Channel Access Priority for Vehicle Intersection Collision Warning

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Abstract—We propose an Intersection Warning Channel Access Priority (IWCAP) protocol to warn drivers of a possible collision when approaching an intersection. Our protocol operates via inter-vehicle communication (IVC) networks with one omni directional antenna per vehicle and one dedicated short range communication (DSRC) channel. The advantage of our protocol is that it can be used as an optional add-on medium access mechanism to the IEEE 802.11a MAC protocol. We describe in details the operation of our protocol and show the performance analysis in terms of latency, bandwidth, the required communication range and the required distance to an intersection to avoid a collision.

I. INTRODUCTION

Recent statistics show that in the United States, motor vehicle accidents cause 9117 fatalities at intersections [1]. The development and deployment of intelligent transportation systems (ITS) technologies will reduce the risk of accidents and fatalities, improve safety, and solve traffic problems [2][3]. The rapid evolution of wireless technologies, especially, the new Dedicated Short Range Communications (DSRC) at 5.9 GHz will support ITS systems and provide wireless data communications between vehicles, and between vehicles and infrastructure. According to the report in [4], a comprehensive list of vehicle safety applications enabled by DSRC was compiled. More than 75 application scenarios were identified and analyzed. One of the identified safety applications is the intersection collision warning. The report suggested the use of infrastructure sensors to determine the locations of vehicles and then transmit this information to other vehicles approaching the intersection using DSRC wireless technology. Researchers have proposed to use TDMA and IEEE 802.11 CSMA MAC protocol for intersection-collision warning system [5]. However, the medium access mechanism in 802.11b/a MAC protocol is based on a random backoff timer. Therefore, a mechanism must be developed to provide fairness [6] among vehicles that contend for the channel. According to the DSRC specifications [7], a system of priority access may be essential as a channel access strategy to support the dynamic environment of vehicle safety applications.

In this paper, we propose an intersection warning channel access priority (IWCAP) protocol. The IWCAP protocol can be either used as a new MAC protocol to support this application or as an add-on component to the IEEE 802.11a MAC protocol. The application may have an option to choose between backoff timer and IWCAP. The paper is organized as follows. In Section II, we describe the intersection warning system architecture and the required technologies to build this system. In Section III, we describe in details our proposed protocol. Then, in Section IV, we analyze our protocol and indicate how the IWCAP can be used as an add-on component to the IEEE 802.11a. Finally, we conclude this paper in Section V with future work.

II. SYSTEM ARCHITECTURE

A. Dedicated Short-Range Communication (DSRC)

In North America, 5.9 GHz Dedicated Short-Range Communications (DSRC) systems are being developed to support a wide range of roadside-to-vehicle and vehicle-to-vehicle safety applications. There are seven non-overlapping 10MHz channels in the 5.850-5.925 GHz band. DSRC also supports data rates of 6, 9, 12, 18, 24, 36, 48, and 54 Mbps. In this paper, we assume that one of the channels is used for intersection-collision warning system. In addition, the MAC protocol that supports DSRC systems is the IEEE 802.11a. In this paper, we use the IEEE 802.11b/a term slot time to represent the time a vehicle has to sense or burst the channel.

B. Measuring Distance to an Intersection

Our proposed protocol relies on vehicle’s speed and on measuring the distance between an intersection and vehicles approaching the intersection. There are several techniques that were proposed to measure the distance to an intersection [8][9]. For example, a GPS device can be installed at the intersection that continuously transmits its coordinates to incoming vehicles. Vehicles, which will also be provided with GPS devices, receive the coordinates from the device and calculate the distance to the intersection. Another approach is by using magnetic strips or markers on the road that are placed at a predefined distance from an intersection. These magnetic strips may carry pieces of information including the distance to intersection, lane number, and direction. Another similar approach is to use RF transmitters that are embedded on the...
road. Vehicles approaching an intersection detect a signal from an RF transmitter and then receive a message that contains information about the distance to the intersection. In this paper, we assume that one of these techniques provide vehicles with information about the distance to an intersection, the lane number and the intersection leg that a vehicle is traveling. We will also assume that these techniques trigger the vehicles to start our proposed protocol at a predefined distance from an intersection.

III. IWCAP PROTOCOL

The proposed protocol operates on three phases: the synchronization phase, the contention phase, and the transmission phase, as shown in Fig. 1. In the synchronization phase, vehicles approaching the intersection sense the channel for an idle status for $T_{sync}$ slot times. If the channel is sensed idle during this period of time, then vehicles can start the next phase: the contention phase.

In the contention phase, vehicles contend for the channel using six variables. We assume that each binary bit in a variable is represented by one IEEE 802.11a slot time. Fig. 2 describes an algorithm on how vehicles contend for their assigned channel. Vehicles contend for the channel one bit at a time, MSB first. A contending vehicle will listen to the channel for a slot time if the value of its bit is 1, and will burst the channel for a slot time if the value of its bit is 0, as shown in Lines 10-13 of Fig. 2. If a contending vehicle senses the channel busy, this vehicle will drop from contending for the channel. If a contending vehicle senses the channel idle for all its 1 bits, then this vehicle continues to contend for the assigned channel. In the contention phase, vehicles approaching the intersection contend for the channel based on the following six sub phases:

1) Priority Flag (PF): The objective of this sub phase (in collaboration with the next sub phase) is to provide fairness for all vehicles approaching the intersection from all intersection legs to transmit their data. By default, the Priority Flag for each vehicle is set to 0. Vehicles that lose the next sub phase set its Priority Flag to 1, as explained in the next sub phase. Setting the Priority Flag to 1 gives those vehicles a higher priority to win the channel on the next contention cycle.

2) Intersection Leg (IL): In our system architecture, we assume that each intersection leg has a unique value. The value of an Intersection Leg is assumed to have a length of $L_i$ bits. The objective of this sub phase is to allow vehicles traveling from one of the legs to continue contending for the channel using the next sub phases. Other vehicles traveling from the other legs lose the contention for the channel. If a contending vehicle senses the channel busy, this vehicle will drop from contending for the channel and set the Priority Flag to 1, as shown in Line 17. Setting the Priority Flag to 1 gives those lost vehicles a higher priority to win the channel on the next contention cycle. The vehicles that win this sub phase will not be able to contend on next cycle since their Priority Flag is 0. In addition, when a vehicle wins the channel and transmits its data, this vehicle updates its Priority Flag to 0, as shown in Line 21.

3) Shortest Time to Intersection (STI): In this sub phase, vehicles approaching the intersection from one leg contend for the channel. A vehicle that reaches the intersection first has a higher priority than other vehicles to win the channel and transmit its data. Vehicles calculate the time to an intersection from their speed and from the distance to the intersection. The value of the calculated time is assumed to be of type integer. The length of this measurement is $L_{st}$ bits. Fig. 3 and Fig. 4 show six vehicles approaching an intersection and contend for the channel. We assume that the length of $L_{st}$ is eight bits in this example. Notice that Vehicles V2, V3, V4, and V6 win this sub phase. These four vehicles reach the intersection in two seconds.

4) Highest Speed (HS): Since the value of the Shortest Time to Intersection is of type integer, vehicles with different speed may have an equal value of Shortest Time to

![Fig. 1. The intersection warning channel access priority (IWCAP) protocol with three phases: synchronization, contention, and transmission.](image)

![Fig. 2. The IWCAP algorithm.](image)
Intersection. Since the impact of collision is greater with high-speed vehicles, we assume that a vehicle with the highest speed has a higher priority than other vehicles to win the channel and transmit its condition. The value of the calculated speed is assumed to be of type integer. The length of this measurement is \( L_{hs} \) bits. As shown in Fig. 3 and 4, Vehicles V3, V4, and V6 win this sub phase since these vehicles have the highest speed of 80 km/h.

5) Shortest Distance to Intersection (SDI): Vehicles with an equal speed value and an equal time to intersection value may have different value of distance to intersection. The reason is that we assumed the value of the Shortest Time to Intersection and the value of Highest Speed are of type integer. Therefore, we assume that a vehicle with the Shortest Distance to Intersection has a higher priority than other vehicles to win the channel and to transmit its condition. We assume that the value of the calculated distance is of type integer. The length of this measurement is \( L_{sdi} \) bits. As shown in Fig. 3 and 4, Vehicles V4 and V6 win this sub phase since these two vehicles have the shortest distance to the intersection, 55 m.

6) Lane Number (LN): As shown in Fig. 3, Vehicles V4 and V6 have the same Shortest Time to Intersection, same Highest Speed, and same Shortest Distance to Intersection. One of these two vehicles should transmit its conditions to avoid any data collision. To resolve this contention, we will use the Lane Number. The length of this measurement is \( L_i \) bits. As shown in Fig. 3 and 4, Vehicle V6 wins the contention phase and immediately starts the Transmission Phase.

![Fig. 3. Six vehicles that won the first 2 sub phases are contending for the channel using the next 4 sub phases.](image)

In the Transmission Phase, a vehicle that wins the Contention Phase transmits its condition to other vehicles approaching the intersection from other legs. The winning vehicle transmits its data using the same omni directional antenna that is used in the Contention Phase. We assume the following will be transmitted: vehicle speed (\( vs \)), vehicle heading (\( vh \)), vehicle position (\( vp \)), and a checksum (CRC). Table I shows our proposed settings for IWCAP protocol.

![Fig. 4. An illustration that shows slot times are used either to sense or burst the channel.](image)

<table>
<thead>
<tr>
<th>Table I. The proposed IWCAP parameters</th>
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<tr>
<td><strong>IWCAP Parameter</strong></td>
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<tr>
<td>( T_{sync} )</td>
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<tr>
<td>( T_p )</td>
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<tr>
<td>( L_i )</td>
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<td>( L_{sti} )</td>
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<td>( crc )</td>
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IV. PROTOCOL ANALYSIS

A. Synchronization Phase

To participate in this protocol, a vehicle has to sense an idle channel for \( T_{sync} \). We set \( T_{sync} \) to 10 slot times since the maximum number of idle slot times is 9 (when IL=3 and STI=254). On the other hand, if a vehicle wins the contention phase, then this vehicle will not contend for the channel for the next \( n \) cycles. This is to allow other vehicles to transmit their conditions. The number of cycles, \( n \), depends on the number of lanes, the number of legs, the wireless range of the omni directional antenna, and vehicles’ length. To increase the bandwidth per vehicle, a vehicle that wins the contention phase will not contend for the channel for the next \( n \) cycles or if it senses an idle channel for duration of \( T_{sync} + \Delta t \). If \( \Delta t \) is zero, then this vehicle will always detect \( T_{sync} \) on the next cycle and participate again in the contention phase. Therefore, \( \Delta t \) is used to detect an idle channel where no other vehicle traveling on the same leg exists to contend for the channel. The value of \( \Delta t \) must be at least equal to \( T_{sync} \).
B. DSRC PHY and MAC Layers:

Our proposed protocol can be used as an add-on to the IEEE 802.11a MAC protocol. Instead of using the random backoff algorithm in 802.11a, the distributed coordination function (DCF), the intersection warning system can use the contention phase in our proposed protocol. In addition, the same DSRC PHY layer can be used in our proposed protocol.

C. Communication Range and Distance to Intersection Analysis:

In our analysis, we study the required communication range and the distance to an intersection to avoid a collision. The distance to an intersection is given by

\[ d = \frac{v^2}{2 \cdot g \cdot (f + G)} + d_p + d_b \]  

(1)

where \( v \) is the velocity of a vehicle, \( g \) is the acceleration due to gravity (9.81 m/s\(^2\)), \( f \) is the coefficient of friction, \( G \) is the grade (slope) of a road, \( d_p \) is the distance a vehicle has traveled after processing the protocol, and \( d_b \) is the distance traveled during the brake reaction time. The brake reaction time is the time between recognizing the warning and applying the brake. We assume that the brake reaction time is 2.5 s [10] if drivers manually apply the brake and a 0.1 s if an automated braking system is developed to react when a warning is received. The frictional force between tires and the road is variable and depends on the pavement and tire conditions. We will assume that \( f \) varies between 0.29 (wet pavement [10]) and 0.8 for 96.5 Km/h (60 MPH). The grade of a road is assumed to be -7%.

To calculate \( d_p \), the protocol has 31 slot times in the contention phase, and 10 slot times in the synchronization phase. According to the DSRC specification [7], a slot time is \( 15 \times 10^{-6} \) s. Therefore, our proposed protocol will spend \( 615 \times 10^{-6} \) s in the synchronization and contention phases.

Further, for our analysis, a vehicle transmits 36 bytes, including the IEEE 802.11a frame header, using one of the DSRC data rates. We also make the following assumptions. There is a four-leg intersection and four lanes per leg. The width of a lane is 3.7 m (12 ft.). There is a divisional island between two opposite directions. The width of the island is 3.7 m. Therefore, the dimension of an intersection zone is \( 34m \times 34m \), and the maximum communication range equals to \( 34 + 2 \cdot d \) m. We vary the number of vehicles approaching an intersection from 1 to 600 vehicles. Each of these vehicles has a chance to win the channel and transmit its condition to other vehicles. Fig. 5 and Fig. 6 show the maximum distance, \( d \), to an intersection for break reaction times of 2.5 s and 0.1 s, respectively. Fig. 7 shows the required vehicle’s communication range for two DSRC data rates (6 Mbps and 54 Mbps), under different friction coefficients, and a brake reaction time of 2.5 s. Fig. 8 shows the required vehicle’s communication range if the brake reaction time is 0.1 s. For a dry pavement (\( f=0.8 \)), the required communication range is \( \sim 270 \) m as shown in Fig. 7. If we consider wet pavement (\( f=0.29 \)) in designing intersection collision warning system, then the required communication range is \( \sim 500 \) m. The communication range can be reduced by \( \sim 100 \) m if an automatic braking system is used to slow down the vehicle. In addition, as shown in Fig. 7 and Fig. 8, the DSRC data rates have minimal effect on the required communication range.

![Fig. 5. Required distance to an intersection with a brake reaction time of 2.5 s and a range of friction coefficients.](image)

![Fig. 6. Required distance to an intersection with a brake reaction time of 0.1 s and a range of friction coefficients.](image)

![Fig. 7. Required communication range with a brake reaction time of 2.5 s and a range of friction coefficients.](image)

![Fig. 8. Required communication range with a brake reaction time of 0.1 s and a range of friction coefficients.](image)

D. Bandwidth and Latency Analysis:

The bandwidth and latency of our proposed protocol depend on the number of intersection legs, number of lanes, number of vehicles approaching the intersection, and the processing time of the protocol. The bandwidth required per vehicle is given by

\[ BW = \frac{36}{\sum_{n=1}^{nl} V_n} \text{ bytes/sec} \]  

(2)

and the latency is given by \( \text{Latency} = p \cdot \sum_{n=1}^{nl} V_n \), where \( p \) is the
processing time of the synchronization, contention and transmission phases, \( l \) is the number of legs, and \( V_n \) is the number of vehicles within distance, \( d \), per leg \( l \). The value of \( V_n \) is given by
\[
V_n = \frac{d \cdot N}{L_v + (V_v \cdot t_b)} \tag{3}
\]
where \( N \) is number of lanes per leg \( l \), \( L_v \) is the average length of a vehicle, \( V_v \) is the speed of the vehicle, and \( t_b \) is the time headway of the vehicle. We assume that the average length of a vehicle is 5 m and the required distance, \( d \), to an intersection is 245 m (from Fig. 5). To study the average latency and bandwidth, a range of headways between 0.5 and 2 s are used with two velocities of 64 Km/h (40 MPH) and 96 Km/h (60 MPH). We assumed that vehicles approach an intersection from three legs with the same speed, and the vehicles at the fourth leg are not moving with a gap of 1 m between vehicles. Each leg has four lanes. Each of these vehicles has a chance to win the channel and transmit its condition to other vehicles. As shown in Fig. 9, the latency increases with the increase in the number of vehicles approaching the intersection and decrease in the speed of vehicles. The maximum latency in our scenario is 0.2 s when vehicles are traveling at 64 Km/h with 0.5 s headway. Consequently, the total required bandwidth decreases with the increase in the number of vehicles and decrease in the speed of vehicles, as shown in Fig. 10. The minimum bandwidth in our scenario is 0.19 Kbytes/s. In normal driving behavior, drivers maintain an average headway of 1.5 s and a speed less than 96 Km/h towards intersections. Therefore, a bandwidth of 0.19 Kbytes/s is sufficient under such normal driving conditions.

![Fig. 8. Required communication range with a brake reaction time of 0.1 s and a range of friction coefficients.](image)

![Fig. 10. Vehicle bandwidth for a range of headways and two vehicle's speed.](image)

In this paper, we proposed an intersection warning channel access priority (IWCAP) protocol to warn drivers of a possible collision when they approach an intersection. Our protocol utilizes one omni directional antenna per vehicle and one DSRC channel for the intersection warning system. Our protocol provides priority and fairness for all vehicles approaching the intersection to transmit their conditions to other vehicles. The analysis shows that drivers can avoid a collision if a warning message is received within 240 m to an intersection, with a communication range of 500 m, a speed of 96 Km/h on a wet pavement, and if the warning message is received within 0.2 s after joining the wireless network. We are currently developing a simulator for several traffic scenarios on different intersection geometric designs.

**REFERENCES**

[10] American Association of State Highway and Transportation Officials (AASHTO); A policy on geometric design of highways and streets, 1990.