SECTION 15.
INFORMATION TECHNOLOGIES AND SYSTEMS

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

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 [1–19]. 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. 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.

Presentation of main material

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 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 definition of the route metric for load balancing is determined by the expression:

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

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. 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. Mathematically, for each bandwidth request *B*, the algorithm will find a group of paths $P=\{P_1, P_2, P_3, \dots, P_n\}$ from all paths between the source and destination, as follows:

$$bandwidth(P) = \sum_i bandwidth(P_i) \geq B, \tag{2}$$

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)*. 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 $P_m(R)$:

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

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:

$$P_s = \frac{C-R}{C} = 1 - \frac{R}{C}. \tag{4}$$

The probability of success of the reservation on each sub-route is described:

$$P_{s'} = 1 - \frac{R}{nC}. \tag{5}$$

Using equations (2) and (4) we obtain:

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

Let $\eta = \frac{R}{n}$, then if $0 \leq \eta \leq 1$ we get: $P_m = \left(1 - \frac{\eta}{n}\right)^n$ and $P_s = 1 - \eta$.
Now we get:

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

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 we can say that:

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

When $0 \leq \eta \leq 1$, *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, we can conclude that the probability of a successful request for bandwidth is higher than a single-route booking.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:

$$P_x = \beta k^{\beta} x^{-\beta-1},\ k > 0, x \geq k, 0 < \beta < 2. \tag{9}$$

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:

$$Energy\cos t = \sum_{k\in r, k\neq d} P(k,r) \tag{10}$$

BEE Dynamic Routing Protocol (Battery Energy-Efficient) is an energy-efficient routing protocol that attempts to combine a lazy packet scheduling scheme with a traffic generation scheme. 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:

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

where R_i is a set of nodes whose 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:

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

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. 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:

$$c_{ij} = e_{ij}^{x_1} \underline{E}_i^{-x_2} E_i^{x_3},\ x_1, x_2, x_3 \geq 0, \tag{12}$$

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.

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; $G_{i,j} = \frac{1}{d_{i,j}^n}$ 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. 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:

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

where *A* is the sum of all routes from the source to the destination. Therefore, the cost of the battery is defined as:

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

Therefore, the desired route is set: $R_j = Min\left(R_j, j \in A\right),$

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.

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

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