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Doppler Effect Analysis and Modulation Code Derivation

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Abstract

To reduce the risk of accidents, traffic, and other safety related problem’s on public roads, the Wireless Access in Vehicular Environment (WAVE) standard was created. The WAVE also known as Dedicated Short Range Communications (DSRC) at 5.9GHz, is part of the Federal Highway Authority’s Vehicle Infrastructure Integration (VII). This standard merely supports Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications for emerging Intelligent Transportation Systems (ITS). Due to the high mobility of this network, nodes involved in communication suffer from intermittent signal degradation. This is partly due to Doppler Effect (DE). This paper investigates and analyses the DE over wide Doppler Shift (DS) ranges. The results of the analysis clearly demonstrate that, sustainable communication links is achievable with DS ranging up to 1400Hz if an appropriate Modulation Code Scheme (MCS) can be selected. It also demonstrates that a BPSK Rate of 1/2 is not always a good candidate when combating DE.

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1. Introduction

To reduce the risk of accidents and improve safety related issues on public roads, the WAVE standard was created for a vehicular network environment [1]. WAVE refers to a set of emerging standards for mobile wireless communications supporting the ITS [2]. The WAVE standard is a combination of two other standards namely the IEEE 802.11p and the IEEE 1609 [3]. The former is designed to handle all operations related to the Medium Access Control (MAC) and Physical (PHY) layers while the later concerns more the operations related to upper layers. IEEE 802.11p makes use of Orthogonal Frequency Division Multiplexing (OFDM) technology. Due to the high sensitivity of OFDM symbols to Doppler Effect [4] and based on the high mobility of the nodes involved in vehicular networks, Doppler Effect
analysis is of great importance for Quality of Service (QoS) delivery in a Vehicular Ad Hoc networks (VANET).

This focuses on the analysis of Doppler Effect (DE) effect on vehicular network performances. Several contributions have been proposed in to enhance the VANET performance. In [5], a new and effective Doppler Effect compensation scheme for OFDM systems based on constellation estimation is presented. The approach makes use of analytical descriptions that quantitatively clarify the mechanism of inter-carrier interferences. It is shown in [6] that the Doppler frequency shift affects the frequencies of the RF carrier, subcarriers, envelope, and symbol timing by the same percentage in an OFDM signal or any other modulated signals. The study also analyzed the Signal to Noise Ratio (SNR) degradation of an OFDM system due to Doppler frequency shift, frequency offset of the local oscillators, and phase noise. In [7], to implement Doppler compensation, a new hybrid polyphase code set combined with a single frequency pulse is proposed to enables Orthogonal Netted Radar Systems (ONRS) to have good resilience to Doppler shifts. The author in [8] considers a novel technique for the measurement and correction of the Doppler shift (frequency offset) in a received QPSK signal in which the Doppler shift may be very high, the signal/noise ratio very low, and the receiver has no prior knowledge of the received data symbols. In [9], a new methodology to reduce the impact of Doppler shift is proposed.

This paper presents a detailed analysis of Doppler Shift effect on IEEE 802.11p channel performance evaluation through simulation. The Doppler Shift values affecting two mobiles moving in opposite directions at a speed of up to 140 km/h is considered.

The remainder of this paper is organized as follows. Section 2 presents a system model developed based on the IEEE 802.11p protocol. This is followed by simulation and analysis detailed in section 3. Section 4 presents an extracted model from the simulations followed by test results using extracted MCS followed by an analysis of the results. Finally, conclusions and perspectives are given in section 5.

2. System Model

A system model based on the specifications of IEEE 802.11p [10] was implemented in MATLAB. Any communication system can be broken down into three basic blocks, namely Transmitter, Channel and Receiver. These blocks are represented in the model depicted in Figure 1, with the exception of the BER block, which is used to compare transmitted data against received data. Each block of this system is made of several subsystems blocks that will be described all along the system model description.

![Figure 1: System Model](image)

2.1. Transmitter Subsystem

Since the IEEE 802.11p Physical Layer was obtained with little modification to the IEEE 802.11a, the data transmission process is similar to it. The fragmentation starts with the Physical Layer Convergence Protocol (PLCP) to form a PLCP Data Unit (PPDU) from the Medium Access Control (MAC) payload, which is called the PLCP Service Data Unit (PSDU) [9]. In the model considered in this study, input data is generated randomly. After padding, Binary to decimal conversion is then conducted based on the
convolutional encoder rate selection. This operation allows binary data to be converted into data symbols. Data symbols are modulated based on the selected modulation code scheme. This step converts data symbols into complex data. Serial to Parallel (S/P) conversion is done based on the number of OFDM subcarriers. This complex data is then converted into time domain through an Inverse Fast Fourier Transform (IFFT) operator. The IFFT also converts received complex data symbols into OFDM data symbols. Parallel to Serial (P/S) conversion is done followed by pilot insertion. The final step for the transmitter is data up conversion. This block converts baseband signals into a higher frequency signal of the transmitter carrier. The diagram of the transmitter diagram is presented in Figure 2.

![Figure 2: Transmitter Subsystem](image)

### 2.2. Channel Subsystem

In order to simulate a VANET environment, a combination of two existing channel models namely a white Gaussian Noise (AWGN) and Rayleigh were implemented. AWGN degrades the signal by adding white Gaussian noise to a complex input signal. These added complex noise values are uncorrelated and Gaussian with zero-mean and noise variance which are defined as:

\[
\text{Noise variance} = \frac{\text{Signal Power} \times \text{Symbol Period}}{\text{Sample Time} \times 10^{\frac{Es}{No} / 10}}
\]

\[
\frac{E_s}{N_0} = \frac{E_b}{N_0} + 10\log_{10}(k)
\]

where \(E_s/No\) is the ratio of symbol energy to noise is power spectral density, \(Eb/No\) is the ratio of bit energy to noise power spectral density and \(k\) is the number of bits per symbol. The combined channel model is depicted in Figure 3.

![Figure 3: Channel Model](image)

In a Rayleigh fading channel, a transmitted signal is subject to fading caused by various factors resulting from the mobile wireless environment behaviour. Rayleigh fading channels are useful models of real-world phenomena in wireless communications. These phenomena include multipath scattering effects, time dispersion, and Doppler shifts that arise from relative motion between the transmitter and receiver. Typically, the fading process is characterized by a Rayleigh distribution for a non-line-of-sight path.
2.3. Receiver Subsystem

The receiver is the reverse process of the transmitter block completed with channel estimation and equalization. After detection and reception of the higher frequency signal carrier, down conversion is first performed. This is followed by frame synchronization and cyclic prefix removal, pilot removal, channel estimation and equalization. The rest of the processes that follow are described by blocks as illustrated in the receiver system presented in Figure 4.

Figure 4: Receiver Subsystem

3. Model Validation

The IEEE 802.11p standard was created to provide radio access to roads and cars so that information can be transmitted at higher speeds and with greater transmission ranges (1000m) compared to the IEEE 802.11b (38-46m). Considering a maximum speed of 140 km/h, the Doppler shift can go up to 1400 Hz. Results from this model were obtained after computation of 100 frames of 1500 bytes each. The OFDM model was used with 52 subcarriers (48 data + 4 pilots) and 64 point FFT. This was done with a channel bandwidth of 10MHz and carrier frequency of 5.85 GHz.

The probability of BER is one of the most common criterion used to analyse the behaviour of a given channel model. This probability depends on a bit constellation size for a given signal symbol. Related formulae and derivation have been analysed and discussed in [11-13].

Based on these theoretical models, it can be seen from Figure 5 that for BPSK, QPSK and 16-QAM modulation curves exhibit the model tests. It can also be seen that 64-QAM is slightly deviated from the theoretical derivation. However, this can still be used to validate the simulations. Using a training sequence for channel estimation under a Rayleigh channel model, the obtained results are depicted in Figure 6. It is assumed that a long training sequence has a magnitude of unity and noise samples are statically independent so that their variance is half the variance of the individual sample, thus enhancing SNR by 3dB [14]. From theoretical derivation, Figure 6 clearly exhibits the performance of the Rayleigh channel model [9]. These channels simulation results are therefore used as the model validation for the Doppler Effect (DE) simulation presented in the next section.

Figure 5: AWGN channel model
Figure 6: Rayleigh channel based on TS estimation
4. Simulation and analysis

To explore the link quality performance of the VANET under a wide range of DS, a Modulation Code Scheme (MCS) model (Figure 8) was derived from simulation and used to test the system model under various channel conditions. Setting SNR at a fixed value of 30 dB over all channel realisations, obtained results are given in Figure 7. Figure 8 was obtained from Figure 7 based on the selected MCS that minimized the BER. Under ideal conditions and smart MCS selections, the channel response of the system can be approximated to that of Figure 8. The selected MCS providing this figure 8 is presented in figure 9.

The MCS presented in figure 9 are then used as a MCS selection model. In Figure 9, MCS 1 to 8 are respectively equivalent to BPSK rate 1/2 and 3/4, QPSK rate 1/2 and 3/4, 16-QAM rate 1/2 and 3/4 and 64-QAM rate 1/2 and 3/4. This MCS selection is then applied to simulations to explore its consistency.

The test results obtained are presented in Figure 10, 11 and 12. The analysis from Figure 9 shows that to obtain the results shown in Figure 8 representing minimal DE selection based on Doppler shift variation, MCS 1 which corresponds to BPSK Rate 1/2 was selected only once at 600Hz. In figure 10, it
can be seen that apart from Frequency Shift (FS) of 300Hz, 700Hz and 900Hz, the selected MCS based on the model performed well. In Figure 11, apart from FS of 600Hz, 650Hz and 900Hz, the system also performed well. Figure 12 also shows that apart from FS of 650Hz, the system performed well on average. It is clear to observe that around FS closer to 600Hz, the BER is very high. This means that the BPSK Rate 1/2 which has demonstrated robustness against noise and interferences do not really work in the case of Doppler Effect. The test results clearly demonstrated that if the appropriate MCS is selected in accordance to a specific FS, a good and reliable communication link over a wide range of FS can be sustained in a vehicular network besides the sensitivity of OFDM symbols to Doppler Effect.

5. Conclusion

This work presented the Doppler Effect analysis and the impact it has on the vehicular network standard. Based on IEEE 802.11p specifications, a model was developed and validated. Doppler analysis with all MCS over a FS range from 0 to 1500Hz was computed and presented in Figure 7. Figure 8 presented the minimal DE which was derived from Figure 7. Using extracted MCS selection of Figure 9, several tests were performed. Results from the tests show that except for some points between 600 to 700 Hz and 900 Hz, the model performed well. This therefore demonstrates that reliable communication can be sustained over a wide range of Doppler Shift if the appropriate MCS can be selected in accordance to a specific FS.

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References


