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DATA FORWARDING SCHEMES FOR VEHICULAR AD HOC NETWORKS: A SURVEY AND FUTURE PERSPECTIVES

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Abstract- ***VANET is a promising communication technology that enables communication among V2V and V2I for improving driving safety and efficiency. In VANET, data transfer is done with the help of multi-hop communication in which vehicles act as data carrier. Intelligent Transportations System (ITS) has deployed a no of RSU (Road Side Units) along the roads to collect and deliver traffic information from TCC (Traffic Control Centre) to the vehicles. This paper compares six vehicle trajectory-based data forwarding schemes, tailored for vehicular ad hoc networks. Nowadays GPS-based navigation systems are used for providing efficient driving paths for drivers. Subsequently it also discusses the performance of those data forwarding schemes and list the merits and demerits and conclude the challenges facing in the present day research in Vehicular ad hoc Network (VANET) .***

Keywords- VANET, IVC, ITS, RSU, Vehicle trajectory, VADD, TBD, TSF, TOAF, STDFS, SDFM

I. INTRODUCTION

Recently, it has been widely accepted by the academic society and industrial corporation that the cooperation between vehicles and road transportation systems can significantly improve driver's safety and road efficiency. Vehicular Ad-hoc NETwork (VANET) is a subgroup of Mobile Ad-hoc NETwork (MANET), where communicating nodes are replaced by moving vehicles. It is an important component of ITS. Recognizing its importance, IEEE has approved a standard 802.11p for Wireless Access in Vehicular Environment (WAVE) in 2009. Much work has been conducted to provide a common platform to facilitate inter-vehicle communications (IVCs). IVC enables the service of exchange and distribution of data IVC is necessary to realize traffic condition monitoring, dynamic route scheduling, emergency-message dissemination and, most importantly, safe driving. In VANETs, [1] vehicles can able to communicate each other (V2V, Vehicle-to-Vehicle communications) also they can connect to an infrastructure (V2I, Vehicle-to-Infrastructure) to get some service like accident alerts, traffic alerts, road condition and weather information. This infrastructure called Road Side Units(RSU) is located along the roads to ensure service coverage. Nodes in VANETs are highly mobile, thus the network topology is ever-changing. Accordingly, the communication link between two vehicles suffer from fast variation, and it leads to disconnection due to the vehicular movements. Fortunately, the vehicle mobility can be predictable along the road because it is subjected to the traffic network and its regulations. In general, VANETs [1] have normally higher computational capability and higher transmission power than MANETs. The vehicular communication [5] for the driving safety

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and efficiency has been feasible through the standardization of Dedicated Short Range Communications (DSRC) as IEEE 802.11p in 2010. IEEE 802.11p [5] is an extension of IEEE 802.11a, considering the features of vehicular networks, such as the high-speed mobility and high node density in roadways . As an important trend for the vehicular based networking, Global Positioning System GPS-based navigation systems [5] are popularly used by drivers.

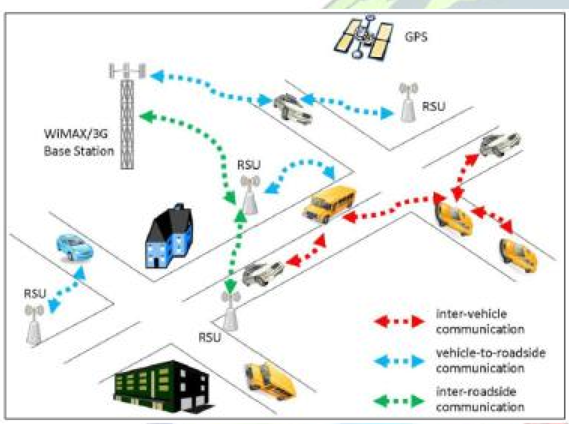

Fig 1: Architecture of VANET

Fig. 1 shows the components and communications with a typical VANET. In a typical VANET, Vehicles communicate with each other through V2V communication in Ad hoc network fashion, and V2I communication through road-side-units (RSU) and mobile broadband (e.g. 4G/LTE).OBUs(On Board Units) of various vehicles form a mobile ad hoc network (MANET). OBUs and road side units together will form ad-hoc network. An RSU can be attached to an infrastructure network, which in turn can be connected to the Internet. RSUs can also communicate to each other directly or via multihop. RSUs allow OBUs to access infrastructure and internet. This paper is structured as follows. The summary of the related work of vehicular networking is elaborated in section II. This is followed by a detailed description of vehicular traffic statistics and vehicular trajectory based six data forwarding schemes in section III. Then the comparative analysis of six data forwarding schemes is provided in section IV. Section V concludes with suggesting the extension of proposed work.

II. RELATED WORK

Most of the data forwarding schemes in VANET are designed aiming at building a path with shorter delivery delay from a source to a destination vehicle. The delay of data forwarding between each hop is very small while most of the latencies can be potentially caused by the *carrying* delay. Vahdat et al. and Becker et al. proposed a routing algorithm with a transmission model in a partially connected MANET [17] in order to maximize the delivery rate and minimize the delivery latency. They introduced the idea of the *carry*-and *forward* which is used in dealing with frequent network partitioning and merging. Packets can be forwarded if there are nodes nearby. Otherwise, the packets has to be carried until the carrier reaches neigbouring nodes in its communication range. However, this protocol is not specifically designed for VANET and ignored the fact that the trajectory of a moving vehicle. Christo Ananth et al. [6] discussed about a Secure system to Anonymous Blacklisting. The secure system adds a layer of accountability to any publicly known anonymizing network is proposed. Servers can

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blacklist misbehaving users while maintaining their privacy and this system shows that how these properties can be attained in a way that is practical, efficient, and sensitive to the needs of both users and services. This work will increase the mainstream acceptance of anonymizing networks such as Tor, which has, thus far, been completely blocked by several services because of users who abuse their anonymity. In future the Nymble system can be extended to support Subnet-based blocking. If a user can obtain multiple addresses, then nymble-based and regular IP-address blocking not supported. In such a situation subnet-based blocking is used. Other resources include email addresses, client puzzles and e-cash, can be used, which could provide more privacy. The system can also enhanced by supporting for varying time periods.. Xu et al. designed a shared trajectory based forwarding scheme for V2V transmission [4] which used the predicted encounter graph to minimize the delivery delay. However, these trajectory based data forwarding schemes are hard to be realized in the real-world since people may not want to share their own trajectories considering the privacy issue. The concept of using public transportation for data delivery has been considered nowadays. Wong et al. proposed an architecture of BUSNet . They attempted to take advantage of public transportation with predictable routes for improving the inter-vehicle communications. The basic idea of BUSNet is to build the data forwarding path by buses for two vehicles that are geographically far away. If two vehicles are far away from each other, then the package delivery will be finish by buses instead of common vehicles.

III. DATA FORWARDING SCHEMES

Data forwarding is the relaying of packets from one network segment to another network segment or from source to destination by nodes in a computer network. The Network Layer of the OSI Layer is responsible for Packet Forwarding. In this section, we describe five data forwarding schemes, such as VADD [4], TBD [2], TSF [3], TOAF[8], STDFS [9] and SDFM[7].

1. VADD: Vehicle-Assisted Data Delivery for V2I Data Delivery

VADD [4] is a data forwarding scheme for the V2I data delivery, based on vehicular traffic statistics, such as the vehicle arrival rate and average speed per road segment along with the digital roadmaps provided by GPS based navigation systems [15]. VADD [5] is explained here at first because TBD [1] (as one of vehicular trajectory-based data forwarding schemes) is based on the stochastic model of VADD.

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Fig. 2. [5] VADD Data Forwarding in Road Network

Data delivery[5] through vehicular *ad hoc* networks is complicated by the fact that vehicular networks are highly mobile and more frequently disconnected. To resolve this issue, the idea of carry and forward[10] , where a moving vehicle carries a packet until a new vehicle moves into its vicinity and forwards the packet is adopted. Vehicle-assisted data delivery (VADD) protocol is to forward the packet to the best road with the lowest delivery delay. For example, as shown in Fig. 2 [5], the current packet carrier (denoted as Carrier) wants to deliver its packet to AP(Access Point) in the road network. It has two neighboring vehicles [10] (denoted as car1 and car2) within its communication range. car1's trajectory passes through a light traffic path where a few vehicles are moving in that path. On the other hand , car2 's trajectory[10] passes through a heavy traffic path where a lot of vehicles are moving statistically, so the data forwarding over communication (network) has a high chance by using intermediate vehicles during the packet's forward-and-carry process. In this case, definitely, Carrier[5] needs to forward its packets to car2 as a next-hop carrier rather than car1 . In VADD [10] , an Expected Delivery Delay (EDD) is computed as a forwarding metric by vehicles adjacent to the current packet carrier. A minimum EDD [10] vehicle will be selected as the next-hop carrier to forward the data. Thus, the EDD computation is a key contribution in VADD.

Even though VADD [5] solves the data forwarding issue nicely through the linear systems of recursive equations , the limitation of VADD [5] does not use the vehicle trajectory available for a better forwarding metric computation.

2. TBD: Trajectory-Based Data Forwarding for V2I Data Delivery

TBD [2] is a data forwarding scheme to improve VADD for the V2I(Vehicle-to-infrastructure) data delivery, using not only vehicular traffic statistics, but also vehicle trajectory in the privacy-preserving manner.

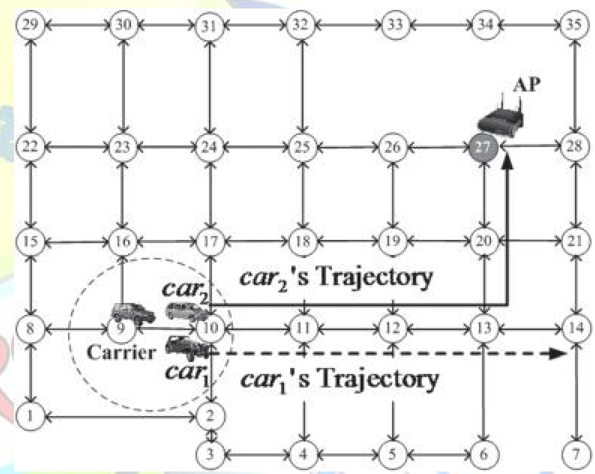

Fig. 3. TBD Data Forwarding in Road Network

Fig. 3 [5] shows the data forwarding in an extremely light-traffic vehicular network. The current packet carrier [5] (denoted as Carrier) has only two neighboring vehicles (denoted as car1 and car2) for the next-hop carrier to forward the data in this road network. Let us assume that only these three vehicles[10] exist in the road network. The next-hop carrier candidates [10] car1 and car2 are moving at the same coordinate and in the same direction towards intersection 11. One difference is that car1's trajectory is far away from the communication range

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[10] with AP(Access Point) and car2's trajectory passes through AP. In this case, car2 should be selected by Carrier as a next-hop carrier to forward the data because car2 has a high chance to deliver Carrier's packets to AP. The main idea of TBD [5] is to divide the data delivery process into two steps: 1) The packet carry process at the current carrier and 2) The delivery process after the packet leaves the current carrier.

Therefore, TBD can allow individual vehicles to calculate their own EDD [10] based on their own trajectory so that the packet carrier can select the best next-hop carrier among its neighboring vehicles to forward the data. However, TBD[5] is designed for the static packet destination. Thus, when the destination is moving in the infrastructure-to-vehicle data delivery, we need a entirely different approach considering the mobility of the destination vehicle.

3. TSF: Trajectory-Based Statistical Forwarding for I2V Data Delivery

TSF [2] is a data forwarding scheme for the infrastructure-to-vehicle (I2V) data delivery, using the trajectory of the destination vehicle. TSF [3] forwards the packets over multi-hop to a selected target point(AP) where the vehicle is expected to pass by. Such a target point(AP) [10] is selected optimally to minimize the packet delivery delay while satisfying the required packet delivery probability. The optimality of target point is achieved analytically by utilizing the packet's delivery delay distribution and the destination vehicle's travel delay distribution.

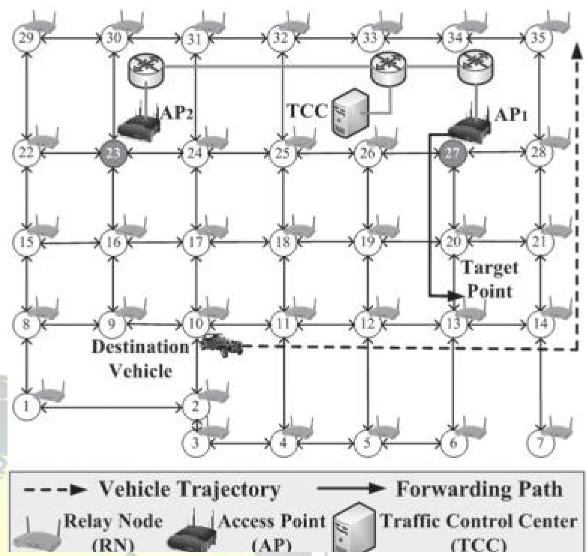

Fig. 4. TSF Data Forwarding in Road Network

Trajectory-based Statistical Forwarding (TSF) scheme is *the first work to investigate the reverse data forwarding scheme based on the vehicle trajectory guided by GPS-based navigation systems* [14]. To ensure the rendezvous of a packet[3] and a moving destination vehicle, an optimal target point is identified as packet destination position in the road network *in order to minimize the packet delivery delay[3] while satisfying the user-required packet delivery probability*. Once the target point [3] is decided or identified, TSF adopts the source routing technique, i.e., forwards the packet using a shortest-delay forwarding path specified by multiple intersections in the target road network. Fig. 4 [5] shows the I2V(Infrastucture-to-Vehicle) data delivery from AP1 to Destination Vehicle. One remarkable difference from VADD and TBD for V2I [10] is that TSF requires relay nodes ie., intermediate nodes at intersections as temporary packet holders that are not

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directly connected to the wired network for the deployment cost reduction unlike Access Points (APs) [22].

In the figure 4 [10] , AP1 selects intersection 13 (denoted as n13) as a target point through the current position and trajectory info., of Destination Vehicle; note that the current positions and trajectories of vehicles are available to APs via Traffic Control Center (TCC) [18] because the vehicles peroidically update their current position and trajectory in TCC. In TSF, the target point selection [5] is performed by the following two delay distributions: 1) Vehicle delay distribution from Destination Vehicle's current position to Target Point and 2) Packet delay distribution from AP(Access Point) to Target Point.

One limitation of TSF [5] is to require relay nodes as infrastructure nodes ie., Access Points or RSU for the reliable I2V data delivery.

4. TOAF: Trajectory-Based Optimal Area Forwarding for Infrastructure-to-Vehicle Data Delivery with Partial Deployment of Stationary Nodes

Trajectory-based optimal area forwarding (TOAF)[8] scheme is tailored for multihop data delivery from infrastructure nodes (e.g., Internet access points) to moving vehicles (infrastructure-to-vehicle) in vehicular ad hoc networks (VANETs) with partial deployment of stationary nodes(Acess Points). It focuses on reducing the delivery-delay and improving the low reliability of infrastructure-to-vehicle communication. Due to the good predictability and controllability in the choice of the next forwarding node or next hop carrier, stationary nodes are more suitable for data delivery compared with mobile nodes [8]. However, increasing the number of stationary nodes is costly and hard to maintain; so it is not very realistic to install stationary nodes on every junction or intersection in VANETs[8]. In fact, many intersections of real world do not have to contain stationary nodes, and some stationary nodes[8] may be located on roadsides rather than at intersections in road. AP [8] selects the optimal area from the trajectory of the destination vehicle and determines the delivery sequence, which includes stationary nodes and mobile nodes from the AP to the optimal area. During packet delivery [8] , if a new node finds that the delay to the next stationary node is less than that of the current carrier, it can be added to the forwarding nodes sequence, reducing the delivery delay. The addition of a new node [8] continues until the forwarded packet reaches the optimal area and infrastructure-to-vehicle communication is achieved.

In figure 5 [8] ,If AP predicts that selecting a stationary node in the trajectory of the destination vehicle in TTL(Time To Live) is impossible, then AP selects a target vehicle as relay node from vehicles that could encounter the destination vehicle [8].

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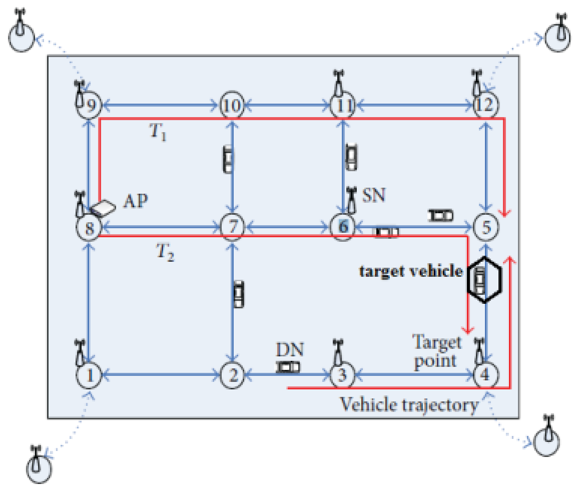

The optimal area is the area where the target point forwards the message to the moving destination vehicle V[8] . AP selects the target point in the VANET when no stationary nodes are available on the trajectories of the destination vehicle. Otherwise, AP finds a vehicle traveling in the opposite route[8] of the destination vehicle and uses this vehicle as the target vehicle. Thus, the target vehicle [8] receives the packet before encountering the destination vehicle. By comparing with the delay that APs predicted[8], the mobile node can easily decide whether to add and forward the data packet or not. So, the delivery sequence could be altered by the addition of the new node which can provides less delivery delay according to the actual VANET circumstances at that time[8].

5. STDFS: Shared-Trajectory-Based Data Forwarding Scheme for V2V Data Delivery

Due to the highly dynamic driving patterns[9] of vehicles, it has been a challenging research problem to achieve effective and time sensitive data forwarding in vehicular ad hoc networks. To address this problem Shared-Trajectory-based Data Forwarding Scheme (STDFS) [9] is proposed, which utilizes shared vehicle trajectory information. STDFS [10] is a data forwarding scheme for the multihop vehicle-to-vehicle (V2V) data delivery through the sharing of the vehicular trajectories moving in a target road network. STDFS is built upon the concept of participatory services in which users of a service (e.g., data forwarding service) share their information (e.g., trajectory) to establish the service ie., data forwarding[9]. The privacy-sensitive users can opt out, while participatory users can exchange privacy information for convenience and performance. STDFS uses shared trajectory information to predict the encounters between vehicles, and a predicted encounter graph[9] is then constructed to find the next hop. Based on the encounter graph, STDFS optimizes the forwarding sequence to achieve the minimal delivery delay given a delivery ratio threshold[9]. The optimal forwarding metrics allow the source vehicle forwards packets to the vehicle in its communication range that provides the best data forwarding performance[9].

Fig. 6 [5] shows the data forwarding from vehicle a (denoted as Va) to stationary vehicle s (denoted as Vs) via the intermediate vehicles b or d (denoted as Vb or Vd). STDFS [10] assumes that vehicles can frequently download the trajectorie information of

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other vehicles from APs sparsely deployed at intersections, as shown in Fig. 6.

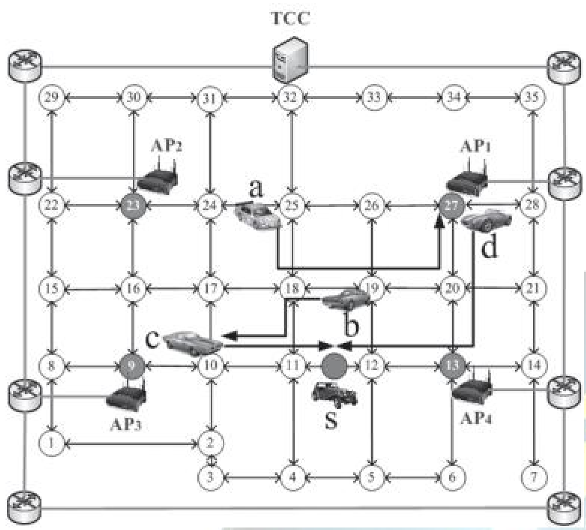

Fig.6. STDFS Data Forwarding in Road Network

In STDFS, source vehicle constructs the predicted encounter graph to determine the next-hop carrier to forward the data that can guarantee the user-defined delivery probability like in TSF[5]. In Fig. 6 [5], Va is the source vehicle and Vs is the destination vehicle. The vehicles Vb, Vc and Vd are intermediate carriers. Vb and Vd may be the next encountered vehicles for Va for data forwarding[5]. In the expansion of the predicted encounter graph, Vb may encounter Vc and then Vc may finally encounter the destination vehicle Vs[10] .In the same way, Vd may finally encounter the destination vehicle Vs .

For the data forwarding in STDFS[10], the packet carrier ie., current node announces the packet destination to neighboring vehicles within its communication range. The neighboring vehicles individually calculate their own EDR(Expected Delivery Ratio)[5] and EDD(Expected Delivery Delay) for the selection of next-hop carrier. The current carrier selects a neighboring vehicle with a minimum EDD such that the next-hop vehicle's EDR is at least the user-defined delivery probability. STDFS requires the sharing of trajectories[5] among vehicles through Access Points. Also, the sharing of trajectories makes concerns about privacy.

6. SDFM: A Social-based Data Forwarding Mechanism for V2V Communication in VANETs

SDFM (A Social-based Data Forwarding Mechanism) is a data forwarding scheme to improve STDFS for the multihop vehicle-to-vehicle data delivery through store-carry-forward method. The SDFM[7] learns vehicles' social characteristics in a distributed manner, and then transfers messages in a "Store-Carry-Forward" method.

SDFM describes the sociality of a vehicle as centrality and community. Based on community and centrality[7], a vehicle forwards it to the vehicle with higher global centrality than itself till it meets a vehicle within the same community as the message's final destination, and then forwards the message to the vehicle with higher local centrality till it is finally delivered[7].

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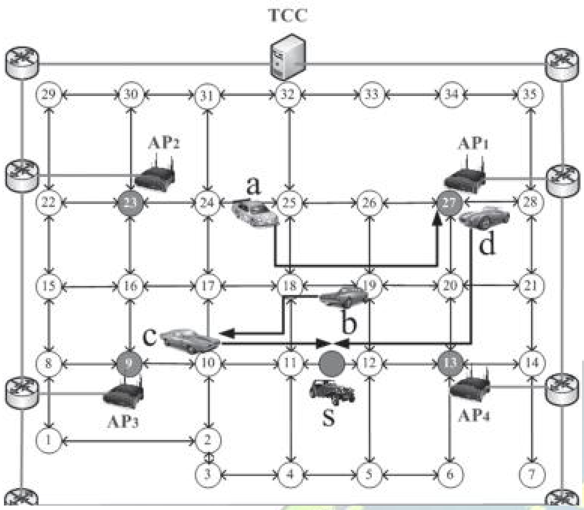

Fig. 7.SDFM Data Forwarding in Road Network

In SDFM[7], vehicles periodically records meeting histories with other vehicles, as well as their own moving trajectories in a certain time window. Based on these two types of information [7], vehicles can estimate their social characters including communities and centralities. The optimal way of assessing centrality is to count how many times the node is on the shortest forwarding paths for all the traffic flows in the vehicular network [7]. For each message stored in buffers, a vehicle forwards it to the vehicle with higher global centrality than itself till it meets a vehicle within the same community as the message's final destination, and then forwards the message to the vehicle with higher local centrality till it is finally delivered[7].

IV. THE ANALYSIS OF FORWARDING SCHEMES

In this section, the Six forwarding schemes (i.e., VADD, TBD, TSF, TOAF and STDFS,SDFM) are analyzed based on the forwarding type that are explained in Section III. Table 4 shows the comparison among those schemes. Fig. 8 shows the performance of VANET data forwarding schemes.

A. FORWARDING TYPE: V2I

The two data forwarding schemes that can support the forwarding type Vehicle-to-Infrastructure are VADD and TBD. VADD uses vehicular traffic statistics to find next hop to forward the data. Whereas TBD uses vehicle trajectory information and vehicular statistics to forward the data.

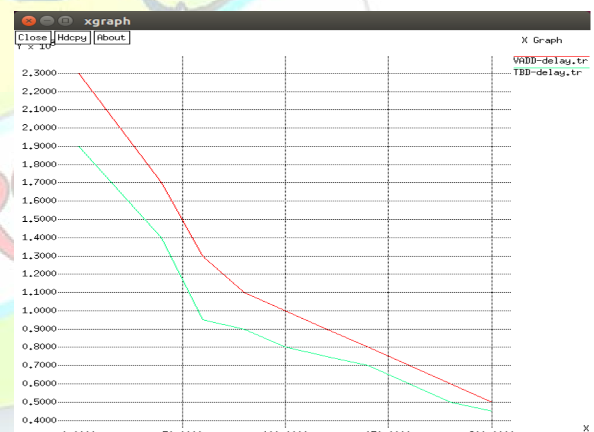

Fig 8a: VADD vs TBD(delay)

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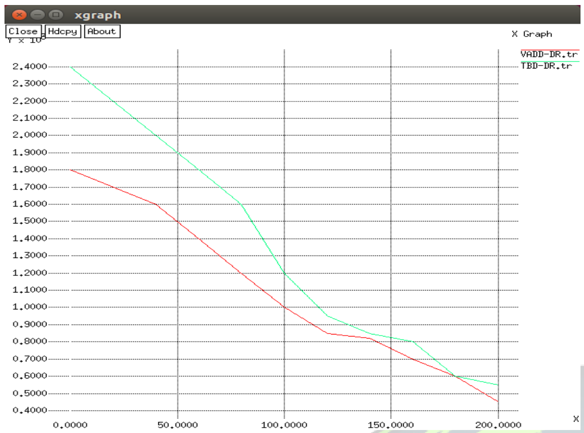

For multihop V2I data delivery, Fig. 8A and table 1 shows the performance of TBD and VADD in average delivery delay by the number of vehicles (i.e., vehicular density) [5]. TBD has a shorter delivery delay than VADD from the lowest vehicular density to the highest vehicular density by a more effective delivery delay estimation using the individual vehicle trajectory.

Table 1: The Comparison between VADD and TBD Forwarding Schemes for Vehicular Ad Hoc Networks

NO OF VEHICLES(50)		
METHOD	DELIVERY RATE(%)	DELIVERY DELAY(MS)
VADD	70%	150ms
TBD	93%	110ms

This indicates that TBD provides better V2I data delivery than VADD. As shown in Figure 8b TBD has the highest delivery rate than VADD because TBD uses vehicle trajectory for EDD computation.

B. FORWARDING TYPE: I2V

The two data forwarding schemes that can support the forwarding type Infrastructure-to-vehicle are TSF and TOAF. TSF uses an intermediate infrastructure node called target point to forward the packet to the moving destination vehicle. Whereas TOAF uses an intermediate vehicle as a target point to forward data to the moving destination vehicle.

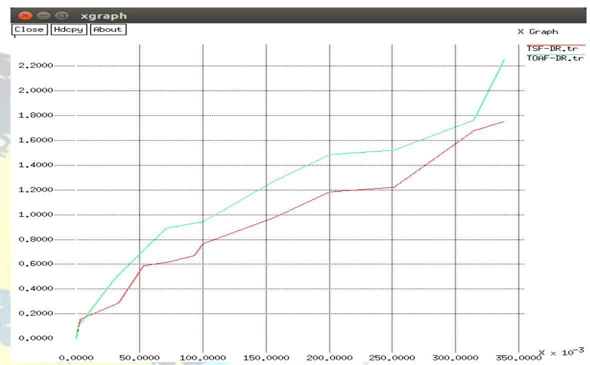

Fig 8c: TSF vs TOAF - delivery rate

As shown in Figure 8c , *TOAF* has much smaller packet delivery delay than TSF at all vehicular densities. As expected, one trend is that the delivery delay in *TSF*, TOAF decrease as the number of vehicles increases. This is because the more vehicles increase the forwarding probability among vehicles, so this reduces the carry delay, leading to the overall shorter delivery delay.

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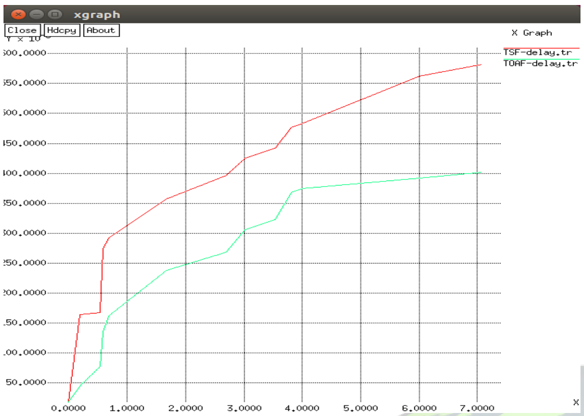

Table 2: The Comparison between TSF and TOAF Forwarding Schemes for Vehicular Ad Hoc Networks

NO OF VEHICLES(50)		
METHOD	DELIVERY RATE(%)	DELIVERY DELAY(MS)
TSF	85%	100ms
TOAF	90%	85ms

As shown in Figure 8d, table 2 TOAF has highest delivery rate compare to TSF even if the number of vehicle increases, because TOAF selects vehicle as target point if there was no access point in the optimal area whereas TSF selects only access points(RSU) as target point. This indicates that TOAF provides better performance than TSF.

C. FORWARDING TYPE: V2V

The two data forwarding schemes that can support the forwarding type Vehicle-to-Vehicle data delivery are STDFS and SDFM. STDFS uses predicted encounter graph and shortest path algorithm to find next hop to forward the data.Whereas SDFM uses community and centrality information of a vehicle to forward the data.

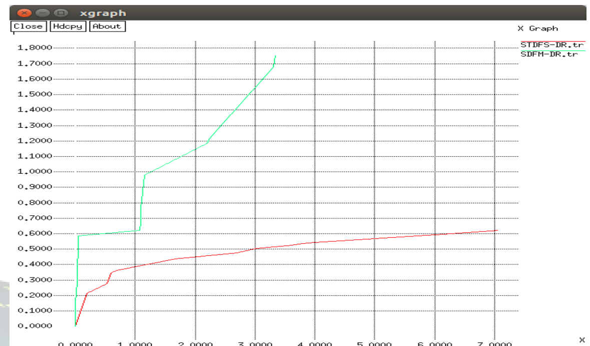

Fig 8e: STDFS VS SDFM-delivery rate

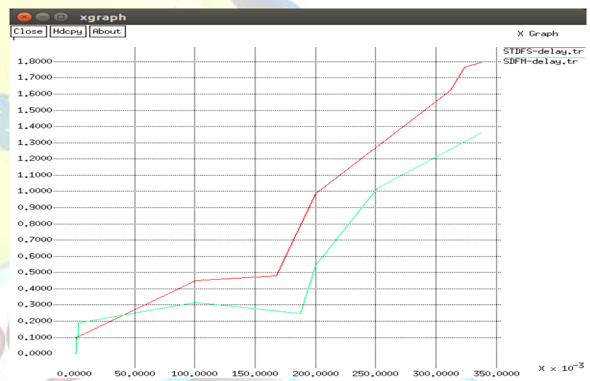

Fig 8f: STDFS VS SDFM(delay)

As shown in Figure 8e,8f, with different densities SDFM always performs better than STDFS. Especially when the vehicle density is high, SDFM still achieves a good performance. Since the community and centrality information provides more detailed knowledge than vehicular statistics, SDFM could forward packets through better paths, and it is more suitable for data forwarding when vehicular networks become sparse.

Table 3: The Comparison between STDFS and SDFM Forwarding Schemes for Vehicular Ad Hoc Networks

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NO OF VEHICLES(50)		
METHOD	DELIVERY RATE(%)	DELIVERY DELAY(MS)
STDFS	91%	98ms
SDFM	95%	70ms

We also find that, SDFM has better performance in terms of both delivery ratio and delivery delay when the density becomes higher. This is because higher vehicular density could increase the connectivity among vehicles and then promote the data forwarding in vehicular network. This indicates that SDFM provides better performance than STDFS.

Table 4: The Comparison among six Data Forwarding Schemes for Vehicular Ad Hoc Networks

FORWARDING SCHEME	FORWARDING TYPE	VEHICULAR STATISTICS	VEHICLE TRAJECTORY	INFRASTRUCTURE NODES	PRIVACY EXPOSURE
VADD	V2I	YES	NO	ACCESS POINTS	NO
TBD	V2I	YES	YES	ACCESS POINTS	NO
TSF	I2V	YES	YES	ACCESS POINTS RELAY NODES,TCC	NO
TOAF	I2V	YES	YES	ACCESS POINTS RELAYNODES(VEHICLE),TCC	NO
STSFS	V2V	YES	YES	ACCESS POINTS, TCC	YES
SDFM	V2V	YES	YES	ACCESS POINTS, TCC	NO

All of six forwarding schemes use vehicular traffic statistics for their forwarding metric computation[10]. Except for VADD, the remaining five schemes take advantage of vehicle trajectory for the more efficient forwarding metric computation

V . CONCLUSION

Data forwarding is one of the important parameter in vehicular communication. Thus this paper explained six data forwarding schemes based on vehicle trajectory in vehicular networks except VADD which is based only on vehicular traffic statistics. The vehicle trajectory is a useful property in the design of data forwarding schemes because it allows for either a better forwarding metric computation or a better destination location estimation . As future work, we will investigate more the characteristics of vehicular trajectory to make better data forwarding schemes that can work well in all the three data forwarding types V2V,V2I,I2V, considering the minimization of delivery delay, the privacy protection on trajectory .

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