PERFORMANCE ANALYSIS OF V2V DSRC COMMUNICATIONS WITH RECONFIGURABLE ANTENNA

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Abstract
This paper discusses the performance of vehicle-to-vehicle (V2V) dedicated short range communications (DSRC). Based on the IEEE 802.11p standard, packets collides at receivers due to hidden note problem. For some applications, it is beneficial to concentrate the radiation energy in certain directions, rather than emitting signal at all directions. Therefore, this paper analyzes the reception performance of V2V communication with different transmit antenna patterns under hidden nodes scenario and explores the employment of reconfigurable antenna technologies to IEEE 802.16p-based DSRC safety applications. Simulation results show that the packet latency can be reduced by up to 66.67% and the unsuccessful packet reception can be decreased by up to 37.6%.

Keywords:
ITS, DSRC, IEEE 802.11p, reconfigurable antenna

I. Introduction

Vehicle-to-vehicle (V2V) wireless communication has the potential to improve driving experience and enhance road traffic safety. The basic idea is to exchange information, such as GPS position, velocity and heading, with neighbouring vehicles. To this end, dedicated short range communication (DSRC) technology has been developed to combat road fatalities [1]-[3].

In the United States, the Federal Communication Commission (FCC) has allocated a bandwidth of 75 MHz at 5.9 GHz frequency band for DSRC operation [4]. Although DSRC radio is primarily for the purpose of automotive safety applications, it also supports a range of non-safety applications. The 75MHz spectrum is divided into seven 10 MHz channels with a 5-MHz guard band at the low end. One of the channels, namely Control Channel (CCH), is reserved for the use of safety communications, such as do not pass warning and emergency electronic brake lights [6]. The remaining six channels, referred to as service channels (SCHs), are to be used for a range of non-safety applications, from electronic toll collection to multimedia downloading [7]. The switching among these channels is defined in IEEE 1609.4 [8].

A WLAN-based DSRC radio has been standardized for V2V and vehicle-to-infrastructure (V2I) communications. Its medium access rules are specified in IEEE 802.11p [3], an amendment to the familiar IEEE 802.11 (WLAN) standard. The basic medium access scheme is the well know Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) [3],[9], which is effective when the medium is not heavily loaded.

For V2V safety applications, broadcast reliability is one of the major performance concerns. However, the IEEE 802.16p-based DSRC radio may suffer from packet collision due to hidden node problem [10]. This problem in Infrastructure-based wireless networks has been extensively studied in the past [11]. However, the results of these studies cannot be directly applied to V2V communication scenarios because of the fundamental differences between infrastructure-based wireless network environments and vehicular ad-hoc network environments. Therefore, this paper addresses the hidden node problem in V2V safety applications by evaluating and analyzing the reception performance of IEEE 802.11p-based DSRC radio.

The rest of this paper is organized as follows. Section II presents the system model and Section III unveils the proposed scheme. Section IV explores the V2V communication performance by numerical simulations. Finally, Section V provides some concluding remarks.

II. System Model

Figure 1 illustrates a one-dimensional highway environment, on which DSRC-equipped vehicles are randomly placed according to Poisson process [12]. That is the V2V distance is negative-exponentially distributed and the number of vehicles in a constant distance is Poisson distributed. Mathematically, The exponential probability density function and Poisson probability density function are respectively defined as

$$f(d) = \frac{1}{\mu} e^{-\frac{d}{\mu}}, \text{ and} \tag{1}$$

$$f(n) = \frac{1}{n!} e^{-\lambda} \lambda^{n}, \tag{2}$$

where μ is the average V2V distance and λ is the average vehicle number per meter. All the vehicles are assumed to move in the same direction and exchange information with neighbours through broadcasting.

According to the IEEE 1609.4 specification, the operation of DSRC channel switching between CCH and SCHs is in a time division manner. Time is segmented into frames, each of duration 100 ms. Each frame consists of one CCH interval of 50 ms followed by one SCH interval of 50 ms. Safety information is set on the CCH in a regular basis. In this paper, each vehicle is assumed to randomly generate one packet of safety information during every CCH sub-frame. The packet size is 100 bytes [13] and is broadcasted at a rate of three Mbps. The wireless medium is shared among the vehicles based on the CSMA/CA protocol, which works as follows.

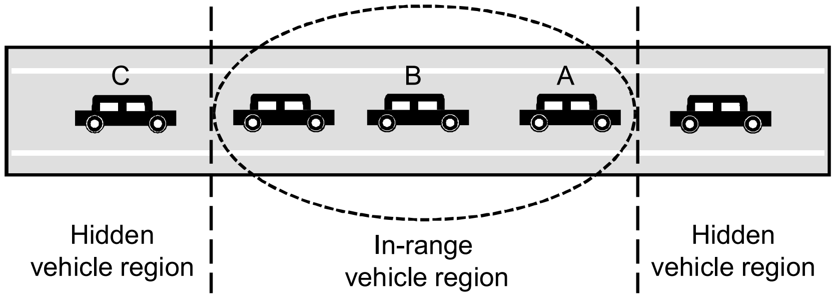


Figure 1 – Illustration of hidden and in-range vehicle regions relative to centre vehicle

Any vehicle has packets to send first senses the medium. If the medium is sensed idle then the vehicle begins transmitting one packet. If the medium is busy (i.e. some other vehicle is transmitting), then the vehicle defers its transmission to a later time based on a backoff process. The backoff process is to select a random interval between zero and contention window (CW) to wait before transmission. The backoff timer is in units of slot times with each slot time being 20 µs. The countdown begins when the wireless medium becomes idle, is interrupted during any non-idle slot times, and resumes when the medium returns to idle. The intention of this random backoff process is to implement channel access in a time-division multiplexing fashion. However, packet collision does occur due to hidden node problem, which is explained as follows.

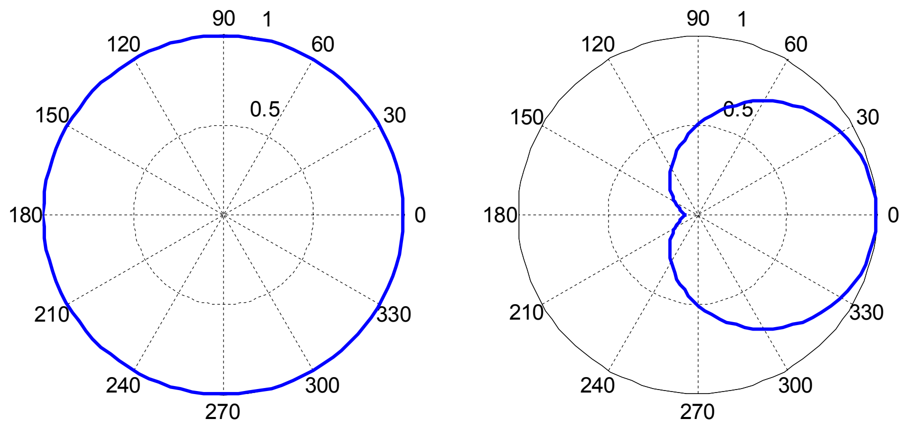
As illustrated in Fig. 1, vehicle A can only pick up signals broadcasted from neighbouring in-range vehicles, because signal attenuates when propagating through space. This paper applies the commonly used path loss model,

$$PL(dB) = 32.45 + 10n\log_{10} d + 20\log_{10} f, \tag{3}$$

where n is the path loss exponent ranging from two to four, d is the distance (in kilometers) between the transmitter and receiver, and f is the carrier frequency in MHz. The in-range vehicle region is defined as the maximum V2V communication range. Based on the CSMA/CA protocol, those vehicles within this region would avoid packet collision by sensing the wireless medium before transmission. The vehicle B in Fig. 1 is supposed to successfully receive the packet broadcasted from the vehicle A. Meanwhile, there are vehicles outside the range, which are known as hidden nodes. There is always a chance of these hidden vehicles broadcasting at the same time when the vehicle A is transmitting signal, because they are outside the communication range of the vehicle A and sense the medium as idle. Consequently, packet collision occurs at the vehicle B, resulting in failure packet reception.

III. Proposed Scheme

For some V2I applications, such as payment at gas stations, the vehicle can simply transmit its signal at all directions through an omni-directional antenna. For some V2V applications, such as do not pass warning and emergency electronic brake lights, it is beneficial to concentrate the radiation of signal at certain directions through directional antennas. Figure 2 plots an omni-directional antenna radiation pattern and a commonly used directional antenna radiation pattern with gain at user direction θ as $G(\theta) = G_{\max} - \min[12(\theta/70)^2, G_m]$, where $-180^0 \le \theta \le 180^0$, $G_{\max}$=0dBi and G_{m}=20dB.



(a) Omni-directional antenna pattern (b) Directional antenna pattern

Figure 2 – Plots of different antenna patterns

Figure 3 illustrates a V2V communication scenario where each vehicle broadcasts its signal at backward direction. By limiting the signal in certain directions, the hidden node problem can be alleviated since the potential hidden vehicles are reduced. Now, the vehicle B is able to receive signal from the vehicle A successfully, because the vehicle C would not cause interference even it is outside the communication range of the vehicle A.

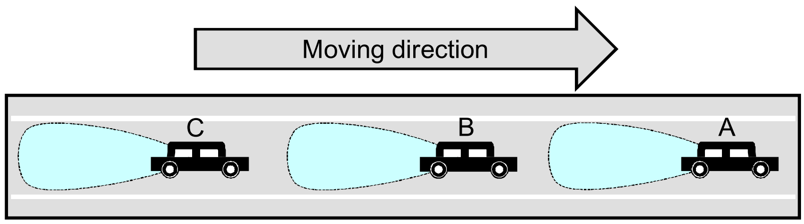


Figure 3 - Illustration a V2V broadcast through directional antenna

Therefore, this paper proposes to equip vehicles with a reconfigurable antenna such as the planar electronically reconfigurable antenna [14]. The architecture of this reconfigurable antenna is based on a parasitic structure composed by a set of microstrip elements that can be electronically reconfigured by means of radio-frequency switches. As a result, the maximum values and zeros of the antenna pattern can be steered towards arbitrarily directions. Based on this reconfigurable antenna technology, the transmitter should adaptively radiate its signal in preferable directions according to its applications. Figure 4 reveals the concept of the proposed adaptive DSRC packet transmission scheme. All the arrival packets are held in a queue. Every vehicle accesses the wireless medium according to the CSMA/CA protocol. The transmitter sends one packet when the medium is available. Prior to the transmission, it reconfigures its antenna to a particular radiation pattern. By so doing, the hidden node problem is expected to be mitigated.

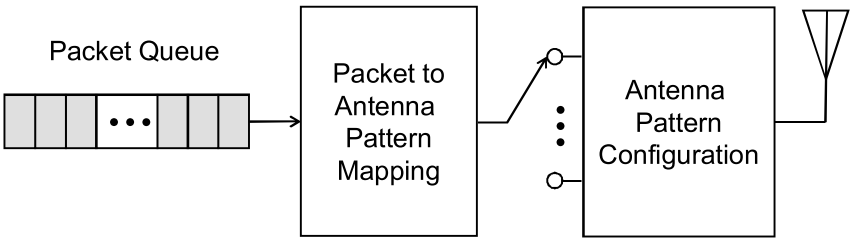


Figure 4 – Illustration of the proposed adaptive packet transmission scheme

Note that the antenna design and the mapping between packet and antenna pattern are out of the scope of this paper. The aim of this work is to analysis the performance of V2V communication with different transmit radiation patterns under hidden nodes scenario and explores the application of reconfigurable antenna technology to IEEE 802.11p-based DSRC systems. Accordingly, the communication performance of vehicles with the two radiation patterns shown in Fig. 2 will be presented in the next section.

IV. Simulation Results

The simulation scenario is a one-dimensional highway environment, with length of three kilometres. Sixty vehicles are randomly dropped on the highway according to Poisson process. The transmit power of each vehicle is 10dBm and the path loss exponent in (3) is set as three. The receiving sensitivity is assumed to be -95dBm, resulting in an maximum communication range of 800 meters.

In the simulations, fifty runs of Monte Carlo simulation were performed, with each run lasting for 100 frames. To evaluate and quantify the system performance, multiple metrics are considered, including 1) packet latency, defined as the interval between the time one packet is generated and the moment it has been transmitted, 2) packet dropping rate, which is the probability that one packet cannot be transmitted by the end of the frame, 3) packet collision rate, defined as the probability of two or more packets collided at one receiver, and 4) received signal-to-interference-plus-noise ratio (SINR) of the collided signal. The packet latency and dropping rates are the performance measures at transmitters while the packet collision and SINR are the measures at receivers.

Figure 5 shows the cumulative distribution function (CDF) of packet latency in units of slot times, where the conventional method represents packet transmission by using omni-directional antenna. For the conventional scheme, one packet can be delayed for as long as 150 slot times for 90% of the transmitters, while most packets can be sent within 55 slot times by using the proposed one. Figure 6 plots the CDF of packet dropping rate. If the maximum acceptable dropping rate is set as 5%, then the percentage of qualified transmitters can be increased from 57.2% to 98.2% by using the proposed method. To sum up, the sender can utilize the wireless channel more effectively by using the proposed adaptive packet transmission scheme.

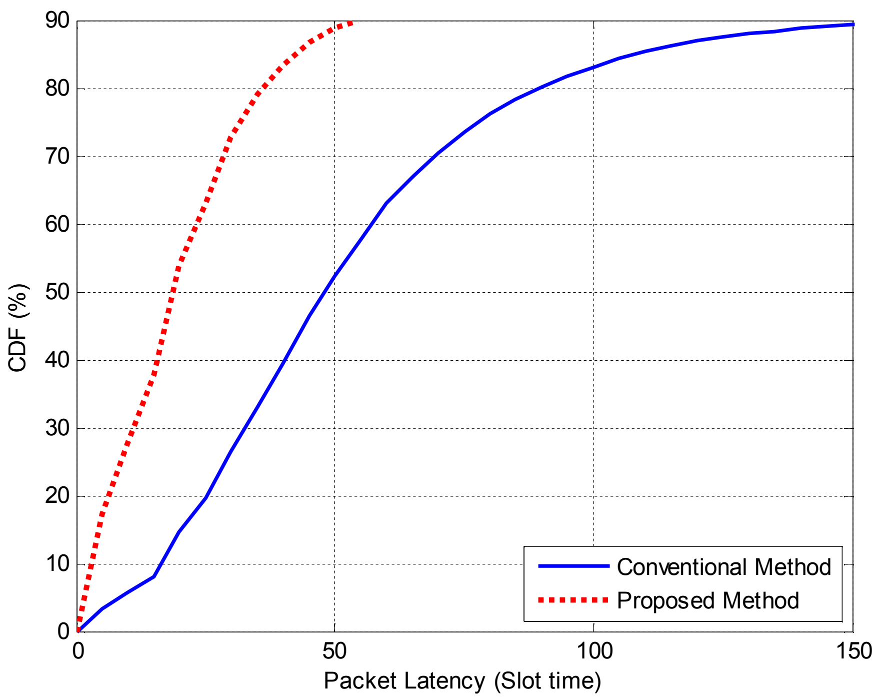


Figure 5 - Comparison of packet latency

Besides the transmission performance, packet receptions are discussed as follows. Figure 7 plots the CDF of packet collision rate. The proposed scheme outperforms the conventional one as 90% of the receivers experience lower collision rates of less than 0.43, down about 20% from 0.51. Here, any packet interfered by another one is counted as one collision, despite the level of the interference. Yet there are changes that the receiver successfully decodes the collided packets at the present of weak interference. Therefore, the SINR of the collided packets is also evaluated, as shown in Fig. 8. If the minimum requirement of the received SINR is set as 3 dB, then 60% of the collided packets can end up with successful receptions by using the proposed scheme, while only 46% of them can be decoded by using the conventional one. Meanwhile, the packet collision rate along with the SINR of the collided packets translate that, for 90% of the receivers, the unsuccessful packet receptions can be decreased from 27.54% by up to 37.6% to 17.2%.

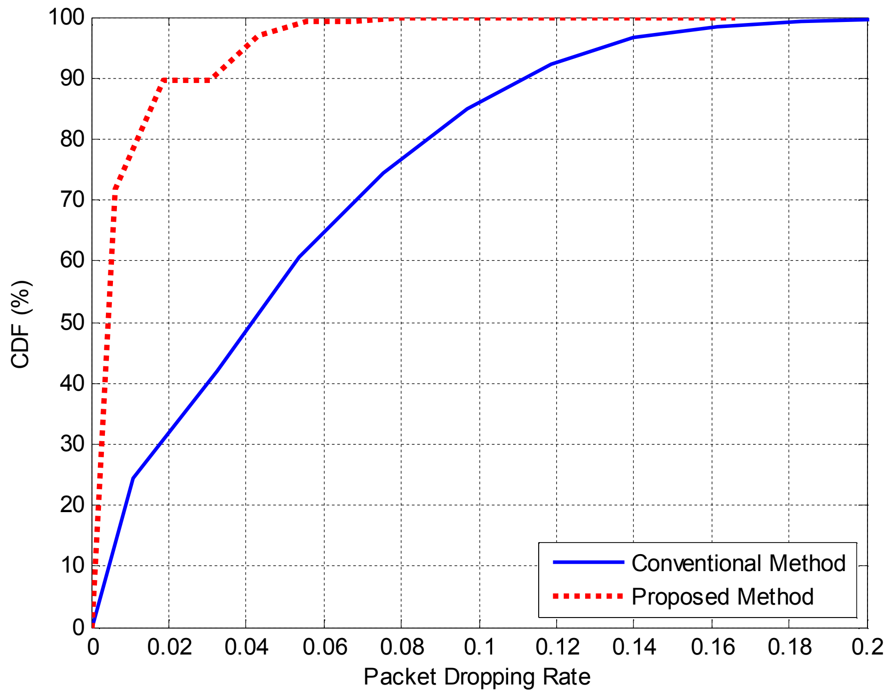


Figure 6 - Comparison of packet dropping rate

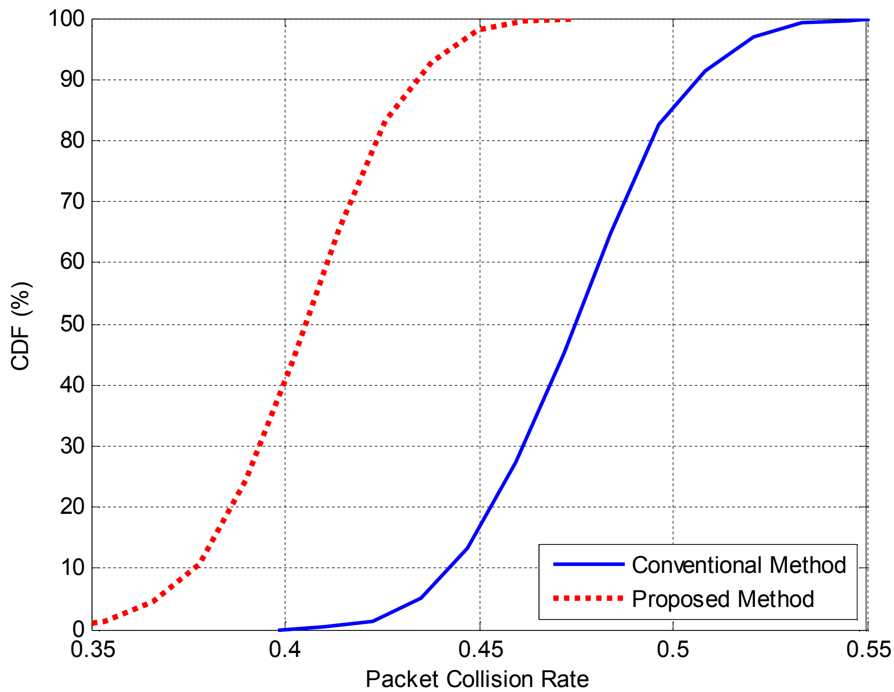


Figure 7 - Comparison of packet collision rate

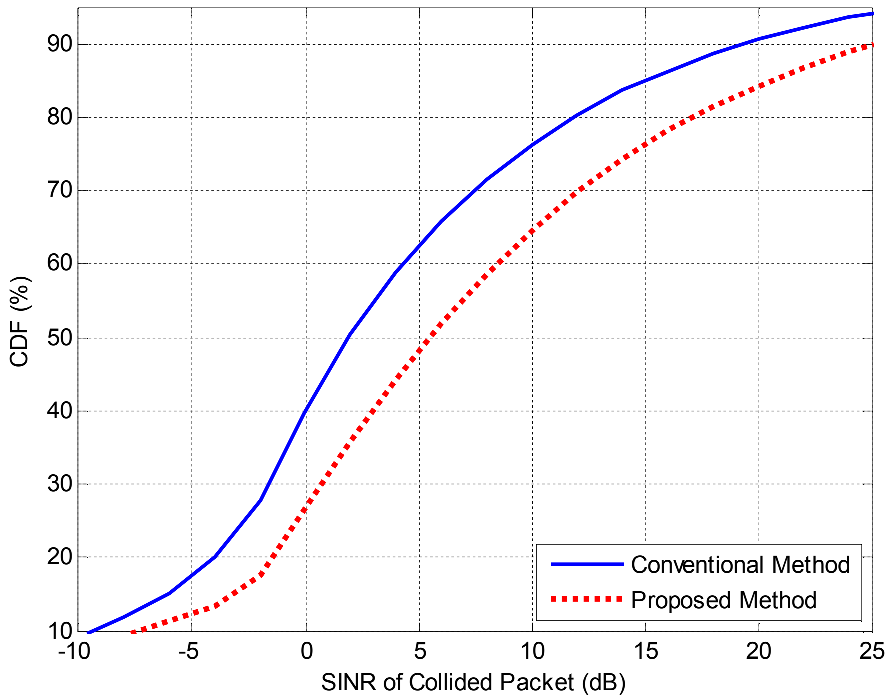


Figure 8 - Comparison of signal SINR of collided packets

So far, this paper has demonstrated the numerical simulations of V2V DSRC communications. To verify the performance of the proposed scheme, there are real-world experiments afoot in our facility's automotive proving ground, where 10 DSRC road side units have been deployed. These real-world data collections will be presented in the near future.

V. Conclusions

This paper has presented the performance analyses of the IEEE 802.16p-based DSRC radio. It suggests to apply adaptive antenna technologies to V2V communications in order to improve the utilization efficiency of the wireless channel. The essential idea is to send information at particular directions according to the associated applications, thus alleviating the probability of packet collisions. By using the reconfigurable antenna, the packet latency can be reduced by up to 66.67% for 90% of the transmitters and that the unsuccessful packet receptions can be decreased by up to 37.6% for 90% of the receivers, compared to using omni-directional antenna. To sum up, the proposed scheme is superior by providing high communication reliability with lower latency, fewer dropped packets, and less collisions for the IEEE 802.16p-based DSRC systems.

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