Closeness-based Routing with Temporal Constraint for Mobile Social Delay Tolerant Networks

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***Abstract*—In mobile social delay tolerant networks, many human-carried mobile devices are moving around in a restricted physical space and occasional contact opportunities among these devices are used to deliver data. Routing design in mobile social delay tolerant networks has been a challenging task due to lack of instantaneous end-to-end paths, large transmission delays, and time-varying network topology. In this paper, aiming to precisely measure the social relationships between mobile nodes, we introduce two kinds of time-varying closeness, direct and indirect closeness, where the temporal constraint is considered. Then we propose both single-copy and multi-copy closeness-based routing schemes, which consider direct and indirect social relationships under temporal constraint. Extensive simulations on real-life data traces show the proposed schemes can achieve better performances than existing DTN routing methods.**

I. Introduction

Delay Tolerant Networks (DTNs) are designed for challenging networks suffering from long end-to-end delays and frequent network partitions [1]. Among many applications of DTNs [2], [3], mobile devices (such as smartphones) are carried by humans and form a mobile social network via occasional contact opportunities. This kind of networks can be called *mobile social DTNs*, which have become an emerging new topic in networking research. In mobile social DTNs, contemporaneous end-to-end paths may never exist, thus traditional ad hoc routing schemes cannot be directly applied. Recently, there are many DTN routing schemes proposed to tackle this challenging problem. Most of the existing schemes adopt the "store, carry and forward" strategy, in which nodes store the packets in their buffers if there is no opportunity for message forwarding and wait for future opportunities. Then the key problem is how to select an appropriate relay node for message forwarding during encounters.

The simplest solution for DTN routing is to give every encountered node a copy of the message, as Epidemic [4] does. However, this approach suffers from huge overheads. To overcome this issue, some routing methods limit the number of copies of a message to a certain constant (such as [5]), while many routing methods aim to carefully choose the relay nodes during encounters. To make the right relay selection, designing a good metric to measure the ability of nodes to deliver the message is essential. Existing methods use historical encounter information [6]–[8], mobility information [2], [9]–[11], or social properties [12]–[15] to define different metrics. During any encountering, the node with higher metric becomes the relay node. Recent studies show that social-based approaches [16] can usually achieve nice performances in mobile social DTNs, since social relationships among people are more stable and easy to maintain. In social-based methods, nodes with higher social activity (measured by centrality [12]–[14], social energy [15], etc.) or closer relationship with the destination (measured by similarity [12], community [13], etc.) are valued with higher metric values. However, how to accurately measure the social activity of a node and the social relationship between nodes is still a challenging task.

In this paper, we propose a new routing scheme with temporal constraint for mobile social DTNs: *Closeness-based Routing* (CBR), by considering the closeness between nodes. We first introduce two types of closeness in Section III: direct closeness and indirect closeness to describe the pair-wise relationship between nodes. The new types of closeness also consider the chances of future encounters under certain temporal constraint. By using this closeness concept, our routing scheme (Section IV) can pick either one or multiple relays smartly to elevate the average packet delivery ratio with a given required TTL constraint. For the multi-copy case, we propose a packet allocation method to share multiple copies among encountering nodes in order to maximize the estimated joint delivery probability. Simulations over two real-life tracing datasets are used to evaluate the proposed method in Section V.

II. Models and Assumptions

Assume the network has n nodes, $v_1, v_2, \cdots, v_n$. When a packet M_q is generated at the source node, it has one destination node v_{D_q} in the network and a *Time To Live* (TTL_q) value as the temporal constraint. This packet needs to be delivered to its destination before the TTL elapses. Hereafter, we use data packet, packet and message interchangeably. Note that here the unit of TTL is unit time slot instead of per hop as in IP protocols. Both *single-copy* and *multi-copy* routing schemes are considered. For single-copy routing scheme, only one copy of each packet is allowed in the whole network,

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while the multi-copy routing scheme allows multiple copies of a packet existing in the network at the same time. The maximum number of copies is bounded by a constant l_{max}. It is obvious that increasing the number of copies can lead to a higher delivery ratio but also higher overhead in the network.

In addition, we also have the following common assumptions on the contacts among nodes in a mobile social DTN. 1) Contacts between a node pairs are symmetrical and sufficient for transferring all buffered packets, which means during a contact between v_i and v_j, either one of them can transfer any packets to the other. 2) The contact process between each node pair of v_i and v_j follows a a homogeneous Poisson process with a constant contact rate λ_{ij}. This assumption has been widely used in mobile social DTNs recently [3], [18] and also been verified by real tracing data [14], [17]. 3) Each node has unlimited buffer size.

III. Time-varying Closeness

In this section, we introduce two types of closeness among nodes, *direct closeness* and *indirect closeness*, both of which will be used by our closeness-based routing methods.

A. Direct Closeness

We define *Direct Closeness* (DC), a pairwise metric, to describe the direct social relationship between two nodes. The larger the DC value is, the higher probability that these two nodes will meet each other in the near future. As we assume that the contact process between nodes follows Poisson process, the possibility that node v_i and node v_j contact k times during Δt of time can be calculated as follows:

$$p = \frac{(\lambda_{ij}\Delta t)^k e^{-\lambda_{ij}\Delta t}}{k!}. \quad (1)$$

The DC metric between nodes v_i and v_j is defined by the probability that v_i and v_j contact at least once within time Δt, i.e.,

$$DC_{i,j}(\Delta t) = 1 - e^{-\lambda_{ij}\Delta t}. \quad (2)$$

To calculate DC, v_i and v_j have to know the value of λ_{ij}. This can be obtained from the historical contacts. Each node will keep records of the contact rates with all its neighbors. The contact rates λ_{ij} can be stable or dynamic over time, depending on mobile networks. Periodical evaluations and updates may be needed in dynamic scenarios.

DC is also time-varying (varies with the value of Δt). This is critical for routing with temporal constraint. Time-varying DC allows us to measure the pairwise social relationship more precisely for different packets at different time. Notice that our definition of DC is different from the cumulative contact probability defined in [14], [17]. We focus on the social relationship between each node pair, while they care about the node's ability to contact with all other nodes. Table I summarizes some notations used in this paper.

TABLE I
NOTATIONS USED

Symbols	*Meanings*
n	total number of nodes
v_i	node i
M_q	q-th data packet
v_{D_q}, TTL_q	destination and value of Time To Live of M_q
$\lambda_{i,j}$	contact rate between v_i and v_j
$DC_{i,j}(t)$	DC between v_i and v_j with time t
$IC_{i,j}(t)$ ($IC_{i,k,j}(t)$)	IC between v_i and v_j with time t(via v_k)
l_{max}, l_q	maximum & current numbers of copies of M_q
X_a	indicator of whether v_a is selected as a potential relay
$p^{l_q}_{i,D_q}(TTL_q)$	probability that v_i delivers M_q to v_{D_q} before TTL_q with l_q copies
$EJDP^{l_q}_{i,j}(D_q, k, TTL_q)$	EJDP when v_i and v_j carrying k and $l_q - k$ copies of M_q, respectively

B. Indirect Closeness

We also consider *Indirect Closeness* (IC) between nodes v_i and v_j, where 2-hop social relationships are considered. In other words, the closeness between v_i and v_j may consider combining the closeness between v_i and v_k and the closeness between v_k and v_j for all v_k.

Consider such a 2-hop scenario, node v_k ($k \neq i, j$) is out of v_i's communication range at the current time. Assume after t_1 units of time, v_k encounters v_i. Then after another t_2 units of time, v_k encounters v_j. The *IC* between v_i and v_j via v_k within Δt can be cacluated as follows:

$$\begin{aligned} & IC_{i,k,j}(\Delta t) = \mathcal{P}(t_1 + t_2 \leq \Delta t) \\ & = \int_0^{\Delta t} f_1(x) \otimes f_2(x) dx \\ & = \int_0^{\Delta t} dx \int_0^{x} f_1(\tau) \cdot f_2(x-\tau) d\tau \\ & = \int_0^{\Delta t} dx \int_0^{x} \lambda_{ik} e^{-\lambda_{ik}\tau} \cdot \lambda_{kj} e^{-\lambda_{kj}(x-\tau)} d\tau \\ & = \begin{cases} 1 - [1 + \lambda_{ik}\Delta t] e^{-\lambda_{ik}\Delta t}, & \lambda_{ik} = \lambda_{kj} \\ 1 + \dfrac{\lambda_{kj} e^{-\lambda_{ik}\Delta t} - \lambda_{ik} e^{-\lambda_{kj}\Delta t}}{\lambda_{ik} - \lambda_{kj}}, & others, \end{cases} \end{aligned} \quad (3)$$

where $f_1(x)$ and $f_2(x)$ are the probability density functions of variables t_1 and t_2, respectively, and $\otimes$ is the symbol of convolution function. Then the *IC* between v_i and v_j is defined as follows:

$$IC_{i,j}(\Delta t) = \max_{k \neq i,j} IC_{i,k,j}(\Delta t). \quad (4)$$

Again, IC is time-varying (related to the value of Δt).

Notice that if v_i has to calculate the value of IC, v_i needs to know not only λ_{ik} but also λ_{kj}. Therefore, to obtain such information (λ_{kj}) outside v_i's range, any two encountering nodes also need to exchange their contact rate table (including contact rates to all other nodes in the network). By doing so, each node can calculate its IC locally.

IV. Closeness-based Routing (CBR)

In this section, we describe our closeness-based routing (CBR) schemes under temporal constraint. We introduce two versions: one single copy and the other multi-copy.

A. Single Copy CBR

Assume that the pairwise contact rates can be obtained from the historical contact information. The contact rate table of each node which records the contact rates between the node itself and all other nodes in the network is initialized. When node v_i, which carries a set of data packets $\mathbb{S} = \{M_1, M_2, ...\}$, encounters with another node v_j, CBR routing scheme is triggered and performs the following steps. First, if v_i and v_j haven't met before, they exchange their contact rate table mutually for the purpose of IC calculation. Then, for each packet $M_q \in \mathbb{S}$, v_i determines whether to deliver it to v_j or not. If v_j happens to be the destination of M_q, v_i delivers M_q to v_j (i.e., v_{D_q}) directly. Otherwise, CBR needs both encountering nodes to calculate their DCs and ICs with v_{D_q} for M_q. Firstly, v_i lets v_j know the destination of M_q. Assume TTL_q is the remaining of TTL of M_q. Then v_i calculates $DC_{i,D_q}(TTL_q)$ and $IC_{i,D_q}(TTL_q)$, and v_j calculates $DC_{j,D_q}(TTL_q)$ and $IC_{j,D_q}(TTL_q)$ simultaneously. Let $R_i = \max(DC_{i,D_q}(TTL_q), IC_{i,D_q}(TTL_q))$ and $R_j = \max(DC_{j,D_q}(TTL_q), IC_{j,D_q}(TTL_q))$. After that v_j sends R_j to v_i, if $R_j > R_i$, v_i delivers M_q to v_j. Otherwise, v_i keeps holding M_q and waits for another contact. Notice that $R_j > R_i$ shows v_j has a closer social relationship with v_{D_q} than v_i before M_q dies out, either directly or indirectly. Algorithm 1 gives the detailed CBR scheme.

Algorithm 1 Single Copy CBR

When node v_i with a set of data packets $\mathbb{S} = \{M_1, M_2, ...\}$ encounters v_j,

```
if v_i hasn't met v_j before then
    v_i and v_j exchange their contact rate tables
for each M_q ∈ S do
    if v_j = v_{D_q} then
        deliver M_q to v_j (i.e. v_{D_q})
    else
        v_i sends the destination of M_q (i.e. v_{D_q}) to v_j
        v_i and v_j calculate R_i and R_j, respectively, where
            R_i = max(DC_{i,D_q}(TTL_q), IC_{i,D_q}(TTL_q)),
            R_j = max(DC_{j,D_q}(TTL_q), IC_{j,D_q}(TTL_q)).
        v_j sends R_j to v_i
        if R_j > R_i then
            v_i delivers M_q to v_j
        else
            v_i continues to hold M_q
```

B. Multi-Copy CBR

In order to elevate the performance of CBR routing, we allow that there can be up to l_{max} copies of a message M in the network. It is obvious that the more redundant copies of packets may lead to a higher delivery ratio. However, it can also cause congestions and waste nodes' resources or energy. Therefore, there is a trade off between the value of l_{max} and the performance. In multi-copy CBR, we add a packet counter for each packet M_q to indicate how many copies of M_q are hold by the node. When the source generates a packet, it sets the packet counter to be l_{max}. When the packet counter is reduced to 0, the local copy has to be deleted.

Assume that v_i has a set of messages $\mathbb{S} = \{M_1, M_2, ...\}$ in its buffer. The probability that v_i can deliver $M_q \in \mathbb{S}$ to its destination node v_{D_q} before TTL_q expires is estimated as:

$$p^{l_q}_{i,D_q}(TTL_q) = \max_{\textit{all valid } X^i_a \textit{ combinations}} \{1 - [1 - DC_{i,D_q}(TTL_q)X^i_i] \cdot \prod_{k \neq i, D_q} [1 - IC_{i,k,D_q}(TTL_q)X^i_k]\}, \tag{5}$$

where l_q is the value of M_q's packet counter and $X^i_a \in \{0, 1\}$ represents whether node v_a is selected to be a potential relay node by v_i. Here we define $X_{D_q} = 0$. As the packet counter is l_q, we request that the valid X_a combination must have $\sum_{a=1}^{n} X^i_a = l_q$. The formula in the braces is the possibility that at least one of the l_q relay nodes can deliver the message M_q to the destination before its TTL_q expires. When calculating $p^{l_q}_{i,D_q}(TTL_q)$, v_i just has to calculate $\mathbb{R}_i$ where $\mathbb{R}_i$ is the l_q largest values in $\{DC_{i,D_q}(TTL_q), IC_{i,k,D_q}(TTL_q)\}(k \neq i, D_q)$. Elements in $\mathbb{R}_i$ can then be used for calculation in Equation (5) instead of enumerating all the cases.

Now we are ready to describe our multi-copy routing scheme. First, we introduce a key concept: *Estimated Joint Delivery Probability* (EJDP).

Definition 1: **Estimated Joint Delivery Probability** is the largest probability that at least one of the two encountering nodes successfully delivers M_q to its destination v_{D_q} before TTL_q expires under certain packet allocation strategy.

If v_i encounters v_j and they altogether can share l_q copies of M_q, we can calculate the EJDP when allocating k copies to v_i and $l_q - k$ copies to v_j. Intuitively, this could be given by

$$EJDP^{l_q}_{i,j}(D_q, k, TTL_q) = 1 - [1 - p^k_{i,D_q}(TTL_q)] \cdot [1 - p^{l_q-k}_{j,D_q}(TTL_q)], k = 0, \cdots, l_q. \tag{6}$$

However, this is not correct, since v_i and v_j may select the same node as the relay node which makes $p^k_{i,D_q}(TTL_q)$ and $p^{l_q-k}_{j,D_q}(TTL_q)$ dependable. See Fig. 1 for such an example. Assume $l_q = 6$ and $k = 3$, the best choice v_i can make at the present time is to deliver 2 copies of M_q to v_a and v_b in the future and keep 1 copy for itself. In this case, v_i can deliver M_q to v_{D_q} with the maximal probability. Correspondingly, $\mathbb{R}_i = \{DC_{i,D_q}(TTL_q), IC_{i,a,D_q}(TTL_q), IC_{i,b,D_q}(TTL_q)\}$ and they are used for calculating $p^3_{i,D_q}(TTL_q)$. Meanwhile, the calculation of $p^3_{j,D_q}(TTL_q)$ also uses $IC_{j,b,D_q}(TTL_q)$. In this case $p^3_{i,D_q}(TTL_q)$ and $p^3_{j,D_q}(TTL_q)$ are not independent

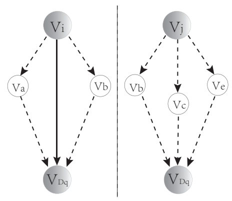


Fig. 1. An example of dependent potential routes in multi-copy CBR.

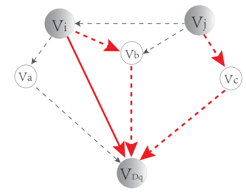


Fig. 2. Illustration of packet allocation rule in multi-copy CBR.

from each other, and we cannot simply multiply them to calculate the EJDP. Note that nodes picked by Equation (5) are all potential relay nodes. Although $IC_{i,b,D_q}(TTL_q)$ is in $\mathbb{R}_i$ now, we do not necessarily force v_i to forward M_q to v_b if it has a better choice in the future. To complete the definition of *EJDP*, for each $a = 1, 2, ..., n$, Equations (5) and (6) subject to:

$$X_a^i \cdot X_a^j \neq 1,$$

which means that the same relay cannot be selected by both nodes.

The main reason of above problem is that the encountering nodes do not know each other's choices about the potential relay nodes in Equation (5). Therefore, we design a *Information Exchange Process* (IEP) to tackle this problem. First, v_i negotiates with v_j in order to select a leader to perform the coordination task (according to their remaining energy, computing power, or IDs.). If v_i is the leader and decides how to route M_q to v_{D_q}, v_j needs to give v_i the value of its packet counter of M_q. v_i then knows they have altogether l_q copies of M_q and it sends the value of l_q back to v_j. v_j selects l_q largest values in $\mathbb{R}_j$ and sends the results along with the potential relay node IDs to v_i. Then the problem mentioned above can be solved.

We further describe our *Packet Allocation Process* (PAP), which aims to find the packet allocation maximizing the EJDP. After IEP, v_i now has every thing and can use the following greedy method to allocate l_q copies of the packet. For the set $\mathbb{R}$ where $\mathbb{R} = \mathbb{R}_i \cup \mathbb{R}_j$, if any of the following cases happens:

1) both $DC_{i,D_q}(TTL_q)$ and $IC_{j,i,D_q}(TTL_q)$ are in $\mathbb{R}$;
2) both $DC_{j,D_q}(TTL_q)$ and $IC_{i,j,D_q}(TTL_q)$ are in $\mathbb{R}$;
3) both $IC_{i,k,D_q}(TTL_q)$ and $IC_{j,k,D_q}(TTL_q)$ are in $\mathbb{R}$,

eliminate the smaller one in each pair of the two values. Then IEP chooses the l_q largest values in $\mathbb{R}$. We denote the result set as $\mathbb{R}'$. Finally, v_i resets its packet counter of M_q to $|\mathbb{R}' \cap \mathbb{R}_i|$ and sends a request to reset v_j's packet counter of M_q to $|\mathbb{R}' \cap \mathbb{R}_j|$. For example, suppose that v_i is encountering with v_j and they carry $l_q = 3$ copies of M_q. $\mathbb{R}_i = \{DC_{i,D_q}(TTL_q), IC_{i,a,D_q}(TTL_q), IC_{i,b,D_q}(TTL_q)\}$, $\mathbb{R}_j = \{IC_{j,i,D_q}(TTL_q), IC_{j,b,D_q}(TTL_q), IC_{j,c,D_q}(TTL_q)\}$. Fig. 2 illustrates such an example. As $DC_{i,D_q}(TTL_q)$, $IC_{i,b,D_q}(TTL_q)$ and $IC_{j,c,D_q}(TTL_q)$ are the top 3 largest values in $\mathbb{R}$, according to PAP, v_i keeps 2 copies while v_j keeps only 1 copy.

Algorithm 2 shows the overall framework of multi-copy CBR scheme.

Algorithm 2 Multi-Copy CBR

When node v_i encounters with v_j with a set of packets $\mathbb{S} = \{M_1, M_2, ...\}$ in their buffers,

```
if v_i hasn't met v_j before then
    v_i and v_j exchange their contact rate tables
for each M_q ∈ S do
    if v_i = v_{D_q} or v_j = v_{D_q} then
        deliver M_q to v_{D_q}
    else
        v_i and v_j exchange information via Information Exchange Process (assume that v_i is the selected leader)
        v_i decides the packet allocation according to the Packet Allocation Process and notifies v_j
        if only v_i or v_j holds M_q then
            deliver M_q to the node without M_q's copy
        v_i and v_j reset the packet counter of M_q in their buffers based on the allocation
```

V. Simulation Results

Extensive simulations have been conducted with real life DTN traces to evaluate the proposed CBR schemes. We compare with the following existing DTN routing methods.

- **Epidemic** [4]: a flooding approach where data duplication and forwarding happen as long as two nodes meet and only one of them has copies of the data packet.
- **Greedy** [6]: a greedy routing which prefers nodes with higher average contact rate with the destination as relays.
- **Greedy-Total** [6]: a greedy routing method which prefers nodes with higher average contact rates with all other nodes in the network as relays.
- **SimBet** [12]: a social-based routing where each node's transmission ability is assessed by its centrality in the network and its similarity with the destination node, and defined as a joint utility. The message is sent or kept by the node with larger utility value during any encounters.
- **PRoPHET** [8]: a probabilistic routing which updates the transmission probability of node v_i and v_j every time when they encounters. At the same time, the "transitive" transmission probability and aging are considered. Nodes with higher transmission probability to the destination are preferred as relays.

Four metrics are used to evaluate the routing performance: 1) *Delivery Ratio:* the ratio between the number of successfully delivered messages and the number of total generated messages. 2) *Average Delay:* the average delay of all successfully delivered messages. 3) *Average Hops:* the average number of relay nodes used by successfully delivered messages. 4) *Average Number of Forwardings:* the average number of forwardings during the routing phase. Among the above metrics, the last considers all messages forwardings no matter they are successfully delivered to the destination or not, while the first three ignore the messages failed to be delivered to their destinations before TTL elapses.

We conduct our simulations over two real-life datasets:

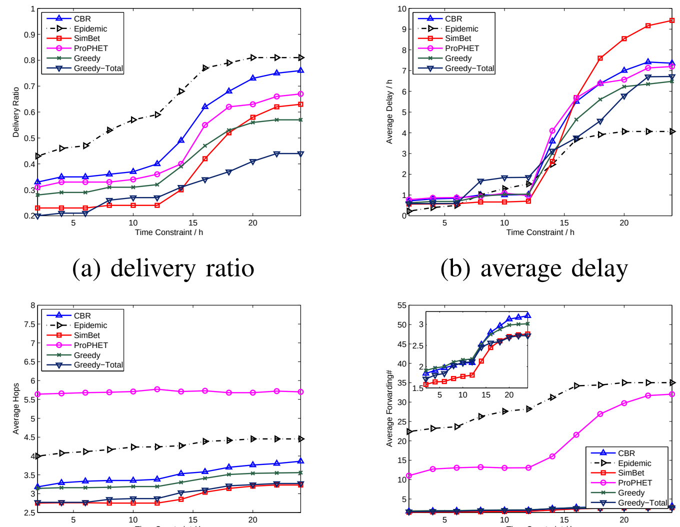
- **InfoCom 2006 Bluetooth** [19]: Bluetooth scanning logs collected from 78 participants in InfoCom 2006 which last 4 days. We can extract encounter information, including node IDs, connect and disconnect time etc., from the records. The records from $93,600$s to $180,000$s(24 hours) are used as our training data and the records from $180,000$s to $266,400$s(another 24 hours) are used for testing of proposed routing methods.
- **MIT Reality Mining** [20]: data collected from 100 mobile phone users over the course of 9 months (September 2004 to June 2005) at MIT. The dataset includes the participants' message and phone call history, Bluetooth discovery records, answers of a survey etc. We again extract encounter information based on Bluetooth records. The data in March 2005 is used as training set and the data from April 2005 is used for testing.

In all simulations, we assume all-to-all communication scenarios, in which each node sends a packet to all other nodes in the network. For simplicity, all packets are set with the same initial value of TTL.

A. Performance of Single Copy CBR

1) InfoCom06 Dataset: Fig. 3 shows the results of all routing methods. The x-axis in each figure represents the value of TTL in each round of simulations. Clearly, relaxer time constraint (larger TTL) can lead to better delivery ratios. From Fig. 3(a), the proposed single-copy CBR outperforms other routing protocols except for Epidemic. Notice that Epidemic offers the upper bound of the delivery ratio that any routing protocol can achieve. Although Greedy and Greedy-Total also take advantage of contact rate, their delivery ratios are still unsatisfactory. On the contrary, the proposed CBR uses DC and IC to estimate the social relationship between nodes, which also takes the advantage from more accurate modeling of the contact process of nodes. Regarding to the other metrics, as shown in Fig. 3(b)-(d), single copy CBR can still achieve competitive performance. As expected, Epidemic and ProPHET have large number of forwarding. Note that Epidemic does not have the lowest average delay in Fig. 3(b), this is mainly due to only successfully delivered messages are considered for average delay. Since Epidemic delivers much more messages successfully, longer average delay is possible.

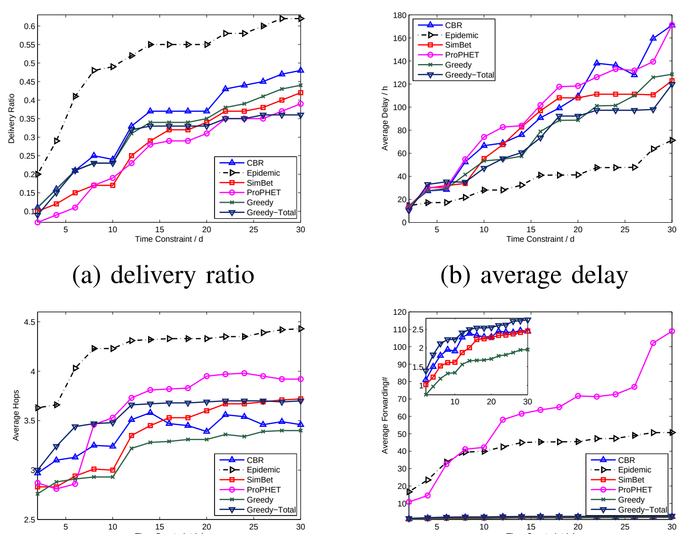
2) MIT Dataset: By leveraging the richer data from MIT dataset, we use one month data for routing simulations. Fig. 4 shows the simulation results. Similar trends with those in InfoCom data can be observed. The delivery ratios are smaller compared with those in InfoCom data, since contacts in MIT dataset is sparser than contacts in InfoCom dataset within the same time constraint.



(a) delivery ratio (b) average delay

(c) average hops (d) number of forwardings

Fig. 3. Simulation results of all different routing algorithms (over InfoCom 2006 data set) with single copy of message.



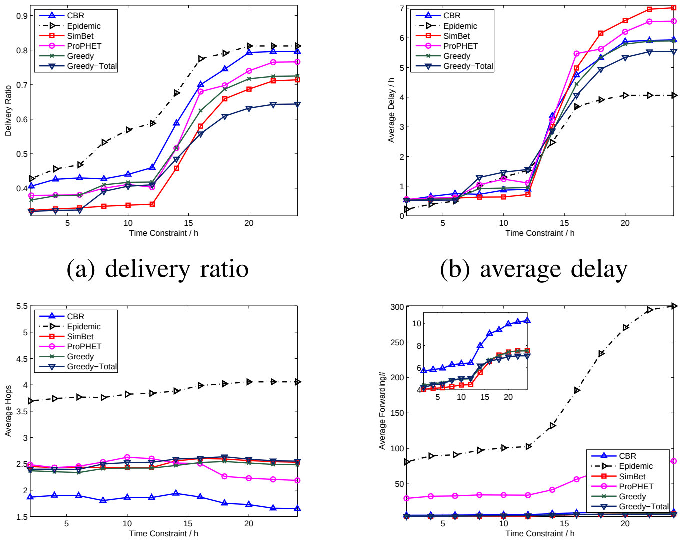
(a) delivery ratio (b) average delay

(c) average hops (d) number of forwardings

Fig. 4. Simulation results of all different routing algorithms (over MIT data set) with single copy of message.

B. Performance of Multi-Copy CBR

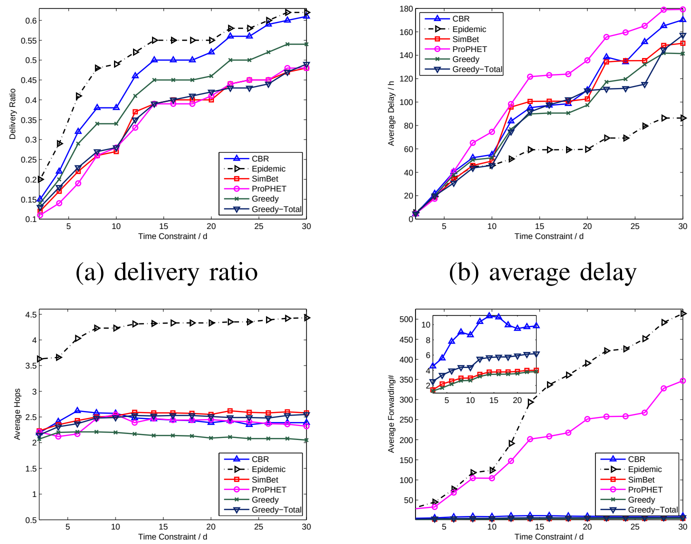
In order to compare our proposed multi-copy CBR with other routing methods, we implement the multi-copy versions of them. For SimBet, when node v_i carrying k messages encounters node v_j, according to their SimBet utility $SimBetUtil_i$ and $SimBetUtil_j$, v_i and v_j keep $\frac{SimBetUtil_i}{SimBetUtil_i+SimBetUtil_j} \cdot k$ and $\frac{SimBetUtil_j}{SimBetUtil_i+SimBetUtil_j} \cdot k$ copies of messages respectively. For other methods, if the forwarding decision is made, half of the data copies are



(a) delivery ratio (b) average delay

(c) average hops (d) number of forwardings

Fig. 5. Simulation results of all different routing algorithms (over InfoCom 2006 data set) with 3 copies of message.



(a) delivery ratio (b) average delay

(c) average hops (d) number of forwardings

Fig. 6. Simulation results of all different routing algorithms (over MIT data set) with 3 copies of message.

transmitted to the encountered node. We fix the number of copies to l_{max} for all routing. Our experiments show that similar results can be obtained with different values of l_{max}. Due to space limit, we only present the results when $l_{max} = 3$.

1) InfoCom Dataset: Fig. 5 shows the simulation results on InfoCom dataset. Fig. 5(a) confirms that our multi-copy CBR can achieve delivery ratio close to that of Epidemic. With more copies of messages in the network, the average delivery ratio, delay and hops of all routing algorithms are better comparing with those in the single copy case. At the same time, the number of forwarding becomes worse as more copies are used. Similar results can be obtained when the number of allowed packet copies is set to be other values.

2) MIT Dataset: Simulation results on MIT dataset are shown in Fig. 6. The conclusions obtained are similar to those above in InfoCom dataset.

VI. Conclusion

In this paper, we study the unicast routing with temporal constraint in mobile social DTNs. By introducing two kinds of time-varying closeness, direct closeness and indirect closeness, the proposed closeness-based routing (CBR) schemes consider both current and future forwarding opportunities. Extensive simulations on real data traces show that both single-copy and multi-copy CBR can achieve satisfactory performances.

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