Enhancing the Physical Layer in V2V Communication Using OFDM – MIMO Techniques

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***Abstract* - Vehicular Ad hoc network (VANET) has recently been attracting the attention of researchers as a new technology in the wireless communication system. Vehicle-to-vehicle V2V communication can be considered an important way to help the drivers to satisfy requirements such as less congestion, accident warning, road exploration, etc. The propagation issues such as multipath fading significantly affect the reliability of V2V communication.**

The goal of this work is to enhance the performance of the physical layer PHY in V2V communication. However, the cellular phone channel has been used to evaluate the possibility of apply it in the vehicular communication V2V. The simulation results observed that the transmitted signal is affected by a multipath fading channel. In order to overcome this problem two techniques are used: Orthogonal Frequency Division Multiplexing (OFDM) technique and Multiple-Input-Multiple-Output (MIMO) diversity technique. The simulation results showed that the OFDM technique overcomes the multipath fading with high transmission power. On the other hand, MIMO diversity technique called Alamouti Space-Time Code for two transmitters and two receivers (MIMO 2x2) is used to improve the error degradation with less transmission power.

Keywords— VANET; V2V; DSRC; OFDM; MIMO; Alamouti.

I. INTRODUCTION

Nowadays the use of electronic technologies and communication devices are used by the manufacturers to make the trip more comfortable and safer in the automobile industry has grown significantly [1]. Technologies have been adopted by vehicle manufacturers for decades [2], while adopting and integrating wireless communications technologies such as vehicular ad hoc networks VANET is a relatively new area [3]. VANET is a technology which uses the moving vehicles as nodes in the wireless network. It can also be considered as a form of advanced mobile ad-hoc network, as it is instantaneous and mobile [4]. An important advantage of VANET is the unlimited battery power generated during the journey [5].

VANET could be represented by different forms of topologies: vehicle-to-vehicle V2V and vehicle-to-roadside V2R [6]. Researchers aim to produce a full wireless communication solution among vehicles, to satisfy requirements such as less congestion, accident warning, road exploration, etc. These requirements will not be achieved unless there are applications that benefit from them. Therefore VANET applications are classified in two main categories: safety and comfort applications that have attracted the most attention during the years [7]. These requirements could be assured, based on the three VANET components, which are: the available wireless infrastructures technologies (Wi-Fi, 3G, GSM and WiMAX), on board units (OBUs) devices and road side units (RSUs) devices [7]. The motorway will be equipped with communication RSU devices which could be operated by government or a private sector that allow vehicles to communicate and/or to access the internet though OBU devices. This paper is first a feasibly study of utilising MIMO and OFDM in the PHY layer in V2V communication and second evaluation based on MATLAB simulation result.

The paper is organized as follows. In Section II, important general background information on VANET and IEEE 802.11p standards is provided. Next, different techniques are explained such OFDM and the benefit of MIMO in VANET in same section. The wireless channel model is discussed in Section III. Simulation Results are presented in Section IV. Finally, Section V and VI discuss and conclude this paper.

II. BACKGROUND

A. DSRC and VANET Standard

Dedicated Short Range Communication DSRC is the wireless communication protocol for the vehicular networks, established in the United State in 1992 [8]. DSRC was approved by the United State Federal Communication Commission FCC to support the Intelligent Transport System ITS applications in the short range communication for such VANETs. In 2004, the DSRC joined the IEEE (Institute of Engineering Electrical and Electronics) and classified as IEEE 802.11 standard [9]. IEEE produced the Wireless Access for Vehicular Environment WAVE, which is considered the core of the DSRC for vehicles fast moving, as shown in Figure 1. [10].

The architecture of the WAVE contains both IEEE 802.11p and IEEE 1609 standards, IEEE 802.11p which release the physical layer PHY and the Medium Access Control layer MAC specifications to enable the VANET communication in the 5.9 GHz spectrum, whereas the IEEE 1609 cooperates with the IEEE 802.11p standards develop the

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specifications of additional layers in the protocol suite of the WAVE [10].

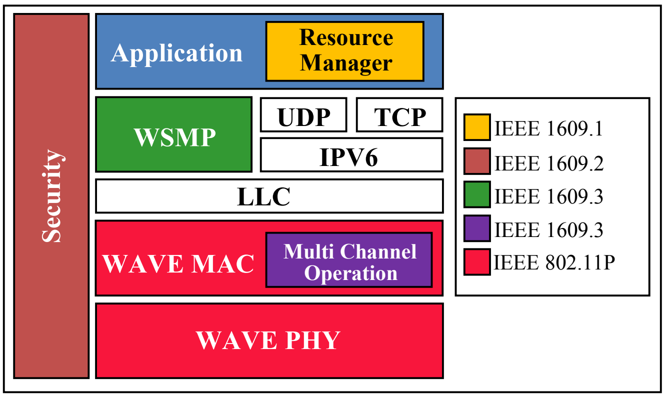

Fig. 1. Wireless Access for Vehicular Environment WAVE Protocol Stack.

B. *Orthogonal Frequency Division Multiplexing OFDM and Modulation*

The IEEE 802.11 standard based on the orthogonal frequency division multiplexing OFDM, three channels allocated to be used with the following bandwidths: 5MHz, 10MHz and 20MHz. The 10MHz channel will universally use for VANET communications while the 20MHz is commonly used for 802.11a [11]. The OFDM channel basic parameters for the IEEE 802.11 at 10MHz bands are shown in table I:

TABLE I
THE BASIC PARAMETERS OF OFDM CHANNEL IN 802.11 AT 10MHZ

Parameters	Values
Subcarrier Numbers	48
Pilot Subcarrier Numbers	4
Subcarrier no. + Pilot Subcarrier no.	52
Subcarrier frequency spacing	156.25 kHz
Guard interval	1.6 µsec
Symbol interval + guard interval	8 µsec

The signal can come in 4 different types of modulation:

- Binary phase shift keying BPSK.
- Quadrature phase shift keying QPSK.
- 16-point quadrature amplitude modulation 16-QAM.
- 64-point quadrature amplitude modulation 64-QAM.

Each modulation technique illustrates a different number of bits encoded per subcarrier symbol as can be seen in Table II.

TABLE II
802.11 OFDM MODULATION TECHNIQUES

Modulation	Bit per subcarrier symbol
BPSK	1
QPSK	2
16 QAM	4
64 QAM	6

The user bits are enhanced by the Forward Error Correction (FEC). This is because the FEC not only improves the probability of successful decoding but it also reduces the effective user bit rate as shown in table III. We can utilise three FEC codes which are 1/2, 2/3, and 3/4. We can formulate 12 combinations between the four different modulations and the three FEC codes. Despite this, only 8 out of these 12 combinations are actually allowed in the 802.11 OFDM.

TABLE III
DATA RATE OPTIONS IN A DSRC 10 MHZ OFDM CHANNEL

Modulation	Coded bit rate (Mbps)	Coding rate	Data rate (Mbps)	Data bits per OFDM symbol
BPSK	6	1/2	3	24
BPSK	6	3/4	4.6	36
QPSK	12	1/2	6	48
QPSK	12	3/4	9	72
16 QAM	24	1/2	12	96
16 QAM	24	3/4	18	144
64 QAM	36	2/3	24	192
64 QAM	36	3/4	27	216

C. *MIMO Technology in VANET*

There is a variety of significant research challenges which need to be overcome. These challenges are caused because multiple - input - multiple - output MIMO technique is exploited in the wireless communication. The key research issues include:

- Channel evaluation.
- The processing of space time signal in V2V.
- Channel modelling.

MIMO provides considerable advantages including having wider coverage area, enhancing the multi fading environments and improving higher data throughputs. Providing high data rate at high quality of service QoS in VANET communication system is considered as the most challenges in this research area [12] [13]. Due to the factors that could affect to the signal strength like scattering, reflection and interference the link reliability is needed to improve the QoS. However, MIMO technology seems to meet these issues in term of increasing the inbound and outbound data traffic [14].

MIMO can be classified into two main categories which are smart antennas and spatial multiplexors. The function of smart antennas is that they utilise diversity gain, array gain and/or interference suppression to offer an increased signal-to-noise-and-interference ratio (SNIR). Each individual transmitter antenna sends the same signal but it has a simple gain and delay difference, as does the receiving antenna. The gain and delay difference can be set appropriately so that an improved SNIR can be accomplished. From this, we can obtain better spectral efficiency, greater range and/or decreased latency [15]. Spatial multiplexors are able to give an increased channel capacity directly. A single transmit antenna sends out an independent sub-stream signals with N transmit and N receive antennas.

There are many different types of smart antenna diversity techniques, such as space diversity, polarisation diversity, time diversity, frequency diversity and angle diversity. This paper considers one of the Time space coding techniques called Alamouti Space-Time code. It is a complex orthogonal space-rime block code technique suitable for two antennas that encodes two consecutive symbols.

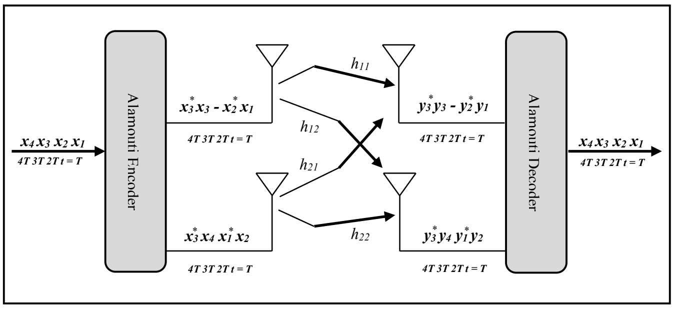

Fig. 2. Alamouti Encoder/Decoder for MIMO (2x2).

As shown in Figure 2, two symbols x_1 and x_2 are simultaneously transmitted from the two antennas then the two symbols $-x_2^*$ and x_1^* are simultaneously transmitted from the two antennas again. Where as x_1^* is the complex conjugate of x_1 while $-x_2^*$ is the negative complex conjugate of x_2, i.e if$x_2 = (1 + i)$ then$-x_2^* = -(1 - i)$.

The overall mathematical model for Alamouti is illustrated in the following equations:

$$Y = H.X + N$$

$$\begin{bmatrix} y1(t) \\ y2(t) \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} . \begin{bmatrix} x1(t) \\ x2(t) \end{bmatrix} + \begin{bmatrix} n1(t) \\ n2(t) \end{bmatrix} \ldots. (1)$$

Whereas,

X is the transmitted symbols vectors,
Y is the received symbols vectors,
H is the channel characteristics matrix
N is the noise vector.

D. The Benefit of MIMO in VANET

MIMO can provide us with a variety of prospective benefits that could convey to meet the major challenges. Furthermore, the benefits of MIMO can aid the exploitation of opportunities in the V2V applications. The benefits of MIMO to VANETS are demonstrated below:

MIMO adaptability best matches various scenarios: The adaptability of the MIMO provides a significant facility for vehicles communications. This adaptability is evident in the capability to constitute the multiple antennas in multiple modes, based on the interference intensity, propagation environment and the vehicular application of interest and to meet the safety requirements and satisfactory user experience applications. In order to obtain the highest possible data rate such as media streaming, spatial multiplexing would have to be used, while the short warning messages, in safety applications, require a diversity schemes. Furthermore, beam forming techniques focuses the transmitted signal, expanding the communication range. In areas where the vehicle density is relatively low, i.e. highway and rural areas, this longer scope of communication can be incredibly useful.

High dynamic network: There is a highly dynamic V2V channel due to the fact the multipath fading environment [16]. MIMO best invest this highly dynamic channel. In terms of MIMO, channel matrices are used to translate the intense multi-path fading. The matrix has to have a rank greater than one. In return, MIMO gathers or moves toward the theoretical diversity and multiplexing gains characterised, space-time signal processing coding scheme [17].

Video stream: The DSRC standard is unable to support High Definition Video with 20 Mbps as it uses single input, single output radios. In addition, the radio won't be able to support high definition stream over internet protocol with 12-15 Mbps per stream, because of the limitation of the data rate which is 27 Mbps [18].

III. CHANNEL MODEL

During the growth of wireless technology, wireless channel models become very significant and helpful when used. Some channel models have been fabricated as well as developed and tested for the optimisation of various wireless standards. These tests are very reliable as the data provided from these tests are repeatable and are widely agreed upon.

Statistical models normally use the assumption of the wide sense stationary uncorrelated scattering (WSSUS) [19]. On the contrary, WSSUS is invalid for long-lasting time periods in V2V channels because it is non stationary. This caused by the physical environment dynamics, dynamics such as the motion of the receiver, transmitter, as well as significant reflectors/scatters.

The handling of the non stationary V2V channels can be approached in two ways. The first approach estimates the length of time it takes for the WSSUS assumption to be applicable. The second approach is based on modelling the channel as a tapped delay line with the tap amplitudes following some probabilistic distribution and modulated by a birth/death (on/off) process [20].

Statistical models have to be used to characterise the time variance of channel impulse response (CIR). This is preferred over standard channel models. The CIR can be used to identify the channel parameter such as the delay and Doppler spreads. These are the most basic parameters. In order to find the consistency bandwidth and the consistency time of channel, the delay and Doppler spreads reciprocals are used [19].

In order to verify the assumptions made concerning the angle-of-departure and/or angle-of-arrival of different time differentiable paths at the transmitter and/or receiver, the spatial correlation between different antennas at the transmitter and receiver will have to be used.

Two multiplexing techniques measurements have been discussed in [20]. The first technique is based on time-division multiplexing (TDM). With this, only one antenna has to be used at a time for both the transmitter and the receiver. Electronic switches have to be utilised so that you can switch between the antennas.

The RUSK channel sounder demonstrates an overview of a V2V radio channel measurement campaign at 5.6 GHz. There are 4-element uniform linear array that makes up the transmitter and the receiver. Each element uniform linear array has half wavelength spacing [21].

The main focus of the measurement campaign was to analyse some of the safety ITS application in certain scenarios. In order to work out the measurement campaign for V2V channels with vehicles that travel along motorways, a channel sounding campaign will be used [22]. The transmitter and receiver (using the 4-element linear array) will be placed on top of the vehicles.

IV. Simulation Results

A. *Channel Charicarstic for VANET*

A Ray-Based model, known as Special Channel Model (SCM), is commonly used in a dynamic MIMO channel as it can take in the account the temporal correlation parameters of the communication channel. In VANET, the power azimuth and the Doppler spectrums are both non uniform due to the scattering environments as shown in Figure 3. As a result, the Ray-Based model represents the summation of the incoming arbitrary arriving plane waves around the vehicle which can be deal various forms of vehicle speed , power azimuth spectrum and Doppler spectrum [23].

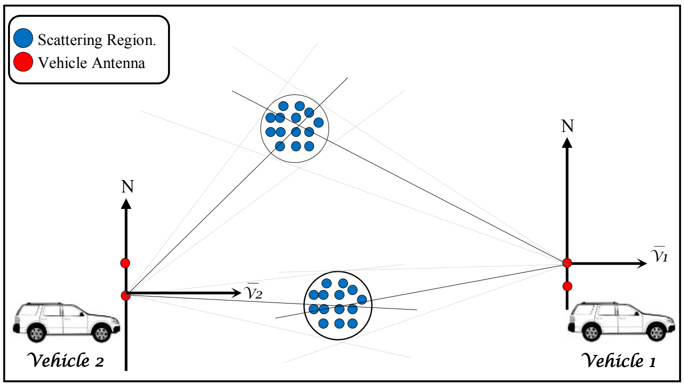

Fig. 3. V2V Channel Model for MIMO (2x2)

Figure 4 illustrates the time domain channel characteristic for V2V communications based on Ray-Based model. The purpose of this scenario test is to estimate the channel fading parameter of IEEE 802.11p in three vehicle speeds (30mph, 60mph and 90 mph) at 5.9GHz carrier frequency and 10 MHz bandwidth.

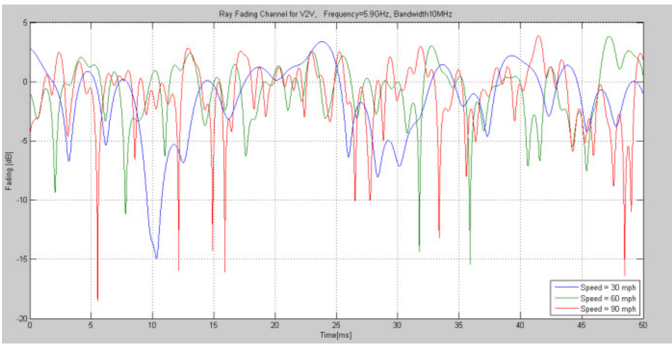

Fig. 4. V2V Time Domain Characteristic Based on Ray Fading Channel.

B. *SISO-OFDM in V2V*

The main features of the OFDM technique are: achieve a high data rate, robustness against multipath fading and the overcome the inter symbol interference. Thus, it's proposed to use the OFDM in VANET [24]. As shown in Figure 4, the fading influences on the V2V communication and using SISO-OFDM will cope with such a channel. Therefore, this paper tests the behaviour of the OFDM in two different channel models; with three modulation schemes. Figure 5 shows the BER vs. SNR for V2V-OFDM in three different modulation schemes (QPSK, 16QAM and 64QAM) in AWGN and Rayleigh channel models. In AWGN the OFDM needs around 30% power to achieve same bite error rate in Rayleigh channel which represent the V2V channel as shown in Figure 5 , therefore OFDM can be a good solution for V2V communication as there is unlimited battery power generated during a vehicle journey.

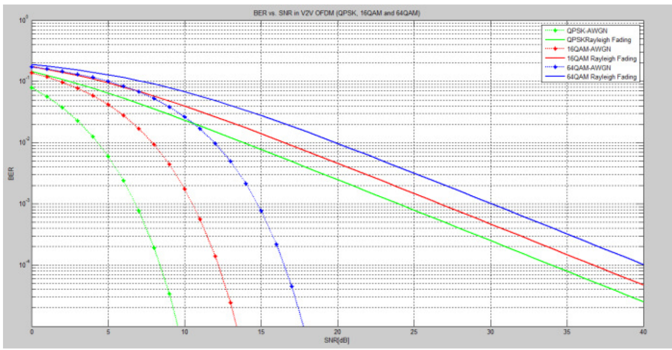

Fig. 5. OFDM in AWGN/Rayleigh Channels for QPSK, 16QAM and 64QAM

C. *MIMO in and V2V Scenario*

The unstable wireless fading channel in V2V caused an unacceptable bite error rate as shown in Figure 5, although SISO-OFDM satisfied an acceptable BER but with high transmit power (SNR). However, MIMO diversity techniques are used to improve the error degradation with less transmission power and this paper uses one of the diversity techniques called Alamouti Space-Time Code for two transmitters and two receivers (MIMO 2x2).

Figure 6 shows BER vs. SNR of using Alamouti 2x2 for V2V for Rayleigh Channel. The three modulation schemes have satisfied one ppm for BER in different SNRs which is better than the previous test in SISO-OFDM. For QPSK, the SNR is 60% less than the previous OFDM test while for 16QAM is 25% less and it is all most the same for 64QAM.

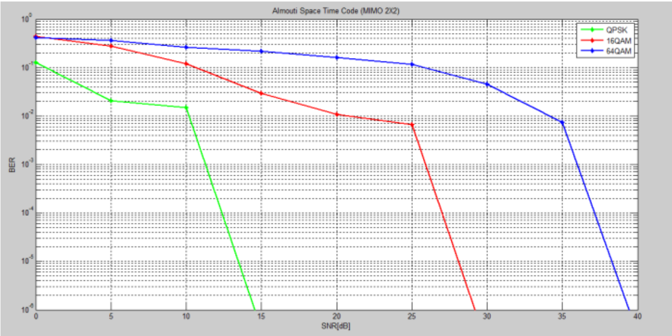

Fig. 6. MIMO 2x2 in Rayleigh Channels for QPSK, 16QAM and 64QAM

V. DISCUSSION

The nature of the V2V communication, due to the multi fading and scatting environments, adds more challenges to estimate the channel characteristics; therefore, it is assumed, this paper discusses only the behaviours of the SISO-OFDM and Alamouti MIMO (2x2).

Figure 3 shows two vehicles are in the same direction and each vehicle has two antennas, and also shows the multipath of the signals due to the scattering environment. Rayleigh fading model represents the V2V multipath channel, while to estimate channel coefficients we modified the special channel model (SCM) for a MIMO in 3GPP [in order to suite the IEEE 802.11p standard requirements i.e. 5.9 GHz frequency and 10 MHz bandwidth.

The result shows that SISO-OFDM could overcome the fading of the V2V channel, and it can be a good solution for V2V communication as there is unlimited battery power generated during a vehicle journey. However, convey Alamouti MIMO 2x2 reduces the transmission power by 30% and enhance the BER as well, but having a high data bit rate thorough 64QAM with less transmission power and low BER is still an issue.

VI. CONCLUSION

Wireless Researcher communities are always keen to offer with wide bandwidth, high data-rates and efficient mobility. MIMO and OFDM techniques are playing an important role in future wireless application. A brief review is presented about the IEEE802.11p standard components such as WAVE, DSRC and IEEE 1609.X. This paper is a feasibility study of utilising the OFDM and MIMO in the highly dynamic V2V environments to achieve higher date rates with less bite error rate. The simulation result showed that consolidates OFDM and MIMO (2x2) with Alamouti Space Time Code have managed to reduce the BER in the multi fading channel problems.

There are several of research issues in VANET, such as channel estimation, space-time signal processing channels, channel modelling. However, it is recommended to combine different type of the Space Time Code for MIMO antenna diversity and the OFDMA techniques as well for better QoS.

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