Pedestrian Collision Avoidance in Vehicular Networks

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Abstract*—Main applications in vehicular networks are primarily looking for road safety improvement. To achieve this goal, position-data information of all interfering road users must be conveyed effectively. This proposal examines the performance made possible using WAVE/DSRC standard when including pedestrians/two-wheels. First, we propose a specific message format for encapsulating pedestrian and two-wheel position-data information. Second, we propose a complete system for collision avoidance at intersection level. Subsequently, we perform tests to analyze the system performance in terms of packets reception rate and transmission delay using WAVE / DSRC standard in two modes of operation. Namely, we perform a comparison between using only the control channel to announce and forward messages as a safety service, and using one of the dedicated channels 172 or 184 after announcing the service on the control channel. Taking into account different levels of network densities, we investigate the modes of operation that provide lower congestion and channel saturation. The findings in this work are relevant to the design of data transmission patterns for pedestrian collision avoidance systems at intersections when using VANETs.

Keywords-component; VANET, WAVE/DSRC, Pedestrian Collision Avoidance, SAE J2735, 802.11a.

I. INTRODUCTION

Road users' localization for safety purposes has received increasing attention in recent years. In many applications such as navigation-aid and parking assistance, user self-location information is used for maneuvering and facilitating navigation. Apart from self-contained systems offered by vehicle manufacturers, a growing research field is studying the generalization of all these services through vehicular ad-hoc networks (VANETs) [1]. With VANETs, an efficient location-data exchange between the various users of the road, including vehicles, cyclists and pedestrians is paramount. The DSRC/WAVE standard [3, 4] aims at establishing a communication framework between vehicles (V2V), between vehicles and infrastructure (V2I) and even with other road infrastructure users such as pedestrians.

This study focuses on how to develop a general vehicular safety application that requires location data exchange between nodes at various speeds. Such application can possibly leverage different wireless technologies to eventually converge on vehicular networks, in conformity with WAVE standard, to deliver information to vehicles in a timely manner. In earlier works, pedestrians were introduced in VANETs as road side units, mobile or stationary nodes according to the considered scenarios [2]. In this work, we study the case where pedestrian and two-wheel nodes are sharing the road with vehicles. In such a scenario, a collision avoidance application seeks to deliver pedestrians/two-wheels location to vehicles that are coming close to an intersection using WAVE/DSRC. Using different modes of operation of WAVE/DSRC, we evaluate the communication efficiency of such application within the context of public safety.

Our contributions in this work are as follows: a) we propose a specific frame format to enclose pedestrian and two-wheel position information; b) we develop a system architecture for pedestrian collision avoidance (PCA) supporting pedestrians with and without DSRC capabilities; c) we investigate two cases where PCA uses DSRC Control Channel only and when the Service Channel is used; and d) finally we evaluate the performance of the system thorough simulations by varying parameters such as messages priority, messaging frequency, communication range and vehicles density to evaluate the packets reception rate and delay.

The remainder of this paper is organized as follow. A brief review of WAVE/DSRC standards are presented in Section 2. In Section 3, we expose the proposed frame format for pedestrian information beaconing. In the same section, we introduce the proposed architecture for an active pedestrian collision avoidance system that uses WAVE/DSRC. Section 4 presents the results of simulations evaluating two possible operation modes. Observations and conclusions drawn are finally discussed in Section 5.

II. OVERVIEW OF DSRC AND WAVE

A. *Dedicated Short Range Communication band*

In 1997, the Federal Communications Commission (FCC) has dedicated 75 MHz of bandwidth in the 5.9GHz frequency band, called DSRC [3, 4, 9] for communications with WAVE, for public safety and privates services. DSRC is meant to provide high data transfer rates for vehicles in a communication zone under 1km with a latency in the range of 100ms. DSRC frequency spectrum, its Control Channel (CCH) and six Service Channels (SCHs), with their transmission power limits are described in Fig. 1.

B. *Wireless Access in Vehicular Environment*

WAVE [3] is the communication standard between nodes in vehicular networks. There are two types of nodes in WAVE;

- Onboard Units (OBU) located in vehicles or handled by pedestrians and two-wheelers.

- Roadside Units (RSU) located on the road and acting as service providers.

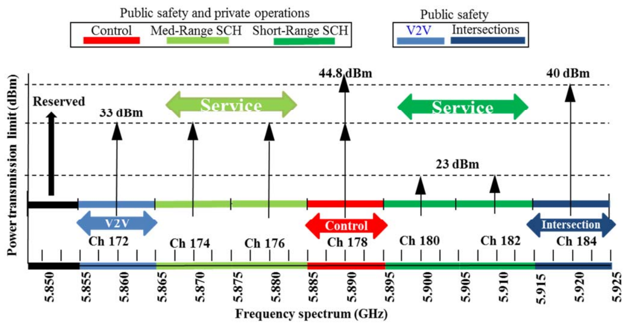

FIG.1. DSRC FREQUENCY SPECTRUM AND CHANNEL ALLOCATION

WAVE is the operation mode used by IEEE 802.11p [4] devices in the DSRC frequency band allocated for Intelligent Transportation Systems (ITS). WAVE model is presented as a layered architecture such as the OSI stack. The illustration in Fig.2. summarizes the layers of the WAVE model and their equivalent in the OSI reference model.

- *IEEE 802.11p:* [4] the standard for Physical and Medium Access Control (MAC) layers of WAVE. It is developed in order to support communication between high mobility nodes up to 280Km/h. The main changes compared to IEEE 802.11a are: a) signal bandwidth reduced to 10MHz, b) removal of scanning and association procedure allowing connection setup and data transfer in only 100ms.
- *IEEE1609.4:* [5] describes the mechanisms of multi-channels operation for switching between control and service channels.
- *IEEE1609.3:* [6] defines addressing and data delivery services to higher layer entities.
- *IEEE1609.2:* [7] Covers the format of secure messages and their processing.
- *IEEE1609.1:* [8] allows the interaction between the OBU and the in-vehicle applications.

IEEE802.11p and IEEE1609.4 were developed based on IEEE 802.11a with some adaptations. The multi-channels operation aims to facilitate the recurrent switching coordination between channels for WAVE units. These units can exchange information either independently over the CCH or by forming a WAVE Basic Service Set (WBSS) and exchange information through one SCH. A WBSS consists on time and frequency allocation, and it is announced in CCH. Two types of WBSS are supported in WAVE; 1) persistent WBSS announced in each CCH interval, and 2) non-persistent WBSS announced only on creation. If an application uses WBSS, WAVE units can communicate using two protocol stacks; 1) WAVE Short Message Protocol (WSMP), which is a WAVE protocol defined to reduce latency and overhead and so be effective for time sensitive applications. 2) IPv6 protocol. Note that only WSMP can be used for applications that do not support WBSS.

Since WAVE introduction, many researches have been conducted to study its performances. To comment on some recent finding, in [10], authors noticed that 90% of successful communications take place at less than 750m. Jiang et al [11] reported that the probability of reception for broadcasted messages, in saturated conditions, is between 20% and 30% at distances less than 100 meters. According to [15], the optimal data rate for safety-related messaging is fixed to 6Mbps using packets of 200 bytes and 500 bytes, while respecting the bearable latency of 100ms for end-to-end message delivery.

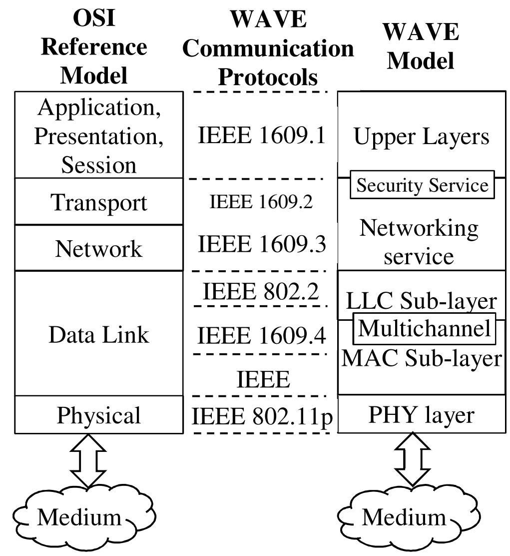

FIG.2. WAVE STANDARD ARCHITECTURE

III. PEDESTRIAN COLLISION AVOIDANCE SYSTEM

This section will be dedicated to; (a) the presentation of the frame formats for the pedestrian positioning data exchange and (b) an overview of the system architecture.

A. *Frame format for pedestrian position data*

Based on SAE J2735 [12] basic safety message standard, we propose a frame format to enclose the pedestrian location data. The format is a direct simplification of frame formats that comply with NMAE2000 [13]. NMAE2000 is used by GPS systems and adopted by the majority of the locating and mapping systems such as Google-maps.

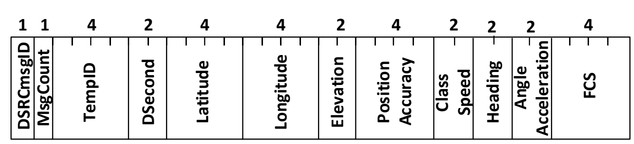

FIG.3. PEDESTRIAN LOCATION DATA FRAME FORMAT

The proposed frame is composed of 12 fields presented in their order of appearance as illustrated in the following:

1. *DSRCmsgID:* determines the type of the current message.
2. *MsgCount:* sequential number incremented at each successive transmission by a given pedestrian. It is primarily used in packet error statistics.
3. *TempID:* as a temporary ID, this field is set a random constant for a period of time, and is changed occasionally for privacy reasons.
4. *DSecond:* clock signal for messages time stamping.
5. *Latitude:* Geographic latitude of pedestrian.

6. *Longitude:* Geographic longitude of pedestrian.
7. *Elevation:* Elevation compared to the sea level.
8. *Position-Accuracy:* used to convey how precise the latitude and longitude values are to evaluate the location information accuracy.
9. *Class-Speed:* is mainly a value determining if it is pedestrian or a two-wheel.
10. *Heading:* Compass heading of pedestrian.
11. *Angle-Acceleration:* Current position of the steering wheel of two-wheel nodes, expressed as a positive angle of longitudinal and lateral acceleration.
12. *Checksum:* checksum parity for error detection.

The Pedestrian position data frame is encapsulated in an IEEE802.11p frame inducing an overhead of 32 bytes as shown in Fig.4.

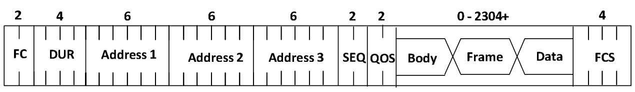

FIG.4. IEEE802.11A DATA FRAME FORMAT

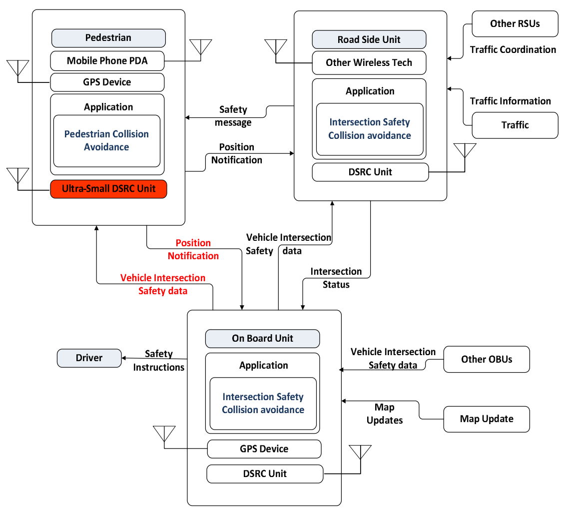

FIG.5. PEDESTRIAN COLLISION AVOIDANCE SYSTEM ARCHITECTURE

B. Intersection collision avoidance with pedestrian participation; System design and architecture

One of the main goals of WAVE is to support delay sensitive application designed to preserve the driver's life, passengers, as well as non-motorized road users such as pedestrians and cyclists. Fig. 5 summarizes the proposed architecture of an active pedestrian collision avoidance system, comprising the principal hardware equipment and data streams of all interfering parts, namely pedestrian (or two-wheels), road side units and on board units. Two major cases are considered; in the first P2V case we consider that pedestrian terminals comprise an ultra-small DSRC Unit. In the second case, called P2I+I2V case, we assume that pedestrian terminals use another wireless technology (e.g. Wi-Fi) to exchange data with the RSU, which in turn will be acting as an intermediary with vehicles' OBUs. In the figure hereafter, the block in red at the pedestrian side is replaced in the second case by a communication unit with the RSU leveraging another technology.

The P2V case is equivalent to V2V taking into account the low velocity of pedestrians which have DSRC units enabling them to communicate directly in a VANET mode. The second case is equivalent to dividing the problem in two parts: 1) P2I, pedestrian transmitting messages to the RSU using some other wireless technology such as Wi-Fi, and 2) I2V, the RSU relaying the message to OBUs leveraging WAVE technology.

IV. SIMULATIONS RESULTS

Simulations are conducted in two main parts based on the aforementioned scenarios, namely P2V and P2I+I2V. An implementation of IEEE 802.11p offering priority service as in EDCF access scheme over NS-2 was used. For each scenario two cases were studied; case 1) using the CCH exclusively or, case 2) announcing the service in the CCH and nodes have to switch to the SCH (for example, the dedicated channels 172 or 184) to join the PCA application. We implemented two priority schemes corresponding to the highest (HP) and lowest (LP) access scheme (AC0 and AC3). We evaluated two major performance metrics, namely End- To-End (E2E) delay and Packet Reception Rate (PRR). These metrics are of upmost importance as both high transmission reliability and low delay transmissions are critical for ensuring the PCA system will be able to operate in a timely manner to potentially save lives.

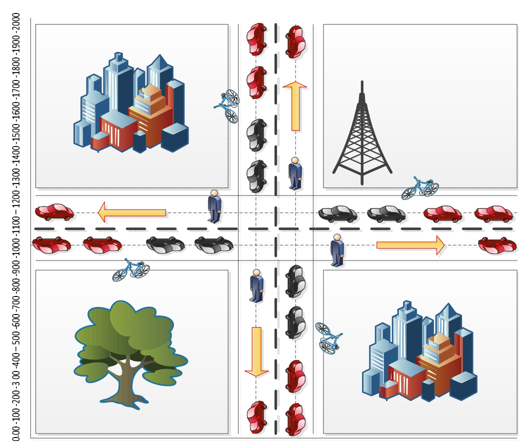

FIG.6. TRAFFIC VIEW AND MOBILITY PATTERN

In the simulations, we considered an intersection similar to the one illustrated in Fig. 6 where 20 vehicles, 4 pedestrians and 4 two-wheels are sharing a 2Km by 2Km road infrastructure area. All vehicles try to navigate the intersection. Two lines are available in each road in the same direction, to allow lane changing and gears shifting. Vehicles in black color, being closer to the intersection are travelling at a maximum speed of 30 Km/h, where the red ones run at speed up to 100 Km/h. Each pedestrian is walking at a maximum speed of 5 Km/h, and wants to attain the opposite side by crossing two roads. The cyclists ride at a maximum speed of 25 Km/h on the side of the road in the same direction as the vehicles. In order to assess the performances of the system in different communication situations, we used, throughout simulations, the communication density metric defined as (1) by Jiang et al. [14] as a combination of; messaging frequency (Mf), Vehicles density (Vd) and Communication Range (Cr).

$$CD = Mf(Hz) * Vd(Veh/KmRoad) * Cr(m) \qquad (1)$$

Simulations parameters are summarized in Table1.

TABLE.1. SIMULATION PARAMETERS

Transmission range	300m, 500m and maximum range
Vehicle Density	Up to 28 nodes on 1000m of road
Data rate	6Mbps [15]
Messaging frequency	10 Msg/s, 20 Msg/s and 25Msg/s
Packet size	200 bytes
Propagation model	Two ray ground with 3.5 path-loss exponent
Power limit	CCH: 44.8dBm/SCH: 33bBm
Access Scheme	E-Distributed Coordination Function (EDCF)

A. *P2V case simulations results*

PCA performance in terms of E2E delay was studied based on the EDCF implemented over 802.11p. Fig.7 shows the effect of increasing the CD in scenarios 1 and 2. In light load condition, E2E delay does not exceed 25ms. In medium and high load conditions, E2E delay increases more rapidly when SCH is used than with CCH. In both cases, using the HP offers a better E2E delay. It is worth noting that using CCH with LP gives better results in terms of delay than using SCH with HP. This confirms the fact that the use of CCH is better suited for delay sensitive applications compared to SCH.

The second performance metric assessed was PRR. PRR is defined as the ratio between successfully received packets and the total emitted packets. PRR is generally affected negatively by the emitter-receiver distance, network load and interferences. As shown in Fig.8, on the one hand, PRR decreases when CD increases. This is due to collisions rising when the network is close to its saturation. In low load conditions, PRR is kept over 75%. On the other hand, using CCH allows maintaining an acceptable PRR with HP traffic. Even if using HP over SCH gives a slight advantage in term of PRR comparatively to using CCH with LP in low communication densities, with medium and high CD values, PRR decreases more sharply with SCH down to20%.

Results noted in in Fig.7 and Fig.8, are mainly due to two reasons: a) the switching mechanism introduced by IEEE1609.4; in the SCH case, the transmission time is less than that available in the CCH case. Indeed the time is cut on CCH intervals and SCH intervals minus a guard time for synchronization purpose. Overall PCA traffic has to wait longer to be successfully transmitted and received leading to a higher E2E delay b) Transmission power difference: SCH provides a lower range which means less packets are received affecting directly the PRR.

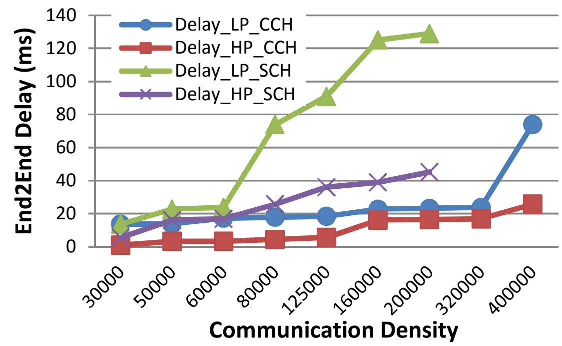

FIG.7. DELAY FUNCTION OF CD IN CCH AND SCH WITH LOW PRIORITY (LP) AND HIGH PRIORITY (HP) IN P2V CASE

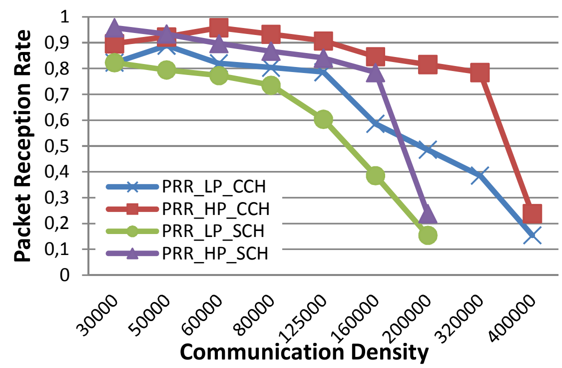

FIG.8. PRR FUNCTION OF CD IN CCH AND SCH WITH LP AND HP IN P2V CASE

B. *P2I+I2V case simulations results*

For the study of this case, an RSU is installed at the intersection level. Its main role is to operate as a mediator between non-DSRC equipped pedestrians and the vehicles OBUs. The RSU relays incoming messages from pedestrian units via Wi-Fi, to the OBUs over DSRC and vice-versa. As illustrated in Fig.9, the E2E delay is much greater than in the first scenario especially for low priority traffic. This is mainly due to the extra delay introduced by the Wi-Fi communication and the conversion of packet formats at the RSU level. Nevertheless, HP traffic (emergency) in the two cases of DSRC over CCH and SCH provides lower delays less than 60ms, respecting the maximum latency required by safety-related applications. However, the E2E delay of LP traffic (beaconing) exceeds 100ms for both SCH and CCH use.

In the same manner as in the first scenario, the PRR diminishes as the CD rises. As illustrated in Fig.10, the maximum achievable PRR for LP traffic in both channels does not exceed 60% even for low traffic. On the contrary, HP traffic offers acceptable PRR superior to 70% in low and medium densities up to 100k CD. In highly dense environment, 40% of packets are successfully received for CD up to 160k.

The difference in the PRR behavior is mainly caused by the traffic priority.

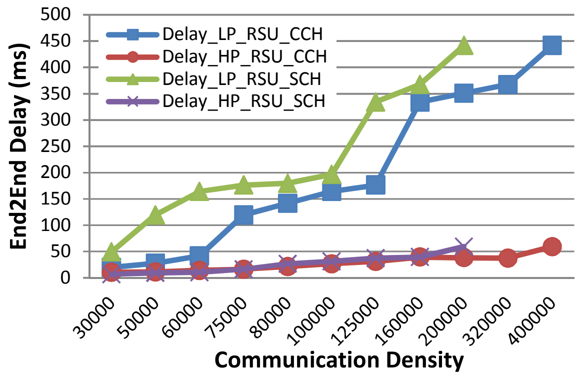

FIG.9. DELAY FUNCTION OF CD IN CCH AND SCH WITH LP AND HP IN P2I+I2V CASE

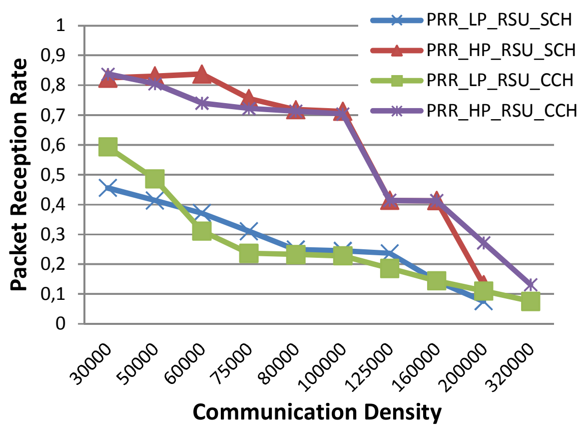

FIG.10. PRR FUNCTION OF CD IN CCH AND SCH WITH LP AND HP IN P2I+I2V CASE

The two major reasons for performance difference between CCH and SCH cases in the P2I scenario remain valid here. Furthermore, the RSU becomes a bottleneck for traffic. At the RSU, the channel distinction is annealed and only the priority-based distinction is maintained with the conversion between 802.11p (channel and priority distinction) and Wi-Fi (priority distinction). This is why priority has a higher impact on messages dissemination than in the P2V scenario.

V. CONCLUSION

In this paper we investigated the performance of a communication scheme for a pedestrian/two wheel collision avoidance system at road intersections. We investigated two possible cases. First the cases where pedestrians/two-wheels are equipped with WAVE/DSRC capabilities to directly communicate their position to vehicles. Second, the case where pedestrian/two wheels are using Wi-Fi to communicate with road side units, and then the latter relay the information to vehicle on-board units by using WAVE/DSRC. Different saturation conditions were examined while using either a high priority or a low priority to send messages over WAVE/DSRC. The results show first, that given a chosen message priority, using CCH for communicating position information over WAVE/DSRC gives an advantage in terms of end-to-end delay and probability of reception, especially at high communication densities in both scenarios. However, using high priority influences also the overall system performance, and especially so in the second case. In fact, in the second scenario, the end-to-end delay and the probability of reception became unacceptable when using low messages priority.

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