A Social-Aware Routing Protocol for Two Different Scenarios in Vehicular Ad-Hoc Network

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Abstract. Vehicular Ad-hoc Network (VANET) has recently attracted wide public attention. A key challenge is to design suitable routing protocols for VANET. In order to get high packet delivery ratio and low end-to-end delay, this paper proposes a social-aware routing protocol based on the "store-carry-forward" strategy, called Tie and Duration Based Routing Protocol (TDRP). To select the best relay node, TDRP takes two social metrics into consideration: community and centrality. We adopt a distributed K-Clique community detection to divide vehicles into different communities, and calculate global and local centralities of vehicles by making full use of strong and weak ties, as well as the duration of historical connections. The ONE simulator is used to evaluate the performance of TDRP and Bubble Rap, a typical social-aware routing protocol. Experimental results show that TDRP outperforms Bubble Rap in both city and highway scenarios in terms of packet delivery ratio and end-to-end delay.

Keywords: VANET · Social-aware routing protocol · Strong and weak ties
City and highway scenarios · The ONE

1 Introduction

As an important part of Intelligent Transportation System (ITS) [1], Vehicular Ad-hoc Network (VANET) works in a self-organized way with short-range communication devices installed on vehicles to improve traffic safety and efficiency. Each vehicle is not only a host, but also a router with a specific routing protocol. However, due to the high mobility of vehicles and the complexity of communication environment, it is difficult to maintain the stable communication links between vehicles. So, it is vital to have a suitable routing protocol for vehicular scenarios.

Opportunistic transmission is based on the "store-carry-forward" strategy, which is first adopted in the Delay Tolerant Network (DTN) [2]. In this strategy, a message is forwarded by multiple relay nodes to the destination, without requiring an end-to-end message routing path. The features of "Delay Tolerant" can meet the demand of VANET, applying to VANET called Vehicular Delay-Tolerant Network (VDTN) [3].

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In VDTN, though the movement of nodes greatly improves the possibility of connection establishment, it is vital to determine when the best time to send the message and which the best relay node is.

In order to solve these problems, people in the study of routing protocols, make full use of dynamic network information (e.g. location information, traffic information and neighbor information) to make decisions. As we all know, in Social Networks (SN) [4], the link between people is largely dependent on the social relationship between them. Liu et al. [5] explored social properties in Vehicular Ad-hoc Networks by using two traces of mobile vehicles from San Francisco and Shanghai. Further, Vegni and Loscrí [6] introduced the concept of Vehicular Social Networks (VSN), exploiting the great impact of social characteristics and human behavior on Vehicular Ad-hoc Networks. Since the movement and communication of vehicles are impacted greatly by human social behavior and social relationships, there are many social characteristics can be used, e.g., community, similarity, centrality, selfishness and so on. Moreover, these social attributes are much more stable than dynamic network information.

Recently, many routing protocols based on social properties have been proposed. Wei et al. [7] had made a survey of social-aware routing protocols in DTN. The properties of social ties such as positive and negative social characteristics are utilized to design social-aware routing protocols. However, in VANETs, high-speed movement of vehicles and frequent changes in the topology make it difficult to extract the social properties from the connection history. Thus it leads to poor performance for most social-aware routing protocols in the V2V communication.

To address the issue, this paper proposes a social-aware routing protocol called Tie and Duration Based Routing Protocol (TDRP). In TDRP, each vehicle records a neighbor list within the transmission range, as well as a connection history list. Then, we use strong and weak ties, as well as duration of historical connections to calculate global and local centralities to make protocol more suitable for VANET, compared with Bubble Rap protocol a typical social-aware routing protocol [8].

The organization of this paper is structured as follows. We briefly review related work in Sect. 2, and then propose the new centrality algorithm based on strong and weak ties and duration of historical connections in Sect. 3. In Sect. 4, we use The ONE simulator [9] to evaluate the performance of TDRP and Bubble Rap routing protocols in two different scenarios. Finally, we conclude our work briefly in Sect. 5.

2 Related Work

There are some typical social-aware routing protocols in DTN. Daly and Haahr proposed the SimBet algorithm [10]. In [10], the utility of a relay node is evaluated by the centrality and similarity of nodes, according to a standard rule. Then, the message will be forwarded to a node with higher utility until to the destination. Hui [11] proposed the LABEL algorithm using the community of nodes, which assigns each node a label to distinguish it from different communities. Note that the nodes with the same label are regarded to belong to the same community. However, the protocol can only improve the message delivery ratio when the message is in the same community as the destination, but ignores the situation where the message is transferred from different communities to the destination. Moreover, there is a lack of the mechanism for transmitting the message to different communities. To fill this gap, Hui et al. [8] proposed a Bubble Rap algorithm combining with community and centrality of nodes to design forwarding strategy based on LABEL protocol. The algorithm forwards the message to the node with higher global centrality until the message arrives at the same community as the destination, and thus improves the message delivery ratio. After that, in the local community, message will be forwarded to the neighbor node with the higher local centrality until to the destination.

In Bubble Rap algorithm, the community detection and the centrality calculation are the most important parts. In the community detection part, the paper [12] proposes three typical algorithms of community detection: Simple, K-Clique and Modularity. In the centrality calculation part, Pan Hui proposed two ways to calculate centrality: S-Windows, and C-Windows, both of which are based on connection history. However, they ignore the current links, which are more important for highly mobile vehicles.

In this paper, we propose a new protocol by considering strong and weak ties of neighbor vehicles with the transmission range as well as the duration of historical connections to make it more suitable for VANET.

3 Design of TDRP Protocol

Due to the features of highly mobile vehicles, in this section, we design a social-aware routing protocol for vehicular scenarios, called Tie and Duration Based Routing Protocol (TDRP). Learning from Bubble Rap algorithm, TDRP takes the “community” and “centrality” into consideration to select the best next relay node. In the community part, since K-Clique algorithm performs the best, we choose it to detect communities. In the centrality part, TDRP uses strong and weak ties of neighbor vehicles with the transmission range, as well as duration of historical connections to calculate global and local centralities.

When the transmission occurs in the same community, the vehicle carrying the message chooses the next relay vehicle with the highest local centrality among its neighbors and higher local centrality than itself. Otherwise, the vehicle carrying the message selects the next hop with the highest global centrality among its neighbors and higher global centrality than itself.

3.1 Centrality Calculation

In the social network, the strength of the connection refers to the degree of intimacy among people, such as the relationship between friends and relatives. This connection is generally considered as a strong tie. However, if the person is an acquaintance, but contacts with each other are not so frequent, this connection is considered as a weak tie. Many studies show that there are a lot of similarities between nodes in the network in this aspect. There are different standards for measuring the strength of connection, according to the specific environment, but the form of expression is the same. Strong ties are gathered into a community, while weak ties exist between communities, as shown in Fig. 1.

There are only two cases of message transmission, to the same community and different communities. In Fig. 1, when the source node *a* (S) sends a message to node *d* (D1), since both of them are in the same community 3, node *f* with the most of strong ties is the best choice for next relay. The path of transmission is *a* -> *f* -> *d*. So, local centrality can be calculated by strong ties. However, when the source node *a* (S) sends a message to node *o* (D2), since they are in different communities, global centrality works, and a weak tie is required as a bridge to send the message out the community first. If node *f* is still chosen as a relay node, it won't forward message to other nodes with lower centrality, and the message will be stuck in the community 3.

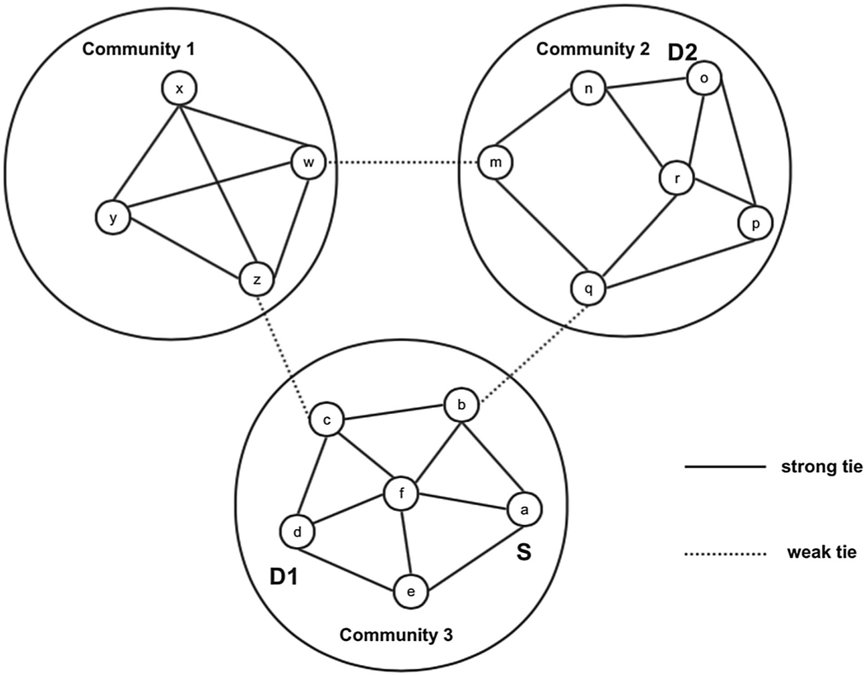

Fig. 1. The strength of ties, weak ties between different communities and strong ties in the same community

In this case, the weak ties between different communities are important. Node *b* and node *c* both have weak ties, but only node *b* has a strong tie with node *a*. Node *b* should be chosen as the next relay node. The path of transmission is *a* -> *b* -> *q* -> *r* -> *o*. So, global centrality should take full account of weak ties. In our real life, the route of taxi is usually based on the driver's preferences and the passengers' requirements, and the bus has a fixed route. Typically, the route of private car is entirely determined by the owner, such as work place, home, and shop stores. Therefore, buses and cars are more likely to constitute communities, while the taxis are more likely to be the bridges between these communities.

In addition, due to high-speed mobility of vehicles, network topology changes frequently in VANET. Hence, the duration of connections becomes very important. The duration has to be longer than the time of message transmission at least. So, in TDRP, we will also consider the duration of historical connections in both global and local centralities.

In order to calculate centrality, we assume every vehicle maintains a neighbor list within the transmission range and a connection history list recording vehicles that had ever connected and the meeting time.

The centrality of a node is calculated by *TieUtil* and *DurationUtil*. As for node *u*, it has a neighbor list. *E(u)* denotes the set of these neighbor nodes, and node *v* is in *E(u)*. Besides, it has a connection history list, *connHistory*.

For Global Centrality of node *u*, we just consider the neighbor nodes in different communities. *TieUtil* is the number of communities, which the neighbor nodes belong to.

$$TieUtil(u) = \sum_{v \in E} c(u, v). \tag{1}$$

$$c(u, v) = \begin{cases} 1 & \text{if } u \text{ and } v \text{ are in different communities} \\ 0 & \text{otherwise} \end{cases}. \tag{2}$$

$$DurationUtil(u) = \sum_{v \in E \&\& c(u,v)=1} \frac{LongDuration}{LongDuration + ShortDuration}. \tag{3}$$

$$TieDurationUtil(u) = \alpha TieUtil(u) + \beta DurationUtil(u). \tag{4}$$

When node *u* and node *v* are in different communities, and they have met at least once time before, *DurationUtil* is calculated by Formula (3). There is a *threshold* for historical connections to distinguish long or short duration connections for every encounter. The threshold is preferably several times larger than the time of message transmission. The bigger *DurationUtil* is, the more *LongDuration* connections node *u* has.

Finally, Global Centrality is denoted by $TieDurationUtil(u)$, which is given by combining the normalized relative weights of the attributes, as shown in Formula (4). Wherein α and β are tunable parameters, and $\alpha + \beta = 1$. Thus, these parameters can be adjusted according to the relative importance of these two utility values in different scenarios.

For Local Centrality of node *u*, we just consider the neighbor nodes in the same community:

$$c(u, v) = \begin{cases} 1 & \text{if } u \text{ and } v \text{ are in the same community} \\ 0 & \text{otherwise} \end{cases}. \tag{5}$$

Only $c(u, v)$ is changed from Formula (2) to Formula (5), the others are the same as the Global Centrality.

3.2 Centrality Algorithm

Since the algorithms of calculating the Global Centrality and Local Centrality are similar, we only show the algorithm of Global Centrality of node *u* as follows:

Algorithm1. Calculate the Global Centrality of Node *u*

```
Begin:
if (COMPUTE_INTEVAL<6)
    return GlobalCentrality
else if (E(u) != NULL)
    for all node v∈ E(u) do
        if (node u and node v are in different communities)
            c (u, v) =1
        else
            c (u, v) =0
        end if
        TieUtil(u) = ∑ c(u, v)
        if node v ∈ E(u) && v ∈ connHistory && c (u, v) ==1
            for all duration of node v in connHistory do
                if (duration (u, v).end-duration (u, v).start>threshold)
                    LongDuration++
                else
                    ShortDuration++
                end if
                DurationUtil (u) = LongDuration /(LongDuration+ ShortDuration)
        end if
end if
TieDuration (u)=α* TieUtil(u)+β* DurationUtil (u)
GlobalCentrality= TieDuration (u)
return GlobalCentrality
end.
```

4 Performance Evaluation

In this section, we analyze and compare the performance of the proposed TDRP to Bubble Rap in two different vehicular scenarios. The ONE simulator is used to evaluate the performance of routing protocols. We mainly consider Packet Delivery Ratio (PDR) and End-To-End Delay (E2ED) metrics.

- Packet Delivery Ratio (PDR) is the ratio of the number of successfully delivered packets to that of generated data packets.
- End-To-End Delay (E2ED) is the average latency that delivered packets are sent from the source node to the destination node.

4.1 City Scenario

In the city scenario, we use the map of Flower City Square in Guangzhou, which is imported from Open Street Map [13] and edited with JOSM tool to remove redundant information (see Fig. 2). The ONE simulator only supports *.wkt* format, so we need to use osm2wkt tool to transform *.osm* file into *.wkt* format. In addition, TDRP needs to be imported to The ONE simulator, with $\alpha = 0.5, \beta = 0.5$, and threshold = 10 s. Based on some test experiments, we set K to be 22 and familiar threshold to be 970 in the K-Clique algorithm under the vehicular scenarios. The simulation time lasts 14000 s, and the topology size of the map is 2200 m * 2200 m. We deploy 100 vehicles in the network, with the speed between 10–50 km/h. The interface transmission speed is set to 6 Mbps and the interface transmission range is set to 500 m, which are commonly used in VANET. The message is set to 750 kB, generated every 50 s. The simulation parameters are shown in Table 1.

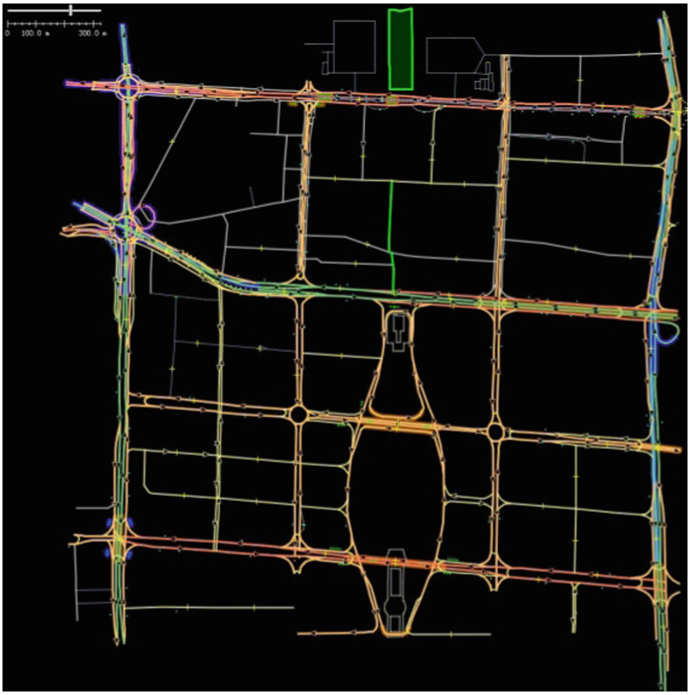

Fig. 2. Flower City Square in Guangzhou imported from OSM and edited with JOSM

Table 1. The simulation parameters for the city scenario

Parameters	Values
Map size	2200 m * 2200 m
Simulation time	14400 s
Number of vehicles	100
Vehicles speed	10–50 km/h
Buffer size	25 MB
Interface transmission speed	6 Mbps
Interface transmission range	500 m
Message size	750 kB
Event interval	50 s
Message TTL	5, 10, 15, 20, 25, 30, 35, 40, 45, 50 min

We compare the TDRP with the typical social-aware routing protocol, i.e., Bubble Rap, and run each experiment 10 times to get the average in all the following simulations.

Figure 3 compares the PDR of two protocols in different Time to Live (TTL) of the message. Both the PDR of two protocols has first increased as TTL increases. Until TTL reaches to 30 min, it begins to become stable, and almost unchanged. In all cases, TDRP consistently outperforms Bubble Rap, with a maximum of 25% improvement. With the increment of TTL, PDR of TDRP significantly raises, even to be 93%, which shows good performance. This is because that the longer a message survives in the network, the more likely it is to reach the destination.

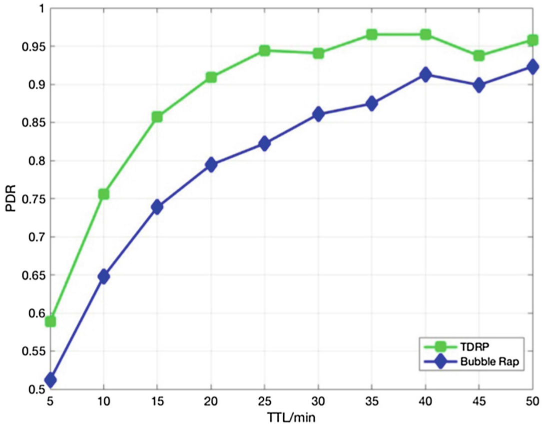

Fig. 3. PDR versus TTL when buffer size is set to 25 MB in the city scenario

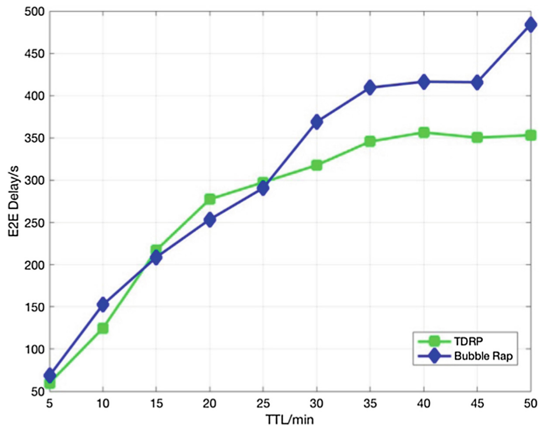

Fig. 4. E2ED versus TTL when buffer size is set to 25 MB in the city scenario

Figure 4 shows the E2ED of TDRP and Bubble Rap, when TTL of messages varies. At the beginning, E2ED of the two protocols increases with TTL and is almost equal. After TTL up to 30 min, although TDRP outperforms Bubble Rap, E2ED of both protocols still keeps increasing, while the corresponding PDR of both protocols approaches to be stable. In addition, the message with higher TTL means that it consumes more resources of the network. Consequently, from the Figs. 3 and 4, it concludes that setting TTL to 30 min is a good choice.

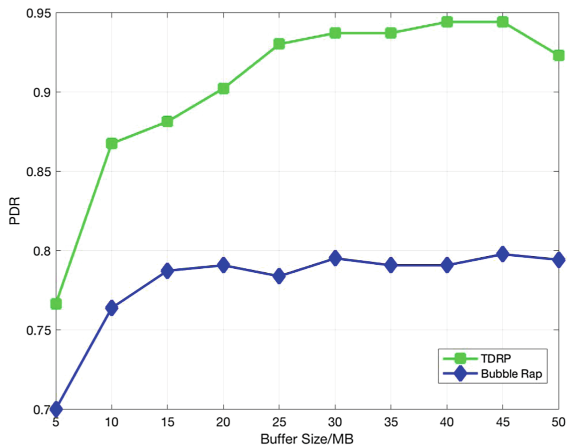

Fig. 5. PDR versus buffer size when TTL is set to 30 min in the city scenario

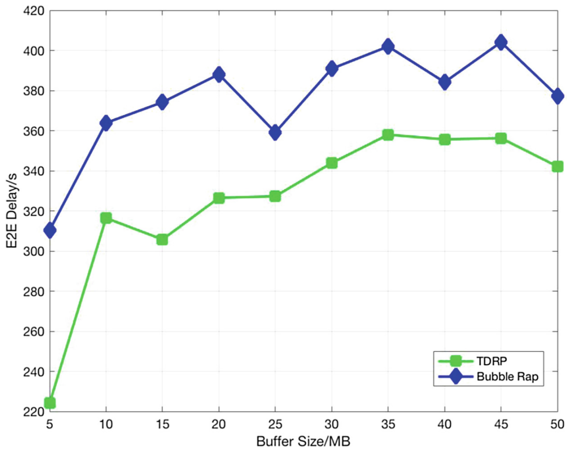

Fig. 6. E2ED versus buffer size when TTL is set to 30 min in the city scenario

In order to find the relation between the performance of protocols and buffer size of the vehicle, another simulation with the same parameters in Table 1 except TTL and buffer size has been done. Figure 5 compares the PDR of two protocols in different buffer sizes of the vehicles when TTL is set to 30 min. TDRP obviously outperforms Bubble Rap in all cases. When buffer size is up to 25 MB, PDR of TDRP is up to 93%, while PDR of Bubble Rap keeps almost unchanged at around 80% after buffer size up to 15 MB. The reason is that every vehicle maintains a neighbor list and a connection history list in TDRP, while only a connection history list in Bubble Rap. Thence, buffer size has a greater impact on TDRP. Figure 6 illustrates E2ED of two protocols in different buffer sizes. It is observed that E2ED of TDRP is lower than that of Bubble Rap in all cases. Given that the buffer of the vehicle becomes bigger and bigger, it follows that TDRP is more promising than Bubble Rap in the city scenario.

4.2 Highway Scenario

In the highway scenario, we use the map of airport expressway in Guangzhou, and choose a section of 4.5 km long highway with two-way eight lanes (see Fig. 7). The speed of vehicles is between 60–100 km/h. Other simulation parameters are the same with the city scenario, which are shown in Table 2.

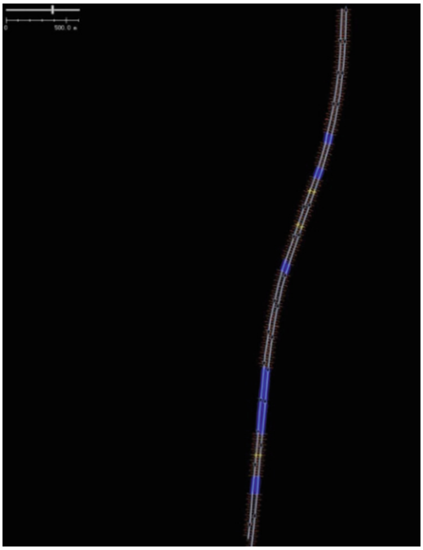

Fig. 7. Airport expressway in Guangzhou imported from OSM and edited with JOSM

Table 2. The simulation parameters for the highway scenario

Parameters	Values
Map size	4500 m * eight-lane
Simulation time	14400 s
Number of vehicles	100
Vehicles speed	60–100 km/h
Buffer size	25 MB
Interface transmission speed	6 Mbps
Interface transmission range	500 m
Message size	750 kB
Event interval	50 s
Message TTL	1, 2, 3, 4, 5, 6, 7, 8, 9, 10 min

Taking the length of this section of highway and the speed of the vehicle into account, it typically takes 2.7–4.5 s for one vehicle to cover this section of highway. This section is not circular, but the movement mode of the vehicle in the simulation is a circle mode, which is very different from the real life. Therefore, TTL of messages can not be large in the highway scenario. Figure 8 compares the PDR of two protocols when TTL is gradually increasing from 1 min to 10 min. It is shown that TDRP outperforms Bubble Rap slightly. When TTL is up to 5 min, PDR is over 95% for both protocols.

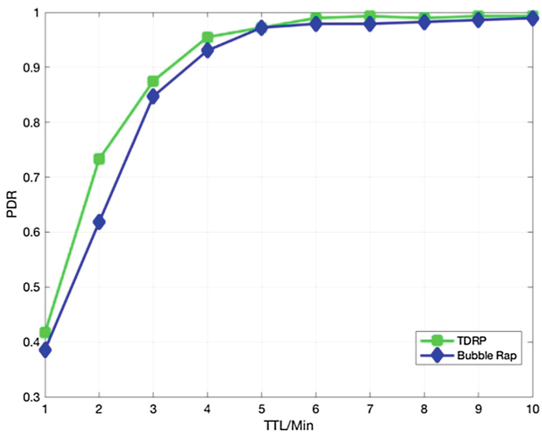

Fig. 8. PDR versus TTL when buffer size is set to 25 MB in the highway scenario

Figure 9 illustrates the E2ED of two protocols, when TTL varies from 1 min to 10 min. We find E2ED of TDRP is less than that of Bubble Rap in all cases, especially when TTL up to 5 min, reducing by 27%. In summary, TDRP not only has the slight higher PDR than Bubble Rap, but also reduces the end-to-end delay significantly. It effectively testifies that TDRP is also a more promising protocol in the highway scenario.

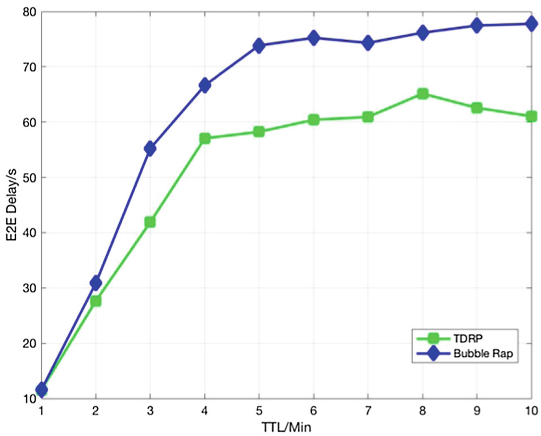

Fig. 9. E2ED versus TTL when buffer size is set to 25 MB in the highway scenario

5 Conclusion

In this paper, we propose a social-aware routing protocol, called Tie and Duration Based Routing Protocol (TDRP), to optimize the performance of vehicular ad-hoc network in terms of PDR and E2ED for two different scenarios. It improves the typical Bubble Rap routing protocol by making full use of the strength of ties and the duration of connections to calculate global and local centralities of nodes. The proposed algorithm is particularly applicable to the transmission of messages between different communities, with taking the features of highly mobile vehicles into account. Simulation results further validates the effectiveness of the proposed protocol. In particular, TDRP obviously outperforms Bubble Rap both in PDR and E2ED performance in the city scenario. While in the highway scenario, TDRP can improve the PDR performance slightly, but still maintains its distinct advantage on the E2ED performance. In conclusion, TDRP is more suitable and more promising than Bubble Rap for VANET.

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