

Research Article

Traffic-Aware Data Delivery Scheme for Urban Vehicular Sensor Networks

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Vehicular sensor network (VSN) is a promising technology which could be widely applied to monitor the physical world in urban areas. In such a scenario, the efficient data delivery plays a central role. Existing schemes, however, cannot choose an optimal route, since they either ignore the impact of vehicular distribution on connectivity, or make some unreasonable assumptions on vehicular distribution. In this paper, we propose a traffic-aware data delivery scheme (TADS). The basic idea of TADS is to choose intersections to forward packets dynamically as the route from a source to destination based on link quality and remaining Euclidean distance to destination. Specifically, we first present an optimal utility function as the criteria of intersection selection. Besides the packet forwarding through intersections, we also propose an improved geographically greedy routing algorithm for packet forwarding in straightway mode. Moreover, in order to decrease the routing overhead brought by the traffic information gathering, we build a traffic condition prediction model to estimate the link quality. The simulation results show that our TADS outperforms existing works on packet delivery ratio, end-to-end delay, and routing overhead.

1. Introduction

With the advance of technology, most of the vehicles are equipped with on-board sensors; thus, a new network is the emerging-vehicular sensor network (VSN). Different from traditional sensor networks, VSN is not limited in energy consumption, owns much powerful processing units and wireless communication, and can determine the position of the nodes through GPS. Because of these properties, VSN has been envisioned to be useful in monitoring the physical world, especially in urban areas in which more vehicles equipped with sensors are available. For example, a vehicular network can be used to monitor traffic [1, 2] (e.g., jams, traffic accident, etc.), for improving driving convenience and efficiency. It can also be used in environmental surveillance [3], since urban areas are full of vehicles especially the taxis. To realize this vision, efficiently data transmission mainly relies on intervehicle communication in VSN. However, the special property of vehicle in mobility brings many challenges to VSN in throughput and latency of data transmission.

For the past decade or so, quite a few number of researchers and institutions were dedicated to improving transportation efficiency in urban VSN. Usually, these protocols mainly focus on selecting an intersection candidate to forward data according to the density of vehicles on the road [4, 5], such as VADD based on historical traffic condition to select a road with high density to forward packets. However, not only the density but also the distribution of vehicles on the road can affect the node connectivity. As shown in Figure 1, although the density is high (Figure 1(b)), unbalance traffic, caused by signal light and car-following driving, will lead to disconnection. Consequently, both the density and distribution of vehicles are needed to be taken into consideration for data transmission. In order to consider the vehicular distribution in routing protocol, some of protocols give unreasonable assumptions. For example, in [6, 7], they assume that the speed of the vehicles in the traffic flow is uniform, so the distribution of the space headway is exponential, which does not hold in reality scenario.

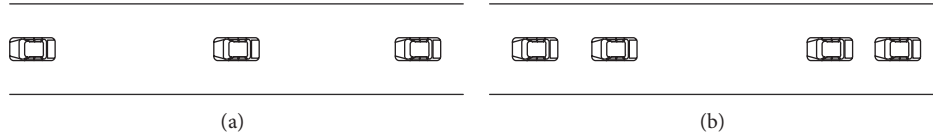


FIGURE 1: Connectivity in VSN.

In this paper, we solve the problem of efficient data delivery in vehicular sensor network when a vehicle sends a delay-tolerant data to some fixed site and how to efficiently route the packet to the destination. We propose a traffic-aware data delivery scheme (TADS), which emphasizes the intersection selection, that is, how to choose a robust route to forward packet. Different from existing routing protocols, TADS takes vehicular real-time spatial distribution together with vehicular density and the remaining Euclidean distance to the destination into consideration to choose an intersection for efficiently forwarding packet in VSN. For data delivery between intersections, we employ improved geographically greedy routing algorithm. We also build a vehicular density and vehicular spatial distribution prediction model based on the traffic pattern and road layout to estimate the link quality with time. Extensive simulations are conducted to evaluate the proposed protocol; the results show that TADS outperforms previous protocols in terms of packet delivery ratio, data packet delay, and routing overhead. TADS paves the way for delay-tolerant VSN applications like traffic surveillance and event reporting.

The major contributions of this paper are as follows.

- (1) Uneven distribution of vehicles has great impact on routing performance; we present a method to denote the vehicular spatial distribution. Once the vehicular distribution can be obtained, the connectivity can be computed more accurately.
- (2) Due to the traffic pattern and road layout, we establish a vehicular density and vehicular spatial distribution prediction model, through which TADS is efficient and resource efficient.
- (3) We take vehicular density, distribution, and the remaining distance to the destination into account to design a routing protocol for VSN. The simulation results show that TADS outperforms most of the existing protocols.

The rest of the paper is organized as follows. In Section 2, we present a brief overview of related work on data delivery. In Section 3, we introduce the model of TADS. The detailed traffic-aware data delivery scheme will be introduced in Section 4. Section 5 evaluates the performance of TADS, and Section 6 summarizes the paper.

2. Related Work

In the last few years, a number of researchers have made many contributions to the routing protocol of ad hoc network.

These routing algorithms are divided into two categories: topology-based and position-based routings. Topology-based protocols [8–10] should establish the route from source to the destination and maintain it in a table before the packet is sent, which are suitable for dense networks. Position-based protocols [11–13] leverage geographic positioning information to select the next forwarding hop; there is no need to create and maintain the global route between source and destination. As more and more vehicles are equipped with GPS and digital maps, position-based routing strategy is more convenient for urban vehicular sensor network. Owing to that the connectivity in urban vehicle networks heavily relies on the traffic condition, we classify position-based routing algorithms into two categories. One category exploits the historical traffic information to assist packet forwarding, and the other exploits the real-time traffic information to forward packet.

For the first category algorithms, there is no need to collect traffic information or make prediction. With the help of the navigation system, the traffic conditions are priori known before the packet to be sent. Vehicle-assisted data delivery (VADD) [4] is a kind of geographic routing protocol. It assumes that vehicles can obtain traffic statistics such as traffic density and vehicular speed on the road at different times of the day through preloaded digital map. The shortest expected delivery delay to the destination of the data depends on each road vehicular density. A drawback is that the historical information will not confirm to the realist traffic conditions that may cause routes to be incorrectly computed.

For the second category, the traffic conditions are gathered through an on-the-fly collection process. Greedy traffic-aware routing protocol (GyTAR) [6] is an intersection-based geographical routing protocol. For the intersection selection process, an estimation score is given to each junction by combining the road density and the curve metric distance to the destination. The junction with the highest value will be chosen for data delivery. The work in [14] selects an optimal route with the best network transmission quality model that takes into account vehicle real-time density and traffic light periods to estimate the probability of network connectivity and data delivery ratio for transmitting packets. Both of these two protocols divide the road into segments, and the vehicle headers in each of the segments, which are highly dynamic, are needed to exchange information. Intersection-based routing protocol (IBR) [15] finds a minimum delay routing path in various vehicular densities. Moreover, vehicles reroute each packet according to real-time road conditions in each intersection, and the packets sent to a node at the intersections depend on the moving

direction of the next vehicle. All of these protocols are needed to periodically collect road information, which significantly increases the routing overhead.

Most of these routing protocols do not take into account the vehicular distribution on the road where there may exist traffic hole [16], which means that it may be possible to lose some good candidate intersections when they try to forward a packet. Moreover, some of these protocols divide roads into segments, which are too complicated to be realized in the networking protocol design. To provide a solution to the aforementioned problems, in this paper, we take the vehicular density and distribution into account to design a new intersection-based routing protocol. The proposed protocol is easy to operate. In the following section, we will give a detailed description of our approach and present its added value compared with other existing vehicular routing protocols.

3. The TADS Model

3.1. Assumptions. We assume that each vehicle in the network is equipped with GPS, which enables them to acquire their own position and speed, and vehicles maintain a neighbor table that is built through beacon messages. The neighbor table records each neighboring vehicle's position, velocity, and moving direction. Furthermore, vehicles are equipped with preloaded with digital map, with the help of which we can determine the current geographical position of the destination. Finally, we assume that the traffic condition will not change significantly for a period of time.

3.2. Problem Statement. In city scenarios, data delivery has two modes: intersection mode and straightway mode. The most important issue is to select a robust route that can reduce delivery latency and improve delivery ratio. Although some of the routing protocols, such as ACAR [14] which always selects route with high density, are sometimes very inefficient for data delivery, as they ignore the distribution of vehicle on the road. As shown in Figure 2, the source node S wants to send a message to the destination D at the corner of intersection I_d . To forward the message through $I_a \rightarrow I_c \rightarrow I_d$ would be better than through $I_a \rightarrow I_b \rightarrow I_d$, even though the route $I_a \rightarrow I_b$ owns higher density. The reason is that the uneven distribution caused by traffic accidents or signal lights may lead to disconnection of the message that has to be carried by the vehicle. Since wireless communication is far faster than vehicle moving, the routing protocols should do their effort to leverage wireless communication.

Therefore, a proper routing protocol is important to forward the packet in VSN, and it is determined by several factors such as vehicular density, vehicular distribution, and road length. In this paper, we first model the link quality and then propose an approach to select the optimal route that can achieve the lowest forwarding delay.

3.3. TADS Model. TADS is an intersection-based multihop routing protocol that is capable of finding optimal route

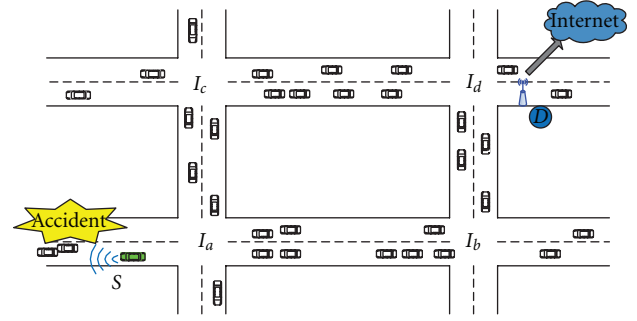


FIGURE 2: The problem of routing in VSN.

according to the real-time traffic condition. Owing to that the traffic flow will not change rapidly within a short time in urban scenario, we can build the link quality prediction model to increase the beacon cycle. To reach these objectives, TADS is organized into two schemes: (1) a scheme for the selection of the optimal route through which packets at each junction make decision to forward the packet to the destination; (2) a mechanism for the estimation of vehicular density and vehicular distribution to estimate link quality with time, which can significantly reduce the overhead of the routing protocol. Using TADS, packets will ultimately reach to the destination.

3.3.1. Intersection Selection. Similar to GPSR, TADS is a partial routing protocol and dynamically chooses the next intersection. When the packet carrier is approaching an intersection, it will calculate the utility function which depends on the link quality and the Euclidean distance from the candidate to the destination. Usually, the optimal route is the geographically closer candidate intersection to the destination and the route having higher link quality.

To better understand how the next intersection is chosen, it is illustrated by Figure 3 as an example. Since the source node S is approaching the intersection, it computes link quality of each neighboring road based on the traffic density and distribution. In order to guarantee the package forward to destination, the shorter distances from the candidate intersection to the destination will make a contribution to selecting the intersection. The source node knows the Euclidean distance from each candidate intersection to the destination through map. Thus, S will not select the intersection far away from destination. Intersection I_a has the optimal utility function and is chosen as the next one.

To formally calculate the utility function, we define the following notations.

- (i) r_{ij} : The road from intersection I to intersection J ;
- (ii) L_{ij} : The Euclidean distance on r_{ij} ;
- (iii) p_{jk} : The position of vehicle k on r_{ij} ;
- (iv) N_{ij} : The number of vehicles on r_{ij} ;
- (v) σ : The vehicular distributions on r_{ij} ;
- (vi) D_j : The Euclidean distance from the candidate intersection J to the destination.

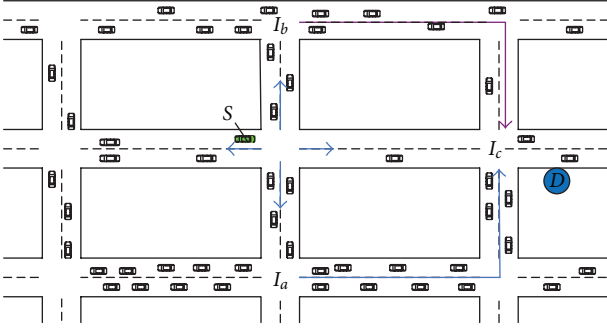


FIGURE 3: An example of selecting an intersection.

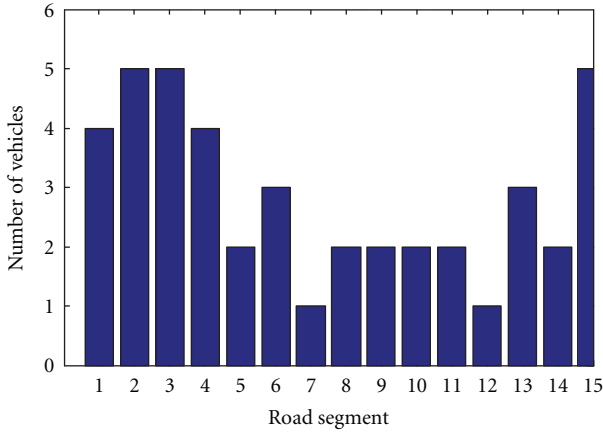


FIGURE 4: Vehicle spatial distribution on road.

Vehicular density depicts the status of the road segment that owns the ability to forward packets, it can be formulated on the road r_{ij} as

$$\rho_{ij} = \frac{N_{ij}}{L_{ij}}. \quad (1)$$

Before giving the vehicular distribution on road r_{ij} , we propose a definition called relative distance degree, which indicates the relative distance between the intersection and the current position of the vehicle.

Definition 1. For any node k and its position is p_{ijk} on the road r_{ij} , the relative distance degree is

$$l_{ijk} = \frac{p_{ijk}}{L_{ij}}. \quad (2)$$

We can apply (2) to all vehicles on road r_{ij} and then acquire the vehicular spatial distribution. For each road, we employ a histogram to obtain the statistics results. Since the radio range is 200 m–250 m, we set the interval of histogram to 100 m; x -axis represents the road segments, the y -axis indicates the number of vehicles per segment, and the fluctuation of the graph indicates the vehicular unbalance distribution. Figure 4 is an example of a single road of length 1500 m. In the graph, the first 100 m has five vehicles, and

there is only one vehicle between 600 m–700 m, which will significantly affect the routing performance.

Histograms of all the road segments are calculated based on the collected beacons from vehicles on the road. Suppose that n_m denotes the number of vehicles in the i th interval zone, the deviation (it indicates the balance or unbalance vehicular distribution) of the road r_{ij} can be expressed as

$$\begin{aligned} \sigma_{ij} &= \frac{\sum_{m=1}^N (n_m - \sum_{m=1}^N (n_m/N))^2}{N} \\ &= \frac{\sum_{m=1}^N n_m^2 - 2 \sum_{m=1}^N n_m + (N_{ij}^2/N)}{N} \\ &= \frac{N \sum_{m=1}^N n_m^2 - N_{ij}^2}{N^2}. \end{aligned} \quad (3)$$

Hence, the utility function can be formulated as

$$\Theta_{\rho\sigma D_I} = \left(1 - \alpha \frac{D_I}{D_K + D_H}\right) \frac{\rho_{ij}}{1 + \sigma_{ij}}. \quad (4)$$

α is used as a weighting factor for the distance. $D_K = \max(D_1, D_2, \dots, D_m)$ and $D_H = \min(D_1, D_2, \dots, D_m)$.

As we can see, the utility function depends on three parameters (ρ, σ, D_I). For a given street, (1) provides the traffic density ρ and through the statistics results of the relative position of vehicles, the deviation σ (indicates if the road is balanced or not) is calculated using (3), whereas $D_I/(D_K + D_H)$ represents distance degree of different route, which guarantees that the packet is forwarded to the destination. $\rho_{ij}/(1 + \sigma_{ij})$ determines how high the whole street link quality is. Thus, by multiplying $\rho_{ij}/(1 + \sigma_{ij})$ with $\alpha(D_I/(D_K + D_H))$, we provide the streets with a correct value since this corresponds to scenarios where the candidate intersections are far away destination.

3.3.2. The Traffic Condition Prediction Model. In order to achieve the intersection selecting, we need to periodically collect the road information (e.g., the vehicle moving direction, speed, and position) to calculate the link quality, which consumes large resources, especially the bandwidth, and has bad impact on routing performance, for example, increasing routing overhead. However, owing to that the traffic flow may keep steady within a short time period, the traffic condition can be predicted based on the intersection historical traffic flow and moving vehicles on the road.

Link quality depends on the vehicular density and vehicular spatial distribution on the road; thus, in this section, we propose a vehicular density and vehicular spatial distribution prediction model to estimate the link quality. For prediction, each packet carrier maintains a road table where three tuples, $s_i(p, v, a)$, are recorded; here the three elements represent the position, velocity, and moving direction of vehicles on the road, and the table is divided into two sets $T1$ and $T2$ according to the vehicle moving direction. Each road periodically broadcasts its state to update the road table.

The problem of prediction of the link stability at time t is to compute the future density $\rho(t)$ and the deviation

$\sigma(t)$. The deviation is determined by the statistics results of relative distance degree; therefore, we just need to predict the vehicular number and their positions on the road. The vehicular number is affected by two parts: (1) the new coming vehicles and (2) the vehicles that have left. Suppose the vehicle arrivals at each intersection follow Poisson distribution. Thus, the probability of i of vehicles coming at time t is

$$P(A(t) = i) = e^{(-\lambda t)} \frac{(\lambda t)^i}{i!}. \quad (5)$$

When $P(A(t) = w) < h_c$, we ignore the possibility of coming vehicles; thus, the average number of arriving vehicles $A(t)$ is

$$A(t) = \sum_{i=1}^{w-1} e^{(-\lambda t)} \frac{i(\lambda t)^i}{i!} = \sum_{i=1}^{w-1} e^{(-\lambda t)} \frac{(\lambda t)^i}{(i-1)!}. \quad (6)$$

At time τ , the packet carrier receives the information from each road, then, it can compute the vehicle arrival rate of each intersection and applies (6) to estimate the number of the new coming vehicles. For the vehicles that have left, it is much simpler. The vehicles moving in the packet expectation direction belong to $T1$, and the others belong to $T2$. In this paper, we use D to denote the number of vehicles that have left. In $T1$, when $P_k + V_k t > L$, we can determine the vehicle has left the road, that is, $D = D + 1$ and in the same way, in $T2$, when $P_k - V_k t < 0$, $D = D + 1$. Thus, the number of vehicles on the road at time t is

$$N'(t) = N(t) + A(t) - D. \quad (7)$$

And then, we can apply (1) to compute the vehicular density on the road. For the vehicular distribution, it is essential to determine the relative distance of the new coming vehicles. We first consider the situation for moving in the packet expectation direction.

For Poisson distribution, N vehicles arrive at the intersection at time t , w_i denotes the i th arrival waiting time, and the conditional probability of waiting time is

$$f(t) = \begin{cases} \frac{n!}{t^n}, & \text{if } 0 < w_1 < w_2 < \dots < w_n < t, \\ 0, & \text{otherwise.} \end{cases} \quad (8)$$

Suppose the new coming vehicles move at the average speed of road, and y_n denotes the n th vehicular position; thus, its relative position is

$$y_n = (t - w_n) V. \quad (9)$$

Hence, the conditional probability density function of the new arrival vehicles relative position is

$$f(y) = \begin{cases} -\frac{n!}{(t - y/V)^n}, & \text{if } 0 < y_1 < y_2 < \dots < y_n < L, \\ 0, & \text{otherwise.} \end{cases} \quad (10)$$

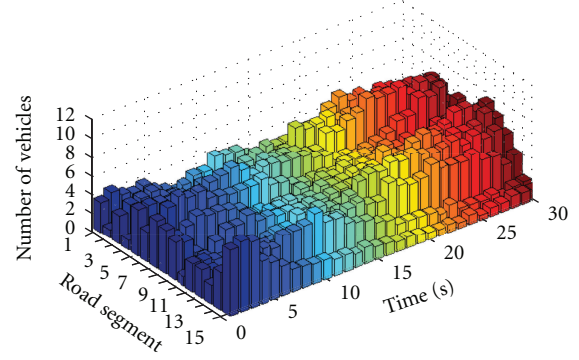


FIGURE 5: Prediction model.

The estimation position of n th vehicle is

$$E(y_n) = \int_0^L -\frac{yn!}{(t - y/v)^n} dy. \quad (11)$$

If the first arrival vehicle belongs to the first zone, the following ones do not need to be calculated, since they will not pass it; else, the second one is also computed until the one falling into the first zone emerges. For the vehicles on the opposite of the expectation direction, the relative position is

$$Y_n = L - y_n. \quad (12)$$

For the vehicles on the road, the relative distance is $P_K + v_k t$, v is a vector. When obtaining all the relative distances, we apply (2) to compute the relative degree and then apply (3) to compute vehicular spatial distribution.

Figure 5 shows an example of the change of vehicular spatial distribution over time. In this scenario, the vehicle arrivals rates of two intersections on the road are 0.6 and 0.3, respectively.

4. Traffic-Aware-Based Data Delivery Protocol

TADS is designed for city scenarios VSN routing, which only has two modes: intersection and straightway. In this section, we orderly present the protocol for the two modes.

4.1. TADS Used in the Intersection Mode. When approaching the intersection, the packet carrier can determine the best forward path deriving from (4) and then check if there is an available relay node to forward packets toward that intersection. As Figure 6(a) shows, vehicle A at intersection has a packet to forward to certain destination. Assume that north is the optimal direction for this packet. Both B and C are available relay nodes, for difference, B moving north and C moving south. TADS will select B as the next hop instead of vehicle C, since it can guarantee that the packet is forwarded to the optimal road. If there is only vehicle C available which is geographically closer to north, A will select C as the relay node, since C has the possibility to forward the packet to D immediately. Due to that the moving direction of C is on the opposite of the expectation direction, A always

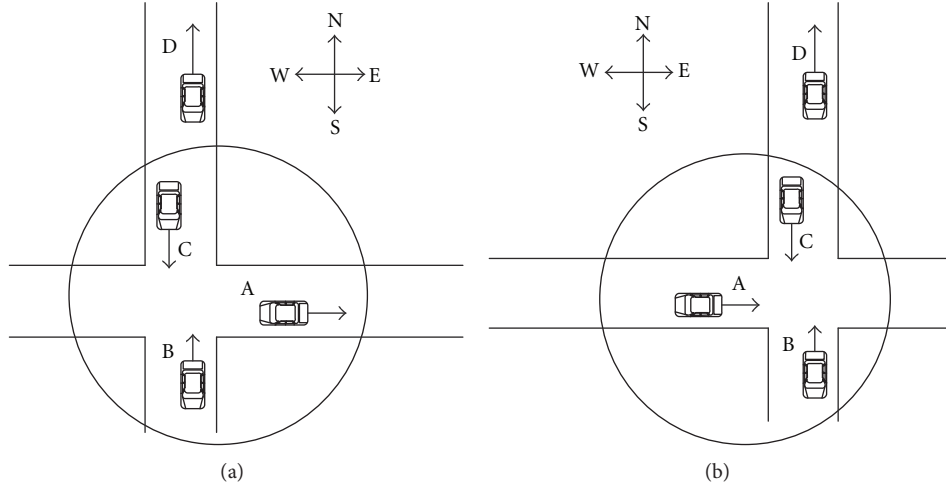


FIGURE 6: Packet forwarding in the intersection mode.

restores the packet until it receives the ACK message from C. If A failed to meet any relay node at current intersection, it will keep holding the packet and move ahead, it still has the opportunity to forward the packet to the expectation direction, as Figure 6(b) shown. When A passes through current intersection, nodes B and C are likely to emerge into the communication scope of A, and it can make a routing planning.

4.2. TADS Used in the Straightway Mode. In the straightway mode TADS applies improved geographically greedy routing algorithm to forward the packets to the destination intersection (the intersection ahead). To implement the scheme, all packets are marked by the location of the next intersection, and the packet carrier needs to record the velocity vector information of each neighbor vehicle. When a packet is received, the forwarding vehicle uses the corresponding recorded information to select the next neighbor that is closest to the destination among the nodes moving in the packet expectation direction. For instance, as shown in Figure 7(a), A has a packet to forward to the next intersection, both B and C are its neighbors, A will select C which is geographically closer to destination to forward the packet. In Figure 7(b), even though B is further from the destination, A will select B to forward the packet, since this seems like better than selecting C. This is because if there is no relay node for C, it will pass the packet to B shortly, which increases the delay, and B can ensure the packet to be sent to destination.

5. Performance Evaluation

In this section, we analyze the weighting factor α and evaluate the performance of the prediction model and TADS. We use VanetMobiSim-1.1 [17], a flexible framework for vehicles mobility modeling, to generate the real traces that can be used by NS2. Since the simulation should be offered a network environment as close as possible to the real world one, we

make an effort to define a realistic scenario where VSN may be deployed.

5.1. The Weighting Factor Analysis. In this section, we analyze the weighting factor of the utility function to determine the good balance between distance and link quality. We simulated the packet delivery ratio of TADS for different values of α . The simulation scenario is shown in Figure 10, and we set the number of vehicles to be 250. As Figure 8 shows, in most of the cases, $\alpha = 0.4$ achieves the highest packet delivery ratio. This is mainly because the vehicle moving speed is much slower than the wireless communication, and it is better to favor a higher link quality to forward the packet.

5.2. Evaluation of the Prediction Model. We simulated a 1500 m long straight road with two bidirectional lanes and set the period of vehicle light to 60 s. The traffic light can cause unbalanced vehicle distribution in various degrees, which has great impact on the performance of prediction model. In order to analyze the performance in various situations, we must set the simulation time to be greater than 60 s (in this section we set the simulation time to be 70 s). Since the different vehicles arrival rate of each intersection has impact on the performance of prediction accuracy, we extract different arrival rate to display our algorithm. In order to give the analysis result of the prediction model, firstly we define the error rate.

Definition 2. $\sigma(t)$ and $\sigma^*(t)$ are the estimated and real deviation of road L at time t , respectively, and the error rate is given as

$$\text{err} = \frac{|\sigma(t) - \sigma^*(t)|}{\sigma^*(t)}. \quad (13)$$

Figure 9 plots the error rate of the prediction of vehicular spatial distribution over time. The figure shows that the error rate is lower than 10% for the low arrival rate and lower than 13% for the higher arrival rate when the estimation time is under 30 s, which means that the estimated deviation

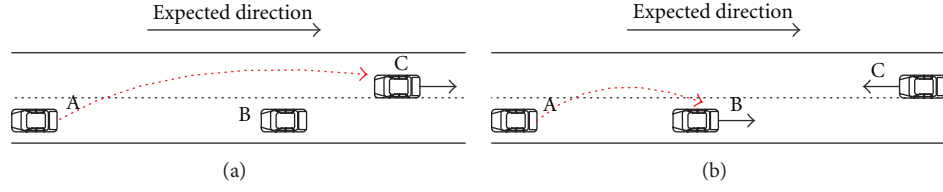


FIGURE 7: Packet forwarding in straightway mode.

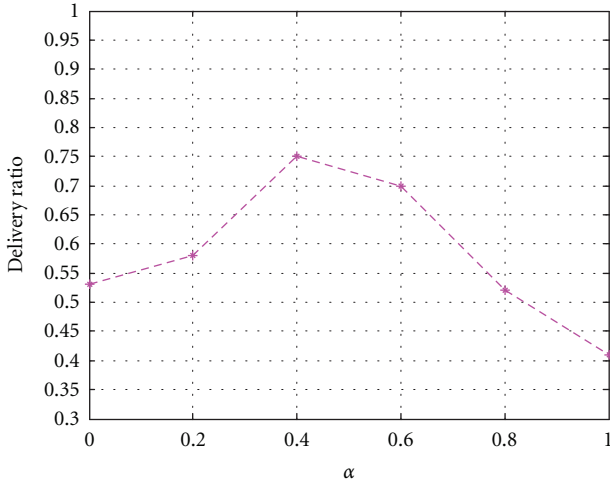


FIGURE 8: The delivery ratio versus weighting factor.

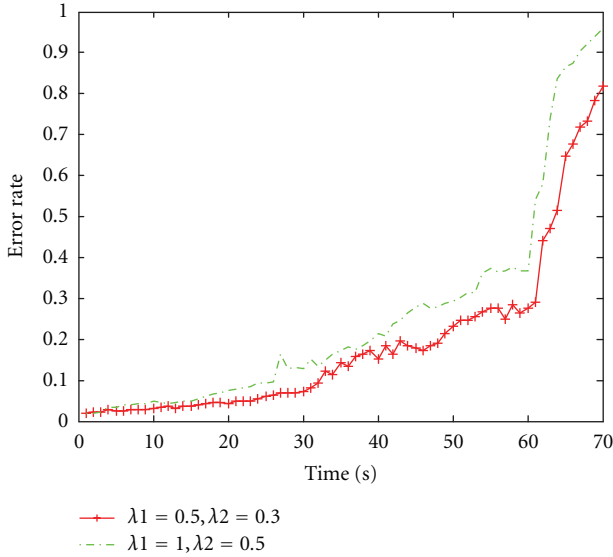


FIGURE 9: The error rate of road over time.

is close to the actual deviation, and it is observed that longer estimation time causes more errors rate. This is mostly explained by the fact that the vehicles are highly dynamic; by contrast, in our model we set a constant arrival rate during the estimation process which causes larger error rate with time increases. Furthermore, it is observed that when the time exceeds 60 s, the error rate sharply increases. This is because,



FIGURE 10: Road topology of simulation area.

in reality scenario, the traffic red light is working beyond 60 s, and at the current intersection the vehicles stop moving into the road, which is consistent with the reality scenarios.

5.3. Evaluation of TADS. To evaluate the performance of the TADS, we conduct a more complex simulation and compare our algorithm with two existing protocols: GSR [18] and ACAR [14]. Since GSR always selects the forwarding node that is closest in geographical distance to the destination and drops packets when the network is disconnected, to have a fair comparison, we extend GSR by adding carry-and-forward schemes in it.

5.3.1. Simulation Setup. The simulation was based on a real street map with the range of $1600 \text{ m} \times 1400 \text{ m}$, which is extracted from an urban area of Chengdu, a city of China. As shown in Figure 10, it consists of 14 intersections and 21 bidirectional roads. At the beginning of the simulation, a number of vehicles are located on the position to the map following the predefined value, and each of them chooses one of the intersections as its destination. Then, they start moving along the road on both directions with an average speed range from 40 to 80 km/h that depends on the speed limit of a specific road. To produce traffic change, the total numbers of nodes are deployed in the region ranging from 100 to 300, and the traffic light period is set to 60 s to produce unbalanced vehicular distribution. Among all vehicles, 10 of them are source nodes to send CBR data packets at 0.1 to 1 per second with a packet size of 512 B. All the key simulation parameters are listed in Table 1.

TABLE 1: Simulation parameters.

Parameter	Value
Simulation time (s)	400
Simulation area (m)	1600 × 1400
Number of intersections	14
Period of traffic lights (s)	60
Number of vehicles	100150200250300
Communication range (m)	250
Vehicle velocity (km/h)	40–80
CBR (packet per second)	0.1–1
Packet size (B)	512
Vehicle beacon interval (s)	1.0, 30

5.4. Simulation Results. We mainly evaluate our algorithm on packet delivery ratio, end-to-end delay, and routing overhead as a function of the data transmission rate and the vehicular density in simulation. As a static metric, packet delivery ratio is the number of successfully received packets at the destination divided by the total number of packets in the networks, which is significantly affected by the simulation of time. End-to-end delay reflects transmission duration between two nodes, which indicates how long it takes for a packet to be forwarded across the network from the source to the destination. Routing overhead denotes the ratio between the total number of the control packets and the number of data packets sent into the networks and the control packets.

The routing protocols are compared under various data transmission rates that set the number of vehicles as 150 and various vehicular densities that set the packet sending rate as 0.3 pkt/s.

Packet Delivery Ratio. Figure 11(a) shows that GSR has the lowest packet delivery ratio, even if it is implemented in a carry-and-forward way, as it always chooses the geographically shortest path to destination without considering the vehicular traffic. Consequently, some data packets cannot reach their destination due to that the wireless transmission quality is low on some sections of the road. On the other hand, for almost all packet sending rates, TADS gives the highest packet delivery ratio, since it forwards packets along the route on the road following the road traffic density, vehicular spatial distribution, and the Euclidean distance to the destination. Hence, a packet will successively arrive at the destination along the streets with the highest transmission quality. ACAR has a lower delivery ratio than TADS, and this is because it just considers vehicular density to estimate the probability of network for transmitting packets. Consequently, some data packets cannot reach their destination due to the problem of traffic hole.

In Figure 11(b), it is observed that as the vehicular density increases, GSR achieves very good delivery ratio, and since the connectivity is much better than the previous scenario, there are more nodes that can help carry and forward the packets to the destination. For ACAR, its packet delivery

ratio will increase when the network density is low, as it will forward packets along the path with higher connectivity. However, when network density is larger than 150 nodes, its packet delivery ratio slightly increases. When the network density becomes larger, ACAR may choose the highest density road to forward the packet, which causes MAC layer collisions, so the delivery ratio cannot drastically increase and sometimes may decrease. Due to full consideration of connectivity in TADS, the optimal utility function may be different; thus, there are few collisions, and the packet delivery ratio of TADS increases when network density increases.

End-to-End Delay. As Figure 12(a) shows, the end-to-end delay is a function of packet sending rates. When the packet sending rates increase, more opportunities are obtained to forward the packet to the destination; thus, the forwarding delay will decrease. GSR has the largest end-to-end delay compared to ACAR and TADS, which is mainly due to the long time vehicles carry packets as there is no next hop available. ACAR has relatively lower end-to-end delay at most of the packet sending rates. An interesting observation is that when the packet sending rate is closer to 0.9 prt/s or when the vehicular density increases (in Figure 12(b)) to 200 nodes, GSR shows lower delay. This is because of the forwarding rules in ACAR; when more packets are injected into the same route, there are more packet collision and longer queuing time. In this case, the end-to-end delay in ACAR will increase.

In Figure 12(b), TADS achieves the lowest end-to-end delay; this is because in TADS, it has an efficient scheme of selecting intersection that guarantees that the packet is sent to the destination with the least delay, and in straightway, the chosen sending node is the one closest to the candidate intersection which reduces the number of hops involved in delivering packets, which to some degree reduces the delivery delay.

Routing Overhead. In this section, we evaluate the routing overhead of these protocols. For certain packet sending rates, the total number of packets sent into the networks is similar for all protocols; thus, the routing overhead is determined by the control message. As Figure 11 shows, although the packet delivery ratio of ACAR is higher than GSR, when the packet sending rate increases, GSR outperforms ACAR in routing overhead (Figure 13(a)), and the major reason is the on-the-fly density collection scheme in ACAR. Due to the prediction scheme, the periodic beacon interval of TADS is much longer (30 s in the simulation) than the other two protocols; thus, TADS has the lowest routing overhead.

As shown in Figure 13(b), the routing overhead will increase along with the increase in vehicular density, since the size of control messages is proportional to the number of vehicles in the networks. Although GSR needs to send hello message to maintain its neighbor table, it achieves lower routing overhead than ACAR for different vehicular density. This is because the cost is lower compared with the real-time density collection for a whole street. In TADS, even if the size of control message increases similarly, the long periodic beacon interval decreases the ratio between the control packets and the total packets sent into the networks.

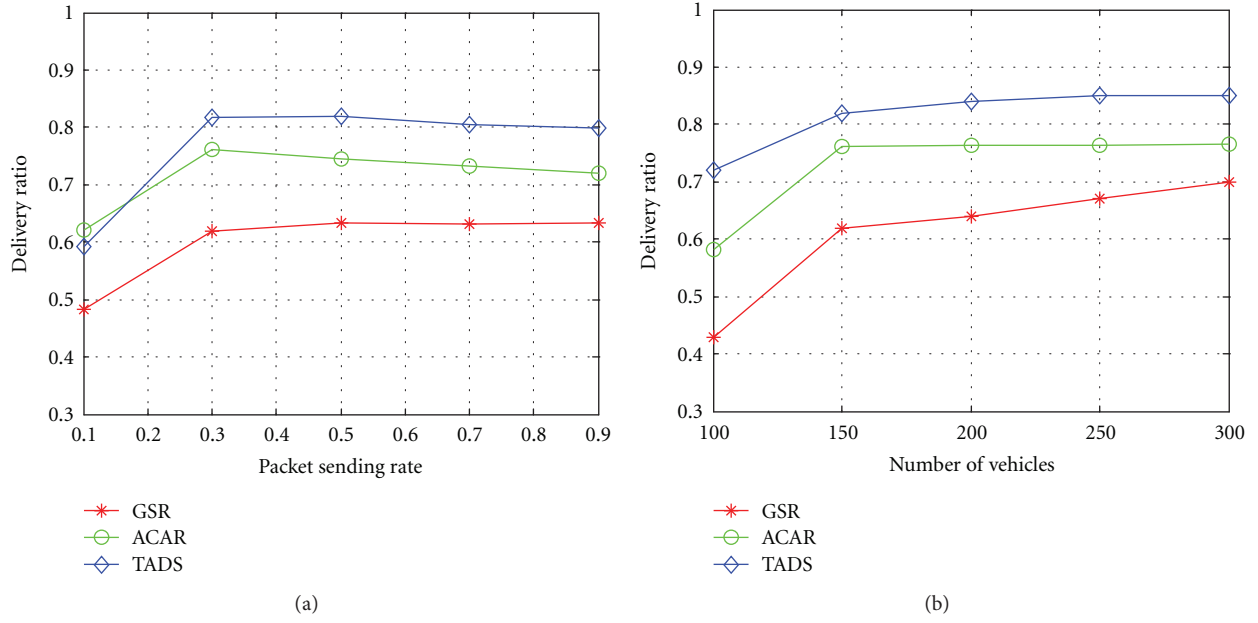


FIGURE 11: Data delivery ratio versus (a) packet sending rate and (b) number of vehicles.

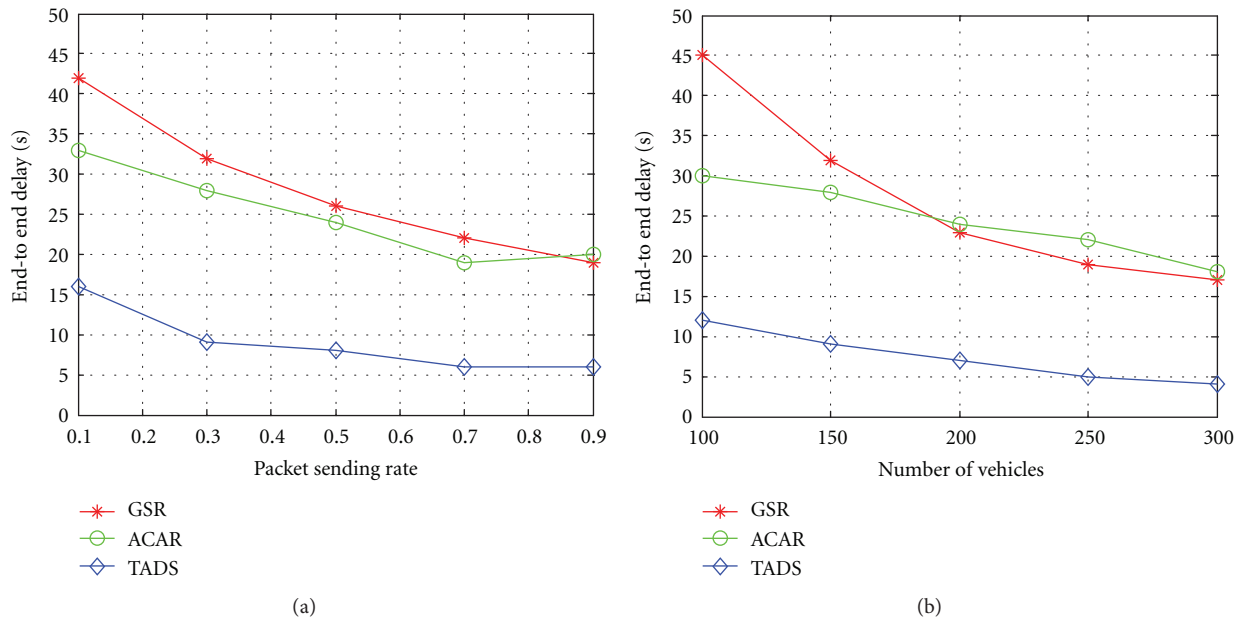


FIGURE 12: Data end-to-end delay versus (a) packet sending rate and (b) number of vehicles.

6. Conclusions

Motivated by the great impact of uneven distribution on the performance of routing protocol, we propose an efficient and a lightweight traffic aware-based data delivery scheme (TADS) to achieve data delivery, which will benefit many applications for urban VSN. The selection of intermediate intersection is based on the optimal utility function to each road. The utility function is determined by the dynamic traffic

density, the Euclidean distance to the destination, and the vehicular distribution. Different from most of the existing protocols, we make use of real realistic vehicular distribution. In this paper, we first give a definition of relative distance degree, which can reflect the real distribution of vehicles. Then, we make use of the mathematical statistics method to calculate the deviation of road per 100 m. The result reflects the different distribution among road segments. Due to the character of vehicle mobility, which is constrained by

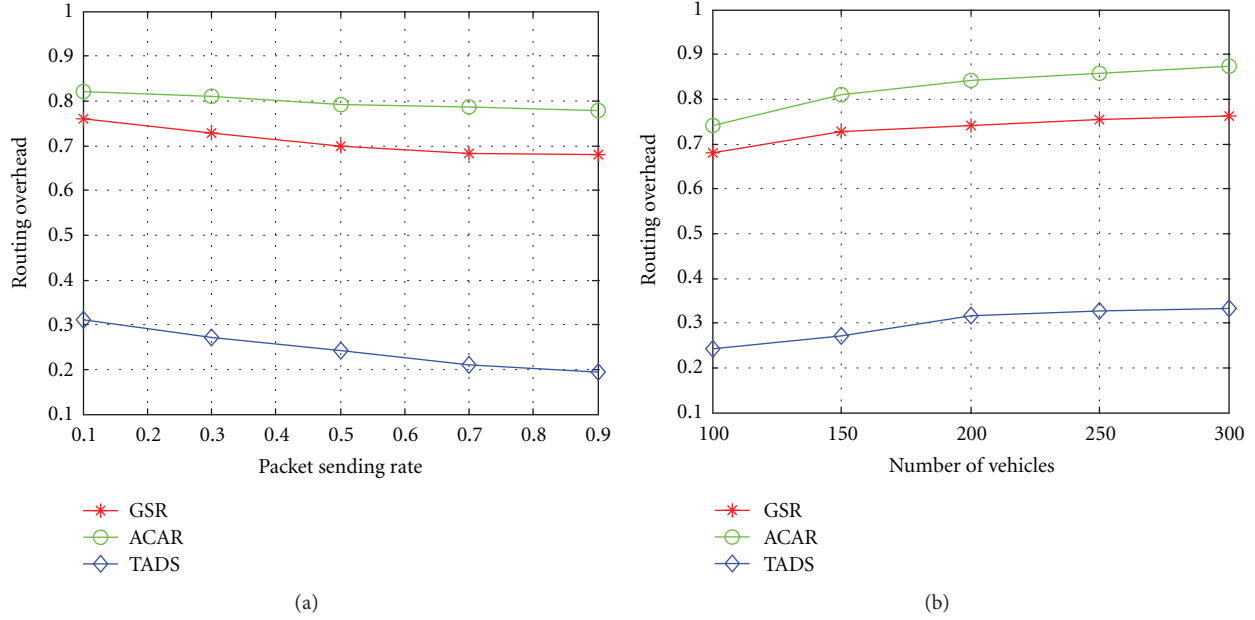


FIGURE 13: Data routing overhead versus (a) packet sending rate and (b) number of vehicles.

the road topology and traffic pattern, we build a prediction model. Our simulation results show that TADS achieves a higher successful throughput and lower delay with low cost compared to GSR and ACAR.

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