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Red or Green: Analyzing the Data Delivery with Traffic Lights in Vehicular Ad Hoc Networks

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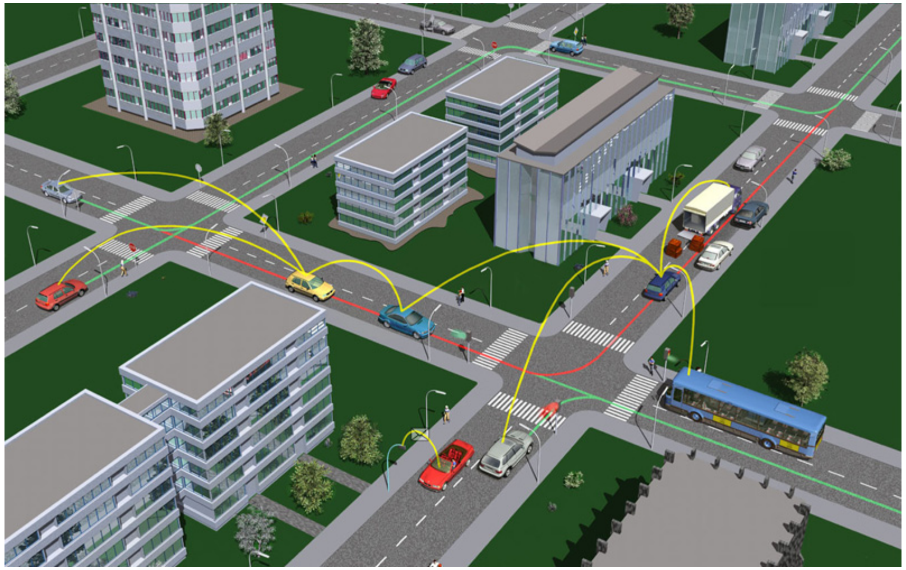
Outline

- Overview
- Influence of Traffic Lights on Data Delivery
- Analysis Model - Mobility Prediction
- Analysis Model - Data Delivery
- Transmission Control Scheme
- Performance Evaluation
- Conclusion

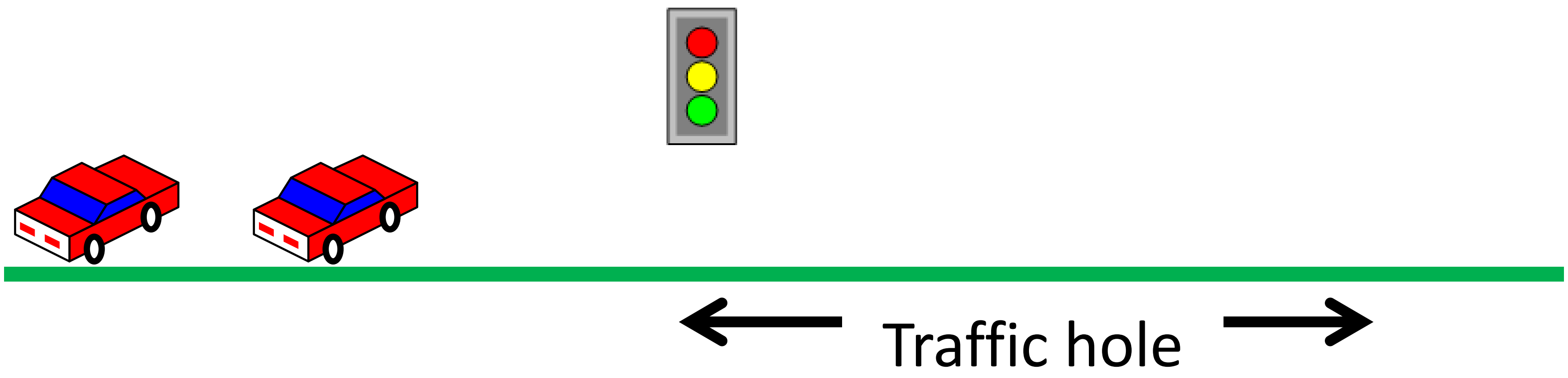
Overview

- Vehicular Ad-hoc Network (VANET)
  - V2V: wireless communication among vehicles
  - V2I: wireless communication among vehicles and infrastructures



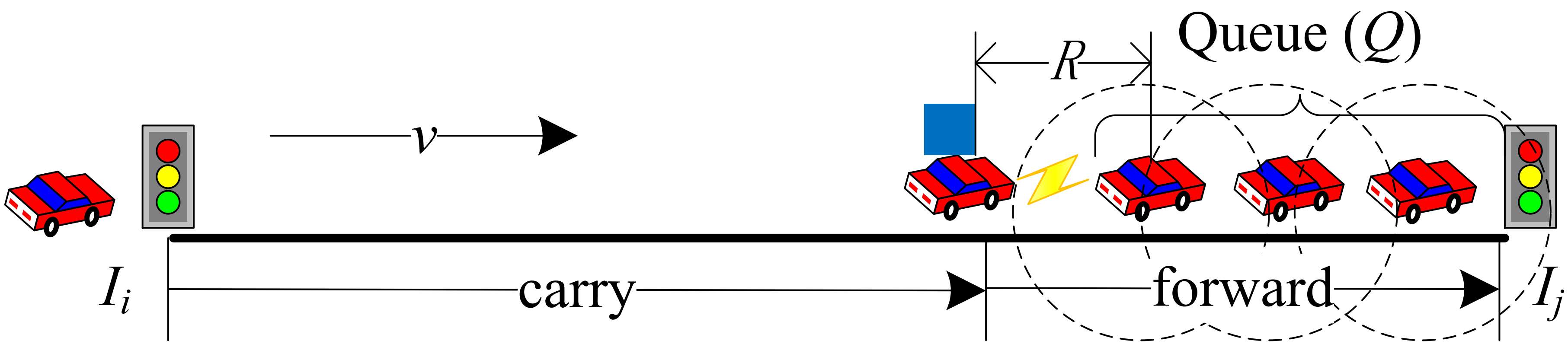
Traffic Light

- The mobility of vehicles is not only affected by itself, but also by the traffic lights.
- Stop at a red light:



Catch Up with Traffic Lights

- The vehicles stopped by the red light could wait for the vehicles moving behind, which could increase the opportunities for vehicles moving behind to catch up in data forwarding.



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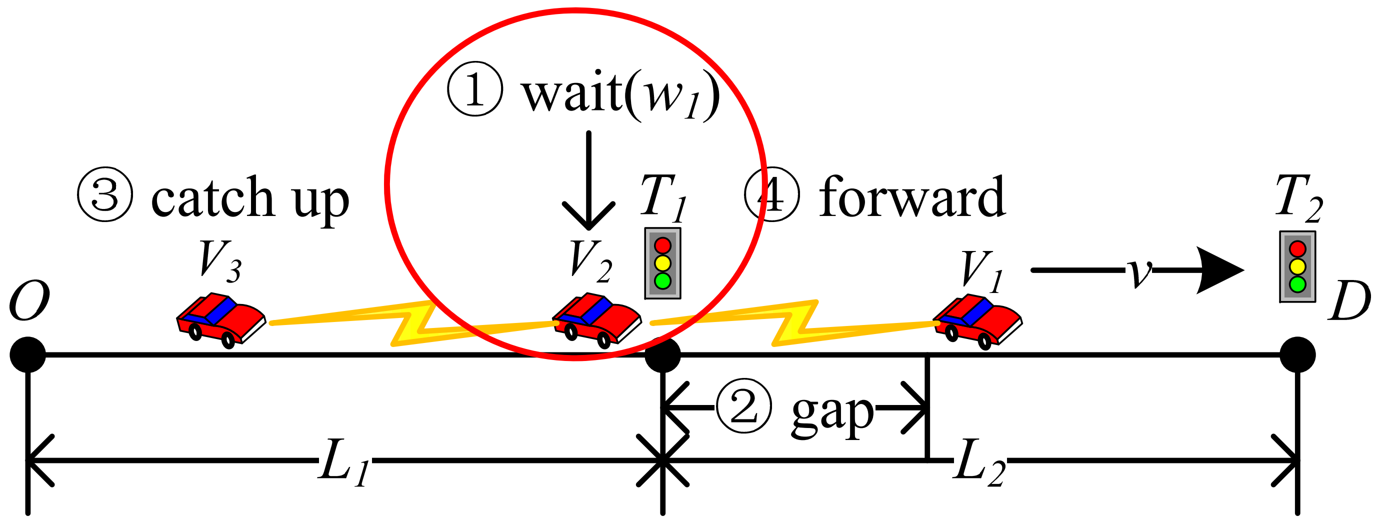
Contribution

- We conduct a comprehensive investigation of the influence of traffic lights on the data delivery in VANETs.
  - We develop an **analytical model** to evaluate the data delivery among the vehicles along a path with multiple traffic lights.
  - Based on this model, we propose a **transmission control scheme** to decide which data packets can be delivered, by giving the deadline of reachable destinations, in order to reduce the resource consumption.

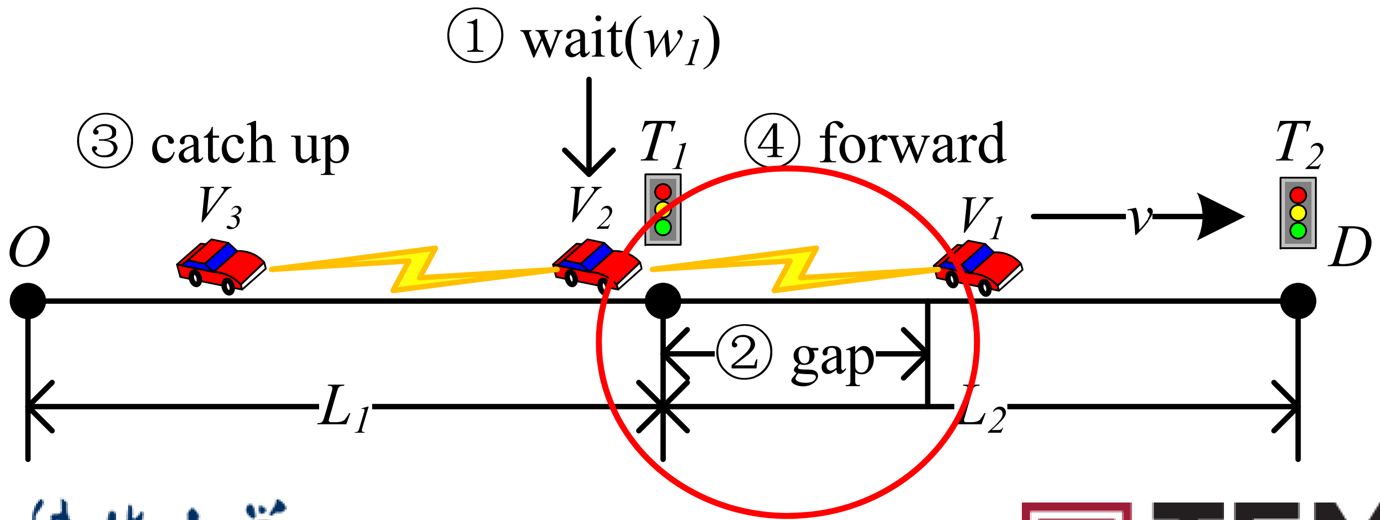
Influence of Traffic Lights on Data Delivery

- Increase delay by stopping vehicles by the waiting time at the traffic light T_1 (denoted by w_1).



Influence of Traffic Lights on Data Delivery

- Traffic hole problem:
  - When a vehicle stops at the intersection due to the red light, the vehicle ahead goes away, and a gap appears between them.



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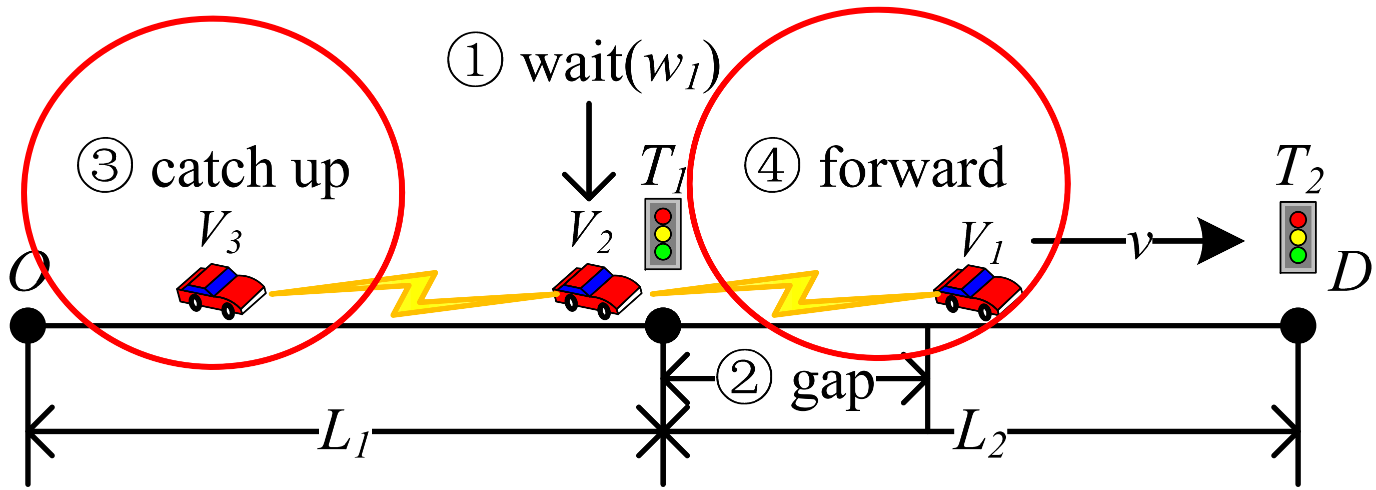
Influence of Traffic Lights on Data Delivery

- Catch up (denoted by *C*)
- Immediate transmission (denoted by *I*)



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Analysis Model - Mobility Prediction

- For evaluating the mobility of vehicles along the path with traffic lights, we define four sets of time as follows:
  - Initial time (*U*)
  - Departure time (*T*)
  - Arrival time (*S*)
  - Waiting time (*W*)

Analysis Model - Mobility Prediction

- $x_i(t)$ is defined as the function for calculating the distance of the vehicle V_i from the initial point O at time t.

$$x_i(t) = \begin{cases} 0, & \text{if } 0 \leq t \leq u_i \\ \sum_{r=1}^{K_i(t)-1} L_r + v\alpha_{K_i(t)}(u_i, t), & \text{if } t > u_i \end{cases}$$

We define $K_i(t) = k$ if, at time t, the vehicle V_i is in the k^{th} road segment.

The length of the k^{th} road segment from T_{k-1} to T_k is denoted by L_k.

We define $\alpha_k(u_i, t)$ as the duration while the vehicle V_i has moved on the k^{th} road segment with the speed v at time t.

Analysis Model - Data Delivery

- The vehicle V_q is defined as the first car that receives a message at the initial point O, and σ_q denotes the time when it receives the message. σ_i can be recursively calculated as follows:

$$\sigma_i(\sigma_q) = \begin{cases} \sigma_{i+1} + t_{hop}, & \text{if } V_{i+1} \xrightarrow{I} V_i \\ s_j(u_{i+1}) - \frac{R}{v} + t_{hop}, & \text{if } V_{i+1} \xrightarrow[j]{T} V_i \\ \infty, & \text{Otherwise} \end{cases}$$

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Analysis Model - Data Delivery

- The condition that the vehicle V_{i+1} can **immediately transmit** the message to the vehicle V_i means: when the vehicle V_{i+1} receives the message at time σ_{i+1}, V_i is in its communication range. Thus, the condition can be calculated with the indicator function, as follows:

$$\mathbb{1}_{V_{i+1} \xrightarrow{I} V_i} = \mathbb{1}_{x_i(\sigma_{i+1}) - x_{i+1}(\sigma_{i+1}) \leq R}$$

Analysis Model - Data Delivery

- The condition that the vehicle V_{i+1} does **not catch up** V_i at the j^{th} traffic light means: before V_i leaves the j^{th} traffic light, V_{i+1} cannot arrive in its communication range. Thus, the condition can be calculated as follows:

$$\mathbb{1}_{V_{i+1} \overset{C}{\underset{j}{\nrightarrow}} V_i} = \mathbb{1}_{x_i(t_j(u_i)) - x_{i+1}(t_j(u_i)) > R}$$

Analysis Model - Data Delivery

- On the contrary, the condition that the vehicle V_{i+1} can catch up to V_i at the jth traffic light means: before V_i leaves the j^{th} traffic light, V_{i+1} can arrive in its communication range.

$$\mathbb{1}_{V_{i+1} \overset{C}{\underset{j}{\rightarrow}} V_i} = \mathbb{1}_{x_i(t_j(u_i)) - x_{i+1}(t_j(u_i)) \leq R}$$

Analysis Model - Data Delivery

- The condition that the vehicle V_{i+1} catches up with V_i and transmits the message at the j^{th} traffic light:

$$\mathbb{1}_{V_{i+1}\xrightarrow[j]{T}V_i} =$$

$$\begin{cases} 0, & \text{if } j < K_i(\sigma_{i+1}) \\ \prod\limits_{K_i(\sigma_{i+1})\le r<j}[\mathbb{1}_{V_{i+1}\overset{C}{\underset{r}{\nrightarrow}}V_i}]\mathbb{1}_{V_{i+1}\xrightarrow[j]{C}V_i}, & \text{if } K_i(\sigma_{i+1}) \le j \le m \end{cases}$$

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Reachable Destinations

- We define **reachability** of the destination as whether the data packets could be successfully delivered from the source to it.
- 1) RSU as Destination: the delivery delay of this message from the source V_q to the destination at T_k

$$d_{V_q \to T_k} = \sigma_{min(\mathcal{M})} \vee s_k(u_{min(\mathcal{M})}) - \sigma_q$$

- 2) Vehicle as Destination: the reachability of the message from V_q to V_p

$$r_{q \to p}(u_q) = \prod_{i=p}^{q} \mathbb{1}_{\sigma_i < t_m(u_q)}$$

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Reachable Destinations

- *Theorem 1 (**Temporally Reachable**)*: On a finite path with m traffic lights, if the data packet carried by V_i, whose destination is V_j, is unreachable at time t_0, and thus is in the future time $t_0 + \Delta t$ ($\Delta t > 0$), it is also unreachable.
- *Theorem 2 (**Spatially Reachable**)*: At the time t_0, if the vehicle V_l is the reachable destination for the data packets carried by V_i, it is also the reachable destination for the data packets carried by V_j ($j < i$), which moves in front of V_i along the path.

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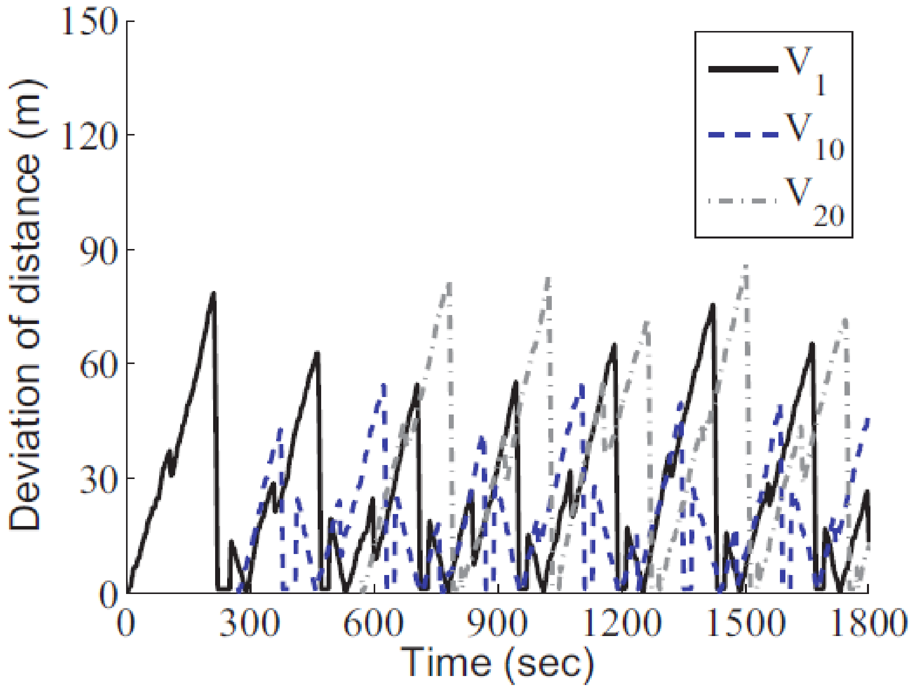
Transmission Control Scheme

Algorithm 1 Transmission control scheme

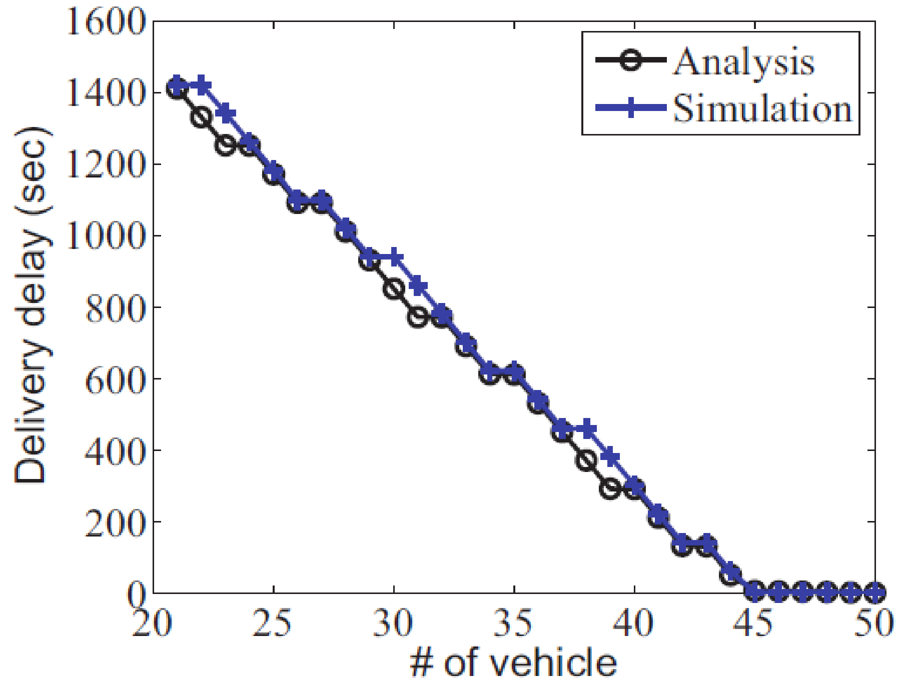
Input: F/G, the sets of the received/generated packets
Output: S, the set of the packets which need to be sent

Select Reachable packets in F and G to S;
Clear the sets of F and G;
Sort the packets in S by their deadlines in ascending order;

Analytical model compared with simulations



(a) Mobility of vehicles



(b) Data delivery delay

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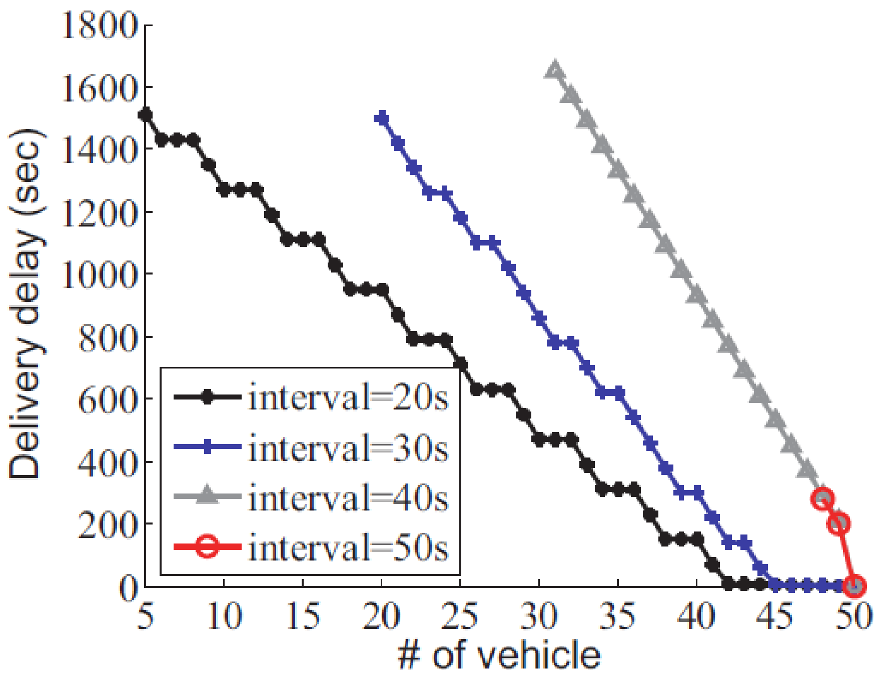
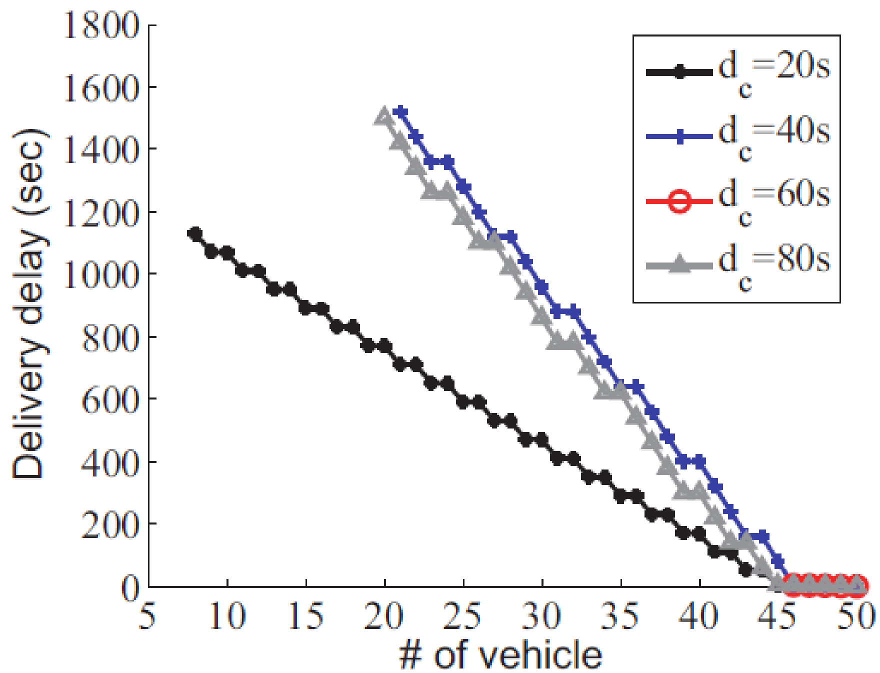
Impact on data delivery delay



(a) Interval of arrival time



(b) Cycle time of traffic light

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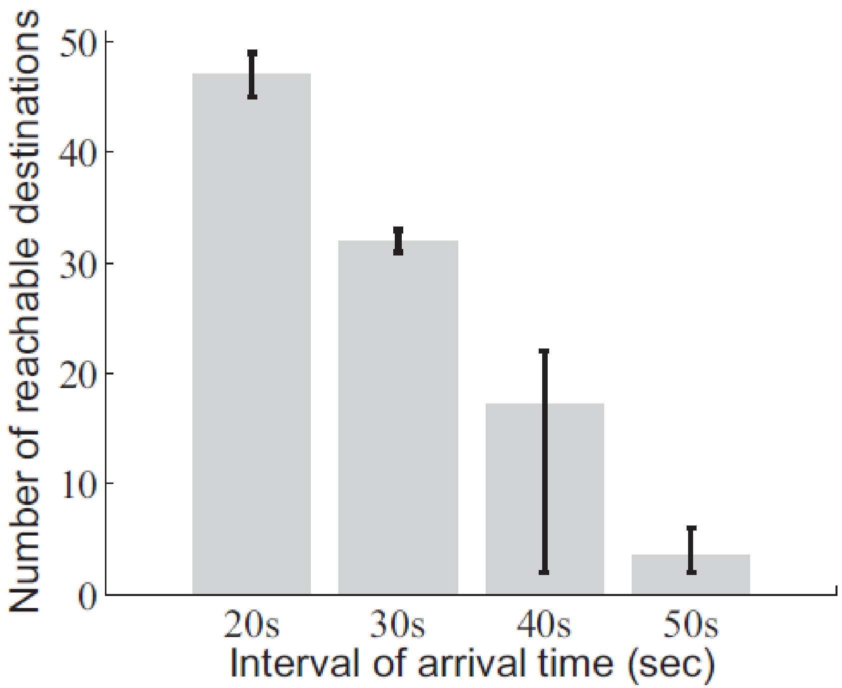
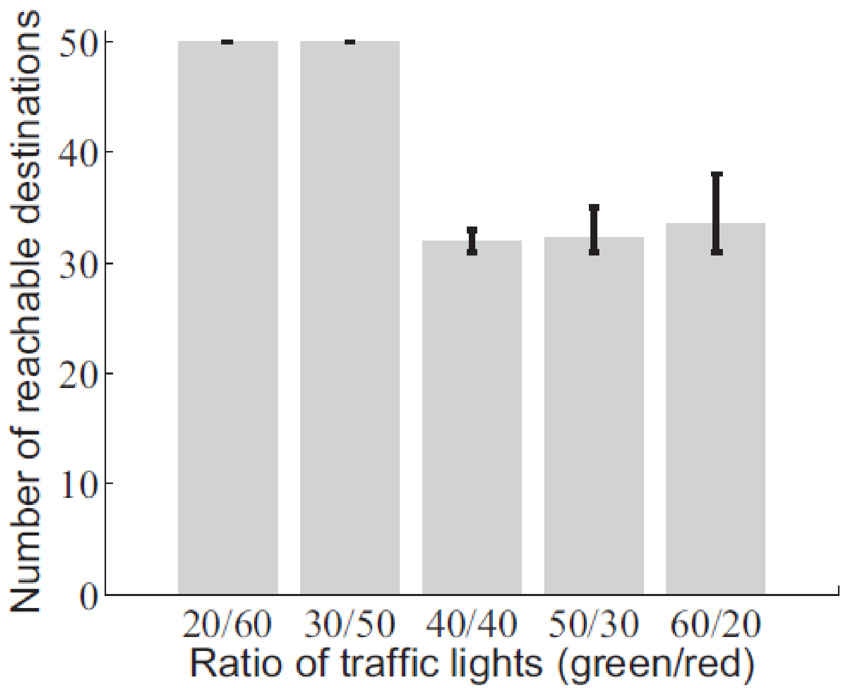
Reachable destinations



(a) Interval of arrival time



(b) Ratio of traffic lights (green/red)

Conclusion

- We investigate the influence of traffic lights on data delivery in VANETs.
- We propose an analysis model to evaluate the influence by given initial headway times of vehicles, and the schedules of traffic lights.
- Based on the analysis model, we propose a transmission control scheme at the transmitters; this scheme filters suspicious transmission requests, which are unlikely to be accomplished.
- The proposed analytical model is under a linear topology. In our future work, we plan to evaluate the data delivery under a two-dimensional topology, such as a ladder or a grid.

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