A SIMULATION STUDY OF AN INTERSECTION COLLISION WARNING SYSTEM

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This paper describes a simulation study of an Intersection Collision Warning System. For the study, an Inter-Vehicle Communication (IVC) Simulator has been developed. The IVC simulator is composed of vehicle traffic and wireless communication simulation modules. The simulator makes it possible to evaluate the vehicle collision issues that arise in the vicinity of an intersection and the impact of inter-vehicle communication on collisions. A collision warning system based on inter-vehicle communication is envisaged, and its performance is tested using the IVC simulator. The results show that such a warning system will be a viable way of decreasing intersection collisions.

1. Introduction

Intersection collisions constitute approximately 26% of all accidents in the United States [1]. Various services and technologies can be used to provide the driver with assistance in avoiding collisions at intersections. In this paper, we describe a simulation study of an Intersection Collision Warning System that uses Inter-Vehicle Communication in the vicinity of an intersection. The system envisaged assumes that vehicles approaching an intersection have access to a local map data base and GPS-provided information. At a certain distance from the intersection, vehicles broadcast their location and direction of travel. An ad-hoc network is established to exchange this information. In order to evaluate this system, we developed the Inter-Vehicle Communication (IVC) Simulator which consists of two components: Vehicle Traffic Simulator (VTS) and Wireless Simulator (WS), as shown in Fig. 1.

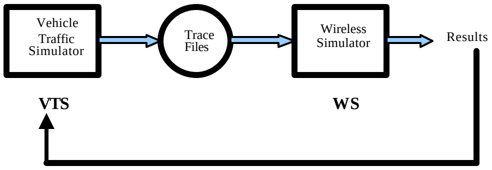

Figure 1. IVC simulator

2. Vehicle traffic simulator

The Vehicle Traffic Simulator (VTS) component of the IVC simulator is set up to create traffic scenarios for different possible intersection collisions. The VTS framework consists of three parts: Vehicle Characteristic Input, Intersection Collision Simulator and Scenario Input.

2.1 Vehicle characteristic input

Vehicle related input is user-specified. There are five kinds of vehicle characteristics that need to be defined for the simulator. These are vehicle class, vehicle size, vehicle speed, vehicle origin and destination, and vehicle flow rate. When a vehicle enters the network, its speed (conservative, normal or aggressive behavior) is randomly assigned and its destination at the intersection (right turn, left turn or go straight) is set. Based on the Poisson arrival rate assumption for vehicles, the vehicle location can be determined for any given time. The size of vehicles is an important factor in evaluating intersection collision scenarios since blocking of the line of sight of vehicles due to an oversized vehicle can cause collisions.

2.2 Scenario input

The scenario input is composed of intersection type and collision type data. The intersection type has two main parameters, namely the number of legs and the signalization (signalized or not) at the intersection.

2.3 Intersection collision simulator

The Intersection Collision Simulator is implemented as a modular simulation system, which is made up of three elements: the road definition, vehicle management and traffic light management. The road module includes information about the intersection, such as the number of lanes and speed limit. The intersection is represented using line segments and arcs.

The vehicle management module maintains and changes vehicle's state between normal driving, vehicle following and turns based on different sensors. The model of vehicle dynamics is a highly simplified model of all vehicle behavior under velocity control.

The traffic light management module is specially designed for signalized intersections. The traffic light has two phases only. Right turn on red is allowed. A left-turning vehicle will yield to straight going vehicles if there is no blockage.

2.4 Collision scenarios description

Four collision scenarios are simulated in the VTS as follows:

- Four-leg Signalized Intersection (Left-turning Collision) - Left Turn Across Path
- Four-leg Unsignalized Intersection (Right-angle Collision) - Violation of Traffic Control Device (TCD)
- Four-leg Unsignalized Intersection Right-turning Collision - Inadequate Gap
- Motorcycle

In our scenarios, cars, buses, and trucks have GPS receivers and map data bases. Motorcycles, on the other hand, do not have maps and they rely on other transmissions for locating the relative position of an intersection [4].

The VTS produces trace files for the WS. With these files, the WS is able to update the position and the speed of each vehicle every 10 msec. Shadowing between pairs of vehicles is also calculated and updated.

3. WS simulator

The Wireless Simulator (WS) is an *event driven* simulator program, which controls the system at discrete time instants. It is based on the CSIM simulation library [5]. WS is composed of one main process and vehicle processes, one for each vehicle, which run in parallel. The main process is responsible for initialization, termination, VTS interface and broadcast decision. Vehicle processes implement the MAC layer and the physical layer. In the current version of the simulator, two MAC layer types (802.11x and DOLPHIN) and two physical layer types (error-free and with errors) exist. Each is coded as a separate *C* file and users select the files according to the desired simulation scenario.

3.1 802.11x

In the simulator, the 802.11 standard family is implemented as the broadcast mechanism. In this paper, we will use 802.11x to refer to all of the 802.11a, 802.11b, and 802.11a R/A standards. The operation principles of the MAC layer of all these standards are the same as the 802.11 standard [6] while their physical layers are different. The MAC layer of 802.11x is based on the carrier sense multiple access / collision avoidance (CSMA/CA) mechanism where the retransmissions of packets are done according to the exponential back-off algorithm. In this algorithm, after each retransmission, nodes wait for a random amount of time T:

$$T \in [0, CW_{min} * 2^{n-1}] \qquad (1)$$

where n is the number of retransmissions and CW_{min} is a constant defined in each protocol. Although the 802.11 standard defines 2-way (DATA, ACK) and 4-way (RTS, CTS, DATA, ACK) handshaking mechanisms, these mechanisms cannot be implemented in broadcast applications since the destination of the broadcast packets is not unique.

The MAC layer of the 802.11x protocol is implemented as follows: Initially, the protocol state stays in the *Idle* state until a broadcast packet is generated by the upper layer. Once there is a broadcast packet in the transmission queue, the state changes to *Broadcast*. In this state, the node starts sensing the channel. If the channel is free for DIFS time, the node broadcasts its packet and the state returns back to *Idle*. On the other hand, if the node detects a carrier during this interval, the state changes to *Backoff* without broadcasting the packet. When a node first enters this state, it sets its back-off timer to T according to Eq. 1 and starts to decrease it after finding the channel idle for DIFS time. Once the back-off timer reaches zero, the node broadcasts its packet and the protocol state returns to *Idle*.

3.2 DOLPHIN

In DOLPHIN [7], time is divided into slots and each vehicle is allowed to transmit one packet in each slot according to a non-persistent CSMA mechanism.

When the MAC layer receives a new packet from the upper layer, its state changes from *Idle* to *Broadcast*. In this state, the node checks if it has sent any other packet in the current slot. If it has sent another packet before, it waits for the next slot. When the node finds a slot where it is allowed to transmit, it listens to the channel and sends its packet if the channel is empty. On the other hand, if the node finds the channel busy, the state changes to *Backoff* and the node waits for a random amount of time before returning back to the *Broadcast* state. Before returning to the *Idle* state, the node stays in the *Broadcast* state until the number of retransmissions is equal to the maximum number of transmissions.

3.3 Physical layer

Two types of physical layers are implemented in the simulator: an error free physical layer and a more realistic physical layer with errors. In the latter one, we used the Large Scale Propagation Model [8] to calculate the signal strength at a given distance:

$$P_r(dBm) = P_t(dBm) - PL(dB) - ?(dB) \qquad (2)$$

where P_r is the received signal strength, P_t is the transmitter power, PL is the path loss, and $?$ is the shadowing due to obstacles in the path of the radio signal.

Path loss is a function of several deterministic factors like antenna heights, antenna gains and transmission frequency as well as distance. In addition to these deterministic factors, there is a random factor known as the *path loss exponent*. Received signal power is proportional to the distance raised to this path loss exponent which varies between 3 and 5 in the urban environment [8].

The shadowing for the receiver is modeled in the simulator as follows: First, a shadowing area of a rectangular shape is defined based on the position of the transmitter and receiver vehicle's mass points. If there is a vehicle in the shadowing area, diffraction will occur during the transmission since the sizes of the vehicles are greater than the wavelength of the transmission. Then, using the Fresnel Integral, the diffraction gain is found and used as the shadowing gain [9], [10].

After computing the received signal power, the SNRT model [11] together with the Gilbert-Elliot fading model is used to decide if the packet is successfully received.

According to the SNRT model, we select the transmission with the largest power as our signal and all other transmissions are treated as noise. Noise is assumed to be cumulative so the total noise power is computed by adding the powers of all transmissions except the largest one. As a result, the packet is received with probability p if i) Received Signal Power = Receiver Sensitivity and ii) SNR = SNR Threshold.

It is important to note the following. In a simple channel model, when more than one transmission is heard at the receiver, all packets are assumed to be lost. However, our approach models the capture effect by treating all transmissions except the strongest one as noise, thereby allowing the successful reception of a packet even under several interfering transmitters.

Although the average power of the transmission can be large enough for the receiver to demodulate the packet, there can still be some erroneous bits in the packet because of instantaneous fading. These errors are simulated by using the Gilbert-Elliot model.

This model is a binary output sequential machine with good and bad states. A '1' in its output indicates that one bit was transmitted with error while a '0' indicates that the bit transmission was successful. The bit error rate (BER) of the channel (Pbe) in the bad state is higher than the BER of the channel in the good state (Pge). In the simulator, we can simulate a fast fading or a slow fading channel by changing the transition probabilities between the two states. According to our packet reception model, whether or not a packet is successful is determined after applying the packet to the fading process.

The WS also models carrier sensing because both 802.11x and DOLPHIN employ a carrier sensing mechanism in their MAC layers. A receiver is assumed to detect a carrier if the received signal power is larger than the *carrier sensing threshold* which can be found in the corresponding 802.11 standard documents.

4. Simulations

The IVC simulator is run 25 times for 20 vehicles including cars, buses, trucks and motorcycles for each scenario discussed in Section 2.4. In each scenario, vehicles broadcast their 64 byte packets when they are 50 m away from the intersection. If the vehicle is a motorcycle, even if it is inside the 50-meter zone, it waits for a transmission from other vehicles in order to locate the intersection.

For a packet to be treated as successful, it should be received by all vehicles in the intersection region. Even if one vehicle cannot hear the transmission, this packet is treated as unsuccessful. We computed the average packet success rate for two different simulation cases:

1. Realistic traffic scenarios generated by VTS and the physical layer with errors.

2. A special case traffic scenario in which more than one vehicle crosses the 50 meter border approximately at the same time and the physical layer without errors.

Fig. 2 shows the maximum, minimum and average packet success rates of 802.11a, 802.11b, and 802.11a R/A (802.11v in the graphs) protocols in the *Left Turn Across Path* scenario at different data rates. Since the other traffic scenarios discussed in Section 2.4 provided similar outcomes, we have included only one of them in this paper due to space limitation. As seen in Fig. 2, the packet success rate decreases with increasing data rate in all protocols. This is due to the increase in the packet error rate of physical layer at high data rates. None of the 802.11x protocols achieves a success rate of more than 75% at any data rate. On the other hand, the DOLPHIN protocol achieves an average success rate of 0.955%. This high success rate shows that increasing the channel load 5 times does not cause a significant number of packet collisions.

A packet collision occurs when two or more vehicles start transmitting a packet approximately at the same time. Thus, for a packet collision to occur, more than two vehicles should cross the 50-meter border at the same time which is only likely to happen when the traffic speed and density are extremely high.

Since it is hard to observe packet collisions with a realistic traffic scenario, we have designed a special traffic scenario where more than one vehicle crosses the 50-meter border approximately at the same time. Moreover, we have used an error free physical layer to observe only the impact of packet collisions on the success rate. In this second set of simulations, packet transmission times of vehicles are uniformly distributed in [0, 10] msec.

Fig. 3 presents the packet success rate as we increase the number of vehicles passing the 50 meter border. The DOLPHIN protocol achieves approximately 100% success rates even when 20 vehicles pass the 50 meter border approximately at the same time. This high success rate shows that when we have a dedicated channel for short intersection warning packets, we can increase the number of retransmissions without causing serious packet collisions. In addition, 802.11x protocols also perform reasonably well, all above 92%. Note that the success rates of the protocols are higher in this scenario since physical layer errors are not included and packet losses are only due to packet collisions.

5. Conclusions

In this paper, we presented a simulator which is capable of simulating 802.11a, 802.11b, 802.11a R/A, and DOLPHIN protocols for various vehicle traffic scenarios. For the intersection warning strategy, we propose that each vehicle broadcasts a warning message when it is 50 m away from the intersection. We tested this mechanism by using different protocols. We have concluded that for a realistic traffic condition, packet losses are mostly due to physical layer errors. As a result, several retransmissions of short packets with a low data rate improve the success rate of an intersection warning system.

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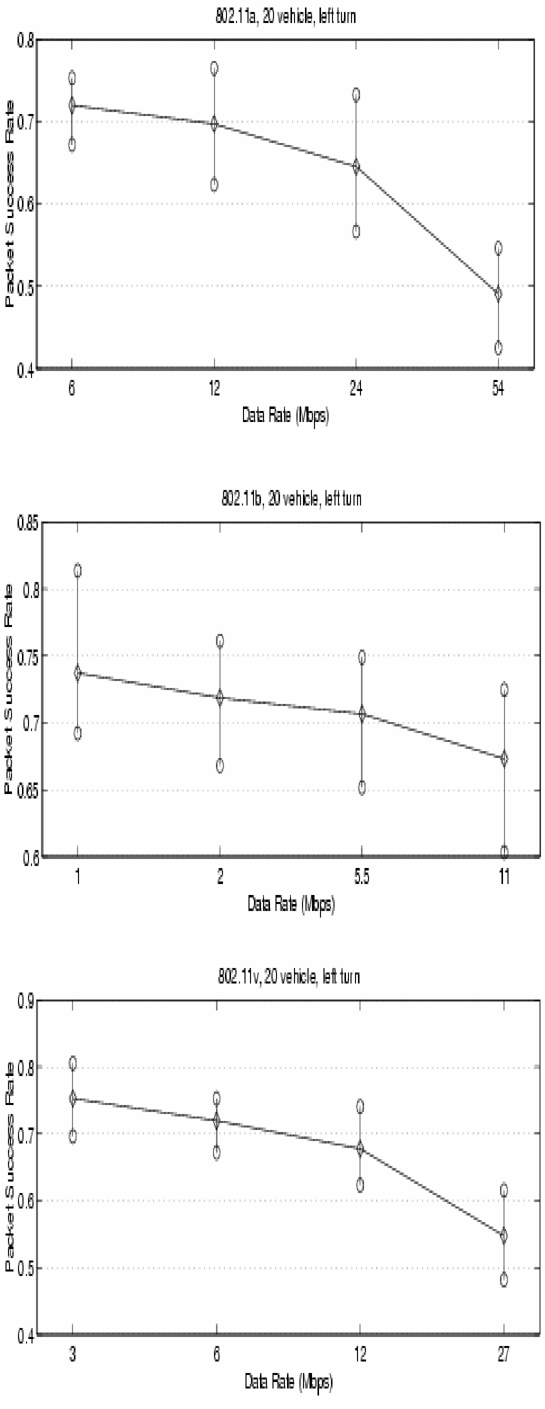

Figure 2. Average packet success rate of 802.11a, 802.11b, and 802.11a R/A for the left turn scenario.

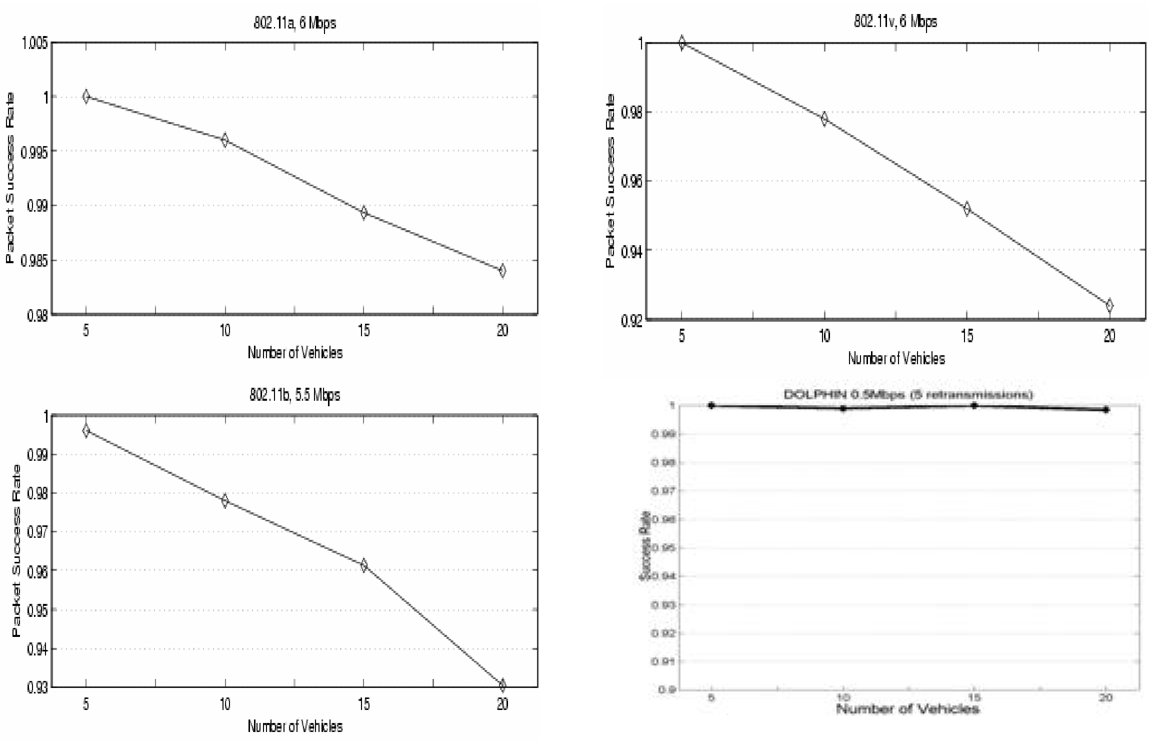

Figure 3. Average packet success rate of 802.11a, 802.11b, 802.11a R/A and DOLPHIN for the left turn scenario.

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