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ORIGINAL RESEARCH PAPER

Dual channel transmission for reliable V2X broadcasting messages

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Abstract

A Vehicle to Anything (V2X) packet data is used for a vehicle safety and automated driving applications. It is broadcasted periodically to provide a warning message or share the vehicular sensor's data among vehicles. This paper proposes IEEE 802.11p based dual channel transmission and packet selection method to improve the Packet Detection Rate (PDR) for V2X broadcasting messages. The PDR gain of the proposed scheme over the single channel transmission is given theoretically by the packet error rate of a single radio channel. And the PDR improvement is evaluated by a computer simulation in a highway or urban multipath fading channel.

1 | INTRODUCTION

Intelligent Transport System (ITS) aims to reduce traffic accidents and save energies, finally reduce CO_2 emissions. IEEE 802.11p based V2X communication technology has been applied for ITS applications, which are Emergency Brake Warning (EBW), Signal Phase and Timing (SPaT) and so on. V2X packets are broadcasted to inform a warning signal or the vehicular sensor's data among vehicles in 100 ms latency and 10% Packet Error Rate (PER) at the receiver [1–3]. Normally it is transmitted periodically or if some events happen. As a Connected Automated Driving (CAD) system emerges, V2X packet messages shall be improved in the packet latency and reliability because CAD applications have the technical requirements which are the order of 10msec in packet latency and less than 1 % in the PER, which are specified in LTE enhanced V2X (eV2X) and 5G mobile communications [4, 5]. There has been studied on an empirical channel model and characterization, and PER analysis for the given modulation type and packet size in 5.9GHz radio frequency band [6, 7].

There are few literatures to improve packet latency and reliability for V2X message broadcasting. A piggyback may be applied for V2X message broadcasting if the packet errors are detected and acknowledgement message is sent to the transmitter [8]. However, the piggyback method makes the packet latency increased. A packet repetition method was proposed in IEEE 802.11bd standard and its performance is degraded due to an increased packet transmission time [9]. And other schemes such as the channel estimation algorithm or diversity techniques at the receiver have been studied to improve the PER [10, 11].

In this paper, we propose IEEE 802.11p based dual channel packet transmission and selection method to improve the PER without a loss of the packet latency. The PER performance of the proposed method is analysed theoretically and evaluated by computer simulation.

2 | THE DUAL CHANNEL TRANSCEIVER MODEL

The conventional transceiver model has a single channel transceiver using one radio frequency as shown in Figure 1. The transmitted packet data is modulated by using f_1 radio frequency and modulated signal is defined as $X(f_1)$. And it is transmitted via the multipath fading channel H. The received signal $\hat{X}(f_1)$ is demodulated and a signal $\hat{x}(t)$ is the recovered packet data.

The proposed dual channel transceiver modulates the packet data by using two radio frequencies f_1, f_2 and modulated signals are defined as $\mathrm{X}(f_1)$ *and* $\mathrm{X}(f_2)$. The received signals and demodulated signals are denoted by $\hat{X}(f_1)$ *and* $\hat{X}(f_2)$, $\hat{x}(f_1)$ and $\hat{x}(f_2)$ respectively. Finally, the recovered packet data $\hat{x}(t)$ is recovered through a packet error detection and selection process as shown in Figure 2. The two radio channels

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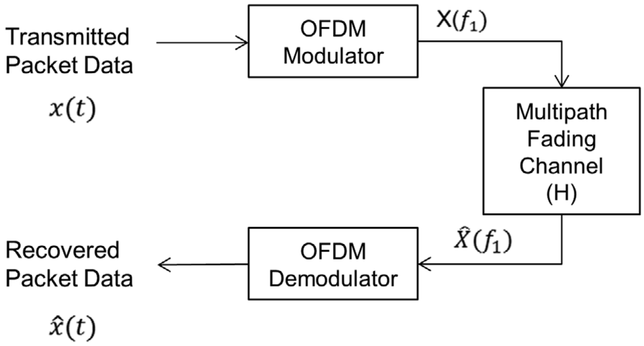

FIGURE 1 Conventional transceiver model

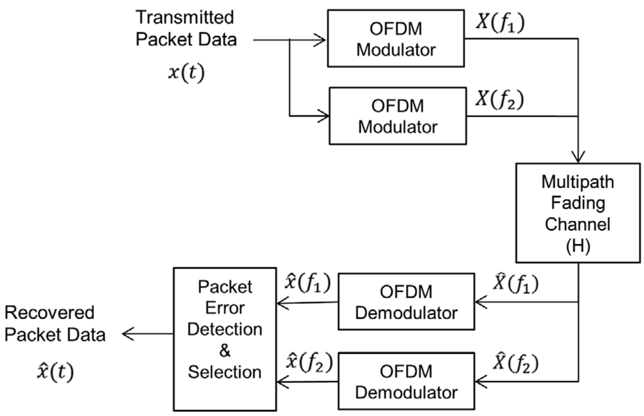

FIGURE 2 Proposed dual channel transceiver model

are uncorrelated because they are separated in the frequency domain.

The recovered packet signals $\hat{x}(f_1)$ and $\hat{x}(f_2)$ may contain corrected bits or errored bits by the channel decoding at the OFDM demodulator. When the packet data is transmitted, Cyclic Redundancy Check (CRC) is added in the tail of packet as shown in Figure 3. When two packets are received, a packet detection with CRC check and selection process is executed as shown in Table 1. If an error is detected in the received packet, the received packet will be discarded, otherwise, the received packet will be selected. If packet errors aren't detected in both packets, any packet can be selected randomly. By doing the packet error detection and selection, the PER of the received packet can be improved. An impact on the packet latency is negligible because a packet selection at the receiver is a simple logic to implement.

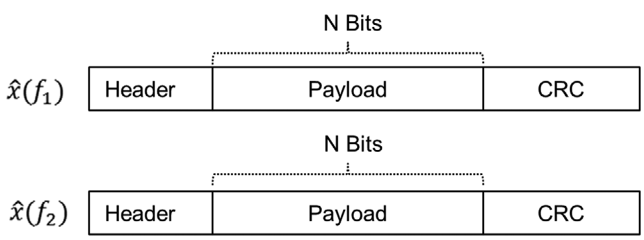

FIGURE 3 Received packet configuration

TABLE 1 Packet detection and selection method

Packet error detection of $\hat{x}(f_1)$	Packet error detection of $\hat{x}(f_2)$	Packet selection
No	No	$\hat{x}(f_1)$ or $\hat{x}(f_2)$
No	Yes	$\hat{x}(f_1)$
Yes	No	$\hat{x}(f_2)$
Yes	Yes	Discard

As shown in Table 1, the received packet can be received correctly expect for simultaneous packet errors.

3 | PACKET DETECTION RATE (PDR) ANALYSIS

In this paper, the performance on the proposed transceiver model is measured as the PDR gain. If the PER for the single transmission is denoted by P_e^S, the packet error rate $P_e^S[\hat{x}(f_1)]$ *or* $P_e^S[\hat{x}(f_2)]$ for the received packet $\hat{x}(f_1)$ *or* $\hat{x}(f_2)$, is the summed probability from the single bit error to N bits errors in the received packet and can be expressed as:

$$P_e^S\left[\hat{x}\left(f_1\right)\right] = \sum_{i=1}^{N} P_b^i \left(1 - P_b\right)^{N-i} \tag{1}$$

$$P_e^S\left[\hat{x}\left(f_2\right)\right] = \sum_{i=1}^{N} P_b^i \left(1 - P_b\right)^{N-i} \tag{2}$$

where, i is the arbitrary number of bit errors and N is the total number of bits in the received packet, and P_b^i is the PER with i bit errors.

As for a single channel transmission, the packet detection rate $P_D^s[\hat{x}(\text{t})]$ for $\hat{x}(f_1)$ or $\hat{x}(f_2)$ is given by:

$$P_D^s\left[\hat{x}\left(\text{t}\right)\right] = 1 - P_e^S\left[\hat{x}\left(f_1\right)\right] \ or \ 1 - P_e^S\left[\hat{x}\left(f_2\right)\right] \tag{3}$$

The packet detection rate $P_D^d[\hat{x}(\text{t})]$ for the dual channel transmission is derived from the multiplication of packet error rate for the two signals $\hat{x}(f_1)$ and $\hat{x}(f_2)$ because the packet will be recovered except for the simultaneous packet errors. And the packet detection rate $P_D^d[\hat{x}(\text{t})]$ is given by:

$$P_D^d\left[\hat{x}\left(\text{t}\right)\right] = 1 - P_e^S\left[\hat{x}\left(f_1\right)\right] \cdot P_e^S\left[\hat{x}\left(f_2\right)\right] \tag{4}$$

Thus, the PDR improvement over the single channel transmission is done by:

$$P_D^d\left[\hat{x}\left(\text{t}\right)\right] - P_D^s\left[\hat{x}\left(\text{t}\right)\right] = P_e^S\left[\hat{x}\left(f_1\right)\right] - P_e^S\left[\hat{x}\left(f_1\right)\right] \cdot P_e^S\left[\hat{x}\left(f_2\right)\right] \ or \ P_e^S\left[\hat{x}\left(f_2\right)\right] - P_e^S\left[\hat{x}\left(f_1\right)\right] \cdot P_e^S\left[\hat{x}\left(f_2\right)\right] \tag{5}$$

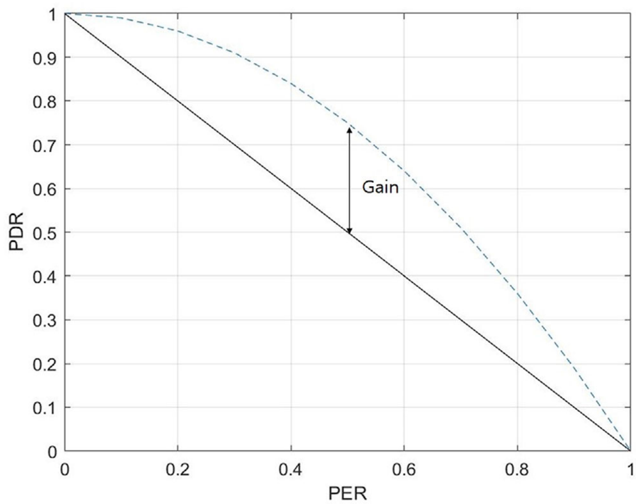

FIGURE 4 PDR versus PER between dual channel transmission and the single channel transmission, bold line indicates PDR of single channel transmission and dotted line indicates PDR of dual channel transmission

If $P_e^s[\hat{x}(f_1)]$ *is assumed to be same as* $P_e^S[\hat{x}(f_2)]$ and is denoted by P_e^S, the PDR gain of dual channel transmission is given by:

$$\text{PDR gain} = P_e^S\left(1 - P_e^S\right) \quad (6)$$

For example, if the packer error rate $P_e^S[\hat{x}(f_1)]$ *and* $P_e^S[\hat{x}(f_2)]$ for some packet size are equal to 0.1(10% PER means 90% PDR in other words), then $P_D^d[\hat{x}(\mathrm{t})]$ will be 0.99 and the PER will be improved by 0.09(9%).

4 | SIMULATION RESULT AND DISCUSSION

When the PER of two radio channels is assumed to be same, PDR versus PER for the single channel and dual channel transmission is shown as Figure 4. The PDR gain over the single channel has a maximum value 0.25 at PER = 0.5 and decreasing value for other cases.

A computer simulation is performed to analyse the PER and verify the theoretical analysis. The PER mainly depends on a modulation type, a packet size and a radio channel environment. In this simulation, the packet size is 300 bits and modulation type is an Orthogonal Frequency Division Multiplexing-Binary Phase Shift Keying Modulation (OFDM-BPSK) because the average size of safety message is known as 300 bits and OFDM-BPSK is the most stable modulation. A Non-Line Of Sight (NLOS) fading channel in highway or urban environment is assumed. Matlab tool is used for simulation modelling and performance analysis.

Table 2 shows computer simulation model which contains simulation condition and parameters.

Figure 5 shows the relationship between the bit energy to normalized noise ratio (E_b/N_0) and the PER for the single channel or dual channel transmission in dense urban NLOS Rayleigh fading channel. When E_b/N_o is equal to 35 dB, the PER values of the single and dual channel transmission are 0.1 and 0.01 respectively. Thus, it has about 9% improvement in the PER. The PER of single channel transmission in highway NLOS Rayleigh fading channel is saturated approximately to

TABLE 2 Computer simulation model

Item	Simulation parameters
Packet size	300bits
OFDM modulation	OFDM-BPSK
Operation mode	Single channel or dual channel
Radio channel	Urban NLOS Rayleigh fading, Highway NLOS Rayleigh fading
E_b/N_o range	1–40 dB

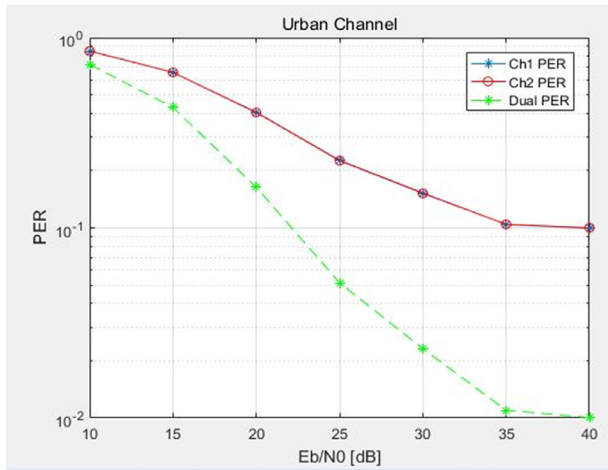

FIGURE 5 PER of dual channel transmission and the single channel transmission in dense urban NLOS channel, bold line indicates PER of single channel and dotted line indicates PER of dual channel transmission

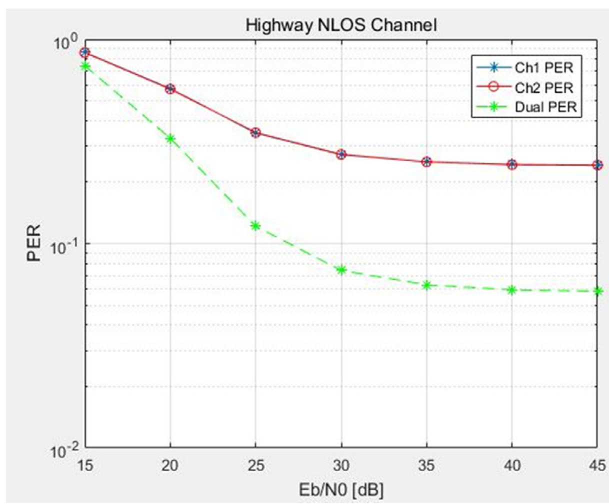

FIGURE 6 PER of dual channel transmission and the single channel transmission in highway NLOS channel, bold line indicates PDR of single channel transmission and dotted line indicates PER of dual channel transmission

0.25 at SNR = 30 dB. Also, it shows the PER improvement in dual channel transmission as shown in Figure 6.

5 | CONCLUSIONS

V2X broadcasting messages have been used for vehicle safety messages and connected automated driving applications. IEEE 802.11p based dual channel transmission is a simple and effective technique to improve the PDR over that of single channel transmission. And the simulation result shows that the PDR gain of the dual channel transmission is about 9% in urban NLOS multipath fading without a loss of packet latency. A channel coding technique can be combined with dual channel transmission. These techniques are applicable for high reliable communication system.

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