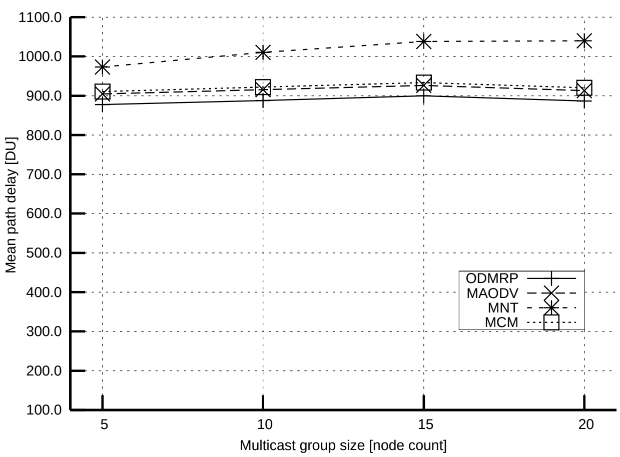

Figure 14. The influence of the number of receiving nodes on the mean path delay (200 nodes)

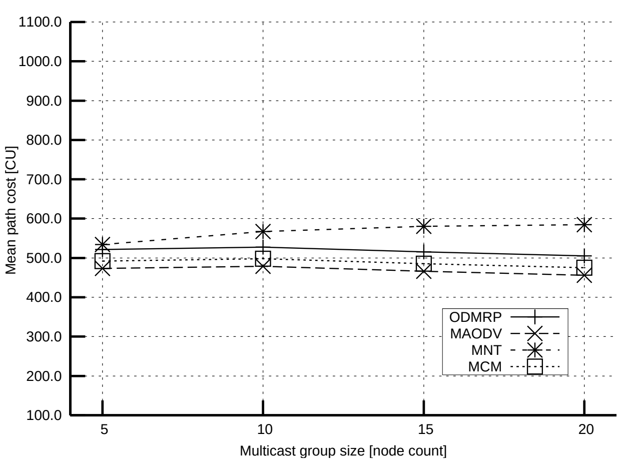

Figure 15. The influence of the number of receiving nodes on the mean path cost (averaged)

is defined. A very similar situation occurs when *mean path delay* is considered – the algorithm which achieved the best

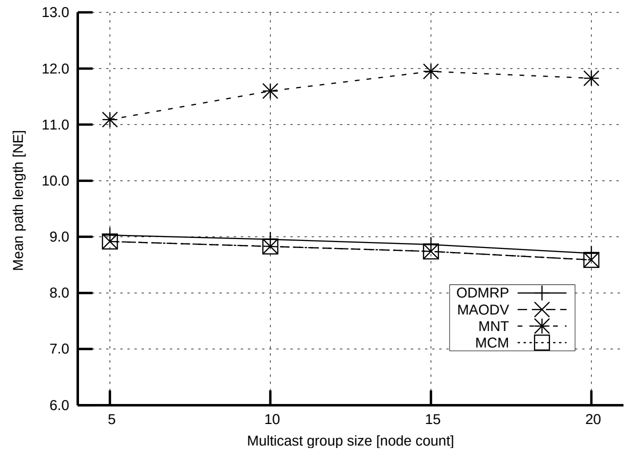

Figure 16. The influence of the number of receiving nodes on the mean path length (averaged)

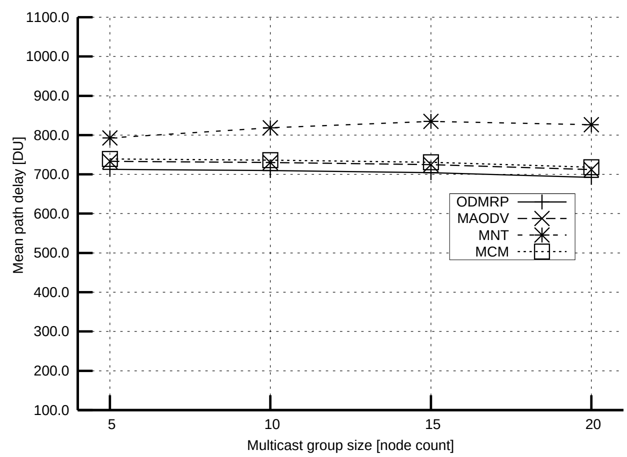

Figure 17. The influence of the number of receiving nodes on the mean path delay (averaged)

results was ODMRP, because this algorithm takes time into consideration while creating the structure.

Concluding, although there are differences between the algorithms, in some cases ODMRP, MAODV and MCM performance is similar. Considering all of the parameters examined, the MAODV algorithm performed slightly better than the others, whereas MNT proved to be the least effective.

B. The influence of the multicast group size on performance of multicast algorithms

The study of the influence of the multicast group size on the performance of multicast algorithms was performed for 50, 100, 150 and 200 nodes and for group sizes of: 5, 10, 15 and 20 (Figs. 7-14).

Network consisting of 50 nodes. Figs. 7 and 10 show that the mean path cost is similar for each algorithm. Together with the growth of the receiving group, the cost drops slightly, which may be caused by the fact that shorter paths to nodes closer to the source might have appeared. Only in the case of the MNT algorithm, the path cost decrease is less dynamic, but this is caused by the algorithm of path construction. The increase in path delay, cost and length for 15 receiving nodes is not surprising, because the values should fluctuate within certain range.

Network consisting of 100 nodes. In the network consisting of 100 nodes the mean path cost and delay change in a different way than in a smaller network. Figs. 8 and 11 show the values of these parameters that seem to stay within a certain range for all of the algorithms except for MNT. As suspected, MNT behaved in a different way - values of the mean cost, delay and path length increase almost steadily.

Network consisting of 150 nodes. In the case of a network consisting of 150 nodes, an improvement may be observed as compared to a network consisting of 100 nodes. MAODV, ODMRP and MCM algorithms show a significant drop in the mean path delay and cost (Figs. 9 and 12). Even though it may indicate that these algorithms are very effective in large networks with an increasing number of receivers, it might also mean that members of multicast groups were chosen in an unfavorable way.

Network consisting of 200 nodes. The results of the evaluation for the network consisting of 200 nodes confirm the previous findings and are presented in Figs. 13 and 14.

C. Conclusions

Despite the differences between ODMRP (*mesh-type*), MAODV (*tree-type*) and MCM (*tree-type*) algorithms their performance is comparable. However, it should be pointed out that as the best candidate to be used in multicast routing the **MAODV** algorithm should be chosen. The analysis and research conducted in this paper show that this algorithm, from among all the tested algorithms, offers the lowest mean path cost (Fig. 15) and the lowest mean path lengths (Fig. 16), only performing slightly weaker than ODMPR as when comes to the lowest mean path delay (Fig. 17).

VI. Conclusions and Future Works

The paper presents performance evaluation of the selected multicast routing algorithms for WMNs. The most interesting results were obtained for MAODV and MNT algorithms.

MAODV uses a *tree* structure to operate, which makes its efficiency in WMNs surprising, because the nature of WMNs suggests that *mesh-based* algorithms should perform better in these networks. Moreover, MAODV was not designed for WMNs, but for ad hoc networks. This makes MNT algorithms results even more peculiar, because it is a *mesh-based* algorithm specifically designed for a multi-hop environment. However, the analysis of the mechanisms used by this algorithm suggests that it is not possible for this algorithm to achieve results even remotely comparable to other tested algorithms.

It is worth mentioning that the MAODV algorithm is used as an example of a multicast routing algorithm by the IEEE 802.11s workgroup responsible for standardizing *Wireless Mesh Networks*. This paper presents the initial stage of the research during which the authors evaluated and compared discussed in literature protocols and algorithms for WMNs. Considering the fact that this paper analyzes only mesh- and tree-based protocols, further papers on the topic of hybrid protocols in WMNs shall follow. In the next stage of this research, the most efficient algorithms will be compared to the solutions proposed by the authors.

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