Estimation of link stability for Ad-hoc routing algorithms

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***Abstract*— The efficiency of MANET network largely depends on the routing mechanism, often working in high-topology-change conditions. It leads to communication interruptions and consequently to delays and data loss. The article presents the concept of routing using metrics based on estimation of connection time between nodes. This solution makes it possible to build routing paths consisting of the most reliable nodes and leads to early reaction to topology changes. The article also describes the results of simulation tests done on modified routing protocol with different estimated link metrics.**

Keywords—routing, MANET, ad-hoc, link stability

I. INTRODUCTION

The main advantage of ad-hoc networks (MANET – Mobile Ad-Hoc NETworks) is the easiness of creating links between network nodes. Mobility of network elements and other phenomena connected with radio transmissions often contribute to uncontrolled network topology changes. This kind of networks are devoid of administrative central points which would supervise how the network and its elements are functioning. Each of network elements (nodes) has the same or similar functionality, acting as the user's terminal and as a point of data forwarding, simply a router. Network susceptibility to topology changes is an advantage but makes it difficult to find and maintain paths for data exchange between nodes. This is due to the inertia of the reaction of routing algorithms to the occurrence of disruptive factors, which results in the loss of continuity in the route consisting of multiple intermediate links. The route path discontinuity means connection break and lack of possibility to exchange data. This state should be detected by suitable routing mechanisms to check route state and search for a new route. 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 time to find a new one cause packet losses. The results obtained in the research carried out as a part of our projects confirm the above. They indicate that the packet loss rate depends on the number of nodes in the network as well as their mobility and it increases as these factors increase.

One of the simplest solution how to reduce the effects mentioned above is increasing the frequency of network state monitoring. It entails increased network traffic load and greater need for node resources. Therefore, this solution is inefficient, particularly in mobile wireless networks with high dynamic of topology changes and a large number of nodes. It is desirable to develop mechanisms based on standard routing and maintenance data exchange which would also make it possible to choose links effectively. For this reason, links in MANET networks are marked with an additional variable – a metric the value of which represents link state. Depending on the use, the metric may represent node resources (e.g. occupancy of interface queues, battery condition, received signal level, etc.) or link quality parameters, like packet loss rate or packet delay. The routing protocol builds paths consisting of links with better parameters. It increases the quality of data exchange but does not resolve the problem of path interruption resulting from topology changes. That is why some attempts are made to assign values defining the link reliability or stability to the metric and to develop an estimation method for these values. In the articles [4], [5], [6], [7] some solutions are considered where the parameters such as link lifespan are assigned to the metrics. The lifespan is estimated on the basis of distinctive parameters of wireless mobile networks.

In the next part of the article (chapter 2) the authors present the idea of a routing protocol basing on metrics dependent on estimated link time parameters. In chapter 3 the proposal of OLSRv2 protocol modification is described. Chapter 4 contains specification and results of simulation tests. The aim of simulation tests was to verify efficiency of proposed mechanisms. In chapter 5 the authors present conclusions from the tests and directions for further future work.

II. ROUTING PROTOCOL WITH LINK STATE ESTIMATION

The MANET routing protocols are divided into two basic categories: proactive and reactive. Proactive routing protocols are based on up-to-date complete routing tables built on a current basis. They gather topology information and store routing paths to each network node, regardless of their real use. Reactive routing protocols, also called on-demand, build routing paths only when it is needed, generally if the source node receives the request to send user data from the application layer. Both kinds of protocols are able to build routing paths on the basis of either recognized up-to-date network topology (proactive protocols) or after receiving a request (reactive protocols). From the point of view of readiness to provide services, the proactive routing protocol seems to be more efficient due to continuously working topology discovery mechanisms, not ones reacting on demand, as in the case of reactive protocols. Maintaining a routing path is done in a similar way in both protocols. The intermediate nodes on the route path verify validity of the connection with their neighbouring nodes cyclically sending information about their own active links. Basing on such information, nodes detect topology changes and if it is needed, the process of routing path search is run again. The time it takes to detect routing path discontinuity and to find a new one depends on the type of routing protocol. In the case of reactive routing protocols it is a period of time needed for detection of lack of control information, propagation of this information to the source node and setting a new routing path. In proactive routing protocols it is the time needed for detection of lack of messages concerning recognition of the environment, propagation of information about local topology changes, and setting a new routing path. If during data transmission the routing path is discontinued and it is necessary to find a new one, the data packets may be delayed or even more frequently lost.

Considering the information above, it seems necessary to develop mechanisms supporting early detection of routing paths destructions, searching alternative routes and switching traffic without data loss during the user's transmissions. Path switching decision should be made on the basis of parameters describing links stability and reliability. In the reference articles [2], [3], [4], [5], the authors propose methods of estimating link stability basing on radio parameters of received radio signals and their changes, relative node location and their movement parameters or node resources (e.g. available energy, traffic load). The estimated data is converted into a link metric, which determines choosing the best links to routing paths.

Below there is a presentation of a solution using links metrics 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 should be 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.

In order to implement the solution above there is a plan to use the OLSR version 2 ad-hoc routing protocol. The OLSR protocol mechanisms cyclically exchange and control data containing link metrics representing quality of link neighbourhood. Metrics are also sent in messages that spread information on topology. Using the advantages of the original OLSR routing protocol, the solution of estimation of times TOLA and TTLA will not affect the functionality of OLSR. It will only require some modification of metric calculation mechanisms, which should be calculated basing on estimated connection and disconnection times.

III. LINK METRICS AND ASSOCIATION TIMES MEASUREMENTS

The time parameters TOLA and TTLA give information about time availability of links or neighbour nodes. The TOLA parameter is a link activity time and TTLA represents the time period when the link is not active. This information is stored in local bases of nodes that have the OLSR routing protocol running. Entries in local bases are refreshed after every update of the sets: Link Set (for links) and Neighbor Set (for nodes), in the Interface Information Base and the Neighbor Information Base accordingly. Therefore, each change in node association (e.g. inactive link becomes active or vice versa) recorded in the local base forces an update of the time parameters (connection and disconnection time). The sets mentioned above have been expanded with additional data fields. Fields that store information about actual time of connection setting <L_up_time> (<N_up_time>) and the actual time of connection loss <L_down_time> (<N_down_time>) have been added to the link and node sets in the local base. These times are used to estimate TOLA and TTLA time parameters, which are also stored in proper sets for links and nodes. Below there is a presentation of examples of local base entries according to RFC6130, describing link to neighbour node and supplemented with the fields mentioned above.

- Link Set: (L_neighbor_iface_addr_list, L_HEARD_time, L_SYM_time, L_quality, L_pending, L_lost, L_time, ***L_up_time***, ***L_down_time***, ***L_TTLA***, ***L_TOLA***).
- Neighbour Set: (N_neighbor_addr_list, N_symmetric, ***N_up_time***, ***N_down_time***, ***N_TTLA***, ***N_TOLA***).

The L_up_time parameter assumes value of actual system time in the case of link activation. In OLSRv2 protocol such an event can be identified when the L_lost flag changes the state from "false" to "true". The L_down_time parameter also assumes the value of actual system time but in other cases when local bases are forced to be updated, such as: link identification as unidirectional, setting L_lost flag or link time L_time expiration.

The values of TTLA and TOLA parameters might be calculated in a trivial way, e.g. as a mean value of the actual measured and the last mean value stored in the local base. The modification of OLSR protocol uses link metrics calculated in the way presented above and additionally, metrics calculated from the expected value and variance of connection time measurements. In the second proposal of metric calculation, local bases collect data on neigbour node association for as long as the network has been active. Then the expected value and variance are calculated and are mapped into a metric understandable for OLSR routing protocol. An additional mechanism of metric degradation has also been included in routing protocol modification. The values of metrics increase as the connection time elapses, so that before the connection is lost the metric value forces a change of intermediate node.

As it was mentioned above the metric values in the modified OLSR protocol are calculated in two manners, using a mean connection time value or expected value and variance of node connection times measured for as long as the network has been active. The simplest metric is calculated according to the following formula:

$$M = (1 / (TOLA_{OLD\_MEAN} + TOLA_{ACTUAL}) /2) * 1000 \quad (1)$$

where:

$TOLA_{OLD\_MEAN}$ – is a previous TOLA mean value;

$TOLA_{ACTUAL}$ – is an actual measured TOLA time.

The calculated metric is a reciprocal of a mean value from a recent mean value and the actual of connection time (TOLA) multiplied by the scale factor. It means that the longer the connection time of neighbour node, the bigger the metric. Thus, the neighbour metric is better for nodes that have been in association for a longer time. Degradation of metric is carried out cyclically, after each received HELLO message from the neighbour. The actual TOLA time is reduced by the period of sending HELLO packet. The metric value gets high values if the activity time of link approaches zero. The higher metric value means worse link reliability.

The second proposal of metric includes expected value and variation of measured connection times. The metric calculation formula is as follows:

$$M = (\sigma / \mu) 1000 \quad (2)$$

where:

σ – variation of TOLA measurements;

μ – expected value of TOLA.

This metric calculation includes expected value of connection time. The higher the expected value, the smaller the metric, which means a better metric. It means that a routing protocol should prefer links (nodes) which remain connected for longer. The second parameter is the variation of connection time measurements and the bigger the variance, the higher the metric, which means a worse metric. Therefore, a routing protocol chooses links (nodes) the movement of which is more stable, more predictable. The metric degradation method has also been implemented. Every time when the message HELLO is received, the metric is multiplied by two to make the metric worse. Thus, the link becomes less reliable and the routing algorithm will change the link in path if a better one appears.

IV. SIMULATION TESTS

The simulation tests have been carried out using the OMNet++ network simulator with the addition of MANET models including OLSR protocol. The routing protocol model has been modified in accordance with the information from chapter III. The Dijkstra routing algorithm is used in the routing protocol model. This algorithm builds the routes to all network nodes basing on the data from topology base (Topology Set) using low-cost links. The cost is represented by link metric.

The simulation tests have been performed for MANET network consisting of two stationary nodes (fixed_hosts) and from 2 to 4 intermediate nodes (hosts) moving between them, in accordance with *LinearMobility* model. In this mobility model, the mobile nodes move at the given speed and the given angle (90^0). After the node reaches the border of the area, it is reflected and moves in the opposite direction. The mobile nodes move at different speeds of 5, 10, 15 and 20 mps. The simulation parameters are presented in the table below:

TABLE I. THE SIMULATION MODEL PARAMETERS

Parameter	**Mobile nodes number**		
	2 nodes	**3 nodes**	**4 nodes**
Area	1000 x 2000m		
Mobility model	Linear Mobility		
Simulation time	24h		
UDP data transmission	100B packets in bulk 10 sec. every 1 sec.		
Node' Speed	5 mps, 20 mps	5 mps, 15 mps, 20 mps	5 mps , 10 mps, 15 mps, 20 mps
Wireless technology	WLAN 802.11g, 54 Mbit/s, radio chanel model Rayleigh, transmission power . 5MW, RTS_treshold 3kB, non EDCA , bitrate 6 Mbit/s		

The network topology model is presented in the figure 1.

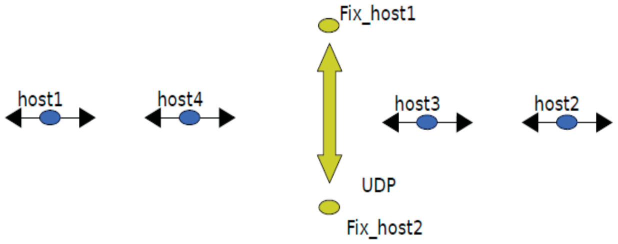

Fig. 1. Simulation MANET network topology

Additionally, the tests have been performed in two other network topologies. The first consists of two stationary nodes and ten mobile nodes moving in accordance with MassMobility mobility model at the speed of 20 mps. The second topology is based on the previous one with the addition of extra five mobile nodes moving linearly (LinearMobility) at the speed from 1 mps to 5 mps. In MassMobility model, nodes move at the given speed and a random angle (range 0 – 360 degrees) and a random period between changes in move parameters (1 – 10 sec.).

The aim of the tests was to verify if the proposed routing protocol modification will cause the preference of those intermediate nodes which are in the range of source node for a longer period of time. It should decrease the number of short-term connections and the amount of path switching and improve the efficiency of provided services.

During the tests we collected data referring to the quantity of the UDP packets sent by the source node and received by the destination node. The efficiency of the service constituted the parameter for evaluation of the influence of the proposed mechanisms on packet loss. It was calculated as the ratio of the number of received packets to the total number of transmitted packets:

$$M = (N_{recv} / N_{sent}) \qquad (3)$$

where:

N_{recv} – number of received packets by source node

N_{sent} – number of sent packets by destination node

The results of the simulation tests of the proposed mechanisms were compared with the results of standard OLSR protocol using ETX metrics. The results of mean UDP service efficiency for N-node networks are presented in Fig. 2.

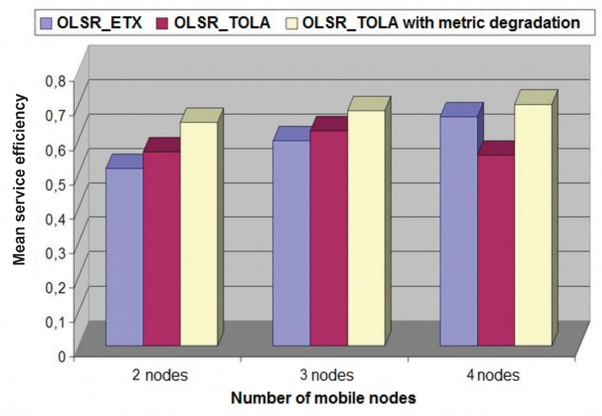

Fig. 2. The charts of mean UDP service efficiency

The confidence intervals of expected values for UDP service efficiency are presented in Table II. They indicate that a minor difference in results between standard and modified OLSR does not come from statistics but from the implemented mechanism.

TABLE II. RESULTS CONFIDENCE INTERVALS

	Number of nodes		
Confidece interval (at the level of 90%)	**2 nodes**	**3 nodes**	**4 nodes**
OLSR_ETX	$8,4 * 10^{-5}$	$4,2 * 10^{-4}$	$9,5 * 10^{-4}$
OLSR_TOLA	$6,1 * 10^{-5}$	$9,2 * 10^{-5}$	$2 * 10^{-4}$
OLSR_TOLA with metric degradation	$1,5 * 10^{-4}$	$5,9 * 10^{-4}$	$9,5 * 10^{-4}$

From the graph above we can see that the proposed mechanism increases the data transmission service efficiency in comparison to the standard OLSR protocol using ETX metrics. It results from a smaller number of routing path interruptions. Only in the case of 4-node network the service efficiency was worse because the routing algorithm sometimes chose the links between mobile nodes to the routing paths for fixed nodes. For these links a high value of variation was presented. A significant increase in service efficiency can be seen in the case of using metric degradation mechanism, which changed the metric value as the estimated connection time was increasing(TOLA), also for 4-node network. The metric degradation forced the link switching on the routing path before the actual link was interrupted in an uncontrolled way. It resulted in much shorter breaks of paths when routing paths were switched or even in the lack of any breaks. We also observed an improvement in the stability of service provision by decreasing the standard deviation of service efficiency measurements. In the case of 4-node network, the standard deviation was decreased by an order of magnitude from $1,6 * 10^{-3}$ to $3,4 * 10^{-4}$. This indicates that the proposed mechanism basing on metrics dependent on connection times improves the stability of services provided by ad-hoc network, contrary to the standard mechanism basing on ETX metrics.

In the case of scenarios with more nodes the improvement in the efficiency of data transmission services took place only if the metric including variance was used.

Figure 3 presents the chart of mean UDP data transmission efficiency for 2-, 3- and 4-node networks. Figure 4 presents the chart of mean UDP data transmission efficiency for 10-node network (the network without featured nodes) and 15-node network (the network with 5 nodes with increased predictability of connection times).

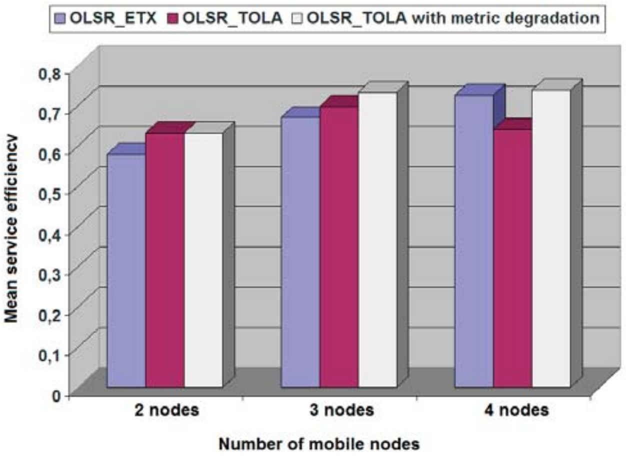

Fig. 3. The charts of mean UDP service efficiency

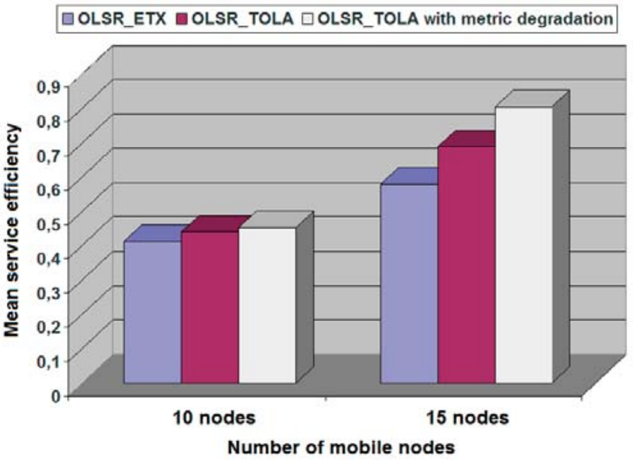

Fig. 4. The charts of mean UDP service efficiency

On the charts above we can see that the mechanism with links marked by the metric consisting of expected value and variation of connection times is able to identify nodes with better and more predictable links. Such nodes are chosen to take part in data packet forwarding. In the case of a 10-node network the proposed mechanism was able to identify more stable nodes despite the existence of equivalent nodes. In 15-node network, the efficiency of service provided increased by about 10%, which was due to the existence of nodes with higher reliability and link stability. These nodes were preferred by the modified OLSR routing protocol.

The metric degradation mechanism was also used in these simulation tests and the metric was multiplied by two in each period of expected HELLO message from the neighbour node. As we can see, the efficiency of service provided was improved in comparison to the metric containing mean and variation only. The improvement resulted from switching links in routing paths before they were interrupted and a new one was available.

V. CONCLUSIONS

The article presents the concept of MANET routing protocol based on the estimation of node connections. The results of simulation tests of the modified OLSR protocol are also presented. The modified OLSR protocol uses link metrics calculated on the basis of the estimation of link activity time. The test results indicate that the proposed mechanisms 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 routing path switching 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 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.

REFERENCES

[1] Bryś Rafał, Zubel Krzysztof, Kącik Szymon, „Mechanizmy adaptacyjnej sieci ad-hoc wsparcia działań sieciocentrycznych - wyniki badań symulacyjnych", Przegląd Telekomunikacyjny - Wiadomości Telekomunikacyjne", ISSN 1230-3496, 2015, p. 1269-1276.

[2] Rafał Bryś, Piotr Gajewski "Routing z estymacją powiązań węzłów sieci MANET", Przegląd Telekomunikacyjny - Wiadomości Telekomunikacyjne, nr 8-9/2018 + CD, s. 646-649, ISSN 1230-3496, e-ISSN 2449-7487, 2018.

[3] Deva Priya, M. and M.L. Valarmathi, "A cross-layered path stability based routing protocol for wimax networks", American Journal of Applied Sciences Volume 10, Issue 11, Pages 1325-1334, 2013.

[4] D.J. He, S.M. Jiang and J.Q. Rao, "Link availability prediction model for wireless ad hoc networks", Proc. 2000 International Conference on Distributed Computing System Workshop, Taipei, Taiwan, 2000.

[5] Hu, X., Wang, J., Wang, C., „Link stability prediction and its application to routing in mobile ad hoc networks", Power Electronics and Intelligent Transportation System (PEITS), 2nd International Conference, 2009.

[6] Hu Xi, Li Zhe, Liu Jun, "A Link Stability Prediction-Based on-Demand Routing Protocol in Mobile", Journal of Electronics & Information Technology, 2010.

[7] M. Gerharz, Ch. de Waal, M. Frank, P. Martini, "Link Stability in Mobile Wireless Ad Hoc Networks", Local Computer Networks, LCN 2002. 27th Annual IEEE Conference, 2002.

[8] T. Clausen, C. Dearlove, J. Dean, C. Adjih, "Generalized Mobile Ad Hoc Network (MANET) Packet/Message Format", RFC54444, 2009.

[9] T. Clausen, C. Dearlove, J. Dean, "Mobile Ad Hoc Network (MANET) Neighborhood Discovery Protocol (NHDP)", RFC6130, 2011.

[10] T. Clausen, C. Dearlove, P. Jacquet, U. Herberg, "The Optimized Link State Routing Protocol Version 2", RFC7181, 2014.