Community-based Message Opportunistic Transmission

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Abstract

Mobile Social Networks (MSNs) is a kind of opportunistic networks, which is composed of a large number of mobile nodes with social characteristic. Up to now, the prevalent community-based routing algorithms mostly select the most optimal social characteristic node to forward messages. But they almost don't consider the effect of community distribution on mobile nodes and the time-varying characteristic of network. These algorithms usually result in high consumption of network resources and low successful delivery ratio if they are used directly in mobile social networks. We build a time-varying community-based network model, and propose a community-aware message opportunistic transmission algorithm (CMOT) in this paper. For inter-community messages transmission, the CMOT chooses an optimal community path by comparing the community transmission probability. For intra-community in local community, messages are forwarded according to the encounter probability between nodes. The simulation results show that the CMOT improves the message successful delivery ratio and reduces network overhead obviously, compared with classical routing algorithms, such as PRoPHET, MaxProp, Spray and Wait, and CMTS.

Keywords: Mobile Social Networks, Message Opportunistic Transmission, Transmission Probability, Encounter Probability

1. Introduction

Mobile Social Networks (MSNs) is a special kind of Opportunistic Networks (ON), which uses many concepts of Delay-Tolerant Networks (DTN) and Mobile Ad-hoc Networks (MANET) [1]. As applications of short-distance wireless mobile devices (such as smart phones, smart bracelets, Apple Watches, iPads, etc.) are so popular, the communication directly and share data for each other are becoming more and more convenient [2]. The typical applications of mobile social networks are booming, such as the pocket switched networks (PSN) [3], the mobile vehicular networks (VN) [4], and the wireless sensor networks [5], and so on.

In mobile social networks, the communication between nodes shows intermittent connectivity because of the node's moving. So the traditional routing protocol cannot run in this kind network, it dependents on the encounter opportunity to forward messages between nodes. Therefore, the "Storage-Carry-Forward" strategy is usually used to deliver messages in mobile social networks. Besides that, nodes show social characteristic, generally tend to congregate together according to social relations in this kind of networks. All nodes form various natural communities, which have respective region, are divided by the real or logical boundaries. Nodes are much active in itself community, while the probability of moving to an external community is very low. Some nodes can visit other communities according to their interests, they set up the ties between different communities. How to forward efficiently messages from source node to destination node is a challenging issue.

Early days, the traditional DTN routing algorithms include flooding-based and probability-based message forward strategies, such as literatures [6-9]. Recently, some papers have proposed social-aware routing algorithms using the sociality and mobility of MSNs. These algorithms detect the communities and compute the values of centrality for each node. Messages are delivered via the nodes with better centrality, such as literatures [10-14]. Despite many routing algorithms have proposed for the mobile social networks, they mostly forward messages to relay nodes with locally best centrality value. Some of them focus on the successful delivery ratio, and others focus on the network delay or the network load.

In this paper, we concern nodes' mobility and social characteristic, suppose a time-varying community network model, and propose a community-based message opportunistic transmission algorithm (CMOT). We assume m communities for n nodes in the mobile social networks. The m communities are empty at first. After the network runs for a period of time, the n nodes are assigned into m communities according to the probability of visiting different communities. In this community-based network model, the number of m and n are variables which are assigned by user, and one node can belong to different community in different periods. So this network model is time-varying. The CMOT includes messages intra-community forwarding and inter-community transmission. Messages intra-community forwarding adopts multi-copy forwarding strategy according to counter probability between nodes within a community. Messages inter-community transmission selects optimal path between the connected communities according to nodes' transmission probability. Since this scheme considers not only local community characteristic, but also the connectivity among communities in global network, so it can achieve the optimal performance. Our major contributions are summarized as following:

1) We define a community-based mobile network model, and periodically computer the community visiting probability victor for each node, then assign the community label to each node according to the highest probability value in each community visiting probability victor. These can adapt to time-varying mobile social network well.
2) We adopt different messages delivery strategies for intra-community and inter-community. These methods not only increase messages successful delivery ratio, but also decrease the algorithm complexity.
3) Using messages opportunistic forwarding transitivity, we can compute the transmission probability of a node to an inaccessible community to find the optimal path to destination community.
4) ACK mechanism is introduced to eliminate redundant message copies. We adopt one-hop forwarding using the encounter opportunity between nodes in intra-community. These methods can reduce network communication load.

The rest of this paper is organized as follows. We introduce the related works in section 2, the social network model and assumption in section 3. Section 4 shows messages transmission strategies. We evaluate the performance of our algorithms through extensive simulations in section 5, and conclude this paper in section 6.

2. Related works

Some researchers have a lot of studies on message forward protocol which are the core problems in opportunistic networks. There are typical message forwarding algorithms, such as Epidemic [15], Spray and Wait [16], Spray and Focus [17], PRoPHET [18], MaxProp [19], CMTS [20], and so on. They all inject a large amount of message copies into the network to improve the successful delivery ratio and reduce transmission delay. However, too many copies will consume a lot of network resources. In addition, these algorithms do not consider the social characteristic of mobile nodes.

Recently, researchers have proposed some community-aware message forwarding algorithms, aiming at the social characteristic in opportunistic networks.

P. Hui et al. put forward a routing label strategy (Label) [21], which uses the social structure to improve a message transmission. It creates a label for each node and tells other nodes about its affiliation. Nodes in the same community have the same label. The larger the encounter probability of nodes in the same communities is, the higher the probability of successful delivery of the message is. However, the routing performance is significantly degraded if nodes do not mix well or messages have short time-to-live.

P. Hui et al. also propose community-based opportunistic message transmission algorithm named Bubble Rap in a delay tolerant network [22]. This algorithm considers that each node is designed to have global or local ranking. Messages are forwarded to nodes which have higher global ranking, until a node in the destination's community is found. Meanwhile the messages are forwarded to nodes which have higher local ranking within the destination's community. However, with single-copy message transmission, this algorithm has lower message successful delivery ratio and larger network latency.

M. Xiao et al. put forward a single-copy community-aware routing algorithm named CAOR [23]. In this algorithm, mobile nodes with a common interest autonomously form a community, in which the frequently visited location is their common home. Nodes with high centralities act as the home of this community. The whole network is composed of some overlapped star-topology communities. The CAOR changes the routing between many nodes into the routing between a few community homes firstly. Then, we can gain an optimal relay set for each home by a reverse Dijkstra algorithm, and select the relay nodes in the optimal relay set to forward messages. Each home only forwards its message to the node in its optimal relay set, and ignores other relay nodes. However, the time complexity of the algorithm is associated with the number of community. When the size of network becomes larger and the number of community increases, it decreases the message successful delivery ratio and increases network transmission overhead.

In addition, Ying Zhu et al. propose a Location-Based Routing to measure nodes' social relations by location similarity [24]. The access locations of nodes are closer, the encounter probabilities of nodes are higher, and the social relations of nodes are tighter. Messages are only forwarded among the closely linked nodes. Eyuphan Bulut et al. propose friendship based routing in Delay Tolerant Mobile Social Networks [25]. A group of nodes which have a directly or indirectly close relationship set up a time-varying friendship community. Messages are only forwarded to the nodes that belong to the same community as the destinations node.

Considering community characteristics, the above-mentioned messages forwarding strategies usually select nodes with the optimal sociality and forward messages to them. Sociality measure mainly includes centrality, activity and betweenness. But they do not consider the influence on nodes mobility of the community distribution. Nodes tend to visit the close relation communities frequently, while visit the estranged relation communities rarely, even do not visit the remote communities. For the above issues, we propose a community-based message opportunistic transmission algorithm (CMOT) in this paper. Before running this algorithm, we need divided the network into communities according to the historical visiting information of nodes. Message transmission is divided into two parts which called inter-community transmission and intra-community forwarding. The inter-community transmission chooses an optimal path of message transmission by comparing the transmission probability between the nodes, while the intra-community forwarding adopts multi-copy forwarding strategy according to counter probability between nodes within a community. The details of CMOT are described as follows.

3. Network model and community division

Before we discuss the message forwarding method in mobile social networks, we need to build a network model based on community. We introduce the concepts, then, present how to divide the communities in this kind network.

3.1. Network model

Based on node mobility in mobile social network, mobile nodes always tend to stay within their own community, and visit the neighboring community frequently, while visit the other communities rarely. Their mobility shows the principle of locality. In this section, we define a community-based mobile network model as follows:

Definition 1: n*etwork model*: Assume that a network has *n* nodes which can be divided by *m* communities. The mobile network model is expressed with $G = \{C, P\}$, where $C = \{c_i \mid c_i \in C, 1 \le i \le m\}$ is the set of communities, and $P = \{P_j \mid P_j \in P, 1 \le j \le n\}$ is the set of probability vector that a node visits each community. Where P_i is a *m*-dimensional probability vector.

Definition 2: *Local Community*: The community which nodes belong to is called local community.

Definition 3: *Accessible Community*: The community which a node can visit is called the accessible community for this node. Obviously, the local community is one of accessible communities for a node.

Definition 4: *Inaccessible Community*: The community which a node can not visit is called the inaccessible community for this node. A community is a accessible community for some nodes, but is a inaccessible community for other nodes.

Definition 5: *Community Activity*: Community activity presents the agglomeration degree of community. The larger community activity has the greater probability that node leaves the local community to other community, and nodes are more dispersive in community. Conversely, the community nodes are more aggregate.

To facilitate the description and analysis, the mobility model of nodes is assigned following assumptions:

1) In a period, each node belongs to only one community, and nodes move in the local community for most of the time. Nodes mobility within a community follows Random-Waypoint mobility model.
2) When a node leaves the local community, it will select an accessible community at random, and stay for a period of time, then select the next community. The probability that a node leaves the local community is determined by the community activity.

3.2. Community division

Depending on the definitions of network model, we periodically count the numbers of node i that visits each community at initialization phase, and we will get probability vector of node i visiting each community $P_i =< p_{ic_1}, p_{ic_2}, ..., p_{ic_j}, ..., p_{ic_m} >$, where p_{ic_j} can be computed by formula (1).

$$p_{ic_j} = \frac{N_{ic_j}}{\sum_{k=1}^{m} N_{ic_k}} \tag{1}$$

In Eq. (1), N_{ic_j} indicates the number of node i visiting community j. The community that node i visits with the highest probability is local community of node i, we create a community label for node i. And nodes in the same community have the same community label. When all nodes have confirmed their community labels, the *n* nodes are assigned into *m* communities in mobile social network. This community division method has follow advantages:

1) The community division is not artificial by somebody, depend on the node itself movement regularity in mobile social networks.
2) With the mobility of nodes, the existing community structure may change over time in the network, so that the number of nodes that visit each community periodically updates. The community affiliation of nodes will be re-divided based on the obtained community access probability vector. It can adapt to time-varying mobile social network well.

4. Message transmission strategies of CMOT

Considering the community characteristic in the mobile social network, the method that nodes are divided into different communities will help improve data transfer performance. If the source node and destination node are in the same community, the message is simply forwarded within the local community to avoid consuming network resources that the message spread into other communities. If the source and destination nodes are not in the same community, the message is first transferred to the target community, and then is forwarded to the destination node by intra-community forwarding strategy. Therefore, CMOT message transmission strategy is divided into inter-community transmission strategy and intra-community forwarding strategy.

4.1. Intra-community forwarding strategy

The PRoPHET that is a classical probability-based transmission algorithm defines delivery predictability to measure delivery probability metric between nodes. If the delivery predictability of node *j* is larger than that of node *i* which carries messages, the node *j* can get a copy of messages. Since nodes move within a community frequently and the encounter probability between nodes is higher, there are large number of copies in MSNs, it will waste a lot of network resources for unnecessary message forwarding. So we propose an improved PRoPHET algorithm for intra-communities message transmission in this paper. It selects one-hop nodes for destination node as forwarding nodes to ensure higher delivery ratio and reduce redundant copies.

Encounter prediction probability between nodes

Each node holds an encounter probability vector to store encounter probability between nodes. The calculation of encounter probability between nodes is divided into encounter updating and time aging.

Whenever node i encounters node j, delivery predictability should be updated according to the formula (2), where $p_{init} \in [0,1]$ is an initialization constant. This formula ensures that nodes have high delivery predictability when they are often encountered.

$$p_{(i,j)} = p_{(i,j)_{old}} + (1 - p_{(i,j)_{old}}) \times p_{init} \quad (2)$$

If node i does not encounter node j in a while, they are less likely to be good forwarders of messages to each other, so the delivery predictability values must age. The aging equation is shown in formula (3), where $\gamma \in [0,1]$ is the aging constant, and k is the number of time units that have elapsed since the last time the metric was aged. The time unit used can differ, and should be defined based on the average interval of nodes encounter within the community.

$$p_{(i,j)} = p_{(i,j)_{old}} \times \gamma^k \tag{3}$$

The simulation results in section 5 show that $p_{init} = 0.75$ and $\gamma = 0.98$ are the most appropriate constant value.

Message Forward Process within community

Intra-community message forwarding uses the encounter prediction probability of node to measure the probability that the message is successfully delivered to destination node from source node, and selects only encounter node whose delivery predictability is larger, then forwards messages to the selected node. The node that carries messages does not delete the messages, but stores and manages the messages in accordance with the "first-in first-out" principle, until TTL (the time to live) value expires or the message is transferred to the destination node.

Meanwhile, ACK mechanism is introduced to eliminate redundant message copies. If the messages are forwarded to the destination node, an ACK packet is sent to the network and the node that receives the data packet will eliminate redundant copies of the messages in the network based on the ACK information.

From the viewpoint of energy saving, this delivery method selects the node with highest encounter probability as a forwarding node to ensure the reliability of delivery. This forward method selects only one-hop node as a forwarding node, reduces the number of redundant copies in the network.

4.2. Inter-community transmission strategy

The key of inter-community message transmission is to find the optimal path between communities from source node community to destination node community.

For any node, communities are divided into two type community which are accessible community and inaccessible community. The mobile nodes can build a communication path between the local community and the accessible community, while the communication path between the local community and the inaccessible community often needs the assistance of relay communities. A large number of mobile nodes may make multiple inter-community communication paths. To find the optimal path in these paths can resolve message transmission problems between the source community and destination community.

Community Transmission Probability

Definition 6: *Community transmission probability*: The probability that a message is delivered to a community is called community transmission probability.

Each node holds a community transmission probability table which stores the transmission probability from the node to each community. The larger transmission probability means the closer connection, and the better path. The community transmission probability is divided into two categories: the accessible community transmission probability and the inaccessible community transmission probability. For the local community, the community transmission probability is 1. For the accessible community and the inaccessible community, the community transmission probability is described as following.

(1) Accessible Community Transmission Probability

Nodes can directly visit the accessible community to create a communication path between the local community and the accessible community. Therefore, the probability that nodes visit the accessible community represents the transmission probability that the node to the accessible community, which is showed in formula (4).

$$p_{ic_j} = \frac{N_{ic_j}}{\sum_{c_k \in C_a} N_{ic_k}} \tag{4}$$

Where p_{ic_j} is the community transmission probability of node i visiting community c_j, C_a is the set of the accessible community of the node i, N_{ic_j} is the number which node i visits community c_j, and the number is updated once every mobile cycle.

(2) Inaccessible Community Transmission Probability

Usually, if node *a* frequently encounters node *b*, and node *b* frequently encounters node *c*, hence node *c* probably is a good node to forward messages destined for node *a*. Similarly, we assume that c_x is the local community of node i, c_y is the local community of node j and the accessible community of node i, and c_z is the accessible community of node j. In another words, there are two community communicating paths: 1) $c_x \to c_y$ that is established by node i, and 2) $c_y \to c_z$ that is established by node j. The scenario is shown in figure 1.

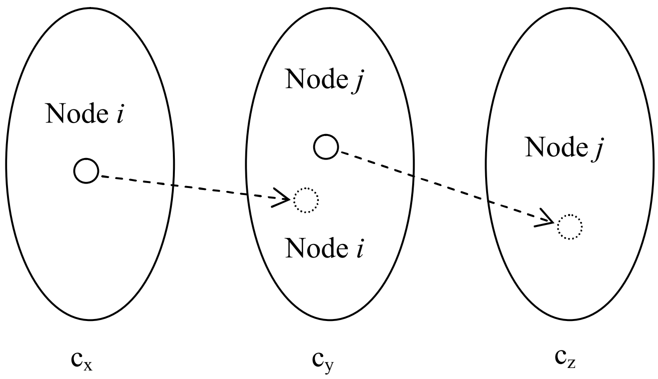

Fig. 1. The node *i* build a community path through node *j*

If node i and node j encounter each other, they exchange community transmission probability table, then node i finds that node j has a community communicating path $c_y \to c_z$, and establishes a communicating path from community c_x to community c_z, i.e. $c_x \to c_y \to c_z$, which makes node i has an opportunity to transfer messages to community c_z through c_y.

Equation (5) shows the transmission prediction probability of the node i to unreachable community c_z.

$$p_{ic_z} = p_{ic_y} \times p_{(i,j)} \times p_{jc_z} \tag{5}$$

Where p_{ic_y} indicates the transmission probability of the node i to the local community c_y of node j, and shows the community path $c_x \to c_y$. Likewise, p_{jc_z} indicates the transmission probability of the node j to the community c_z, and shows the path $c_y \to c_z$. $p_{(i,j)}$ indicates the encounter probability of node i and node j, which connects the two community transmission probability p_{ic_y} and p_{jc_z}, represents the transitivity from c_x to c_z, provides the opportunity for messages transmission from community c_x to community c_z.

The formula 5 shows that messages can transfer to inaccessible community through relaying community, meanwhile shows that if messages deliver to further community, need across more relaying communities, and get lower community transmission probability.

Nodes constantly update transmission probability of the inaccessible community at community transmission probability table during the mobility. The updating operation is divided into replacement update and aging update.

Replacement update is as follows: If node i and the node k encounter each other, a new communication path to the community c_z is built. According to formula 5, we can calculate the community transmission probability $p_{ic_z}^{new}$. Compare $p_{ic_z}^{new}$ with the old value of the transmission probability $p_{ic_z}^{old}$, if $p_{ic_z}^{new} > p_{ic_z}^{old}$, the new value updates old value at the community transmission probability table.

On the other side, since the communication path that the node establishes to the inaccessible community usually consists of multiple community communication paths, which is a dynamic path changed with time. If the transmission probability of the node i to the community c_z is not updated for a period of time, its transmission prediction probability will age, the aging formula is as follow.

$$p_{ic_z}^{new} = p_{ic_z}^{old} * \eta^T \tag{6}$$

Where $\eta \in [0,1]$ is an initialized constant. The simulation results show that $\eta = 0.98$ is an ideal constant value. And T is the number of time units that have elapsed since the last time the metric was aged. The time unit used can differ, and should be defined based on the transmission delay expectation caused by the mobility of nodes.

Inter-community Message Forward Process

When messages are forwarded between communities, the transmission probability of a node to the target communities is used to choose the best community communication path. Compare transmission probability of the node that carry the message with encounter node to the target community, if community transmission probability of encounter nodes is higher, it is indicated that the node creates a better path to the target community, and then select the encounter node as a forwarding node. So the node with the highest probability is often chosen as a forwarding node between communities, until the message is delivered to the target communities. Obviously, the transmission probability of node to the local community is the largest and the path is optimal. Therefore for inter-communities forwarding, messages are forwarded to the node which is the same community as the target node.

4.3. Message transmission process

Before describing the message transmission, we set two kind routing tables for each mobile node. One is encounter probability routing table which includes two items: 1) the node id, 2) the encounter probability value. The other is community transmission probability routing table which includes two items also: 1) the community id, 2) the community transmission probability.

The flow chart of intra-community and inter-community are shown in figure 2.

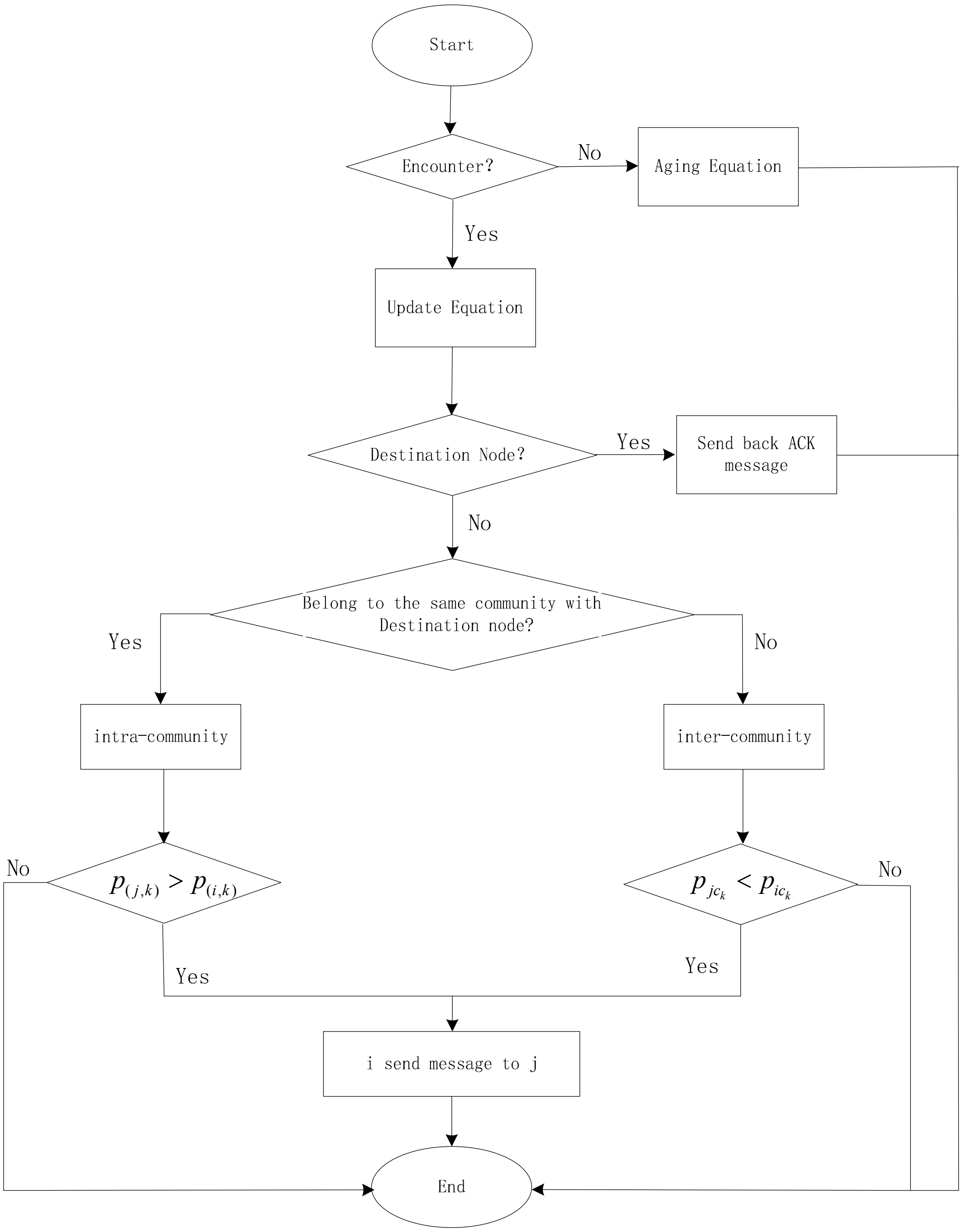

Fig. 2. The flow chart of message transmission process

5. Simulations scenario and results analysis

5.1. Simulation Scenario and parameters

In this paper, CMOT algorithm uses the ONE (Opportunistic Network Environment) to simulate, and compare with typical algorithms such as PRoPHET, Spray and Wait, MaxProp and CMTS. Communities are laid out in accordance with 4×4. The boundary for each community is set as a circle with fixed center and variable radius. The interest of nodes is set to priority visit the nearest community, and nodes leave the local community only to visit the nearest neighbor communities from the local community without visiting other communities. Community distribution simulation interface is shown in Figure 3.

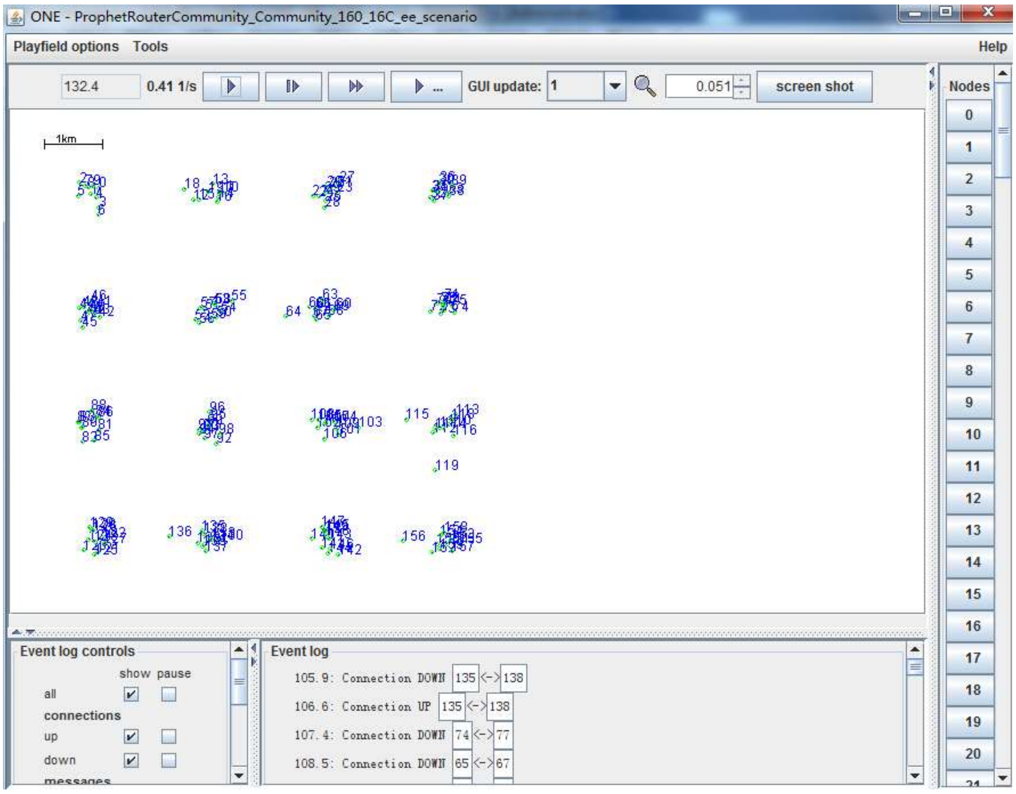

Fig. 3. The Community distribution of simulation interface

Before the simulation, 10000s pretreatment process is conducted to complete community division. Specific simulation parameters are set in Table 1.

Table 1. The parameters of simulation scenario

Category	Parameter (unit)	Values
Scenario features	Simulation time (s)	60000
	Simulation region (m^2)	7500m×7500m
Community characteristics	Community quantity	16
	Community distribution	4×4
	The radius of community (m)	100/300/500/700/900
	The number of nodes in a community	10
Node characteristics	Mobility model	Random Waypoint
	Movement speed (m/s)	0～7
	Community activity	0.03/0.06/0.09/0.12/ 0.15/0.18/0.21
	Transmission rate (KB/s)	250
	The maximum transmission range (m)	30
	Cache size (MB)	10
	Wait time (s)	5～10
Data packet characteristics	Event generator	external events
	Data packet size (MB)	0.5～1.5
	TTL (s)	1000/2000/4000/6000/8000/12000
	The total number of data packets	1000

5.2. Experimental results and analysis

In this section based on the above scenario, we compare the performance of five algorithms, PRoPHET, MaxProp, Spray and Wait, CMTS and CMOT in different community size, degree of community activity, nodes movement speed, messages TTL. The metrics include 1) average delay, 2) average hops, 3) overhead ratio, and 4) successful delivery ratio.

The impact of changing communities sizes

In this section, we set the average speed of the node to 5 m/s, the node cache to 10M, community activity to 0.21, the message TTL to 100 minutes, and set community size to 100m, 300m, 500m, 700m, 900m respectively.

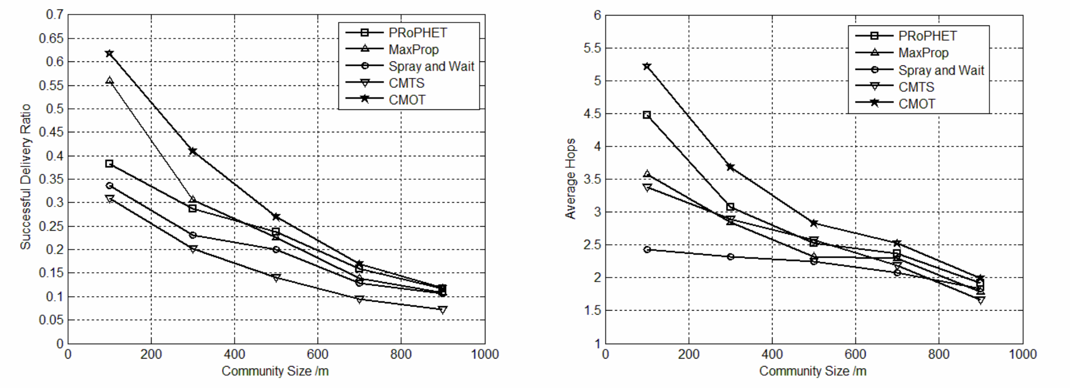

Fig. 4. Comparison of delivery ratio and average hops in different community sizes

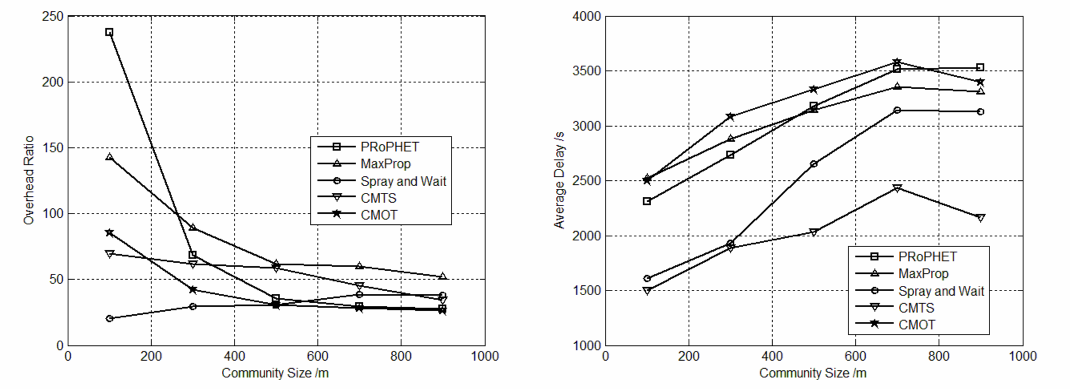

Fig. 5. Comparison of overhead ratio and average delay in different community sizes

Figure 4 shows that the successful delivery ratio and average hops are decrease with increasing the radius size of community, have the same trends. Compared with the other four algorithms, the delivery ratio and average hops of CMOT both increase by 5% to 30%. The experimental results indicate that CMOT is higher delivery ratio and more average hops than the other algorithms. Especially, when the community radius is less than 500m, CMOT is more obvious than other four algorithms, which show that CMOT is more suitable for smaller community sizes in the mobile social network.

The overhead ratio is defined as formula (7), indicates the communication costs in the mobile social network when messages are delivered successfully.

$$overhead\_ratio = \frac{relayed - deliveried}{deliveried} \quad (7)$$

From Figure 5, we can see that COMT shows a little better than others with the overhead ratio, but shows the worst one with the average delay. Because COMT has better delivery ratio and average hops, messages need cross more communities to arrive destination node, and need more time to finish delivery processes.

The impact in different community activity

In this section, we set the community radius to 300m, the message TTL to 100 minutes, the average speed of the node to 4 m/s, and the node cache to 10M, and set community activity to

0.03, 0.06, 0.09, 0.12, 0.15, 0.18, 0.21 respectively. The simulation results are shown as following.

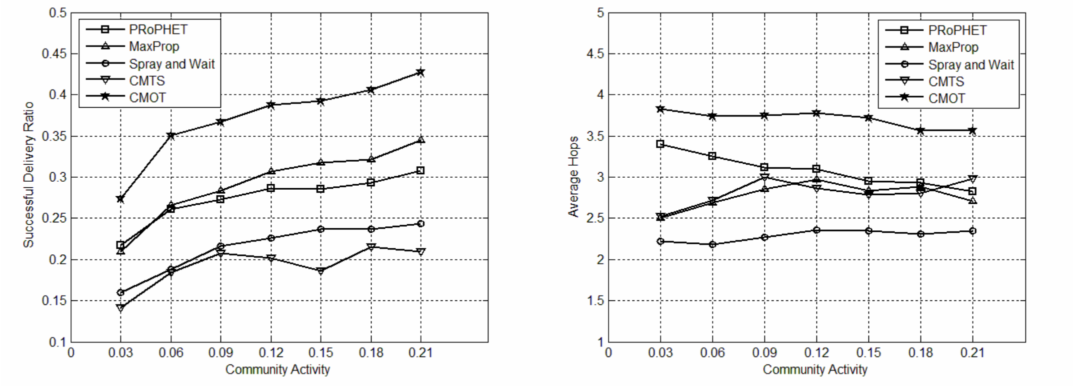

Fig. 6. Comparison of delivery ratio and average hops in different community activity

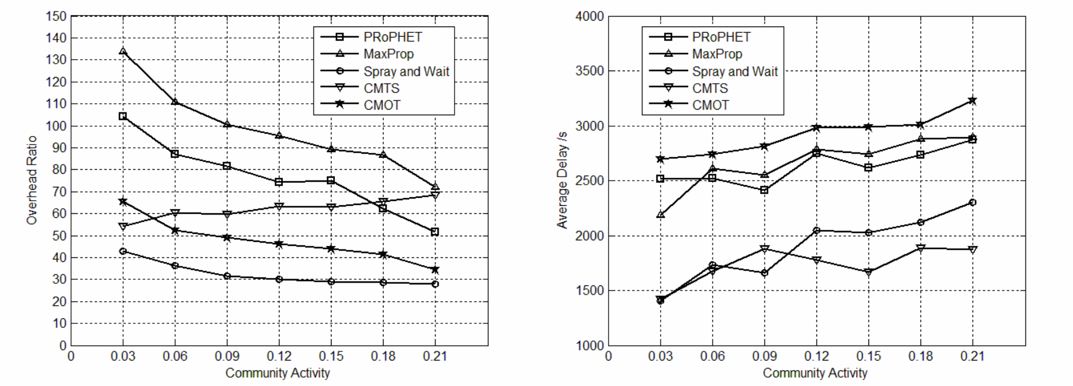

Fig. 7. Comparison of overhead ratio and average delay in different community activity

From figure 6, when the community activity increases, the delivery ratio improves, while the average hops do not almost change. And we can see that CMOT shows the best in both delivery ratio and average hops. The figure 7 shows that the overhead ratios are reduced when the community activity is increased, while average delays are increased slowly. The overhead ratio of Spray and Wait is lowest, and COMT shows better than PRoPHET, MaxProp, and CMTS. But CMOT has longest average delay in all algorithms.

PRoPHET, MaxProp, Spray and Wait algorithm do not use the node community characteristic, so they have lower delivery ratio than COMT and CMTS. Although CMTS uses community characteristics of nodes, and selects the node with high activity to forward message, the active node can only carry a copy to the accessible community, and can not get to the inaccessible community. When the node activity increases, messages diffusion becomes faster. However, this increased diffusion of messages do not improve the delivery ratio, it increases the network communication load. Using the transmission probability prediction for nodes to communities, the CMOT algorithm improves the delivery ratio of message by finding a reliable path to deliver messages to destination community. Of cause, CMOT consume more network delay than others.

The impact of node moving speed

We set the experimental community radius to 300m, the message TTL to 100min, the node cache to 10M, community activity is 0.21, and set node movement speed from 1m/s to 7m/s. The experimental results are shown in figure 8 and figure 9.

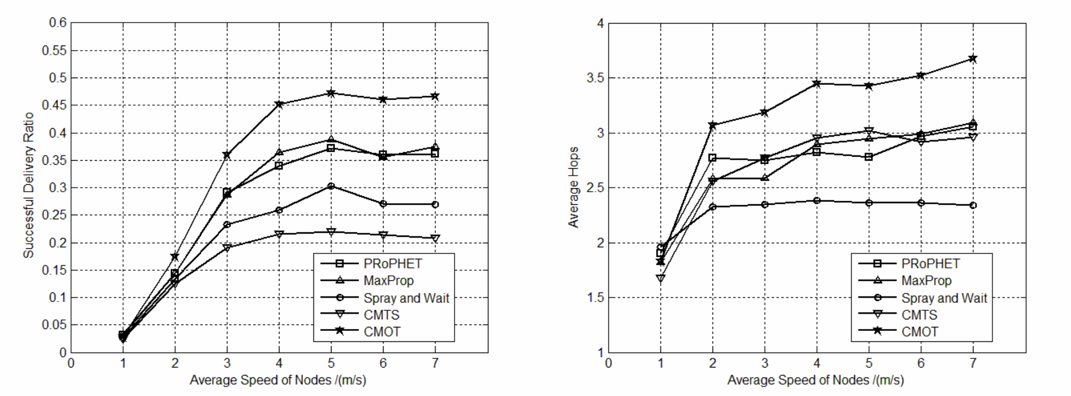

Fig. 8. Comparison of delivery ratio and average hops in different nodes' average speed

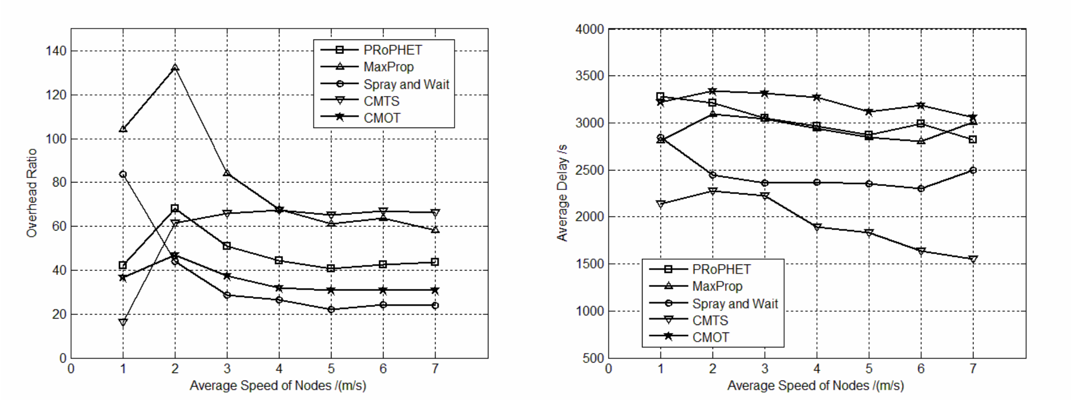

Fig. 9. Comparison of overhead ratio and average delay in different nodes' average speed

We can see in figure 8, when the average speed of the nodes changes from 1m/s to 4 m/s, the delivery ratios in all algorithms increase, while the average speed of the nodes is bigger than 4 m/s, the delivery ratios in all algorithms almost do not increase at all. The delivery ratio of CMOT is fastest increase and has the biggest delivery ratio comparing with other algorithms. The average hops show the similar law for all algorithms.

Figure 9 shows that the overhead ratios increase in other algorithms except CMTS when the average movement speed of nodes increases. When the average speed is lower, network load of each algorithm is higher. When the average speed is bigger than 4 m/s, the overhead ratios almost do not change. Because the CMTS algorithm uses nodes activity to forward messages, the nodes with higher activity move in local regions and can not move to any further position, so that this messages forwarding is blind, the better nodes mobility will increase the more network load.

When the average speed of the nodes increases, the average delays are decreased slowly in all algorithms, the CMTS shows the best performance, and PRoPHET, MaxProp, CMOT have similar average delay.

The impact in different messages TTL

In this section, we set the community radius to 300m, the average speed of the nodes to 4 m/s, the node cache to 10M, community activity to 0.21, and set message TTL (Time to Live) to 1000s, 2000s, 4000s, 6000s, 8000s, 10000s and 12000s.

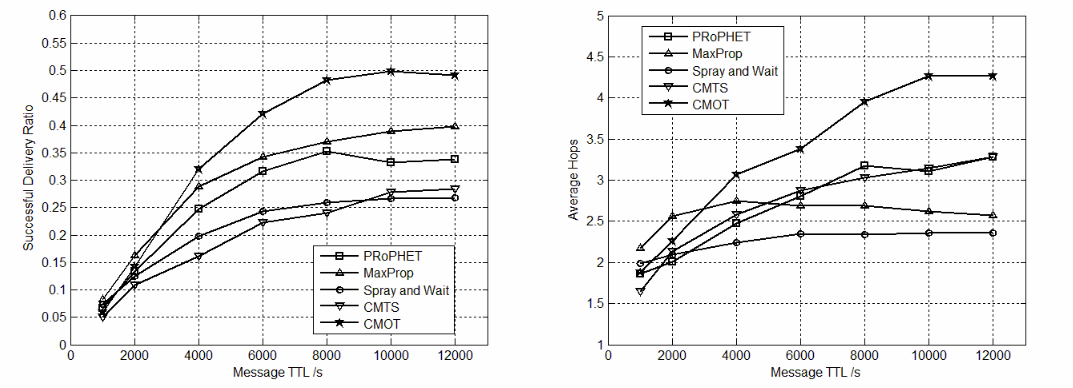

Fig. 10. Comparison of delivery ratio and average hops in different TTL

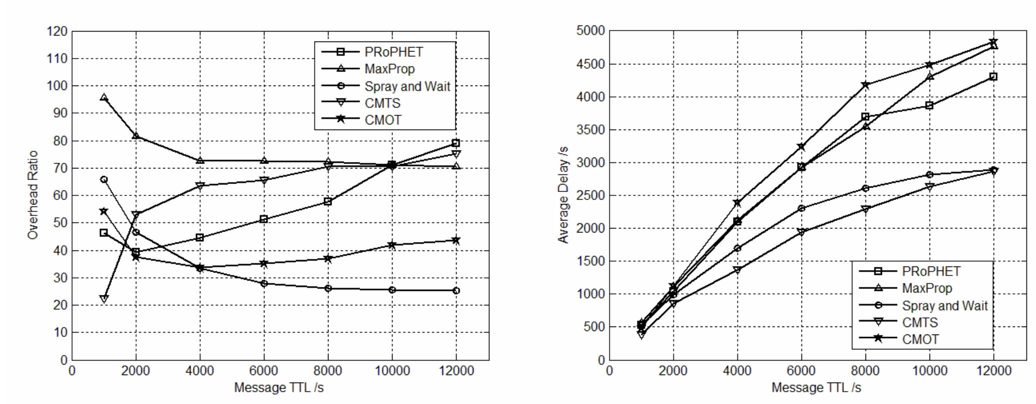

Fig. 11. Comparison of overhead ratio and average delay in different TTL

Figure 10 shows that messages can not be fully forwarded and the successful delivery ratios of all algorithms are low when the message TTL is small. When the messages TTL increased to 6000s, the delivery ratio of CMOT algorithm is significantly higher than other algorithms. We can see the similar law for average hops.

As shown in Figure 11, compared with the other four algorithms, CMOT has lower overhead ratio than PRoPHET, MaxProp, and CMTS, just exceeds overhead ratio of Spray and Wait algorithm. For whole time, overhead ratio curve of CMOT algorithm is smooth, it indicates that CMOT algorithm is not sensitive to the change of messages TTL. The average delays increase for all algorithms with the increasing messages TTL and the CMOT has the longest average delay.

6. Conclusions and future works

We model an MSN into a time-varying community-based network, and propose a community-aware message opportunistic transmission algorithm (CMOT) in this paper. We divide the CMOT algorithm into two parts: 1) for inter-community messages transmission, the CMOT chooses an optimal community path by comparing the community transmission probability, 2) for intra-community in local community, messages are forwarded according to the encounter probability between nodes. Meanwhile we use ACK mechanism to eliminate redundant message copies, and adopt one-hop opportunistic forwarding between nodes in intra-community to decrease network communication load. Compared with previous classical routing algorithms, the CMOT achieves the optimal performance in the message delivery ratio and overhead ratio. But its average delay is longer than that of others.

Acknowledgements

This work is partially supported by the National Natural Science Foundation of China (61162002, 61364023), and the Jiangxi province National Natural Science Foundation of China (20151BAB207038).

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