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Utility-aware data transmission scheme for delay tolerant networks

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Abstract Social-based routing approaches in delay-tolerant networks have attracted widespread attention in recent years, which attempt to import social behaviors and relations in real scene for node mobility. However, most social-based schemes resort to users' contact history and social relations that are dynamic, causing it so hard to establish stable relations between nodes. In this paper, we propose a utility-aware data transmission scheme which considers both internal property and external contact of nodes. Inspired by the concept of transfer station in real life, we set a central group and choose nodes for message forwarding, which have higher utility, i.e., enough energy, adequate cache, and more nodes encountered during the motivation. Two extensions are proposed also to further reduce the overhead. Simulation results demonstrate the increase in delivery ratio and decrease in overhead ratio, especially in large scale scenarios.

Keywords Utility-aware · Central group · Data transmission · Delay-tolerant networks

1 Introduction

With the development of computer science and communication technology, several new networks appear, mainly applied to the harsh environment, including interplanetary network [1], wireless vehicle network [2], connectivity of developing countries [3], disaster recovery network [4], remote rural network [5], wireless sensor network [6] and etc.. Different from traditional networks, they are characterized by intermittent connectivity, limited power and longtime delay. These characteristics are abstracted by researchers, and called Delay Tolerant Networks (DTNS) [7]. Because of the mobility of nodes and lack of connectivity in delay-tolerant networks, messages cannot be delivered directly through the network in a traditional way. To solve this problem, a novel technology called Device-to-Device (D2D) communication was introduced, which allows mobile users within a certain range of communication to communicate directly with each other without any cellular networks. Since traditional TCP/IP protocols cannot be applied directly in these networks, the establishment of a new message forwarding scheme based on the D2D communication has become a research hotspot in the field of DTNS.

The earliest routing which was proposed in Delay-Tolerant Networks is Epidemic routing [8]. It is a flooding-based routing, which spreads message copies to every node that encountered. This kind of method does not need acknowledge of the network, and can reach a high delivery-probability if the buffer size of every node is enough. However, as the scale of nodes increases, messages cannot be delivered to destinations easily, causing the reduction in the performance. To improve the delivery ratio, Prophet routing [9] was proposed. It

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improves Epidemic routing by restrictions of message forwarding, which strictly forces all its transmissions to happen only when the carrier meets with the node that has a higher probability of success. However, overhead is not well improved when the scale of nodes is large. In addition, both schemes mentioned above use contact traces only in transmission process which have traps and pitfalls proved by N.Ristanovic in [10], but ignore the performance of the node itself, i.e., energy and buffer size, which has a great influence on the transmission of messages.

A novel energy-aware priority transmission scheme based on context-metric queuing for delay-tolerant networks was proposed by Cabacas Regin [11], as far as we know, this is the state-of-the-art work for data transmission in DTN. Their approach introduces a Node Delivery Capacity (NDC) metric, uses node's remaining energy, estimated distance to the destination and speed for queuing and sorting messages in a buffer. However, NDC is a simple linear combination of three factors, higher speed and shorter distances cannot completely represent a higher delivery ratio in some respects in delay-tolerant networks. In addition, the update of node's location information is based on the complex calculation and extra overhead.

Recently, routing schemes based on the social performance have drawn widespread attention, which are committed to importing social behaviors and characteristics in the real scene for node mobility. However, the social relations of nodes change frequently and quickly, causing difficulties of establishing stable relations between nodes for message forwarding. In addition, tremendous overhead is caused in a large-scale network, as every node needs to frequently update their knowledge of the network. What's more, the establishment of relations between nodes and the classification of social areas are based on a large amount of calculation, causing a higher consumption and a longer transmission delay.

Different from the existing routing schemes, we propose a utility-aware data transmission scheme, which combines node's internal property with external contact. We introduce the concept of transfer station in real life, create a central group and choose the appropriate number of nodes for message forwarding, which have higher utility, i.e., enough energy, adequate cache, and more nodes encountered during the motivation. Compared with the traditional routing schemes, our advantages lie in the following several aspects: firstly, our scheme owns a great improvement in balancing energy. For each message, our scheme strictly forces all its transmissions to happen only when the carrier meets with the nodes in the central group, which are more powerful in terms of energy, transmission range, buffer size, etc., as compared to the normal nodes. Therefore, nodes with weak capacity get well protected on the basis of small influence on the delivery ratio, which can prolong the lifetime of networks. Another advantage embodies in simplifying the process. Considering the traces of some types of nodes (i.e., buses and trams) are stable, we do not need to update the nodes in the central group whenever nodes are encountered. We perform the update operation on a longer period, which can both guarantee the stability of nodes in central group and ensure the real-time.

The remainder of this paper is organized as follows: section 2 reviews some related work. In section 3, we present our proposed routing in detail. Section 4 concentrates on simulation and evaluation. Finally, we conclude this paper in Section 5.

2 Related works

In daily life, people are accustomed to using the Internet to transmit information. In this way, you need to upload the message to the Internet firstly, and then people can download it. However, as for the aforementioned delay tolerant networks, the network often be partitioned because of the mobility of nodes and lack of connectivity. The network cannot play its role in message transmission. To solve this problem, we should allow mobile users with communication devices like phones, sensors, laptops, and other mobile equipment to communicate directly with each other without any cellular networks or Wi-Fi, called D2D (device to device) method.

The study of D2D scheme has already made a lot of achievements, great deals of routing protocols have been proposed. It is proved in [10, 12] that only using contact traces in process without the characteristics of the node itself, i.e., energy, transmission range, and buffer size, has traps and pitfalls. To solve this problem, the concept of ferry nodes was introduced. In [13–16], some special users with devices are selected as ferry nodes that are more powerful in terms of energy, buffer size, etc., compared to normal nodes. These ferry nodes are capable of determining an optimal route in delay-tolerant networks.

In [13] proposed by Sanjay K. Dhurandher and etc., instead of considering the partition and intermittent connectivity of the network as problems, they regard them as characteristics of the opportunistic network. Some nodes which are powerful enough are chosen as ferry nodes for establishing a mobile infrastructure for delivering messages to their destinations. A scheme is introduced in [14] that ferry nodes are similar to mobile agents in active networks, they can actively change their own movement patterns, i.e., mobile trajectory and speed, to minimize the delay of message transmissions and maximize the delivery rate. The EEHC algorithm discussed in [15, 16], organizes the nodes in the network into clusters with a hierarchy of cluster heads (CHs). The CHs collect the information from the sensor nodes within their clusters and send message through the hierarchy of cluster heads to the destination.

Through a depth-study of above papers, we find that these methods either need to constantly update the ferry nodes which are used to transfer messages, or just update only once. The former has a very large amount of calculation and a large number of resource consumption. The latter ignores the movement change of nodes that may result in the reduction of algorithm performance.

Considering the stability and the need for updates, we propose a cyclical algorithm in this paper. We perform the update operation on a longer period, considering the traces of some types of nodes (i.e., buses and trams) are stable. Through this method we guarantee both the stability of nodes in central group and the real-time.

The major contributions of our work are as follows:

- A utility-based model is proposed as the metric to choose some special nodes as ferry nodes for message forwarding.
- A utility-aware data transmission scheme in delay-tolerant networks is presented to increase the delivery ratio and reduce the overhead ratio, especially in a large scale.
- Two extensions are put forward to further reduce the overhead during message transmissions.

The proposed scheme is evaluated in simulation platform ONE, and simulation results demonstrate the competitive performance.

3 Utility-aware data transmission scheme

3.1 Network model

Firstly, we present a brief introduction to the network model of our scheme. Inspired by the taxicabs and buses model which was proposed by Zhang et al. [17], we differ the nodes into four groups, including pedestrians, buses, cars and trams and import their traces and features for node mobility, as shown in Fig. 1. For these participants with mobile devices, they can contact with others through Wi-Fi, Bluetooth, ZigBee, etc. As we stated earlier in this paper, the prerequisites of our scheme is owing a central group for transmission, with proper number of nodes inside. Here, Bus1 and Tram1 are superior to other nodes seen clearly from their parameters, i.e., enough buffer, sufficient energy and higher node-activeness. So we can all agree that they can deliver messages to destinations more easily and choose them into the central group.

Next, we walk through an example to describe our data transmission scheme. We assume that Alice generates a message that is going to pass to Bob, when she encounters Bus1, which belongs to the central group; she disseminates a message copy and operates a forward. Bus1 does the same operation if he encounters Tram1. Either Bus1 or Tram1 senses Bob in his communication range, he transfers the message from Alice to Bob and a successful process of message transmission is completed.

3.2 The utility value of node

Firstly, as shown in Table 1, we make a table of key notations used in the following part of our paper to make it more readable to readers.

Secondly, we introduce our new metric using node's remaining energy, remaining buffer size and activeness to indicate node's utility value of message delivery, shown in Formula 1. It identifies the probability of the encountered node to deliver messages successfully. The higher the node's energy ($E_N(n_i)$), node's activeness ($S_N(n_i)$) and larger it's buffer size ($B_N(n_i)$), the higher is the value of node's utility. $E_N(n_i)$,$B_N(n_i)$,$S_N(n_i)$ are all the values after normalized. n_i is the id of nodes. The scope of i is determined by the number of nodes in the scenario.

$$U(n_i) = \varepsilon_1 \times E_N(n_i) + \varepsilon_2 \times B_N(n_i) + \varepsilon_3 \times S_N(n_i) \qquad \sum_{j=1}^{3} \varepsilon_j = 1 \tag{1}$$

$E_N(n_i)$,$B_N(n_i)$ and $S_N(n_i)$ are explained in detail as follow.

(a) $E_N(n_i)$ denotes the rank of node's energy among all the nodes in the scenario. It is used to estimate that whether the node is energy-enough to forward messages successfully. It is defined in Formula 2.

$$E_N(n_i) = E(n_i)/E_{\max} \tag{2}$$

Where $E(n_i)$ is the current energy value of node n_i, $E_{\max}$ indicates the maximum energy value of nodes in the network. As for the definition of $E(n_i)$, we divide it into three conditions as follows:

Firstly, we give an initial energy value $E_{init}(n_i)$ for every node and define the consumption of energy for scanning (E_{scan}) and transferring ($E_{transfer}$) separately. $E(n_i)$ is initially defined in Formula 3.

$$E(n_i) = E(n_i) - E_{scan} \times t_i \tag{3}$$

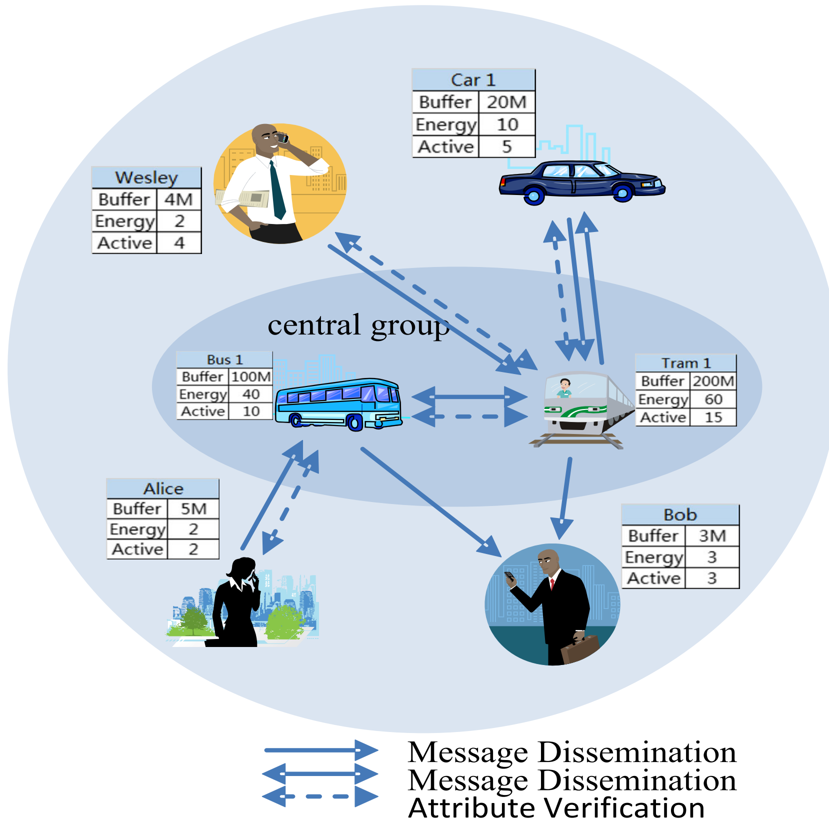
where t_i indicates the time of the node to keep scanning. The initial value of $E(n_i)$ is $E_{init}(n_i)$.

Secondly, when the node delivers a message successfully, the value of $E(n_i)$ is updated, shown in the next formula.

$$E(n_i) = E(n_i) - E_{transfer}$$

Finally, we set a threshold for nodes. when $E(n_i) \prec E_{threshold}$ happens, which means the death of the node, we stop the update process.

Fig. 1 Networks model of different nodes



(b) $B_N(n_i)$ describes the rank of node's buffer size among all the nodes in the scenario. It is defined in Formula 4

$$B_N(n_i) = B(n_i)/B_{\max} \tag{4}$$

where $B(n_i)$ shows the rest of buffer size of this node, and $B_{\max}$ presents the max-value of buffer size among all the nodes.

(c) $S_N(n_i)$ reflects the number of nodes encountered during the process of motivation per unit time period. It is a normalized value which defined as follows:

$$S_N(n_i) = S(n_i)/S_{average}$$

Where $S_{average}$ is introduced for the normalization which is determined according to the experimental results. Considering that there may be more than one nodes are sensed in the range of transmission at the same time during the motivation, we set up an array *num*[] to save the number of nodes encountered every location update of the current node. Taking account of both the metric's integrity and real-time performance, $S(n_i)$ is defined in Formula 5:

$$S(n_i) = \alpha S_{old}(n_i) + (1-\alpha) S_{new}(n_i) \tag{5}$$

where $S_{old}(n_i)$ can be considered as a smoothing factor which occupies a smaller weight. Suppose the times of location update of the current node is N, then $S_{old}(n_i)$ is defined as follows.

$$S_{old}(n_i) = \sum_i num[i]/N.$$

$S_{new}(n_i)$ describes the number of nodes encountered in the recent period of time, which plays an important role on node's activeness. Suppose the number of nodes encountered during

Table 1 Initial definitions of notations

Notation	Understanding definition
$U(n_i)$	Utility value of nodes for delivering messages.
$E_N(n_i)$	Rank of node's energy among all the nodes in the scenario.
$B_N(n_i)$	Rank of node's buffer size among all the nodes in the scenario.
$S_N(n_i)$	Number of nodes encountered during the process of motivation per unit time period.
ε_i	Tunable system parameters reflecting the effect of each factor.
$num[i]$	Number of nodes encountered every location update of the current node.

the latest *n* periods of time can reflect the recent activeness of the node. $S_{new}(n_i)$ can be calculate:

$$S_{new}(n_i) = \sum_{i=N-n+1}^{N} num[i]/n$$

As for the value of *n*, it can be adjusted according to the scale of the scenario, can neither too high nor too low. If *n* gets a high value, the activeness of nodes may not be distinguished well. On the contrary, if *n* gets a low value, we cannot get accurate judgment whether the node can encounter more nodes during a long period because of the existence of explosive phenomenon occasionally.

In addition, we will give an explanation for the determination of the value of ε_1, ε_2 and ε_3. They are tunable system parameters, which can be changed according to actual scene conditions. For example, in some harsh environment, it is difficult to recharge nodes' power or redeploy nodes. In this case, nodes' energy should occupy a larger proportion. In our simulations, we set their proportion to 3:3:4, which mean that nodes' activeness occupies a larger proportion compared with the other two factors.

3.3 Utility-aware router (UAR)

The utility-aware Data Transmission Scheme proposed by us consisted of two steps, and Algorithm 1. gives the details of the first step.

```
Algoritm 1. Choose nodes for central group
procedure choose nodes for central group{
firstly we choose the top n nodes in terms of energy and buffer size as the initial nodes in central group
while (the period is done){
if (the U(n_i) of nodes in central group < =that is not in central group){
replace the nodes which has the lower U(n_i) in central group with other nodes that has a higher U(n_i) not in central group
else
keep the nodes in central group
end if}
else
keep the nodes in central group
end while}
calculation U(n_i) {
E(n_i) = P(n_i) / P_max
B(n_i) = C(n_i) / C_max
S(n_i) = αS_old(n_i) + (1 − α) S_new(n_i)
U(n_i) = ε_1 × E(n_i) + ε_2 × B(n_i) + ε_3 × S(n_i)
return U(n_i)
end calculation}
end procedure
```

We set up a central group and choose the appropriate number of nodes for message forwarding, which have higher utility. This part is the core of our scheme. We choose some initial nodes into the central group at first, according to the energy and buffer size of nodes. Then we update the nodes in central group at set intervals based on the utility value of every node. The second step is the routing process which is explained in detail in Algorithm 2, Messages are randomly generated among all the nodes. Only when the carrier meets with another node that belongs to the central group, a message copy is created and delivered. The process continues like this until the message is delivered to the destination or dropped.

```
Algoritm 2. Routing Strategy
procedure routing strategy {
message m //m presents a message
node A=m, node B //A and B respectively //different nodes and A generate m
if (A encounters B){
if (B belongs to central group){
A forwards m to B
if (B encounters destination){
B forwards m to destination
else
B keeps moving
end if}
else
A dose not forward m to B
end if}
end if}
end procedure}
```

3.4 Extensions of our scheme

To further reduce the overhead, we introduce two extensions based on the initial scheme. The first one called UAR_prob-improved Router introduces the delivery-probability calculator in Prophet Routing [9]. When encounter a node, the carrier should not only determine whether the node encountered belongs to the central group, but also take account of the possibility of success. In the second improvement called UAR_buffer- improved Router, we add a buffer management mechanism. When a message's TTL drops to a low value, we should not consume too many resources to transfer this message. We only deliver this message to the nodes which are energetic enough.

4 Simulations

In order to evaluate the performance of our algorithms, we use a simulator called ONE for simulation. The simulation is

Table 2 Initial parameter settings of the nodes

Scope of the simulation Scenario	4500×3400 m			
Types of Nodes	Pedestrians	Buses	Cars	Trams
Numbers of Nodes	160	20	20	6
Buffer/M	10	40	40	50
Speed/m/s	[0.5,1.5]	[2.7,13.9]	[2.7,13.9]	[7,10]
WaitTime/s	[0,60]	[10,30]	[0,10]	[10,30]
TransmitRange/m	10	100	100	100

grouped into the following three parts. (1) varying percentage of the number of chosen nodes in central group: we choose the suitable proportion of nodes among all the nodes in the simulation scenario in order to achieve the best efficiency of transmission (2) Comparing different routing algorithm: we compare our routing algorithm (UAR) with Epidemic Router and Prophet Router in terms of performance, including delivery ratio and overhead ratio. (3) Comparing the extensions: we compare our routing scheme with two extensions: UAR_prob_improved Router and UAR_buffer_ improved Router.

4.1 Simulation setting

Reference to real life social scene, we differ the nodes in the simulation area into four groups, including pedestrians, buses, cars and trams and import their traces and features for node mobility. The initial parameter setting is given in Table 2.

Messages are generated randomly among all the nodes with 30 s interval. Messages source and destination are randomly chosen and the size of the messages is set in the random boundary ranging from 500 k to 1 M. To match the simulation region size, we set the messages TTL to 5 h. We set the simulation time to 10 h with the first 2 h as warm-up period.

4.2 Simulation results

1) Varying percentages of nodes chosen for central group: in this section, we want to choose the suitable proportion of nodes to join the central group, in order to achieve the best efficiency of transmission. We compare the performance under different percentages of the nodes which are chosen for forwarding messages. We set the percentage of chosen nodes to 3, 5, 10, 15 and 20 % respectively and observe the performance of the algorithm

From Fig. 2, we can see that the delivery-ratio climbs up at first and then declines with the increase of numbers of nodes which are chosen for transmission. It reaches to the maximum value when the number of nodes in the central group occupies 5 % of the total. This is because too many nodes for forwarding messages may result in insufficient buffer space. Messages cannot be passed to the destination node when the buffer size is filled.

The overhead ratio of the scheme is shown in Fig. 3, which is defined as the ratio of the differences between total numbers of relayed messages and the number of messages which is successfully delivered to the number of transmissions for those successfully delivered messages. Figure 3 shows us that the scheme exhibits an increasing trend on the overhead ratio as the increase of the percentage of the number of the nodes, which is consistent with actual situation obviously.

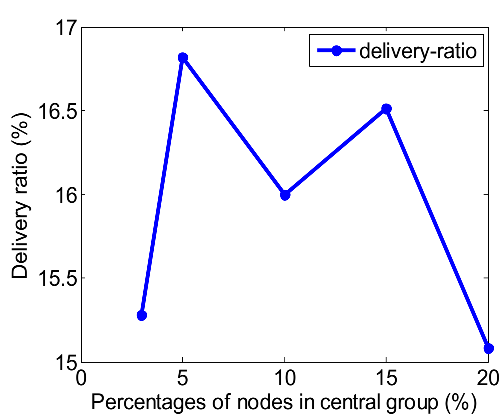


Fig. 2 Delivery-ratio for part (1)

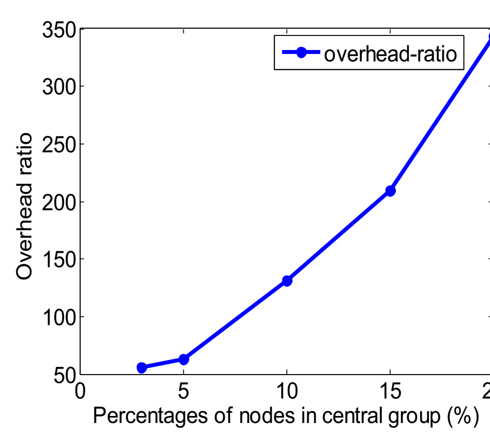


Fig. 3 Overhead-ratio for part (1)

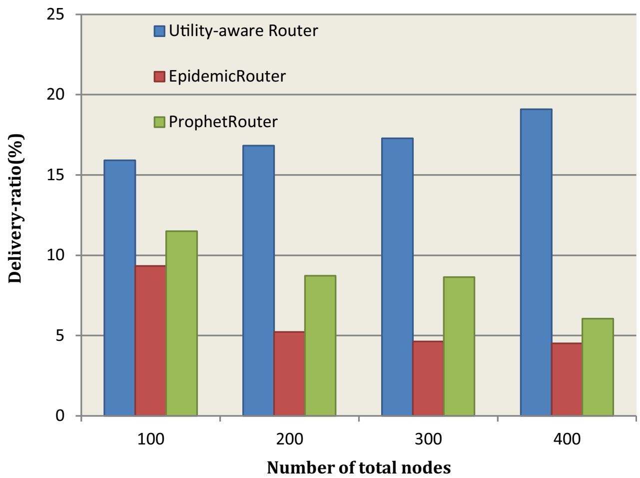


Fig. 4 Delivery-ratio for part (2)

Considering the characteristics of Delay Tolerant Networks are intermittent connectivity, limited network capacity and etc., our purpose is to achieve higher delivery ratio on the basis of less overhead. From Figs. 2 and 3, we notice that the highest delivery ratio occurs when the percentage is 5 %. There is no guaranteed on the delivery ratio, if the percentage of the selected nodes is too low. On the other hand, too many nodes for transmitting will result in more resource consumption. The results indicate that five percentages is the most appropriate and the ratio can be adjusted with the change of scale.

2) Comparing different routing algorithm: in this section, we compare our scheme with Epidemic Router and Prophet Router in terms of performance, including delivery ratio and overhead ratio. From Figs. 4 and 5, we can see that our scheme has the highest delivery ratio and the lowest overhead in each case, i.e., regardless of the number of nodes in the simulation scenario. More specifically, in terms of delivery ratio, the ratio achieved by our scheme is much higher than the other two schemes and the gap gets bigger when the scale of nodes increases. Meanwhile, a very obvious and desirable observation is that, with the increase of the number of nodes, our scheme exhibits an increasing trend on the delivery ratio, while the other two schemes show a decreasing trend. This is because the other two schemes do not own an effective buffer management, especially Epidemic Router. The buffer size of some nodes with smaller storage capacity will be easily filled up when the number of nodes increased. Therefore, a certain amount of messages cannot be delivered successfully as their destination's buffer size is filled up. On the contrary, for each message, our

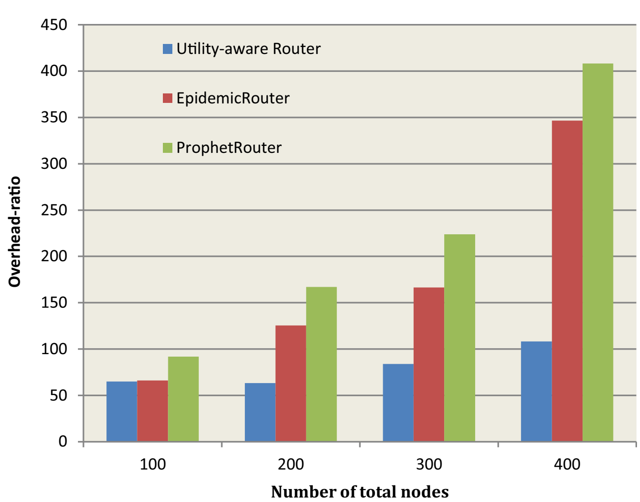


Fig. 5 Overhead-ratio for part (2)

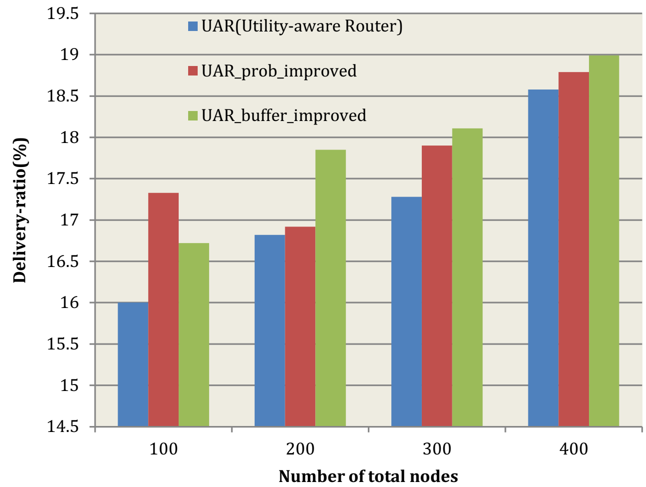


Fig. 6 Delivery-ratio for part (3)

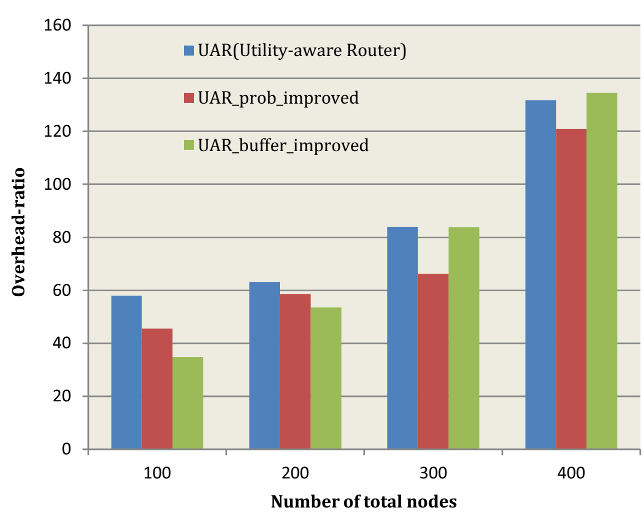


Fig. 7 Overhead-ratio for part (3)

scheme strictly forces all its transmissions to happen only when the carrier meets with the nodes in the central group, which are more powerful in terms of energy, transmission range, buffer space, etc., as compared to the normal nodes. Saved buffer space creates more transmission chances for messages going out and new messages coming in. More nodes are used for forwarding messages when the number of nodes increases, which improves the delivery ratio. In terms of overhead, our scheme achieves the lowest overhead ratio and it keeps in a low level, even if the number of nodes increases. As a comparison, the other two schemes exhibit a sharp rise on overhead ratio as the increase of the number of total nodes.

3) Comparing with the extensions: in this section, we compare different methods in two extensions: UAR_prob_improved Router and UAR_buffer _improved Router. From Figs. 6 and 7, we can see that both extensions can reach the goal of further reducing the cost on the basis of the guarantee of delivery ratio. The difference is that when the number of nodes is relatively low, UAR_buffer_improved router performs better than the other two schemes, seen from the perspective of overhead, and UAR_prob_improved Router gradually shows greater advantages as the number of nodes increases. Results indicate that the improvement based on the probability is more practical because the scale of nodes is always large in the social life.

5 Summary and future work

In this paper, we propose a utility-aware data transmission scheme in delay-tolerant networks (DTNs). Our scheme is divided into two parts:the selection of ferry nodes for message forwarding and multi-copies routing. Two extensions are presented to further improve the performance of our scheme. Through the stimulation platform ONE, we verify both efficiency and thriftiness of the proposed routing schemes. Extensive performance comparisons with other schemes have shown the great advantages of our scheme. Our future work will include more experiments to decide how many nodes should be selected for transmission along with the change of the number of nodes in the scenario. We also plan to verify the feasibility of our scheme in real scenes.

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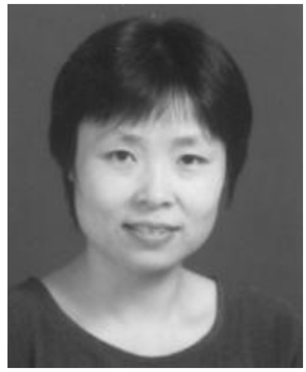

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