Energy Efficient Social-Based Routing for Delay Tolerant Networks

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Abstract. Delay Tolerant Network (DTN) is one kind of emerging networks characterized by long delay and intermittent connectivity. Traditional ad hoc routing protocols are inapplicable or perform poorly in DTNs because nodes are seldom fully connected. In recent years, many routing protocols (especially social-based routing) are proposed to improve the delivery ratio in DTNs, but most of them do not consider the load of nodes thus may lead to unbalanced energy consumption among nodes. In this paper, we propose an *Energy Efficient Social-based Routing* (EESR) protocol to reduce the load of nodes while maintaining the delivery ratio within an acceptable range by limiting the chances of forwarding in traditional social-based routing. Furthermore, we also propose an improved version of EESR to dynamically adjust the controlling parameter. Simulation results on real-life DTN traces demonstrate the efficiency of our proposed algorithms.

Keywords: Energy Efficient, Load Balancing, Social-based Routing, Delay Tolerant Networks.

1 Introduction

In delay tolerant networks (DTNs), the end-to-end path does not exist all the time from the current node to the destination node. Thus, routing in DTNs becomes very challenging compared with traditional wireless networks [14]. In recent years, many DTN routing protocols [13, 18] are proposed to leverage the node mobility for packet delivery.

The simplest DTN routing protocol is Epidemic [17], in which whenever a node carrying a message encounters with another node, it copies a replica of the message and forwards the replica to the encountered node. However, such

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flooding-based solution also causes relatively high network overhead. To overcome the shortage of Epidemic routing, many DTN routing protocols limit the number of replicas, such as Spray and Wait [16]. Generally, the delivery ratio of flooding-based strategies is relevant high, but the heavy load of nodes may cause serious congestions in DTNs.

Most of the existing routing protocols adopt "store-carry-forward", where if there is no connection available, the current node stores and carries the message, and then makes a decision whether to forward the message when it encounters another node. For example, PRoPHET [11] predicts the delivery probability in the future network based on historical contacts, and then decides whether to forward the message. Fresh [3] forwards packets to the encountered node if it meets the destination node more recently than the current node does. Greedy-Total [4] forwards messages to the encountered node if it has a higher contact frequency to all other nodes than v_i does.

To further improve the prediction of future encounters, many social-based routing protocols [12, 18] are proposed. More and more mobile devices in DTNs are used and carried by human beings, so the behaviors of the networks can be better characterized by their social attributes. SimBet [2] is a representative routing protocol for such social-based DTNs. When current node encounters another node, the message is more likely to be forwarded to the node with higher social centrality and more similar with the destination node. Label [7] and Group [10] try to forward the message to the node whose group is the same with the destination node. Bubble Rap [8] forwards the message includes two phases: a bubble-up phase based on global centrality and a bubble-up phase based on local centrality.

All of the above routing protocols focus on improving the delivery ratio without considering the battery usages of the mobile nodes, which could significantly affect the life-time of mobile devices. In this paper, we propose an *Energy Efficient Social-based Routing* (EESR) protocol which aims to reduce the load of nodes in social-based routing by limiting the chances of forwarding at each encounters. We also propose an improved version of EESR (EESR-I) to dynamically adjust the controlling parameter so that the delivery ratio can still be at certain level. The performance of our proposed methods are evaluated through simulations over real-life data traces and compared with other existing social-based routing protocols.

The rest of this paper is organized as follows: Section 2 reviews existing social-based routing methods for DTNs. Section 3 presents the detailed design of the proposed EESR and EESR-I. Section 4 describes simulation results and Section 5 concludes the paper.

2 Related Works

In the previous studies, many routing protocols have been proposed for DTNs. They can be roughly divided into two categories: store-carry-forward strategy and flooding based strategy [13]. For the store-carry-forward strategy, the current node stores and carries the message, and makes a forwarding decision when encounters another node. For the flooding based strategy, there will be multiple copies of each message in the whole network, such as Epidemic [17]. Though the delivery ratio of flooding-based method is usually high, the multi-copy strategy may greatly increase the loads of nodes and cause serious congestions in DTNs. Since in this paper, we will focus on social-based DTN routing methods, in this section, we briefly review the existing social-based routing methods.

Recently, social-based routing has attracted a lot of attention since most mobile devices (such as smart phones) are now used and carried by people, and the network behaviors can be better characterized by their social attributes. Social-based routing methods aim to carefully choose the relay nodes by choosing a good *social metric* to measure the capability of nodes to deliver the message to the destination. During any encounter, if the encountered node has higher social metric than the current node, the current node will forward its message copy to the encountered node. For example, SimBet [2] uses betweenness centrality and the similarity with destination node as the social metric. Bubble Rap [8] uses global centrality and local centrality to decide whether to forward the message. Gao et al. [5] also utilizes centrality (defined by a cumulative contact probability) and community as the social metrics to design social-based multicast routing protocols. Friendship [1] defines its friendship community as the set of nodes having close friendship (defined by using contact probability) with itself either directly or indirectly. SEBAR [9] introduces social energy (generated by the encounters and shared by communities) to quantify the social ability of forwarding messages to other nodes, which consists of two parts: the reserved energy generated by itself from direct node encounters with other nodes and the reallocated energy gained from its communities.

In this paper, we are committed to reduce the load of nodes in social-based DTNs. It is well-known that the energy of mobile devices is very precious due to the limited capacity of battery. When some nodes run out of energy, it may have a great impact on the performance of the network, especially for sparse networks such as DTNs. Existing social-based routing methods usually choose a node with higher social metric to be the next relay, and they do not consider the energy consumption. In order to save node energy in social-based DTNs, we aim to minimize the number of forwards for message transmission while maintaining acceptable delivery ratio.

3 Energy Efficient Social-Based Routing

In this section, we introduce our proposed *energy efficient social-based routing* (EESR) protocol for DTNs. The aim of EESR is to save the energy consumption by limiting the number of message forwarding. Recall that the message will not be forwarded to the encountered node unless the current node has lower *social metric* than the encountered node. Here, *social metric* ($\mathcal{SM}$) could be any existing social metrics, such as centrality and similarity in SimBet [2], friendship in Friendship [1], and social energy in SEBAR [9]. The proposed EESR is a general scheme to reduce the load of each node, and it can be applied to any existing social based routing methods as long as they use social metric per node for relay selection and forwarding decision.

To calculate the social metric value of a node, a social graph is needed to describe the social relationships among nodes. Usually such a social graph is generated from historical contacts [6]. Assume that $V = \{v_1, v_2, \ldots, v_n\}$ is the set of nodes in the DTN. Each node can send and receive messages when it encounters another node (the physical distance between them is less than the transmission range of their radios). To generate the social graph, we set a threshold on contact frequency to judge whether there is a close relationship between two nodes in the network. If the number of contact times between two nodes is larger than or equal to the threshold, there is an edge between these two nodes in the generated social graph. The generated social graph contains all nodes and their relations. Given this graph, a variety of social metrics can be calculated and used by our routing algorithms. We use $\mathcal{SM}(v_i)$ to denote the social metric of node v_i.

3.1 EESR: Basic Version

In traditional social-based routing protocols, the messages are forwarded to the encountered nodes with larger social metrics. This may help to achieve higher delivery ratios, but nodes with large social metric values may run out of battery soon due to their heavy load. Therefore, we consider to improve the traditional social-based routing methods by enlarging the social metric of current node v_i to *amp_ratio* times of the original value. Here, $amp\_ratio \geq 1$. Thus, it becomes more difficult for the current node to transfer its message because the encountering node needs to have *amp_ratio* times higher social metric than that of current node to be chosen as a relay. By doing so, the number of forwarding in the network will be reduced. Naturally, the delivery ratio of the new method decreases, thus we dynamically adjust the amplification ratio *amp_ratio* according to the *Time to Live* (TTL) of the packet to avoid low delivery ratio. TTL of the packet indicates whether the packet is out-of-dated and when should be discarded. At the beginning, the TTL value of a message is set to a constant TTL_0. After each hop, the value of TTL will minus one. When TTL is reduced to zero, the message will be discarded.

In EESR, the forwarding happens only when the social metric of the encountered node is *amp_ratio* times larger than that of the current node. The basic idea of dynamically adjusting *amp_ratio* is as follows. At the beginning, when TTL is large, EESR puts minimizing the load of nodes as its first priority, thus the value of *amp_ratio* is set high. However, after several hops, when TTL is reduced to a small value, which means the packet will be discarded soon, EESR puts improving the delivery ratio as its first priority, so the value of *amp_ratio* should be set small. Therefore, we set

$$amp\_ratio = 1 + \frac{ttl}{TTL_0} \cdot \theta,$$

where θ is a predefined constant used to determine the initial value of *amp_ratio*, and TTL_0 and *ttl* are the initial TTL value and the current TTL value of the

Algorithm 1. EESR: Energy Efficient Social-based Routing

Node v_i with message M meets v_j which does not hold M.

if v_j is the destination **then**
  v_i forwards M to v_j
else
  $amp\_ratio \leftarrow 1 + \frac{ttl}{TTL_0} \cdot \theta$
  if $\mathcal{SM}(v_i) \cdot amp\_ratio \leq \mathcal{SM}(v_j)$ **then**
    v_i forwards M to v_j
    $ttl \leftarrow ttl - 1$
  else
    v_i holds the M and waits for the next encounter
  end if
end if

message, respectively. Note that EESR regresses to the traditional social based routing when $amp\_ratio = 1$. Algorithm 1 shows the detailed description of EESR.

Compared with traditional social-based routing methods, EESR aims to reduce the load of nodes. We illustrate an example in Figure 1, which shows the connectivity among nodes from $T = 0$ to 3. The number inside each node represents its $\mathcal{SM}$ value. Assume that node v_1 has a message destined to v_5. The message will go through v_2, v_3, v_4 and reach v_5 eventually by traditional social-based routing. Thus the loads of each node are 1, 2, 2, 2, and 1 respectively. Here, we assume that every time when a message is forwarded from one node to another node, the load of both involving nodes will plus one. In this example, the increase ratio $\theta = 0.5$ and $TTL_0 = 5$. In EESR, v_1 will not forward the message to v_2 at $T = 0$ because $\mathcal{SM}(v_2)$ is not 1.5 times larger than or equal $\mathcal{SM}(v_1)$. The message will be forwarded from v_1 to v_3 at $T = 1$ because $\mathcal{SM}(v_3)$ is 1.5 times larger than $\mathcal{SM}(v_1)$. At $T = 2$, the message will be forwarded to v_4 because $\mathcal{SM}(v_4)$ is 1.4 times larger than $\mathcal{SM}(v_3)$. Here, $amp\_ratio = 1 + \frac{4}{5} \times 0.5 = 1.4$. At $T = 3$, the message will be forwarded to the destination node v_5. Therefore, the packet will go through v_3, v_4 and reach v_5 with EESR. The loads of each node are 1, 0, 2, 2, and 1 respectively. Overall, the load of v_2 is reduced in this example by EESR. Our simulation results in Section 4 confirm that EESR can reduce the loads of nodes in DTNs.

3.2 EESR-I: Improved Version

If the $\mathcal{SM}$ value of source node is very large, it might be difficult to find a node whose $\mathcal{SM}$ value is amp_ratio times larger than itself except for the destination node. This phenomena could have a great impact on delivery ratio. To prevent it from happening, we design an additional mechanism to further dynamically adjust amp_ratio based on past encounters. When a node encounters more than K nodes whose $\mathcal{SM}$ values are larger than itself, but still does not forward the message (since the $\mathcal{SM}$ values of the encountered nodes are not greater enough

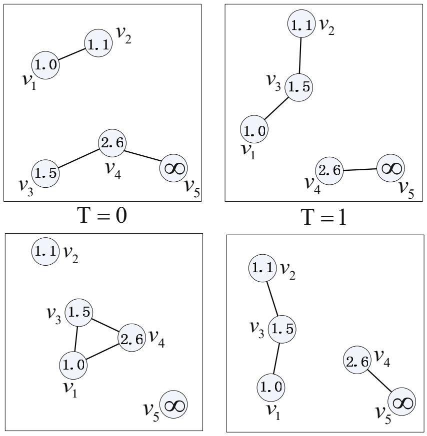


Fig. 1. An example of EESR

than *amp_ratio* times of the current node), then our method slowly relaxes the forwarding condition by gradually decreasing the value of *amp_ratio*. In this improved version (denoted by EESR-I), the amplification ratio *amp_ratio* is dynamically adjusted by: both (1) TTL of the packet and (2) the number of encounter nodes (i.e., *node_counter* in Algorithm 2) whose $\mathcal{SM}$ values are larger than that of the current node but smaller than *amp_ratio* times of that. Here, K is the pre-defined threshold for *node_counter*. Algorithm 2 shows the detailed method.

4 Simulations

We have conducted extensive simulation experiments over real-life wireless DTN traces to evaluate our proposed EESR and EESR-I. In our simulations, we use the SimBet utility value [2] as our $\mathcal{SM}$ value per node. Recall that in SimBet routing [2], the message is more likely to be forwarded to the node with high social centrality and more similar with the destination node. The SimBet utility value basically is a weighted value of the centrality and the similarity with the destination node. We compare EESR and EESR-I with the following existing routing methods.

- **Epidemic [17]**: during any encountering, the node copies a replica of the packet and forwards it to any encountered nodes.
- **SimBet [2]**: the packet is only forwarded from node v_i to node v_j if the SimBet utility of node v_j is larger than that of node v_i.
- **FRESH [3]**: the packet is only forwarded from node v_i to node v_j if v_j has met the destination more recently than v_i does.

Algorithm 2. EESR-I: Improved EESR

Node v_i with message M meets v_j which does not hold M.

if v_j is the destination **then**
  v_i forwards M to v_j
else
  if $\mathcal{SM}(v_i) < \mathcal{SM}(v_j)$ **then**
    $node\_counter \leftarrow node\_counter + 1$
    if $node\_counter \geq K$ **then**
      $amp\_ratio \leftarrow 1 + \frac{ttl}{TTL_0} \cdot \theta \cdot \frac{1}{node\_counter - K + 1}$
    else
      $amp\_ratio \leftarrow 1 + \frac{ttl}{TTL_0} \cdot \theta$
    end if
  end if
  if $\mathcal{SM}(v_i) \cdot amp\_ratio \leq \mathcal{SM}(v_j)$ **then**
    v_i forwards Msg to v_j
    $ttl \leftarrow ttl - 1$
    $node\_counter \leftarrow 0$
  else
    node v_i holds the Msg and waits for the next encounter
  end if
end if

– **Greedy-Total [4]**: the packet is only forwarded from v_i to v_j if v_j has a higher contact frequency to all other nodes than v_i does.

In all experiments, we compare the performance of each routing method using the following routing metrics.

– *Delivery Ratio:* the average percentage of the successfully delivered packets from the sources to the destinations.
– *Maximum Load:* the largest load of all nodes within a certain period of time.
– *Average Load:* the average load of all nodes within a certain period of time.
– *Average Hops:* the average number of hops during each successful delivery from the sources to the destinations.
– *Average Forwards:* the average number of forwarding times during each delivery (not only limit to successful delivery) from the source to the destination.
– *Average Delay:* the average duration of successfully delivered packets from the sources to the destinations.

We choose InfoCom 2006 trace data [15] to simulate the mobile DTN environment. This trace data includes connections among 78 mobile iMote Bluetooth nodes carried by participants of a student workshop for four days during InfoCom 2006 in Barcelona, Spain. Each record in the data set contains information about the ID of the device who recorded the sightings and the device who was seen. It also contains the starting time and the ending time for a certain contact. The contact information from the first 62 hours is treated as historical data to generate the social graph, then the performance of routing tasks are evaluated

Table 1. Parameters used for EESR and EESR-I

Parameter	Value or Type
Social metric $\mathcal{SM}$	SimBet Utility
Number of selected nodes	78
Number of routing tasks	6006
Initial value of TTL (TTL_0)	5
Increase ratio θ	0.5
K (Only for EESR-I)	2

over the remaining 30 hours. Each node tries to send a packet to all other nodes. Therefore, we have $78 \times 77 = 6006$ source-destination pairs and routing tasks. Here, we consider single-copy version of all routing methods, where only one copy is allowed within the network for any messages. To generate the social graph, we add an edge between two nodes if their total contact times is greater than one, which is the same as the setting in SimBet. Table 1 summarizes all parameters used in EESR and EESR-I.

4.1 Simulation Results of EESR

Figure 2 demonstrates the performance comparison among EESR and other four existing routing methods. As Figure 2(a) shows, Epidemic has the highest delivery ratio because it offers the upper bound of the delivery ratio that any routing protocol can achieve. The delivery ratio of EESR is not very high, since EESR aims to save the energy by reducing the opportunity of message forwarding. If the $\mathcal{SM}$ value of the source node is large, it will be difficult to find an encountering node whose $\mathcal{SM}$ value is *amp_ ratio* times higher than that of the source node. But EESR has outstanding performance in terms of the maximum and average loads as shown is Figure 2(b) and (c). Note that these two subfigures do not include the results of Epidemic because its maximum load is usually higher than $14,000$ and its average load is usually higher than $4,000$. Figure 2(e) and (f) indicate that average hops and average forwards of EESR are the smallest among all the methods.

4.2 Simulation Results of EESR-I

We then test the performance of improved version (EESR-I). Figure 3 show the detailed results. Interestingly, EESR-I has very close, even slightly better delivery ratio than that of SimBet, and its average delay is at the similar level with that of SimBet. Although the maximum and average loads of EESR-I increase over time, the load of EESR-I is still much lower than other algorithms. EESR-I still maintains the smallest numbers of hops and forwards. Compared with EESR, the improved version has similar delivery ratio with the original social based routing method while reducing the overall load, number of hops and forwards. The standard deviation of the load for different routing methods are reported

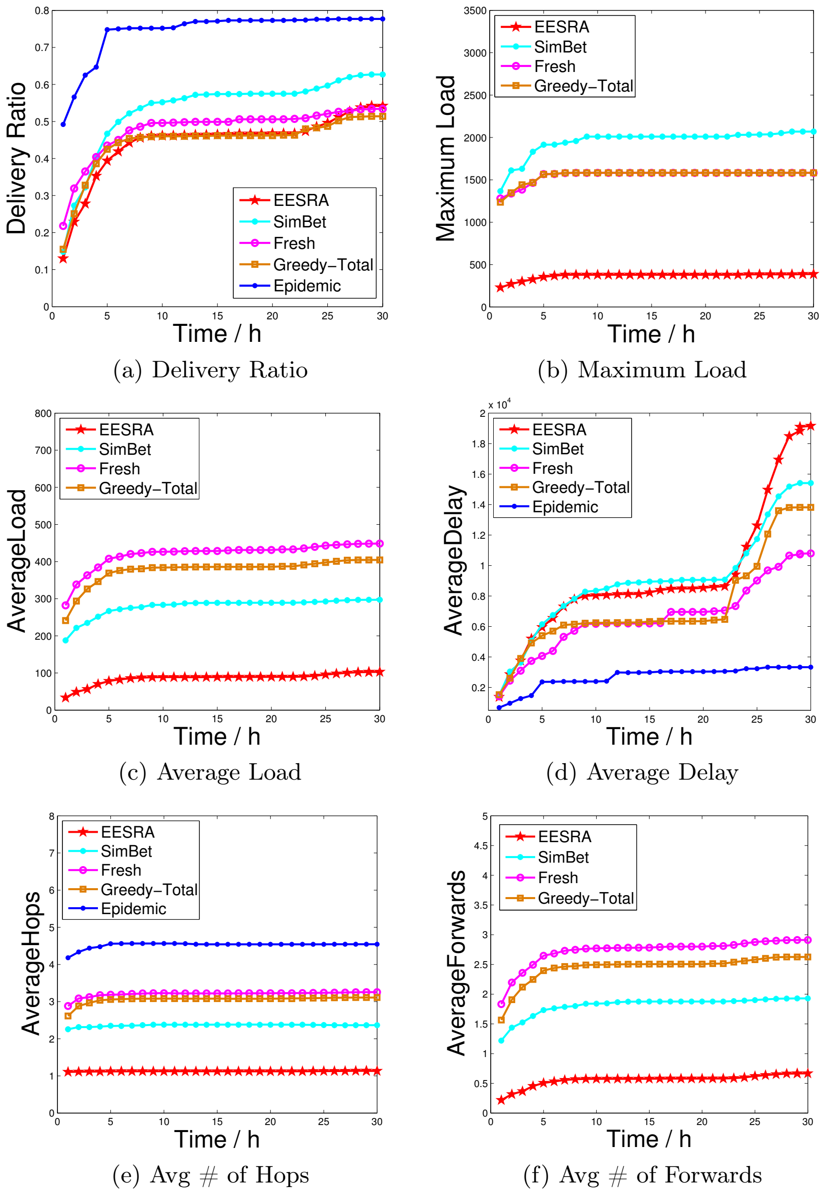
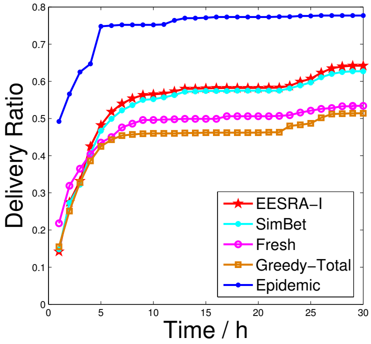
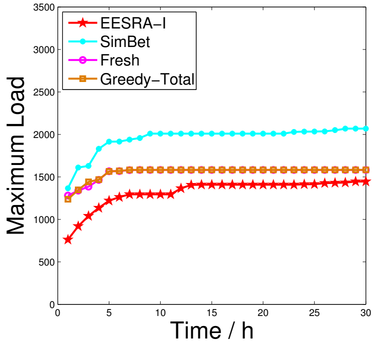


Fig. 2. Simulation Results of EESR over InfoCom 2006 trace data

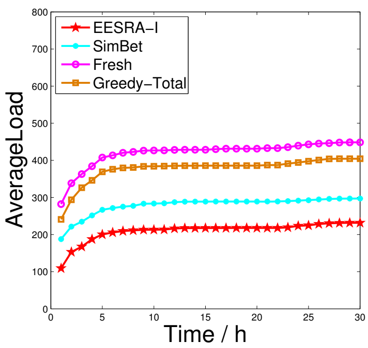
in Table 2, which demonstrates that our proposed EESR and EESR-I can also limit the variation range of the load. Overall, EESR and EESR-I can reduce the energy consumption while maintaining the similar or even better delivery ratio with the original social based routing. By carefully selecting the parameters, EESR-I can find a balance between load reduction and high delivery ratio.



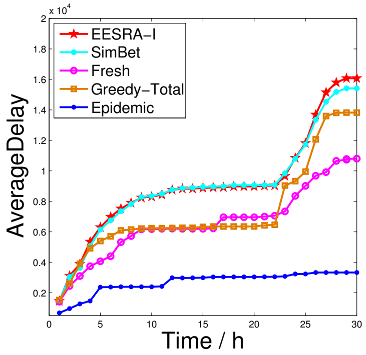
(a) Delivery Ratio



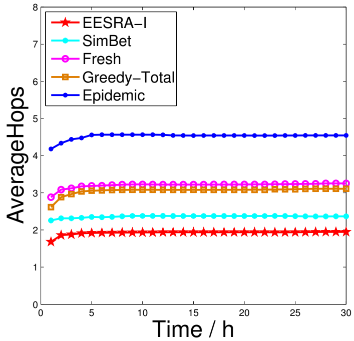
(b) Maximum Load



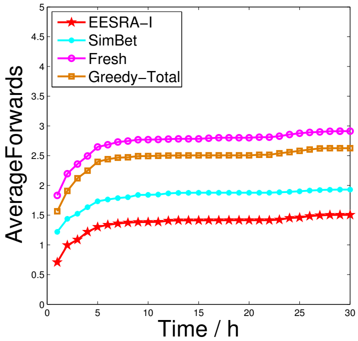
(c) Average Load



(d) Average Delay



(e) Avg # of Hops



(f) Avg # of Forwards

Fig. 3. Simulation Results of EESR-I over InfoCom 2006 trace data

Table 2. Standard Deviation of Loads for Different Routing Methods

Method	Standard Deviation of Load
EESR	64.84
EESR-I	209.95
SimBet	325.97
Fresh	374.85
Greedy-Total	327.16
Epidemic	3,994.94

5 Conclusion

Delay tolerant networks are partitioned wireless ad hoc networks which usually cannot guarantee end-to-end paths between any pair of nodes. Routing in DTNs is a challenging problem. Many social-based routing protocols are proposed to improve the delivery ratio over time, but most of them do not consider the load of nodes. In this paper, we propose an energy efficient social-based routing method to reduce the load of nodes. The proposed general scheme can be applied to any existing social-based routing methods which use social metric per node for relay selection. Simulation results over real-life data traces demonstrate the efficiency of our proposed method.

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