Vehicle to Vehicle Communication

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Abstract: Safety architecture that combines vehicle-to-vehicle communication and vehicle-to-roadside sensor communication. Opposed to dedicated roadside units, which require major investments for purchase, installation and maintenance, roadside wireless sensor and networking technology represents a cost-effective solution and can leverage the deployment of the system as a whole [1].

This article presents an overview of highway cooperative collision avoidance (CCA), which is an emerging vehicular safety application using the IEEE- and ASTM-adopted Dedicated Short Range Communication (DSRC) standard. Along with a description of the DSRC architecture, we introduce the concept of CCA and its implementation requirements in the context of a vehicle-to-vehicle wireless network, primarily at the Medium Access Control (MAC) and the routing layer.[2] A system and protocol architecture with a fully distributed concept for efficient and secure storage of sensor data. For deployment, this architecture will likely be combined with an alternative approach using dedicated road-side units as a centralized network element for communication and data storage. For the proposed system, we describe the main components (radio, networking and services, security). An example of the safety performance of CCA using simulated vehicle crash experiments [1]·.The results from these experiments are also used to demonstrate the need for network data prioritization for safety-critical applications such as CCA. Finally, the performance sensitivity of CCA to unreliable wireless channels is discussed based on the experimental results.

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I. INTRODUCTION

Different factors contribute to vehicle crashes, such as vehicle mechanical problems and bad weather, driver behavior is considered to be the leading cause of more than 90 percent of all accidents. The inability of drivers to react in time to emergency situations often creates a potential for chain collisions, in which an initial collision between two vehicles is followed by a series of collisions involving the following vehicles. In emergency situations, a driver typically relies on the tail brake light of the car immediately ahead to decide his or her own braking action. Under typical road situations, this is not always the best collision avoidance strategy for various reasons. In many cases, the ability to detect an emergency event occurring at some distance ahead is limited by the inability of drivers to see past the vehicle in front of them. If drivers choose to follow the vehicle ahead too closely, as is often the case, then they may not have enough time to apply the brake and stop their vehicle after they see the brake lights of the vehicle ahead illuminate. Driver reaction time (the duration between when an event is observed and when the driver actually applies the brake) typically ranges from 0.75 to 1.5 s [3]. At a speed of 70 mph, this means that between 75 and 150 ft is traveled before any reaction occurs. In dense traffic, the effects of cumulative reaction times, as one vehicle after another reacts to the vehicle ahead braking, can further exacerbate the situation [4]. As a result, a single emergency event can often lead to a string of secondary crashes, creating a multicar chain accident.

Chain collisions can be potentially avoided, or their severity lessened, by reducing the delay between the time of an emergency event and the time at which the vehicles behind are informed about it [4]. One way to provide more time to drivers to react in emergency situations is to develop Intelligent Transportation System applications using emerging wireless communication technology. The primary benefit of such communication will be to allow the emergency information to be propagated among vehicles much quicker than a traditional chain of drivers reacting to the brake lights of vehicles immediately ahead.

II. COOPERATIVE COLLISION AVOIDANCE

The mechanism of CCA is explained using a three-car highway platoon example. In the example, all cars are assumed to cruise initially at a steady speed of 72 mph (32 m/s), and with an inter car spacing (or headway) of 1 s (32 m). The platoon dynamics after the front car (car 0) initiates an emergency deceleration (at 4 m/s2) as a result of an emergency event, the driver in car 1 starts to decelerate when he sees the tail brake light of car 0, and the driver in car 2 does so when he sees the brake light of car 1. With an assumed driver’s reaction time of 1.5 s, car 0 gets hit by car 1 at a distance of 120 m, and subsequently, car 1 is hit by car 2. The conclusion from this example is that if drivers react only on visual information, all three cars in the platoon end up in a chain collision. For the same platoon, the effects of CCA with wireless communication are used. In this case, upon meeting the emergency event, car 0 starts sending wireless collision warning messages (W-CWM) to all cars behind it. These messages are forwarded in a multi-hop manner in order to ensure a complete coverage within the platoon. Upon reception of a W-CWM, a driver reacts by decelerating, even if the brake light on the car ahead is not already lit. Car 1 still collides with car 0. However, car 2 can avoid a collision if it receives the W-CWM with sufficiently small delivery latency.

For instance car 2, with a delivery latency of 0.1 s from car 0 to car 2, car 2 manages to stop without a collision at a distance of 115 m from the site of the emergency event.[1] However, for a delivery latency of 0.4 s, car 2 cannot avoid the collision as the driver is not given enough time to start decelerating well in advance.[1]

III. STATE OF THE CURRENT RESEARCH

Protocol research for vehicle-to-vehicle communication can be broadly categorized in the areas of Medium Access Control (MAC) and data forwarding across moving vehicles. IEEE 802.11a is considered to be the de facto MAC protocol for DSRC-based communication. Although 802.11a provides a means for rapid application development, in dynamic vehicular environments the protocol suffers from a number of performance limitations as reported in [5]. The first limitation is a hop-unfairness problem due to which the effective data throughput of a multi-hop flow over 802.11 MAC can be severely limited due to 802.11's self-competition between adjacent nodes in the same flow. The second limitation is a lack of MAC protocol stability, and its subsequent performance inefficiency in highly mobile vehicular environments. Although a number of improvements, including better fairness, quality of service, and the support for differentiated services have been proposed in the literature [5], the basic nondeterministic nature of 802.11 is still an issue for its applicability to dynamic DSRC applications. A set of Time Division Multiple Access (TDMA)-based slotted MAC protocols have been proposed for avoiding the inherent randomness and delay unpredictability of 802.11 [6]. A slot reservation MAC protocol (R-ALOHA) for inter-vehicle communication was proposed in [7]. The common idea across all these protocols is to dynamically allocate transmission time slots to individual vehicles within a group of vehicles.[1] This requires accurate time synchronization using onboard GPS receivers.[1] Although GPS receivers are becoming more and more common in vehicles, TDMA-based protocols face the following implementation difficulties. First, in the absence of a centralized scheduling entity, distributed slot synchronization and allocation across multiple hops is known to be a difficult spatial TDMA problem [1]. Moreover, high vehicular mobility makes MAC coordination much more difficult than the traditional distributed slot allocation scenarios. Considering these difficulties, it is easy to conclude that further research will be needed before TDMA protocols can be applied to inter-vehicle DSRC applications [1]. As an interim, 802.11a with appropriate performance optimizations is still likely to be the preferred MAC protocol for emerging DSRC applications. While the traditional Mobile Ad Hoc Network (MANET) routing protocols such as Ad Hoc Distance Vector (AODV) may seem to be appropriate for DSRC applications, the main limitation is that they need a explicit route establishment phase before the data transmission starts. The low delivery-latency requirement for the ITS safety applications (less than 200 ms [3]) prohibits such a route-establishment phase. Also, for several ITS safety applications, the classical definition of routing cannot be applied for packets from source to destination, because the identities of the prospective receivers are a prior unknown. Considering these two factors, we can conclude that the MANET style packet-forwarding protocols may be applicable only for relatively large delay-tolerant data applications such as in-vehicle Internet services. But they will not be adequate for low-latency vehicle safety applications such as CCA or cooperative cruise control. Based on the above analysis it can be concluded that, for vehicular safety applications, the routing protocols should preferably be broadcast oriented and they should rely on packet forwarding based on geographic, directional, and other relevant temporal contexts of the source and the destination vehicles. To explain this further, consider an example scenario in which a packet broadcast by a vehicle traveling on a freeway is received by a vehicle moving in the opposite direction. In this case, if the packet contains data relevant only to the CCA application, it will not be forwarded any further since the context of the received packet indicates that the data is of no use for vehicles traveling in the direction opposite to the source vehicle. Packet-forwarding protocols for such applications can be designed based on constraints such as geographical location, as originally proposed for mobile networks in [10]. This idea has been adapted for vehicular networks in several protocols [11], in which selective forwarding of a packet is performed based on the packet's information content and the receiver's geographic location [1]. Note that specific context and constraint parameters will have to be designed in an application-specific manner, and the parameters may differ significantly based on the nature of the respective target applications.[1]

IV. COMMUNICATION PROTOCOLS FOR COOPERATIVE COLLISION AVOIDANCE

In this section we present a class of example context-aware packet forwarding protocols to demonstrate their effectiveness in designing a CCA application for intra-platoon scenarios, where all vehicles within a platoon are assumed to be equipped with DSRC devices. DIRECTION-AWARE BROADCAST FORWARDING For the CCA application defined in Section 2, when a vehicle meets an emergency situation, it needs to send a W-CWM to all cars behind with - in its platoon[1]. Since the identities of those prospective receivers may not be known a prior, classical unicast and multicast routing will not work. In the present approach, the vehicle in an emergency situation broadcasts a W-CWM first, and then all its recipients selectively forward the message based on its direction-of-arrival. This mechanism ensures that the W-CWM will be eventually delivered to all the vehicles within the platoon. The following design targets have been identified for this CCA system: [1]

• Minimize the number of vehicles involved in intra-platoon chain collisions [1]

• Prioritize data from safety-related ITS applications over low-priority ITS applications [1]

• Limit vehicle collisions in the presence of radio channel errors Upon detecting an emergency event, a WCWM is broadcast by the detecting vehicle. [1]

The message contains an origin vehicle id number (of the event detecting vehicle) and an event id number (unique within the detecting vehicle), which are used for uniquely identifying the emergency event. An msg_seq_no is also added so that the car {origin_vehicle_id, msg_seq_no} can uniquely identify a message across the platoon [1]. A message_type field identifies the associated ITS application, which is CCA in this particular case. Naive Broadcast — Naive broadcast (NB) forwarding serves as a baseline packet-routing mechanism for the target CCA application. After detecting an emergency event, the detecting vehicle starts sending W-CWM messages periodically at regular intervals [4]. Upon receiving a W-CWM message, a vehicle executes the logic and decides whether to decelerate and start generating its own W-CWM messages. According to the NB logic, a vehicle ignores a message if it comes from behind with respect to its direction of movement. However, if it comes from the front, it infers that there is an emergency event in the front and, in that case, the vehicle immediately starts deceleration and starts broadcasting periodic W-CWM messages of its own. Executing the NB logic will ensure that all vehicles within the platoon will eventually receive a warning message and will decelerate to avoid collisions with vehicles ahead. Note that no explicit mechanism has been provided to stop W-CWM propagation. The warning message propagation for an event will stop only when the message arrives at the last car of the platoon, where there is no more receiver vehicle behind it. [1]

Acknowledgment — The primary limitation of NB is its excessive message forwarding, which escalates message collisions for 802.11 MAC.[1] High MAC collisions reduce the message-delivery rate, and also increase the delivery latency, because successful delivery after message drops will have to rely on the periodic retransmissions from the event-detecting vehicle. To avoid these, we introduce an implicit acknowledgment-based message generation and transmission strategy, intelligent broadcast with implicit acknowledgment (I-BIA), that can improve the system performance by reducing the number of messages that are injected within a platoon for a given vehicle emergency event.[1]

V. SAFETY PERFORMANCE OF COOPERATIVE COLLISION AVOIDANCE

An ns-2-based hybrid simulation system [12] for joint evaluation of ITS applications, wireless network protocols, and vehicle-following logic with drivers' behavior has been used for demonstrating the performance of CCA with the presented packet-forwarding protocols. The representative performance in this section corresponds to CCA for a one-lane intra-platoon scenario, as described. Vehicle emergency situations are created by forcing the vehicle at the front of a platoon (of 50 cars) to rapidly decelerate (8 m/s2), which triggers a CCA process by initiating a wireless collision warning message. This high deceleration rate models a vehicle hitting a fixed object and stopping within a very short distance. All results correspond to a scenario in which a single emergency event at the platoon front causes chain collisions of vehicles. With the CCA system turned off, if the vehicles decelerate based only on the tail brake light of the front cars, then for this entire range of vehicle spacing, all cars in the platoon will collide in a chain collision. By turning the CCA system on, with NB as the direction-aware forwarding protocol, it is possible to bring the platoon collision down to 48 percent, when the vehicle spacing is nearly 1s [1]. With increased vehicle spacing, the CCA system is able to save more vehicles from the chain crash. The performance of the CCA can further be improved by applying the I-BIA forwarding. At vehicle spacing of 0.9 s, the percentage platoon collision is reduced from 48 percent with NB to 20 percent with I-BIA [1]. In absolute terms, this amounts to saving 14 more vehicles from crashing, as compared to the NB. Latency is defined as the time duration between when the emergency event occurs at the platoon front and when a corresponding W-CWM message is delivered to a vehicle.. Since the vehicle length is assumed to be 4 m, any relative stop distance of 4 m or less corresponds to a collision [1]. For vehicles avoiding a collision, the relative distance indicates the margin of safety provided by CCA with the involved DSRC protocols. Effects of Prioritized Communication for CCA Traffic — Performance of the CCA has also been evaluated with a link-layer priority structure, in which safety-critical CCA data packets are given higher priority compared to the background data traffic generated by non-CCA ITS applications [4]. This has been accomplished by providing two link-layer queues: one for CCA traffic and the other for background non-CCA traffic. A CCA-first pre-emptive scheduling has been implemented so that the MAC layer will not transmit any background traffic until the queue for the CCA traffic is found to be empty[1]. With 80 kb/s/vehicle background traffic, the link-layer priority does not improve the crash performance when the vehicle spacing is small (0.3 s or 9.6 m). However, as the vehicle spacing increases, the benefits of prioritized delivery becomes more pronounced. But for very large vehicle spacing (greater than 0.9 s or 28.8 m), the gap between the two scenarios again shrinks. Even though the message delivery latency for non-priority cases is large in this particular case, the vehicles have enough time to stop without colliding due to their large physical spacing. It should be noted that even though the difference in the percentage of collisions is not too large, it does make a significant difference in terms of the number of vehicles that are saved. For example, for a vehicle spacing of 0.9 s (28.8 m), the priority model saves six additional cars over the non-priority approach and this underlines the need and effectiveness for priority-based data networking in ITS safety-critical applications such as CCA [1]. Without priority for CCA messages, the vehicle crash performance degrades almost linearly with increasing background traffic. However, with priority turned on, the number of additional vehicles involved in the chain crash does not increase significantly [1]. Without priority, for an order of magnitude increase in the background load (from 80kb/s/vehicle to 800 kb/s/vehicle), the number of cars crashed in the platoon increases from 10 to 28. With priority turned on, the number of crashed vehicles increases only from four to six. Packet errors in this experiment were caused by independent bit errors. The effects of fading and burst errors have not been considered[1]. Observe that with very small vehicle spacing (i.e., 0.3s), the channel condition makes very little difference since almost the entire platoon crashes in this situation. With higher vehicle distance, the crash performance does not change significantly until up to 50 percent of the

WCWM messages become corrupted due to channel errors. Beyond that point, packet loss affects the CCA operation, as a result of which more vehicles in the platoon collide. To understand the insensitivity of vehicle crash rates up to 50 percent packet loss, relative packet-delivery latencies between consecutive vehicles have been measured for a wide range of packet error rates [1]. High relative latency may indicate that a vehicle in the platoon received the W-CWM message a long time after the vehicle in front of it received the message and in such a situation, the lack of reaction time is likely to lead the car behind to crash. This is primarily due to the fact that a given W-CWM message is broadcast in the platoon by multiple vehicles. Due to this transmission redundancy, even when a certain number of transmissions for that packet are corrupted (up to 50 percent), the message manages to go across the platoon with an average relative latency of 23 ms, which is fairly low compared to the drivers' reaction time of more than 750 ms [1]. That is why the vehicle crash rate does not go up significantly. However, for very large packet error rates (beyond 50 percent), the built-in redundancy of I-BIA becomes exhausted [1]. The average relative message delivery latency shoots up to more than 1600 ms, which is way more than the average drivers' reaction time of 1100 ms. This explains the drastic degradation of CCA performance. Finally, note that the simulations in this work were conducted with a simplistic two-ray-ground propagation model. More work is needed to capture the effects of mobility, channel fading, and multipath on the networking as well as the integrated vehicle collision performance.

VI. CONCLUSION

In this article we have tried to give an overview of vehicle cooperative collision avoidance (CCA) application using the emerging Dedicated Short Range Communication (DSRC) infrastructure for inter-vehicle wireless networking [1]. Specific constraints and future research directions have then been identified for packet-routing protocols to support an effective CCA system within the DSRC environment. The results from these experiments were also used to demonstrate the need for network data prioritization for safety-critical applications such as CCA. Finally, the performance sensitivity of CCA to unreliable wireless channels has been discussed using these experimental results.

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