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Research Article

LMOP Based Hybrid Routing Strategy for Delay/Disruption Tolerant Networks

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Abstract

In this paper, routing problem of Delay Tolerant Networks (DTN) was investigated and a new routing scheme was proposed based on the Epidemic routing. By combining the advantage of a variety of related routing algorithm, a Limited Multi-copy Optimal Path-Hybrid Routing (LMOP-HR） was put forward belonging to the flooding message copies strategy. An optimal tree mixed strategy based on priority was proposed for the message distribution. Further, this strategy adopted priority-based cache management mechanism. It was proved that the proposed scheme could guarantee the optimal message delivery rate and reduce node energy consumptions. Numerical results showed that system performance could be effectively improved based on the proposed algorithm.

Keywords: DTN, unicast routing, space communication network

1. Introduction

Recently, the exploration activities of deep space have entered a new chapter. Meanwhile, higher requirements are produced in the space communication networks. Due to the complexity and specificity of the deep space environment, it brings lots of problems on the deep space communication such as long transmission distance and huge transmission delay. To solve the above problems, a network architecture named Delay/Disruption Tolerant Networking (DTN) [1,2] was proposed by Kevin Fall and his research team in the Intel Berkeley Research Laboratory, which was message-oriented, universal, and reliable.

In DTN networks, communication nodes do not have the default communication facilities and they move randomly. The characteristics of their energy and bandwidth are also constrained. Therefore, routing problem in DTN is more complex than the traditional networks routing. In this paper, a LMOP-HR routing scheme based on flooding/message copy strategy was proposed to guarantee the message delivery rate. At the same time, it could effectively reduce node energy consumptions. Zhang et al. [3] proposed a network architecture shown in Fig.1, which includes planetary exploration network, deep space backbone network and deep space planetary exploration network.

The rest of this paper is organized as follows. Section 2 presents the related works of DTN routing. Section 3 provides the LMOP-HR algorithm Performance evaluation is given in Section 4 and finally, conclusion is offered in Section 5.

2. Related work

DTN is a hot research topic which attracts lots attentions. At the earliest, it was proposed to solve the problem of interplanetary Internet communications through establishing a new network model in space system. This new model could meet data transmission and other communication needs on the business in the space communications [4, 20]. Due to the characteristics of intermittent connection and dynamic topology change, routing in DTN is not as simple as in the traditional network, which should be reconsidered and redesigned. It is essential to analyze the routing problem in DTN.

This paper focuses on unicast routing of DTN networks, which can be roughly divided into four classes: routing methods based on the strategy of flooding/copy message, routing methods based on the strategy of forwarding, routing methods based on the strategy of topology knowledge and routing methods based on the strategy of historical/forecast. In [5], Kevin Fall proposed a series of routing algorithms based on the strategy of forwarding, mainly including: First Contact(FC), Minimum Expected Delay(MED), Earliest Delivery(ED), Earliest Delivery with Local Queue(EDLQ), Earliest Delivery with All The stabilizer's bloc Queue(EDAQ), Linear Program(LP) and so on. Regarding the strategy of topology knowledge, please refer to [6-8]. Some routing methods based on the strategy of historical/forecast were introduced in [9-11]. In this paper, a scheme was proposed based on the strategy of flooding/copy message. Routing methods based on the strategy of flooding/copy message focused on increasing the message delivery rate. The message would be copied before being forwarded by the node with copy function and then it would be forwarded again. In [12], Vahdat et al. designed a scheme named Epidemic Routing (ER) to maximize the message delivery rate. This routing strategy was simple and did not require additional network information. It increased the network throughput and made use of mobility to increase the chance of connection between nodes, but the network overhead was huge. Prioritized Epidemic (PREP) was

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proposed in [13] adding a priority mechanism based on ER. It managed message transmission, discarded priority level and improved the rate of infectious route message delivery effectively. Transmit Priority and Drop Priority methods were used to manage the priority level of message being transmitted or discarded, effectively improving the rate of infectious route message delivery. In [14], a meeting and access routing policy (Meetings and Visits, MV) was proposed which assumed that the source node was moving and the destination node was stationary. For local news, the node's storage capacity was infinite, but for news of other nodes, the storage capacity was limited. Nodes should exchange their message lists and calculate the transmission probabilities when they were meeting. Nodes would reorganize the stored messages according to their probabilities of message transmission and send messages to direction of greater probability. Authors in [15] gave out a routing strategy based on Fixed Point. It set up relatively static nodes in DTN network to auxiliary the message transmission. This method should increase the chance of available connection. MaxProp routing protocol was put forward in [16]. The nodes set priorities to the storing messages, adopting the method of average increment to estimate the probability of successful transmission among nodes. It gave a higher priority to greater probability message. This protocol set a threshold of hop t. If the hop of message was less than t, the priority would be determined by the hop. Otherwise, it was determined by the probability of successful transmission. In [17], a Two forward one Copy (Two-Hop Relay, Single-Copy) routing algorithm was proposed. In the transmission process, only one relay node was used. When the message was forwarded, the relay node received the message from the source node and stored it for a long time until connection was established between relay node and destination node. And then, the message was forwarded to the destination node. The author in [18] also proposed a two forwarding routing policy. Unlike literature in [17], its strategy adopted multiple copies (Multi-Copy) stratagem. Firstly, the source node copied the message before forwarding it. And then, it sent the message copy to the nodes within its communication range. Neighbor nodes stored the message for a long time and further forwarded it to the destination node.

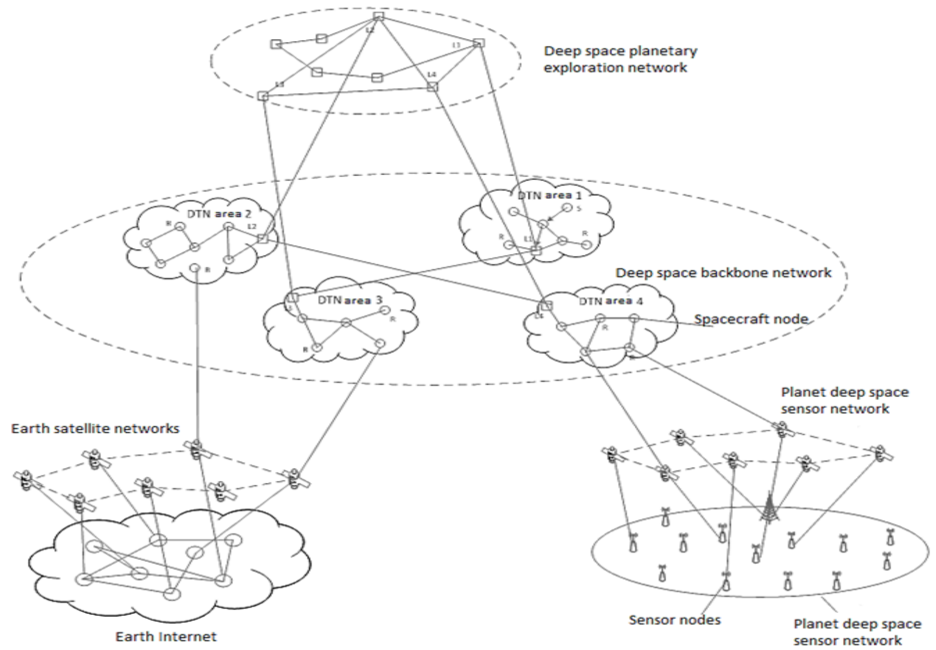

Fig. 1. DTN architecture model

In this paper, an algorithm was proposed based on the hybrid of ER strategy and Forward Routing strategy, which would prevent excessive message copy degrading the performance of the network. Otherwise, it could solve or alleviate the transmission failure and the information missing problems caused by the intermittent connection, the node failure or routing errors. It reduced the network transmission delay effectively on the basis of ensuring the success transmission rate.

3. LMOP-HR algorithem

This paper designed an improved routing algorithm based on ER algorithm to reduce the consumption of bandwidth and storage space. Therefore, we should analyze ER as the basic at first.

3.1 Analysis of Epidemic Routing

ER [19] algorithm was based on the flooding/message copy mechanism to maximize the message delivery rate and minimize the delay time. In this method, it set an upper limit threshold for the hop of each message and the storage space of each node. To ensure the final message passing rate, it needed to establish connection within the prescribed time limit.

There was a message buffer in each node set by ER. In order to improve the transmission efficiency, a hash table was established in the node's cache area to index the message, and a unique identifier was assigned to each message entering the network. Each node stored a bit vector called Summary Vector that indicated the number of messages set by its local hash table. When two nodes come into their communication range and connection was established, the node containing smaller identifier should actively initiate an entropy session to another node for passing message. While the two nodes meet and connected again in a short time, there was no doubt to cause the waste of network resources and time. In order to avoid redundant links, each node also assigned a special period of buffering to store an object list which had been connected. When a node came into the communication, it would be found in the list. If it existed, connection should be refused. An example is shown next.

Assuming that node A is going to communicate with B, they initiate an anti-entropy session to exchange messages. As shown in Fig. 2, the exchanging process can be described as following.

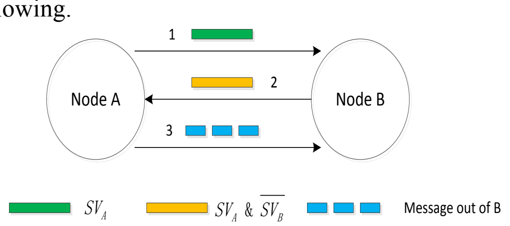

Fig. 2. The information exchange of ER

Step 1 A sends its summary vector SV_A to B;
Step 2 B performs a logical and operation between its negative summary vector $\overline{SV_B}$ and SV_A. That is, B determines the set difference between the message buffered in A and B. Then A transmits a vector request message;
Step 3 A transmits request messages to B.

This process is repeated transitively when B comes into contact with a new neighbor. Given sufficient buffer space and time, these anti-entropy sessions guarantee eventual message delivery through such pairwise message exchange. However, ER algorithm takes a large number of storage space and bandwidth resources. If the energy and storage space of node are limited, the routing performance will be greatly reduced. This paper designs an improved routing algorithm based on ER to reduce the consumption of bandwidth and storage space. In the case of limited network, it will make the routing performance achieve balance and unity.

3.2 Description of LMOP-HR

There are three stages in LMOP-HR algorithm as following.
(1) Message copy distribution stage

In this step, it adopts the champion tree distribution method based on the priority. First of all, the source node sets a reasonable message copy number threshold according to the size of the network, the existing network resources status and their remaining energy information. And then, it decides the copy message number and sets priority for the neighbor nodes within the rational communication range. According to the champion tree distribution method, a higher priority node is given a copy message and it forwards the message to the next node. This process will continue until to the destination node.

(2) Message spread stage

In this process, it adopts the method of k jump copy forwarding. The node which carries copy message decides the forwarding hop according to the copy number. When the message is forwarded for k jumps, it will be copied following the first stage. The first and second stages are repeated until k equals to 1. If the message is forwarded to the destination node, routing will end. Otherwise, enter the third stage.

(3) The optimal path selection stage

The node which carries single copy message will calculate the optimal path subjecting to three factors which are the unpredictable bandwidth resources, the buffer space and the energy of neighbor node. Then it gets an optimal path for minimum delay and maximize success deliver rate. At the same time, the message is forwarded.

3.3 Detailed Design of LMOP-HR

(1) Message distribution based on the priority
i. Determine the message copy number
In this step, firstly, the source node confirms its neighbors within its communication range, looking up the summary vectors and excluding the nodes which have been communicated recently. Secondly, it determines the neighbor nodes number a. Meanwhile, it sets threshold of the message copy number b, taking

$$n = \min(a, \frac{b-1}{2}) \tag{1}$$

where n is the message copy number.

At last, the priority of the delivery objects is set well. If $n = a$, it seems that the node's energy and the network resources are abundant or neighbor nodes become fewer. In this case, message will be copied to all neighbors and the priority-setting process will be skipped. If $n = \frac{b-1}{2}$, the priority-setting process is needed.

ii. Priority setting for copy target
Assuming the target's node type is S_i, the node energy is $E(t_i)$, the number of neighbor nodes is N_i. Then we define the priority value as:

$$P_i = \alpha \cdot S_i + \beta \cdot E(t_i) + \gamma \cdot N_i \tag{2}$$

where α is the weight of node type, β is the weight of remaining energy and γ is the weight of neighbor number and

$$\alpha + \beta + \gamma = 1 \tag{3}$$

where $\alpha \in [0,1]$, $\beta \in [0,1]$ and $\gamma \in [0,1]$.

The definition of node type S_i is shown as following table 1.

Table 1. Definition of Node type

Node type	S_i
Deep Space Spacecraft	10
Satellite	7
Detection sensor	4
Detect vehicle, robot	2
Other small detection node	1

Before copying message, the source node selects its neighbor as object which has larger weight according to the formula (2).

(2) Semi-hop mechanism

In DTN network, there is a long delay to wait for each available contact. So, the selection of the distribution should guarantee the delivery delay as small as possible. At the same time, considering that the energy and bandwidth resources are constrained, it should not copy message frequently. Here, this paper involves a semi-hop forward mechanism. It improves the original flooding algorithm message copy strategy and is a good way to balance the existence question.

In the first step, there are n message copy nodes to forward message during their movements. Meanwhile, they forward a message containing the forwarding time and the remaining copy time. The node which receives the message minus the forwarding time by one, and if it's more than zero, keep forwarding, or check and update the remaining copy time and copy message.

Assuming k is the remaining copy time, and $k = n/2$, which means the node will forward message for k times after message copy. And then, continue the next message copy. The forwarding process is as shown in Fig. 3.

In Fig. 3, the source node S sets the message copy number b equaling to 9 through analyzing the network traffic. There are 7 neighbor nodes within the communication range of S. With equation (1), we have the copy time n is 4. Different colors of the node represent different priorities. Choose 4 nodes with higher priorities to copy message. When copy process ends, the node which carries message will forward for $k = n/2 = 2$ hop times. And then, it continues message copy for the second time with the champion tree distribution strategy. Repeatedly, end the process until the forward number and the remaining copy time all are 1.

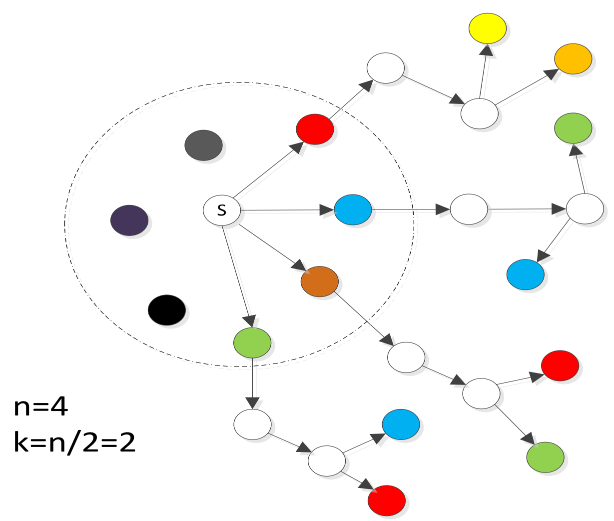

Fig. 3. The process of message copying and forwarding

(3) Priority-based optimal path selection

In the third step, the nodes carrying message forward messages independently. Considering three priority factors to make routing decisions, they are the message delivery possibility, the target node's residual energy and the remaining buffer capacity. Define the priority as:

$$Weight_i = \delta \cdot P(x, y_i) + \theta \cdot \frac{E(t_i)}{E_{i0}} + \mu \cdot \frac{C_i}{C_{i0}} \tag{4}$$

in which:

1) δ is the weight of the node's delivery possibility;
2) θ is the weight of the node's remaining energy;
3) μ is the weight of the node's remaining buffer capacity;
4) $P(x, y_i)$ is the probability to build a connection between node x and y_i;
5) $E(t_i)$ is the remaining energy of node i;
6) E_{i0} is the full energy of node i;
7) C_i is the remaining buffer capacity of node i;
8) C_{i0} is the full buffer capacity of node i.

During the time of message forwarding, node x filters the neighbors with its summary vector and sets priorities for the rest nodes with formula (4). It selects the node which has biggest weight as the forward object. Then the node which receives the message copy will repeat the forward process again and again until it reaches the destiny one.

i. Delivery possibility

Most nodes' moving locus cannot be predicted directly in DTN. To connect with other node, it needs the history information. In this paper, the method of the reference [5] is used to resolve the problem of possibility of nodes' meeting.

Assuming the encounter possibility of node x and y_i is $P(x, y_i)$. When they meet, there is [5,6]:

$$\begin{aligned} P(x, y_i) &= P(x, y_i)_{new} \\ &= P(x, y_i)_{last} + P(x, y_i)_{init} \cdot (1 - P(x, y_i)_{last}) \end{aligned} \tag{5}$$

In which:

1) $P(x, y_i)_{new}$ is the updated encounter possibility after the new meet between nodes x and y_i;
2) $P(x, y_i)_{last}$ is the old encounter possibility before the new meet between nodes x and y_i;
3) $P(x, y_i)_{init}$ is the initial encounter possibility between nodes x and y_i decided by the position of the two nodes and $P(x, y_i)_{init} \in [0,1]$.

If the two nodes do not meet each other in a period time, their encounter possibility will reduce. It also needs to update the encounter possibility as following:

$$P(x, y_i) = P(x, y_i)_{last} \cdot \gamma^k \tag{6}$$

In which:

1) γ represents the reduction constant of the encounter possibility of nodes, and $\gamma \in [0,1]$;
2) k represents the time units passed after last reduction of the encounter possibility of nodes.

ii. The message exchange process between nodes

Refer to Fig. 4, there are five steps in the message exchange process as following:

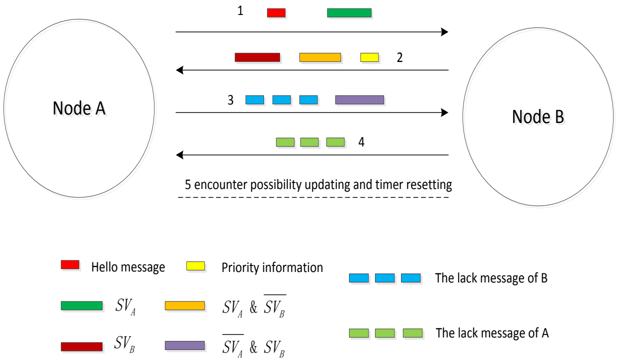

Fig. 4. The message exchange process

Step 1 When the node A and B meet with each other, A sends a hello message which contains the summary vector SV_A to B. At the same time, it asks for the summary vector SV_B;

Step 2 When B receives the message from A, it first refers to the summary vector SV_B and checks it out whether the two nodes have been communicated with each other recently. If they have, the node B will transmit a deny message to A and finish the connection. Or B will send its summary vector SV_B and a message about the remaining energy and other information of the priority factors to A. And it also computes the value of $SV_A \& \overline{SV_B}$, confirms the lack messages and sends the request to A;

Step 3 When A receives the message from B, it analyzes the priority level of B. If B doesn't meet the requirement, A will send a deny message to B and the connection will be finished. Or A will send the message copy to B. It also computes the value of $SV_A \& \overline{SV_B}$, confirms the lack messages and sends the request to B;

Step 4 At the time B receiving the message from A, it will send the message copy which A needs;

Step 5 When A receives the message copy, it will finish the connection. Both the two nodes will update the encounter possibility with each other and reset their timers.
The specific flow chart is as shown in Fig. 5.

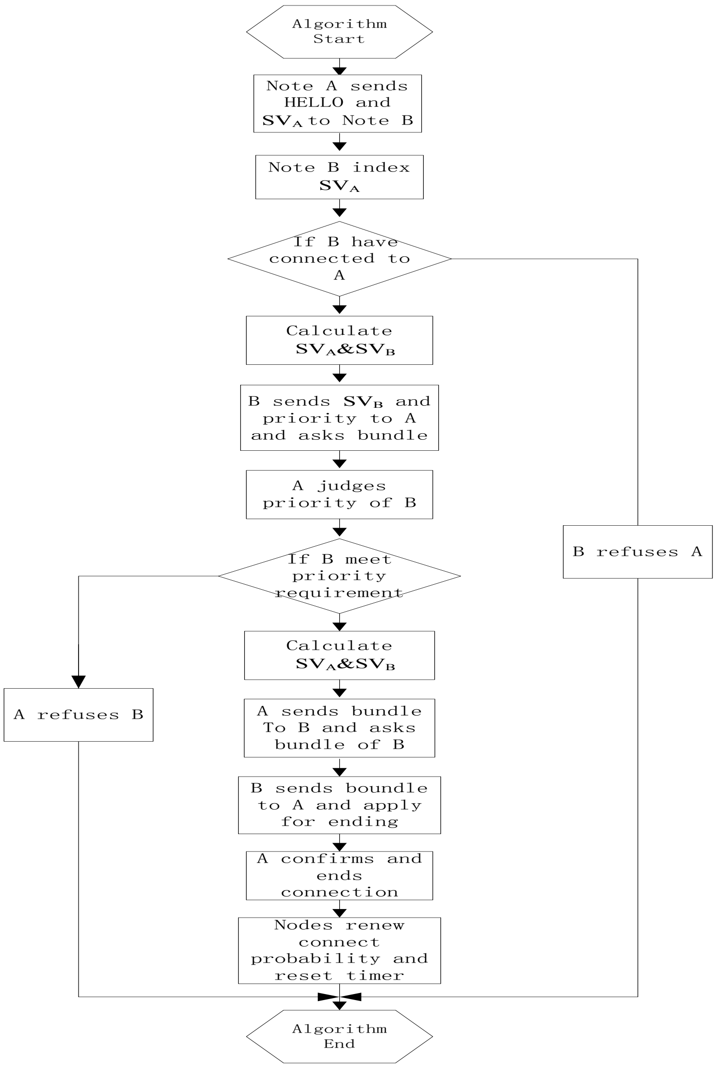

Fig. 5. The flow chart of notes message exchange

4. Analysis of simulation results

In this part, the performances of system are simulated with LMOP-HR and ER strategies using NS-2 simulation tools under different backgrounds. Setting different node numbers, we make the average transmission delay, the message delivery rate and the average residual energy of the nodes as the routing performance indicators to compare the two routing algorithms.

(1) The average transmission delay

Following by:

$$average\ transmission\ delay = \frac{the\ whole\ delay}{forwarding\ times} \tag{7}$$

the average transmission delay of the entire network can be calculated as the following Fig. 6.

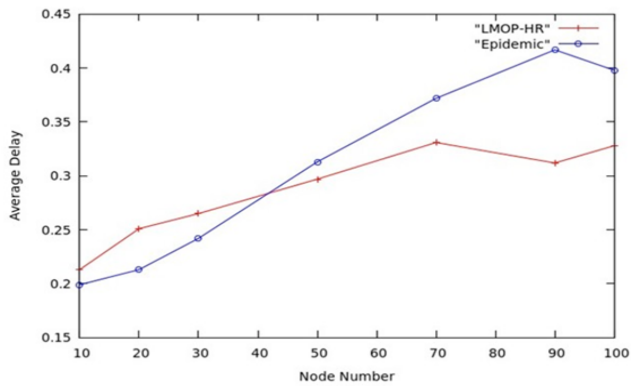

Fig. 6. The curve of average delay in cases of different number of nodes

It's clearly that the average transmission delays of the two kind of routing algorithms are closed. But as the number of nodes gradually increasing, the average transmission delay of the LMOP-HR becomes lower than that of ER. That means the performance with LMOP-HR strategy is much better.

(2) The message delivery rate

Following by:

$$message\ delivery\ rate = \frac{number\ of\ message\ the\ destiny\ receives}{totle\ number\ of\ message} \tag{8}$$

the message delivery rate of the entire network can be calculated as the following Fig. 7:

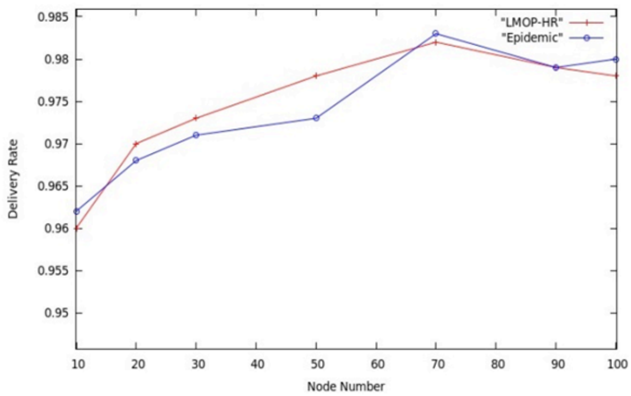

Fig. 7. The delivery rate curve in cases of different number of nodes

As we can see, the delivery rates of the two routing are consistent and the routing performances are fairly.

(3) The average residual energy

Due to the time of simulation is short, the initial energy value of the nodes is set at a low level. It's a little bit of difficult to analyze the value exactly, so we choose the percentage of the residual energy as the reference index qualitatively and analyze the routing performance through the graphic.

The percentage of the average residual energy of the node is:

$$average\ residual\ energy\ rate = \frac{sum\ of\ residual\ energy}{totle\ initial\ energy} \times 100\% \tag{9}$$

The simulation result is shown in Fig. 8.

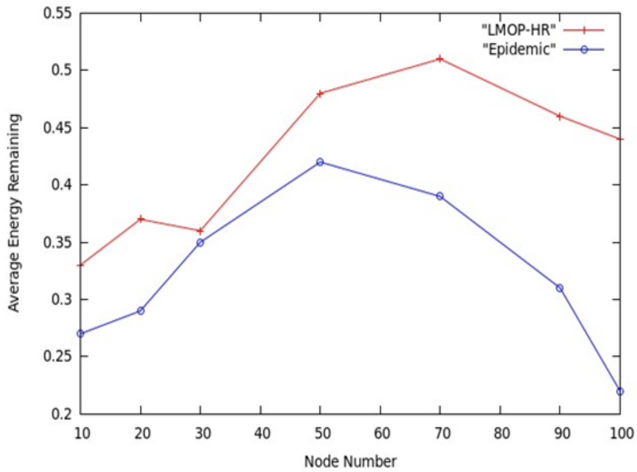

Fig.8. The average residual energy curve in cases of different number of nodes

According to the comparison, it can be found out that the average residual energy of the network with LMOP-HR is higher obviously than that of Epidemic routing, especially when the number of nodes in the network is increasing. For ER, with the operation of message copy being more frequent, the cost of energy is growing larger. That means the improved strategy LMOP-HR can efficiently reduce the energy consumption of the message copy.

5. Conclusions

The paper mainly focused on the DTN unicast routing. Based on the fully analysis of the routing process and routing performance of the Epidemic routing, an improved LMOP-HR routing algorithm was proposed based on the strategy of flooding/message copy. The routing algorithm used a hydroid strategy of priority and optimal tree to forward messages. While guaranteeing the message delivery rate, it could efficiently overcome the lack of the large energy consumption of the Epidemic routing algorithm and reduce the network overhead. At last, using the NS2 simulator tools, the performances of LMOP-HR algorithm and Epidemic routing algorithm were separately simulated under the same environment. Comparing three routing performance indexes of the average transmission delay, message delivery rate and the average residual energy, it was verified that the routing performance objectively achieved the expected effect.

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