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MATHEMATICAL MODEL OF CLUSTER ROUTING PROTOCOL

Анотація: Дана стаття присвячена розробці моделі кластерного протоколу маршрутизації для мобільних Ad Hoc мереж. При написанні моделі використовувались математичний апарат теорії графів, теорії множин та логіки предикатів.
Ключові слова: Ad Hoc, кластер, маршрутизація.
Аннотация: Данная статья посвящена разработке модели кластерного протокола маршрутизации для мобильных Ad Hoc сетей. При написание модели использовались математический аппарат теории графов, теории множеств и логики предикатов.
Ключевые слова: Ad Hoc, кластер, маршрутизация.
Abstract: The paper is devoted to development of mathematical model of cluster routing protocol for mobile Ad Hoc networks. In the research mathematical tools of graph theory, set theory and predicate logic were used.
Key words: Ad Hoc, cluster, routing.

Introduction

Mobile wireless network has become very popular nowadays. A wireless ad hoc network is a decentralized type of wireless network. Ad hoc (from Latin) means "for this purpose". Spread of laptops and 802.11/Wi-Fi wireless networking has made mobile Ad Hoc networks (MANET) a popular research topic. A lot of academic papers evaluate protocols and their abilities, assuming varying degrees of mobility.

MANET is a dynamic self-configuring wireless network. It consists of mobile nodes, which are easily attached or disconnected to the network with minimal difficulties. Previously, such network was used in military communication or in the places of natural disasters. After the development of new modern technologies (e.g. Bluetooth, 1994) the area of use for such networks has become wider.

Relevance

Due to the increasing spread of wireless communication, requirements for routing protocols which are used in mobile AD HOC computer networks, are growing. Multilevel routing is typical for modern large networks, thus on-demand protocols are generally used, as they are effective in a small number of nodes and low network mobility. Otherwise, when the network is large, it is advisable to use a hierarchical management, which splits the network into separate zones.

Objective

The main goal is using cluster analysis for splitting network into separate zones. It is also used to decrease the time for routes formation and packets losses.

Tasks

Following tasks are formulated in the research purpose:

1) To find the main advantages of protocols which use similar approach in routing for mobile Ad Hoc networks.

2) To suggest the mathematical model of cluster routing protocol for mobile Ad Hoc networks.

Problem solution

Mobile ad hoc network routing protocols are classified into three types: reactive, proactive and hybrid. The examples of protocols which use the approach to split the network into separate zones are ZRP [1], SHARP [2], CBRP [3,4]. All of them are hybrid routing protocols.

Zone Routing Protocol is the first hybrid routing protocol that divides the network into local "neighboring" zones, which can be of any size. The zone around each node consists of k-neighboring nodes. The advantage of the proposed hybrid routing protocol for mobile networks is the possibility to use two routing schemes: proactive and reactive, which lead to the delay decrease. But large overlapping areas of routing and low latency to find new routes are the main disadvantages.

Cluster Based Routing Protocol or CBRP is a routing protocol where nodes are divided into several clusters (similar to routing zones in the ZRP protocol). Each cluster contains a cluster-head, which is responsible for the routing process. According to this method there are such states of nodes: indefinite, the cluster-head and cluster members. Indefinite status is assigned when the node does not belong to any of the clusters, usually it is the case when a new node appears in the network. The cluster-head is responsible for routing process, which has the largest number of "neighboring nodes", the other nodes are considered as members of the cluster.

The main features of the cluster routing algorithm are that each node periodically informs about itself by sending a message which contains the data about its address and cluster-head, also each member of the cluster sends to its cluster-head the information about cluster-heads nearby, which it has received from neighboring nodes. As a result, the cluster-head combines all the information about the network and writes it to the table which contains data about its members and about neighboring clusters. Members of the cluster, which are connected with members of another cluster, are called gateway nodes. In cases when the node joins another cluster, it clears its routing table. Also, if the node changes its state from cluster-head to cluster member, it clears its routing table. Accordingly, the table of neighboring clusters is removed since it is not typical for members of the clusters.

One of the advantages of this protocol is traffic decrease by sending route requests only between cluster-heads. One of the drawbacks is that when the size of the cluster increases the delays according to the distance to the cluster-head, because the information about each node of the route is stored in the routing packet. The package size increases in proportion to the length of the path that leads to the increase of the transmission time. Also, with packet size growth increases the size of HELLO messages.

Routing protocol SHARP (Sharp Hybrid Adaptive Routing Protocol) automatically finds equilibrium value between proactive and reactive routing. Automatic creation of the proactive zones around the "hot" nodes is the special feature of this protocol. "Hot" nodes are the destinations which receive information from many sources. At the beginning all nodes use reactive routing, but after a certain period of time (which depends on traffic and network features) proactive zones are created and their size can be changed with time. Nodes, that are located within this zone, contain information about the path to the central node. Such defined zones are around every central node. The disadvantage of the proactive protocol component is losses growth when the radius of the zone increases.

Existing approaches were analyzed to detect common limitation of above described protocols (large overlapping and large zone sizes), and the fulfillment of the task would allow us to present our own approach to determine optimal routing zones, which would take into account most of the benefits and would solve disadvantages which are described above.

One of the most important parameters that affect network performance is its dimension. Therefore, it is reasonable to split the mobile network into clusters.

The task to develop a mathematical model of cluster routing protocol for mobile Ad Hoc networks arises, which would take into account most of the benefits of existing routing protocols described above.

The new approach to define centers of areas for cluster routing protocol will be described in this model, which may allow us to make a simulation and to compare results with existing routing protocols for mobile Ad Hoc networks.

Mathematical model of protocol

The mobile network topology is represented as oriented graph *G (N, L)* (see picture 1).

The set $N=\{n_1, n_2, n_3,.., n_m\}$ of vertices gives the set of m mobile nodes, and $L=\{l_1, l_2, l_3,.., l_k\}$ is the set of edges of the graph for k communication channels. Than we should note that to each pair of vertices n_1 and n_2, which has a connection $(n_1,n_2 \in N)$ corresponds the pair of edges $l=(n_1,n_2)$ and $l=(n_2,n_1)$, where $l \in L$.

Network topology graph with its dimension *mxm* is shown below like a matrix:

$$D_G = \begin{bmatrix} d_{1,1} & d_{1,2} & \dots & d_{1,a-1} & d_{1,a} \\ d_{2,1} & d_{2,2} & \dots & d_{2,a-1} & d_{2,a} \\ \dots & \dots & \dots & \dots & \dots \\ d_{a-1,1} & d_{a-1,2} & \dots & d_{a-1,a-1} & d_{a-1,a} \\ d_{a,1} & d_{a,2} & \dots & d_{a,a-1} & d_{a,a} \end{bmatrix}$$

where $a=\{1:m\}$, $d_{n1,n2}=0$ if the connection between nodes n_1 and n_2 does not exist or $d_{n1,n2}=1$, if the connection exists.

Mobile network *G(N, L)* is divided into subnets which are called clusters. Each cluster C_k (where *k* is a number of clusters in the network) has the characteristics set $C_k=\{n, metric\}$.

Also we suggest the following definitions:

- *M* – number of nodes in network;
- *H* – average path length (in hops);
- *R* – average number of active routes per node;
- *b* – average number of link-breakages per second;
- *f* – "route activity" is new route requests/second generated by each node;
- *p* – "route concentration factor" is average % of each node's active routes that use each link.

R is the number of other nodes that each node has active data-plane communications with. The parameter *b* is an indication of how fast the nodes are moving with respect to each other. The parameter *f* measures two separate effects. The first is how fast a given node changes its set of destination nodes. The other is the holding time of a node's IP sessions, since the RRP route caches eventually "timeout" unused routes.

Finally, the *p* parameter accounts for traffic hot-spots within the MANET. The *p* parameter also accounts for the fact that a given link-breakage may not cause a given route to break. So, a low *p* favors reactive routing.

For proactive routing, each link-state change must be propagated to every other node over an average distance of *H*. As such, the total number of link state update packets per second *(T)* roughly scales as:

$$T_1 = b \cdot H \cdot M2$$

For reactive routing, each route-search generates approximately *M* Route-Request packets. As such, the total number of route-request packets roughly scales as:

$$T_2 = (f + p \cdot R \cdot b) \cdot H \cdot M2,$$

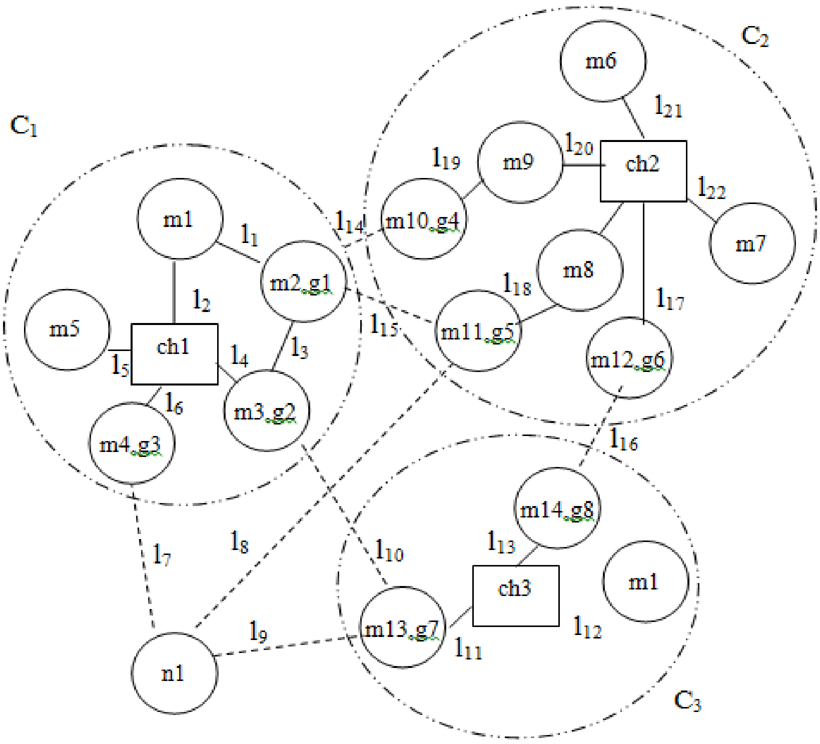
where this formula includes the Route-Request messages due to both new routes (*f*) and also broken routes (*b*). So, as a very rough qualitative comparison, reactive routing tends to generate less overhead than proactive routing if

$$b \cdot H \cdot M2T_2 > (f + p \cdot R \cdot b) \cdot H \cdot M2, or 1 > (f/b) + p \cdot R$$

That is why in our approach we will use two types of routing: one will be used within the zone another between the zones.

Nodes *n*, according to the cluster structure of routing protocols may take the following four states:

1. State cluster-head indicates the center of the cluster, the node that receives information from many sources, and the frequency of appeals to him is the biggest;
2. State member indicates node of the cluster, which is located in the zone of the corresponding cluster-head;
3. State gateway indicates marginal members of the cluster, which are adjacent to marginal members of another cluster;
4. State new indicates new node which does not belong to any of the existing clusters.



Picture 1 An example of Ad hoc network that is divided into clusters (where *m* – member node, *m, g* – member and gateway node simultaneously, *ch* – cluster-head, *l* – edges of the graph, *n* – new node, *C* – cluster)

The feature of this approach is that nodes with the highest frequency of appeals are selected to be cluster-heads, unlike existing cluster protocols, where the center is selected randomly.

Let the metric be the radius of the routing zone which will take constant value *R = 2* hops, as in ZRP protocol (the metric review as a variable is planned in further research).

The cluster formation algorithm is described below.

1. To set the state new for all nodes at the beginning, routing is reactive (on-demand);
2. To determine the frequency of references to nodes, if the frequency of node $n_1 > n_2$, than n_1 take on the state cluster-head;
3. To determine cluster members and adding them to the routing table, taking into account that the radius is two hops (state member is at $R = 1$, state gateway is at $R = 2$).

Proactive routing technique is used within the zone. When a new node appears in the network, it takes on the state new.

This approach will be used in further researches in a simulation of routing in mobile networks with hierarchical topology and will be compared with routes formation in another approach of leading routing protocols for MANET.

Conclusion

In this work, taking into account the main characteristics of clustering and combining features of existing routing protocols, the mathematical model of the protocol for mobile networks on the base of cluster analysis is described. In our further research we will make the simulation of such approach in Network Simulator 2 and improve the proposed model by identifying routing zones, which will vary in time according to the changes in network characteristics.

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