Nalapko, Oleksii; Sova, Oleg; Shyshatskyi, Andrii et al.

Article

Analysis of methods for increasing the efficiency of dynamic routing protocols in telecommunication networks with the possibility of self-organization

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**Oleksii Nalapko,
Oleg Sova,
Andrii Shyshatskyi,
Nadiia Protas,
Serhii Kravchenko,
Andriy Solomakha,
Yevhenii Neroznak,
Oleksandr Gaman,
Dmytro Merkotan,
Hennadii Miahkykh**

ANALYSIS OF METHODS FOR INCREASING THE EFFICIENCY OF DYNAMIC ROUTING PROTOCOLS IN TELECOMMUNICATION NETWORKS WITH THE POSSIBILITY OF SELF-ORGANIZATION

The object of research is the military radio communication system. Effective operation of routing protocols is possible only if there is reliable information about the network topology for network nodes, given that the mobility of individual nodes is insignificant in special purpose wireless networks. Because nodes in the network demonstrate the mobility property of the node groups. This paper solves the problem of the analysis (decomposition) of methods of protocols efficiency increase of dynamic routing in telecommunication networks with a possibility to self-organization.

In the course of the research, the authors used the main provisions of the queuing theory, the theory of automation, the theory of complex technical systems and general scientific methods of cognition, namely analysis and synthesis. This research analyzes various methods to increase the efficiency of dynamic routing protocols. Energy efficiency methods focus on three main components in energy management: battery management, transmission energy management and system energy management methods. Reliable multicast has become indispensable for the successful deployment of special purpose wireless networks, such as in tactical military operations and emergency operations. The results of the research will be useful in:

- *development of new routing algorithms;*
- *substantiation of recommendations for improving the efficiency of the route selection process in networks with the possibility of self-organization;*
- *analysis of the electronic situation during hostilities (operations);*
- *while creating promising technologies to increase the efficiency of mobile radio networks.*

Areas of further research will focus on the development of a methodology for the operational management of interference protection of intelligent military radio communication systems.

Keywords: *military radio communication system, routing protocols, Ad Hoc Networks, self-organizing networks, data transmission systems.*

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1. Introduction

According to the experience of local wars and armed conflicts in recent decades, during operations (combat operations), radio communication devices are usually the basis of any military and weapons control system, as well as communication and information transmission systems. It happens because of the high dynamics of combat operations, long range and the ability to work in motion [1, 2].

Currently, work is underway to implement data transmission systems using networks with the possibility of self-organization (Ad Hoc Networks).

In the classic version of building wireless networks, where all clients connect to the router, data is transmitted only through it. In a decentralized network, each of these devices can move in different directions, breaking and establishing new connections with neighboring devices as a result of the move.

The main tasks of networks with the ability to self-organize data transmission are:

- construction of fault-tolerant network infrastructure;
- increasing the use of radio frequency resources;
- ensuring the adaptation of networks to the action of external factors;

– reducing the cost of deployment and operation of the network in comparison with the classical principles of construction.

A self-organizing decentralized network consists of routers and mobile devices that are interconnected and act as both a client and a router.

Effective operation of routing protocols is possible only if there is reliable information about the network topology for network nodes. Thus, with this information, packets can be redirected correctly between sender and recipient.

Given that the mobility of individual nodes is insignificant in special purpose wireless networks, as nodes in the network demonstrate the mobility of the node groups. This observation is directly related to the very existence of military wireless networks with the possibility of self-organization, so to support group interaction and group activities.

The object of research is the military radio communication system.

And *the aim of research* should be considered the analysis (decomposition) of methods to improve the efficiency of dynamic routing protocols in telecommunication networks with the possibility of self-organization.

2. Methods of research

Routing protocols in special-purpose networks with the ability to self-organize have many key indicators in defining many features of a wireless network. Common performance indicators are the information latency and throughput, as well as service quality (QoS), energy dissipation, reliability and fairness. Table 1 shows the requirements for the characteristics of the information transmission channel depending on the type of information being transmitted [3].

Table 1

Requirements for the characteristics of the information transmission channel depending on the type of information being transmitted

Parameters	The type of information that is transmitted	
	Audio	Video
Traffic priority	The highest	High
The nature of traffic	Constant, predictable	Pulsating, unpredictable
Delay	Up to 150 msec	Up to 400 msec
Jitter	Up to 30 msec	Up to 50 msec
Packages loss	Up to 1 %	Up to 1 %
Capacity	From 30 Kbp/s	From 384 Kbp/sec

There are many scientific researches that solve the problem of rapid changes in network topology, which are inherent in special purpose wireless networks with the ability to self-organize [4, 5].

Thus, dynamic routing protocols with adaptation, which solve the problem of topological changes in wireless mobile networks, include:

– DSR (Dynamic Source Routing – dynamic routing from the source) [1, 6];

– MSR (Multipath Source Routing – routing with multiple sources) [2, 7];

– TORA (Temporally Ordered Routing Algorithm – time routing algorithm) [3, 8];

– SOAR (Source-tree On-demand Adaptive Routing – adaptive source-based routing) [4, 9].

The topology of a wireless network can be affected by many factors, such as node mobility, disconnection, adding new nodes to the wireless network, and so on.

However, the issues of synthesis of highly efficient protocols for information transmission of network nodes remain little studied and require further research. In the course of the research, the authors used the main provisions of the theory of queuing, automation theory, theory of complex technical systems, information transfer theory and general scientific methods of cognition, namely analysis and synthesis.

3. Research results and discussion

The MP-DSR or MSR protocols [2, 10] propose to increase the performance of the DSR protocol, giving it the ability to transmit packets over several routes, while applying load balancing between them. The MSR protocol uses the measurement of the time required to transmit a packet to the destination node and vice versa on all available routes to determine load balancing. The definition of the route metric for load balancing is determined by the expression:

$$W_i^j = Min\left(\left[\frac{d_{\max}^j}{d_i^j}\right], U\right)\cdot R, \qquad (1)$$

where $d_{\max}^j$ is the maximum delay time of all routes; d_i^j is the delay time on the i-th route; U is required W_i^j not to be too large; R is the coefficient that regulates the frequency of switching between routes. Sensing is also an improvement on the route maintenance mechanism, but sensing only one route is not effective. It would be more efficient to probe all available routes for productive load balancing.

The QoS-MSR protocol also uses a probing mechanism to support QoS information. There are two types of sounding: on demand and periodic. In addition to active probing, QoS-MSR uses passive data copying to obtain QoS information for each node. Mathematically, for each bandwidth request B, the algorithm will find a group of paths $P=\{P_1, P_2, P_3,..., P_n\}$ from all paths between the source and destination, as follows:

$$bandwidth(P)=\sum\nolimits_i bandwidth(P_i)\geq B, \qquad (2)$$

where $bandwidth(P_i)$ is the bandwidth request of path i. To request the bandwidth R between the source of the node S and the destination node D, let:

– the number of available paths will be n (n>1);

– the possibility of each path will be C;

– available bandwidth of each path will be B_{avl} ($B_{avl}\leq C$);

– the probability of success of the repeated request for bandwidth R will be $P(R)$.

Assume that $P(R)$ has a uniform distribution on [0, C]. Then the expansion of R into n non-negative bandwidths of queries R_i (i=1, 2,..., n) between n paths would give the probability of success $P_m(R)$:

$$P_m(R)=\prod_{i=1}^{n}P_{s'}(R_i), \qquad (3)$$

where $P_{s'}$ is the most successful probability of reserving each path. The probability of success of booking one route P_s can be specified:

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$$P_s = \frac{C-R}{C} = 1 - \frac{R}{C}. \quad (4)$$

Let's suppose that the n-th route has the same capacity C and the query R is divided on average by n number of routes, so $R_i = R/n$. The probability of success of the reservation on each sub-route is described:

$$P_{s'} = 1 - \frac{R}{nC}. \quad (5)$$

Using equations (2) and (4) let's obtain:

$$P_m = (P_{s'})^n = \left(1 - \frac{R}{nC}\right)^n. \quad (6)$$

Let $\eta = R/n$, then if $0 \le \eta \le 1$ let's obtain:

$$P_m = \left(1 - \frac{\eta}{n}\right)^n \text{ and } P_s = 1 - \eta.$$

Now let's obtain:

$$\gamma = \left(1 - \frac{\eta}{n}\right)^n - (1 - \eta). \quad (7)$$

Thus, $\gamma = P_m - P_s$ is the difference between the probability of success and the probability of success of a single-route reservation. Then it is possible to say that:

$$\frac{d\gamma}{d\eta} = 1 - \left(1 - \frac{\eta}{n}\right)^{n-1} > 0. \quad (8)$$

When $0 \le \eta \le 1$, γ is an increasing function. When $\eta = 0$, then $\gamma = 0$ and when $\eta > 0$, then $\gamma > 0$. Also $R > 0$ leads to $\eta > 0$ that gives $P_m > P_s$. Thus, it is possible to conclude that the probability of a successful request for bandwidth is higher than a single-route booking.

CAMP Protocol (Core-Assisted Mesh Protocol) [11]: Mesh-based multicast routing delivers more data than tree-based multicast protocols by using multiple routes from the sender node to the destination node.

Nodes in a wireless mobile network are limited by the maximum battery capacity for their operation. Energy management is an important issue in such networks. To use a multi-hop radio, it is necessary a sufficient number of relay nodes to maintain a network connection. Energy conservation can be done using the following methods:

– battery management schemes;
– transmission power control schemes;
– system power control schemes.

System power management can be divided into categories: device control circuits and processor power control circuits.

Battery management schemes, which are solved at the network level, are aimed at increasing the service life of the network. The main solution is given to the development of routing protocols that use low energy metrics, as well as the battery charge level.

Considering the on-off process, each of which requires one part of the charge, the on-off time is a random variable based on the Pareto distribution:

$$P_x = \beta k^{\beta} x^{-\beta-1},\ k > 0,\ x \ge k,\ 0 < \beta < 2. \quad (9)$$

Thus, by further delaying the discharge request, a significant improvement in battery performance is achieved.

The model used has an N-number of nodes that are evenly distributed among each other in a special purpose wireless network. Each of the nodes has $R(s,d)$-number of routes between the sending node s and the destination node d, and $P(k,r)$ is the required power to transmit a packet to the node k of route r. The energy consumption of the route r is given by the expression:

$$Energy\cos\text{t} = \sum_{k \in r, k \ne d} P(k,r). \quad (10)$$

BEE Dynamic Routing Protocol (Battery Energy-Efficient) [12] is an energy-efficient routing protocol that attempts to combine a lazy packet scheduling scheme with a traffic generation scheme. The BEE routing protocol attempts to find a balance in power consumption between all nodes in a dedicated wireless network. This protocol introduces new metric called energy consumption. From the available routes, the route with the lowest energy cost is selected. Even if there is a route with more jumps, it can be selected provided that the route on these nodes has a minimum connection capacity. The algorithm also gives an advantage while choosing a route with a higher battery charge at all nodes to allow the effect of restoring batteries with a lower residual charge. Provided that the network has K nodes with S sending nodes and D destination nodes, and each $s \in S$ node can transmit to the $d \in D$ destination node through repeater nodes. The average energy required for node i to transmit a packet is set through:

$$e_i = \frac{1}{|R_i|} \sum\nolimits_{j \in R_i} e_{ij},$$

where R_i is a set of nodes which distance from nodes i is less than p. The energy cost function used in BEE is defined for the k-th r_{sd}^k route is the following:

$$F_k = \sum_{l_{ij} \in r_{sd}^k} \left[\Psi(\lambda_i) e_{ij} + P_{ij}\right] - \min\nolimits_{i \in r_{sd}^k} b_i, \quad (11)$$

where s and d are the sending nodes and, accordingly, the destination nodes; l_{ij} is the connection between nodes i and j on the route r_{sd}^k; $\Psi(\lambda_i)$ is a weighing function equal to $\Psi(\lambda_i) = A$. λ_i and A are constants, otherwise $\Psi(\lambda_i) = 1$; P_{ij} denotes the energy penalty that occurs whenever the required power level exceeds the average power level and is equal to $\max(0, e_{ij} - e_i)$ and $\min_{i \in r_{sd}^k} b_i$ is the minimum value of the battery charge status among the nodes of the r_{sd}^k route. The main purpose of the algorithm is to find a connection with minimal costs, which leads to maximizing the service life of the network. There are three main factors influencing the cost: c_{ij} is the energy required to transmit the packet over the communication line, e_{ij} is the initial energy and E_{ij} is the instantaneous energy. Given the above, the cost calculation is the following:

$$c_{ij} = e_{ij}^{x_1} \underline{E}_i^{-x_2} E_i^{x_3},\ x_1, x_2, x_3 \ge 0, \quad (12)$$

where x_1, x_2, x_3 are the weights e_{ij}, $\underline{E}_i$, E_i. The cost of a route is the sum of the costs of all connections on the route. The battery charge at the network level of the

OSI model (Open Systems Interconnection model) can be saved by reducing the power consumption of the two main operations, namely for communication and computing.

The COMPOW (Common Power Protocol) protocol, proposed and described in the work [13], solves three main tasks: increasing the battery life of network nodes, increasing network bandwidth and reducing disputes between nodes in the network. The main reason for the control in the optimum level of transmission power for nodes in a special wireless network is that the battery energy is saved by reducing the transmission range of the node. Thus, it reduces the level of interference in the network.

The authors proved that the COMPOW protocol works well only in a network with a uniform distribution of nodes and exists only as a special case of the CLUSTERPOW protocol, proposed by them in the work [14]. They have extended their COMPOW protocol to work with inhomogeneous node dispersion. This advanced power management protocol, called CLUSTERPOW, is a power management clustering protocol in which each node executes a distributed algorithm to select the minimum power p to reach the destination in a few jumps. Unlike COMPOW, where all network nodes agree on a common power level, in CLUSTERPOW the value of p must be different for different nodes and it is proved that it does not increase in sequence to the destination. The authors in [15] proposed an architectural design for the implementation of CLUSTERPOW at the network level.

The power required to transmit the packet from node A to node B is inversely proportional to the SNR_j-th power of the distance between them, so where n varies from 2 to 4 depending on the distance and terrain between nodes. Successful transmission from node n_i to node n_j requires that the signal-to-noise (SNR) ratio of node j be greater than a specific threshold.

This can be represented mathematically. For successful transmission SNR-receiver node n_j specified SNR_j must meet the condition:

$$SNR_j = \frac{P_i G_{i,j}}{\sum_{k \neq i} P_k G_{k,j} + \eta_j} \psi_j(BER), \tag{13}$$

where P_i is the transmission power of the node; $G_{i,j} = 1/d_{i,j}^n$ is the gain between nodes n_i and n_j; η_j is the thermal noise at node n_j; BER is the level of bit error, which is based on the threshold value ψ_j.

The MBCR (Minimum Battery Cost Routing) algorithm takes into account the individual battery charges of the nodes while selecting the route, so the selected route should not contain nodes that have less residual battery power. This can be done in several ways. If c_i^t indicates the cost of the battery at any time t, so $f(c_i^t)$ is a function of the battery consumption of the node n_i. Now suppose that the function displays the residual capacity of the node battery, then:

$$f_i(c_i^t) = \frac{1}{c_i^t}. \tag{14}$$

Expression (14) means that the higher the value of the f_i function, the more unwanted node will participate in the route algorithm. If the route contains N-nodes, then the total cost of the route R_i is the sum of the cost functions of all these N-nodes. The routing algorithm selects this path with the minimum value of the total cost among all routes that exist between the source and destination:

$$R_i = \min(R_j) \quad \forall j \in A, \tag{15}$$

where A is the sum of all routes from the source to the destination. The main disadvantage of this scheme is that the use of the summation of the residual energy of the nodes as a metric chooses a path that has on average more energy for all its nodes, rather than for individual nodes.

Min-Max battery routing cost method. The objective function of the Min-Max Battery Cost Routing (MMBCR) routing algorithm is to make sure that the route is selected based on the battery capacity of all nodes separately. Therefore, the cost of the battery is defined as:

$$R_j = Max_{i \in route_j} f_i(c_i^t). \tag{16}$$

Therefore, the desired route is set:

$$R_j = Min(R_j, j \in A),$$

where A is the set containing all possible routes. A variant of this routing algorithm minimizes the maximum cost after routing N-packets to the destination or after a time period of t seconds. This algorithm provides a uniform discharge of batteries. A closer look shows that the chosen path does not provide the minimum transmission power and therefore quickly reduces the service life of all nodes.

Localized methods focused on energy consumption (Localized Power-Aware Routing Techniques). The purpose of this routing protocol is to find the shortest path to the destination to increase the resource of the power supply using localized algorithms. Localized algorithms are propagated by greedy algorithms that try to achieve a global goal based on the information available on the site. The location of the nodes can be obtained by the following methods:

– with the help of the Global Positioning System (GPS) location of nodes it is possible to get information from the satellite;

– receiving control messages from neighbors at regular intervals and tracking the signal strength received at different points in time, provides data on their distance from the corresponding node, which is disclosed in the work [13];

– the routing protocol must be loopless so that the selected path uses the minimum transmission power.

The limitations of the research include the fact that it does not fully cover all the main methods of improving the efficiency of routing protocols. The research is theoretical and was conducted by analytical modeling. In turn, a number of factors were not taken into account by the authors. It necessitates the clarification of the research when it is tested in practice.

4. Conclusions

This research analyzes various methods to increase the efficiency of dynamic routing protocols. Energy efficiency methods focus on three main components in energy management: battery management, transmission energy management and system energy management methods.

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As a result of the dynamic protocols properties analysis routing the directions of their improvement can be the following:

– increasing the efficiency of establishing connections between network nodes;
– improvement of mechanisms for maintaining routes in the network;
– improvement of energy conservation mechanisms;
– increasing the noise immunity of information transmission routes;
– increasing the bandwidth of information transmission routes, etc.

Research results will be useful in:

– development of new routing algorithms;
– substantiation of recommendations for improving the efficiency of the route selection process in networks with the possibility of self-organization;
– analysis of the radio electronic situation during hostilities (operations);
– while creating promising technologies to increase the efficiency of mobile radio networks.

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Oleksii Nalapko, *Postgraduate Student, Central Scientific Research Institute of Armament and Military Equipment of the Armed Forces of Ukraine, Kyiv, Ukraine, ORCID: https://orcid.org/0000-0002-3515-2026*

Oleg Sova, *Doctor of Technical Sciences, Senior Researcher, Head of Department of Automated Control Systems, Military Institute of Telecommunications and Information Technologies named after Heroes of Kruty, Kyiv, Ukraine, ORCID: https://orcid.org/0000-0002-7200-8955*

✉***Andrii Shyshatskyi,*** *PhD, Senior Researcher, Research Department of Electronic Warfare Development, Central Scientific Research Institute of Armament and Military Equipment of the Armed Forces of Ukraine, Kyiv, Ukraine, e-mail: ierikon13@gmail.com, ORCID: https://orcid.org/0000-0001-6731-6390*

Nadiia Protas, *PhD, Associate Professor, Department of Information Systems and Technologies, Poltava State Agrarian University, Poltava, Ukraine, ORCID: https://orcid.org/0000-0003-0943-0587*

Serhii Kravchenko, *PhD, Associate Professor, Department of Software Engineering, National Aviation University, Kyiv, Ukraine, ORCID: https://orcid.org/0000-0002-8163-8027*

Andriy Solomakha, *Senior Lecturer, Department of Military Training, The Bohdan Khmelnytsky National University of Cherkasy, Cherkasy, Ukraine, ORCID: https://orcid.org/0000-0001-7390-4156*

Yevhenii Neroznak, *Postgraduate Student, Department of Automated Control Systems, Military Institute of Telecommunications and Information Technologies named after Heroes of Kruty, Kyiv, Ukraine, ORCID: https://orcid.org/0000-0001-5641-5473*

Oleksandr Gaman, *Senior Lecturer, Department of Automated Control Systems, Military Institute of Telecommunications and Information Technologies named after Heroes of Kruty, Kyiv, Ukraine, ORCID: https://orcid.org/0000-0003-4676-3321*

Dmytro Merkotan, *Lecturer, Department of Automated Control Systems, Military Institute of Telecommunications and Information Technologies named after Heroes of Kruty, Kyiv, Ukraine, ORCID: https://orcid.org/0000-0003-1425-9948*

Hennadii Miahkykh, *Lecturer, Department of Automated Control Systems, Military Institute of Telecommunications and Information Technologies named after Heroes of Kruty, Kyiv, Ukraine, ORCID: https://orcid.org/0000-0003-4491-5395*

✉*Corresponding author*