A Novel Routing Protocol Based on Reputation and Service Level in Opportunistic Networks

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Abstract: In the routing protocol of opportunistic networks, nodes tend to make requests to the forwarding nodes that have higher successful probability. As a result, the number of forwarding tasks of a higher successful probability nodes will increase, then this node will become more selfish due to the limitations of the node's own resource, which will lead to a sharp decrease in a amount of forwarding tasks that higher successful probability nodes are willing to forward, and thus increase the overall delay time and decrease the delivery ratio of the routing protocol in opportunistic networks. In this context, to solve this problem, a reputation routing protocol is proposed in this research. Firstly, based on Social-based Watchdog System (SoWatch), a reputation model is constructed. Each node has computation reputation and recommendation reputation. The computation reputation consists of systematic reputation and subjective reputation. When the computation reputation is greater than the recommendation reputation and the difference exceeds a certain threshold, the recommendation reputation is updated. Secondly, from previous researches, the service level can effectively stimulate the enthusiasm of nodes to participate in data forwarding. So, by considering reputation, service level and routing protocol, a reputation prophet routing protocol(re-prophet) is designed based on prophet protocol. Simulation is performed to evaluate the performance of the proposed reputation routing protocol. The re-prophet is compared with the prophet, and the result shows that the reputation routing protocol is better and the delay time of the re-prophet is reduced by about 15%.

1. Introduction

With the development of the Internet and portable smart terminals, the world has entered the era of mobile Internet. According to Cisco's forecast, global mobile data traffic will grow sevenfold between 2016 and 2021, and by 2021 video traffic will account for more than 78% of the total traffic [1]. Therefore, cellular networks are becoming more and more crowded, and mobile users may face the problem of declining service quality. In addition, driven by the continuous installing of new apps on smart devices, users need more and more mobile data traffic. To solve this problem, data offloading was developed in opportunity networks. In opportunistic networks, the routing protocol does not need to establish a complete route between source node and destination node, but uses a *storage-carry-forward* approach to perform data forwarding through the encounter between nodes. However, in the case of a node's limited cache space, limited CPU processing capacity, limited power and network bandwidth, nodes will show selfishness. At the same time, as the nodes move in opportunistic network, the topology of the route and the nodes within the communication range change in real time, and the trust relationship of the cooperative data forwarding between the nodes also changes. However, reputation mechanism can help establish a good trust relationship between nodes, which is beneficial for encouraging nodes to participate in data forwarding service.

In an opportunistic network, although the reputation-based incentive mechanism motivates nodes to actively participate in forwarding, the nodes tend to request a forwarding service to a node with higher reputation. In addition, as constrained by a node's own power and cache space, the node will show selfishness for its own benefit. With the continuous increasing of forwarding, the successful probability of forwarding will decrease and the reputation of high-reputation node will also do,

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which in turn leads to increase the delay time and decrease the delivery ratio of the routing protocol in opportunistic networks, and even the routing protocol paralysis.

To solve the above problems, this paper establishes a reputation model and proposes a reputation routing protocol by considering node reputation, service level, and the existing routing protocols. The proposed reputation routing protocol provides different levels of forwarding services by considering the reputation of nodes. The proposed protocol not only encourages nodes to participate in forwarding in a more active way, but also affirms node's long-term participation in forwarding. At the same time, the problem that multiple nodes compete for limited high-quality resources is alleviated and the unoccupied nodes can also be fully utilized in opportunistic network.

The contributions of this paper are as follows. Firstly, a reputation model is proposed. In the calculation of reputation, this research considers the reputations from both control center and users. At the same time, the environmental factors that nodes face are also considered, so as to objectively reflect the contribution of forwarding nodes to data forwarding. In addition, the reputation of nodes is divided into computation reputation and recommendation reputation. The computation reputation records the reputation that a node gains in every forwarding. The recommendation reputation is the value that one node is trusted by other nodes. Secondly, by combining reputation, prophet routing protocol and hierarchical service, this paper proposes a reputation routing protocol named Re-prophet. Based on historical selection probability, this paper also considers the impact of the reputation of forwarding nodes on the process of selecting nodes. Considering the reputation of forwarding nodes is beneficial for forwarding nodes to participate more actively in forwarding in opportunity networks.

The rest of this paper is organized as follows. The second section describes the related research work. The third section introduces the system model, and establishes the reputation model. Simulation is performed in Section 4. Conclusions are made in Section 5.

2. Related Work

Some methods have been recently proposed to alleviate the problem of data offloading in opportunistic networks. Yifeng Zhou [2] proposed a novel distributed reputation detection model following the pattern of *From Path to Individual* to solve the problem that it is difficult to obtain interactive reputation in the case of insufficient direct interactions. This model can produce individual reputations by the evidences of path reputations which are actually the perception of agents' actions. The obtained individual reputations can be considered as an alternative for the interactive reputations in the cases of insufficient direct interactions resulting from the same information source. This model consists of two components, one for the transformation from path reputations to individual reputations of agents and the other one for the detection of path reputations in information diffusion scenario. Literature [3] proposed a data forwarding algorithm named TOSS. The algorithm combines online social network with offline mobile network, and considers the social relationship and contact probability of nodes to select the appropriate seed node set. Also, TOSS considers the request delay of different users. Literature [4] proposed an incentive mechanism for opportunistic network IRONMAN, by taking advantage of social network information to guide the detection of selfish nodes. Literature [5] proposed a routing protocol named ICRP that is compatible with incentive mechanism. ICRP is based on two multi-copy routing protocols of game theory. The routing protocol considers the probability of encounter and the cost of transmission when processing a selfish node. This research also uses the optimization scheme and Vickrey-Clarke-Groves auction to select the best forwarding nodes. Literature [6] designed a novel social optimal evaluation protocol based on game theory that combines pricing and reputation mechanism. Each user indicates their social status by rating and users are encouraged to increase their ratings through the mechanism of the higher the rating, the greater the reward. Literature [7] analyzed the limitations of dialogue reputation model and proposed a reputation model named Resilient Reputation Model (RRM). This model not only encourages nodes to provide optimal services, but also punishes the nodes that attempt to cheat. Literature [8] propose PROPHET-TC. Through a reasonable assessment of node transmission capacity and combined with the traditional probabilistic routing, this paper proposes a probabilistic routing algorithm based on the node transmission capability, which makes the selection of the next hop node more reasonable and efficient, and compensate the deficiency of the traditional probabilistic routing in selecting the next hop node. Simulation results show that the proposed algorithm can improve the delivery ratio and reduce the overhead of the network.

3. System Model

In the reputation routing protocol, as the node with higher reputation has higher service quality in data forwarding, the other nodes generally tend to make requests to the forwarding nodes with higher reputation. The forwarding tasks of a node with higher reputation are further increased. Due to the limited resources of a node, the nodes will get more selfish, and a sharp decline will occur in the delivery ratio and increase delay time of data forwarding for the node with higher reputation. Therefore, the reputation of the node and the performance of the data forwarding in opportunistic network will be reduced, as shown in FIGURE 1.

To solve this problem, a reputation routing is proposed in this research. When the nodes with different reputations request forwarding service, the nodes are divided into different levels, and are provided with different levels of services from the reputation routing protocol. The flow chart of reputation-based incentive forwarding is shown in FIGURE 2. First of all, based on SoWatch, this paper divides reputation into computation reputation and recommendation reputation. The computation reputation is derived from the combination of systematic reputation and subjective reputation. The systematic reputation is the reputation given by the control center to a forwarding node according to the amount of data forwarding completed by a forwarding node. The subjective reputation refers to the reputation given by the user according to the time taken by a forwarding node to complete a data forwarding. Secondly, the control center obtains the computation reputation of a node and compares it with its recommendation reputation. When the node’s computation reputation is greater than its recommendation reputation and the difference exceeds a certain threshold, the control center updates the node's recommendation reputation. Thirdly, when a node does not participate in forwarding service for a certain period, the recommendation reputation of the node begins to attenuate. In addition, according to the recommendation reputation of the node and the waiting time of the request of the destination node, the control center calculates the node service level and then queues requests based on the service level of the requesting node. The higher the service level of the node, the higher the forwarding node with a higher probability of forwarding. Therefore, the reputation routing protocol proposed in this paper solves the problem that forwarding nodes are excessively concentrated on the nodes with high reputation in data forwarding service, through making full use of the idle nodes in opportunistic network. Finally, after the data is divided into packets, the forwarding node carries the entire portion of the data for forwarding[9].

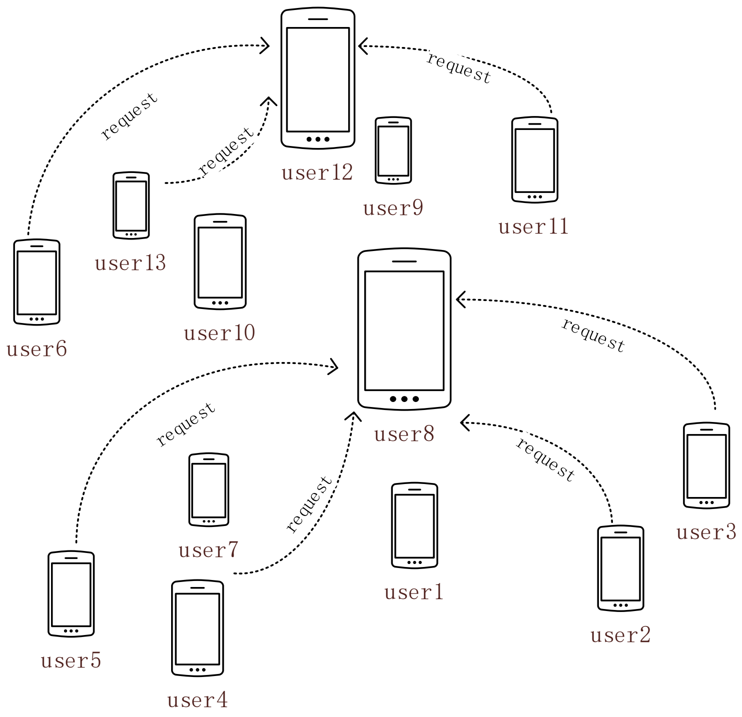

Figure 1. Requests and users

The forwarding service request in reputation routing protocol. In Figure. 1, the larger the size of a graph, the higher the reputation of the user, and the reputations of user8 and user12 are the highest in the Figure.

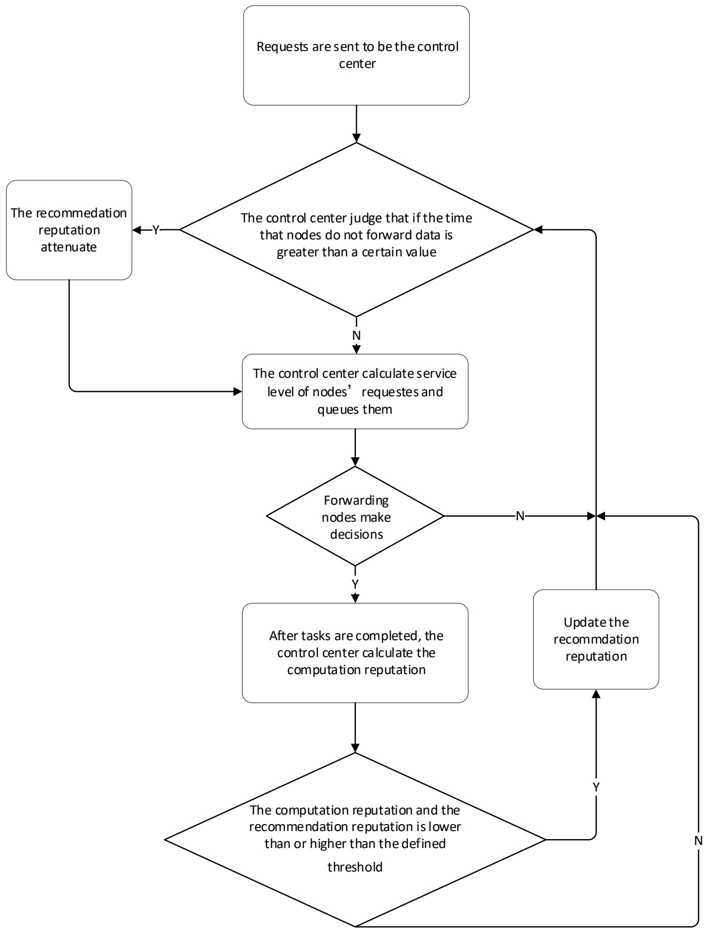

Figure 2. Flow chart of forwarding with reputation routing

3.1 Reputation Model

Firstly, each node is registered at the control center to obtain an identity which includes identity number, computation reputation, and the update times of reputation. The identity information table of a node at this node, including identity number, recommendation reputation, and node service type. The computation reputation refers to the reputation obtained by completing a forwarding for a forwarding node and the reputation is recorded at the control center. The recommendation reputation is the reputation value that is displayed to other nodes when the node performs data forwarding. Secondly, when a node sends a data request to the control center, the control center calculates the service level of the node based on the reputation of the node and then makes a response. The higher the service level of a node, the faster the response of data forwarding service, the higher the probability and smaller delay time of data forwarding service. Finally, when a forwarding node has completed the data forwarding service according to the reputation routing protocol, both the user and the control center give an evaluation. After the control center obtains the computation reputation of a forwarding node, the computation reputation will be compared with the recommendation reputation, and the recommendation reputation will be updated when the difference between the computation reputation and the recommendation reputation is greater than a certain threshold. When a node does not participate in data forwarding for a certain period, its recommendation reputation value is attenuated.

3.1.1 Computation Reputation

The computation reputation of each node consists of two parts: the subjective reputation and the systematic reputation. The subjective reputation refers to the reputation given by a requesting node according to the time when a forwarding node completes data forwarding service. The systematic reputation refers to the reputation given by a trusted third-party platform, i.e. the control center, to a forwarding node based on the amount of data forwarded by the forwarding node each time. The computation reputation is obtained by weighing the subjective reputation value and the systematic reputation value in the previous data forwarding. The computation reputation is defined by

$$R_{i,j}(n) = \begin{cases} 0, & i = 0 \\ R_{i-1,j}(n) + \alpha * r_c + (1-\alpha) * r_u, & r_c, r_u \epsilon (0,1] \end{cases} \tag{1}$$

where $R_{i,j}(n)$ is the computation reputation of node n, i represents the number of times the forwarding node n has performed data forwarding service, j represents the number of updates of the forwarding node n, r_c stands for systematic reputation, r_u stands for subjective reputation and.

3.1.2 Reputation Update

After a destination node gives the forwarding node a reputation, the control center determines whether the difference between the computation reputation and the recommendation reputation of the forwarding node is higher or lower than a certain threshold. When the difference is lower than or higher than the defined threshold, the control center updates the recommendation reputation of the forwarding node and the recommendation reputation update function of the forwarding node, which are expressed by

$$R_i^K(n) = \begin{cases} R_{i,}(n), & R_{i,j}(n) < R_i^K(n) + \gamma \\ R_{i,j}(n), & R_{i,j}(n) < R_i^K(n) - \gamma \end{cases} \tag{2}$$

$$K_i(n) = \begin{cases} K_i^+(n) + 1, R_{i,j}(n) < R_{i,}^K(n) + \gamma \\ K_i^-(n) + 1, R_{i,j}(n) < R_{i,}^K(n) - \gamma \end{cases} \tag{3}$$

where $R_i^K(n)$ is the recommendation reputation of the node n, γ is the threshold, $K_i(n)$ is the function of the update times of node n, and $K_i^+(n)$ is the number of times that the computation reputation is greater than the recommendation reputation for the node n, $K_i^-(n)$ is the number of times that the computation reputation is smaller than the recommendation reputation for the node

n .

Definition1:

The service active node means that $K_i^+(n)$ of the node n is greater than or equal to $K_i^-(n)$.

The service negative node means that the $K_i^+(n)$ of the n node is smaller than the $K_i^-(n)$.

3.1.3 Reputation Attenuation

When a node does not participate in data forwarding for a certain time, the node's computation reputation and recommendation reputation are both reduced. The reputation attenuation is defined by

$$\mathrm{R(n)} = \begin{cases} R(n), & t_0 - t < \delta \\ \rho * R(n), & t_0 - t > \delta \end{cases} \tag{4}$$

Algorithm1.

input: *message_space* (*node*), *delay_time* (*node*), t_0, t *Input node offloads the amount of data and the delay time for completing the data forwarding service, completes the time for data forwarding service, and the time of the most recent data forwarding service*

output: *reputation (node),*

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Step1 if    t_0 − t > δ
Step2 if    K_i^+(n)>=K_i^−(n)
Step3         // Service active node attenuation coefficient
Step4          R_i^K(n) = ρ1 ∗ R(n)
Step5     else if  K_i^+(n)<K_i^−(n)
Step6         // Service negative node attenuation coefficient
Step7             R_i^K(n) = ρ2 ∗ R(n)
Step8 R_{i,j}(n) = R_{i−1,j}(n) + α ∗ r_c + (1 − α) ∗ r_u ∗ c_i
Step9     if  R_{i,j}(n) − R_i^K(n) > γ| R_{i,j}(n) − R_i^K(n) < −γ
Step10             R_i^K(n) = R_{i,j}(n);
Step11        if  R_{i,j}(n) − R_i^K(n) > γ|
Step12     K_i(n) = K_i^+(n) + 1
Step13   else
Step14     K_i(n) = K_i^−(n) + 1
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where t_0 is the current time; t is the last time of reputation calculation for the forwarding node; δ is the time window; ρ is the reputation attenuation coefficient. A node has different types of data forwarding services, and the corresponding attenuation coefficients are different.

3.2 Reputation-based Routing Protocol

Based on prophet routing protocol[9], this paper considers recommendation reputation and service level to propose a reputation-based route named re-prophet. The principle of the proposed routing protocol is as follows. When a node needs a data forwarding service, the node sends a request to the control center and the request includes the information of recommendation reputation, destination address, data name, and node service type. Then, the control center calculates the node service level according to the request information and the waiting time for the data to be forwarded. According to the node service level, the control center recommends forwarding nodes according to different node service levels. After that, the node selects the forwarding node according to its social relationship and the success ratio of the previous data forwarding[10]. The control center sends a request for the node's selection[11]. When the forwarding node receives the request of data forwarding service, it decides whether to participate in the data forwarding service according to the reputation of the node and the node service type[12]. Finally, after the data forwarding service is completed, the node and control center perform reputation evaluation and reputation update according to the data forwarding service of the forwarding node[13].

3.2.1 The Control Center Calculates Service Level

According to the recommendation reputation of the node and the waiting time of the request of the destination node, the control center calculates the node service level [14], and the control center preferentially responds to the request of the node with a high service level. The service level of node is defined by

$$\mathrm{degree(n)} = R_{i,}^K(n) + waitetime(n) \tag{5}$$

where $\mathrm{degree(n)}$ represents the request level of the node n, $R_{i,}^{K}(n)$ represents the recommendation reputation of the node n, and $waitetime(n)$ represents the waiting time of the node request.

3.2.2 The Probability of Forwarding Nodes

The control center considers the reputation of the node that sends the request (requesting node), the type of node service, and the social relationship to predict the probability that the forwarding node provides data forwarding service. When the requesting node has a social relationship with the forwarding node, the forwarding node usually does not consider the reputation of the node providing the data forwarding service for it; but when the requesting node does not have a social relationship with the forwarding node, the forwarding node will consider the reputation of the forwarding node. The reason for the above situation: according to previous researches, the forwarding node is more likely to provide data forwarding services to the requesting nodes with which it has a social relationship; and greater reputation of the requesting node indicates the more active data forwarding of the requesting node, and therefore, the forwarding node is more likely to forward its data. If the node service type is the service active node, then the requesting node has better service quality, and the forwarding node has greater probability forward its data.

Definition 2: Trust probability

The trust probability$\mathrm{P_{trust}}$is the probability that a node is trusted by other nodes in opportunistic network. $\mathrm{P_{trust}}$t is defined by

$$\mathrm{P_{trust}} = \frac{R_a^K}{\sum_{j=1}^{n} R_j^K} \tag{6}$$

where R_a^K is the recommendation reputation of the forwarding node a, and $\sum_{j=1}^{n} R_j^K$ is the total recommendation reputation of the opportunistic network.

Definition 3: Data forwarding quality

The data forwarding quality q reflects the quality of data forwarding by nodes in the opportunistic network. q is defined by

$$q = \frac{K_a^+ - K_a^-}{|K_a^+ - K_a^-|} \frac{K_a^+}{K_a^+ + K_a^-} \tag{7}$$

Based on the trust probability and data forwarding quality, the mechanism for node b to select node a as the forwarding node is expressed by

$$P_{(a,b)} = \begin{cases} \left(1 + \mathrm{P_{trust}} * (1+q)\right) * P_{(a,b)old}, social\ relationship \\ (1+q) * P_{(a,b)old}\text{，} no\ socail\ relationship \end{cases} \tag{8}$$

where $P_{(i,t)old}$ is the probability of successful service between nodes in previous services.

3.2.3 Forwarding Probability

After the requesting node selects the forwarding node set, the control center performs data forwarding according to the service level of the forwarding node. The probability of the forwarding changes as the service time of the node requesting changes, as shown in Eq. (9) [15]. In data forwarding, node *a* encounters node *b*, and node *b* encounters node *c*. the probability of inter-node forwarding is defined in Eq. (10).

$$P_{(a,b)} = P_{(a,b)old} * \omega^k \tag{9}$$

$$P_{(a,c)} = P_{(a,c)} + \left(1 - P_{(a,c)old}\right) * P_{(a,b)} * P_{(b,c)} * \beta \tag{10}$$

where ω is the attenuation function and k is the time from the previous encounter to present time.

Algorithm2.

input: *node, reputation*

output: value, //value is reputation value of nodes.

Step1 degree(node)= $= R_{i,}^{K}(n) + waitetime(n)$
Step2 while i<set&&i!=node //set is the amount of node.
Step3 if they have the relationship with the requesting and the forwarding
Step4 $P_{(a,b)} = \left(1 + \frac{R_a^K}{\sum_{j=1}^{n} R_j^K}\left(1 + \frac{K_a^+ - K_a^-}{|K_a^+ - K_a^-|}\frac{K_a^+}{K_a^+ + K_a^-}\right)\right) P_{(a,b)old}$ *//The requesting node has a social relationship with the forwarding node*
Step5 else $P_{(i,t)} = \left(1 + \frac{K_a^+ - K_a^-}{|K_a^+ - K_a^-|}\frac{K_a^+}{K_a^+ + K_a^-}\right) * P_{(a,b)old}$ *//There is no social relationship between the requesting node and the forwarding node.*
Step7 $P_{(a,b)} = P_{(a,b)old} * \omega^k$
Step8 $P_{(a,c)} = P_{(a,c)} + \left(1 - P_{(a,c)old}\right) * P_{(a,b)} * P_{(b,c)} * \beta$
Step9 nodeset// Forwarding node set with high probability of forwarding
Step10 M←nodeset// Forwarding node set determined by the requesting node
Step11 M_help←nodeset// the set of nodes that provide offloading service
Step12 if M and M_help// If there are the same nodes
Step13 Data forwarding service

4. Simulation

4.1 Simulation Environment and Settings

The experimental data are from the SIGCOMM 2009 dataset [16]. The dataset is from the SIGCOMM 2009 conference held in Barcelona, and the participants are required to log in Facebook with their smart devices to obtain their profiles. At last, 100 people participating in the conference use their Bluetooth to perform data forwarding in the opportunistic network. 76 smart devices were adopted for Matlab simulation in this research.

In data forwarding, based on the random waypoint node movement model, data is forwarded in fragment. In this simulation, the size of data fragment is equal to the cache space of the node[17]. Extensive simulation was performed on re-prophet routing protocol, prophet routing protocol. The performances of the routing protocols were investigated under the condition of different cache spaces and request volumes. The performance was evaluated by message delivery ratio, average delay time, and average reputation value.

(1) Message delivery ratio [18]:

$$\text{delivery ratio} = \frac{delivered\ \ messages}{total\ messages} \tag{11}$$

(2) Average delay time [18]:

$$\text{average latency} = \frac{\sum latency(i)}{all\ delivered\ messages} \tag{12}$$

TABLE 1. Settings

Parameter	Default	Range
Size	4500 m×3400 m	-
Number of nodes	100	76
Transmission ratio	250 KB/s	
Message size	500 KB-1024 MB	32 MB, 64 MB, 128 MB, 256 MB, 384 MB, 512 MB, 768 MB, 1024 MB, 1152 MB, 1280 MB
Size of cache space	32 MB-1280 MB	32 MB, 64 MB, 128 MB, 256 MB, 512 MB, 1024 MB,1152 MB,1280 MB
Mobility models	Random waypoint	
Simulation time	7 days	-
Message TTL	60 min	30-120 min

4.2 Simulation Results and Analysis

In this paper, α, γ and δ are set as shown in Table 2.

TABLE 2. Settings

Parameter	Default
α	0.5
γ	0.6
δ	168 min
ω	0.9
β	0.85

4.2.1 Size of Cache Space

When the cache space was 128 MB and the data size ranged from 32 MB to 1280 MB, comparison was performed on the re-prophet, prophet routing protocol in terms of delay time and message delivery ratio, as shown in FIGURE 3. The comparison results show that the delay time of re-prophet was smaller than that of prophet routing protocol. Due to the incentive of reputation on forwarding node, the forwarding node actively participated in data forwarding to obtain a good reputation, and the forwarding node obtained a higher level in the data request. When a node requested a data forwarding, other nodes gave priority to the data forwarding service. Therefore, the node actively participated in data forwarding. As shown in FIGURE 4, the delivery ratio of re-prophet was not significantly improved compared with prophet routing protocol. This shows that the reputation mechanism and the rating service had no effect on message delivery ratio. The above results result from that the delay time of the forwarding node by re-prophet was smaller than delay time that by prophet, and the delivery ratio of re-prophet was higher than that of prophet. This verifies the effectiveness of the reputation model and the reputation routing established in this paper.

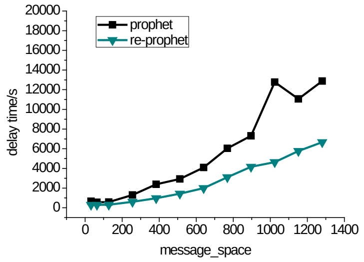

Figure 3. Delay time varies with the amount of data

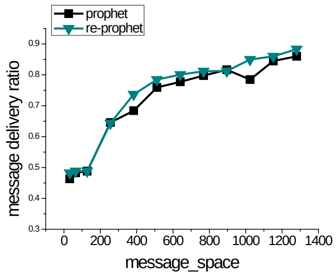

FIGURE 4. Message delivery ratio varies with the amount of data

4.2.2 Message TTL

When the cache space was 128 MB, the data size was 512 MB. Comparison was performed on re-prophet and prophet routing protocol routing protocol in terms of delay time and message delivery ratio, and the results are shown in FIGURE 5 and FIGURE 6. As the msgTTL increased, decrease was observed in the performance of reputation routing protocol and the routing protocol used for data forwarding would generate a large amount of network redundancy, resulting in the loss of many messages, and the reduction in the average delay time of data forwarding and the average delivery ratio. Compared with the original protocol, the re-prophet utilizes reputation and services level to select forwarding nodes, and therefore it performed better in terms of delay time. However, compared with the original routing protocol, the message delivery ratio of the reputation routing protocol has not improved significantly. Each time the data is forwarded, the control center arranges forwarding nodes according to the service level, and this forwarding nodes are only nodes with a high probability of forwarding rather than the highest probability of forwarding in the entire opportunistic network when scheduled. When a forwarding node had a task, the control center will not give the other task. If the msgTTL be longer, the probability of forwarding node and the number of forwarding nodes which are selected by the control center are smaller. At the same time, the reputation motivates each node to actively participate in the task. So the message delivery ratio of the reputation routing protocol has not improved significantly.

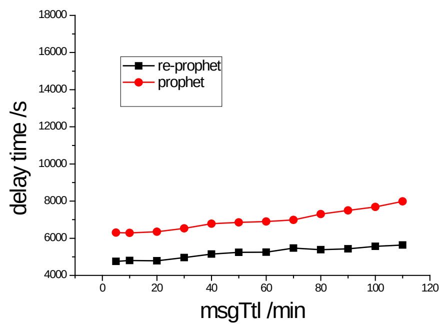

Figure 5. Delay time varies with msgTTL

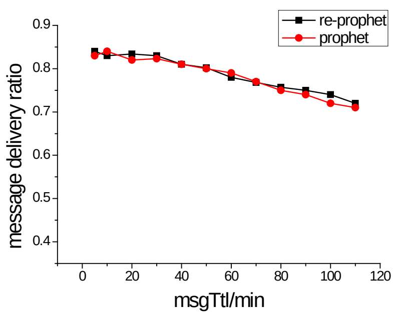

Figure 6. Message delivery ratio varies with msgTTL

5. Conclusion

We proposes a reputation model and a kind of reputation routing protocol that combines reputation, services level and prophet routing protocol to form the re-prophet. We have shown through experiments that Re-prophet routing protocol performs better than prophet routing protocol, and the delay time of re-prophet reputation routing protocol in data forwarding is greatly reduced. However, the proposed routing protocol shows no significant improvement in message delivery ratio compared with the prophet routing protocol. Since the reputation routing protocol proposed in this paper improves the enthusiasm of nodes to forward data and allows more idle nodes to participate in data forwarding, it decreases the delay time in data forwarding, but fails to improve the message delivery ratio in data forwarding. In the future work, the node preferences should be considered, and mobility model can be used to further optimize the routing protocol in data forwarding.

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