Limitations in Optimizing the Routing Protocol in ad hoc Mobile Networks

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***Abstract* — The margin between real ability of connection among mobile nodes and actuality of knowledge about current topology at routing level is identified. The connection probability is considered and determined for the routing as well as physical layer level. The difference between them indicates that the routing protocols do not fully use the network abilities, which is confirmed by the results of simulation tests presented in the paper. The results for the modified version of the routing protocol with increased efficiency are also presented. Nonetheless, there is still some space for optimization to improve protocols efficiency measured, for instance, by the packet delivery ratio (PDR).**

Keywords* — *MANET, V2X, VANET, ad-hoc, network connectivity, routing, protocols.

"This paper was originally presented at the NATO Science and Technology Organization Symposium (ICMCIS) organized by the Information Systems Technology (IST) Panel, IST-200RSY – the ICMCIS, held in Skopje, North Macedonia, 16-17 May 2023".

I. Introduction

Contemporary communication networks are characterized by increasing decentralization. It is reflected in data transmission between users' terminals, directly without the use of specialized devices. Each of the network elements (nodes) has the same or similar functionality, acting as the user's terminal and as a point of data forwarding. Networks of this kind are called ad-hoc networks. The main advantage of ad-hoc networks is minimizing device configuration while it is being joined to the network as well as the increase in mobility connected with it joining the network and associated increase in mobility. The ad-hoc networks have found their application in many fields i.a. military use on the contemporary battlefield as the self-organized data exchange network. It can be used as the low level network, e.g. voice network for operating platoon or on the high levels in the HQ centres. Hence they can come in different varieties, such as MANET (Mobile Ad-hoc NETwork), VANET (Vehicular Ad-hoc NETwork) or V2X (Vehicle to Everything). The most popular MANET networks operate on the basis of a routing protocol. Two main types of the routing can be identified: reactive and proactive. The reactive routing protocols find the path to the destination node on-demand. The path searching mechanism is triggered when the source node starts the transmission to the destination node. The proactive routing protocols periodically recognize their neighbourhood and build the knowledge about surroundings and the routing paths to each network node.

On the other hand, nowadays we can observe rapid development of 5G technology and broad spectrum of its possible applications. Among others, there is the Internet of Things (IoT), strongly connected with mMTC (massive Machine Type Communication) slice of 5G networks architecture, as well as various types of mobile communications like Vehicle-To-Everything using cellular systems (C-V2X) or a cloud of drones, where another profile of 5G is proposed, e.g. eMBB (enhanced Mobile BroadBand) and URLLC (Ultra Reliable Low Latency Communications). IoT applications is a massive but rather static case in contradiction to C-V2X communication where hi-speed scenarios as well as various modes of operation are considered: device-to-device or device-to-network. Point-to-point communications is the simplest case but, in a scenario where a certain number of vehicles are acting together there is a problem of end-to-end connectivity. In such a case some nodes are achievable only in multi-hop manner, which is connected with the use of routing protocols.

The fact that there are the real abilities of connections resulting from the sufficient radio range, is reflected in the routing protocol with some delay. Thus, any change in the topology could result in out-of-date routing knowledge of topology .

In the paper the margin between the real ability of connection (on the physical layer level) and the actuality of knowledge about the current topology at routing level is identified.

The rest of the paper is organized as follows. Section II describes the problem of delay in recognition of network topology at routing protocol level. Section III presents theoretical probability of end-to-end connection at physical layer as well as the results of some MATLAB simulation. Section IV deals with the results of research on probability of connection from the routing protocol layer point of view. Finally, Section V offers some conclusions.

II. Problem Definition

The advantage of ad-hoc networks is how easily links between network nodes can be created. Mobility of network elements and other phenomena connected with radio transmissions often contribute to uncontrolled network topology changes. Network susceptibility to topology changes is an advantage but it also makes it difficult to find and maintain paths for data exchange between nodes. This is due to the inertia of the routing algorithms' reaction to the occurrence of disruptive factors. It, in turn results in the loss of continuity in the route consisting of multiple intermediate links. The route path discontinuity means a connection break and the lack of possibility to exchange data. This problem should be detected by suitable routing mechanisms which check the route condition and search for a new route in the case of an interrupted path. These mechanisms work in specific cycles and therefore, disruption of the route takes a certain amount of time. Connection breaks resulting from routing path disruption and the time needed to find a new one cause packet losses. The results obtained in the our research [1] indicate that the packet loss rate depends on the number of nodes in the network as well as on their mobility and it increases as these factors increase. One of the simplest solutions to reduce the effects mentioned above is increasing the frequency of network condition monitoring. However, it entails increased network traffic load and greater need for node resources. This solution is inefficient, particularly in mobile wireless networks with high dynamic of topology changes and a large number of nodes. Therefore, it can be seen that the routing protocols efficiency to establish the routing path is smaller than the network real possibilities (measured on physical layer level). While there is a physical layer connection between the respective nodes, routing protocols require time to find it and set a new path. In the case of reactive routing protocols, it is the time needed to detect the lack of control information, to send information about the interrupted link to the source node and to set a new routing path. In proactive routing protocols it is the time needed to detect the lack of control messages concerning recognition of the neighbourhood environment, to send information about local topology changes and to set a new routing path. Hence, the main goal of the development of ad-hoc networks is to find an efficient solution to use the availability of physical network resources.

III. PROBABILITY OF CONNECTION AT PHYSICAL LAYER

The connectivity in Vehicle-to-Vehicle networks was considered from many points of view in numerous papers. In [1] an exact formula for the probability that the network is fully connected is provided for one-dimensional network. It is a function of the transmission range and the number of nodes under the assumption of uniform distribution of nodes along the road. Such scenarios are very common in many papers.

The authors of [3] considered two-dimensional connectivity for sparse VANET in the case of some number of intersected roads in the shape of a lattice. Actually, this is the second most popular scenario. It takes into account such connectivity-related parameters as the average number of intersections as well as the arrival rate of the vehicles at the entrances into the area. The papers mentioned above are examples of numerous works considering some aspects of one- or two-dimensional probability of connection in wireless networks. Similar formulas can be found e.g., in [4], [5]

Taking into account our previous efforts on MANET routing protocols [9] the most interesting analyses are shown in [6]. It considers a case of Vehicle-to-Vehicle network on a motorway. Base Stations (gNB) are located at the entry and exit points and on the road there are vehicles arriving randomly according to Poisson's process. The generic model is presented in Fig. 1.

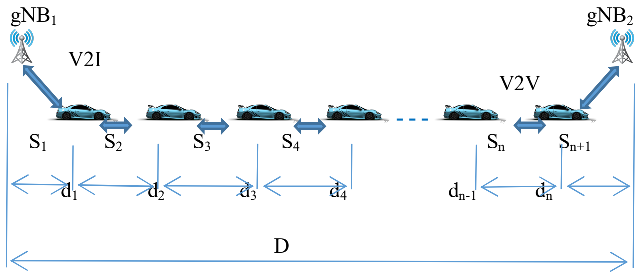

Fig. 1. A vehicular network consisting of *n* vehicles and two gNBs

The mobility model is as follows:

- vehicles arrive randomly with the intensity described by Poisson's distribution;
- the speed of each vehicle is independent identically distributed (*iid*) random variable, normally $v_i = (V_{mean}, \delta)$ or uniformly $v_i \in \langle V_{\min}, V_{\max} \rangle$ disstributed.

A. *The connectivity models*

The total distance between gNBs is D. Each vehicle is equipped with the transceiver that has the maximum transmission range Rt. Since Rt < D the transmission is possible only in a multi-hop manner. In fact, the transmission range of gNB is wider than the range of the vehicles but bidirectional communications is possible only within the range of the vehicles. So, the same communications range for all the nodes in the scenario is assumed.

It is assumed that nodes transfer data only to adjacent nodes, and each node can form at most a single link at a time, thus an end-to-end link is maintained when there is a connection from one gNB to another. In such circumstances the existence of the link depends on three factors:

- the intensity of arrivals λ – the higher the intensity, the higher the number of vehicles on the road (n);
- the speed of the vehicles – higher speed is connected with a higher departure rate, so it is inversely proportional to the arrival rate and;
- the range of the communications.

Taking into account the distance between gNBs a normalized transmission range can be defined as:

$$a = R_t / D \tag{1}$$

According to eq. 11 in [6] the probability that the network is fully connected is equal to:

$$P\left(VANET\,is\,connected \mid N(t) = n\right) = \sum_{j=0}^{\lfloor a^{-1} \rfloor} \binom{n+1}{j} (-1)^j (1 - ja)^n \tag{2}$$

where $\lfloor x \rfloor$ is the largest integer not greater than x.

An important aspect which shall be taken into account is the velocity distribution of the vehicles on the section of the road under consideration. When the arrival intensity is constant, the average number of vehicles travelling at the time moment t, $N(t) = n$ is inversely proportional to its velocity V. Thus, the spatial density λ_d of vehicles between two gNBs is the arrival rate scaled by $E[V^{-1}]$:

$$\lambda_d = \lambda E\left[V^{-1}\right] \tag{3}$$

As a consequence, the average number of vehicles between gNBs is:

$$E\left[N(t)\right] = \lambda_d D \tag{4}$$

Taking into account the mobility aspects above eq. (2) takes a form (5):

$$P\left(VANET\ is\ connected\right) = e^{-\lambda_d D} \sum_{n=0}^{\infty} \sum_{j=0}^{\lfloor a^{-1} \rfloor} \binom{n+1}{j} (-1)^j (1-ja)^n \frac{(\lambda_d D)^n}{n!} \tag{5}$$

$\therefore$

The probability of connection at physical layer is a bound of ability of the network and gives the reference level to any optimizations on higher layers of protocol stack. In other words, we can estimate optimization potential of the routing protocol under consideration in VANET network. For this purpose an analytical program, intended to be used with OmNET++ simulator, was developed and evaluated.

B. Evaluation of analytical program

First of all, some simulations were made in order to assess the compliance with theoretical curves.

The input parameters were as follows:

- the length of the section of the road: D = 3000m
- an average number of vehicles depends on:
  - the average velocity with normal distribution: 40, 50, 60 km/h and;
  - Poisson's' arrival rate (in a one-minute interval): 0.25, 0.5, 0.75 … 5;
- the range of communications $R_t = 600m$
- simulated time 200 min.

During the simulation the position of each vehicle was calculated with 1 second resolution. Next, the analytical program developed in MATLAB was used to assess the time of full network connection taking into account positions of nodes and communications range. The results are shown in Fig. 2. The solid line curve is for theoretical probability according to equation (2), whereas the dots represent the percentage of full connection time for three different values of velocity.

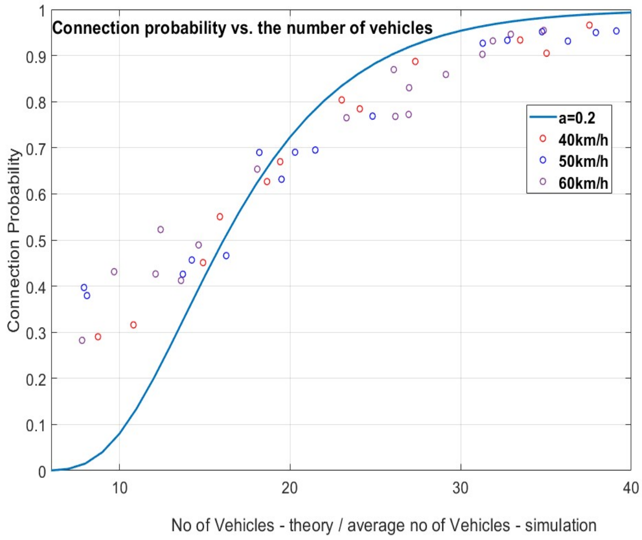

Fig. 2. Connection probability as a function of no of vehicles – λ=5

For the number of vehicles over 15, our results are consistent with the theoretical probability. The inconsistency in probability level for lower numbers of vehicles is caused by the method used for traffic simulation. The number of vehicles arriving each minute is generated according to the declared value of λ. For low intensity of arrivals, the number of vehicles on the road during the simulation is varying significantly enough to influence the results referenced to the average number of vehicles in the whole simulated time.

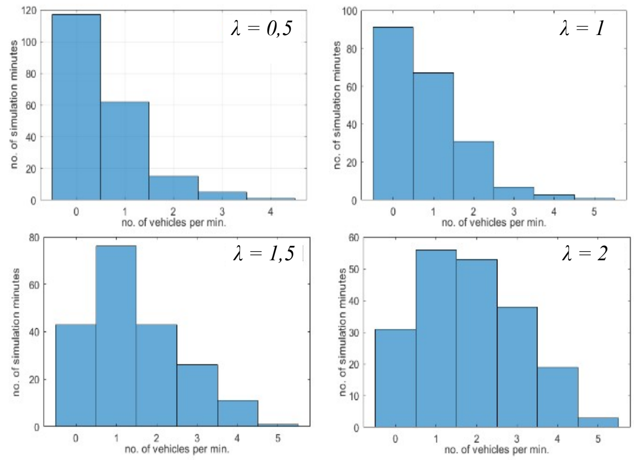

Fig. 3. Histograms for arrival rate in one-minute periods

Fig. 3 presents histograms of arrival intensity and the mean number of vehicles on the road during the simulation. At low intensity of arrival e.g., λ = 0.5, 1 vehicle in most time intervals (i.e., numbers of 1-minute intervals) there were no new vehicles arriving at the starting point. For of λ =1 in 91 out of 200 one-minute intervals there were no new vehicles. The referencing time of full connection of the network to the average number of vehicles gives results deviating from the theory but showing the importance of velocity distribution. However, the main goal, i.e. the validation of the analytical programme, was accomplished.

IV. ROUTING PROTOCOL EFFICIENCY

In our work we verified possibilities of increasing ad-hoc routing protocols efficiency. The research was conducted using OSLR protocol in a 20-node ad-hoc network. The simulations were carried out in the OmNET++ network simulator. The scenario consists of up to 20 nodes moving in a closed area with the constant speed of 20mph, in accordance with *MassMobility* model. This mobility model represents the random movement of people in a closed area, e.g. a stadium. Table I presents simulation scenario parameters.

TABLE I. THE SIMULATION MODEL PARAMETERS

Parameter	Value
Area	1000 x 2000m
Mobility model	Mass Mobility
Simulation time	24h
UDP data transmission	100B packets in bulk 10 sec. every 1 sec.
Node Speed	20 mps
Wireless technology	WLAN 802.11g, 54 Mbit/s, radio chanel model Rayleigh, transmission power . 5MW, RTS_threshold 3kB, non EDCA , bitrate 6 Mbit/s

During the simulation the UDP packets were streamed between two arbitrarily chosen nodes (S – source, D – destination) and the Packet Delivery Ratio (PDR), Physical Connection Probability (PCP) and the Routing Connection Probability (RCP) were measured. The PDR indicates the efficiency of packet delivery. The connection probability is understood as the ratio of the connection lifetime (time of full path existence) between nodes S and D to the total observation time. The PCP probability is on the physical layer (the nodes are in the common radio range) whereas the RCP is on the routing protocol level the nodes are connected by two-way link.

We also used physical and theoretical PDR parameters as well as those measured in simulations. The physical PDR was calculated as the ratio of the number of packets that could be delivered taking into account the fact of physical layer connection (one-hop or multi-hop) between S and D nodes to the whole number of packets sent. The theoretical PDR was calculated as the ratio of the number of packets that could be delivered considering the routing path existence to the whole number of packets sent. The measured in simulations PDR was a combination of physical and theoretical PDR (further called “simulation PDR”). The possibility of packet delivery was taking into account the existence of physical layer connection and routing path simultaneously. All these ideas are presented in Fig. 4.

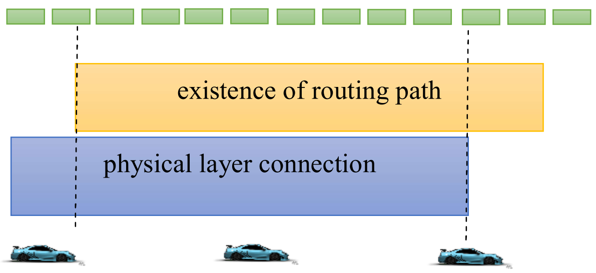

Fig. 4. The idea of PDR calculations

The first test was to verify the impact of the network state monitoring frequency on the PDR parameters. The HELLO packet sending interval was changed and the PDR parameters were calculated. The results are shown in Fig. 5.

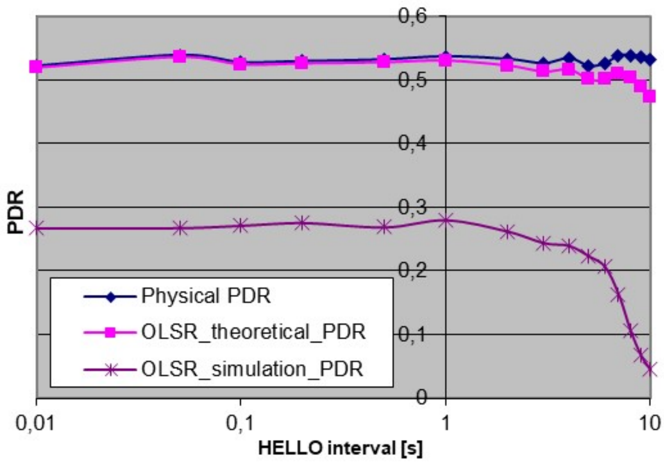

Fig. 5. Influence of HELLO intervals on packet delivery ratio

The physical PDR is independent of the HELLO packet interval as it is the physical layer connection only that is considered in the calculations. As it can be seen in Fig. 5, the PDR parameters for OLSR protocol get worse with long intervals between HELLO packets. However, increasing the frequency has only limited influence and is visible for intervals longer than 3 sec. (which is the standard value recommended by RFC [8]). The packet delivery rate decreases as the interval increases. It is clearly visible in the simulations where the routing protocol is cannot keep up with topology changes. The increase in the network state monitoring frequency (decreasing HELLO interval) has no influence on the packet delivery ratio. It is necessary to look for other solutions to increase the connectivity potential of ad-hoc networks.

Our attention was focused on the path searching algorithms. The standard version of OLSR routing protocol uses the link metric (called ETX) calculated from the packet losses and delays. Our modified version [9] uses the link metric calculated from link activity times (according to formulas 6 and 7) which is simply correlated with link availability period.

$$M = (1 / \mu) * 1000 \quad (6)$$

$$M = (\delta / \mu) * 1000 \quad (7)$$

where μ is an average value of link activity time and δ stands for standard deviation of link activity times.

Our solution using links metrics is based on estimated connection times between neighbouring nodes. These times are TOLA (Time Of Link Activity), when the nodes remain connected, and TTLA (Time To Link Activation), when the nodes are out of their radio range. Having the knowledge about the availability time of a specific link, the routing algorithm makes a decision to search for a new link or a new route before the degradation of the current one can be detected by standard mechanisms of topology recognition and creation of a new route. Similarly, basing on the knowledge about possible availability of nodes, the routing algorithm takes into account the nodes that are currently not available but will be available within an estimated time (TTLA). The knowledge about such time dependencies of connections between nodes helps to predict topology changes and react properly in advance. However, it should be noted that the estimation of the connection and disconnection times is not a simple task due to its random character, resulting mainly from the random character of node mobility.

The presented method requires periodical collection of data on connections between nodes. These data include connection and disconnection time and are stored in local bases of nodes and processed in order to estimate a link metric. In the case of reactive routing protocols it can be difficult since data exchange is done only when the route is active. Greater efficiency will be achieved in the case of proactive routing protocols because they maintain exchanges and control data continuously. It is also one of the reasons for choosing the OLSR routing protocol.

The metrics calculated in this way resulted in path recalculations before the specified link was broken. The routing algorithm selected the links whose expected activity time was longer than the current one, and switched to such links when they appeared. This is due to the fact that the metric is inversely proportional to the estimated average activity time. Additionally, taking into account the standard deviation, the metric includes information about predictability of estimated time of this activity. If the standard deviation is small, then the actual activity time should be equal to the average value.

The link metrics determined according to the above dependencies take a specific value and maintain it at this level throughout the duration of the connection. Therefore, in order to identify the moment when the node disconnection is expected (loss of connection within the meaning of the routing protocol), a method of deterioration of the metric along with the elapsed time of the existing connection with the neighbouring node has been proposed. The new value of the metric is recalculated cyclically according to the formulas below, depending on the method of determining the metric (taking into account the standard deviation or not):

$$M_{curr} = \frac{1}{\mu_T - T} * 1000 \tag{8}$$

$$M_{curr} = \frac{\delta}{\mu_T - T} * 1000 \tag{9}$$

The metric is determined cyclically by recalculating it, taking into account the previously determined parameters, i.e. the standard deviation and the average value of the connection time. The average connection time value is reduced with the time T that has elapsed since the detection of the neighbouring node as capable of transmitting user data. As a result, the value of the metric tends to infinity in the time determined by the average value of the connection time.

Deterioration of the metric in a simple and clear way points to the routing algorithms that a given link to a neighbour node may soon be disconnected. These algorithms periodically analyse the database of links and metrics describing them and build local routing tables on an ongoing basis. Hence, as the metric deteriorates, nodes whose estimated connection time is coming to an end will be treated as worse. Thus, when the new nodes appear in the environment, the route can be switched if the new route is predicted so as to be able to maintain a stable route for a longer time than the previous one.

Fig. 6 presents the simulation results in which the PDR parameter was measured for the standard and modified version of the OLSR protocol as a function of the number of nodes.

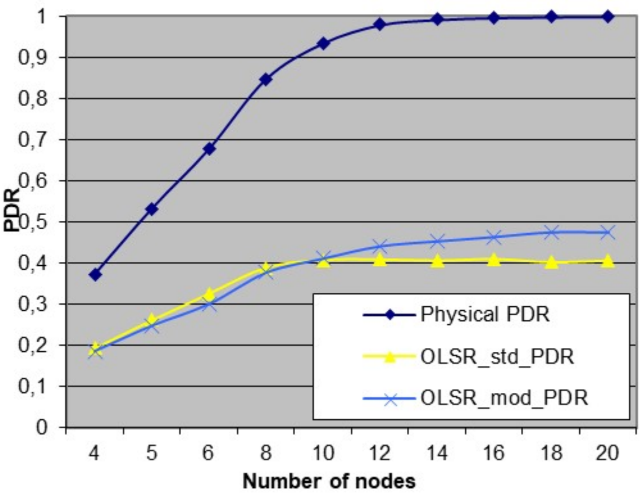

Fig. 6. Packet delivery ratio for standard and modified OLSR protocols.

As one can see in Fig. 6, the PDR for standard and modified OLSR protocol is nearly half of the theoretical PDR (Physical PDR). This is due to the packets loss in the ad-hoc wireless network, packet loss resulting from link switching done by OSLR protocol and routing algorithm inertia. It shows the margin between the network's real ability of connection among mobile nodes and the actuality of the knowledge about the current topology at routing level. The standard OLSR protocol switches links after detecting a broken route. Whereas the modified one in many cases switches it before the expected link deactivation, thus eliminating the loss effect when searching for a new route path. The PDR of modified OLSR protocol is higher than the standard version as the packet delivery probability has been improved.

The comparison of PCP and RCP is shown in Fig. 7. Analysing the connection probability from the OLSR point of view we can see that RCP is bigger than network physical connectivity PCP.

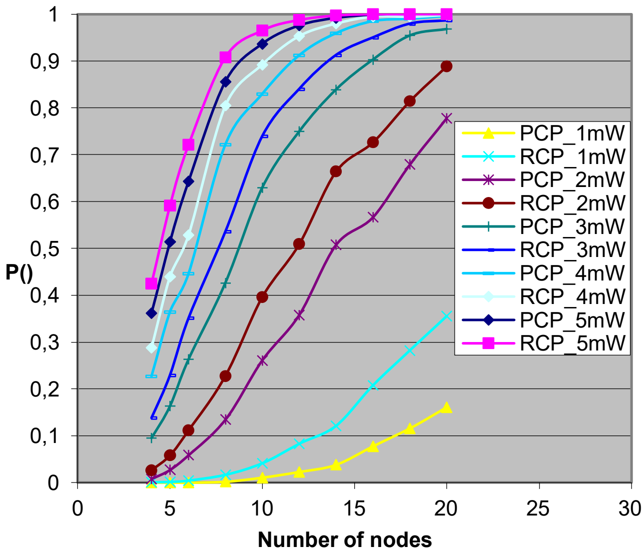

Fig. 7. Connection probability PCP (physical) and RCP (routing).

The difference between those two probabilities is inversely proportional to the radio range of the nodes. It means that the routing protocol is unable to take full advantage of the network. Therefore, this is an area for increasing the effectiveness of the protocols we, for instance, indicated in the studies of the modified OLSR protocol.

V. SUMMARY

In the article, we presented the theoretical basis of the probability of connection in comparison with the probability estimated on the basis of the simulation. The theoretical probability represents the network possibility to forward the user data. As we can see, the probability basing on routing protocol knowledge is smaller than the theoretical one. It means that the routing protocols are not able to fully use the network possibilities, which causes additional packet loss. We proved that changing routing parameters related to the frequency of refreshing the network state knowledge does not improve its effectivity. Then, we presented the simulation results of the modified version of ad-hoc routing protocol. This modification was made in the choosing path mechanisms of protocols and, as a result, the effectiveness was improved (significant improvement for networks above 10 nodes – Fig. 6). This is especially important for military low level networks where the resources (like bandwidth) are limited. This will avoid repeating lost data thus the resources will effectively used. The test results indicate that the proposed mechanisms may have a positive effect on efficiency and quality of services (UDP data transmission in simulation tests). It results from a smaller number of cases of switching the routing path in the proposed routing protocol modification than in a standard one. The modified routing protocol using estimation mechanisms preferred the least variable part of the mobile network topology and switched routing paths in a controlled way. Moreover, the addition of variation values in the link metric calculation makes it possible to identify links which are predictable in terms of connection time and their preferable choice in creating a routing path. The metric degradation mechanism improves the data transmission efficiency even further. It happens because as the time connection goes by, the metric becomes worse and the routing algorithm chooses a better link if it is available. In conclusion, the connection probability analysis indicates that there is a scope for work on increasing the effectiveness of the protocol and the area we should work on is the functionality, not the parametrization.

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