Community-Based Routing in Vehicular Social Networks

Zifeng Hao
College of Information Engineering, Capital Normal University, Beijing, China
2191002040@cnu.edu.cn

Xiaolan Tang*
College of Information Engineering, Capital Normal University, Beijing, China
tangxl@cnu.edu.cn

Qun Wang
China Intelligent and Connected Vehicles (Beijing) Research Institute Co., Ltd., Beijing, China
buaawq1988@163.com

Wenlong Chen
College of Information Engineering, Capital Normal University, Beijing, China, chenwenlong@cnu.edu.cn

Yongting Zhang
College of Information Engineering, Capital Normal University, Beijing, China
2181002032@cnu.edu.cn

ABSTRACT

Considering the social features of drivers and passengers on vehicles, different communities may have different levels of demand for each packet. In order to represent this difference, we design a significance value for each packet. Furthermore, a community-based routing protocol in vehicular social networks is proposed, named CRP. When selecting relays, the forwarding priority is calculated by combing the direct and indirect forwarding contributions. The direct forwarding contribution is computed based on the number of neighbor nodes in each community as well as its significance value, while the indirect forwarding contribution indicates the delivery ability in future by using the contact probabilities between communities. Then according to the forwarding priorities and the number of replicas, the new relays are selected and the number of replicas are distributed among new relays. Finally, experiments using real road map and well-designed routes for three communities in Beijing show that CRP outperforms other protocols in terms of the community delivery ratio, while keeping a short delay.

CCS CONCEPTS

• **Networks**; • **Network protocols**; • **Network layer protocols**; • **Routing protocols**;

KEYWORDS

Vehicular social networks, Community, Routing protocol, Forwarding priority

ACM Reference Format:
Zifeng Hao, Xiaolan Tang*, Qun Wang, Wenlong Chen, and Yongting Zhang. 2021. Community-Based Routing in Vehicular Social Networks. In *The 5th International Conference on Computer Science and Application Engineering (CSAE 2021), October 19–21, 2021, Sanya, China.* ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3487075.3487183

CSAE 2021, October 19–21, 2021, Sanya, China

ACM ISBN 978-1-4503-8985-3/21/10…$15.00
https://doi.org/10.1145/3487075.3487183

1 INTRODUCTION

In Vehicular Ad hoc Networks (VANETs), the moving vehicles percept local information and share data with other transportation entities (such as vehicle, roadside infrastructure, pedestrian, service platform, etc.) via Dedicated Short Range Communications (DSRC) or LTE-V2X technologies [1]. The data, such as the real-time location of vehicles and the position of available parking spots, can be processed at the edge or uploaded to the cloud server for big data processing, so as to provide users with safe, efficient and intelligent driving experience and traffic services.

In VANETs, the transmission efficiency greatly affects the quality of service, and how to select an appropriate forwarder is a key issue for data transmission. Traditional routing protocols often consider local indicators, such as location and speed, to choose next-hop relays [2-3]. However, the relations between vehicles and persons (drivers and passengers) are not taken into account. In recent years, some researchers explore Vehicular Social Networks (VSNs), trying to improve the transmission efficiency of VANETs by considering the social characteristics, such as the drivers' travel habits and occupational attributes (relevant with the data requests). The social features of drivers and passengers affect the mobility models of vehicles as well as the requests sent by vehicular nodes. In VSNs, those vehicles with similar social features can be regarded as a community, in which the vehicles have similar moving trajectories and data requests [4]. How to improve data transmission in VSNs by considering the community characteristics is our concern.

For example, in Figure 1, there are three communities, *TEACHER*, *WORKER* and *RESIDENT*. Each community has its popular passing roads. The packet p_1 is related to teaching activity and should be disseminated in *TEACHER* community, while p_2 is a job advertisement whose targets are vehicles in *WORKER* community. A more detailed case will be discussed in our experiments in Sec. 5.

In this article, we propose a Community-based Routing Protocol in VSNs, named CRP, in order to improve data forwarding efficiency. Different communities may request different packets. To represent the different requests, we design a significance value for each packet. Furthermore, for the relay selection, the direct forwarding contribution based on the valid neighbor nodes and significance values, and the indirect forwarding contribution regarding the contact probability in future, are merged to compute the forwarding

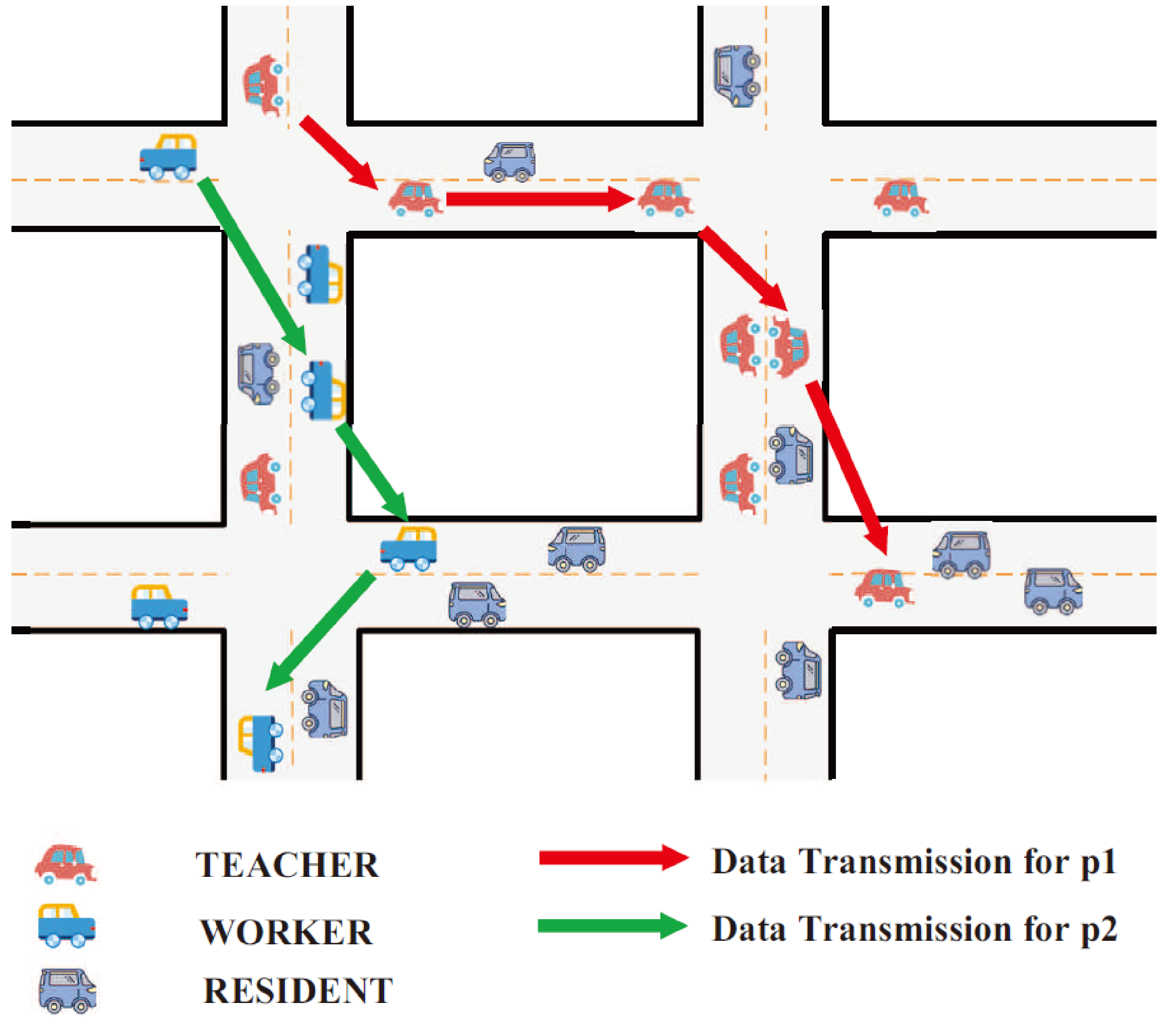

Figure 1: An Example Scenario of Data Transmission in Different Communities.

priority. Then according to the forwarding priorities of the current node and its neighbors as well as the number of replicas, the new relays are selected. Based on SUMO, Veins and OMNeT++, we conduct simulation experiments with three communities around a university in Beijing. The results show that, compared with other schemes, CRP achieves the highest community delivery ratio with a short delay in VSNs.

2 RELATED WORK

Traditional routing protocols in VANETs usually use location or speed to select the next relay [5], which suits highway scenarios. In urban vehicular networks, vehicles have typical social features and routing protocols for VSNs are proposed. Rahim et al. propose the Social Acquaintance-based Routing Protocol (SARP) that observes the changes of community members around the current node to determine whether it remains active in or between communities, so as to select the next suitable node [1]. Chang et al. propose the Socially-Aware Trajectory-based Routing (SATR) protocol in [6]. SATR uses vehicle trajectories in different periods and the social relationship between information and vehicles to improve transmission performance and reduce computational complexity. Li et al. design a new metric, social energy, that is generated via node encounters and shared by the community composed of encountering nodes [7]. Motivated by the energy radiation in physics, they propose the Social-Energy-Based Routing protocol (SEBAR), in which the node with a higher social energy in its or the destination's social community takes priority to be selected as the next relay.

In order to promote transportation efficiency in urban VSNs, the trajectory data are analyzed to detect abnormal traffic flow [8]. Zhong et al. propose two metrics, space-time approachability and social approachability, to represent the absolute and relative distances between nodes, respectively, and integrate these two metrics to design a data forwarding algorithm to improve transmission efficiency [9]. In order to solve the content delivery problem in VSNs, Yi et al. utilize the relationship strength and the interest degree to support community detection and packet forwarding and propose the vehicle-adaptive caching scheme to improve the delivery rate [10]. Existing studies do not provide a general framework to deal with the different data requests from several communities, and the mobility features in VSNs are not fully utilized to enhance data transmission efficiency.

3 NETWORK MODEL

In the vehicular social network, there are several communities denoted by $C = \{C_1, C_2, \ldots, C_m\}$, and each community has a group of vehicular nodes. Each vehicular node v_i is included in a unique community C_j, represented as $v_i \in C_j$. When two vehicles drive into the communication range of each other, the control information or the data packets can be transmitted between them. For a vehicle v_i, all the vehicular nodes within its communication range are called its neighbor nodes, denoted by $N_i = \{v_1^i, v_2^i, \ldots, v_j^i\}$.

Definition 1 (Significance value) When disseminating packets in the scenario, a packet p_k has its own significance value, denoted by $S_k = [s_1^k, s_2^k, \ldots, s_m^k]$, where s_m^k is the significance of those vehicular nodes in the community C_m to receive the packet p_k. Here the constraints are $0 < s_m^k < 1 (j = 1, 2, .., m)$ and $\sum_{j=1}^{m} s_j^k = 1$. A larger s_j^kmeans that those vehicles in community C_j have more expectations about the delivery of packet p_k than the vehicles in other communities.

For example, in a scenario, there are two communities $C = \{TEACHER, RESIDENT\}$ and three packets p_1, p_2 and p_3. The packet $p_1$works for the teaching services, and hence its community significance vector is $S_1 = [1, 0]$; the packet p_2 is an advertisement for furnishing whose target group is the resident community, so $S_2 = [0, 1]$. Hence p_1 only needs to disseminate to those vehicles in *TEACHER* community, and p_2 only propagates to those nodes in *RESIDENT* community.

When evaluating the routing performance, the delivery ratio of packet p_k, as a traditional metric, is computed by

$$DR_k = \frac{\sum_{j=1}^{m} \sum_{v_i \in C_j} G_i^k}{\sum_{j=1}^{m} |C_j|} \tag{1}$$

where G_i^k indicates whether the vehicle v_i receives the packet p_k ($G_i^k = 1$) or not ($G_i^k = 0$). If the vehicles have no expectations about the delivery of packet, they will not be counted in the delivery rate. Still in the above scenario with two communities and three packets, all the vehicles in *TEACHER* community receive p_1 and p_2, but no vehicles in *RESIDENT* community receive p_1 or p_2. In the above instance, the delivery ratio of p_1 is 1, while that of p_2 is 0. These values are in line with the actual performance.

4 COMMUNITY-BASED ROUTING IN VSNS

In VSNs, after a data packet p_k is generated, the source node v_i carries this packet. In order to accelerate data dissemination, each packet has several replicas to be forwarded among vehicles. The number of replicas of p_k is denoted by δ_k, and a larger δ_k helps to accelerate data delivery with a larger resource cost. During the process of relay selection, we prefer to find a unique relay for each replica if there exist sufficient candidate relays, in order to deliver p_k as quickly as possible.

According to the number of replicas of p_k carried by v_i and the forwarding priorities, one or more vehicles with higher priorities are selected as the next relays, and the number of replicas that should be carried by each relay are calculated. In this process, how to calculate the forwarding priority is a key issue to improve the transmission efficiency.

4.1 Forwarding Priority Calculation

Since each neighbor node of the data carrier v_i belongs to one community, v_i disseminates the packet to its neighbors in $N_i$and hence to these communities.

Definition 2 (Direct communities) The direct communities of the current node v_i are all the communities that the neighbor nodes N_i belong to. It is computed by

$$DC_i = U_v x_{\in N i} \{C_j | v_i \in C_j\} \tag{2}$$

Definition 3 (Valid neighbor nodes)

Among the neighbors N_i, those nodes which have not received the packet p_k are the valid neighbor nodes, denoted by VN_i^k. They are the potential destination nodes of the packet, while other neighbor nodes do not need to receive the packet again. For each direct community in DC_i, the number of valid neighbor nodes in this community indicates how many new nodes receive the packet through this forwarding, and hence implies the delivery capability. Moreover, the community significance vector also affects the transmission performance. The direct forwarding contribution is

$$DFC_i^k = \sum\nolimits_{cj \in DCi} \left| U_{vx}{}^{\in VN_i^k} \{v_x \in C_j\right| \cdot s_i^k \tag{3}$$

A larger direct forwarding contribution means that more valuable nodes will obtain the packet p_k through the data forwarding from the current node to v_i its neighbors.

Definition 4 (Indirect communities) Except the direct communities, other communities in C are indirect communities, that are computed as

$$IC_i = C - DC_i \tag{4}$$

Although the carrier v_i cannot transmit data to vehicles in IC_i in this communication chance, the data may reach these vehicles through multi-hop forwarding in future.

Definition 5 (Contact probability) Considering that the inter-vehicle contacts have regular features in social networks, the contact probability between two vehicles from communities C_j and C_q,

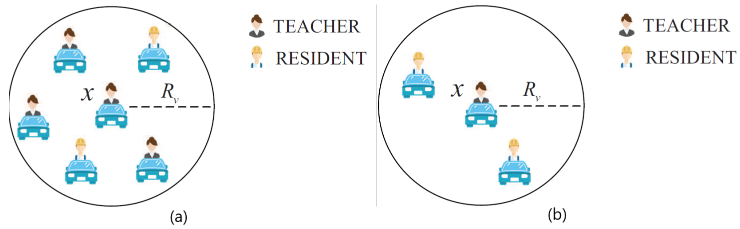

Figure 2: Instance Scenarios for Forwarding Priority Calculation. (a) High-density VSN; (b) Sparse VSN.

denoted by $r_{j,q}$, is calculated from historical mobility data. Specifically, $r_{j,q}$ is the ratio of the number of contacts between C_j and C_q to all the contacts in the whole network.

The community of the current node v_i is denoted by $C_q(v_i \in C_q \text{ and } C_q \in C)$. We utilize the contact probability of the current community C_q and each indirect community as well as the importance of packet to compute the indirect forwarding contribution as

$$IFC_i^k = \sum_{C_j \in IC_i} r_{j,q} \cdot s_i^k \tag{5}$$

A larger indirect forwarding contribution indicates that v_i probably makes more contribution towards disseminating p_k to indirect communities when it drives in future.

Combining the direct and indirect forwarding contributions, the forwarding priority of the current node v_i to transfer the packet p_k is calculated as

$$FP_i^k = \alpha \cdot DFC_i^k + (1 - \alpha) \cdot IFC_i^k \tag{6}$$

where α is the weight for the direct forwarding contribution and $0 < \alpha < 1$.

Two instance scenarios of forwarding priority calculation are illustrated in Figure 2. There are two communities, $C = \{TEACHER, RESIDENT\}$. The contact probability for two vehicles in $TEACHER$ community is 0.4, and the weight for direct forwarding contribution is $\alpha = 0.5$. There are two packets: p_1 is related to teaching activity, and $S_1 = [1, 0]$; p_2 is catering recommendation message, having $S_1 = [0.2, 0.8]$. The current node x carries p_1 and p_2, and two cases for its neighbors are shown in Figure 2. (a) is a scenario for high-density vehicular network, in which $DC_i = C$ and $IC_i = \emptyset$. The forwarding priorities for the two packets are $FP_x^1 = 0.5 \times DFC_x^1 = 1.5$ and $FP_x^2 = 0.5 \times DFC_x^2 = 1.1$, respectively. Figure 2(b) is a scenario for sparse vehicular network, where $RESIDENT$ is the direct community and $TEACHER$ is the indirect community. Hence, the forwarding priorities for two packets are $FP_x^1 = 0.5 \times IFC_x^1 = 0.2$ and $FP_x^2 = 0.5 \times DFC_x^2 + 0.5 \times IFC_x^2 = 0.8 + 0.04 = 0.84$, respectively.

4.2 Community-based Routing Protocol

When a vehicular node v_i carrying a data packet p_k has some neighbor nodes, it needs to propagate the data to its neighbors and select appropriate next-hop relays. Firstly, v_i collects the control information from each neighbor node in N_i, including the vehicle ID, the community ID and the state whether this node has already received p_k or not. Then the states are used to calculate the valid neighbor nodes VN_i. The data packet p_k and its community significance vector S_k are sent from v_i to VN_i and N_i, respectively.

After transmitting p_k to neighbors, v_i selects new relays. Here the number of replicas of p_k carried by v_i is denoted by $num_i^k (num_i^k \leq \delta_k)$. In order to find suitable relays, the forwarding priority of v_i, FP_i is computed by Eq. 6. Similarly, each neighbor node in N_i calculates its forwarding priority and sends it to v_i. After gathering the forwarding priorities from N_i, v_i selects those neighbors whose priorities equal to or are larger than FP_i, named candidate relays *canRelay*. If *canRelay* only has v_i, the relay selection stops, and the replicas of p_k are still carried by v_i. If the number of candidate relays is larger than num_i^k, then the num_i^k candidate relays with the highest priorities are chosen as the next relays, and each relay carries one replica of p_k. Otherwise, the replicas are distributed to candidate relays on average, while the candidate relay with the highest priority carries the remainder replicas if exist.

Based on the community significance vector, the proposed CRP protocol utilizes the real-time traffic status and the social characteristics to compute the forwarding priority, and hence improves the community delivery ratio of the whole network.

5 RESULTS AND DISCUSSION

5.1 Simulation Setup

We use SUMO, Veins and OMNeT++ to conduct simulation experiments. The real road map around West 3rd Ring Road in Beijing, China, is utilized to construct the vehicular scenario. As shown in Figure 3(a), the area is $2000 \times 1600m^2$, covering Zizhu Bridge and Huayuan Bridge. In the mobility simulator SUMO, the intersections on main roads are taken as the anchors, and their relative coordinates are illustrated in Figure 3(b). There are several campuses of universities, office buildings and residential buildings in the selected area. Therefore, we set three main communities, $C = \{TEACHER, WOEKER, RESIDENT\}$. Since different communities have different mobility features, we design 12 routes for each community according to the spatial layout of buildings and roads, as illustrated in Figure 4. From the heat maps, we see that the most popular roads are different for the three communities.

Considering the daily heavy traffic in the selected area, we set 800 vehicles driving with the departure interval 20s and the speed 36km/h. The community significance vector of the packet is [1 0 0], and the number of replicas is 4. Parameter analysis will be discussed in Sec. 5.3. The main network configurations are listed in Table 1.

In the experiments, we set $\alpha = 0.5$ in our CRP protocol. Thus, both the direct and indirect forwarding contributions are utilized

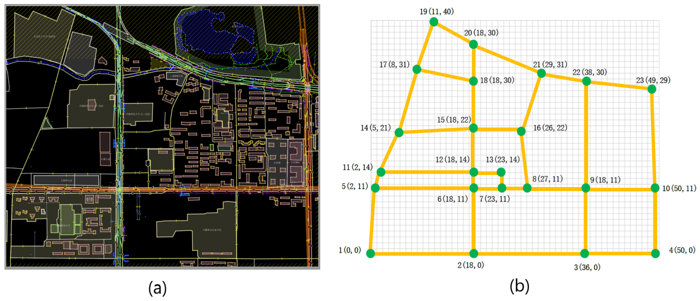

Figure 3: The Road Map Around West 3rd Ring Road in Beijing. (a) Road Map; (b) Map with Coordinates.

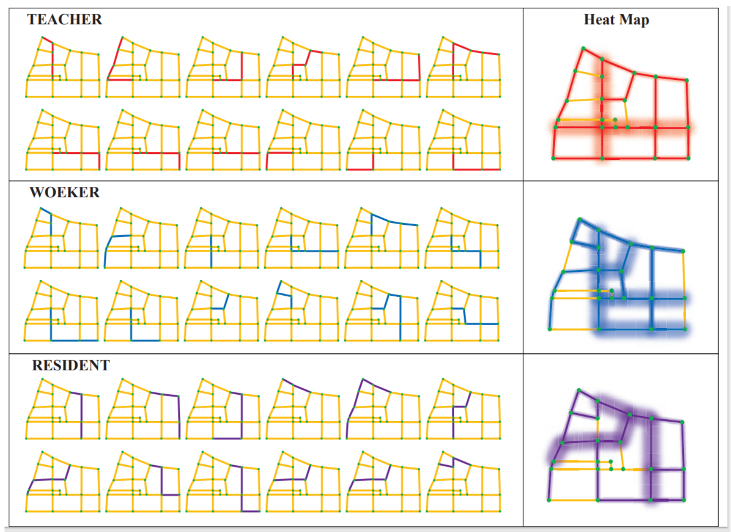

Figure 4: The Routes for Three Communities.

Table 1: Network Configurations

Parameter	Value
Simulation time	300s
Number of vehicles	800
Number of data replicas	4
MAC protocol	IEEE 802.11p
Transmission radius	200m
Bit rate	6Mbps
Data packet size	12.8Kb

to compute the forwarding priority in Eq 6. In order to evaluate the performance of CRP, we take the Social Acquaintance-based Routing Protocol (SARP) [1], the random routing protocol (RRP), the greedy routing protocol considering the most neighbors (MRP) and CRP with $\alpha = 1$ (CRPa1) as compared methods.

5.2 Simulation Results

Two main metrics are analyzed, the community delivery ratio (ref. Eq. 2) and the average delivery delay. The simulation results of the five protocols, i.e., CRP, SARP, RRP, MRP and CRPa1, are illustrated in Figure 5. We use the 50s at the beginning to allow more vehicles driving into the scenario and obtain the stable vehicle distribution.

In Figure 5(a), the initial delivery ratio of CRP and SARP are almost the same and much larger than RRP, MRP and CRPa1. There are two main reasons: (1) CRP and SARP select suitable forwarders considering the social characteristics, while RRP randomly selects the next-hop relay and MRP only considers the number of neighbors. (2) CRPa1 does not take into account the indirect forwarding contribution and performs worse when direct communities have small significance values or in sparse scenarios. Additionally, when the simulation time reaches 300s, the delivery ratio of CRP increases to about 94%, which is higher than that of SARP. This is because CRP considers the community significance vector to choose better relays. Overall, CRP has the highest community delivery ratio among the compared schemes.

Figure 5(b) shows that, the average delivery delays of all the protocols increase as time goes by. MRP has a sharp rise and reaches the longest delay, while CRP and SARP have shorter delays.

In conclusion, compared with other protocols, CRP has the highest delivery ratio with a relatively short delay. Compared with

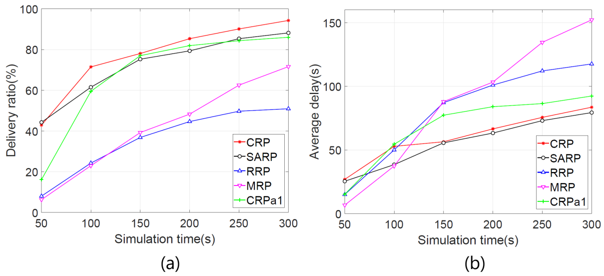

Figure 5: Simulation Results. (a) Delivery Ratio; (b) Average Delay.

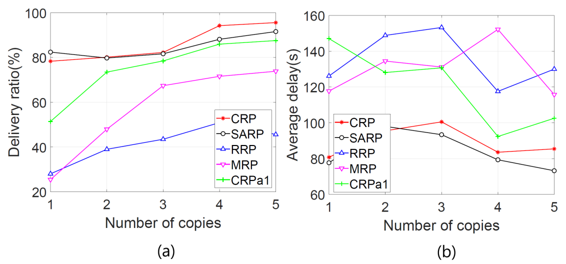

Figure 6: Results with different Numbers of Replicas. (a) Delivery Ratio; (b) Average Delay.

CRPa1, CRP increases the delivery ratio by about 27% because of the indirect forwarding contribution.

5.3 Analysis of the Number of Replicas

Range the number of replicas from 1 to 5, and the results are shown in Figure 6. With more replicas, all the protocols have clear upward trends in the delivery ratio. This is because more copies result in more forwarding nodes, which help to deliver data to more targets. For more than 4 copies, the delivery ratios do not increase significantly, indicating that the bottleneck of the performance improvement switches from the number of replicas to other factors, like the V2V contact opportunities. Furthermore, most delivery delays increase first and then decrease, because more vehicles receive the packet after a longer waiting time and then much more replicas accelerate data propagation, respectively. Note that a proper number of replicas is very important for CRP. It can be selected by analyzing the QoS requirement and conducting sampling tests in simulation experiments.

6 CONCLUSION

We propose a community-based routing protocol in VSNs, namely CRP, which aims to improve data dissemination in target communities. The forwarding priority of a vehicular node is composed of direct forwarding contribution and indirect forwarding contribution. The data carrier calculates its priority and gathers the neighbors' priorities. Considering the forwarding priorities and the number of replicas, the next relays are selected, and the number of replicas on each relay is determined. Finally, the experimental results show that CRP has a higher community delivery ratio than other schemes, while keeping a short delay.

We will explore the forwarding direction selection based on the social features in VSNs in future.

ACKNOWLEDGMENTS

We gratefully acknowledge the support from the Beijing Natural Science Foundation (4202012), the National Natural Science Foundation of China (61872252), and the Science Technology Project of Beijing Municipal Commission of Education in China (KM201810028017).

REFERENCES

[1] A. Rahim, T. Qiu, Z. Ning, J. Wang, N. Ullah, A. Tolba, and F. Xia (2017). Social acquaintance based routing in vehicular social networks. Future Generation Computer Systems, vol. 93, no. APR., pp. 751-760.
[2] F. Shabnam and A. Jamalipour (2020). A secured geo-routing protocol for vanet with an enhanced junction selection mechanism, in GLOBECOM 2020 - 2020 IEEE Global Communications Conference, pp. 1-6.
[3] J. Zheng, H. Tong, Z. Wang, and Y. Wu (2016). A destination and moving direction information based probabilistic routing protocol for VANETs, in 2016 IEEE Global Communications Conference (GLOBECOM), pp. 1-5.
[4] A. M. Vegni and V. Loscr´I (2015). A survey on vehicular social networks. IEEE Communications Surveys Tutorials, vol. 17, no. 4, pp. 2397-2419.
[5] Niansheng Liu, Huihuan Qian, Jingyu Yan, and Yangsheng Xu (2009). Performance analysis of routing protocols for vehicle safety communications on the freeway, in 2009 3rd International Conference on Anticounterfeiting, Security, and Identification in Communication, pp. 85-88.
[6] I. Chang and C. Chang (2017). SATR: Socially-aware trajectory-based routing in vehicular social networks, in 2017 IEEE 8th International Conference on Awareness Science and Technology (iCAST), pp. 456-461.
[7] F. Li, H. Jiang, H. Li, Y. Cheng, and Y. Wang (2017). SEBAR: Socialenergy-based routing for mobile social delay-tolerant networks. IEEE Transactions on Vehicular Technology, vol. 66, no. 8, pp. 7195-7206.
[8] Z. Ning, F. Xia, N. Ullah, X. Kong, and X. Hu (2017). Vehicular social networks: Enabling smart mobility. IEEE Communications Magazine, vol. 55, pp. 16-55.
[9] L. Zhong, W. Cheng, S. Lu, C. J. Jiang, and C. X. Wang (2017). Exploiting traveling information for data forwarding in community characterized vehicular networks. IEEE Transactions on Vehicular Technology, vol. PP, no. 7, pp. 1-1.
[10] B. Yi, X. Wang, and M. Huang (2021). Content delivery enhancement in vehicular social network with better routing and caching mechanism. Journal of Network and Computer Applications, vol. 177, p. 102952.