ABSTRACT

A platoon of trucks driving at the same, mutually agreed speed while keeping a minimum inter-vehicle distance will reduce fuel consumption, enhance transport efficiency as well as improve the safety of other adjacent road users. The European profile of IEEE 802.11p for inter-vehicle communications uses a single 10 MHz control channel dedicated to safety-critical data, shared by periodic status updates, and event-triggered warnings. Coupled with the random access delay inherent to the 802.11p medium access method, the strict timing and reliability requirements of platoon applications are not easily met. To this end, we evaluate the effect of IEEE 802.11p-compliant send rate adaptations and message type prioritizations and the choice of warning dissemination strategy in a platooning scenario. Simulation studies of a platoon of 10-20 vehicles in a busy highway scenario show that a context-aware choice of send rate, priority class and dissemination strategy not only reduces the hazard warning dissemination delay but also has a significant effect on the throughput of periodic beacons.

Categories and Subject Descriptors


Keywords

VANET; cooperative driving; IEEE 802.11p; ITS; platooning.

1. INTRODUCTION

Cooperative Intelligent Transport Systems (C-ITS) have the potential to considerably improve safety, comfort and efficiency on our roads. Many emerging traffic safety applications are based on the periodic exchange of status messages between vehicles, while others rely on the fast dissemination of hazard warning messages. An application area where the gain from inter-vehicle communications (IVC) is particularly advantageous is platooning. A platoon of trucks driving at the same, mutually agreed speed while keeping a minimum inter-vehicle distance will reduce fuel consumption, enhance transport efficiency and increase road safety.

The recent allocation of dedicated frequency channels for IVC and the introduction of IEEE 802.11p [1], constitute the first step towards future C-ITS applications. ETSI has standardized two types of messages, Cooperative Awareness Messages (CAM) [2] and Decentralized Environmental Notification Messages (DENM) [3]. CAMs are beacons, broadcasted periodically, typically at a rate of 2-10 Hz, stating vehicle speed, position and driving direction, whereas DENMs are event-driven and application specific warning messages. One dedicated control channel is reserved for and shared by CAMs and DENMs. If the control channel is heavily loaded with data traffic, the random delays inherent to the IEEE 802.11p MAC method may prevent proper functionality of a platooning application, or alternatively, the required safety distance between members in a platoon may be too long to enable reduced fuel consumptions. If a platooning application based on IEEE 802.11p is to be realized, it is thus important to reduce the DENM dissemination delay (DENM DD) for hazard warnings. At the same time, periodic status messages or beacons will be required both by the platooning application itself and by other coexisting applications. Hence, the CAM up-to-dateness (CAM UTD) must be kept at an acceptable level even in the presence of DENM. To increase the safety and efficiency of platooning applications, we investigate the effect of a range of parameters on both DENM DD and CAM UTD: the choice of IEEE 802.11p priority settings, the choice of send rate for DENMs and finally the dissemination strategy used to spread DENMs to all platoon members. All the suggested and evaluated schemes and parameter settings are in compliance with the IEEE 802.11p standard. The overall goal is to reduce the DENM DD within a platoon, while maintaining acceptable performance to co-existing CAMs.

2. PARAMETER SETTINGS

The IEEE 802.11p standard defines four different priority classes to support traffic with different quality of service requirements. The distinction between priority classes is achieved by different AIFS durations and different contention window sizes [1]. Each node has to listen to the channel for the specified AIFS duration determined by its priority class. Only if the channel remains idle during the entire AIFS, is the node allowed to transmit. A higher priority class has a shorter AIFS. A node that finds the channel busy starts a backoff timer that is only counted down while the channel is free. Once the timer reaches zero, the node is allowed to transmit. The value of the backoff timer is chosen randomly from a given set of numbers depending on the size of the contention window. Lower priorities have longer contention windows and thus a higher probability of selecting a longer backoff time.

Due to the broadcast nature of CAMs and DENMs, no acknowledgements are sent and vehicles are therefore unable to determine if packets have been successfully received. This implies that DENMs should be repeated periodically until the entire platoon has received the warning. ETSI suggests a DENM send rate of 1-20 Hz for such repetitions. Depending on the nature of the event, the relative speed of the vehicles, the number of platoon members and the current channel load, the DENM send rate could potentially be increased beyond the suggested 20 Hz, provided that acceptable service still can be given to CAMs. To this end, we evaluate two different DENM rates: 10 Hz and 100 Hz.
Simple flooding by letting each vehicle repeat a DENM periodically x times, can provide a trade-off between the need to maintain a low DENM DD and the goal to reduce the overall network load to not reduce CAM UTD. As we consider a DENM spreading from the leading vehicle backwards as the most common scenario in platooning, we suggest that a vehicle seize its re-broadcasts as soon as it receives a DENM from a vehicle situated further back in the platoon. The vehicle sees this as an indication that the warning has successfully progressed backwards in the platoon and will continue doing so without its help.

Improved service for safety messages in C-ITS applications has been considered previously, e.g., [4-7]. In [4], the impact of the contention window sizes is studied. The authors of [5] uses the distance to a potential collision as input to a context aware transmission policy, and in [6] the CAM send rates are adapted according to the role of each vehicle in an overtaking warning application. Finally, in [7] several selective DENM broadcast algorithms are compared, amongst others intelligent flooding that seizes after overhearing re-broadcasts. However, no previous papers have evaluated the performance of the two messages types jointly.

3. SIMULATION RESULTS

We consider a busy highway scenario and a network consisting of a platoon of 20 members with a spacing of 30 m (antenna to antenna) and 100 surrounding vehicles that are not part of the platoon, but within radio range of all members. Each vehicle sends out CAMs periodically with 10 Hz whereas DENMs are sent only by platoon members. DENMs are triggered by the platoon leader for dissemination backwards in the platoon. Following ETSI standard, we use a packet size of 400 byte and a data rate of 6 Mbit/s. The AIFS and backoff window sizes are based on a slot time of 13 µs. The choice of radio range of approx. 500 m is based on field trials conducted in [8]. We model shadowing by Rayleigh fading in addition to the model in [8] and reduce the probability of line-of-sight to 20% when a vehicle is located in-between a sender and a receiver, and another 5% reduction for each additional vehicle.

The performance is measured using two different performance metrics: DENM DD and CAM UTD. The former is defined as the delay from the generation of the first DENM by the platoon leader until every platoon member has received a DENM. The CAM UTD can be considered as the packet inter-arrival time, i.e., the time elapsed between when a particular receiver gets a CAM from a particular sender, to when it gets the next one from the same sender. For simplicity, we only monitor CAMs generated by platoon members received from the closest neighbor in-front. While the average CAM UTD should be around one CAM period, it is the worst-case CAM UTD that is of interest for platooning.

Figures 1 and 2 evaluate the impact of different priorities. It can be seen that letting CAM and DENM have the same priority leads to decreased performance in terms of both DENM DD and CAM UTD. The slight advantage using priority level 2 compared to priority 1 can be explained by fewer backoff values with higher priority, resulting in a higher probability of nodes selecting the same backoff value and thereby accessing the channel simultaneously after the backoff phase. It can be concluded that lowering the CAM priority to 2 or even 3 actually has a positive effect on CAM UTD even if DENMs have higher priority.

Figures 3 and 4 show the impact of different DENM send rates on the DENM DD and the CAM UTD, respectively: a higher send rate actually results in a longer DENM DD. Since a full platoon warning is achieved within a single DENM period for a majority of all cases, the periodic generation of new DENMs after 10 ms simply slows down the dissemination process by introducing packets into an already heavily loaded network without adding much benefit. In Figure 4, it is very clearly visible that the choice of DENM send rate influences the CAM performance. However, it is less clear which case actually is the best when considering the CAM UTD. A high DENM send rate means a greater burst of DENM packets, but during a shorter time period. This means that
Finally, we study the effect of the different dissemination models on the DENM DD and CAM UTD in Figure 5 and 6 respectively. The DENM DD is about the same regardless of the number of repetitions and chosen dissemination strategy. However, the number of DENM packets involved in the dissemination process is reduced from 100 packets on average to merely 18 on average for the “until DENM reception from behind” model. Further, it can be seen that this model not only gains advantage in terms of DENM DD but also leads to a significant improvement in CAM UTD. Keeping the total number of packets to a minimum thus has a positive effect on the performance of both CAM and DENM.

4. CONCLUSIONS
We evaluated the co-existence of periodic and event-driven data traffic in a safety-critical platooning application. We assessed the impact of the priority settings and send rates for CAM and DENM traffic, as well as suggested and evaluated a DENM dissemination strategy adapted to the platooning scenario. We concluded that performance is considerably reduced when both CAM and DENM are given the same priority class. Even if CAMs are assigned lower priority, performance is better both in terms of CAM UTD and DENM DD when the message types have different priority. Increased DENM send rate does not necessarily lead to lower platoon warming time. We showed that large bursts of DENMs can impair the successful channel access of both CAMs and DENMs. The key to successful co-existence of periodic beacons and hazard warnings on a common channel is to not overload the medium with unnecessary data traffic. To keep the number of DENMs at a reasonable level we therefore proposed a dissemination strategy that showed significant improvements in terms of CAM UTD while still maintaining a DENM DD of 10 ms or lower.

5. REFERENCES