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

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Outline

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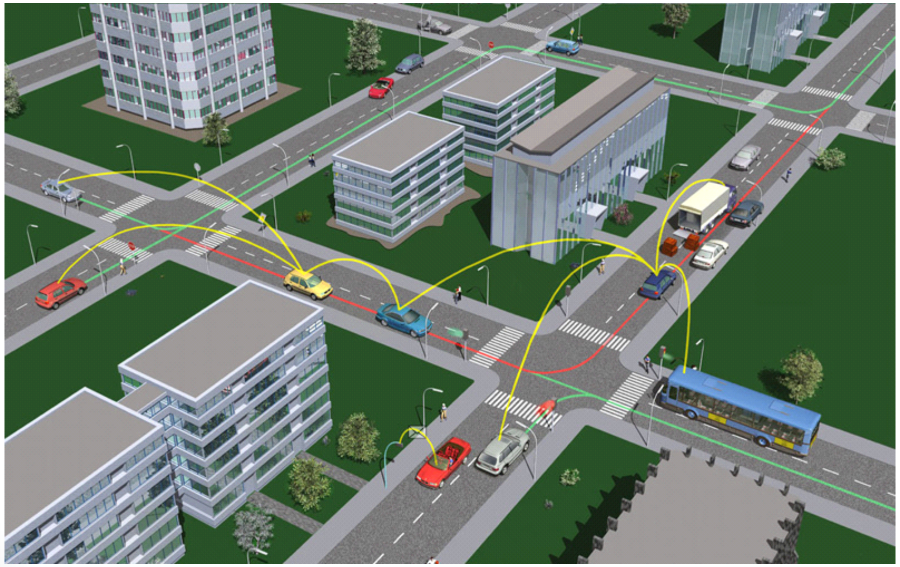
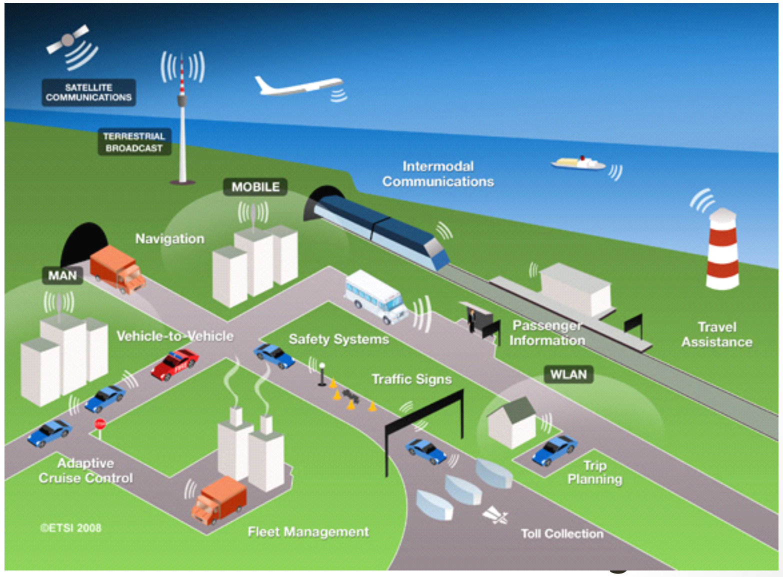
- Traffic Hole Problem
- Mitigation wigh Backward Traffic
- Similation Reslusts
- Conclusion

Overview

- The data delivery in vehicular ad hoc networks (VANETs) is based on the wireless communication among vehicles (V2V) and infrastructures (V2I).





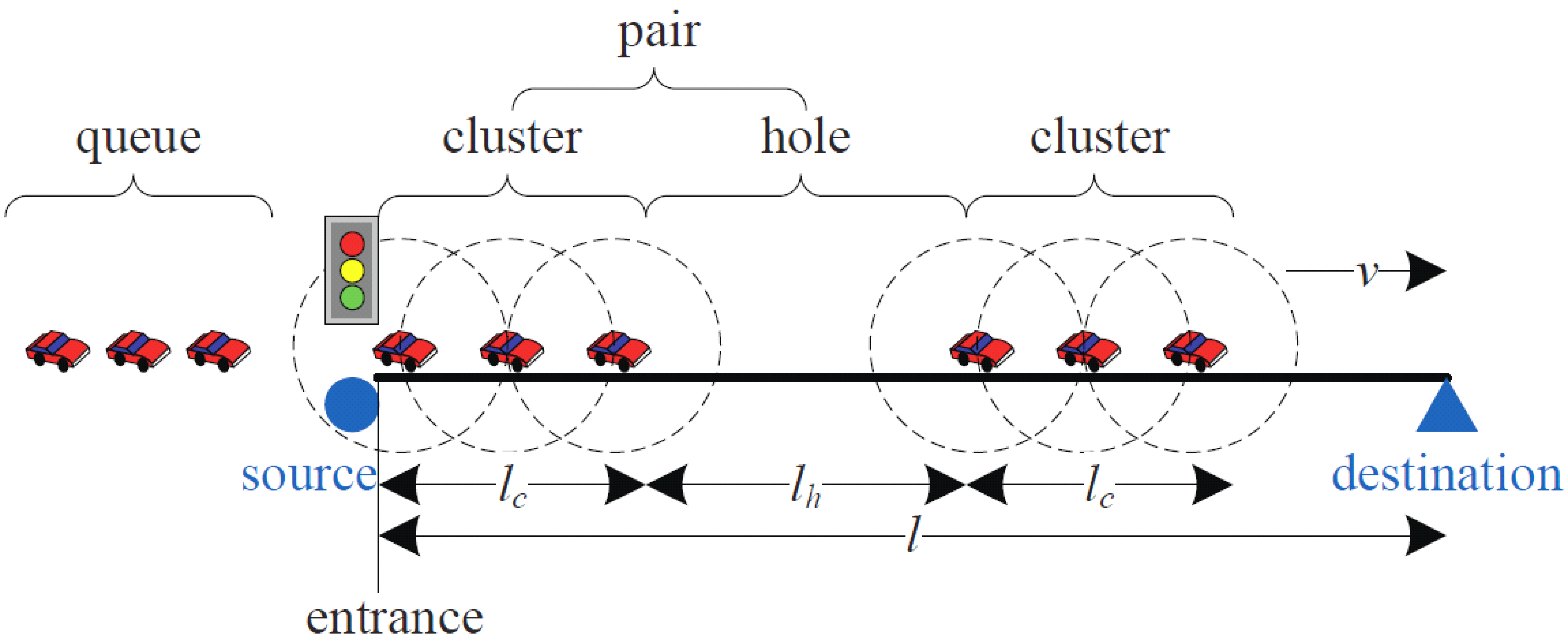
Traffic Hole

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

- The road 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.

Traffic Hole

- **Traffic Hole**: the gap in a traffic flow on the road, whose length (denoted by l_h) is larger than the communication range of vehicles, i.e. $l_h > R$.



Distribution of Traffic Hole

- **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, $c = g + r$.
- **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. 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. $(l_c+l_h)/v$.

Traffic Flow

- 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, time to queue clearance after the start of effective green can be calculated as:

$$t_c = \frac{\lambda r}{\mu - \lambda}$$

Saturated Traffic Flow

- During the green time, the number of vehicles leaving from the upstream intersection is equal to the number of vehicles in a connected cluster can be calculated as:

$$\mathcal{N} = \lfloor s \cdot g \rfloor$$

The length of a connected cluster is:

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

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

$$l_h = c \cdot v - l_c$$

Under-saturated Traffic Flow

- Under the D/D/1 queuing model, the length of a connected cluster can be calculated as:

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

Under M/D/1 queuing mode, the length of a connected cluster can be calculated as:

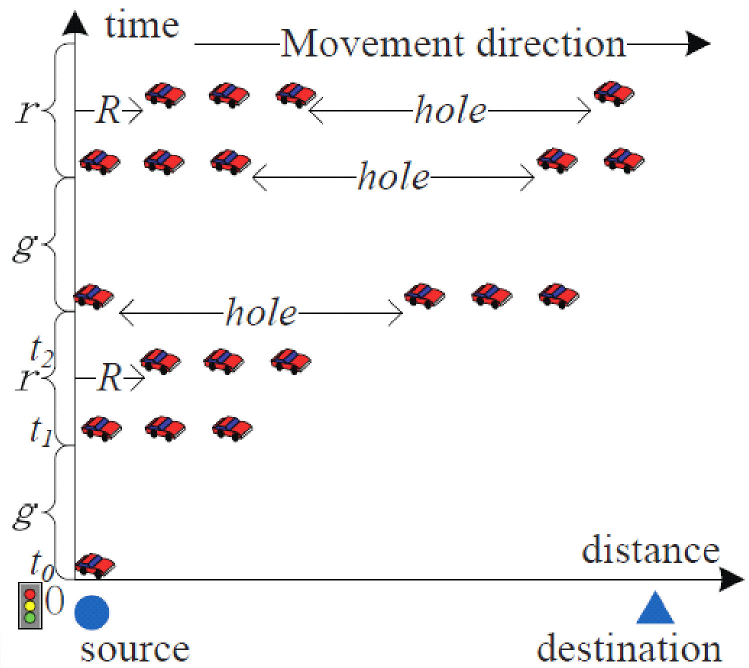
$$E[l_c] = \frac{v}{s} \cdot (\mathcal{N}_s - 1) + E[l_\lambda] + \frac{1}{\lambda}$$

The expected length of the traffic hole can be calculated as:

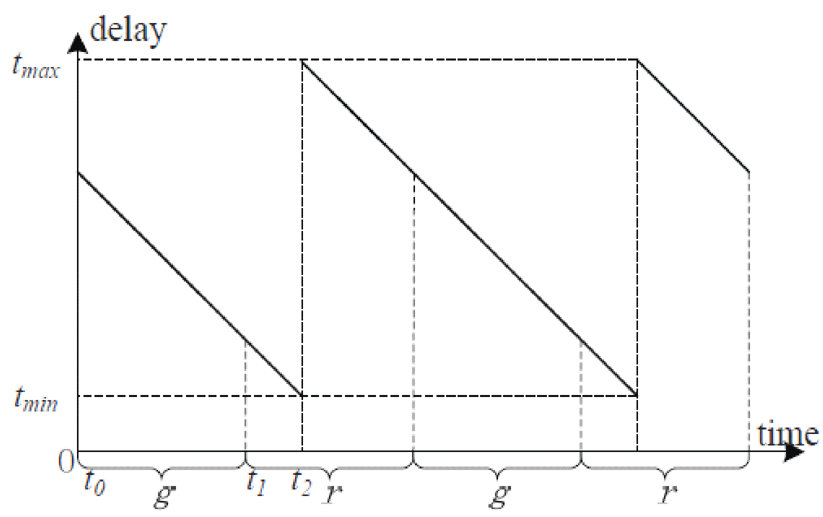
$$E[l_h] = c \cdot v - E[l_c]$$

Impact of Traffic Hole

- We analyze the impact of the traffic problem on routing protocols in VANETs, which includes connection-based and movement-assisted routing protocols .



Distribution of the vehicles on the road



Data delivery delay

Impact of Traffic Hole

- **Short connected cluster**: the connected cluster cannot connect to the destination (i.e. $0 < l_c \leq l - 2R$).
- **Long connected cluster**: the length of the connected cluster is
- long enough to simultaneously connect to both the source and destination (i.e. $l_c > l - 2R$).
- The minimal data delivery delay is calculated as:

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

Impact of Traffic Hole

- The maximal data delivery delay is as:

$$d_{max} = \frac{l + l_h - 2R}{v}$$

The expected data delivery delay along this road by the movement-assisted routing protocols can be calculated as:

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

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.
- The connected cluster and the traffic hole along the traffic flow *f* and its backward flow should be satisfied as follows:

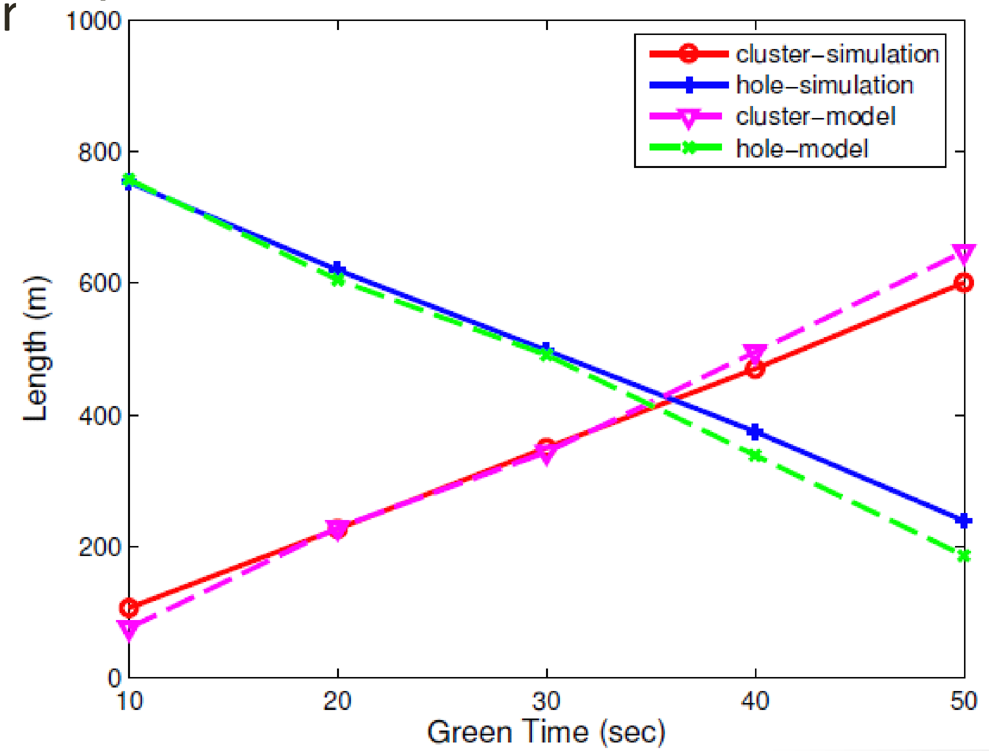
$$\bar{l}_c > l_h - 2R \quad and \quad \bar{l}_h < l_c + 2R$$

For a cluster in traffic flow f, the duration of the opportunity for forwarding the packets from it to the cluster ahead by a backward traffic cluster can be calculated as:

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

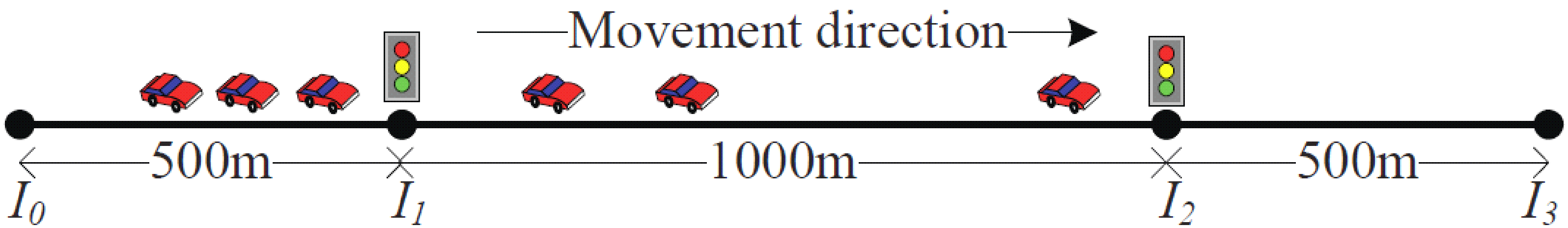
Influence of the Signal Operations on the Traffic Flow

- 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 r

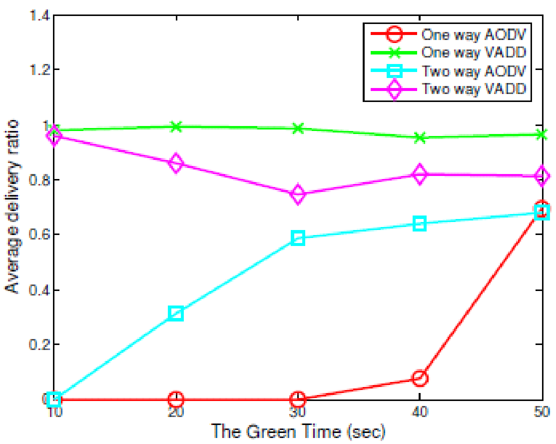


Impact of the Green Time for the Routing Protocols

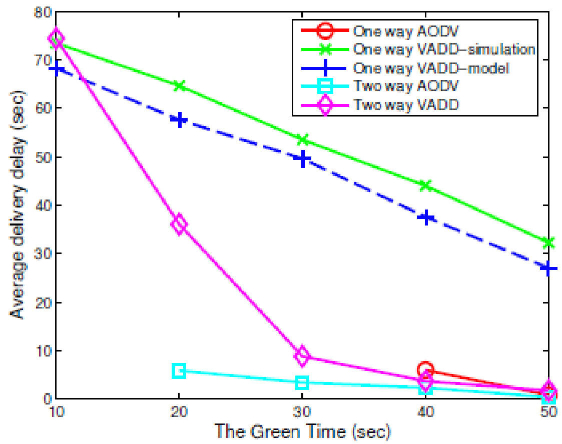
- We evaluate the influence of the signal operations on the performance of routing protocols under the following scenario:



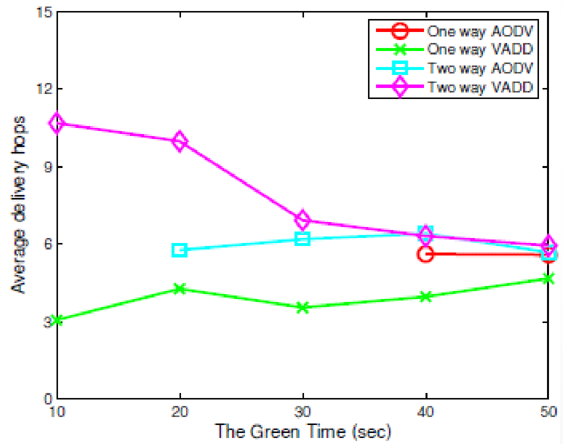
Impact of the Green Time for the Routing Protocols



(a) Average data delivery ratio



(b) Average data delivery delay



(c) Average data delivery hops

Conclusion

- Due to the traffic light or pedestrian signal, a traffic hole would appear in the road, even under heavy traffic.
- 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.
- We propose to utilize the backward traffic flow to mitigate the influence of traffic hole problem on the data delivery.

Thank You!