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Proficient Friendship Based Routing in Delay Tolerant Mobile Social Networks

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Abstract— Delay Tolerant Networks are a class of wireless networks where the connection between the nodes changes frequently. It is not possible to find a path from source to destination at any time instance, thus long and variable delays occur in routing of messages. Mobile Social Network is a delay tolerant network in which there is a frequent absence of end-to-end path for any source-destination pair, due to the intermittent connectivity between nodes. To solve the intermittent connectivity problem that arises between the nodes in delay tolerant network a new metric which detects the quality of friendship between the nodes is introduced. Using the metric, each node defines its friendship community as the set of nodes having close friendship with itself either directly or indirectly. Then, Friendship Based Routing is used in which temporally differentiated friendships are used to make the forwarding decisions of messages.

Keywords— Delay Tolerant Networks, Mobile Social Networks, routing, efficiency

I. INTRODUCTION

Delay Tolerant Networks (DTN) [1][2], are sparse mobile wireless networks in which the connection between nodes changes over time and it is usually not possible to find path from source to destination at any time instance. Among many real life examples of such networks, mobile social networks (MSN) (called also pocket switched networks) are of growing significance as a result of the rapid and wide spread usage of different kinds of devices (e.g., cell phones, GPS devices) with wireless capabilities among people and their surroundings. Since mobile social networks has the potential of collaborative data gathering via already deployed and human maintained devices, opportunistic routing of messages in these networks has attracted a great interest recently. However, due to the intermittent connectivity and lack of continuous end-to-end path between the nodes, routing is a challenging problem in these networks. To ease these difficulties and enable nodes to give better forwarding decisions through routing, inherent social network properties of these networks have been utilized. The connectivity (opportunity for message transfers) between human-carried devices is achieved when they get into the range of each other. Thus, the relationship defining the frequency and duration of the connectivity between nodes has to be analyzed to route messages efficiently. For example, consider a high school network. Students in the same class have higher chance to see (so also to transfer data to) each other than the students from other classes that can meet only during breaks.

In this paper, utilizing the social network Features of an MSN, we present Friendship Based Routing. To analyze social relations between nodes (i.e. people), we need to define their friendships in terms of their behaviour. For this purpose, we define a new metric measuring different aspects of friendship behaviour recorded in the history of their encounters with other nodes. We consider both direct and indirect friendship. We also differentiate friendships according to time of day and propose to use different friendship communities in different time periods.

The rest of the paper is organized as follows. In Section II a brief overview of previous work is presented. In Section III the detailed design of proposed algorithm is described.

II. RELATED WORKS

In the previous studies, several routing algorithms have been introduced for DTNs based on different techniques (multi-copy based [3]-[5], single-copy based [6]-[8], erasure coding based [9]-[11]). Besides these studies, most of which assume simplistic random mobility models such as rando m walk, many recent studies have focused on DTNs consisting of human- carried devices (we call them MSN) and tried to analyze the social network properties of these networks to aid the design of efficient routing algorithms. In [12], Daly et al. use both the betweens and the similarity metric to increase the performance of routing. In each contact of two nodes, the utility function containing these two metrics is calculated for each destination, and then the node having higher utility value for a destination is given the messages. In [13], each node is assumed to have two rankings: global and local. While the former denotes the popularity (i.e. connectivity) of the node in the entire society, the latter denotes its popularity within its own community. Messages are forwarded to nodes having higher global ranking until a node in the destination's community is found. Then, the messages are forwarded to nodes having higher local ranking. Then, the messages are forwarded to nodes kinds of encountered nodes. In [15], a community-based epidemic forwarding scheme is presented. First, it efficiently detects the community structure using local information of nodes. Then, it forwards the message to each community through gateways.

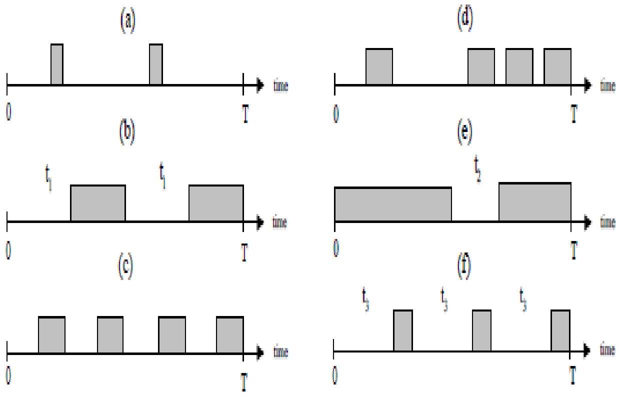

Fig. 1. Six different encounter history between nodes i and j in the time interval [0, T]. Shaded boxes show the encounter durations during which the nodes are within their communication ranges.

In some other studies several interesting properties of social networks are considered. In [16], irregular deviations from the habitual activities of nodes are addressed and it is shown that worst-case performance of routing can be improved by scattering multiple copies of a message in the network such that even deviant (less frequently encountered) nodes will be close to at least one of these copies. In [17], the effect of socially selfish behaviour of nodes on routing is studied.

In this paper, we introduce a new routing algorithm different from all above studies. First, we define a new metric to understand relations between nodes more accurately. Second, we propose a local community formation based on this new friendship detection metric. We use not only direct relations but also indirect ones in a different way than it was considered previously. Third, we introduce a new approach to handle temporal differentiations of node relations. Throughout the presentation of all these features of our design, we show in detail how they differ from the previous work.

III. PROPOSED METHODOLOGY

A. Analysis of Node Relations

Since the nodes in an MSN encounter intermittently, the link quality between each pair of nodes needs to be estimated to learn about the possible forwarding opportunity between nodes. Then, the temporal encounter information between nodes can be condensed to a single link weight and the neighbouring graphs of nodes can be constructed.

Previously, several metrics, including encounter frequency, total or average contact period and average separation period [15] were used to extract the quality of links between pairs of nodes. However, all these metrics have some decencies in the accurate representation of forwarding opportunity between nodes. For example, consider the six different encounter histories of two nodes, i and j in Figure 1. Shaded boxes show the encounter durations between these nodes in the time interval T . In cases a and b, the encounter frequencies are the same but the contact between the nodes last longer in case b than in case a. Therefore encounter pattern b offers better forwarding opportunities than a does. Comparing cases b and c, we notice that the contact durations are the same but the encounter frequencies are different. Since frequent encounters enable nodes to exchange messages more frequently, case c is preferable to b for opportunistic forwarding.

Among the previously proposed metrics, encounter frequency fails (to represent the stronger link) in the comparison of cases a and b, and total contact duration fails in the comparison of cases b and c. Although average separation period can assign correct link weights representing the forwarding opportunity in cases a, b and c, it fails in other cases. When we compare cases c and d, both the contact durations and encounter frequencies are the same. However, case c is preferred to d due to the even distribution of contacts. In [15], preference of case c is achieved by utilizing irregularities in separation period as penalty factor. However, deciding on how much it will affect the link quality in different cases is still difficult. Moreover, for the cases such as e an f ,average separation period fails to assign accurate link weights. If t1 = t2 , average separation period cannot differentiate cases b and e but case e is preferable due to its longer contact duration (average separation period can even give preference to case b if t1 is slightly less than t2). Similarly, if t1 = t3 , average separation period cannot differentiate cases b and f even though case b offers better forwarding opportunity.

To find a better link metric that reflects the node relations more accurately, we have considered the following three behavioural features of close friendship: high frequency, longevity, regularity. That is, to be considered friends of each other, two nodes need to contact frequently, their contacts must be long lasting and regular. Note that frequency and regularity are different. Two nodes may meet infrequently but regularly (for example, once a week) and still be considered friends. This is of course a weaker friendship than the one with contacts both frequent and regular. The previous metrics take into account some of these features but not all of them at the same time. To account these properties in one metric, we introduce a new metric called social pressure metric (SPM) that may be interpreted as a measure of a social pressure that motivates friends to meet to share their experiences. In our setting, this amounts to answering the question ‘what would be the average message forwarding delay to node j if node i has a new message destined to node j at each time unit? Then, we define the link quality ($w_{i,j}$) between each pair as the inverse of this computed value.

More formally:

$$SPM_{i,j} = \frac{\int_{t=0}^{T} f(t)dt}{T} \text{ and } w_{i,j} = \frac{1}{SPM_{i,j}}$$

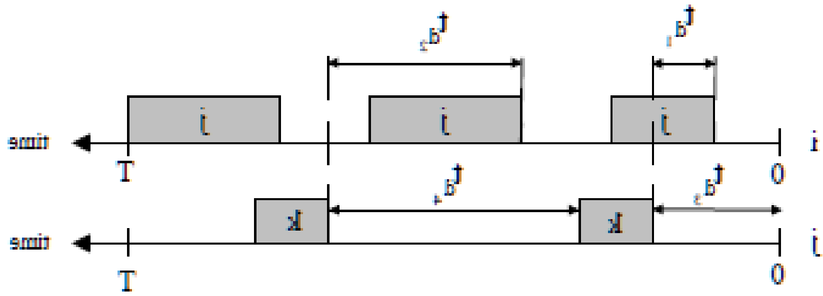

Fig. 2. Encounter history between node i and j(upper) and between j and k(lower) in the same time interval[0,T].

B. Friendship Community Formation

Each node can compute its link qualities ($w_{i,j}$) with other nodes from its contact history. Then, it can define its friendship community as a set of nodes with link quality with itself larger than a threshold (τ). But this set will include only direct friends. However, two nodes that are not close friends directly (they even may not have contacts at all) still can be close indirect friends. This happens if they have a very close friend in common so that they can contact frequently through this common friend. To find such indirect friendships between nodes, we propose to use conditional SPM (or simply CSPM) between nodes. Consider the sample encounter history in Figure 2. While the upper one shows the contacts between nodes i and j, the lower one shows the contacts between nodes j and k. We define $CSPM_{j,k|i}$ as the average time it takes node j to give node k the message received from node i.

Note that the introduced method for detecting the indirect strong links between nodes is different than previous approaches (transitivity) which basically consider the links between node pairs separately and assume a virtual link between node i and k if $w_{i,j}\ w_{j,k} > \tau$. However, in our model we can detect indirect relations more accurately. For example, if node j has a weak link with node k, $w_{i,j}\ w_{j,k}$ may be less than τ . However, if node j usually meets node k in a short time right after its meeting with node i, our metric can still consider node k as a friend of node i.

$$F_i = \{j \mid \omega_{i,j} > \tau \text{ and } i \neq j\} \cup \{k \mid \omega_{i,j,k} > \tau \text{ and } \omega_{i,j} > \tau \text{ and } i \neq j \neq k\}$$

Each node can detect its direct friendships from its own history. To detect indirect friendships, a node needs CSP M values of its friends for its non-contact nodes.

C. Forwarding Strategy

Once each node constructs its friendship community for each period, the forwarding algorithm works as follows. If a node i having a message destined to d meets with node j,it forwards the message to j if and only if node j's current friendship community (in the current period) includes node d and node j is a stronger friend of node d than node i is. It should be noted that even if node j has a better link with node d than node i's has, if node j does not include d in its current friendship community, node i will not forward the message to node j.

We also need to handle period boundary cases which arise when the encounter of two nodes is close to the end of the current period. In such a case, nodes use their friendship communities in the next period. For example, if we use three hour periods for community formation and node i meets node j at 2:45pm, it would be better if the nodes use their communities in the next three hour period (3pm − 6pm) to check whether the destination is included. Since the time remaining in the current period is very limited, using the current communities may lead to wrong forwarding decisions. In our algorithm, we use threshold tb and let the nodes use next period's community information if remaining time to the end of current period is less than tb .

IV. **DISCUSSONS AND FUTURE WORK**

A. Complexity of Introduced Algorithm

Since in the introduced algorithm each node determines its friendship community in each period using mainly its own history, there is no much control message or system maintenance transfers occurring between nodes. The only information (to decide its indirect close friends) that a node needs from its contacts is their CSPM values with its non-contact nodes. However, this information is requested from only close friends of nodes and performed with small size messages compared to data messages. On the other hand, the control message overhead in Prophet and SimBet is significantly higher than in our algorithm, because nodes change their summary vectors during contact times.

B. Number of Periods vs. Performance

Obviously, increasing the number of periods that a day is divided into (thus the local friendship communities each node has) will enable the node to make better forwarding decisions. On the other hand, the cost of computing the friendship communities in each period and also the space required to hold different communities will increase as well. However, as long as this cost could be handled and there is enough space at nodes, better results could be achieved.

C. The Effect of Thresholds
Each node forms its friendship community from nodes with strong links (i.e., with weights larger than a threshold) with itself. Clearly, as the threshold increases (decreases), friend lists of nodes get smaller (bigger) and routing performance of our algorithm changes. Similarly using different tb values can change the routing performance. Therefore, in future work we will look at this issue and try to find optimum values of τ and tb .

V. CONCLUSIONS
The routing problem in mobile social networks is determined. A new metric is used to detect contact relations between nodes accurately based on friendships. A new routing algorithm in which each node forwards their messages to nodes that contain the destination node in their friendship communities. Those friendship communities were differentiated depending on the period of the day in which forwarding is done.

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