Catching Up with Traffic Lights for Data Delivery in Vehicular Ad Hoc Networks

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- Mobility of Vehicles
- Catch Up
- Waiting Queue
- Data Delivery
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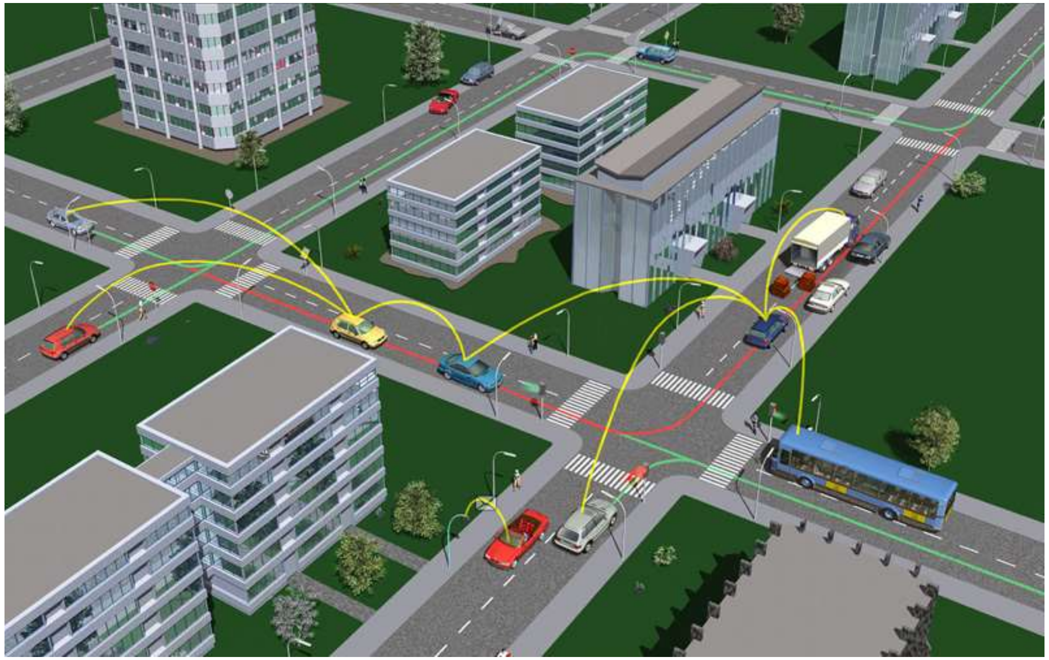
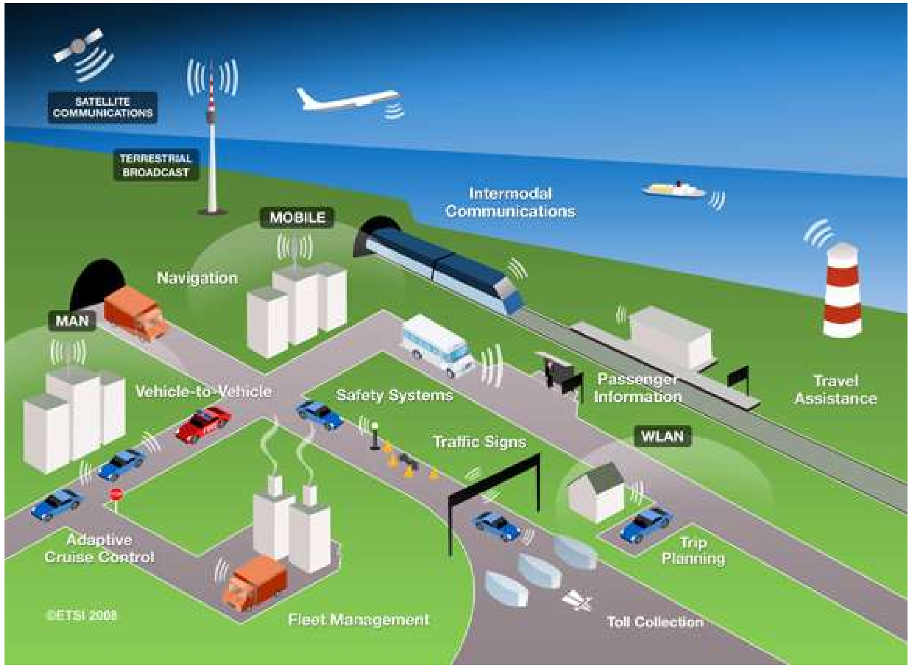
Overview

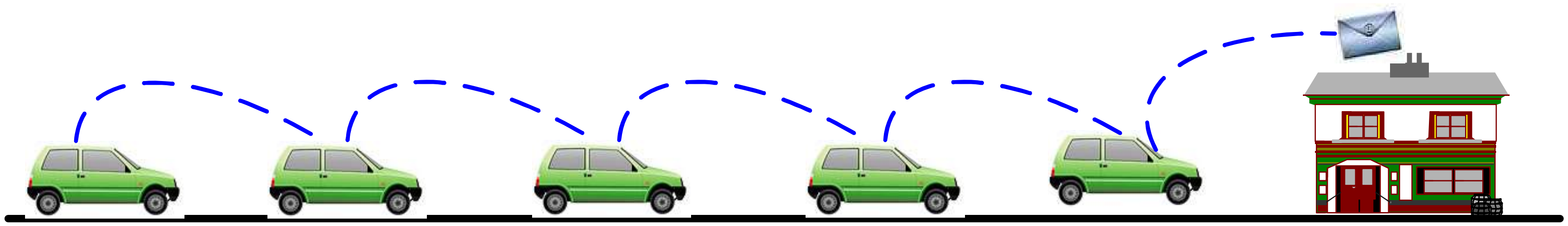
- The data delivery in vehicular ad hoc networks (VANETs) is based on the wireless communication among vehicles (**V2V**) and infrastructures (**V2I**).





Store-forward

- The traditional connection-based routing protocols, 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.



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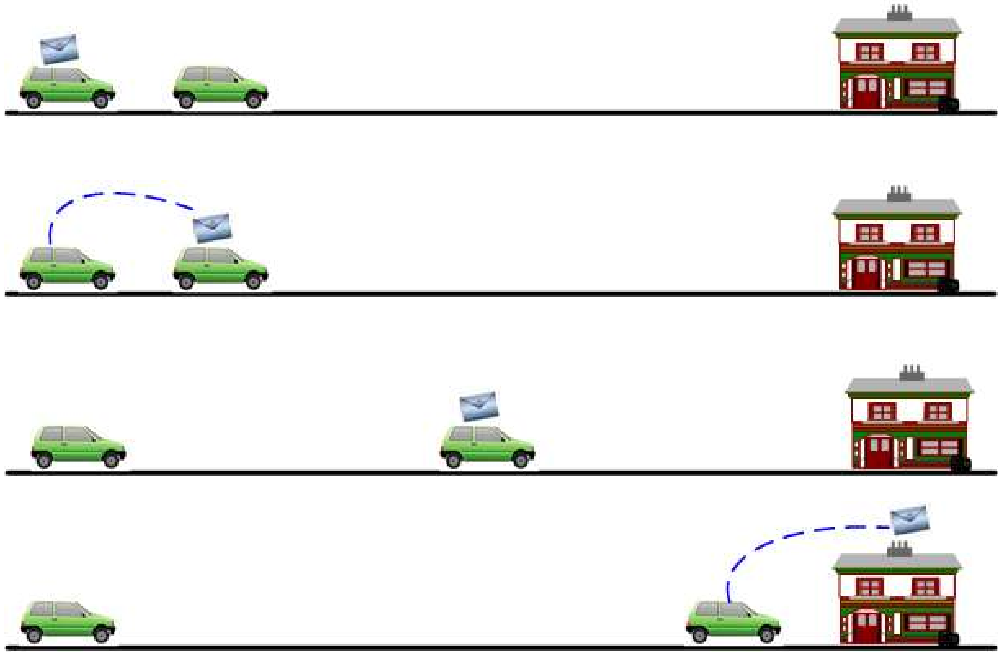
Store-carry-forward

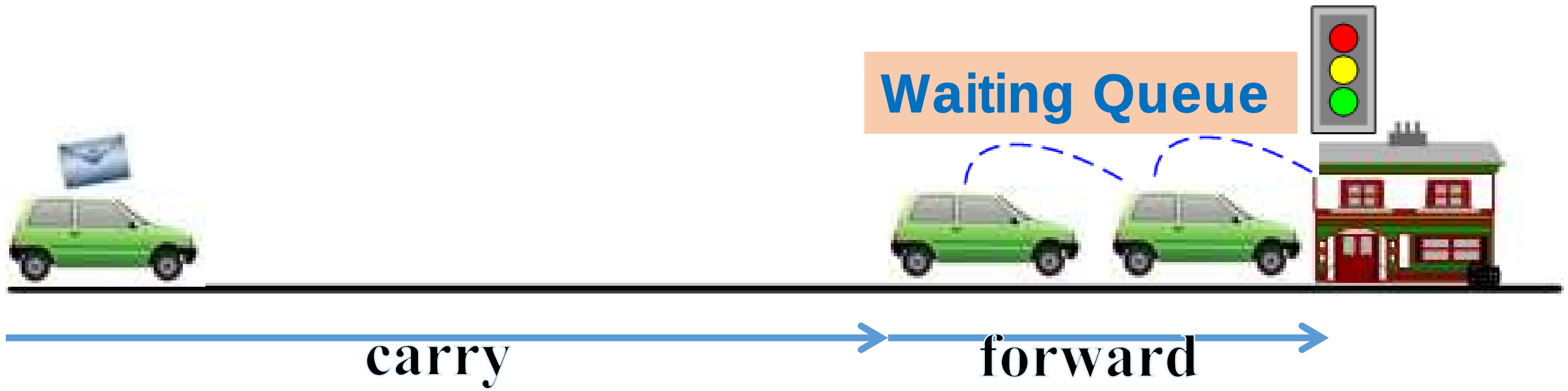


- The mobility of vehicles not only affects the connections or the forwarding opportunities among vehicles, but also affects the performance of data delivery with carrying.

Carry *vs.* Forward

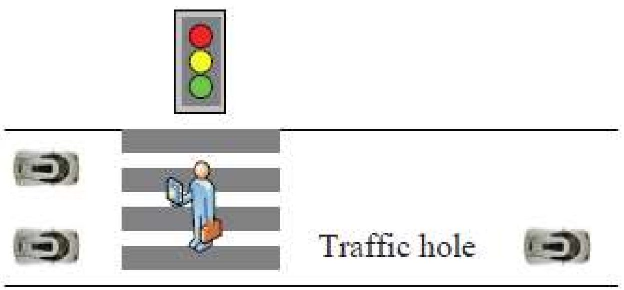
- A vehicle takes 90 seconds to travel along a road segment of 1 mile at a speed of 40 MPH.
- Due to the data rate in DSRC being 6~27 Mbps, it takes only tens of milliseconds to forward a packet over the same road segment.

Jeong, Jaehoon, et al. "TSF: Trajectory-based statistical forwarding for infrastructure-to-vehicle data delivery in vehicular networks." in Proc. of IEEE ICDCS, 2010.

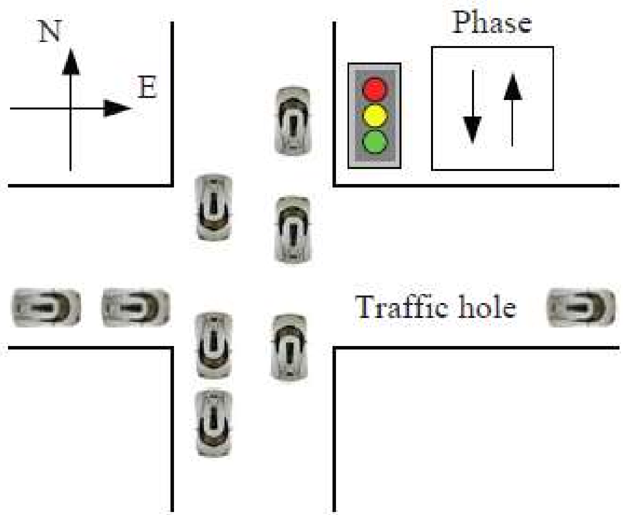


Traffic Light

- The mobility of vehicles is not only affected by the vehicle itself, but also by some external means, such as the signal operations of traffic lights.



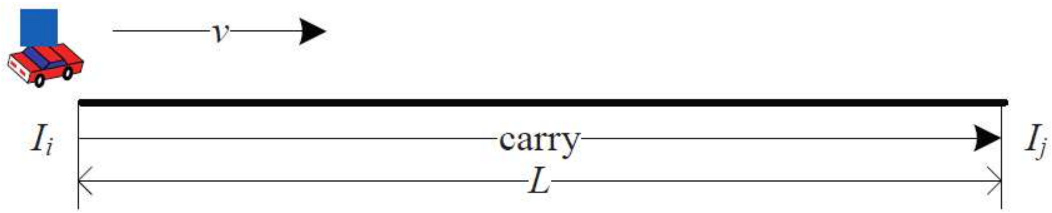
(a) Pedestrian crossing



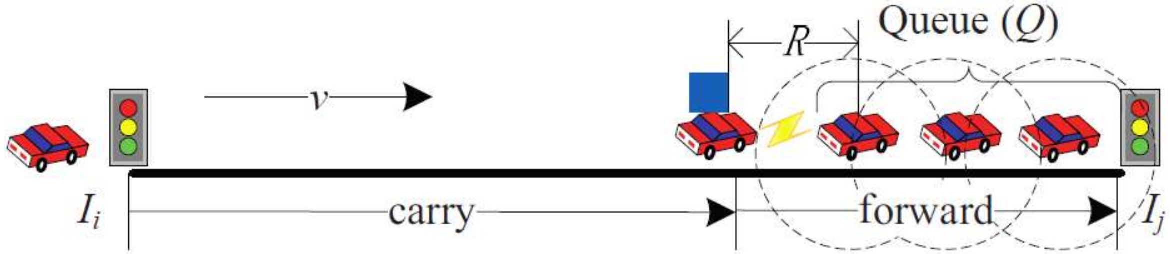
(b) Four-way intersection

Catch Up

- 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.



(a) Delivery without queue



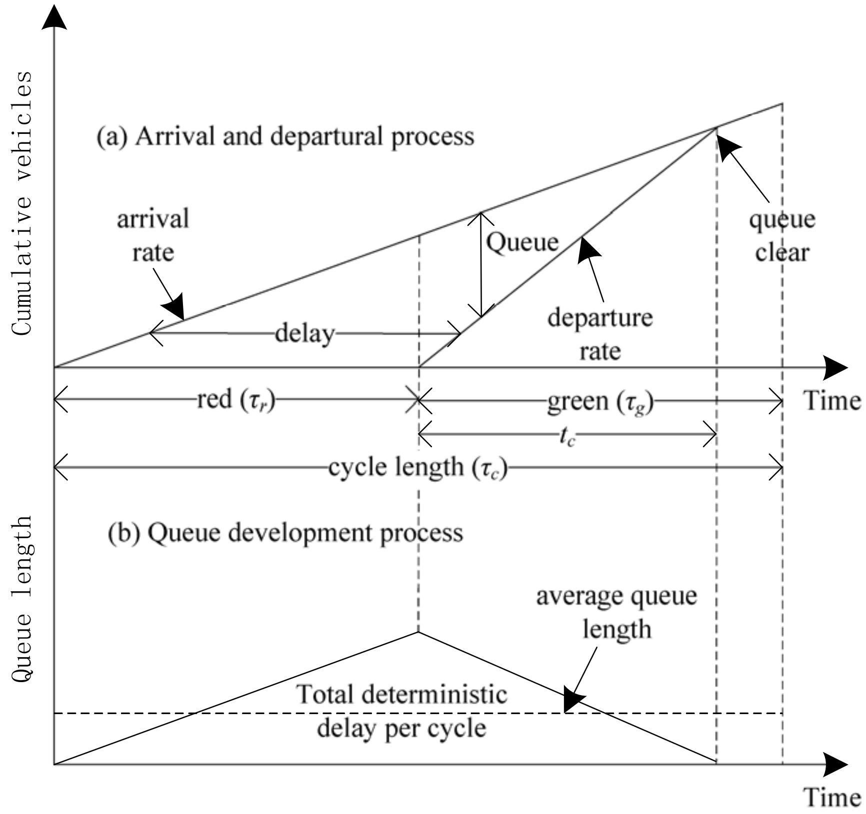
(b) Delivery with queue

Waiting Queue

If the number of queued vehicles at the start of the red phase is represented by *Q(0)*, the queue during the red phase is given by:

$$Q(t) = Q(0) + A(t)$$

where *A(t)* represents the cumulative arrivals of vehicles.



Relationship between arrivals, departures, queue length, and queuing delay (D/D/1 queueing model)

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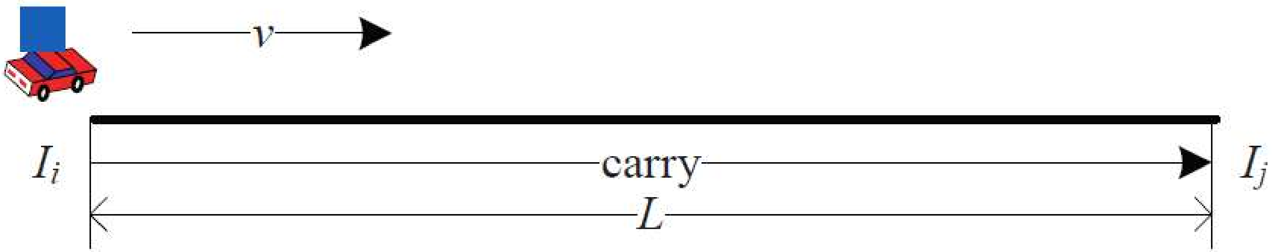
Delivery Delay without Waiting Queue

- The message delivery delay along this road segment without traffic lights is equal to the travel time of the vehicle, which is equal to the moving time along the road:

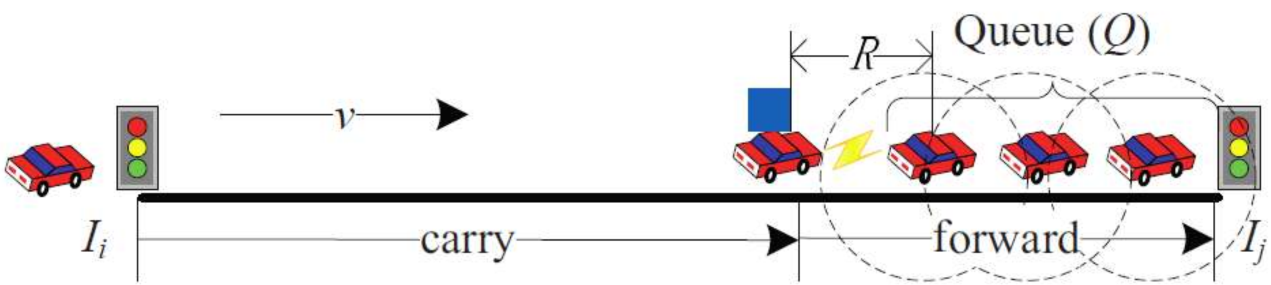
$$E[T_{ij}] = \frac{L_{ij}}{v}$$



(a) Delivery without queue

Delivery Delay with Waiting Queue

- When the vehicle carrying the message moves into the communication rage of the vehicles in the waiting queue, the message can be immediately forwarded to the downstream intersection by wireless communication.

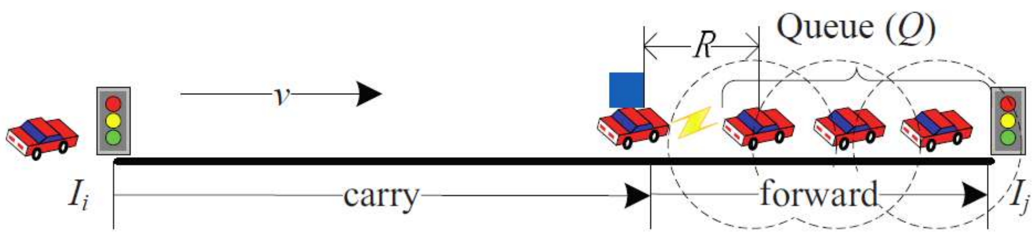


(b) Delivery with queue

- Length of the queue (l_q): $l_q = Q \cdot \Delta d$, where Δd denotes the average spacing of each vehicle in the queue, and Q denotes the number of vehicles in the waiting queue.

Delivery Delay with Waiting Queue

- The message delivery delay along this road segment includes two parts:
  - **Carrying delay** (denoted by d_c): the message is carried by the vehicle on the road with the **speed of the vehicle**, until it catches up with the waiting queue at the downstream signalized intersection.
  - **Forwarding delay** (denoted by d_f): when the vehicle catches up to the queue, the message can be immediately forwarded to the downstream intersection by the vehicles in the queue with the **speed of wireless communication**.



(b) Delivery with queue

Delivery Delay with Waiting Queue

- Let $C_{ij}(Q)$ denote the data delivery delay by catching up with the waiting queue involving Q vehicles on r_{ij}, which can be calculated as:

$$
\begin{aligned}
C_{ij}(Q) &= d_c + d_f \\
&= \frac{L_{ij} - R - l_q}{v} + \lceil \frac{R + l_q}{R} \rceil \cdot t_{hop}
\end{aligned}
$$

where t_{hop} denotes the average transmission delay per hop.

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Expected Data Delivery Delay

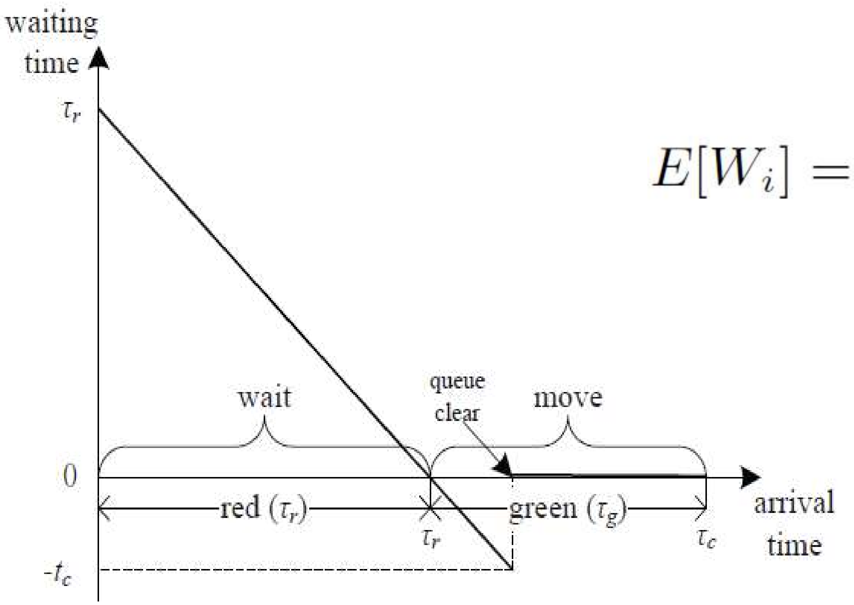
- Based on the probability distribution of queue length at the traffic light ***$P_i(k)$***, the expected delay along this road can be calculated as follows:

$$E[D_{ij}] = P_i(0) \cdot E[T_{ij}] + \sum_{k=1}^{\infty} P_i(k) \cdot C_{ij}(k) + E[W_i]$$

- If there are **no vehicles** waiting at the traffic light, the data packet is carried by the vehicle to move, and the data delivery delay on the road is equal to the travel time of the vehicle.
- If there exists **a waiting queue** at the traffic light, the data packet can be immediately forwarded downstream when the carrying vehicle moves into the communication range of the queue.

Expected Waiting Time

- The expected waiting time at the upstream intersection can be calculated as follows:



$$E[W_i] = \frac{\tau_r^2 - [max\{\bar{t}_c, \tau_g\}]^2}{2\tau_c}$$

Waiting time of a data packet at a signalized intersection with different arrival time

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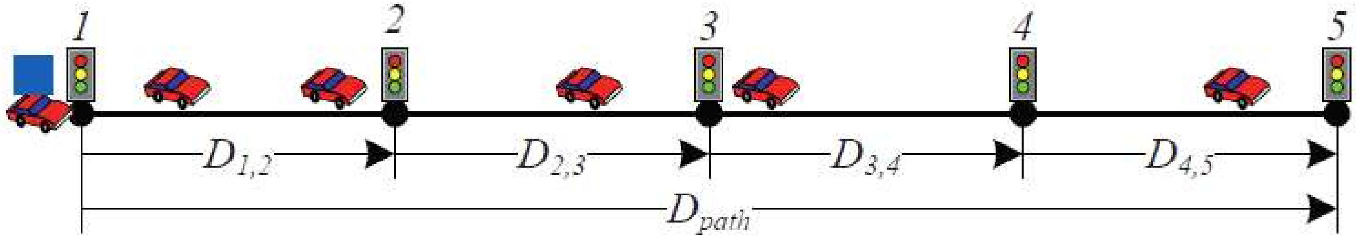
Data delivery along a path



- Given a routing path from the vehicle's current position to a target point in front, we suppose that the queue length distributions are independent of each other under the asynchronous traffic lights.
- The expected data delivery delay along a path with several road segments can be calculated as follows:

$$E[D_{path}] = \sum_{r_{ij} \in path} E[D_{ij}]$$

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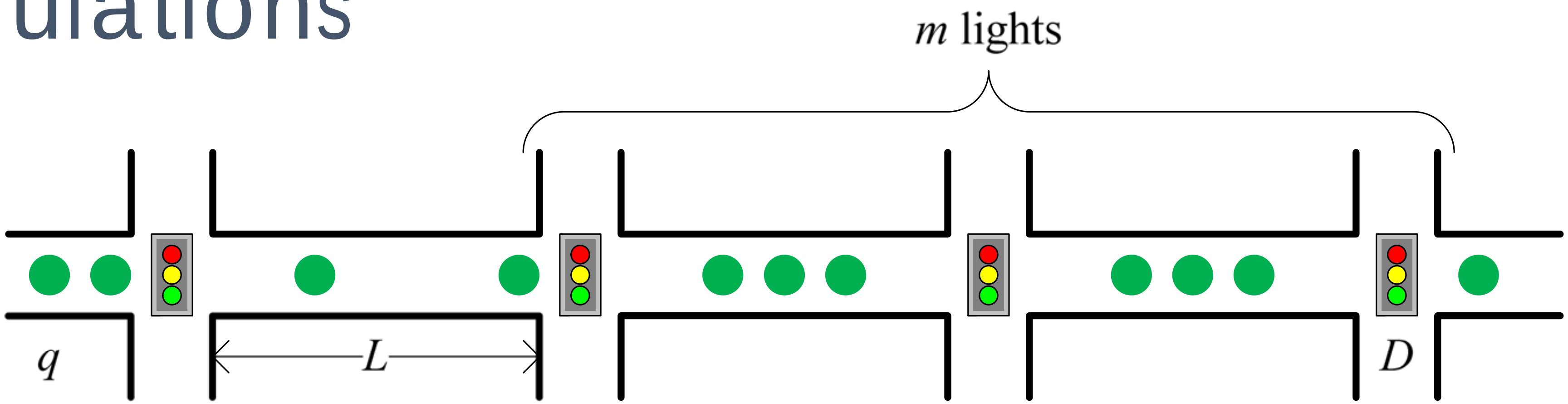
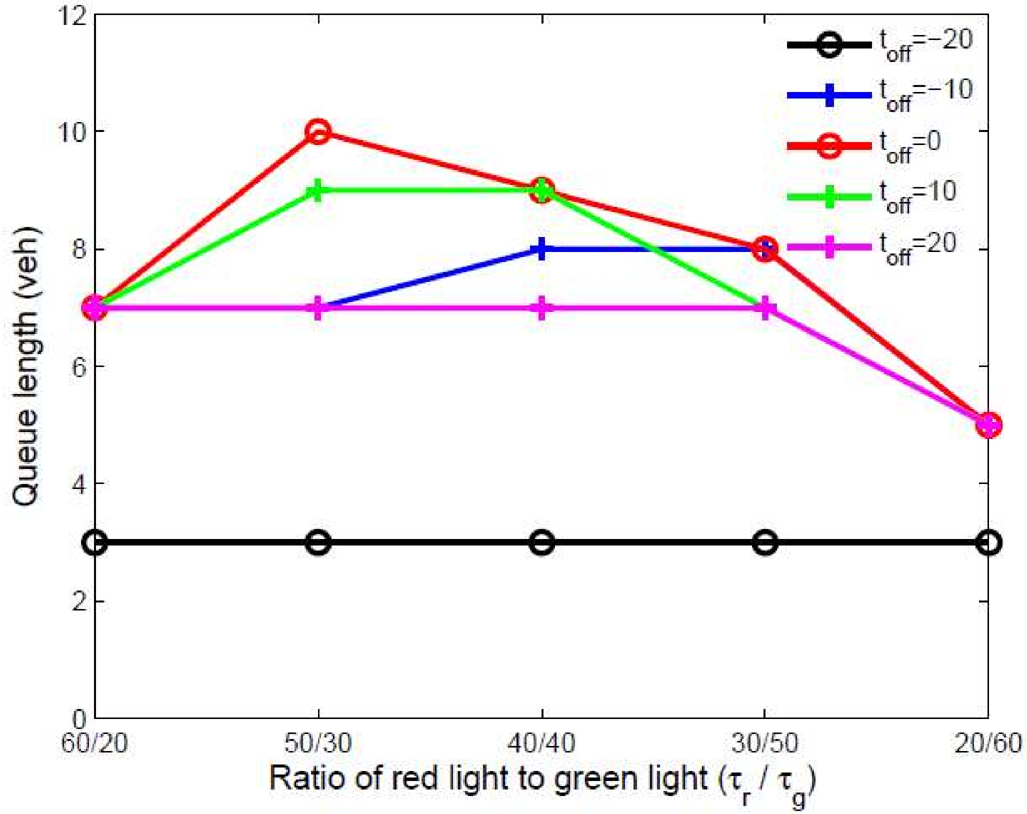
Simulations



Parameter	Default value
Average arrival rate (veh/s)	0.1, 0.2
Average departure rate (veh/s)	0.3
Length of each road segment (m)	500
Cycle time of traffic light (sec)	80
Duration of green light (sec)	40
Duration of red light (sec)	40
Communication range (m)	200
Average speed of vehicles (m/s)	9

Simulation results

- Queue length on a road



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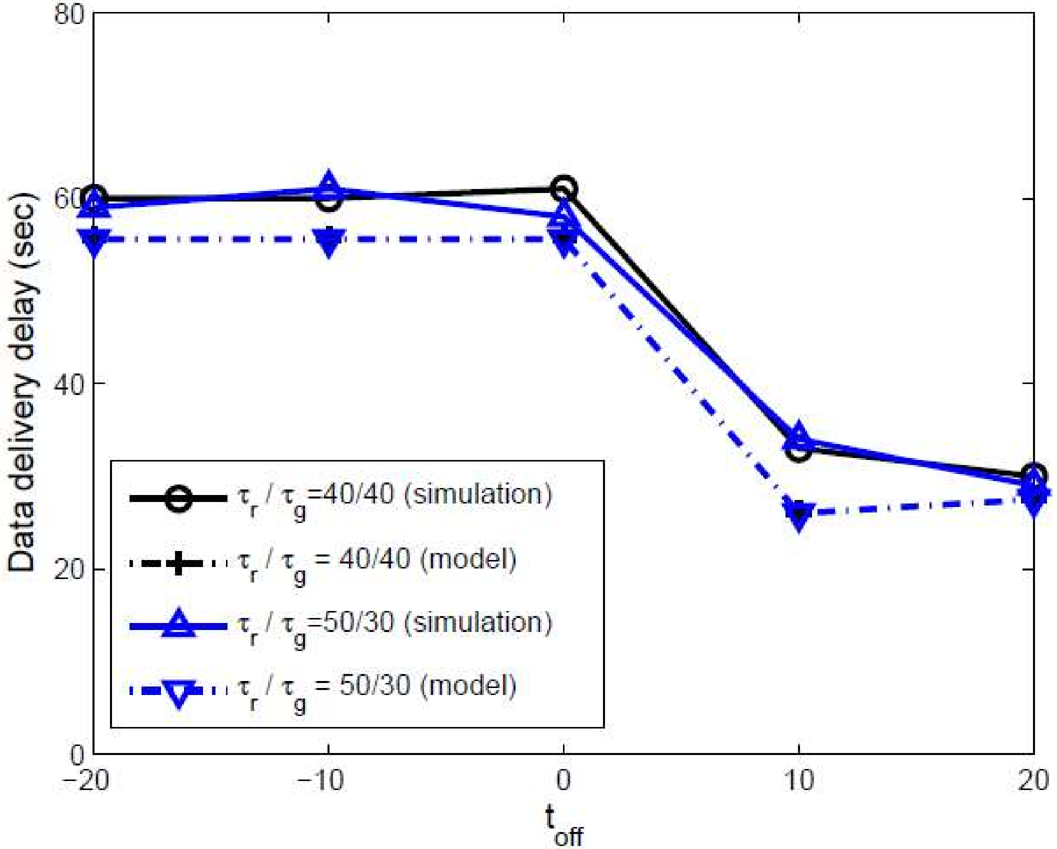
Simulation results

- Data delivery delay on a road



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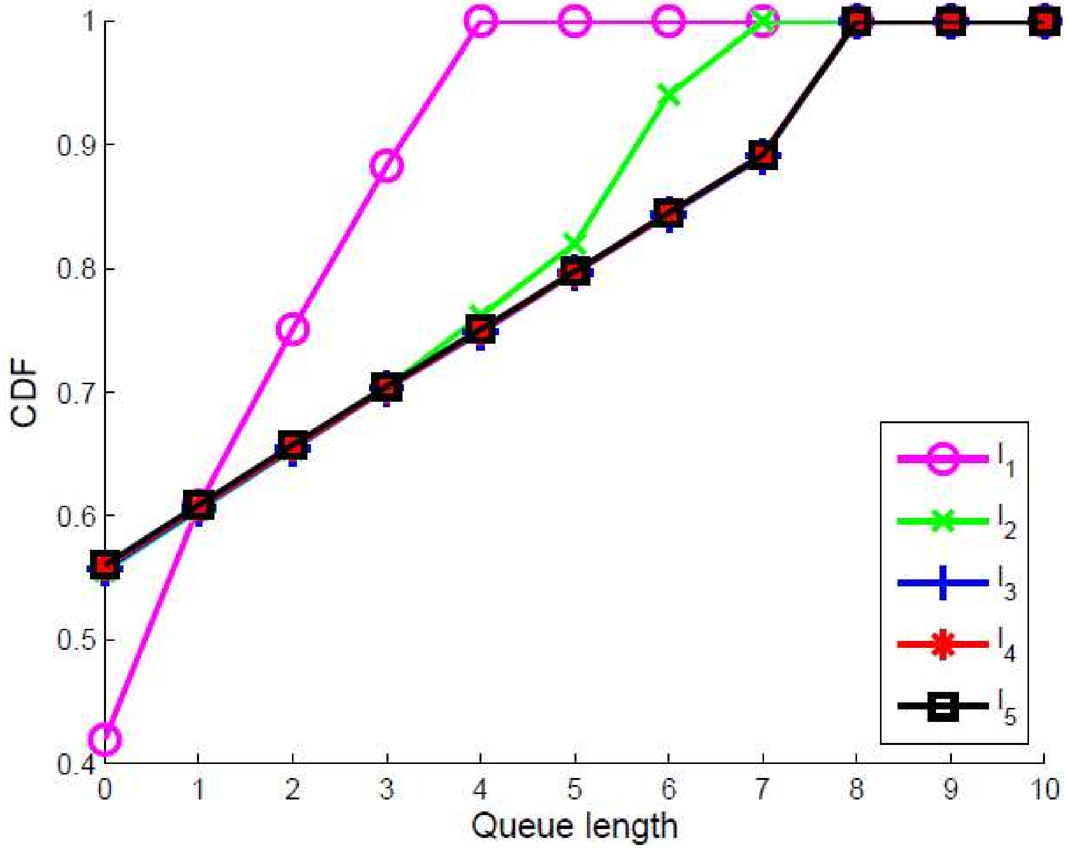
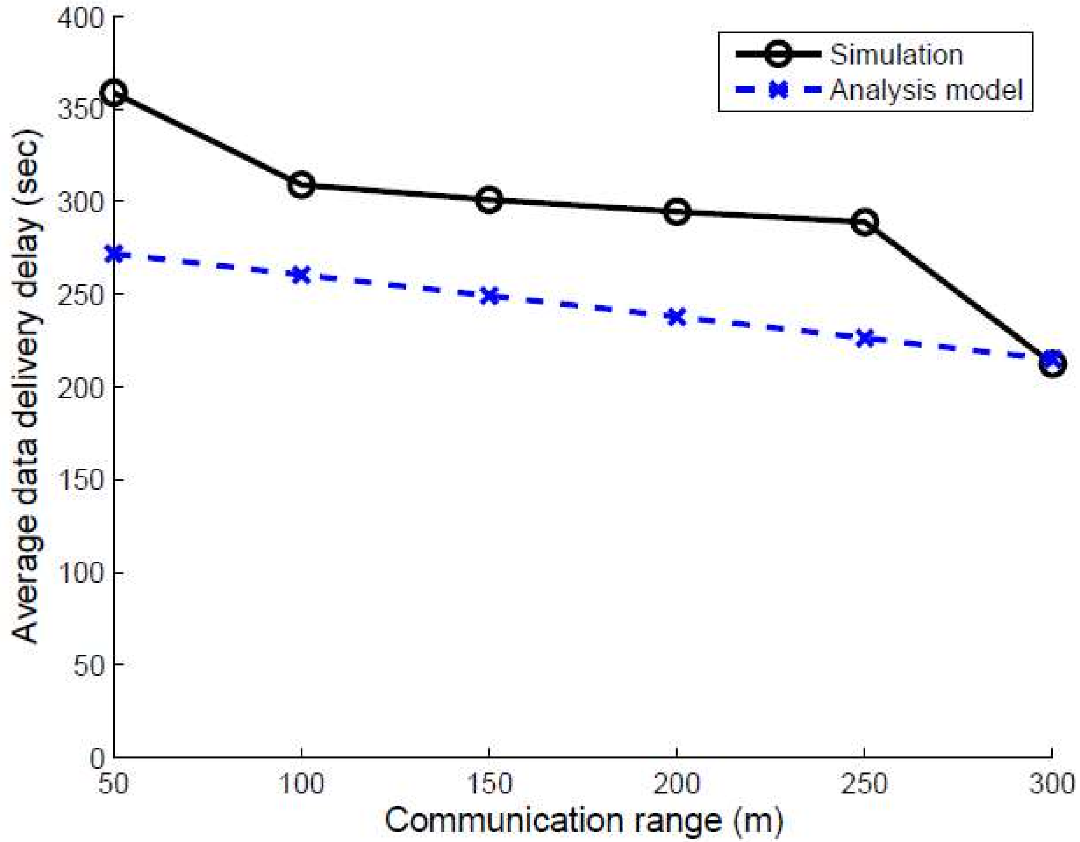
Simulation results

- Distribution of queue length (equal cycles)



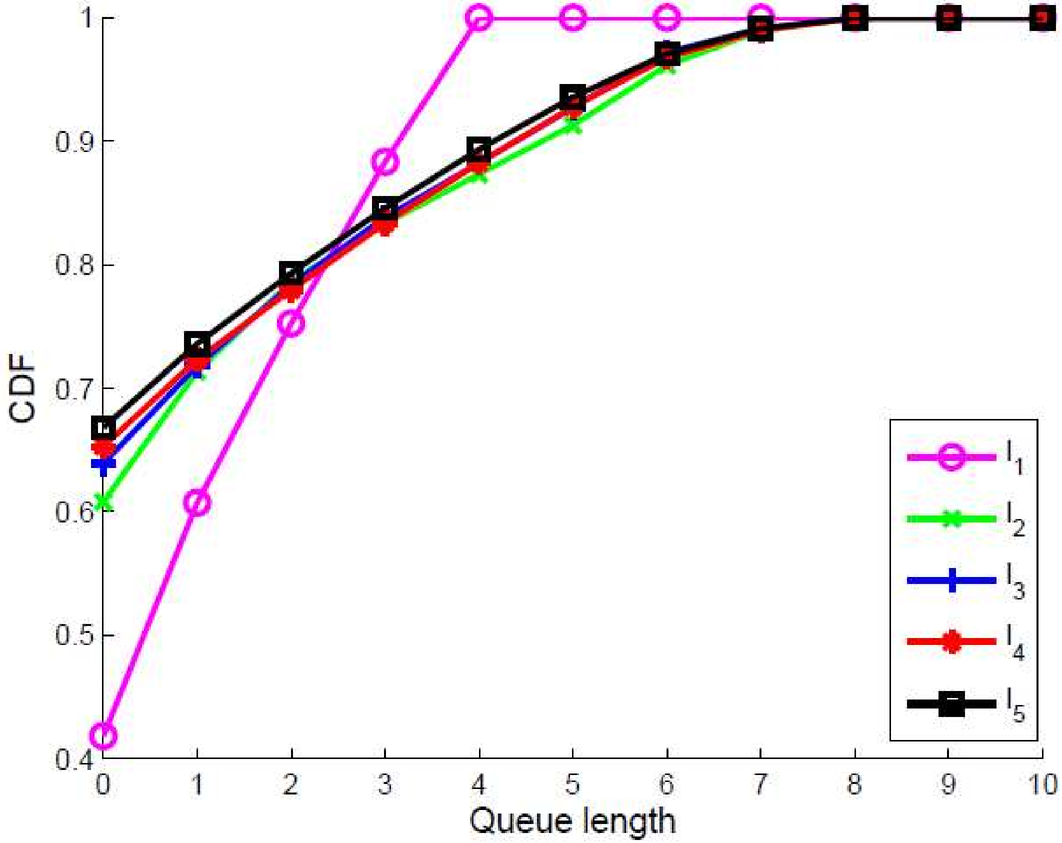
Simulation results

- Impact of communication range (equal cycles)



Simulation results

- Distribution of queue length (unequal cycles)



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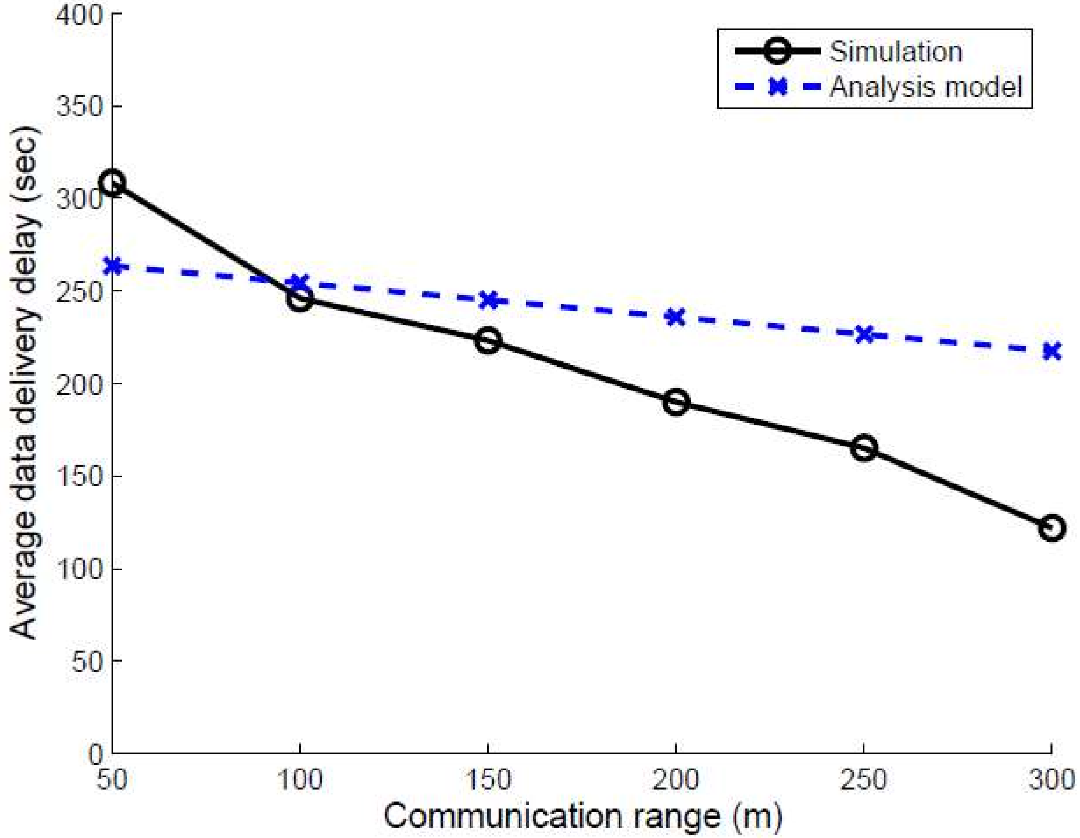
Simulation results

- Impact of communication range (unequal cycles)



Conclusions

- Traffic light affects the mobility of vehicles moving on the road, so it also affects the data delivery among vehicles in VANETs.
- The traffic light can stop the vehicles, as to increase its travel time, and can also help the vehicles moving behind catch up with the waiting vehicles, and experience increased forwarding opportunities.
- We propose the utilization of the event of catching up to the waiting queue at the downstream intersection, as to reduce the delay.
- Our intensive simulations verify the proposed model, and evaluate the influence of the traffic lights on data delivery.

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Thank you!

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