Social Contact Probability Assisted Routing Protocol

for Mobile Social Networks

Pitiphol Pholpabu and Lie-Liang Yang

School of ECS, University of Southampton, SO17 1BJ, United Kingdom

Tel: 0044-(0)23-8059 3364, Email: pp1c12,lly@ecs.soton.ac.uk, http://www-mobile.ecs.soton.ac.uk

***Abstract*—This paper concerns the problem of dynamic routing in mobile social networks (MSNs). By exploiting the social characteristics of mobile nodes (MNs) in MSNs, a routing protocol is proposed, which is referred to as the Social Contact Probability assisted Routing (SCPR) protocol. This protocol can efficiently integrate the merits of high delivery ratio, low delivery latency and low resource consumption of the existing Epidemic, Prophet and SimBet protocols for MSNs, while circumventing their shortcomings. The performance of our SCPR protocol and of the above-mentioned other three routing protocols are evaluated in the context of our proposed mobility model, which jointly takes into account of MNs’ social characteristics, including randomness, waypoint and community behaviors.**

这篇论文关注的是在移动社会网络（后文简称 MSNs）中，动态路由的问题。通过研究 MSNs 中社会移动节点（后文简称 MNs）的社会特征，参考基于社交活跃度的路由协议，建立起基于社会活跃度的路由控制协议（后文简称 SCPR）。对比已经存在的 Epidemic 协议、Prophet 协议与 SimBet 协议，SCPR 有效地将高传信率，低延迟损耗与低资源消耗整合，并规避了他们的缺点。SCPR 协议与以上所提到的协议将在我们所提出的移动模型中评估性能，这个模型将 MN的社会属性，包括随机漫步性与通信行为整合在内。

1. INTRODUCTION

Nowadays, most people carry at least a mobile device that employs short-range wireless communication functionalities, such as, IEEE 802.11, Bluetooth, or/and other radio-based solutions. These devices may create cheap infrastructureless networks providing connectivities among mobile devices referred to as mobile nodes (MNs). In these infrastructureless networks, there are scenarios where insufficient number of MNs can be found to form a connected path from some source nodes (SNs) to their corresponding destination nodes (DNs). Thus, the existing routing approaches dependent on connected paths fail to apply in such scenarios. Consequently, sub-category networks have been classified, which include, for examples, delay tolerant networks(DTNs), opportunistic networks (OPNETs) and mobile social networks (MSNs). Specifically, in terms of MSNs, the characteristics of long delay of communications and opportunistic data transmission resulted from short encounters are inherited from DTNs and OPNETs, respectively. However, MSNs make use of the mobility behavior of devices’ carriers as well as their relationship in order to upgrade the routing performance. By exploiting the unique characteristics of MSNs, a number of routing techniques have been developed, which include,such as, LABEL [1], BUBBLE [2], SimBet [3], HiBop [4], Social-Greedy Routing [5], etc.

如今，越来越多的人至少携带一部可以运行短距通讯功能的无线通信移动设备，例如，IEEE 802.11 ，蓝牙，包括但不仅限于其他基于无线电的通信方案。以上移动设备可以看作为 MNs，他们可以构建起相互连通的廉价基础网络。这这个基础网络中，有一种状况，不足量的 MNs 需要构建起从一些源节点（SNs）到他们的通信目标节点（DNs）的连接路径。因此，目前基于已连接路径的路由方式，将会在这样的状况中失效。结果，一些次级网络因此得到区分，例如，延迟容忍网络（DTNs）、机会网络（OPENTs）与 MSNs。尤其对于 MSNs，分别从 DTNs 与 OPENTs 继承的短期偶遇性导致了通信与机会数据传输长延迟的特点。然而，MSNs 利用了设备携带者的移动行为与他们之间的关系，以提高路由性能。通过研究 MSNs 独一无二的特性，一系列的路由技术得以发展，诸如[LABEL][1] 、[BUBBLE][2]、[SimBet][3]、[HiBop][4]、[Social-Greedy Routing][5]，等。

In terms of the route discovery in MSNs, while direct connection between a SN and a DN is an option, there are possible alternative routes consisted by in-between connections via other nodes, which may provide higher delivery rate with shorter delivery time than the directly connected route. In this paper, we first analyze the mobility behaviors of human beings and quantify the social factors that we believe have strong impact on route discovery in MSNs. Specifically, based on the encounter history of MNs, three factors affecting the social contact probability (SCP) of MNs are introduced and investigated so as to make use of them for routing. First, we consider the encounter frequency of any two MNs. Then, the regularity of encounters of MNs is analyzed and quantified. Finally, the aging effect of encounters is addressed. By considering the impacts of these three factors on the SCPs of MNs, we then propose a routing protocol named as the Social Contact Probability assisted Routing (SCPR) protocol. Furthermore, in order to evaluate the performance of our SCPR routing algorithm and compare it with some well-known routing protocols for MSNs, such as, the Epidemic [6], Prophet [7] and the SimBet [3] algorithms, a mobility model is designed by jointly taking into account of MNs’ social characteristics, including randomness, waypoint behavior and community dependent. Our studies show that the SCPR protocol is capable of integrating the merits of the Epidemic, Prophet and SimBet protocols, while circumvents their shortcomings.

对 MSNs 的路由研究，当一个 SN 与一个 DN 的直接连接是一个选择时，考虑经由其他的节点连接是另一种选择，这可能会比直接连接在更短的传输时间下有着更高的传信率。在本文中，我们首先分析了人类的移动行为，接着将我们认为对于 MSNs 有着重要影响的社会指标量化。尤其在基于节点随机相遇的历史记录的算法中，提出和研究并使用了三个影响 MNs 社会活跃度（SCPs）的参数用来路由。首先，我们考虑了任意两个 MNs 的相遇频率。然后，我们考虑到 MNs 的相遇规律是可以被分析和量化的。最后，提出了 aging（TODO） 效应。通过对比这三个指标对于 MNs SCPs 的影响，我们得出了名为 SCPR 的路由协议。为了评估 SCPR 路由算法的性能并且与其他为 MSNs 设计的知名算法，如[Epidemic][6] 、[Prophet][7]与[SimBet][3] 算法做比较，设计了一个综合考虑了 MNs 的社会属性，包括随机性、航点性与社交依赖性。我们的研究表明了 SCPR 协议有能力整合 Epidemic、Prophet 和SimBet 协议的优点，同时规避了他们的缺点。

1. ANALYSIS OF SOCIAL CHARACTERISTICS OF MOBILE NODES

In this section, we analyze and quantify the social factors of MNs in MSNs, in order to exploit them for our routing algorithm. The strength of two nodes’ social relationship is reflected by the so-called social contact probability (SCP). First, let us consider the scenario where two MNs directly meet.

在本节，为了研究社会指标对我们的路由算法的作用，我们将分析和量化 MSNs 中 MNs 的社会指标。两个 MNs 之间的社交关系强度将以 SCP 定义。首先，让我们考虑有两个 MNs 直接相遇的情况。

# A. Direct Connection

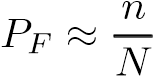
In order to analyze the relationship between two MNs that directly meet each other, we focus on the egocentric encounter history, which does not depend on the global knowledge of the entire system. As a result, we can find that there are three factors substantially affecting the probability of information delivery, which are the *frequency of encounters*, *regularity of encounter* between two MNs, and the *duration of two adjacent encounters* between two MNs. While a higher encounter frequency simply implies a better chance of future meeting, a higher regularity of encounter may make the prediction of future meetings more accurate. In this section, we explain how we invoke the first two factors in our routing algorithm to be addressed in Section III, in order to enhance the efficiency of information delivery. The last factor will be considered in the aging process, which will be described in Section II-C.

为了分析两个 MNs 之间直接遇到彼此的关系，我们关注的是以节点为中心的相遇记录，这并不依赖整个系统的全局信息。因此，我们找到了根本影响信息传递可能性的三个指标，有两节点的相遇频率和相遇规律（frequency of encounters，regularity of encounters）与两个节点的两次相邻间隔（duration of two adjacent of encounters)。有着更高的相遇频率暗含了未来有更多的相遇机会，有着更常见的相遇规律也许可以更准确预测未来的相遇。在本节，我们将解释我们如何将在我们的路由算法中首先引进两个参数，并在第三节使用。最后一个参数将会在 aging 中被考虑到，这将在第二节 C 部分被描述。

|  |
| --- |
| 978-1-4799-4482-8/14/$31.00 ©2014 IEEE |

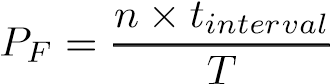
Based on the fact that mobile devices have the neighbor discovery mechanisms, which repeatedly occur in a periodic way, as shown in Fig. 1, we use the intervals of encounters to measure the encounter probability. Let the two reference MNs are observed from ** = 0 till ** = ** (now). As shown in Fig. 1, let *n* denote the number of encounters between the two reference MNs within (0**). Let *N* be the number of times that the discovery mechanism is activated within (0**), which represents the maximum number of encounters of two MNs. Then, the encounter probability of the two reference MNs can be measured as

基于这样一个事实，移动设备拥有探索临近设备的功能，在一个周期内，可以重复使用，如图1所示，我们使用相遇的间隔去描述相遇的可能性。图中描述了两参考个MNs在直到(现在)。如图1所示，设描述了两个参考节点在之间的相遇次数。设是在之间激活探索功能的次数，同时也代表了两个MNs的最大相遇次数。然后，两个参考节点的相遇可能性用下式计算：

 (1)

which becomes more declared as ** increases. Let ** represent the period that the neighbor discovery processes activate. Then, we have ** = **. Applying this into Eq. (1), we obtain

这会因为的提高而更为显著。将记为临近探索工程的激活周期。接着，我们就有了.将之代入式（1），我们得到了：

 (2)



t

2

t

3

t

1

t

n

T

Fig. 1. A time line demonstrating encounter history.

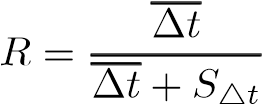
In terms of the regularity of encounter, explicitly, the frequency of encounters between two MNs, as above considered, is one of the elements. However, the frequency of encounters may not fully embrace the regularity of encounter. For example, let us consider two scenarios, both of which have the same encounter probability when measured by Eq. (2). However, in the first scenario, we assume that the interval 4**, ** = 2**3**, between the **th and (** − 1)th encounters is a constant, while in the second scenario, we assume that this interval is a random variable with the mean of and the standard deviation of **4**. Then, in practice, the first scenario is preferred for information delivery, as it yields a smaller average waiting time than the second scenario [8], or we say that the first scenario has a higher regularity than the second one.

由于相遇的规律性，显然，两个MNs之间的相遇频率也许不能完全表现相遇的规律。例如，让我们考虑两种相遇的状况，当使用式（2）计算时有着相同的相遇可能性。在第一种情况，我们假定这样的时间间隔

在第次和第次之间相遇是一个常数，在第二张情况，我们假定相遇间隔是一个随机的变量，使用均值和标准差来描述。然而，在实际中， 第一种情况更利于信息的传递，因为它比第二种情况有着更为接近的平均等待时间[8],或者我们可以说，第一种情况比第二种更为规律。

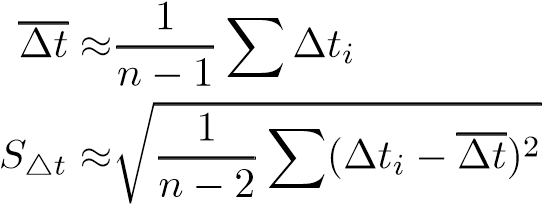
As the frequency of encounters has been considered as a separate (first) factor, as shown in Eq. (2), in this paper, the regularity of encounter is measured by

当相遇的频率考虑第一种情况时，在这篇论文中，相遇规律可以用下式表示：

 (3)

where, when given 4** = ** −**−1, *i* ∈{2, 3, 4, ..., n}and **4** are evaluated from the formulas

当给定,和用下式计算：

(4)

(5)

Eq. (3) shows that the maximum value of ** is one, which occurs when ∆**’s are constant. When the standard deviation increases, the regularity of encounter decreases.

式子（3）表示当为常数时出现，有最大值。当标准差变大，相遇的规律下降。

When considering the above-mentioned two factors, the direct-connection resultant SCP (**) can be defined by the product of ** given by Eq. (2) and ** of Eq. (3), i.e.,

当考虑以上两个指标时，直接联系的SCP（）可以被(2)定义的和被(3)定义的所得出。

(6)

Note that, at the start of the process when there are no encounter records, both the encounter probability ** and regularity factor *R* are set to zero.

值得注意的是，在过程的开始，当没有相遇被记录时，相遇可能与相遇规律指标都设定为0。

N

7

N

1

N

3

N

12

0.2

0

0.5

0.5

0.7

0.3

Fig. 2. An example showing the relationship among four nodes.

# B. Transitivity Property

Apart from direct connection, we also use the transitivity property of nodes’ relationship, in order to expand the scope of knowledge about the system. In a network, when an intermediate node has better relationships simultaneously with both an original sender (not necessary the SN) and a corresponding DN than the direct relationship between the sender and the DN, it might be more efficient that information is sent from the sender to the DN via the intermediate node (forwarder) than information is directly delivered from the sender to the DN. Similarly, more than one forwarders may be invited to form a route connecting an original sender to a desired DN. In order to make a decision about whether forwarders should be used, a metric called *transitive delivery probability* (**) is defined, which is given by the product of the **’s of the hops along the route from the sender to the destination, which can be expressed as

直接连接的部分，为了扩展系统的定义，我们使用节点关系的传递价值。在一个网络中， 当一个中间节点与一个原发信者（并不都是SN）和相符合的DN比发信者和DN直接有着更好的关系，因此信息从发信者传输到DN经过中间节点（传送）要比一个信息直接从发信者到DN要更有效率。相同地，超过一个传递者会被受邀参与到构建一个从信源到DN的一个路由连接。为了决策传递着是否要被使用，一个被叫做传递到达可能性（）将被定义，通过从发送者到目标的跳数得出，将表示为：

** = **(**1) × **(**1**2) × ** × **(**) (7)

(7)

where **1* *2** are the first, second and the **th forwarding nodes on the route from the sender ** to the DN **. Note that, ** itself is not necessary the node initializing the messages (i.e., the SN), it may also be a forwarder currently holding the messages.

此处为从信源S到目标节点D第一次、第二次以及n次传递节点。S自身并不是节点初始化消息所必须的（例如SN），其也许会是一个正在携带信息的传递者。

As an example, Fig. 2 shows the two-way relationship among nodes **1, **3, **7, and **12. Assume that **1 has a message to **7, explicitly, this message should be directly sent to node

**7 by **1. However, when **1 has a message to **12, it needs first to give this message to **3 or **7, as **1 does not directly contact **12. Furthermore, **1 needs to make a decision between **3 and **7. As seen in Fig. 2, there are four possible routes from **1 towards **12, which are:

1. Route 1: **1 via **3 to **12;
2. Route 2: **1 via **7 to **12;
3. Route 3: **1 via **3 and then via **7 to **12; 4) Route 4: **1 via **7 and then via **3 to **12.

图二作为一个例子，展示了节点与.假定

有一个消息要传递至,明显地，这个消息应该通过传递至。然而，当有一个要传给的信息时，他首先要将这个信息给或 ,当不能直接和相联系的时候。更进一步的，需要在和之间做出选择。如图2所示，从到 有四种可能的路径。他们是：

1. 路径1：经过到达
2. 路径2：经过到达
3. 路径3：经过接着经过到达;
4. 路径4：经过接着经过到达。

According to Eq. (7), the delivery probabilities of the four routes can be calculated, which are 

 and, respectively. Since

Route 2 has the highest delivery probability, **1 will choose it, in order to deliver the message to **12. Additionally, when **3 has a message destining to **1, as seen in Fig. 2, there are three routes:

1. Route 1: **3 directly to **1;
2. Route 2: **3 via **7 to **1;
3. Route 3: **3 via **12 and then via **7 to **1.

根据公式（7），四种路径的传输可能性()可以被计算，它们依次是,,,。因此路径2有着最高的传递可能性。将会选择它，使得消息可以传递至。再加上当有一条目的地为的消息，现在在图二中，有三种路径：

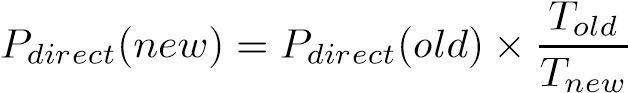
1. 路径1：直接传给;
2. 路径2：经过传给;
3. 路径3：经过接着进过到达。

It can be shown that they have respectively the delivery probabilities. Hence, Route 2 will be chosen for delivering the message to **1, instead of the direct Route 1.

它们依次的传输可能性为,和。因此，路径2将会被用为传递消息，而不是直接使用路径1。

# Ageing

In general, the delivery probability decreases over the time to the next meeting between two nodes, aging effect should be considered in routing protocols in MSNs. The aging mechanism has been introduced by a number of existing routing techniques, such as, the FRESH [9] and SimBetAge [10] protocols. In this paper, the aging effect is taken into account by modifying the SCPs. Specifically, when the observation time ** in Eq. (2) is changed from ** to ** but without further encounters between two reference nodes, the SCP of Eq. (6) is updated to

 (8)

通常，传递可能性在两个节点下一次遇到的时间内下降，时间效益应当在移动社会网络的路由协议中被考虑。其时间效应的机里被已存的几种路由协议中被讨论，例如，FRESH[9]和SimBetAge[10]协议。在这篇论文中，时间效应被认为时社会活跃度的的一部分。尤其是当在式（2）中显著时间被到所代替，但是在两个参考节点之间没有更新的相遇，式（6）的社交活跃度属性被更新为：

(6)

Note that, unlike **, ** depends on the **’s of intermediate nodes, which should be handled by the original sender. However, our system is operated in an egocentric fashion, the update of ** is only possible, when new encounters occur. Hence, in our protocol, the aging effect is only considered with **.

这样，不同于，基于被源发送者处理的中间节点。我们的系统操作基于以自我为中心的流行度，当新的相遇发生时，更新的只有可能性。因此，在我们的协议中，时间效应只与有关。

III. SOCIAL CONTACT PROBABILITY ASSISTED ROUTING

Based on the metrics investigated in Section II, in this section, we propose the Social Contact Probability assisted Routing (SCPR) protocol, which is operated in two phases. During the first phase, the metrics reflected by delivery probabilities are calculated while encounter records are collected. Specifically, when two nodes meet, this is added respectively to their record databases. Then, they recalculate the SCPs from the updated encounter history according to Eq. (6) in Section II-A, while the aging process is taken into account according to Eq. (8) in Section II-C). In order to update the transitivity records, whenever two MNs meet, the MN with a lower identity (first node) sends a request for the delivery probability table, while simultaneously sending its own table to the second node. After receiving the delivery probability table, the second node first compares and updates its probability table. Then, it sends the first node the records which have higher values than the corresponding ones in the first node’s table. Finally, the first node updates its delivery probability table by combining its existing table with the records received from the second node.

In the second phase, messages are forwarded from one node to another according to the following rules.

1. When a sender (which can be either a SN or an intermediate node) encounters the DN, messages are certainly sent to the destination node.
2. When a sender encounters a MN, which has a stronger relationship with the DN than the sender itself has, messages are forwarded to the MN encountered. In other words, when either the direct-connection resultant SCP (**) of Eq. (6) or the transitive delivery probability ** of Eq. (7) between an encountered MN and the DN is higher than both ** and ** between the sender itself and the DN, the sender forwards the messages to the encountered MN.

In order to explain the operations of our SCPR protocol, let us consider a network shown in Fig. 2. Given that **1 has messages destined to **3, **7 and **12. When **1 encounters **3, the messages for **3 are delivered, since the above first rule is satisfied. However, **1 will not forward **3 the messages destined to **7 and **12, as it knows that there are better routes to **7 and to **12, as shown in Section II-B. On the other hand, when **1 encounters **7 before encountering **3, it will then sends all the messages to **7, as **7 has strong relationships with **3 and **12, according to the above second rule.

IV. PERFORMANCE EVALUATION

# A. System Setup

In order to evaluate the performance of our SCPR protocol operated in MSNs, we propose a new mobility model by considering human movement behaviors. This new mobility model is designed by exploiting the advantages of the random mobility model, random Waypoint model [11], and the communitybased model similar to [7] and [12]. In detail, we consider a MSN covers an area of 1000×1000 square meters (**2). Within this area, there are fifteen communities of each covering an area of 100×100 **2. The fifteen communities are randomly located and they may overlap with each other. At the start of simulation, fifteen MNs are randomly placed inside the areas covered by the communities, each node is assigned to a random number of communities, representing its preferable communities, and each MN may be belong to one to several communities. Refer to Schneider et. al. [13], their research shows that approximately 10%, 30% and 20% of human-dependent MNs move within one, two and three places, respectively. Furthermore, beyond three locations, the percentage of MNs moving towards more places becomes less and less. Accordingly, in our mobility mode, we set the probabilities of 12.5%, 37.5% and 25% for MNs to move within one, two and three communities. After three communities, the probability is halved whenever one more community is added. In other words, the probability of one MN belonging to four communities is 12.5%, which is half of the probability of 25%, denoting the probability that one MN falls within three communities. Similarly, the possibility that one MN falls in five communities is 6**25%, and so on. After the initial assignments of MNs to communities, for each MN, a number of random probabilities are generated according to the above observations, which are used to decide the MN’s future movements among communities.

As an example, Fig.3 shows the constraints on node 1’s mobility pattern. There are ** communities (**1 to **) located within the area of MSN. Node 1 starts with community **1 and travels to communities **1, **2 and **3, which are node 1’s preferable places, with the probabilities of **1, **2 and **3, respectively. According to the same experiment of Schneider et. al. [13], approximately 10% of nodes’ mobilities could usually not be captured by their preference-point-based assumption. Therefore, in the considered example, we have **1+**2+**3 ≈ 0**9 and there is a probability of about 0**1 that node 1 moves to the other communities.

Node 1

C

1

C

n

C

3

C

2

C

4

P

3

P

2

P

1

Fig. 3. An example showing the mobility model used in simulation.

In addition to the randomness as above-stated, our mobility model inherits the characteristics of the Random Waypoint mobility model [11]. A node first randomly chooses a point within a selected community as its next destination. It then moves towards that position with a speed randomly chosen between 0 and **. After arriving at the destination, the node pauses for a fixed time **. Then, the above process is repeated until one simulation session is completed.

During the simulations, messages are generated by nodes at an update interval (**) with a probability of 0.125. Then, nodes detect their neighbors within the range of **. When a neighbor node is found, the processes for routing metric update and message transmission, as describes in Section III, are triggered. In detail, all the parameters invoked are summarized in Table I.

TABLE I

PARAMETERS FOR THE SIMULATION

|  |  |  |
| --- | --- | --- |
| Parameter | Value | Unit |
| Simulation area  Community area  Number of communities | 100010015×× 1000100 | (**)**2  **2  *communities* |
| Number of nodes | 15 | *nodes* |
|  | 20 | *m/(s)econd* |
|  | 30 | *m* |
|  | 600 | *s* |
|  | 60 | *s* |
|  | 15 | *days* |
| Probability of message generation | 0.125 | - |

In order to illustrate the performance of our SCPR algorithm, we compare it with other three existing routing protocols, which are the Epidemic, Prophet and SimBet algorithms. For comparison, first, at the beginning of the experiment, communities, nodes, mobility pattern of each of the nodes as well as messages are generated and saved into a file. Then, simulations in the context of each of the four routing protocols are executed in order to generate the results for performance.

Note furthermore that, in our experiments, we ignore messages’ transmission time and messages’ lifetime or time-tolive (TTL). We also ignore the constraint on the memory for messages. In addition, the acknowledgment mechanism in Epidemic algorithm is not implemented in our experiments. In this case, when a message arrives at its destination, all its copies stored at the other nodes are directly removed. In the context of the SimBet algorithm, we only consider the original SimBet algorithm instead of its extended version, SimBetAge, for the sake of simplicity.

# B. Performance Results

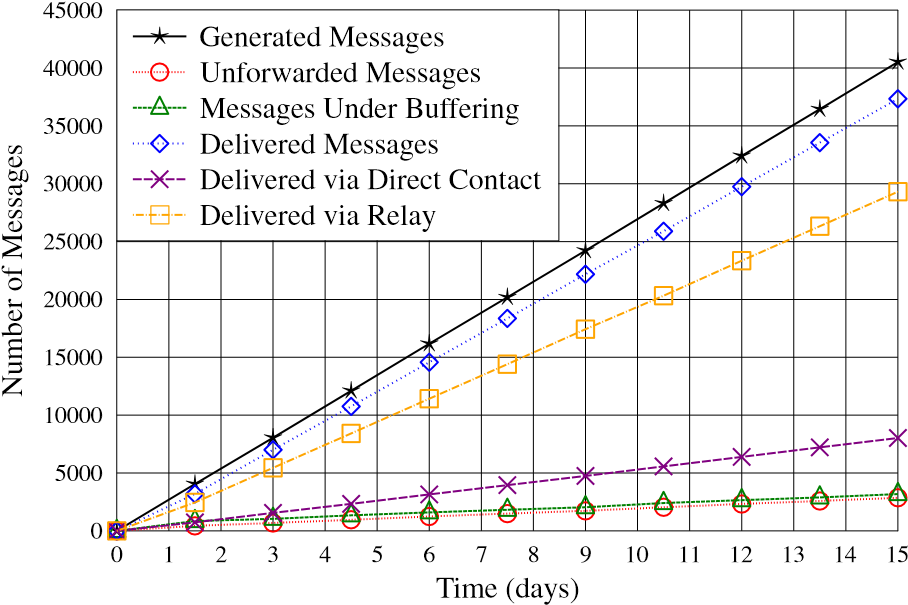


Fig. 4. States of message delivery via time under the SCPR protocol.

Fig.4 shows the states of messages via time. As seen in the figure, most of the messages are successfully delivered to their designated destinations, among which most of them are delivered with the help of intermediate nodes and only a small fraction of messages are delivered by direct contact. While there are a small number of undelivered messages, we can see that the messages forwarded by relay nodes are mostly successfully delivered. This can be reflected by the difference between the number of messages under buffering and the unforwarded messages.

0.0

0.1

0.2

0.3

0.4

0.5

0.6

0.7

0.8

0.9

1.0

DeliveryRatio

11

12

13

14

15

2

0

1

3

4

5

6

7

8

9

10

Time(days)

SCPR

Epidemic

Prophet

SimBet

Fig. 5. Comparison of message delivery ratios of four routing protocols.

Fig.5 compares the delivery ratios of the four considered routing protocols for MSNs. Explicitly, as the Epidemic protocol is a multiple-copy resource-greedy routing protocol, it has the highest delivery ratio amongst the four from the beginning to the end of the experiment. Specifically for the experiment, the delivery ratios of the other three are similar. However, with the increase of the simulation time, the Epidemic protocol demands a huge amount of resources for buffering the message copies, as shown in Fig.6. By contrast, the buffers required by the other protocols are very small and stable, which are also similar to each other.

Fig.7 and Fig.8 portray the average delay and the average number of hops of delivered messages, respectively. Owing to

0

5000

10000

15000

20000

25000

30000

35000

40000

45000

MessageUnderBuffering

2

15

14

13

12

11

10

9

7

6

5

4

3

8

0

1

Time(days)

SCPR

Epidemic

Prophet

SimBet

Fig. 6. Comparison of buffer usages of four routing protocols.

using multiple copies, the Epidemic protocol yields the lowest average delay among the four protocols considered, and it also has a low average number of hops. When comparing our SCPR protocol with the Prophet protocol, we find that they have similar successful delivery ratio and also similar end-toend message delivery latency. However, as shown in Fig.8, when the Prophet algorithm is invoked, more than twice of intermediate nodes than that required by our SCPR algorithm are required, in order to deliver the same amount of messages. Therefore, for delivery of the same amount of messages, the Prophet protocol requires about twice of the energy required by the SCPR protocol. From the results shown in Fig.8, we can see that the nodes operated under the SimBet protocol prefer to direct message transmission more than forwarding messages via intermediate nodes, as the time goes by. As the results, the average number of hops of delivered messages decreases, whereas the average message delivery latency becomes higher, as time increases.

0

5000

10000

15000

20000

25000

30000

35000

40000

45000

50000

AverageDelayofDeliveredMessages

15

14

13

12

11

10

9

8

7

5

4

3

1

0

2

6

Time(days)

SCPR

Epidemic

Prophet

SimBet

Fig. 7. Comparison of average delay of four routing protocols.

V. CONCLUSIONS

A SCPR routing protocol for MSNs has been proposed by exploiting three main social characteristics of human beings, including encounter frequency, regularity of encounters and freshness of encounters. Both direct connection and indirect connections are taken into account by the SCPR routing protocol. The proposed SCPR routing algorithm has been investigated along with three existing routing algorithms for MSNs

0

1

2

3

4

5

6

7

8

9

AverageHopCountofDeliveredMessages

2

15

14

13

12

11

10

9

7

6

5

4

3

8

0

1

Time(days)

SCPR

Epidemic

Prophet

SimBet

Fig. 8. Comparison of average number of hops of four routing protocols.

in the context of a proposed mobility model, which jointly considers people’s social characteristics, including randomness, waypoint effect and community-based. Our studies and performance results show that the SCPR protocol is capable of integrating the merits of the Epidemic, Prophet and SimBet protocols, while circumvents their shortcomings of, such as, the Epidemic protocol’s resource-greedy, Prophet protocol’s dependence on a high number of relays and the SimBet protocol’s high message delivery latency.

REFERENCES

1. P. Hui and J. Crowcroft, “How small labels create big improvements,” in *Proc. of the 5th IEEE Int. Conf. on Pervasive Comput. and Commun. Workshops*, Washington, DC, 2007, pp. 65–70.
2. P. Hui, J. Crowcroft, and E. Yoneki, “Bubble rap: social-based forwarding in delay tolerant networks,” in *Proc. of the 9th ACM Int. Symp. on Mobile Ad Hoc Networking and Computing*, New York, 2008, pp. 241–250.
3. E. M. Daly and M. Haahr, “Social network analysis for routing in disconnected delay-tolerant manets,” in *Proceedings of the 8th ACM International Symposium on Mobile Ad Hoc Networking and Computing*, ser. MobiHoc ’07. New York, NY, USA: ACM, 2007, pp. 32–40.
4. C. Boldrini, M. Conti, and A. Passarella, “Exploiting users’ social relations to forward data in opportunistic networks: The hibop solution,” *Pervasive and Mobile Computing*, vol. 4, no. 5, pp. 633–657, 2008.
5. K. Jahanbakhsh, G. C. Shoja, and V. King, “Social-greedy: a sociallybased greedy routing algorithm for delay tolerant networks,” in *Proc. of the 2nd Int. Workshop on Mobile Opportunistic Networking*, New York, USA, 2010, pp. 159–162.
6. A. Vahdat and D. Becker, “Epidemic routing for partially-connected ad hoc networks,” Duke University, Tech. Rep., 2000.
7. A. Lindgren, A. Doria, and O. Schele´n, “Probabilistic routing in intermittently connected networks,” *ACM SIGMOBILE Mobile Computing and Communications Review*, vol. 7, no. 3, pp. 19–20, Jul. 2003.
8. D. Bertsekas and R. Gallager, *Data Networks*, 2nd ed. Englewood Cliffs, N.J. : Prentice Hall, 1992.
9. H. Dubois-ferriere, M. Grossglauser, and M. Vetterli, “Age matters: Efficient route discovery in mobile ad hoc networks using encounter ages,” 2003, pp. 257–266.
10. J. A. Bitsch Link, N. Viol, A. Goliath, and K. Wehrle, “Simbetage: utilizing temporal changes in social networks for pocket switched networks,” in *Proceedings of the 1st ACM Workshop on User-provided Networking: Challenges and Opportunities*, ser. U-NET ’09. New York, NY, USA: ACM, 2009, pp. 13–18.
11. J. Broch, D. A. Maltz, D. B. Johnson, Y.-C. Hu, and J. Jetcheva, “A performance comparison of multi-hop wireless ad hoc network routing protocols,” in *Proceedings of the 4th annual ACM/IEEE International Conference on Mobile Computing and Networking*, ser. MobiCom ’98. New York, NY, USA: ACM, 1998, pp. 85–97.
12. E. Bulut and B. Szymanski, “Exploiting friendship relations for efficient routing in mobile social networks,” *IEEE Transactions on Parallel and Distributed Systems*, vol. 23, no. 12, pp. 2254–2265, 2012.
13. C. M. Schneider, V. Belik, T. Couronne´, Z. Smoreda, and M. C. Gonz´alez, “Unravelling daily human mobility motifs,” *J. R. Soc. Interface*, vol. 10, no. 84, May 2013.