Computer Networks 113 (2017) 230–243

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

Social-based routing scheme for fixed-line VANET

Junling Shi[a], Xingwei Wang[b,*], Min Huang[c], Keqin Li[d], Sajal K. Das[e]

[a] College of Computer Science and Engineering, Northeastern University, Shenyang, Liaoning 110169, China
[b] College of Software, Northeastern University, Shenyang, Liaoning 110169, China
[c] College of Information Science and Engineering, Northeastern University, Shenyang, Liaoning 110819, China
[d] Department of Computer Science, State University of New York, New Paltz, New York 12561, USA
[e] Department of Computer Science, Missouri University of Science and Technology, Rolla, Missouri 65409, USA

ARTICLE INFO

Article history:
Received 6 March 2016
Revised 28 December 2016
Accepted 29 December 2016
Available online 29 December 2016

Keywords:
VANET
Fixed-line transportation
Routing
Community
Messages buffering

ABSTRACT

Vehicle Ad hoc NETwork (VANET) routing is facing a lot of challenges, such as efficient and effective message forwarding in the distributed network, as well as exploring and exploiting the movement regularity among vehicles and the social ties among passengers. Oriented to the fixed-line VANET, we propose a social-based routing scheme to enable the efficient and effective message routing among passengers. In the proposed scheme, passengers are divided into different communities based on the Improved *K*-Clique community detection algorithm (IKC). For determining the forwarding and dropping order of messages, a Social-based Message Buffering scheme at vehicles (SMB) is devised with their closeness and contribution considered. A Bilateral Forwarder Determination method (BFD) is proposed to make the optimal message forwarding, including Intra-Community Forwarder Determination (ICFD) and intEr-Community Forwarder Determination (ECFD). Simulation results show that the proposed scheme has better message delivery ratio and lower network overhead than other existing ones.

1. Introduction

A city becomes smart when investments in human and social capital and traditional (transportation) and modern (ICT, Information and Communication Technologies) communication infrastructure fuel sustainable economic growth and high quality life with a wise management of natural resources through participatory governance. It is required to develop and manage a variety of innovative services that provide information to all citizens about all aspects of city life via interactive and internet-based applications [1]. As a new technology that integrates the potentials of new-generation wireless networks into vehicles to enable communication among vehicles via Mobile Ad hoc NETwork (MANET) [2,3], VANET (Vehicular Ad-hoc NETwork) is attractive to be integrated into smart cities [4]. VANET is distinguished from other kinds of ad hoc networks due to its rapidly changing topology, large scale and variable node density, etc. [5]. Generally, VANET can be classified into Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V); the former is the communication mode via infrastructures and the latter is that established by vehicles [2]. In this paper, we classify VANET into fixed-line VANET and none-fixed-line VANET. In the former one, vehicles run along fixed lines (e.g., public buses) and their routes cannot be changed by the driver or passenger, while in the latter one, they do not run along fixed lines (e.g., private cars) and their routes depend on the purpose and habit of the driver or passenger. However, VANET poses a lot of significant challenges to networking, such as data dissemination and sharing as well as security issues, etc. To this end, the design of an efficient and effective routing scheme for VANET is crucial.

In MANET, nodes are strongly interdependent, and they are also human-centric in many scenarios, such as Pocket Switched Network (PSN) [6] and Mobile Social Network (MSN), because nodes in these networks contact with each other following the communication way of human beings. This phenomenon motivates researchers to borrow the concept of Social Network Analysis (SNA) to design routing schemes in MANET [7]. Since VANET is also a kind of MANET formed by human-centric nodes, the social concept can be employed to solve the VANET routing issue. In addition, social based routing algorithms in VANET have benefits in several aspects: (i) People with similar social profile (e.g., habit and economic situation) encounter or contact with each other easily and frequently when they travel. Therefore, the effectiveness (e.g., delivery ratio) and the efficiency (e.g., latency) of the routing mechanism can be improved by identifying and utilizing the properties of people's social behaviours in VANET [8]. (ii) By exploiting people's social characteristics (e.g., tie strength), the node can

* Corresponding author.
E-mail addresses: shijunlingdhr@163.com (J. Shi), wangxw@mail.neu.edu.cn (X. Wang).

http://dx.doi.org/10.1016/j.comnet.2016.12.016
1389-1286/

optimize routing by forwarding the message to the node that encounters the destination more often rather than the blind forwarding (e.g., broadcasting [9], which produces additional overhead by redundantly forwarding the message). (iii) Since people's social relations generally have long-term characteristics and are less volatile than their mobility [10], the social based routing information is not frequently updated and thus the communication overhead can be reduced. Therefore, we introduce social relationship into routing scheme design for the fixed-line transportation to enable effective and efficient message delivery among passengers.

A community is a set of nodes with a high density of internal links, whereas links between communities have comparatively lower density [7]. In the fixed-line transportation, passengers with similar social attributes have high probability to encounter each other and are more likely to communicate with each other during their travelling. We can define such passenger nodes to be a community since their links toward the nodes inside the community are more than those outside the community, thus facilitating the message delivery and improving the routing scheme.

In V2V VANET, due to the limited contact time window and buffer space, one vehicle should determine which message to be forwarded when it encounters others or discarded when its buffer is full, in order to make the overall network message delivery ratio increase. As the most commonly used buffering strategy, the FIFO (First In First Out) [11] is hard to achieve network-wise message delivery optimally and win-win among nodes, due to its local viewpoint (the message's arrival time) rather than global one. Furthermore, during the social interaction, friends with close relationships and frequent interactions cooperate with each other to benefit themselves, promoting win-win situation [12]. Therefore, a buffering management scheme for the message handling should consider the contribution of the message's source (the issuer) to the forwarder and the intimacy with the forwarder so as to help maximize the overall network message delivery ratio and promote win-win emerging.

A message gets different forwarding order when forwarded by different node, and its preferential forwarding is beneficial for the fast delivery. Classical forwarding schemes (e.g., SimBet Routing [13]) often simply consider candidate forwarders' abilities to deliver messages (e.g., the node's social similarity to the destination), which are determined by candidate forwarders' self-conditions. However, they often neglect the message's forwarding orders got by the candidate forwarder, which is determined by the attribute of the message, e.g., the arrival time of the massage in FIFO. Therefore, to select the forwarder for a message, both the delivery ability of the candidate forwarder and the forwarding order of the message by the candidate forwarder should be considered.

Based on the above, we propose a social-based routing scheme for VANET in the fixed-line transportation to enable efficient and effective message delivery among passengers, and the major contributions are summarized as follows.

- We propose a social-based routing algorithm to forward messages hop by hop based on the statistical social information accumulated during network operation. It has low overhead and does not need any prior knowledge of vehicles when routing.
- We improve the well-known *k*-clique community detection algorithm [14] with our devised lowliest place elimination method so that the passengers with strong encounter regularities and closely social relationships could be merged into the same community to improve the forwarding efficiency.
- Based on the social regularity under which cooperation happens more likely among friends with close relationships and frequent interactions, a social-based message buffering scheme at vehicle is proposed. It uses contribution and intimacy to improve message delivery within the limited contact time window. It tries to improve the forwarding efficiency of the network rather than that of one single node.
- We propose a bilateral forwarder determination method. When selecting the forwarding node for the message among candidates, it considers not only the candidates' physical and social conditions but also the buffering priority of the message got by the candidates.

The rest of this paper is organized as follows. Section 2 reviews related works and compares our work with them. Section 3 presents the system framework of the proposed routing scheme. Section 4 presents the improved *k*-clique community detection algorithm. Section 5 describes the devised contribution and intimacy based buffering management scheme. Section 6 presents the bilateral forwarder determination method. Section 7 describes the proposed social-based routing algorithm. Section 8 reports the simulations and performance evaluations. Section 9 draws conclusions.

2. Related work

There are already a lot of routing schemes proposed for VANET. Among them, some regard the fixed-line transportation [31–43], some regard the none-fixed-line transportation [25–30], and others regard both [11,15–24].

Many classical Delay Tolerant Network (DTN) routing schemes, such as Epidemic [11] and First Contact [15], can be applied to both the fixed-line and the none-fixed-line VANET. In addition, in [16], an optimization of zone based hierarchical link state routing protocol for VANET was proposed, and its routing parameters were optimized based on the traffic awareness and network performance. In [17], a geographic stateless routing scheme combined with node location and digital map was proposed, which could enhance the forwarding path to solve local maximum and sparse connectivity problem. In [18], an acknowledgment-based broadcast protocol for reliable and efficient data dissemination for VANET was proposed. It was suitable to a wide range of vehicular scenarios, and solved the propagation at road intersections without any need to recognize intersections. In [19], by exploring the spatial and temporal properties of the contact behaviors among buses and taxis, a multi-modal VANET message dissemination scheme was proposed, by allowing the buses to assist the message dissemination among taxis. In [20], a hybrid bee swarm routing protocol for VANET was presented, which was based on the continuous learning paradigm and combined the features of topology routing with those of geographic routing, aiming at both urban and rural scenarios. In [21], buses were regarded as the mobile backbone of VANET to aid data transmissions, and a table driven and bus based routing protocol to increase the packet delivery and reduce the average delay was proposed. In [22], a hierarchical bloom-filter routing was introduced to tackle mobility, large population, and rich content challenges of VANET. It achieved low latency and high content availability with relatively low overhead in practical VANET scenarios. In [23], a routing protocol for VANET in urban area was designed. It had an optimized and adjustable forwarding range, which changed with different environments based on the path loss and the city model. It was novel in computing the connectivity of roads and the adjustable strategy in a sparse network. In [24], a hop greedy routing scheme was proposed, which took connectivity into consideration and yielded a routing path with the minimum number of intermediate intersection nodes.

As general-purpose routing schemes, the above researches do not fully take the specific characteristics of the fixed-line transportation VANET into account, and thus do not take advantage of, e.g., vehicle's high encounter regularity, when routing. In addition, they do not consider the influence of social relations among passengers on message forwarding. In contrast, our proposed scheme takes these factors into account and thus improves routing efficiency and effectiveness.

Regarding to the none-fixed-line VANET routing, in [25], a distance aware epidemic routing protocol was proposed to improve the bundle delivery ratio. In [26], a prediction-based soft routing protocol was proposed, in which the traffic trace and the real digital road map were utilized to assist packet routing. In [27], an approach for geographic routing which exploited the predictive locations of vehicles was proposed. In [28], a self-balancing supply/demand routing protocol was proposed. It was a controlled flooding protocol and could reliably deliver messages over predictable distances. In [29], a routing metric was proposed to exploit the true opportunism, which was stochastically calculated by taking the expectation of the minimum delays over all possible routes and could be computed online by relying only on local information sharing. In [30], a reliable freestanding position based routing algorithm was proposed. It considered the constraints of the environment and implemented mechanisms to overcome them. However, the above none-fixed-line transportation oriented routing schemes cannot solve the fixed-line transportation routing issues efficiently because the characteristics of the fixed-line transportation are not taken into account.

Regarding to the fixed-line VANET routing, in [31], the message was delivered to the bus, of which route overlapped the trace of the destination vehicle; moreover, when the bus traveled in the overlapped route, it broadcasted the message to any vehicle that it encountered. In [32], an anchor bus based street and traffic aware routing scheme was proposed. It was designed specifically for performance improvement in city environment of VANET and inherited the characteristics of geographic routing. In [33], an end-to-end transmission time based opportunistic routing framework was proposed, and three different routing protocols were designed which considered three different end-to-end transmission time metrics. In [34], a bus ad hoc on demand distance vector routing protocol was proposed, which could reduce the high end-to-end packet delay produced by vehicle specific movement patterns. In [35], the original routing problem was formulated as a specific stochastic shortest path problem on a particular stochastic graph. An optimal single-copy routing algorithm was devised and it was extended to cases where several copies of the same data were permitted. In [36], a position based routing protocol for metropolitan bus network was proposed. It used street map information and bus route information to identify a stable geographic route with high connectivity for data delivery. However, the above researches make routing or forwarding decision based on message broadcasting [31,33,34], which incurs high overhead, or needs prior knowledge of vehicles, such as street map [32,36] and bus schedule [35]. In contrast, our proposed routing scheme considers the social characteristics of passengers, which are accumulated and analyzed during network operation. It routes the message to the destination hop by hop with single copy by social guidance, and thus it can decrease network overhead and improve routing efficiency.

There exist some researches on the fixed-line VANET routing with certain social guidance applied. In [37], a social interest based routing scheme was proposed, which incorporated the user interest into the working movement model and leveraged the diversity of interest in bus movement for data delivery. In [38], by analyzing large-scale bus traces, it was found that vehicles demonstrated dynamic sociality and had strong temporal correlations. The Markov chains were used to infer future vehicular sociality and one greedy heuristic was applied to select the most “centric” vehicles as seeds for mobile advertising. Although the above researches consider social characteristics of the fixed-line transportation to a certain extent when routing, however, they neglect the community structures which exist in the fixed-line VANET. In [31], a community based backbone was built by applying community detection techniques in the bus system, and a two-level routing scheme was proposed to operate over the backbone. It performed sequentially in the inter-community level and the intra-community level to support message delivery for mobile vehicles. In [39], a context-aware community-oriented routing approach was presented, which exploited the community and the context awareness of nodes for efficient message delivery, and nodes with a common point of interest formed a dynamic community. However, the community detections in [31] and [39] are put forward regarding to vehicles rather than passengers who are actually the sources and destinations of the produced messages. In this paper, we extract community structures among passengers by analyzing their contact regularities and controlling community size, making passengers with closely social relationship be in the same community and thus helping improve message delivery efficiency.

Moreover, when determining the forwarder for the message, the above researches do not consider the buffering priority of the message got by the forwarder. For example, a received packet was forwarded towards the selected destination junction using street awareness and traffic awareness in [32], the transmission failure probability and waiting time at the next stop before the arrival of the next bus were considered when forwarding the packet from one bus to another in [35], and the location of the destination was used for packets forwarding in [40]. Besides, in [41], once a bus met another one belonging to the same line, it simply forwarded the packet to that bus. Compared with them, our proposed scheme considers not only the candidate’s physical and social conditions but also the buffering priority of the message got by the candidate when determining the message forwarder.

About buffering management scheme for message handling at vehicles when routing, in [11], the finite buffers were managed as FIFO queues. In [42], a Drop Least Encountered (DLE) algorithm was used, in which messages with the lowest delivery likelihood were dropped. In [43], a buffer management scheme was proposed based on prioritizing both the schedule of packets to be transmitted to other peers and the schedule of packets to be dropped by considering the message hop count and delivery possibility. In [41], when the buffer became full, each newly arrived packet was simply dropped. Compared with the above mentioned schemes which manage buffers only based on the message attributes, our proposed social-based message buffering mechanism can provide more efficient message forwarding by facilitating reciprocity among vehicles.

Table 1
Abbreviations.

Abbreviation	Full name
ACD	Accumulated Contact Duration
BFD	Bilateral Forwarder Determination method
CMD	Community Member Density
ECM	intEr-Community Message
ECFD	intEr-Community Forwarder Determination
ICM	Intra-Community Message
ICFD	Intra-Community Forwarder Determination
IKC	Improved *K*-clique Community detection algorithm
LET	Link Expiration Time
PES	Periodical Encounter Strength
SFR	Social-based Fixed-line transportation Routing scheme
SMB	Social-based Message Buffering scheme at the vehicle

3. System framework

For convenience, the abbreviations used throughout this paper are listed in Table 1.

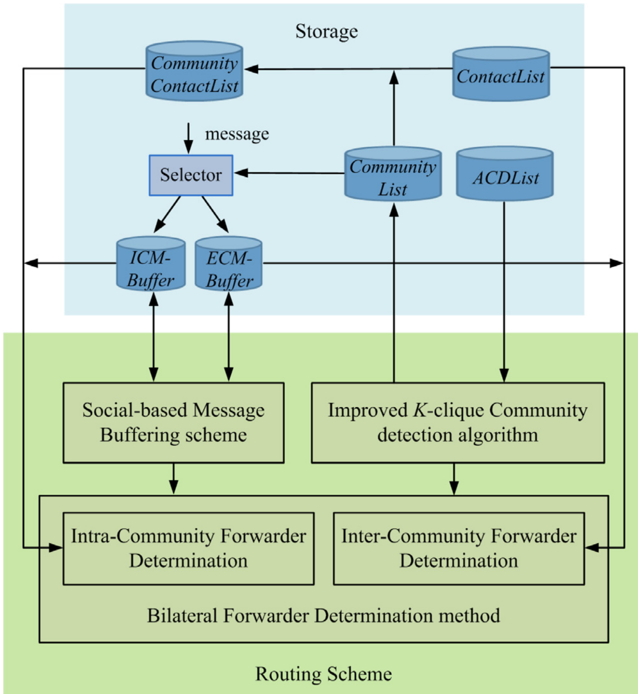


Fig. 1. SFR system framework.

The system framework of our proposed SFR is shown in Fig. 1. Assume that SFR runs on the wireless router equipped with GPS (Global Positioning System) [44] at vehicle, which is denoted as vehicle node for convenience. If one passenger wants to send messages to another one, he sends them from his mobile device (denoted as passenger node) to SFR at his vehicle node, and SFR delivers them to their destinations. At first, based on the *ACDList* of the passenger nodes (see Section 4), these passenger nodes are divided into different communities by IKC (see Section 4), and their vehicle nodes are recorded. That is to say, a community has the information about passenger nodes and vehicle nodes. These communities are stored in the *CommunityList*.

When a vehicle node receives a new message (except the delivery message which is already on the vehicle node taken by its destination passenger node), this message is determined to become an ICM or an ECM by the selector, which makes decisions according to the *CommunityList*. If the destination node of this new message is in the same community with this vehicle node, it stores the message into the *ICM-Buffer*, and sorts buffering ICMs stored in the *ICM-Buffer* based on SMB so as to determine the ICM's forwarded or dropped order (see Section 5); otherwise, it stores the message into the *ECM-Buffer* and sorts ECMs in it. When a vehicle node encounters other ones, it determines the forwarder for the message based on BFD (see Section 6). Specifically, if the destination passenger node of the message is in the same community with the message's forwarder, the next forwarder is determined by ICFD from the *CommunityContactList*, which stores the encounter nodes in the same community with the message's forwarder; otherwise, it is determined by ECFD from the *ContactList*, which stores the encounter nodes of the message's forwarder. For the forwarded message, SMB and BFD handle it hop by hop until being delivered to the destination or dropped.

As depicted in Fig. 2(a), assume that there are four buses, that is, bus1 and bus4 of bus line LINE1 ($A-E-F-C$), bus2 of bus line LINE2 ($A-E-B-F-C$), and bus3 of bus line LINE3 ($A-D$). Assume that Bob and Lucy are first-year students in the university near A and they do not know each other, however, both of them like exercising in the gym near C, then they probably take bus1 and bus4 respectively from A to C. Assume that Jim is a student in the university near B and he also likes exercising in the gym near C, then Jim may take bus2 from B to C. LINE1 and LINE2 have the overlapped segment $F-C$, bus1 and bus4 run along the same bus line, then the communication opportunities among Jim, Lucy and Bob are high. This example indicates that routing efficiency and thus message delivery effectiveness can be improved by employing the regularity of the fixed-line transportation taken by passengers.

Table 2
Communities with passenger nodes and vehicle nodes.

Community	Passenger nodes	Vehicle nodes
C_1	P_1, P_2, P_3, P_4 (Lucy) P_5, P_6, P_7 (Jim) P_8, P_9 (Bob)	bus4 bus2 bus1
C_2	P_{10}, P_{11}, P_{12} P_{13}, P_{14} (Tom)	bus8 bus3
...	...	...

As depicted in Fig. 2(b), based on IKC, Jim, Lucy and Bob (together with bus2, bus4 and bus1) are in the same community but Tom (together with bus3) is not. When Tom sends m_a to Bob, at first he sends m_a to his taken bus3, and m_a is stored in bus3's *ECM-Buffer* since bus3 and Bob are not in the same community. Then, bus3 forwards m_a to Jim's taken bus2 based on ECFD and m_a is stored in bus2's *ICM-Buffer* since bus2 and Bob are in the same community. At this moment, bus2 forwards m_a to Lucy's taken bus4 based on ICFD. When bus4 encounters bus1, it forwards m_a to Bob's taken bus1. Then bus1 stores m_a in its *deliver-Buffer*, and delivers it to Bob finally when he takes bus1.

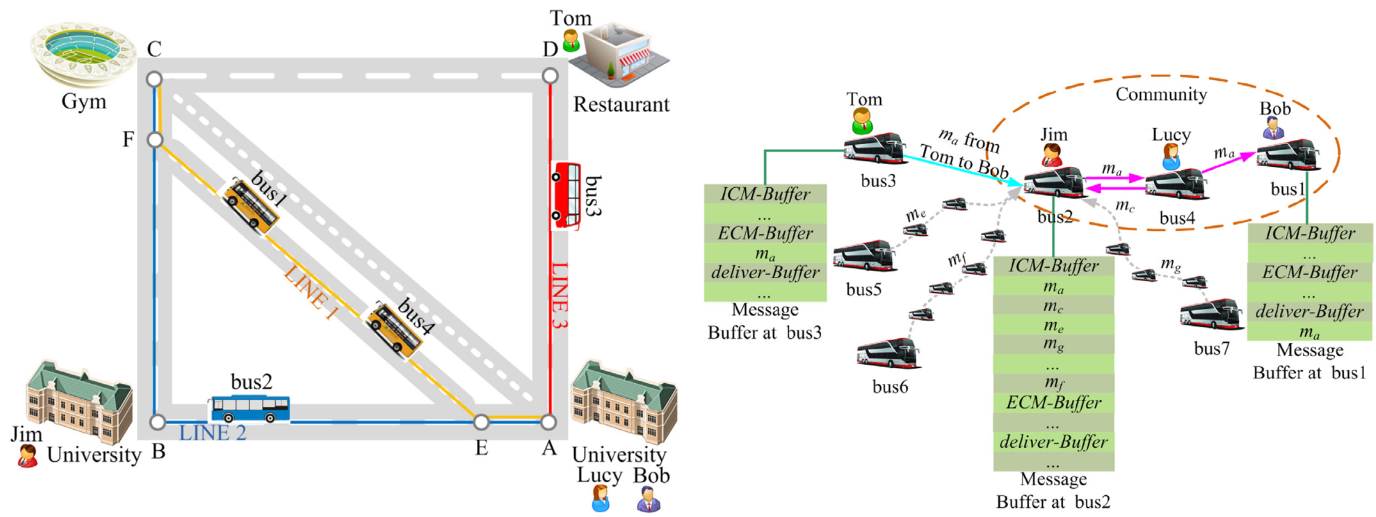
Assume that bus2 buffers m_c from Lucy, m_e, m_f and m_g from passenger nodes on bus5, bus6 and bus7 respectively, and these messages are all stored in the *ICM-Buffer* of bus2. When bus2 receives m_a, it sorts the ICMs in the *ICM-Buffer* by SMB. The ICMs are forwarded from buffer head (m_a in Fig. 2(b)) when bus2 encounters other buses while dropped from buffer bottom when the buffer is full (m_f in Fig. 2(b)).

4. Improved *k*-clique community detection algorithm

The community detection algorithm can be used to identify the unknown structures that have inherent or external specified similarities among nodes [45]. For the fixed-line VANET, the community detection needs to extract passenger nodes as well as vehicle nodes with contact regularity to build communities at the same time to control the community size appropriately.

The well-known *k*-clique algorithm [14] extracts communities based on contact duration among nodes and the number of the common members among communities. In this paper, we improve it by adding the lowliest place elimination method to identify the communities among passenger nodes and vehicle nodes, called the Improved *K*-clique Community detection algorithm (IKC). In IKC, passenger nodes with high contact regularities are firstly assigned into the same community, and then those communities, of which the number of the common members exceeds a certain upper bound, are merged. The communities consist of the passenger nodes and their taken vehicle nodes are illustrated in Table 2, where each vehicle node holds a community table.

The Accumulated Contact Duration (ACD) among people, which is the total contact time in the predefined period, can reflect their contact strength. People with high ACD always have strong contact strength and likely to encounter each other. Each vehicle node can obtain an *ACDList* which contains ACDs among passenger nodes,



(a) Application scenario (b) SFR workflow

Fig. 2. Illustration example.

Fig. 3. Contact modes.

```
Input: ACDList, Ω, θ, k
Output: CommunityList
01: Initialize all communitis in CommunityList to be ϕ;
02: for i=1 to n, do
03:   for j=1 to n, do
04:     Take ACD_ij from ACDList;
05:     if ACD_ij > Ω
06:       Put p_j into lcl−community_i;
07:     end if
08:   end for
09: end for
10: for i=1 to n, do
11:   for j=1 to n, do
12:     if (lcl−community_i != ϕ) and (lcl−community_j != ϕ) and (the number of
        common members between lcl−community_i and lcl−community_j > k)
13:       Merge lcl−community_j into lcl−community_i;
14:       Set lcl−community_j be ϕ;
15:     end if
16:   end for
17: end for
18: for i=1 to n, do
19:   if lcl − community_i != ϕ
20:     if the size of lcl−community_i > θ
21:       Sort the members of lcl−community_i in descending order according to
          average ACDs;
22:       Delete the last m passenger nodes and let each of them become a
          single−node−community with the vehicle node recorded;
23:     end if
24:     Set lcl−community_i be a community and record the corresponding
        taken vehicle nodes of the passenger nodes;
25:     Put the community and single−node−communities into CommunityList;
26:   end if
27: end for
28: return CommunityList
```

Fig. 4. Improved k-clique community detection algorithm.

by exchanging social information of their taking passenger nodes when two vehicle nodes encounter. When the signals from two passenger nodes (e.g., cell phones) or from their taken vehicle nodes overlap, the two passenger nodes are considered to be contacted with each other, as shown in Fig. 3. We use ACDs among passenger nodes to divide them into communities.

Assume that there are n passenger nodes, and IKC is described as follows.

At first, the local community of each passenger node is created, and it stores other passenger nodes that have close relationship with the passenger node. Specifically, for a passenger node, if its ACD with another one is larger than the predefined bound Ω, this another one will be a member in its local community, denoted as *lcl-community*. In this way, we get n *lcl-communities*, which correspond to the n passenger nodes. Take passenger node p_i for example, the ACDs between p_i and the other $n-1$ passenger nodes are got from the *ACDList* in turn. Assume that p_j is one of these $n-1$ passenger nodes, if ACD_{ij} between p_i and p_j is larger than Ω, p_j will be a member in the local-community of p_i, denoted as *lcl-community*$_i$.

Next, we merge those *lcl-communities* with too many common members in order to limit the number of communities. If the number of common members between two nonempty *lcl-communities* is above the predefined threshold k, we merge them into one of these two *lcl-communities* and set another be empty.

At last, those over-sized *lcl-communities* are downsized, that is, the lowliest place elimination for each *lcl-community* is done. Specifically, if the number of members in a *lcl-community* is larger than the predefined bound θ, the members of this *lcl-community* are sorted in descending order according to the average ACDs of each member (the average ACD of a member is defined as the sum of ACD between this member and any other member divided by the number of members of this *lcl-community*), and the members beyond θ are eliminated from bottom up. Each of the eliminated passenger node becomes a *single-node-community* that has only this passenger node with its taken vehicle node. After that, each nonempty *lcl-community* becomes a *community* with the recorded passenger nodes' taken vehicle nodes. These *communities* and *single-node-communities* are stored into the *CommunityList*, which has communities with passenger nodes and their taken vehicle nodes.

The IKC is shown in Fig. 4. Here, lines 2–9 are the formation of the local communities. Lines 10–17 are the merging of the local communities. Lines 18–27 are the lowliest place elimination for the local communities and forming the *CommunityList*.

5. Social-based message buffering scheme

5.1. Basic ideas

People often have such experience in their daily lives that indirect friendship, i.e., a *friend's friend*, does not have the same strong relationship as direct friendship. Although a *friend's friend* may offer help to the issuer of a request, his intention usually is weaker than that of his friend, and thus intimacy among people impacts the request fulfillment. Friends should contribute and share resources and thus help should be mutually provided among friends rather than one unconditionally pays for another. People are willing to help others, who have helped them, i.e., contributed to them, and thus contribution among people also has impact on the request fulfillment.

5.2. Priority calculation

Inspired by the above ideas, vehicle node calculates the priority for each message in its buffer. The priority for a message is calculated based on the intimacy of the message's issuer (the taken vehicle node of the source passenger node) with the message's forwarder and the contribution to the message's forwarder. Suppose that m is a message on a vehicle node v, and that $P(m, v)$ is the priority of m at v, then

$$P(m, v) = \alpha P\_contri(v_{iss}, v) + (1 - \alpha)P\_inti(v_{iss}, v) \quad (1)$$

Here, $P\_contri(v_{iss}, v)$ is the priority calculated based on the contribution of v_{iss} (the issuer of m) to v, defined in Eq. (2); $P\_inti(v_{iss}, v)$ is the priority calculated based on the intimacy of v_{iss} with v, defined in Eq. (3); α and $(1 - \alpha)$ indicate the weights of contribution and intimacy, which reflect their relative influence on the social relationship. We use the weighted average method to calculate the priority because P_contri and P_inti have the same range of values (from 0 to 1). Besides, the result obtained by the weighted average method can well be traded-off between the two considered factors.

$$P\_contri(v_{iss}, v) = \frac{2}{\pi} arctanCtr(v_{iss}, v) \quad (2)$$

Here, $Ctr(v_{iss}, v)$ is the contribution of v_{iss} to v in terms of the number which the former forwarded messages for the latter by now. We use arctan function to calculate P_contri because it can reflect the social phenomenon properly. Specifically, as P_contri shown in Fig. 5, the social phenomenon can be observed as follows. When one person has helped another one more than certain times (here $Ctr = 7$), the helped one considers the helper as a person who has made great contribution to him (here $P\_contri = 0.9$). With the increasing of Ctr, the increased amplitude of P_contri decreases, that is, if the helper offers his help continuously, the helped one is gradually accustomed to his help. Moreover, P_contri approaches 1 gradually, that is, one always hopes to get the help from others, and the more help means the better feelings.

$$P\_inti(v_{iss}, v) = e^{1 - Cls(v_{iss}, v)} \quad (3)$$

Here, $Cls(v_{iss}, v)$ is the intimacy of v_{iss} with v in terms of the message's hop count from the former to the latter. We use exponential function to calculate P_inti because it can reflect the social phenomenon properly. Specifically, as P_inti shown in Fig. 6, the social phenomenon can be observed as follows. When two persons are close to each other (here $Cls < 6$), they have relatively high intimacy (from 0.018 when $Cls = 5$ to 1 when $Cls = 1$), while they have relatively low intimacy (no more than 0.007) when they are far from each other ($Cls \geq 6$). It accords with the famous small world phenomenon [46].

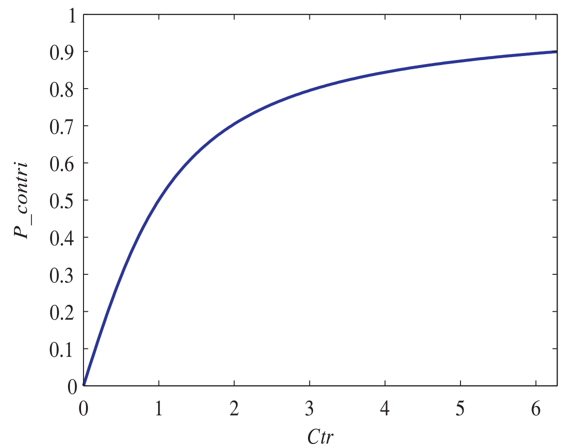


Fig. 5. *P_contri*.

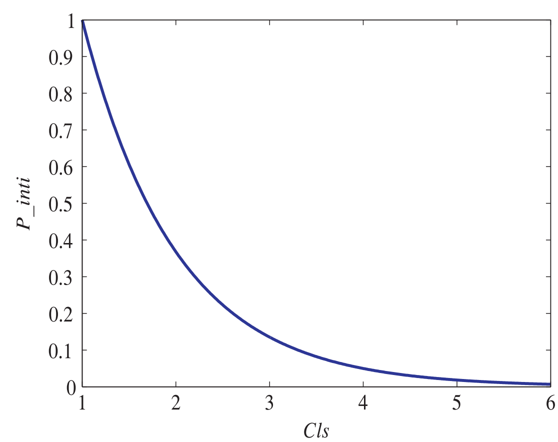


Fig. 6. *P_inti*.

According to the Eqs. (1)–(3), the larger the number the issuer of the message has helped the forwarder and the more intimate the issuer with the forwarder, then the higher the forwarding priority of the message.

5.3. Message buffering scheme

Each message has a priority calculated by Eq. (1). SMB sorts messages according to their priorities in descending order. A message with the highest priority is forwarded firstly, while a message with the lowest priority is dropped firstly when necessary. Assume that the message buffer of bus2 in our illustration example is shown in Fig. 7. We can see that the issuer of m_a, bus3 has intimacy with bus2 with 1 and contribution to bus2 with 3, which has the higher priority than other buffering messages, thus it is forwarded firstly. However, the issuer of m_f, bus6 has intimacy with bus2 with 5 and contribution to bus2 with 1, which has the lower priority than other buffering messages, thus it is dropped firstly when necessary.

6. Bilateral forwarder determination method

Whether one message has arrived at the community or not, to which its destination belongs, has significant influence on the message delivery. In the example mentioned above, Tom often takes bus3 of LINE3 from D to A, and Jim and Bob are in the same community while Tom and Bob not. When bus2 receives m, it can

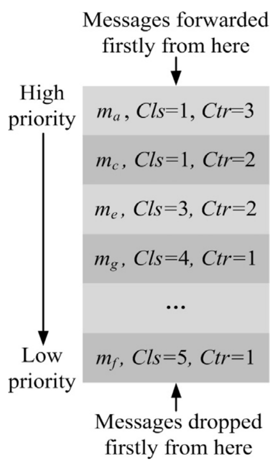


Fig. 7. SMB at bus2.

forward m to bus1, and then to Bob rapidly; however, when bus3 receives m, it should forward m not only to bus1 but also to the taken buses of Bob's community members (e.g., bus4), so that the message's forwarding scope can be extended to speed up its delivery. In this paper, messages are divided into two types: Intra-Community Message (ICM), which has arrived at its destination community (the community of its destination passenger node), such as m_a for bus2 and bus4 in our illustration example; and intEr-Community Message (ECM), which has not, such as m_a for bus3. We design the forwarding determination methods for ICM and ECM respectively.

6.1. ICM forwarder determination

For the ICM forwarding, the forwarder is determined by comparing the forwarding utilities of candidates. The forwarding utility is decided by the following two aspects: (1) physical and social conditions of candidates and (2) buffering priorities of the message got by the candidates. To explain why we consider the buffering priorities of the message got by the candidates, we consider another scenario in Fig. 2(a) as follows. The node bus1 forwards a message m and it has two encounter nodes bus2 and bus3, in which the two buses have the same delivery ability for m, then bus1 should forward m to bus2 if it can get the prior forwarding order from bus2 rather than bus3.

6.1.1. Link expiration time

For physical condition, we consider Link Expiration Time (LET) among vehicle nodes. LET in VANET is defined as the time to keep contact between two contacting vehicle nodes. Two nodes have higher LET means that they can keep contact with each other longer than those in the opposite way, and thus they can transmit messages with less interruption. Depending on the GPS equipped at each vehicle node, we can calculate LET by the location and velocity information. We calculate LET based on the definition in [47], which is calculated in Eq. (4). Assume that each vehicle node has the same signal transmission ability and the same transmission range R. The LET between vehicle nodes v_a and v_b is denoted as $LET(v_a, v_b)$ and defined as follows.

$$LET(v_a, v_b) = \frac{R + \beta * dis(v_a, v_b)}{\left|\overrightarrow{v(v_a)} - \overrightarrow{v(v_b)}\right|} \tag{4}$$

Here, $\beta \in \{-1, 0, 1\}$, specifically, $\beta = 1$ if two nodes are moving towards each other, $\beta = -1$ if two nodes are moving far away from each other, otherwise $\beta = 0$; $dis(v_a, v_b)$ is the distance between v_a and v_b; $\overrightarrow{v(v_a)}$ is the velocity of v_a and $\overrightarrow{v(v_b)}$ is the velocity of v_b.

Calculation about acceleration is discussed in [47], in which an extra-large-bonus of the number of seconds is added to LET. In order to make the two factors in M_{ICM} (see Eq. (7)) and M_{ECM} (see Eq. (11)) have the same range of values, after obtaining LET between two vehicle nodes, we do the normalization on it by calculating $2/\pi * \arctan LET$ to make its value within [0,1).

6.1.2. Community member density

We consider the Community Member Density (CMD) for social condition. In order to provide fast and accurate delivery, an ICM should be forwarded to the community member with strong delivery capability. In common sense, when a member is able to encounter more members than others, it may have stronger capability for message delivery. Therefore, we introduce CMD to measure such capability. The CMD of one node for an ICM is the ratio of the number of this node's encounter nodes, which belong to ICM's destination community, to the number of total members of the community. Suppose that $CMD(v, m)$ is the CMD of a vehicle node v for a message m, then

$$CMD(v, m) = \frac{S(v, m) + 1}{N(m)} \tag{5}$$

Here, $S(v, m)$ is the number of v's encounter vehicle nodes belonging to m's destination community and $N(m)$ is the total number of vehicle node members in this community. Due to the fact that v is also one community vehicle node member of the community, we add 1 to $S(v, m)$.

6.1.3. ICM forwarding utility

As mentioned above, the ICM forwarding utility considers candidates' physical and social conditions, and the buffering priorities of the message got by the candidates. Assume that v_{enc} is an encounter vehicle node and m is a forwarding message of vehicle node v. We define the ICM forwarding utility of v_{enc} for m in Eq. (6), which is calculated by v.

$$U_{ICM}(v_{enc}, m) = \eta M_{ICM}(v_{enc}, m) + (1 - \eta)P(m, v_{enc}) \tag{6}$$

Here, $M_{ICM}(v_{enc}, m)$ is the utility produced by the vehicle node's own physical and social conditions, which is defined in Eq. (7), and $P(m, v_{enc})$ is defined in Eq. (1); η and $(1 - \eta)$ are the weights to indicate the relative influence of M_{ICM} and P on U_{ICM}. The weighted average method is used to do trade-off between $M_{ECM}(v_{enc}, m)$ and $P(m, v_{enc})$.

$$M_{ICM}(v_{enc}, m) = \lambda CMD(v_{enc}, m) + (1 - \lambda)LET(v_{enc}, v) \tag{7}$$

Here, $CMD(v_{enc}, m)$ is the social factor and $LET(v_{enc}, v)$ is the physical factor, λ and $(1 - \lambda)$ are the weights to indicate the relative influence of social condition and physical condition on M_{ICM}. The weighted average method is used to do trade-off between $CMD(v_{enc}, m)$ and $LET(v_{enc}, v)$.

6.1.4. ICM forwarding

In case of the ICM forwarding, one encounter vehicle node needs to be selected as the forwarder for ICM. As mentioned above, ICM is the message that has arrived at its destination community. Thus, to avoid ICM being forwarded out of its destination community, the ICM forwarding only focuses on the vehicle nodes belonging to this community. Assume that a vehicle node v forwards a message m, and the encounter vehicle nodes of v, which belong to m's destination community, are stored in $CommunityContactList_m$, which has s nodes. The ICM forwarding is described as follows. At first, the $CommunityContactList_m$ is checked whether it has the destination passenger node's taken vehicle node of m, which is denoted as $v_{des}(m)$. If it has, m is forwarded to $v_{des}(m)$; otherwise, the s nodes are sorted in the $CommunityContactList_m$ in descending order according to U_{ICM} in

```
Input: a message m, CommunityContactList_m
Output: a forwarding vehicle node
if v_des(m) is in CommunityContactList_m
  Forward m to v_des(m);
  return v_des(m);
end if
Sort CommunityContactList_m by U_ICM in descending order;
for enc=1 to s, do
  Calculate CMD(v_enc, m) and CMD(v, m);
  if CMD(v_enc, m) > CMD(v, m)
    Forward m to v_enc;
    return v_enc;
  end if
end for
```

Fig. 8. Intra-community forwarder determination.

```
Input: a message m, ContactList_m
Output: a forwarding vehicle node
if v_des(m) is in ContactList_m
  Forward m to v_des(m);
  return v_des(m);
end if
Sort ContactList_m by U_ECM in descending order;
for enc=1 to r, do
  Calculate PES(v_enc, v_des(m)) and PES(v, v_des(m));
  if PES(v_enc, v_des(m)) > PES(v, v_des(m))
    Forward m to v_enc;
    return v_enc;
  end if
end for
```

Fig. 9. Inter-community forwarder determination.

Eq. (6), and then each of them is taken from the list in turn. Assume that v_{enc} is one taken node by v, we compare CMD for m of v_{enc} and v, which are denoted as $CMD(v_{enc}, m)$ and $CMD(v, m)$. If $CMD(v_{enc}, m)$ is larger than $CMD(v, m)$, v forwards m to v_{enc}; otherwise, it continues comparing with the next node in the $CommunityContactList_m$. If the CMD of these s nodes for m are all not larger than $CMD(v, m)$, v continues carrying m and does not forward it to any encounter node. ICFD is described in Fig. 8.

6.2. ECM forwarder determination

For the ECM forwarding, the optimal forwarder is determined by the forwarding utilities of candidates, which are defined similar to that of ICM. Instead, the so-called periodical encounter strength is used to reflect the social condition.

6.2.1. Periodical encounter strength

Encounter regularities among vehicle nodes in the fixed-line VANET always depend on their encounter number and periodicity. In order to speed up the ECM delivery, we introduce the Periodical Encounter Strength (PES) as the social metric for ECM forwarding, which can reflect the influence of encounter number and periodicity on the regularity. Define $PES(v_a, v_b)$ as the PES of vehicle nodes v_a and v_b, which is calculated as follows.

$$PES(v_a, v_b) = \psi PES_{old}(v_a, v_b)\sigma^{p(v_a, v_b)} + (1-\psi)EN \tag{8}$$

Here, we define $EN \equiv 1$ to represent one time encounter; ψ and $(1-\psi)$ are the weights to indicate the relative influence of encounter periodicity and encounter number on *PES;* σ is the decay factor, which is designed based on [48]; $p(v_a, v_b)$ is the encounter periodicity between v_a and v_b, which is defined in Eq. (9). The weighted average method is used to do trade-off between encounter periodicity and encounter number.

$$p(v_a, v_b) = \left| t(v_a, v_b) - \overline{t(v_a, v_b, n)} \right| \tag{9}$$

Here, $t(v_a, v_b)$ is the time interval between this encounter moment and the previous encounter moment between v_a and v_b, and $\overline{t(v_a, v_b, n)}$ is their average time interval over n last encounters. $PES(v_a, v_b)$ is updated whenever v_a and v_b encounter each other.

According to Eqs. (8) and (9), the PES increases with vehicle nodes' encounter number, and strong encounter periodicity enhances PES. Indeed, the stronger the encounter periodicity and the higher the encounter number, the larger the PES.

6.2.2. ECM forwarding utility

Assume that v_{enc} is an encounter node and m is a forwarding message of vehicle node v. We define the ECM forwarding utility of v_{enc} for m in Eq. (10) , which is calculated by v.

$$U_{ECM}(v_{enc}, m) = \gamma M_{ECM}(v_{enc}, m) + (1-\gamma)P(m, v_{enc}) \tag{10}$$

Here, $M_{ECM}(v_{enc}, m)$ is the utility produced by the vehicle node's own physical and social conditions, which is defined in Eq. (11); γ and $(1-\gamma)$ are the weights to indicate the relative influence of M_{ECM} and P on U_{ECM}. The weighted average method is used to do trade-off between $M_{ECM}(v_{enc}, m)$ and $P(m, v_{enc})$.

$$M_{ECM}(v_{enc}, m) = \mu PES(v_{enc}, v_{des}) + (1-\mu)LET(v_{enc}, v) \tag{11}$$

Here, $PES(v_{enc}, v_{des})$ is the social factor, in which v_{des} is the taken vehicle node of m's destination passenger node; $LET(v_{enc}, v)$ is the physical factor; μ and $(1-\mu)$ are the weights to indicate the relative influence of social condition and physical condition on M_{ECM}. The weighted average method is used to do trade-off between $PES(v_{enc}, v_{des})$ and $LET(v_{enc}, v)$.

6.2.3. ECM forwarding

Similar to the ICM forwarding, the ECM forwarding needs to select one encounter vehicle node as the forwarder for the ECM. Assume that a vehicle node v forwards a message m, and the encounter vehicle nodes of v are stored in $ContactList_m$, which has r nodes. The ECM forwarding is described as follows. Firstly, the $ContactList_m$ is checked whether it has the destination passenger node's taken vehicle node of m, which is denoted as $v_{des}(m)$. If it has, m is forwarded to $v_{des}(m)$; otherwise, the r nodes are sorted in the $ContactList_m$ in descending order according to U_{ECM} in Eq. (10), and then each of them is taken from the list in turn. Assume that v_{enc} is one taken vehicle node by v, then we compare PES for $v_{des}(m)$ of v_{enc} and v, which are denoted as $PES(v_{enc}, v_{des}(m))$ and $PES(v, v_{des}(m))$. If $PES(v_{enc}, v_{des}(m))$ is larger than $PES(v, v_{des}(m))$, v forwards m to v_{enc}; otherwise, it continues comparing with the next node in the $ContactList_m$. If the PES of these r nodes for $v_{des}(m)$ are all not larger than $PES(v, v_{des}(m))$, v continues carrying m and does not forward it to any encounter node. ECFD is described in Fig. 9.

7. Social-based fixed-line transportation routing scheme

In the proposed SFR, a message is processed by vehicle nodes as follows according to the concrete situations until it is delivered to its destination successfully or failed. (1) If the destination passenger node of the message is the one that takes the vehicle node, for example, m_a for bus1 in our illustration example, the message is delivered directly to its destination; (2) if the destination passenger node of the message is not the one that takes the vehicle node but is in the community to which the vehicle node belongs, for example, m_a for bus2 and bus4, it is forwarded as one ICM to the next hop; (3) if the destination passenger node of the message is not the one that takes the vehicle node and is not in the community to which this vehicle node belongs, for example, m_a for bus3, it is forwarded as one ECM to the next hop.

We demonstrate how SFR works by a vehicle node v. Firstly, v gets the $CommunityList$ according to IKC to obtain the communities

```
Input: ACDList, Ω, θ, k
01: Get CommunityList by IKC;
02: upon receive a message m
03:   if v_des is v
04:     Store m into deliver-Buffer;
05:   else if m is an ICM
06:     Store m into ICM_Buffer;
07:     Sort ICM_Buffer by SMB;
08:   else Store m into ECM_Buffer;
09:     Sort ECM-Buffer by SMB;
10:   end if
11: end upon
12: upon ICM_Buffer is not empty
13:   for m_icm ∈ ICM_Buffer
14:     if CommunityContactList_m_icm !=ϕ
15:       do ICFD;
16:     end if
17:   end for
18: end upon
19: upon (ContactList !=ϕ) and (ECM_Buffer !=ϕ)
20:   for m_ecm ∈ ECM_Buffer
21:     do ECFD;
22:   end for
23: end upon
```

Fig. 10. SFR at vehicle nodes.

of passenger nodes as well as their taken vehicle nodes. When v receives a message m, if m's taken vehicle node of its destination passenger node, denoted as v_{des}, is v, m is stored into the *deliver-Buffer*; otherwise, we determine m is an ICM or an ECM according to the *CommunityList*. If m is an ICM, it is stored into the *ICM-Buffer*. If m is an ECM, it is stored into the *ECM-Buffer*. Due to the fact that a message stored in vehicle node's *deliver-Buffer* is already on its destination vehicle node and will be directly forwarded to its destination passenger node, thus message routing among vehicle nodes is no more needed. Consequently, SFR only sorts the *ICM-Buffer* and the *ECM-Buffer* based on SMB. When v has ICMs, that is, the *ICM-Buffer* is not empty, we take ICM from the *ICM-Buffer* in turn, and assume that the taken ICM is m_{icm}. When v encounters other community vehicle node members of m_{icm}, that is, the $CommunityContactList_{m_{icm}}$ is not empty, m_{icm} is forwarded according to ICFD. When v encounters other vehicle nodes and has ECMs, that is, the *ContactList* and the *ECM-Buffer* are not empty, we take ECM from the *ECM-Buffer* in turn. Assume that the taken ECM is m_{ecm}, it is forwarded according to ECFD.

In summary, SFR is described in Fig. 10. We get communities by IKC in line 1. Lines 2–11 are for handling of the received message. Lines 12–18 are for ICM forwarding. Lines 19–23 are for ECM forwarding.

8. Simulations and performance evaluation

8.1. Simulation setup

In this paper, we use ONE (Opportunistic Network Environment) [49] to do simulation for the proposed SFR. We select a popular MaxPropRouter [43] (MPR) routing algorithm as the benchmark compared with the proposed SFR. MPR is based on prioritizing both the schedule of messages transmitted to the encounter nodes and the schedule of messages to be dropped, in which the priorities are based on the path likelihoods to destinations according to the historical data. Due to the treatment method similarity (both prioritizing the schedule of messages) and its fixed-line transportation oriented routing nature, we choose MPR as the comparison benchmark. We do performance evaluations over loop, intersection and complex shaped routes which are based on 10 practical bus lines in Shenyang city, which is the biggest city in Northeastern China. When simulating, we assume that the buses (vehicle nodes) running from 6:00 a.m. to 8:00 p.m. in each day,

Fig. 11. The loop shaped route.

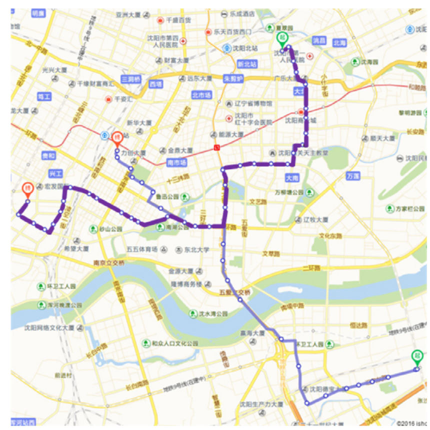


Fig. 12. The intersection shaped route.

and the passenger nodes' departure time, departure station and arrival station are generated randomly. The three shaped routes are described as follows.

- *The Loop shaped route*: we choose the LINE *Huanlu* in Shenyang city, which is shown in Fig. 11, as the loop shaped route. The bold line represents the bus route and the empty circles represent the bus stations. We assume that there are 10 *Huanlu* buses running when simulating, and 200 passengers take these buses at each moment during the running time. The message producing interval is 30 s, with the source and destination randomly chosen.
- *The Intersection shaped route*: we merge LINE *No.117* and LINE *No.152* in Shenyang city, which is shown in Fig. 12, as the intersection shaped route, because they have an overlapped segment. We assume that there are 10 buses running along *No.117* bus line and 10 buses along *No.152* bus line when simulating, and for each bus line there are 200 passengers, that is, we have 400 passengers in total that take the buses at each moment during the running time. The message producing interval is 15 s, with the source and destination randomly chosen.
- *The Complex shaped route*: we merge LINE *Huanlu*, LINE *No.117*, LINE *No.152*, LINE *No.225*, LINE *No.239*, LINE *No.244*, LINE *No.272*, LINE *No.282*, LINE *No.K801* and LINE *No.K802* in Shenyang city, which are ten bus lines in total and shown in Fig. 13, as the complex shaped route, because they form a complex structure. We assume that for each bus line there are 10 buses running when simulating, that is, we have 100 buses in total; and for each bus line there are 200 passengers, that is, we have 2000 passengers in total that take the buses at each moment during

Fig. 13. The complex shaped route.

Table 3
Parameter settings.

Parameter	Ω	k	θ	α	η	λ	σ	ψ	γ	μ
Setting	400	6	20	0.2	0.4	0.5	0.98	0.7	0.3	0.4

the running time. The message producing interval is 3 s, with the source and destination randomly chosen.

When do performance evaluations, we use Message Delivery Ratio (MDR), Average HoP (AHP), Average DeLay (ADL) and Network OverHead (NOH) as the metrics. The MDR is defined as the ratio of the number of all delivered messages to the number of all issued messages. The AHP is defined as the ratio of the traversed hops of all delivered messages to the number of these delivered messages. The ADL is the ratio of the experienced delay of all delivered messages to the number of these delivered messages. The NOH is defined as the ratio of the forwarded times of all issued messages (include their copies) to the number of all delivered messages.

The adopted values of the parameters are shown in Table 3. σ is set referring to [48]. Other parameters are set based on the best performance when simulations have been done.

When analyzing contact durations among nodes in the three shapes, we find that the data follow approximate power-law distributions, of which exponents are 1.97, 2.89 and 2.87 respectively for the loop, the intersection and the complex shaped routes. Moreover, contact times are also following the same way, of which exponents are 2.77, 2.16 and 2.5 respectively for the corresponding three shaped routes. These match the observation with the existing relevant literature [50].

8.2. SFR effectiveness

8.2.1. IKC effectiveness

We compare SFR equipped with the proposed IKC and the counterpart without it (denoted as SFR-C) on MDR, AHP, ADL and NOH over the loop shaped route, the intersection shaped route and the complex shaped route. The results are shown in Fig. 14. We can observe that SFR shows better performance on MDR, AHP, ADL and NOH over all routes than SFR-C, indicating the effectiveness of IKC. The reason is mainly as follows. SFR divides passenger nodes and vehicle nodes with closely social relations into the same community with the help of IKC, and this facilitates SFR's more targeted message forwarding than SFR-C's. Especially, as the number of encounters among vehicle nodes decreases from the loop shaped route and the complex shaped route to the intersection shaped route, it becomes hard for the vehicle nodes to make effective message forwarding without community awareness, and consequently the influence of IKC on routing performance becomes strong.

8.2.2. SMB effectiveness

We compare SFR equipped with the proposed SMB and that without it (denoted as SFR-B and we use FIFO instead of SMB to manage the buffering messages) on MDR, AHP, ADL and NOH over the loop shaped route, the intersection shaped route and the complex shaped route, and the results are shown in Fig. 15. We can observe that although SFR and SFR-B all show good performance with the help of IKC and BFD, SFR still shows a slight advantage. Specifically, SFR shows better performance on MDR, AHP and NOH over all routes than SFR-B, indicating the effectiveness of SMB on these three metrics. However, the effect of SMB on ADL is not obvious, because FIFO also has relatively positive influence on ADL of messages and this makes SMB very hard to improve ADL significantly.

8.2.3. BFD effectiveness

We compare SFR equipped with the proposed BFD and that without it (denoted SFR-D) on MDR, AHP, ADL and NOH over the loop shaped route, the intersection shaped route and the complex shaped route, and the results are shown in Fig. 16. We can observe that SFR shows better performance on MDR, AHP, ADL and NOH over all routes than SFR-D. Because BFD considers not only physical and social conditions of candidates, but also buffering priorities of messages got by the candidates, it can forward messages to the forwarders which not only encounter the destinations with high probability and good transmission conditions, but also give messages prior forwarding orders.

8.3. SFR and MPR comparison

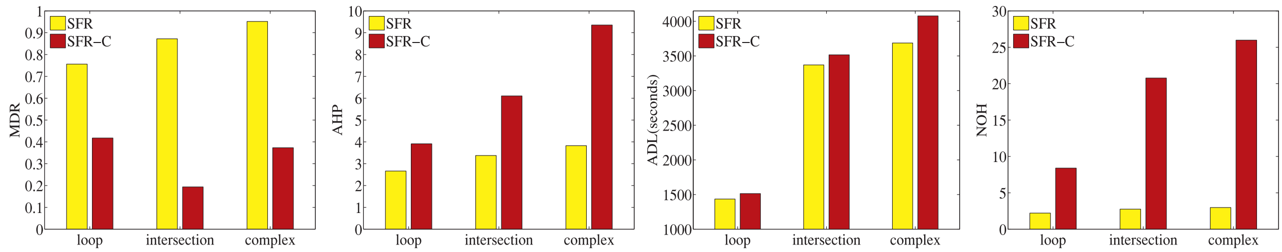
8.3.1. SFR v.s. MPR in three shapes

The MDR, AHP, ADL and NOH of SFR and MPR under different message Time To Live (TTL) over the loop shaped route, the intersection shaped route and the complex shaped route are shown in Figs. 17,18 and 19 respectively.

We can observe that SFR improves the routing efficiency and thus performs better than MPR. The main reasons are as follows. The passenger nodes with strong relationship become members in the same community, and their taken vehicle nodes are recorded in *CommunitList*, which improves routing efficiency. In contrast, MPR neglects the communities which exist among passenger nodes. Moreover, the *delivery likelihood* used in MPR is calculated by nodes' encounter number only, which cannot reflect social regularities of passenger nodes deeply when they take fixed-line vehicles. Furthermore, by considering both the message issuer's contribution to the buffering vehicle node and intimacy with it, the cooperative relations among nodes improve message delivery within the limited contact time window in SFR. However, MPR is only based on the message attributes, which cause lower routing efficiency compared with SFR.

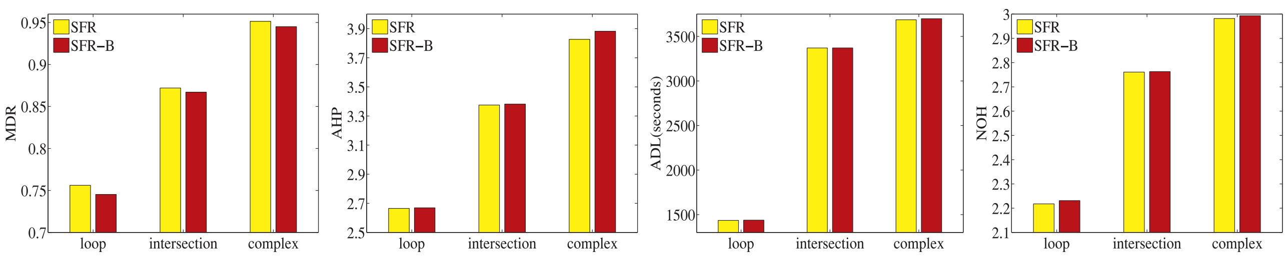
We can also observe that MPR has much higher NOH than SFR. The main reasons are as follows. MPR forwards message with multiple copies, and each forwarder saves message copy even it has forwarded this message to another node, resulting in a large amount of message copies existing in the network. Moreover, the copy amount increases with the message's TTL since the bigger TTL makes each message live longer. In contrast, when SFR has forwarded message successfully to the forwarder, it deletes this message copy, thus SFR holds a single copy for each message. Moreover, SFR forwards message socially and enables message to go towards its destination efficiently, thus it limits the NOH effectively.

From Figs. 17(c), 18(c) and 19(c), we can observe that SFR just has slightly lower ADL than MPR, the reasons are described as



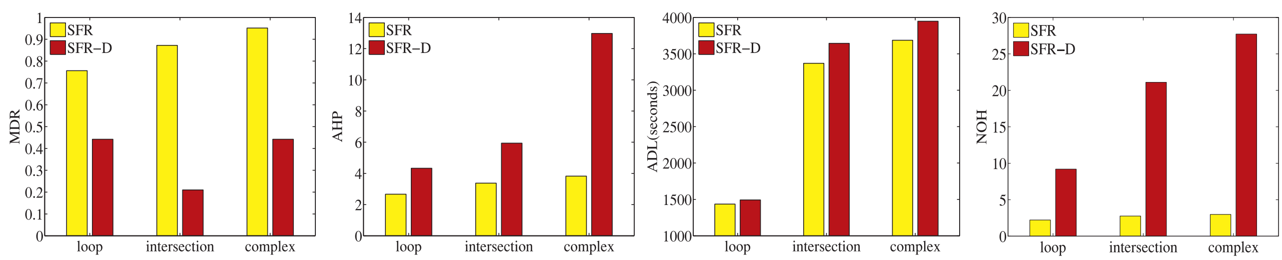
(a) MDR (b) AHP (c) ADL (d) NOH

Fig. 14. Effectiveness of the proposed IKC.



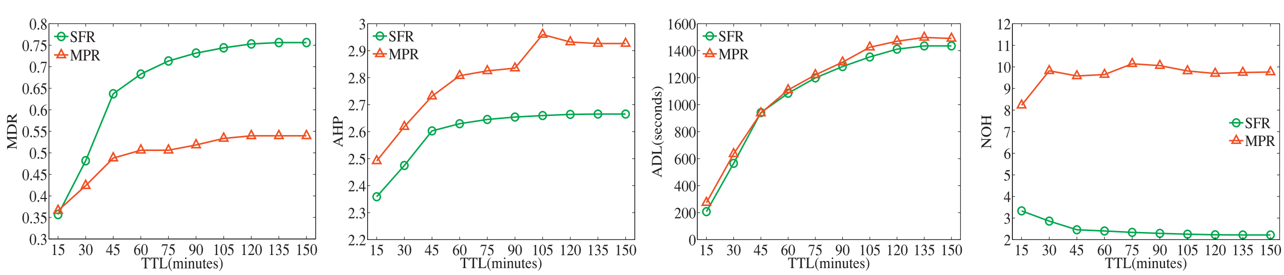
(a) MDR (b) AHP (c) ADL (d) NOH

Fig. 15. Effectiveness of the proposed SMB.



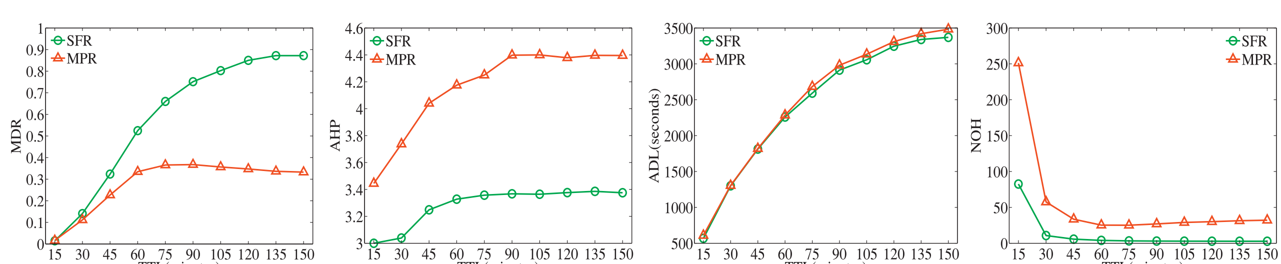
(a) MDR (b) AHP (c) ADL (d) NOH

Fig. 16. Effectiveness of the proposed BFD.



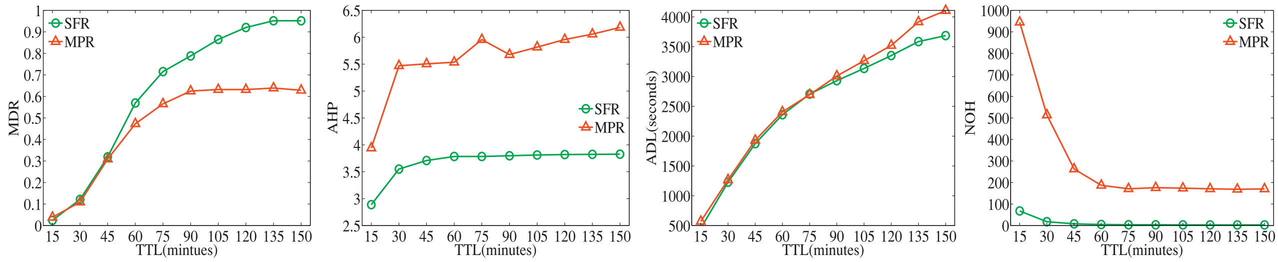
(a) MDR (b) AHP (c) ADL (d) NOH

Fig. 17. Performance under the loop shape.



(a) MDR (b) AHP (c) ADL (d) NOH

Fig. 18. Performance under the intersection shape.



(a) MDR (b) AHP (c) ADL (d) NOH

Fig. 19. Performance under the complex shape.

follows. With the help of IKC, messages are firstly forwarded to the community members of the destination passenger nodes, and then to the destinations, which accelerates the delivery of messages. Moreover, when selecting the forwarder for a message, BFD considers both the forwarding abilities of the candidates and the handling orders got by the candidates. This also makes messages delivered to their destinations fast. Although MPR cannot select the best forwarders for messages, as a multi-copy routing scheme, it can propagate a message very fast from one to another, thus it shows relatively close ADL to SFR.

In addition, from Figs. 17(a), 18(a) and 19(a), we can observe that all the MDR curves of SFR and MPR exhibit significant rise, which matches the existing relevant literature [51].

8.3.2. MPR in three shapes

From Figs. 17–19, we can observe that MPR is less effective on MDR in the intersection shaped route than in the loop shaped route and the complex shaped route. The reasons are described as follows. Intuitively, vehicle nodes on different bus lines have less encounter opportunities than those on the same bus line. Vehicle nodes in the loop shaped route are all on the same bus line, thus they have more encounter opportunities than those on different bus lines in the intersection shaped route. Besides, vehicle nodes in the complex shaped route have more abundant encounter opportunities than those in the intersection shaped route. Due to the used *delivery likelihoods* that mainly consider encounter numbers among vehicle nodes rather than passenger nodes, MPR cannot effectively use relatively less encounter opportunities in the intersection shaped route to maintain the same performances as those in the loop shaped route and the complex shaped route.

Besides, NOH in the complex shaped route is much higher than that in the other two. The reasons are described as follows. Due to the fast massage producing interval, the number of issued message in the complex shaped route is large. However, MPR keeps copies of packets that has already passed on to other nodes, which produces a large number of redundant copies, and thus makes NOH get high when these messages copies being forwarded hop by hop.

8.3.3. SFR in three shapes

From Figs. 17–19, we can observe that SFR gets the best ADL and AHP in the loop shaped route and the best MDR in the complex shaped route. The reasons are as follows. Because vehicle nodes in the loop shaped route have higher encounter frequency than those of different bus lines in the other two shaped routes, messages are delivered fast with low hops. Moreover, the vehicle nodes are dense in the complex shaped route, while the densities of vehicle nodes in the loop shaped route and the intersection shaped route are relatively low. Consequently, the proposed IKC and BFD have advantages to be effective in the complex shaped route.

Meanwhile, SFR has generally stable performance in these three shaped routes, because SFR forwards messages based on the social considerations and encounter regularities among passenger nodes, and forwards messages towards the forwarders that have the best social relation with the destinations. As a result, although the three shaped routes have different number of nodes, SFR keeps good performance in these three circumstances. Furthermore, in IKC, the used ACD can help detect the passenger nodes with closely social relationship among them, resulting in their taken vehicle nodes being recorded in the same community. With the detected communities, vehicle nodes forward messages firstly to the communities which the messages' destination passenger nodes belong to, and then forward them to their destination passenger nodes. Although the encounter opportunities are different in these three shaped routes, the community-based forwarding makes SFR show relatively stable performance.

9. Conclusions

Based on social method, a routing scheme is proposed for the fixed-line VANET. The improved *k*-clique community detection algorithm is devised to divide passenger nodes and vehicle nodes with closely social relationship into communities. A novel message buffering scheme is used to determine the forwarding and dropping orders of messages. The forwarder of a message is decided by a bilateral forwarder determination method. Simulation results show that the proposed scheme is more effective and efficient than MPR. Our routing ideas can be extended to other distributed networks, and provide new thoughts for the routing problems to be solved in VANET. Our future work is to deploy SFR on real routers equipped at the fixed-line transportation vehicles to verify its practicality, and to extend it to the none-fixed-line transportation routing scheme, in which the interests of the none-fixed-line vehicle drivers are mainly considered.

Acknowledgements

This work is supported by the National Science Foundation for Distinguished Young Scholars of China under Grant No. 61225012 and No. 71325002; the National Natural Science Foundation of China under Grant No. 61572123.

References

[1] J. Lee, H. Lee, Developing and validating a citizen-centric typology for smart city services, Gov. Inf. Q. 31 (2014) S93–S105.
[2] M. Bonola, L. Bracciale, P. Loreti, R. Amici, Opportunistic communication in smart city: experimental insight with small-scale taxi fleets as data carriers, Ad Hoc Netw. 43 (2016) 43–55.
[3] B.T. Sharef, R.A. Alsaqour, M. Ismail, Vehicular communication ad hoc routing protocols: a survey, J. Netw. Comput. Appl. 40 (2) (2014) 363–396.
[4] N. Benamar, K.D. Singh, M. Benamar, D.E. Ouadghiri, J. Bonnin, Routing protocols in vehicular delay tolerant networks: a comprehensive survey, Comput. Commun. 48 (8) (2014) 141–158.
[5] S. Al-Sultan, M.M. Al-Doori, A.H. Al-Bayatti, H. Zedan, A comprehensive survey on vehicular ad hoc network, J. Netw. Comput. Appl. 37 (1) (2014) 380–392.
[6] P. Hui, A. Chaintreau, R. Gass, J. Scott, J. Crowcroft, C. Diot, Pocket switched networking: challenges, feasibility and implementation issues, Auton. Commun. 3854 (2006) 1–12.

[7] D. Katsaros, N. Dimokas, L. Tassiulas, Social network analysis concepts in the design of wireless ad hoc network protocols, IEEE Netw. 24 (6) (2010) 23–29.
[8] N. Vastardis, K. Yang, Mobile social networks: architectures, social properties, and key research challenges, IEEE Commun. Surv. Tutorials 15 (3) (2013) 1355–1371.
[9] W.H. Kuo, S. Dong, J.S. Huang, Pheromone-based V2V unicast routing scheme in VANETs, in: Proceedings of the ICCVE, 2013, pp. 783–784.
[10] M. Xiao, J. Wu, L. Huang, Community-aware opportunistic routing in mobile social networks, IEEE Trans. Comput. 63 (7) (2014) 1682–1695.
[11] A. Vahdat, D. Becker, Epidemic Routing for Partially Connected Ad Hoc Networks, Duke University, 2000 Technical report cs-200006.
[12] Win-win/ game, https://en.wikipedia.org/wiki/Win-win_game.
[13] E.M. Daly, 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, 2007, pp. 32–40.
[14] P. Hui, E. Yoneki, S.Y. Chan, J. Crowcroft, Distributed community detection in delay tolerant networks, in: Proceedings of 2nd ACM/IEEE International Workshop on Mobility in the Evolving Internet Architecture, 2007, pp. 29–38.
[15] S. Jain, K. Fall, R. Patra, Routing in a delay tolerant network, in: Proceeding of ACM SIGCOM, 2004, pp. 145–158.
[16] M. Shoaib, W.C. Song, Traffic aware optimized zone based hierarchal link state routing protocol for VANET, in: Proceeding of International Symposium on Personal, Indoor and Mobile Radio Communications: Mobile and Wireless Networks, 2013, pp. 3117–3122.
[17] Y. Xiang, Z. Liu, R. Liu, W. Sun, W. Wang, GeoSVR: a map-based stateless VANET routing, Ad Hoc Netw. 11 (7) (2013) 2125–2135.
[18] F.J. Ros, P.M. Ruiz, I. Stojmenovic, Acknowledgment-based broadcast protocol for reliable and efficient data dissemination in vehicular ad hoc networks, IEEE Trans. Mob. Comput. 11 (1) (2012) 33–46.
[19] L. Zhang, Y. Zhuang, J. Pan, L. Kaur, H. Zhu, Multi-modal message dissemination in vehicular ad-hoc networks, in: Proceeding of ICCC, 2012, pp. 670–675.
[20] S. Bitam, A. Mellouk, S. Zeadally, HyBR: a hybrid bio-inspired bee swarm routing protocol for safety applications in vehicular ad hoc networks, J. Syst. Archit. 59 (10) (2013) 953–967.
[21] T. Abdeldjalil, F. Li, R. Li, X. Li, Table-driven bus-based routing protocol for urban vehicular ad hoc networks, in: Proceeding of Wireless Algorithms, Systems, and Applications, 2014, pp. 90–101.
[22] Y.T. Yu, M. Gerla, M.Y. Sanadidi, Scalable VANET content routing using hierarchical bloom filters, Wireless Commun. Mob. Comput. 15 (6) (2015) 1001–1014.
[23] X. Li, H. Li, K. Yand, L. Qiao, An optimization forwarding range routing protocol for VANET in city environments, Chin. J. Electron. 23 (1) (2014) 191–192.
[24] P.K. Sahu, H.K. Wu, J. Sahoo, M. Gerla, BAHG: back-bone-assisted hop greedy routing for VANET's city environments, IEEE Trans. Intell. Transp. Syst. 14 (1) (2013) 199–213.
[25] H.Y. Huang, P.E. Luo, M. Li, D. Li, X. Li, W. Shu, M.Y. Wu, Performance evaluation of SUVnet with real-time traffic data, IEEE Trans. Veh. Technol. 56 (6) (2007) 3381–3396.
[26] G. Xue, Y. Luo, J. Yu, M. Li, A novel vehicular location prediction based on mobility patterns for routing in urban VANET, EURASIP J. Wireless Commun. Netw. 11 (2012) 1–12.
[27] Y. Zhu, R. Jiang, J. Yu, M. Li, Geographic routing based on predictive locations in vehicular ad hoc networks, EURASIP J. Wireless Commun. Netw. 1 (2014) 1–9.
[28] A.M. Ouksel, D. Lundquist, Demand-driven publish/subscribe in mobile environments, Wireless Netw. 16 (8) (2010) 2237–2261.
[29] J. Jeong, K. Lee, Y. Yi, I. Rhee, S. Chong, ExMin: a routing metric for novel opportunity gain in delay tolerant networks, Comput. Netw. 59 (11) (2014) 184–196.
[30] G.A. Galaviz-Mosqueda, R. Aquino-Santos, S. Villarreal-Reyes, R. Rivera-Rodriguez, L. Villaserior-Gonzalez, A. Edwards, Reliable freestanding position-based routing in highway scenarios, Sensors 12 (11) (2012) 14262–14291.
[31] F. Zhang, H. Liu, Y.W. Leung, X. Chu, B. Jin, Community-based bus system as routing backbone for vehicular ad doc networks, in: Proceeding of IEEE 35th International Conference on Distributed Computing Systems, 2015, pp. 73–82.
[32] A.A. Mohammadi, G.S. Raj, R.V. Karthick, ABSTAR: improves Qos for city environment in VANET, in: Proceeding of 5th International Conference on Advanced Computing, 2013, pp. 458–462.
[33] L. Kuang, Z. Wang, X.U. Ming, Y. Chen, End-to-end transmission time-based opportunistic routing protocols for bus networks, Turk. J. Electr. Eng.Comput.Sci. 21 (2) (2013) 470–492.
[34] S.T.F. Al-Janabi, Y.S. Yaseen, B. Askwith, The bus ad hoc on-demand distance vector (BAODV) routing protocol, Proceeding of Annual Post Graduate Symposium on the Convergence of Telecommunications, Networking and Broadcasting, 2012.
[35] U.G. Acer, P. Giaccone, D. Hay, G. Neglia, S. Tarapiah, Timely data delivery in a realistic bus network, IEEE Trans. Veh. Technol. 61 (3) (2011) 446–450.
[36] T. Li, A mobile ad hoc routing protocol for metropolitan bus networks, in: Proceeding of IEEE 6th International Conference on ITS Telecommunications, 2006, pp. 737–740.
[37] R.H. Khokhar, R.M. Noor, K.Z. Ghafoor, C.H. Ke, M.A. Ngadi, Social interest-based routing in delay tolerant networks, in: Proceeding of 2015 International Conference on Emerging Technologies, 2015, pp. 1–5.
[38] J. Qin, H. Zhu, Y. Zhu, L. Lu, G. Xue, M. Li, POST: exploiting dynamic sociality for mobile advertising in vehicular networks, in: Proceeding of IEEE INFOCOM, 2014, pp. 1761–1769.
[39] R. Johari, N. Gupta, S. Aneja, CONCOR: context-aware community-oriented routing for intermittently connected network, EURASIP J. Wireless Commun. Netw. 148 (2015) 1–13.
[40] H. Park, J. Kim, Wi-Fi-based modeling and hybrid routing scheme for delay-tolerant public bus network, Wireless Commun. Mob. Comput. 15 (2015) 1117–1130.
[41] M. Sede, X. Li, D. Li, M.Y. Wu, M. Li, W. Shu, Routing in large-scale buses ad hoc networks, in: Proceeding of IEEE Wireless Communications & Networking Conference, 2008, pp. 2711–2716.
[42] B. Burns, O. Brock, B.N. Levine, MORA routing and capacity building in disruption-tolerant networks, Ad Hoc Netw. 6 (4) (2008) 600–620.
[43] J. Burgess, B. Gallagher, D. Jensen, B.N. Levine, MaxProp: routing for vehicle-based disruption-tolerant networks, in: Proceedings of the IEEE INFOCOM, 2006, pp. 1–11.
[44] E.D. Kaplan, Understanding GPS: principles and application, Artech House Mob. Commun. 59 (5) (2005) 598–599.
[45] L. Danon, J. Duch, A. Diaz-Guilera, A. Arenas, Comparing community structure identification, J. Stat. Mech. TheoryExp. 9 (2005) 1–10.
[46] S. Milgram, The small world problem, Psychol. Today 61 (1967) 60–67.
[47] V. Namboodiri, L. Gao, Prediction-based routing for vehicular ad hoc networks, IEEE Trans. Veh. Technol. 56 (4) (2007) 2332–2345.
[48] A. Lindgren, A. Doria, O. Scheln, Probabilistic routing in intermittently connected networks, Acm Sigmobile Mob. Comput. Commun.Rev. 7 (3) (2003) 19–20.
[49] A. Keränen, J. Ott, T. Kärkkäinen, The ONE simulator for DTN protocol evaluation, in: Proceedings of the 2nd International Conference on Simulation Tools and Techniques, 2009, pp. 1–10.
[50] A.S. Cacciapuoti, F. Calabrese, M. Caleffi, G.D. Lorenzo, L. Paura, Human-mobility enabled networks in urban environments: is there any (mobile wireless) small world out there? Ad Hoc Netw. 10 (2012) 1520–1531.
[51] A.S. Cacciapuoti, F. Calabrese, M. Caleffi, G.D. Lorenzo, L. Paura, Human-mobility enabled networks for emergency communications during special events, Pervasive Mob. Comput. 9 (2013) 472–483.

Junling Shi received the B.S. degree in network engineering from Liaoning Technology University, Huludao, China, in 2012, and the M.S. degree in computer technology from the Northeastern University, Shenyang, China, in 2014. She is currently a Ph.D. candidate at the College of Computer Science and Engineering, Northeastern University. Her research interests include mobile social networks and vehicle ad hoc network routing, etc.

Xingwei Wang received the B.S., M.S., and Ph.D. degrees in computer science from the Northeastern University, Shenyang, China, in 1989, 1992, and 1998 respectively. He is currently a Professor at the College of Software, Northeastern University. He has published over 100 research papers. His research interests include cloud computing and future Internet, etc.

Min Huang received the B.S. degree in automatic instrument, the M.S. degree in systems engineering, and Ph.D. degree in control theory from the Northeastern University, Shenyang, China, in 1990, 1993, and 1999 respectively. She is currently a Professor at the College of Information Science and Engineering, Northeastern University. She has published over 100 research papers. Her research interests include the modeling and optimization for the logistics and supply chain system, etc.

Keqin Li received the B.S. degree in computer science from Tsinghua University, Beijing, China, in 1985, and Ph.D. degree in computer science from the University of Houston, Texas, USA, in 1990. He is currently a SUNY distinguished professor of computer science in State University of New York at New Paltz. He has published over 200 journal articles, book chapters, and research papers in refereed international conference proceedings. His research interests include parallel and distributed computing and computer networking, etc.

Sajal K Das received the B.S. degree in computer science from Calcutta University, Kolkata, India, in 1983, the M.S. degree in computer science from the Indian Institute of Science, Bangaluru, India, in 1984, and the Ph.D. degree in computer science from the University of Central Florida, Orlando, in 1988. He is currently with the Department of Computer Science, Missouri University of Science and Technology. He is the author of more than 400 published papers and more than 35 invited book chapters. He is a Fellow of the IEEE.