On Characterization of the Traffic Hole Problem in Vehicular Ad-hoc Networks

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***Abstract*—Data delivery in Vehicular Ad Hoc Networks (VANETs) is based on the vehicles on the roads. However, the distribution of vehicles could be affected by some external means. For example, the traffic light or pedestrian signal could block the traffic flow moving onto a road. Thus, a gap between vehicles will appear at the entrance of the road, where the distance is larger than the communication range of the vehicles. We term it as a traffic hole, which not only affects the forwarding opportunities in VANETs, but also affects the performance of data delivery on the road, even under heavy traffic. In this paper, we model and analyze the traffic hole problem to characterize the pattern of traffic holes in VANETs. Then we discuss its influence on the data delivery in VANETs, and propose to utilize the backward traffic to mitigate the traffic hole problem. We conduct intensive simulations for discussing the traffic hole problem in VANETs. The simulation results imply that signal operations can affect the performance of data delivery in VANETs, and suggest that the backward traffic can mitigate the traffic hole problem.**

Keywords*—Routing, traffic hole, traffic light, vehicular ad hoc networks

I. INTRODUCTION

With the increasing demands of various applications on vehicles, both academic researchers and automotive industries pay a lot of attention to Vehicular Ad-hoc Networks (VANETs). Timely and lossless multi-hop data delivery among vehicles is essential for VANETs, and various routing protocols were proposed for infrastructure-less vehicle-to-vehicle (V2V) communications [1–3]. In the case of V2V communications over VANETs, the data delivery normally follows the traffic flows that are determined by the roads. However, a traffic flow could be interrupted by the signal operations of the traffic lights or the pedestrian crossing, resulting in network partitioning. We call such a situation a *traffic hole*. It has been observed that traffic holes could happen even during rush hours. The traffic hole could stop the data delivery along a particular traffic flow, which could prevent the data from flowing source to destination.

Existing routing protocols in VANETs are vulnerable to traffic holes, often causing poor performance. Routing protocols in VANETs can be classified into two categories [4], which are connection-based and movement-assisted routing protocols. The traditional connection-based routing protocols [1, 5], which should establish a stable end-to-end path to transmit packets, is often infeasible due to low traffic density and the high mobility of vehicle nodes [2, 6]. By considering the delay-tolerance network (DTN) [7] for intermittent connectivity in VANETs, many have proposed that routing protocols adopt the mechanism of carry-and-forward, which increases the data delivery delay for higher data delivery ratio. Specifically, a mobile node can carry the received packet on the move until it meets a node with a higher possibility of transmitting the packet to the destination. Due to the opportunistic forwarding in VANETs, both the connection-based protocols and movement-assisted protocols are sensitive to the traffic flow. With these routing protocols, the data packets are routed along the roads with high traffic volume. However, the effectiveness of these approaches is also hampered by the traffic hole problem, even under high traffic volume. For example, the existence of traffic holes could interrupt the end-to-end connective path along each road, and could also congest packets en-route in a subset of mobile nodes, and thus increase the delivery delay significantly.

In this paper, we conduct a comprehensive investigation of the traffic hole problem in VANETs. Our technical contributions are multi-fold, including:

- We propose a model to characterize the traffic hole problem in VANETs. This model provides a fundamental basis for understanding the pattern of traffic holes in VANETs caused by the upstream signalized intersection and the distribution of input traffic flow (deterministic or stochastic).
- We analyze the impact of the traffic hole problem on data delivery delay of routing protocols. We also discuss its influence on forwarding opportunities for both connection-based and movement-assisted routing protocols in VANETs. Then we propose an approach by utilizing the backward traffic flow, as to mitigate the traffic hole problem.
- Our NS-2 and SUMO based simulation results show that the signal operations not only affect the distribution of traffic flow, but also affect the performance of routing in VANETs. It is suggested that the backward traffic flow can mitigate the traffic hole problem.

This paper is organized as follows: in Section II, we discuss related work in this area. Section III presents the traffic hole problem. Section IV discusses the patterns of traffic holes in detail. In the next section, we will analyze the impact of the problem, and propose to utilize the backward traffic flow for mitigating traffic hole problem. In Section VI, we describe the results from our simulations. Finally, in the last section we conclude the paper.

II. RELATED WORK

There are a lot of vehicular applications based on the communications among vehicles. Ahn *et al.* [8] present the


(a) 0 min (b) 2 min (c) 3 min

Fig. 1. Appearance of a traffic hole

Road Information Sharing Architecture (RISA), a distributed approach to road condition detection and dissemination for vehicular networks. SignalGuru [9] relies solely on a collection of mobile phones to detect and predict the traffic signal schedule. For such an infrastructure-less approach, multiple phones in the vicinity use opportunistic ad-hoc communications to collaboratively learn the timing patterns of traffic signals, and to predict their schedules. MARVEL [10] utilizes the communications among vehicles to determine their relative locations.

Many protocols in VANETs assume that the intermediate nodes can be found to set up an end-to-end connection; otherwise, the packet will be dropped. Naumov and Gross [1] present a position-based routing scheme called CAR for inter-vehicle communication in a city and highway environment. CAR integrates locating destinations with finding connected paths between source and destination. Once a path is found, it is auto-adjusted to account for changes, without another discovery process. Wisitpongphan *et al.* [6] indicate that, although the average re-healing time for an I-80 type of freeway is, on average, less than 30 seconds. Such long network disconnection time could be a major problem for conventional ad hoc routing protocols such as AODV [5], which can only tolerate a network disconnection time of up to 2-3 seconds. In addition, some time-critical applications may not be able to function properly in disconnected VANET, as the end-to-end delay could be on the order of several minutes. Zhao and Cao [2] make use of the predicable vehicle mobility, which is limited by the road traffic pattern and road layout. Based on the existing road traffic pattern, a vehicle can find the next road to forward the packet, as to reduce the delay. The estimation of packet forwarding delay through each road is based on some statistical data, such as the average vehicle density.

We have proposed the traffic hole problem in [11]. In this paper, we will model this problem, and analyze its influence on the data delivery in VANETs.

III. TRAFFIC HOLE PROBLEM

In this section, we give the assumptions, and then we will introduce the traffic hole problem.

A. Assumptions

The assumptions in this paper are as follows:

1) Traffic model: We assume that each vehicle knows its location by the GPS service, which is already available in most new cars, and will be common in the future. For investigating the signal operations, the network in the paper is with the right-hand traffic. Let r_{ij} denote the road from the intersection I_i to I_j. The traffic flow moving on the road r_{ij} is denoted by f_{ij}. The well-known car-following model [12] states that a vehicle moves at or near the same speed as the vehicle in front of it, while there is a vehicle within sufficient range of the current vehicle. Thus, due to the speed limitation, we assume that the speed of the vehicles in a road are all the same, which is denoted by v.

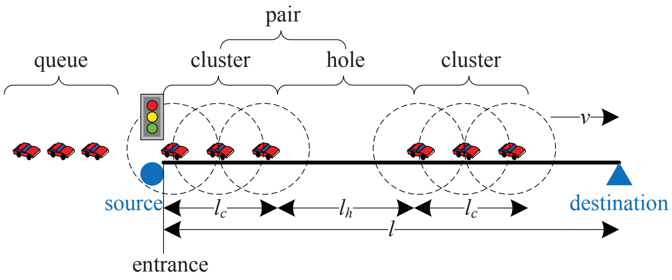


Fig. 2. The traffic hole and connected cluster on a road

2) Communication model: Vehicles communicate with each other through short-range wireless channels. Let R denote the communication range of each vehicle node. For a vehicle, the neighbors of it refer to the vehicles which are in its communication range. Vehicles can find their neighbors through beacon messages, which have been discussed in [1].

B. Traffic Hole Problem

The traffic hole problem can be seen everywhere under the transportation environment, even during the rush hour, with the highest traffic volume. The road shown in Figure 1 is Shudu Road with the heaviest traffic in Chengdu, which is a city with over 2 million vehicles in China. The time when the photos was taken was during the rush hour in the afternoon. In the beginning, the flow of the traffic on this road was saturated as shown in Figure 1(a). However, 2 minutes later as shown in Figure 1(b), the flow of the traffic sharply decreased. 3 minutes later from the beginning as shown in Figure 1(a), there was no vehicles on this road, and a gap has appeared. All the vehicles moving onto the road were blocked at the entrance by the traffic light. If the length of this gap is larger than the communication range of vehicles (R), the gap can block the wireless communication among the vehicles.

The traffic flow, which is regulated by the interactions among vehicles and interactions between vehicles and the roadway, such as the vehicles traveling on an interstate highway, is termed as *uninterrupted flow*. In contrast, the traffic flow, which is regulated by an external means, such as a traffic light or pedestrian signal, is term as *interrupted flow*. Figure 2 shows a example for illustrating the interrupted traffic flow along a road. The source for sending data packets is at the entrance of the road, which is also a signalized intersection. The destination is either on the road or at the exit of the road. The distance between the source and the destination is l.

***Definition** 1 (Traffic Hole):* Let *traffic hole* be the gap in a traffic flow on the road. As shown in Figure 2, its length (denoted by l_h) is larger than the communication range of vehicles, i.e. $l_h > R$.

***Definition** 2 (Connected Cluster):* Let *connected cluster* be a group of vehicles on the road that can communicate with each other via either one-hop or multi-hops communication, and its length is denoted by l_c as shown in Figure 2.

IV. DISTRIBUTION OF TRAFFIC HOLE

In this section, we investigate the distribution of the traffic hole and connected cluster on a road.

***Definition** 3 (Cycle of traffic light):* A *cycle* in the signal operation is defined as a complete sequence of intervals or phases. The duration of a cycle is denoted by c. A simple traffic control system has two states in a cycle, which are the *green* for moving, and the *red* for stopping. The durations of each are denoted by g and r, respectively. Thus, $c = g + r$.

***Definition** 4 (Cycle of traffic flow):* Due to the periodicity of signal operations at the intersection, the appearance of the *pair* of traffic hole and connected cluster is alternative and periodical, as shown in Figure 2. Let the *cycle of traffic flow* be the duration for each pair of traffic hole and connected cluster along the traffic flow past a fixed point, i.e. $(l_c + l_h)/v$.

According to the queuing theory, two factors affecting the length of the traffic hole and connected cluster are as follows: (a) the arrival rate of the input traffic flow at the upstream intersection (denoted by λ); (b) the signal operation at the upstream intersection (r and g). For the vehicular queue waiting at the signalized intersection shown in Figure 2, time to queue clearance (denoted by t_c) after the start of effective green can be calculated as: $t_c = \frac{\lambda r}{\mu - \lambda}$.

In traffic engineering [13], the degree of saturation of an intersection (typically under traffic signal control) or road is a measure of how much demand it is experiencing compared to its total capacity. While the time to queue clearance t_c is equal to, or larger than, the green time (i.e. $t_c \geq g$), the input of the traffic flow at the intersection is termed as *saturated* or *over-saturated* flow. While the time to queue clearance at the intersection is less than the green time, (i.e. $t_c < g$), the input of the traffic flow at the intersection is termed as *under-saturated* flow.

For the saturated or over-saturated traffic flow, the departure rate of the intersection is equal to the saturation flow rate of the intersection (denoted by s). We assume that the distance between two adjacent vehicles under the saturation flow rate is less than their communication range, i.e. $v/s < R$. Thus, we can only consider the influence of the signal operations (r and g) on l_c and l_h. During the green time, the number of vehicles leaving from the upstream intersection is equal to the number of vehicles in a connected cluster (denoted by $\mathcal{N}$), which can be calculated as: $\mathcal{N} = \lfloor s \cdot g \rfloor$.

In traffic engineering [13], the *headway spacing* is a measurement of the distance between vehicles in a transit system. Under the saturated traffic flow, the headway spacing of vehicles in a connected cluster is equal to v/s. As shown in Figure 2, the length of a connected cluster is as follows:

$$l_c = \frac{v}{s} \cdot (\mathcal{N} - 1) \tag{1}$$

Due to the alternative and periodical appearance of the traffic hole and connected cluster, the length of a traffic hole can be calculated as:

$$l_h = c \cdot v - l_c \tag{2}$$

For the under-saturated intersection, all the vehicles arrive at the intersection during a cycle can depart during the green light. Thus, the number of vehicles which depart from the upstream intersection is equal to the arrival vehicles during the cycle, which can be calculated as: $\lfloor \lambda c \rfloor$. During the green time, the headway spacing among the vehicles which depart from the upstream intersection can be divided into two stages, which are the time for queue clearance, and the time after queue clearance. During the time for queue clearance with saturation flow rate, the departure rate of vehicles is s, and the headway spacing of vehicles in a connected cluster is equal to v/s. The number of vehicles which depart from the intersection during this time (denoted by $\mathcal{N}_s$) is: $\mathcal{N}_s = \lfloor s \cdot t_c \rfloor$.

During the rest of the time after queue clearance, the departure rate of vehicles is equal to the arrival rate λ, and the headway spacing between two adjacent vehicles is equal to arrival rate (v/λ). Let $\mathcal{N}_\lambda$ denote the number of vehicles which depart from the intersection during the rest time after queue clearance. The D/D/1 queueing model for the intersection assumes that arrival, and that departure of vehicles are deterministic and one departure channel exists. Thus, under the D/D/1 model, $\mathcal{N}_\lambda = \lfloor \lambda \cdot (g - t_c) \rfloor$. The length of a connected cluster can be calculated as:

$$l_c = \begin{cases} \frac{v}{s} \cdot (\mathcal{N}_s - 1) + \frac{v}{\lambda} \cdot \mathcal{N}_\lambda, & \text{if } \frac{v}{\lambda} \leq R \\ \frac{v}{s} \cdot (\mathcal{N}_s - 1), & \text{if } \frac{v}{\lambda} > R \end{cases} \tag{3}$$

The M/D/1 queuing mode at the intersection assume that the arrival rate of vehicles follows the exponential distribution. Thus, $\mathcal{N}_\lambda$ can be calculated as follows:

$$\mathcal{N}_\lambda = \lceil \frac{\beta(1-\beta)}{\alpha}(g - t_c)v \rceil - 1 \tag{4}$$

where $\alpha = ve^{-\lambda R/v}(\frac{1}{\lambda} - (\frac{R}{v} + \frac{1}{\lambda})e^{-\lambda R/v})$ and $\beta = 1 - e^{-\lambda R/v}$.

Let $E[l_\lambda]$ denote the expected length of the cluster with these vehicles during the time $(g - t_c)$, which can be calculated as follows:

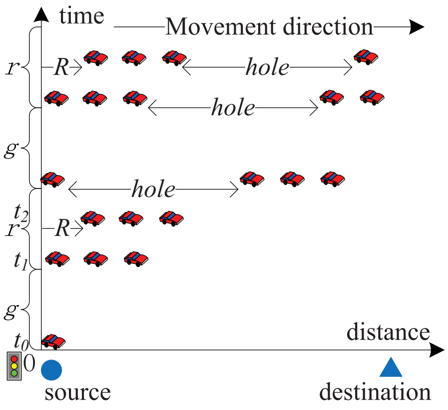
$$E[l_\lambda] = \alpha \times \sum_{k=1}^{\mathcal{N}_\lambda} k\beta^k \tag{5}$$

Because of the page limit, the derivation of Equations 4 and 5 is omitted, which is motivated by [14]. The difference from the problem in [14] is to compute the expected sum of the inter-distance within the connected cluster, which connects to the cluster ahead for finite interval time $(g - t_c)$.

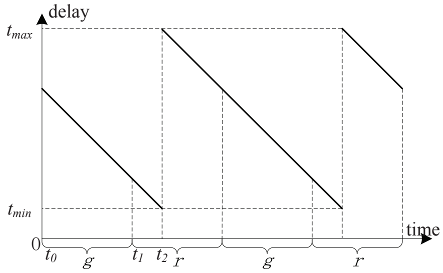
The expected length of the connected cluster can be calculated as follows:

$$E[l_c] = \frac{v}{s} \cdot (\mathcal{N}_s - 1) + E[l_\lambda] + \frac{1}{\lambda} \tag{6}$$

Thus, the expected length of the traffic hole can be calculated as: $E[l_h] = c \cdot v - E[l_c]$.



(a) Distribution of the vehicles on the road



(b) Data delivery delay

Fig. 3. Vehicle-to-vehicle data delivery with different packet arrival time

V. MITIGATION OF TRAFFIC HOLE PROBLEM

In this section, we will analyze the impact of the traffic problem on routing protocols in VANETs, which includes connection-based and movement-assisted routing protocols [4]. Then, we will discuss the approach by utilizing the backward traffic flow, as to help forwarding the data packets across the traffic hole controlled by signal operation at the downstream intersection.

A. Impact of Traffic Hole on a Road

We assume each cycle starts from the green time to the red time. Figure 3 presents the variation of data delivery delay under different packet arrival times.

At time $t_0 = 0$, the traffic light at the upstream intersection starts to turn green. Consecutive vehicles start to move onto the road, and the length of the connected cluster has been discussed in the previous section. Since the vehicles move at the constant speed v, the forwarding distance increases linearly at the rate of v, and the data delivery delay correspondingly decreases linearly at the rate of -1.

At time $t_1 = g$, the traffic light at the upstream intersection starts to turn red, and vehicles that need to move onto the road are blocked at the intersection. However, the packet from the source can still be sent to the connected cluster, which is also in the communication range of source.

At time $t_2 = g + R/v$, the distance between the last vehicle in the connected cluster and the source is equal to the communication range (R). If the connected cluster cannot connect to the destination, i.e. $0 < l_c \leq l - 2R$, we term it as a *short connected cluster*. The packet at this time has maximal forwarding distance ($l_c + R$) and minimal carrying distance ($l - l_c - 2R$). If the length of the connected cluster is long enough to simultaneously connect to both the source and destination (i.e. $l_c > l - 2R$), we term it as a *long connected cluster*.

With the help of long connected cluster, the connection-based routing protocols have opportunities to establish the connected routing path in each cycle of traffic light. The connection between the source and the destination is from the time $\frac{l-R}{v}$ to the time $\frac{l_c+R}{v}$ in each cycle of traffic light. Thus, the minimal data delivery delay is calculated as follows:

$$d_{min} = \begin{cases} \frac{(l_c+R)\cdot t_{hop}}{R} + \frac{l-l_c-2R}{v}, & l_c \in (0, l-2R] \\ l \cdot \frac{t_{hop}}{R}, & l_c \in (l-2R, \infty) \end{cases} \quad (7)$$

where t_{hop} is the average one-hop packet transmission delay.

In VANETs, opportunistic forwarding at intersections is the challenging issue for routing protocols [2, 15]. While a traffic hole appears at the entrance of a road, no data can be delivered into this road. Therefore, with the movement-assisted routing protocols, the opportunities for delivering data onto the road is from the beginning time 0 to the time $\frac{l_c+R}{v}$ in each cycle of traffic light.

After the time t_2, the forwarding distance will reduce to zero for the arrival packets. The data delivery delay includes the waiting time for the vehicles moving onto the road. Thus, the maximal data delivery delay is as follows:

$$d_{max} = \frac{l + l_h - 2R}{v} \quad (8)$$

With the help of Equations 7 and 8, the expected data delivery delay along this road can be calculated as follows:

$$E[d] = \begin{cases} \frac{d_{min}+d_{max}}{2}, & 0 < l_c \leq l - 2R \\ \frac{d_{max}^2 v + d_{min}^2 v + 2 d_{min}(l_c+2R-l)}{2vc}, & l_c > l - 2R \end{cases} \quad (9)$$

B. Mitigation with Backward Traffic

In order to mitigate the influence of traffic hole problem on data delivery, we propose an approach by utilizing the backward traffic flow.

Let $\bar{f}$ denote the backward traffic of f moving on the two-way road, and its speed is denoted by $\bar{v}$. Due to the downstream signalized intersection with alternative green and red states, there are also alternative connected clusters and traffic holes along the backward traffic $\bar{f}$. Let $\bar{l}_c$ and $\bar{l}_h$ denote the length of the connected cluster and the traffic hole along the backward traffic $\bar{f}$. For the traffic f, while the packet is congested by the traffic hole problem, the backward cluster can help to forward it across the traffic hole. The connected cluster and the traffic hole along f and $\bar{f}$ should be satisfied as follows:

$$\bar{l}_c > l_h - 2R \quad and \quad \bar{l}_h < l_c + 2R \quad (10)$$

For a cluster in traffic flow f, the duration of the opportunity for forwarding the packets from it to the cluster ahead

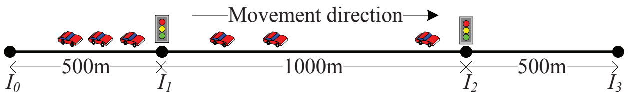


Fig. 4. The simulation scenario

by a backward traffic cluster can be calculated as follows:

$$t_{forward} = \frac{\bar{l}_c - l_h + 2R}{v + \bar{v}} \tag{11}$$

The duration of carrying the packets by the cluster, or the waiting time for the next opportunity of forwarding can be calculated as follows:

$$t_{carry} = \frac{l_h + \bar{l}_h - 2R}{v + \bar{v}} \tag{12}$$

VI. SIMULATION RESULTS

In this section, we will evaluate the performance of routing protocols (connection-based routing and movement-assisted routing) under different signal operations. The protocols chosen for evaluating include: (1) AODV [5] which is a conventional end-to-end connection-based routing protocol in adhoc networks; (2) VADD [2] which is a typical movement-assisted routing protocol in VANETs based on the way of carry-and-forward with single-duplicate, and it improves the geographically greedy forwarding [16] for the data delivery on the road. We will investigate their performances along the roads affected by the traffic hole problem. For comparing the protocols, we chose to evaluate them according to the following three metrics:

- *Data delivery ratio*: The ratio between the number of packets received by the sink at the final destination and the number of packets originated by the source.
- *Data delivery delay*: The duration of the packet delivery from the moment it is generated by the source to the arrival time at the destination.
- *Data delivery hops*: The average amount of hops of packets that have successfully arrived.

A. Simulation Setup

We use the combination of NS-2 [17] and SUMO [18] for the simulations. SUMO (Simulation of Urban Mobility) is an open-source traffic simulator to model realistic vehicle behavior. NS-2 is an open-source discrete event network simulator that supports both wired and wireless networks, including most MANET routing protocols and an implementation of the IEEE 802.11 MAC layer. In our simulations, the speed limit of each road with one lane is 50 kilometers per hour. The wireless communication range for each node is 250m, and the buffer size of each node is 50 packets. The data packet size is 200B. The simulation time is 1000s.

The road topology used is shown in Figure 4, and the road r_{12} is between two signalized intersections I_1 and I_2. During the simulation time, 200 vehicle nodes move from the road r_{01} to r_{23}. The duration of the cycle for the signal operations is 60s. The green time changes from 10s to 50s, so the related red time changes from 50s to 10s.

B. The Influence of the Signal Operations on the Traffic Flow

We evaluate the influence of the duration of signal operations at the two-way intersections, which have two phases for the green and red state, on the length of the cluster and the traffic hole on the road. Figure 5 shows the length of the connected cluster and the traffic hole on the road r_{12} with different green time at I_1. The solid lines are the results obtained by the simulation, and the dotted lines are obtained by the model presented in Section IV. While the green time is increasing, we notice that the length of the vehicle cluster is approximately linearly increasing, and the length of the traffic hole is approximately linearly decreasing. The results show that our model approximates to the simulation.

C. Impact of the Green Time for the Routing Protocols

In this subsection, we evaluate the influence of the signal operations on the performance of routing protocols under the scenario shown in Figure 4, and we will also evaluate the mitigation of the traffic hole problem with the help of backward traffic flow. There are two fixed APs on the intersection I_1 and I_2, which are S and D. The AP S sends CBR data to D by the V2V delivery on the road r_{12}, and the CBR data sending interval of S is 2 sec. S starts generating the data packets 100 seconds after the simulation's start, and stops 100 seconds before the simulation's end. For evaluating the performance with the help of the backward traffic flow, there will also be 200 vehicle nodes moving from the road r_{32} to r_{10}, and the signal operations for both of the traffic lights at I_1 and I_2 are the same.

Figure 6(a) shows the data delivery ratio of the protocols as a function of the green time. While the green time is less than 30s, no data packet can be delivered through the road with AODV. While the green time is longer than 40s, the length of the cluster on the road is long enough to establish an end-to-end connective path for data delivery. Thus, we notice that increasing the green time can increase the ratio of AODV, and reduce the delay of it as shown in Figure 6(b). However, with the help of the backward traffic flow, only while the green time is 10s, no data packets can be delivered through the road with AODV. This is because the length of the traffic hole is too long, and the length of the connected cluster in the backward traffic is too short to forward the packets. While increasing the green time, the duration for transmission along this road is also increasing, and this will improve the connectivity on the road. Therefore, the ratio of AODV is increasing, and the delay of it is also decreasing.

For VADD, the ratios are all approximated to 1 as shown in Figure 6(a), especially while the green time is less than 30s. As shown in Figure 6(c), the hops of the VADD is the lowest. This is because most data packets are congested by the traffic hole problem and carried to D, and this can reduce the packet loss caused by the wireless communication. While the green time is increasing, the delay of it is decreasing, as shown in Figure 6(b). In Figure 6(b), the solid lines are obtained by the simulation, and the dotted lines are obtained by the model presented in Section V. The result shows that our model approximates to the simulation. The hops of data delivery is shown in Figure 6(c), because data packets may be blocked by the traffic holes, vehicles under VADD will carry more packets

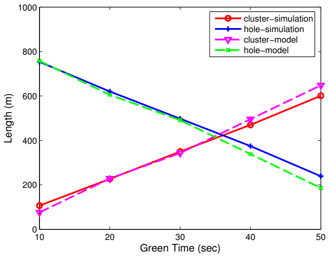
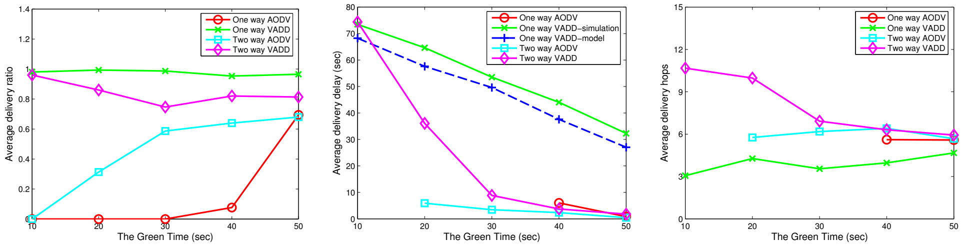


Fig. 5. Influence of the signal operations on the traffic flow



(a) Average data delivery ratio

(b) Average data delivery delay

(c) Average data delivery hops

Fig. 6. Impact of the signal operations on data delivery

to the destination than AODV, and decrease the hops for data delivery. We notice that the backward traffic flow can reduce the delay of VADD, and it is decreasing while the green time is increasing. However, it increases the hops of data delivery, especially the transmission with the backward traffic flow. In addition, it also increases the routing errors of delivering the packet to the backward cluster which cannot forward it across the traffic hole with the cost of data delivery hops. Thus, it increases the packet loss and reduces the data delivery ratio.

VII. CONCLUSION

Due to the traffic light or pedestrian signal, a traffic hole would appear in the road, even under heavy traffic. In this paper, we analyze the traffic hole problem, and discuss its impact on the data delivery in VANETs. It will not only affect the forwarding opportunities in VANETs, but will also affect the performance of data delivery on the road. Thus, we propose to utilize the backward traffic flow to mitigate the influence of traffic hole problem on the data delivery. With our NS-2 and SUMO based simulation results, the traffic hole problem is affected by the signalized operations at the upstream intersection, and it obviously affects the performance of routing protocols in VANETs.

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