A SIMULINK-BASED MODEL AND ANALYSIS OF THE PHY LAYER IN VEHICULAR COMMUNICATIONS

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ABSTRACT

Advancements in wireless communication systems are giving rise to newer technologies of communication not only between multiple mobile devices, but also between mobile devices and any other kind of machines. Moreover, frequency bands that are higher than the Ultra high frequency (UHF), range of 300 MHz to 3 GHZ, will be used for the next generation of communication systems. Vehicular communications is one of such advancing areas, with numerous potential applications such as safety, reduction of traffic congestion, and entertainment. Dedicated Short Range Communications (DSRC), centered at the 5.9 GHZ band, is currently used as the propagation standard for Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication systems. The IEEE 802.11p standard has been formulated specifically for describing the PHY and MAC layer parameters of DSRC-based vehicular communication. However, despite a growing interest in this area, there are very few simulations of the PHY Layer of DSRC available. Performance analysis of DSRC that uses high frequency is needed and has potential to support current and new policies and regulations. Our paper mainly focuses on a Simulink-based design of the 802.11p PHY layer, and a study of the performance of this simulated model in different kinds of realistic noise. This DSRC PHY simulator consists of a transmitter and receiver, both created based on IEEE 802.11p standards, and a user-configurable multipath/noise channel.

1. INTRODUCTION

Recently there has been an enormous rise in LTE and public safety system usage. These systems mostly operate at frequencies less than 3 GHz. However, it is becoming increasingly obvious that higher frequency systems will be used heavily in the future, and it is essential to prepare for such high frequency systems by creating/revising regulation. To establish appropriate regulations for systems operating above 3GHz, specific performance evaluations of these systems are needed. Dedicated Short Range Communications (DSRC) is an example of a communication standard for use at high frequencies. Centered at 5.9 GHz and following the IEEE 802.11p standard, DSRC is mainly used for Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication systems. As shown in Figure 1, the DSRC spectrum is separated into seven 10 MHz channels; channel 178 is the Control Channel (CCH) reserved for safety communications, the two channels at either end of the spectrum band are reserved for special uses and the remaining channels are Service Channels (SCH).

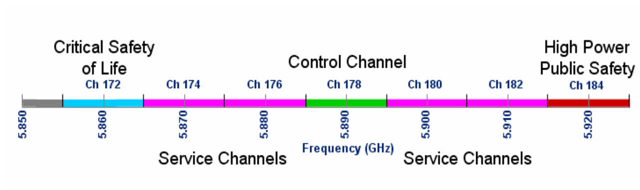

Figure 1. DSRC Spectrum Bands in U.S.A. [1] [1]

Because of its robustness in fading and low latency, DSRC possesses enormous potential for public safety and as a reference for design of future communication systems that use such high frequencies. For fulfilling this role of a reference, a good performance is required; however, published papers that characterize DSRC performance present a variety of results that are not entirely consistent and some of them are not following the 802.11p standard. Therefore, a simulation that strictly follows the standard is required. The following sections will be discussing the physical (PHY) layer design for IEEE 802.11p standard and simulation results which are based on the standard.

2. IEEE 802.11P PHY STANDARD

The IEEE 802.11p standard is an amendment to IEEE 802.11-2007 for Wireless Access in Vehicular Environments (WAVE) applications [2]. It combines a variation of the IEEE 802.11a PHY layer with the IEEE 802.11e Medium Access Control (MAC) layer [3]. The signal processing of IEEE 802.11p is essentially the same as processing of IEEE 802.11a, OFDM PHY. However, IEEE 802.11p allocates 10 MHz bandwidth for each individual channel while IEEE 802.11a uses wider channels of 20 MHz bandwidth. Also the

[1] © 2008 IEEE. Reprinted, with permission, from [1]

subcarrier spacing and the data rate of IEEE 802.11p are half of IEEE 802.11a's specification, but symbol interval including cyclic prefix (CP) is doubled [2]. More specific compared values between IEEE 802.11a and IEEE 802.11p is shown in Table I.

Thus, the parameters for IEEE 802.11a and IEEE 802.11p are almost identical except for doubling in time units and halving for frequency units. These changes have been made in order to mitigate the effect of frequency-selective fading and thus accommodate the high mobility of vehicular networks.

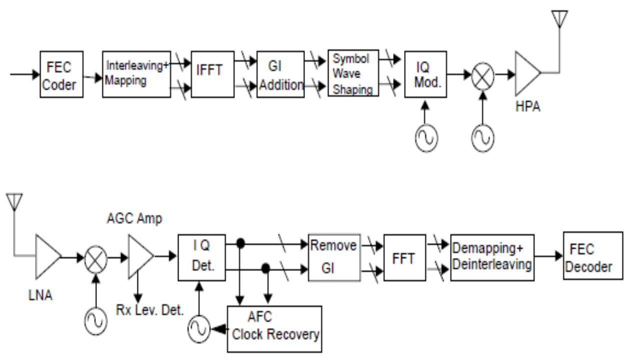

Figure 2. Transmitter and Receiver Block Diagram for OFDM PHY [4] [2]

Table I. Comparison Between IEEE 802.11a and IEEE 802.11p

	IEEE 802.11a	IEEE 802.11p
Bandwidth	20 MHz	10 MHz
Bit Rate	6, 9, 12, 18, 24, 36, 48, 54	3, 4.5, 6, 9, 12, 18, 24, 27
Modulation Scheme	BPSK, QPSK, 16 QAM, 64 QAM	BPSK, QPSK, 16 QAM, 64 QAM
Code Rate	1/2, 2/3, 3/4	1/2, 2/3, 3/4
Data bits per OFDM symbols	24, 36, 48, 72, 96, 144, 192, 216	24, 36, 48, 72, 96, 144, 192, 216
# of Subcarriers	52	52
# of Data Subcarriers	48	48
# of Pilot Subcarriers	4	4
Subcarrier Spacing	0.3125 MHz	0.15625 MHz
FFT Period	3.2 µs	6.4 µs
FFT/IFFT Size	64	64
Guard Time	0.8 µs	1.6 µs
Preamble Duration	16 µs	32 µs
Symbol Duration	4 µs	8 µs
Signal Field Duration	4 µs	8 µs
CP Interval	0.8 µs	1.6 µs
OFDM Symbol Interval	4 µs	8 µs
Max EIRP	800 mW	2W

For PHY layer simulation, only one transmitter and one receiver are necessary. The transmitter and receiver design for IEEE 802.11p includes the same functional blocks as the

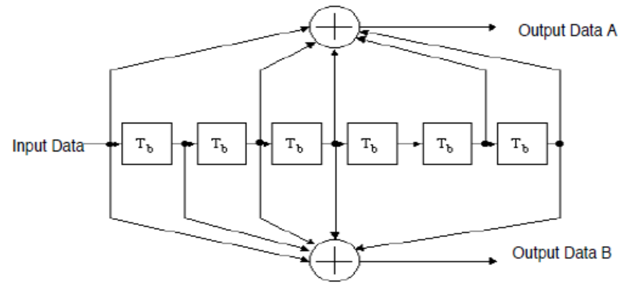

Figure 3. Convolutional Encoder (K=7) [4] [2]

design of IEEE 802.11a, and both of them are use OFDM in the PHY layer. Figure 2 shows transmitter and receiver block diagrams for OFDM PHY.

The OFDM PHY's Forward Error Correction (FEC) coder uses a convolutional code with K=7 and coding rates of R=1/2, 2/3, or 3/4. Also the convolutional encoder uses the generator polynomials g_0=133 and g_1=171. In Figure 3, output data "A" shall be output from the encoder before the output data "B". A Viterbi decoder is recommended and used for the simulation.

All encoded bits are interleaved to a block size corresponding to the number of bits in one OFDM symbol. Bits in one OFDM symbol differ based on the combination of modulation schemes and coding rate.

48 data subcarriers, 4 pilot subcarriers (which are located on subcarriers -21, -7, 7, and 21), one null subcarrier, and 11 subcarriers for guard are in one OFDM symbol that has 6.4µs period time. After creating one OFDM symbol, a guard interval and preamble are inserted. More specific numerical parameters are shown in Table I.

3. SIMULATOR DESIGN

The IEEE 802.11p simulator is modified from an IEEE 802.11a simulation file which is provided by MATLAB Simulink [5]. The simulator is fully implemented in software, and it contains one transmitter, one receiver, modulation/coding rate controller, noise environment selection, and performance analyzer. Figure 4 shows block diagram of whole simulator.

The Transmitter block performs the following tasks: random bit generation, pilot addition, training sequence addition, OFDM and modulation. It can also adapt to preselected modulation schemes and coding rates. The available options

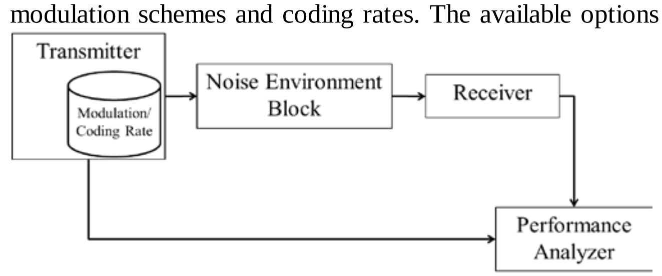

Figure 4. Block Diagram of Simulator

[2] © 1999 IEEE. Reprinted, with permission, from [4].

are BPSK 1/2, BPSK 3/4, QPSK 1/2, QPSK 3/4, 16-QAM 1/2, 16-QAM 3/4, 64-QAM 2/3, and 64-QAM 3/4. The modulation scheme also decides the number of data bits per OFDM symbol: 24, 36, 48, 72, 96, 144, 192, and 216 respectively. Each OFDM symbol has 48 data subcarriers, and each frame has 20 OFDM symbols. Therefore, total data bits per each frame are 480, 720, 960, 1440, 1920, 2880, 3840, and 4320 respectively. The randomly generated digital signals will be modulated through modulation, OFDM modulation, pilot addition, and training sequence addition processes and transmitted.

The Noise Environment Block performs the function of selecting a user-defined noise (and/or fading) environment. Since DSRC is mainly designed for vehicular communication, fading is generally the dominant propagation phenomenon. DSRC is usually Line-of-Sight (LOS) communication, so Rician fading is more common than Rayleigh fading. Therefore, the simulation is mostly focused on Rician fading with various parameter values. As already mentioned, the block possesses both fading functionality and Additive White Gaussian Noise (AWGN) functionality. The reason of existence of AWGN is not only to create realistic noise environment but to also compare the performance between IEEE 802.11p and IEEE 802.11a in the absence of fading. By the noise environment block, the simulator can run in different realistic noise environments which can be controlled by users.

The Receiver performs OFDM demodulation, training sequence removal, discarding of pilot, and demodulation functionalities. The receiver also has a copy of the original bits that were subjected to noise and fading, to be used as a reference by the performance analyzer.

The performance analyzer has two major inputs: the randomly generated bits at the transmitter and the bits after receiver. Also, it possesses the information as to which modulation scheme and code rate have been used, and uses this for calculations. The main purpose of the performance analyzer is to measure Signal-to-Noise-Ratio (SNR), calculate E_b/N_0 and find the Bit-Error-Rate (BER). Using data collected from performance analyzer, the simulator can then visualize the performance.

4. SIMULATION RESULTS

The simulations consist of the following steps: comparison of performance between IEEE 802.11a and IEEE 802.11p, performance of IEEE 802.11p through Rayleigh fading and Rician fading with different k factors in linear scale, fading performance with different modulation schemes, and fading performance with different coding rates. Figure 5, 6, 7, 8 and 9 are the simulation results. The simulator runs 10,000 frames for each combination of noise value, modulation schemes, and coding rates.

Figure 5 shows performance of IEEE 802.11a and IEEE 802.11p in terms of BER vs SNR. The bold lines and points are the results for IEEE 802.11a and dashed lines and triangle markers represent IEEE 802.11p. The figure shows all combinations of modulation schemes and coding rates. As shown in Figure 5, the BER-SNR relationship of IEEE 802.11p is same as that of IEEE 802.11a; IEEE 802.11p shows small SNR advantages on BPSK 1/2, QPSK 1/2, 16-QAM 1/2, and 64-QAM 2/3 due to artifacts of the simulator. All BER graphs have steep slope and BER=0.5 at low SNR.

Figure 6 demonstrates the performance of IEEE 802.11p in Rayleigh fading and in Rician fading with different k factors, which are linear units: 1, 2, 4, 10, 15, and 20. The simulation is run with QPSK 1/2 and a velocity of 10 mph. When k=1 and 2, the performance is similar; however, the performance improves for larger values of the k factor. Also for higher k factors, 10~20, the performance is within a few dB of that in AWGN.

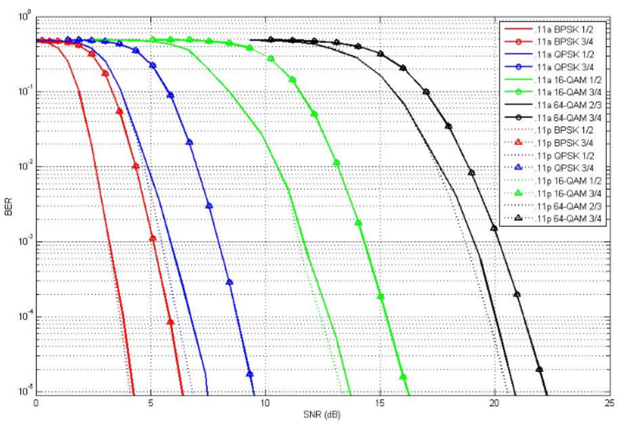

Figure 5. Comparison between IEEE 802.11a and IEEE 802.11p

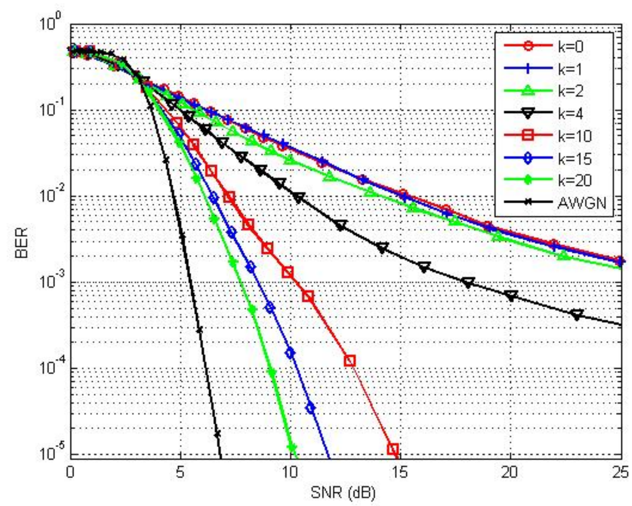

Figure 6. Performance of IEEE 802.11p through Rayleigh fading and Rician fading

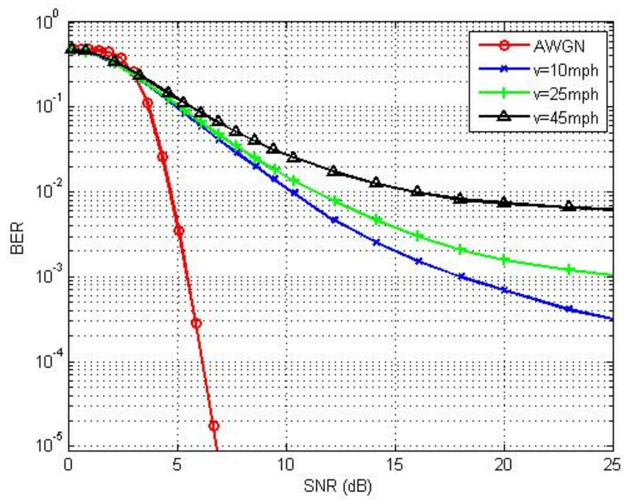

Figure 7. Performance of different velocity through Rician fading with k=4

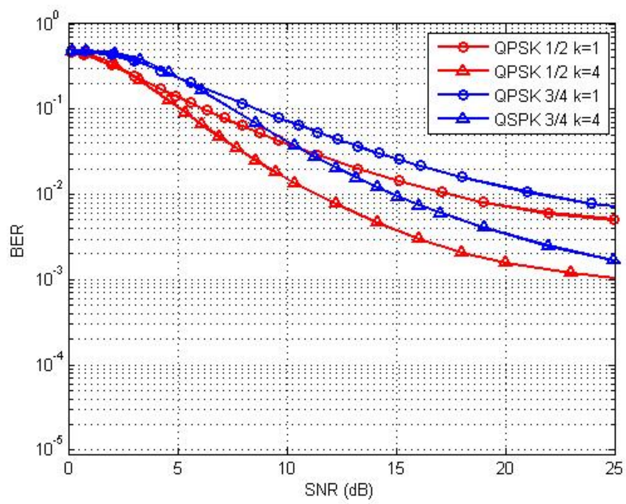

Figure 8. Performance of different coding rates through Rican fading with k=1 and k=4 at a velocity of 25 mph

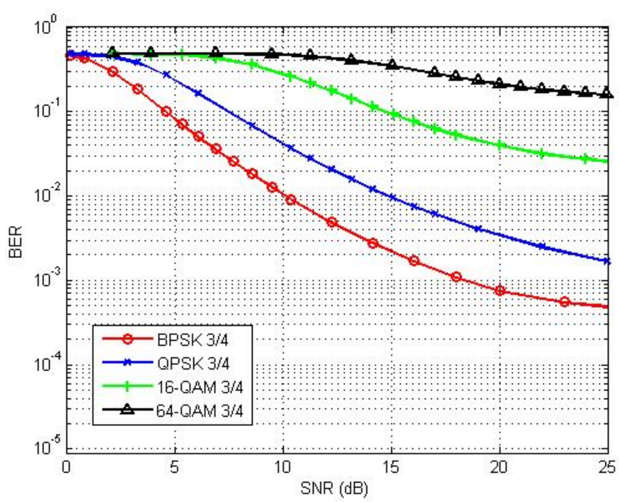

Figure 9. Performance of different modulation schemes through Ricean fading with k=4 at a velocity of 25 mph

Figure 7 shows the performance of IEEE 802.11p through Rician fading with different velocity which affects the Doppler shifts, also AWGN data has been plotted together for reference. The simulation used QPSK 1/2 and k=4; the velocities that used are 10, 25, and 45 mph which are usually used in real life. The result shows that higher velocity will give worse performance.

Figure 8 describes the performance of IEEE 802.11p in Rician fading with k factor of 1 and 4, using QPSK 1/2 and QPSK 3/4, and velocity of 25 mph. The reason for choosing k factor of 1 and 4 is that these two values are mean values for two frequent environments for vehicles: urban crowded areas and suburban expressways, respectively [6] [7]. The value of coding rate advantage, stays constant at approximately 3 dB, irrespective of the type of fading environment.

Figure 9 shows the performance of IEEE 802.11p through Rician fading using different modulation schemes: BPSK, QPSK, 16-QAM, and 64-QAM. Both the k factor and velocity are fixed, at 4 and 25 mph respectively. As shown in the figure, the relative performance of the modulation schemes is about the same as shown in Figure 5.

The simulator currently possesses the capability to control modulation scheme, coding rates, type of fading, LOS factor and AWGN metrics such as SNR and E_b/N_0. Further possible developments include simulating over various other noise environments and testing more metrics for a desired result.

5. CONCLUSION AND FUTURE WORK

Communication systems of the future are expected to face a severe problem of limitation in frequency availability, and one solution to this problem is to use a higher frequency band. Already some regulations for such bands have been formulated by the FCC; however, considering the potential for frequencies above the 5 GHz band, it is necessary to create more such regulations. DSRC, using IEEE 802.11p standard, is one such communication system operating above 5 GHz. Referencing DSRC can thus significantly ease the creation of future regulations for all such high frequency bands. However, in current literature, there are very few papers on the performance of IEEE 802.11p; these also often have inaccurate results that do not match with each other or do not follow the standard. The Simulink-based simulator which follows IEEE 802.11p standard has been implemented for resolving this problem and hopefully aiding future research on DSRC. Although the simulator currently includes only AWGN, Rayleigh fading and Rician fading, its modular design will allow simulation using other fading models. Also by modifying the performance analyzer, the performance can also be evaluated using metrics other than BER. The current simulator is simulating only about PHY layer, and future versions will add MAC layer and possibly

Network layer simulation capability. The Simulink-based simulator is created for the purpose of providing a reference for use in research on DSRC radios. Future enhanced versions of the simulator will create more realistic noise, fading, and/or interference scenarios and analyze performance using more metrics to provide better information for regulators and enable future research related to the IEEE 802.11p standard.

6. ACKNOWLEDGMENT

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