Performance Analysis of IEEE802.11 MAC Based Collision Avoidance in Vehicular Platoon

Sumit Roy & Ching-Ling Huang
Dept. EE, University of Washington

V2VCOM, San Diego
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Introduction

- A key component of the emerging ITS (Intelligent Transportation System) is the potential for vehicle-to-vehicle (v2v) and vehicle-to-roadside (v2r) infrastructure communications based on spectrum allocation for DSRC (Dedicated Short Range Communication) worldwide.
  - In North America, the IEEE802.11p Task Group is attempting to standardize WAVE (Wireless Access for a Vehicular Environment).

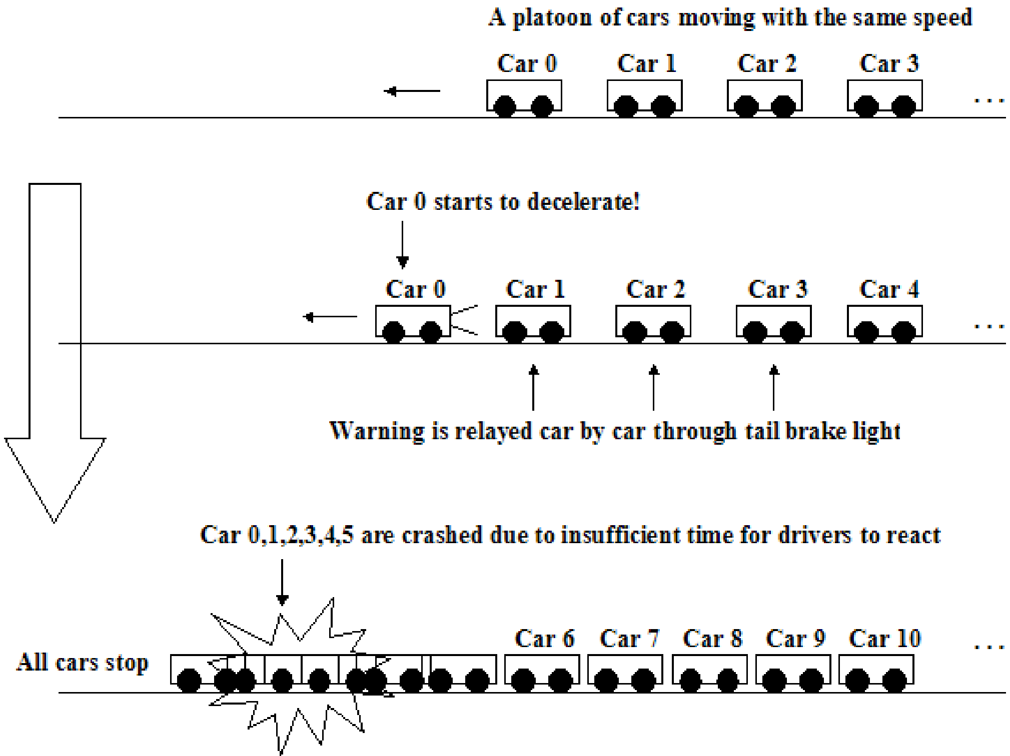
- An early use for DSRC is anticipated to be enhanced vehicular safety via an improved anti-collision warning system based on intra-vehicle communication.
  - In this paper, we proposed a Collaborative Collision Avoidance (CCA) algorithm and analyze its performance compared with platoon without CCA.

Design Classification of DSRC

- Dynamic TDMA/Reservation Based Random Access:
  - Such as R-ALOHA and other slot-reservation schemes that dynamically allocate time slots for each vehicle within a transmission group.
  - The main challenge in this class of methods is the need for precise synchronization between vehicles.
- CSMA/CA based schemes:
  - Such as IEEE802.11 which obviates the need for synchronization between vehicles and is currently preferred for DSRC applications.
  - However, several limitations have been identified in, such the hop-unfairness issue and the instability due to high mobility of vehicles.
  - In this paper, we modify 802.11 MAC to provide CCA.

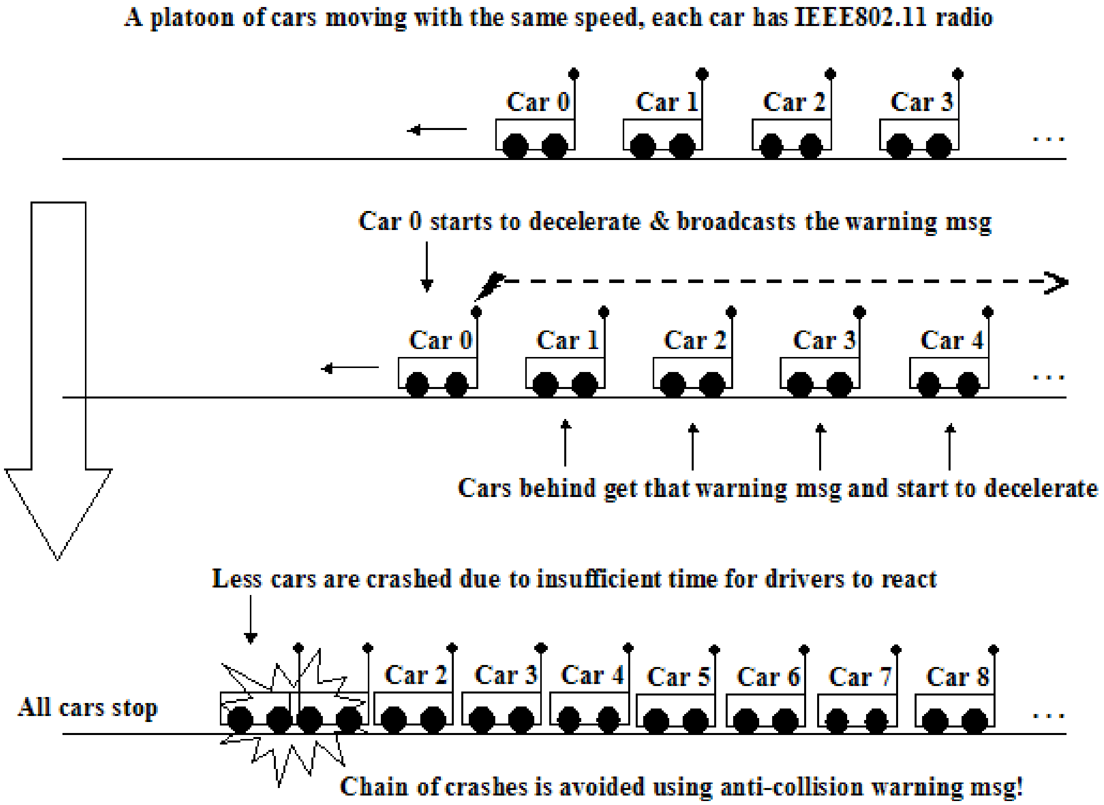
Reasons of collisions in the platoon

- Normally, drivers only rely on the tail brake light of the car immediately ahead to initiate his/her own braking action.
  - the inability of any driver to see past the car immediately in front greatly reduces the time available for drivers to react and contributes to the depth of the crash.



Collaborative Collision Avoidance

- CCA is an important application of v2v comm. for highway safety:
  - The potential of enhanced collision avoidance is using IEEE802.11 transceiver to broadcast warning message along the platoon when some emergency happens.

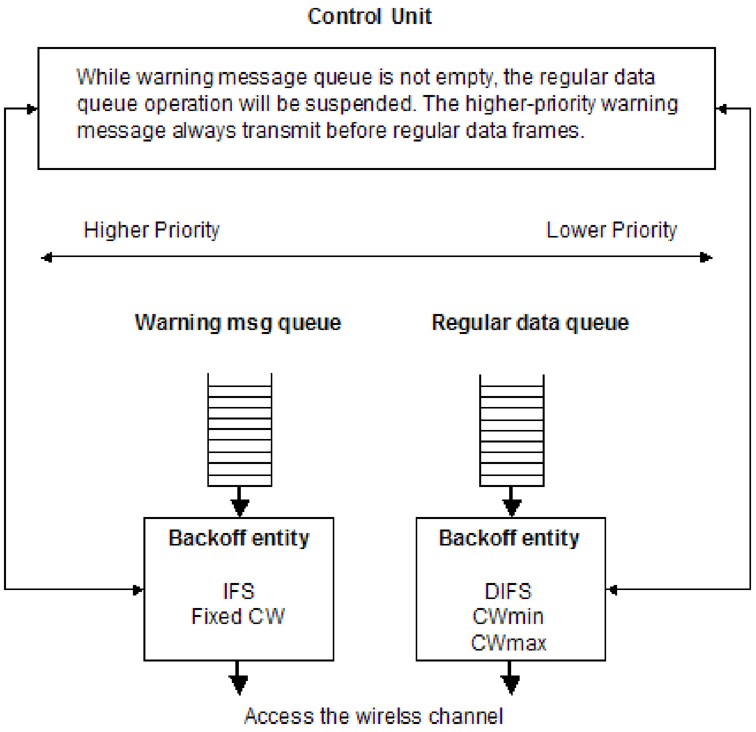


Proposed CCA Operations

- Each car in the platoon is assumed to be equipped with:
  - *A localization device that provides self-location information;*
  - *IEEE802.11 transceiver in ad-hoc mode for v2v communication.*
- When an emergency is detected, the lead car starts to decelerate and simultaneously releases an *Emergency Warning Message* (EWM):
  - EWM contains *(sender’s location, event’s location, event ID)* that indicates event location and the nature (class) of event.
  - Cars receiving EWM: i) start to decelerate after a fixed human reaction time; ii) attempt to broadcast EWM to the cars behind them.

Modified IEEE802.11 MAC for CCA

- The operation of regular data queue is the same as those defined in IEEE802.11 DCF.
- Whenever the EWM queue is not empty, regular data queue operation is suspended. Thus, the EWM has absolute priority over regular data traffic within the same vehicle.
- The warning message queue uses shorter IFS and fixed *CW* so that it has relatively higher probability of accessing the channel before regular data traffic from other vehicles.
- A vehicle will keep contending for the channel to relay the EWM until it receives an EWM broadcast with same event ID from any succeeding vehicle.
- *Unlike regular operation of DCF for data, there is no explicit ACK required for EWM; the receipt of EWM from a subsequent car in the platoon serves as an implicit ACK.*



While warning message queue is not empty, the regular data queue operation will be suspended. The higher-priority warning message always transmit before regular data frames.

Assumptions of Analysis

- The platoon constitutes a linear topology with *fixed* (inter-car) spacing, and motion with (common) uniform velocity.

- Because the warning message queue has shorter IFS and fixed CW, we assume that the regular data traffic from vehicles outside the active nodes *never* wins channel access, i.e. we ignore the presence of any other traffic.

- For the simplified analysis in this paper, we assume *no channel losses* (i.e. the physical layer is ideal) and ignore the impact of multipath fading due to vehicle motion. Any losses occur only due to the contention between multiple active nodes while trying to relay EWM.

Analysis Results

- Time constraint for the *n-th* car to get warning and achieve CA :

$$C_n = n \times \left(\frac{d}{V} \right) - T_{react}$$

- “Visual” warning delivery time (no CCA) for the *n-th* car :

$$A_n = (n - 1) \times T_{react}$$

- Expected EWM delivery time (CCA) for the *n-th* car :

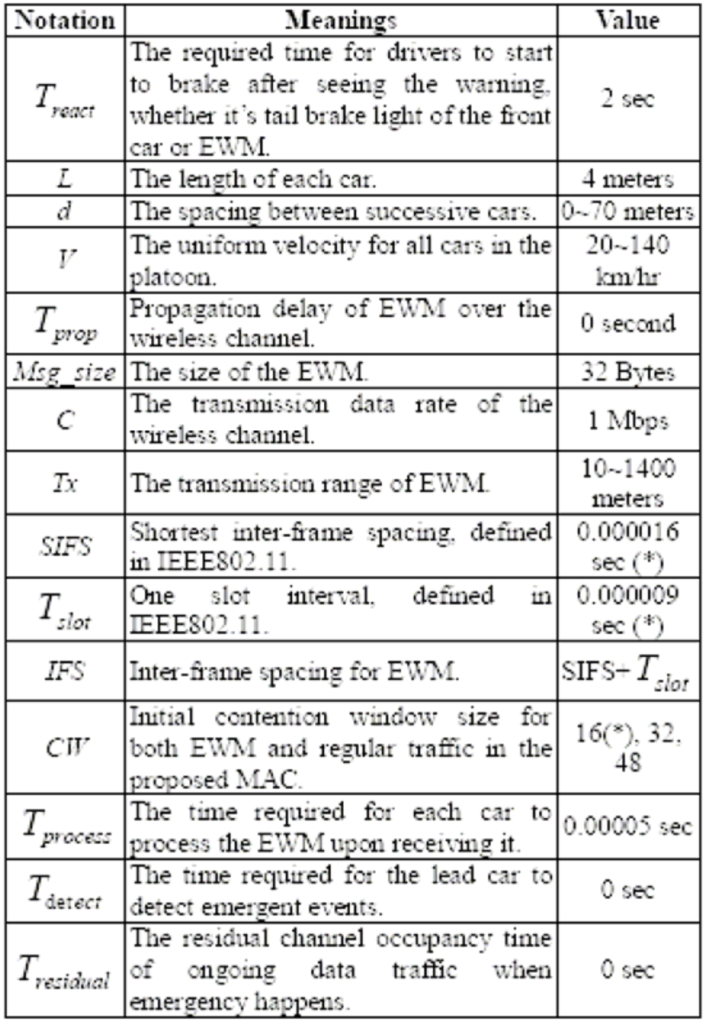
$$n \le M \qquad E[D_n] = E[T_{relay*}]$$

$$n > M \qquad E[D_n] \cong E[T_{relay*}] + \frac{n - M}{E[\Omega]} \times E[T_{relay}]$$

where

$$M = \left\lfloor \frac{Tx}{d + L} \right\rfloor + 1$$

Table 1. Parameters for generating computational results



Notation	Meanings	Value
T_{react}	The required time for drivers to start to brake after seeing the warning, whether it's tail brake light of the front car or EWM.	2 sec
L	The length of each car.	4 meters
d	The spacing between successive cars.	0~70 meters
V	The uniform velocity for all cars in the platoon.	20~140 km/hr
T_{prop}	Propagation delay of EWM over the wireless channel.	0 second
Msg_size	The size of the EWM.	32 Bytes
C	The transmission data rate of the wireless channel.	1 Mbps
Tx	The transmission range of EWM.	10~1400 meters
SIFS	Shortest inter-frame spacing, defined in IEEE802.11.	0.000016 sec (*)
T_{slot}	One slot interval, defined in IEEE802.11.	0.000009 sec (*)
IFS	Inter-frame spacing for EWM.	SIFS+T_{slot}
CW	Initial contention window size for both EWM and regular traffic in the proposed MAC.	16(*), 32, 48
$T_{process}$	The time required for each car to process the EWM upon receiving it.	0.00005 sec
T_{detect}	The time required for the lead car to detect emergent events.	0 sec
$T_{residual}$	The residual channel occupancy time of ongoing data traffic when emergency happens.	0 sec

(*) Those are default parameters for IEEE802.11a.

Effectiveness of Using CCA

- There is a high platoon crash ratio for the platoon without CCA while only two cars crashed for the platoon with CCA confirming the effectiveness of the proposed CCA algorithm. (Figure 1-a)
- Using CCA, most of the crashes happen in the front of the platoon because these vehicles have more stringent time constraint than others. (Figure 1-b)

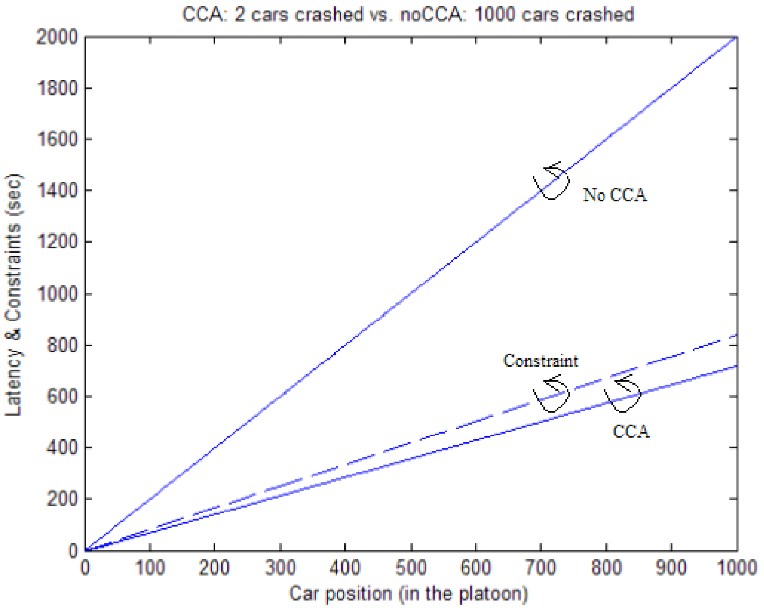


Figure 1-a. Constraint (dashed line) & latency (solid curve) vs. car position; ((*d*= 21m, *V* = 90km/hr, *Tx*=100m)

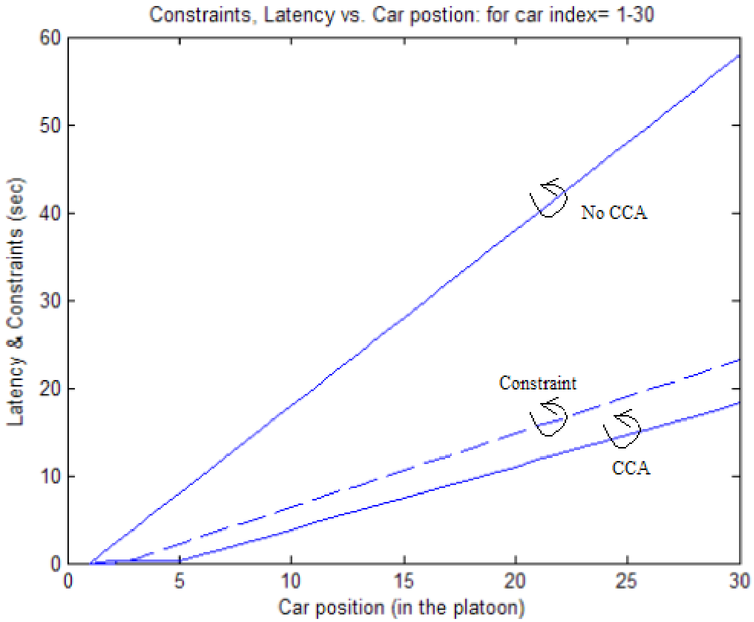


Figure 1-b. Enlarged from Figure 10-a for car index= 1st –30th.

Performance Improvement of CCA

- Significant performance improvement of CCA:
  - it can tolerate smaller inter-car spacing than the platoon without CCA. (Figure 2-a)
  - it can tolerate higher velocity than the platoon without CCA. (Figure 2-b)

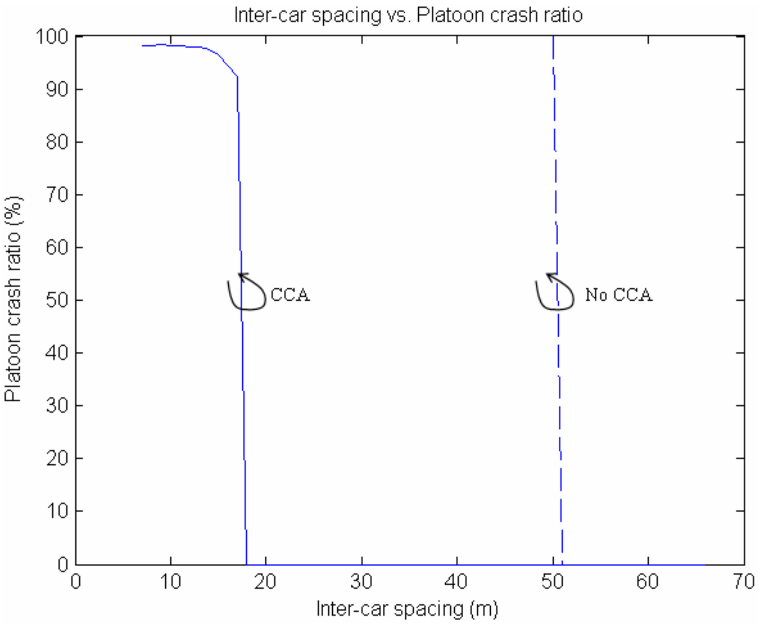


Figure 2-a. Inter-car spacing vs. platoon crash ratio; (*V* = 90km/hr, *Tx*=100m)

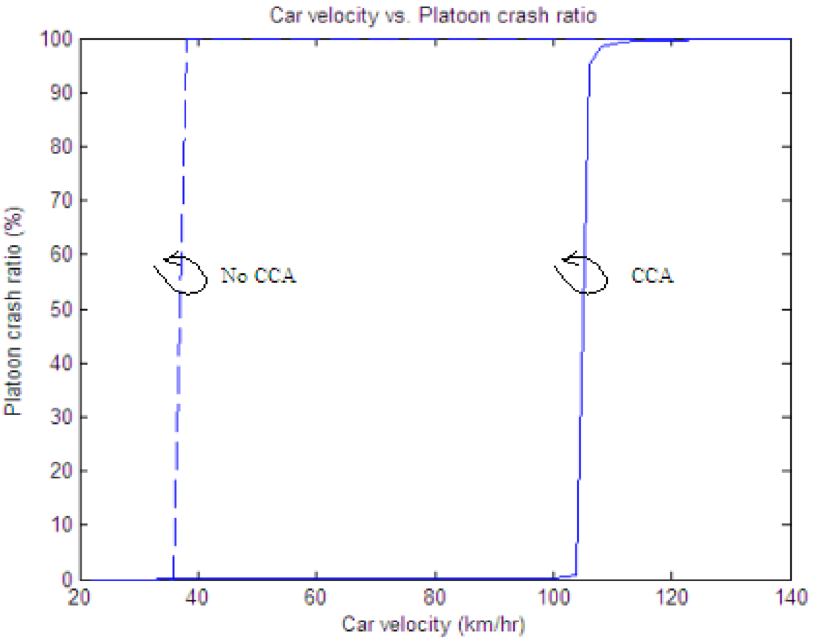


Figure 2-b. Velocity vs. platoon crash ratio; (*d*= 21m, *Tx*= 100m)

Safe Region of Transmission Range

- There is a “safe” operating region of the transmission range where platoon crash ratio is low.
- The region between the two intersects of the curves in Figure 3-b is approximately the safe region in Figure 3-a.

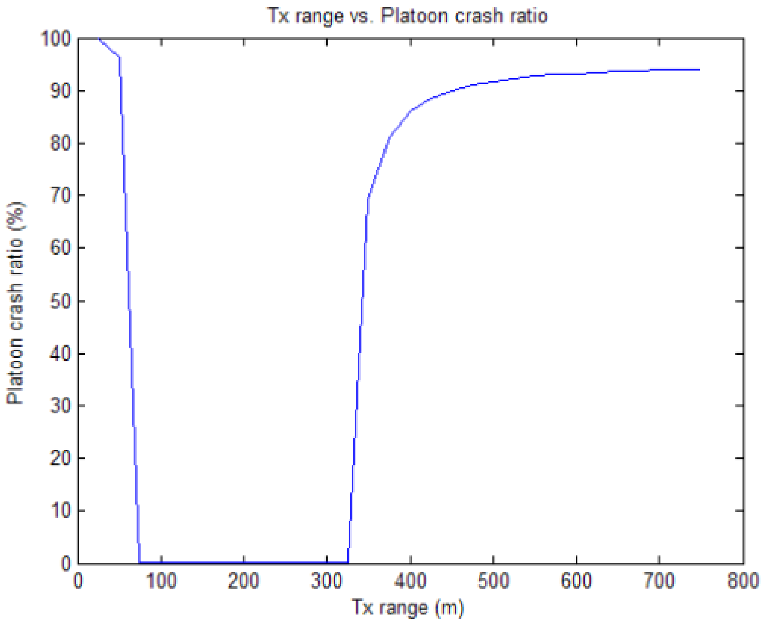


Figure 3-a. Transmission range vs. platoon crash ratio; (*d*= 21m, *V*= 90km/hr)

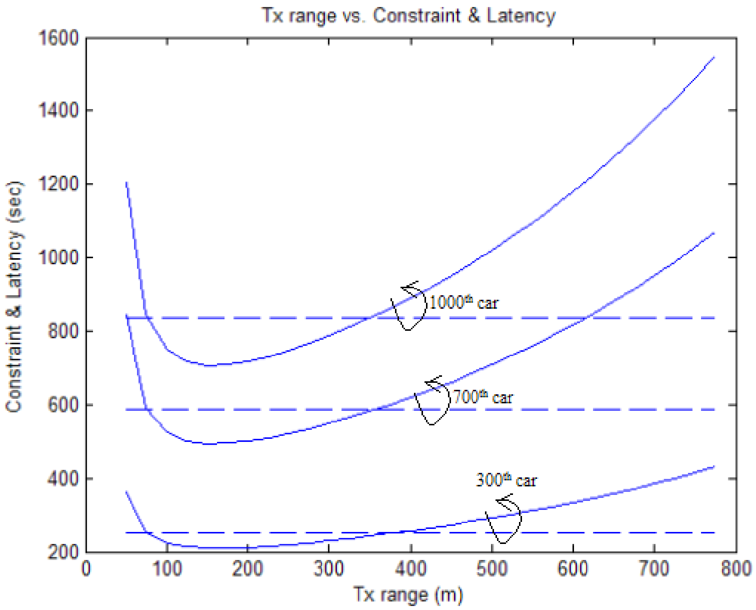


Figure 3-b. Tx range vs. latency (solid curve) & constraint (dashed line) of the 300th, 700th, 1000th car

The Latency of EWM

- The latency curve of Figure 3-b can be understood as following:
    - When *Tx* range is increased, the latency goes down because EWM can reach more cars in one transmission and it takes fewer iterations for EWM to reach the *n-th* car.
    - When *Tx* range increases, the number of contending nodes per relay iteration is also increased and more collisions would occur during contention resolution between these active nodes. Thus, on average, it would take more time to relay EWM per iteration.

- These two offsetting factors lead to an optimum value of the transmission range at *Tx*= 100m -200m in Figure 3-b where latency is minimum for three curves.

Impact of Initial Contention Window

- As *CW* value is made larger, the safe operating region of transmission range is larger.
- Increasing *CW* can lower the latency: *CW* value does not have obvious impact when transmission range is small. However, the impact of *CW* on the latency becomes significant when transmission range is larger.

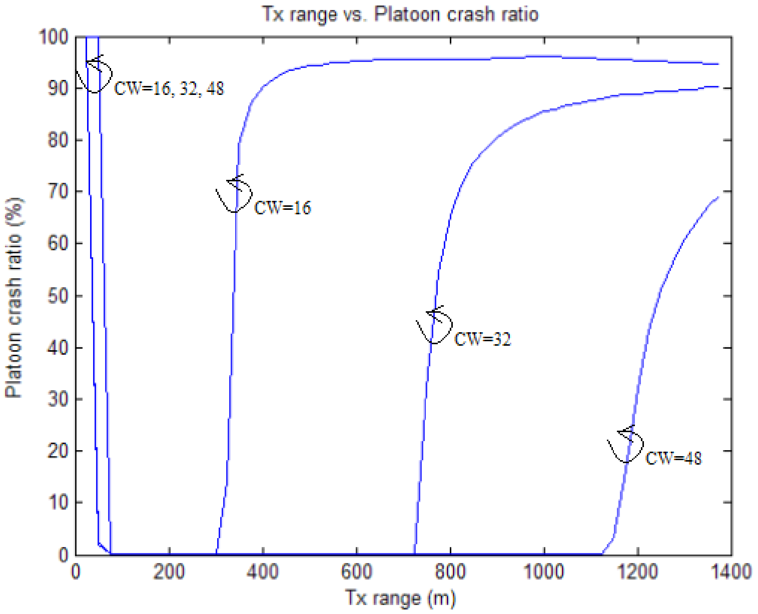


Figure 4-a. Transmission range vs. platoon crash ratio for *CW*= 16, 32, & 48; (*d*= 25m, *V*= 90km/hr)

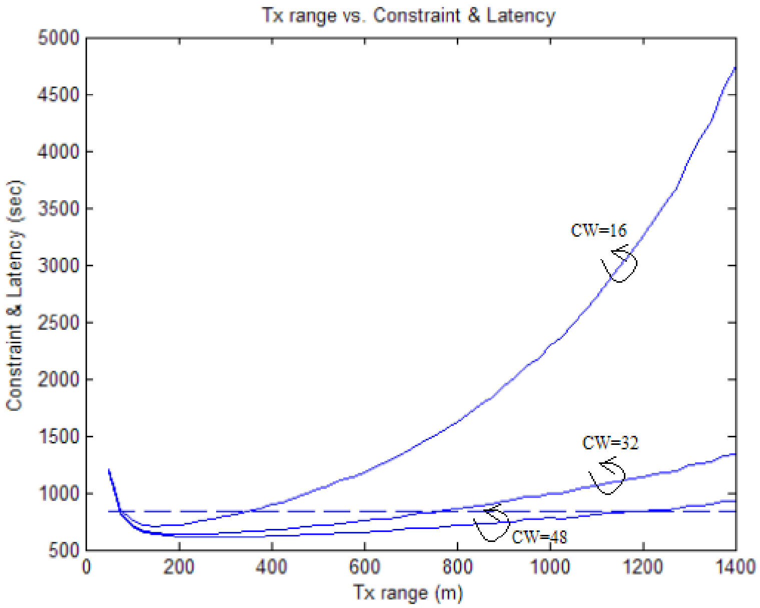


Figure 4-b. Tx range vs. latency (solid curve) & constraint (dashed line) for *CW*= 16, 32, & 48.

Summary & Future Work

- Analytical results show that the platoon with CCA can achieve collision avoidance and has significant performance improvements:
  - It can tolerate smaller inter-car spacing and higher platoon velocity than without CCA.
  - There exists a “safe” operating region for transmission range such that platoon crash ratio is small.
  - Even with CCA, inter-car spacing and velocity still have be bounded to prevent a chain collision.
  - Increasing initial contention window size will enlarge safe operating region and have lower latency.

- Future work includes the generalization of current analysis to consider more realistic scenarios that includes the impact of link layer errors on protocol performance.