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LETTER

Performance of DSRC systems using conventional channel estimation at high velocities

Harb Abdulhamid, Kemal E. Tepe*, Esam Abdel-Raheem

Department of Electrical and Computer Engineering, University of Windsor, 401 Sunset Avenue, Windsor, Ont., Canada N9B 3P4

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Abstract

In this paper, we present a study of the dedicated short range communications (DSRC) receiver performance under varying signal to noise ratio, velocity, symbol durations and packet lengths. Conventional channel estimation, which is used in IEEE 802.11a, assumes static channel characteristics for the entire packet duration. That is found to be infeasible for high velocity DSRC applications. Simulation results show that the packet-error-rate increases with the increase in relative velocity. Viterbi decoding substantially improves the performance, but the sensitivity to Doppler shift still exists. Analysis and simulation results show that extending the symbol duration or increasing packet length results in an increase of the packet-error-rate. These results may serve as benchmarks for future DSRC channel estimation methods.
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1. Introduction

In 1999, the dedicated short range communications (DSRC) standard was established at 5.9 GHz band for vehicle-to-vehicle and vehicle-to-roadside communications. Currently, the DSRC is being developed by work group of IEEE 802.11p [1]. The United States Department of Transportation (USDoT) has been considering DSRC for accident prevention, intelligent transport systems, open road tolling, and electronic payment systems [2].

The physical layer (PHY) of DSRC was originally adopted from IEEE 802.11a standard [3] to leverage existing hardware, research and development efforts in IEEE 802.11a. However, IEEE 802.11a was designed for stationary indoor environments, and poses several issues in outdoor environment, where mobility, fading and shadowing significantly distort the signal. Among those, the multipath propagation in urban canyons results in high multipath delay spread [4], which exacerbates the intersymbol interference (ISI). Consequently, the most recent DSRC standard has increased the symbol duration to better mitigate the effects of ISI.

The feasibility study in [4] examined the robustness of the system in high multipath delay spreads and only considered situations where strong specular components existed. In [5], the packet efficiency at varying velocities has been investigated with Viterbi decoding without channel estimation. It was shown that the packet error rate increased with increasing velocities. In [6], a pseudo pilot channel estimation scheme was proposed to improve the packet error rate (PER) performance at high velocities. However, that design sacrificed the PER performance at low velocities.

In this paper, we investigate the DSRC receiver performance in varying packet lengths, symbol durations, signal to noise ratios (SNRs) and velocities to capture the

* Corresponding author. Tel.: +1 519 253 3000.
E-mail addresses: abdul1@uwindsor.ca (H. Abdulhamid), ktepe@uwindsor.ca (K.E. Tepe), eraheem@uwindsor.ca (E. Abdel-Raheem).

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performance of conventional channel estimation in DSRC through analysis and simulations. Based on those observations, we will illustrate the performance limits of a DSRC system and provide insights for possible remedies, which do not require a design change in the transmitter.

2. DSRC PHY specifications

The DSRC PHY standard utilizes orthogonal frequency division multiplexing (OFDM), in which a single serial transmission channel is divided into a number of orthogonal parallel subcarriers to optimize the efficiency of data transmission. The modulation/demodulation can be achieved in the discrete domain through the use of Fast Fourier Transform (FFT). One of the advantages of OFDM is to mitigate ISI without utilizing channel equalization. The ISI can be mitigated using a *guard interval* in OFDM symbols whose length, G, exceeds the maximum excessive delay. The guard interval consists of a cyclic prefix, which is a copy of the symbol tail that is placed at the front of the symbol, and is later removed at the receiver. This makes OFDM an ideal candidate for multipath scatter environments, where ISI inherently exists.

The DSRC standard is currently the same as IEEE 802.11a, with an exception to the symbol duration. The symbol duration of DSRC is 8.0 µs with 1.6 µs guard interval and signal bandwidth of 10 MHz. DSRC uses 64 subcarriers with only 52 subcarriers actually used for signal transmission. Of the 52 subcarriers, 4 are pilots used for phase tracking, while the remaining 48 subcarriers are used for data. The DSRC PHY packet format is shown in Fig. 1. As shown in that figure, there are two preambles. The first preamble consists of ten short training symbols for packet detection, frequency offset estimation, and symbol timing as in [7]. The second preamble consists of two identical training symbols used for channel estimation (X_{train}) subsequent to a long guard interval of length $G_{\text{CE}} = 3.2\,\mu\text{s}$.

The information data rate, R_{data}, is calculated using the following relation:

$$R_{\text{data}} = \frac{\log_2(m) R_c N_{\text{ds}}}{T_s}, \tag{1}$$

where m is the number of modulation points, R_c is the code rate, N_{ds} is the number of data subcarriers, and T_s is the OFDM symbol duration. In DSRC, T_s and N_{ds} are fixed at 8 µs and 48 subcarriers, respectively. The data rate is then determined only by selecting a modulation scheme and coding rate.

3. Channel overview

Fading channel generally induces ISI when T_s is less than 10 times the RMS delay spread, σ_τ, and this is called "frequency-selective fading" [8]. In [4], channel measurements for 900 MHz short range non-mobile vehicle-to-vehicle channels were presented. Though these results may not accurately reflect a DSRC channel, that study gives a range of values for RMS delay spread of outdoor environments in different situations. Here, we use RMS delay spreads reported in that study.

The movement of the vehicle introduces a time varying channel in addition to multipath fading. The time varying nature of the channel is quantified by the coherence time, T_c, obtained from the relation

$$T_c = \frac{0.423}{f_m} \;\Rightarrow\; f_m = \frac{v f_c}{c}, \tag{2}$$

where f_m is the maximum Doppler frequency, v is relative velocity, f_c is the carrier frequency, and c is the speed of light [8]. The channel is characterized as "fast fading" when the symbol duration exceeds the coherence time. This means that the channel impulse response is changing within the symbol duration. Therefore, extending the symbol duration, which is the case for DSRC, increases the receiver sensitivity to Doppler shift. In the following sections, we will investigate the effect of extending symbol duration on DSRC receiver performance.

4. System model

In this section, we describe the system components and the channel model used in this study. Fig. 2 shows the transmitter and receiver components and configuration. Here, we investigate the effect of conventional channel estimation to the receiver performance, mainly probability of packet errors.

At the receiver, the guard interval is removed from the received signal, then the received signal is converted to parallel signals denoted as $y_{n,k}$ in Fig. 2(b). The signal $y_{n,k}$ is fed into the Fast Fourier Transform (FFT), yielding the following output in the frequency domain:

$$\text{FFT}[y_{n,k}] = Y_{n,k} = H_{n,k} X_{n,k} + W_{n,k}, \tag{3}$$

where $H_{n,k}$ denotes the channel frequency response at the nth symbol index of the kth subcarrier, $W_{n,k}$ represents the additive white Gaussian noise (AWGN), and $X_{n,k}$ is the data that was input to the Inverse FFT (IFFT) of the transmitter. The channel estimator employs the second preamble, which

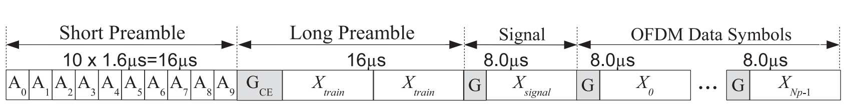

Fig. 1. DSRC transmission packet format.

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