Selective MIMO in Vehicular Communication for Reliable Safety Services and High Speed Non-Safety Services

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***Abstract*—There are lots of advancements going on in the vehicular community in terms of technological improvements. Vehicular communication is one of the domains which is driving the expectations of the people from vehicular technology. These expectations include more safety services while driving a car on roads and highways like vehicle collision warning, intersection warning, emergency brake warning, etc. Vehicular communication not only supports safety services but also provides non-safety services like navigation support, toll collection, parking payment, etc. Consequently, people's demands on vehicular technology are increasing even more. So, the vehicular community needs to adopt new technology and upgrade communication framework so that it can fulfill t he d esired e xpectations. T herefore, an increment in reliability and data rate is required. Multiple Input Multiple Output (MIMO) is a next generation technology that can be helpful in this regard. Hence, we propose a modified PHY layer to accommodate two types of MIMO (Transmit Diversity and Spatial Multiplexing) and to use them in a selective way based on the service requirements. Our experimental results demonstrate that our proposed model can achieve up to 15 dB gain in terms of reliability and improve the throughput up to 2.3 times compared to the conventional DSRC model.**

***Index Terms*—IEEE 802.11p, VANET, ITS, V2X, DSRC, OFDM, MIMO, bit error rate, throughput**

I. Introduction

In recent times, vehicular communication networks have drawn significant attention in the domains of academia, industry, and government. Vehicular communication frameworks are being evolved to be fit f or n ew g eneration technologies. It can support a variety of safety and non-safety services using these networks and frameworks via sharing information among vehicles [1]–[3]. The prime targets of vehicular communication are to guarantee not only road safety, reduce fuel consumption, avoid accidents but also provide a next level driving experience having much more comfort [4]–[6]. To reach these targets, Vehicle-to-Everything (V2X) is the type of vehicular communication that is used. V2X communication consists of two major divisions which are Vehicle-to-Vehicle (V2V) communication and Vehicle-to-Infrastructure (V2I) communication. V2V communication refers to the exchange of information among vehicles which is purely adhoc and termed as Vehicular Adhoc Network (VANET). V2I communication takes place in between vehicle and infrastructure which is termed as roadside (RSU) units.

V2X communication utilizes one special technology called Dedicated Short-Range Communication (DSRC) which supports a variety of services. V2X communication was investigated for multimedia transmission over LTE-A in a OMNET++ simulated environment [7]. DSRC was primarily developed for vehicle safety services like collision prevention applications. The idea of the DSRC-based safety application is that each vehicle having DSRC functionalities will broadcast it's basic information like speed, locations, etc. in continuous frequency. Similarly, other vehicles must have DSRC functionalities to receive and process the broadcast messages. Once the neighbouring vehicles process this information, they can take necessary steps to alert the driver. So, V2V safety services include blind spot warning, forward collision warning, emergency brake light warning, do not pass warning, etc. Several safety services like intersection warning, disabled or emergency vehicle warning use exchange of messages between vehicle and DSRC enabled RSU. In some cases, these messages reach a vehicle that is far enough using multi hop communication through RSU. If these safety services can be employed effectively it can address up to 82% of all crashes in the United States using DSRC enabled V2V communication, estimated by the U.S Department of Transportation (DOT). [8], [9] On the other hand, DSRC can support a variety of infotainment services like navigation assistance, congestion warning, roadside service finder, toll payment, parking payment, traffic light warning, media streaming, voice over IP, etc. The major impediments that all the aforementioned services face are various mobility patterns, varying speed of vehicles, adverse road conditions, unfavorable weather conditions, different traffic conditions, obstacles on road, and many more [10], [11]. As a result, reliability for safety services and high speed for non-safety services are the prime goals to make vehicular communication more robust.

There are a variety of approaches that have been proposed to make vehicular communication more reliable and provide a high data rate. An improved MAC layer scheme called WAVE-based Hybrid Coordination Function (W-HCF) was used to communicate alternately using centralized and distributed channel access methods. [12] This scheme keeps enough bandwidth for non QoS-sensitive services while fulfilling the requirements of QoS-sensitive services. A new PHY layer model using Alamouti Space-Time Code as MIMO technique for two transmitting antennas and two receiving antennas was proposed to improve the data error rate while minimizing the transmitting power [13]. MIMO has become a key technology to expand the capabilities of transmitters and receivers to support better spectral and energy efficiency [14], [15]. There are two major types of MIMO to achieve diversity gain over multiple antennas which are Transmit Diversity (TD) and Spatial Multiplexing (SM) [16]–[18]. A MIMO-enabled PHY layer model using Orthogonal Space-Time Block Codes (OSTBC) was proposed for more robust communication [19]. MIMO technique was also proposed to employ in between vehicle and infrastructure unit in [20]. The communication link was implemented using Software Defined Radio (SDR) to improve bit error rate and throughput. Spatial Multiplexing MIMO was also proposed in DSRC and twice throughput was recorded compared to the existing model while keeping the bit error rate lower than the conventional model [21]. 5G NR was also proposed to use along with Spatial Multiplexing MIMO which enhances the data rate much better than the combination of MIMO and DSRC while keeping the bit error rate same as MIMO enabled existing DSRC model [22].

The proposed approaches mentioned above either use Transmit Diversity (TD) or Spatial Multiplexing (SM) so far when it comes to set up a V2V or V2I communication link. TD is most appropriate when safety services are required since reliability is more important than the data rate. Whereas SM is mostly appropriate for non-safety and infotainment services since the data rate is more important than reliability. Hence, SM provides a certain level of reliability so that the required services can function. We combined both the MIMO techniques under the DSRC standard to employ one of the techniques selectively based on the required services. We designed a PHY layer model to accommodate both the techniques and evaluate the performance.

The rest of the paper is organized as follows: Section II describes on DSRC standard elaborately. It displays the layerwise protocol structure and channelwise 5.9 GHz spectrum analysis. It also explains the existing PHY layer model and radio channel parameter values. It also demonstrates how the signal can be affected due to various channel characteristics. Section III shows how Transmit Diversity and Spatial Multiplexing MIMO are employed in a selective fashion according to our proposed model. Then, the details on experimental setup are depicted in section IV and it also describes two metrics based on which the simulation results are evaluated. After that, experimental results are displayed in section V and comparative analysis on those results is presented. Finally, section VI concludes the work by mentioning possible future plans for this work.

II. Details on DSRC Standard

The protocol stack for the DSRC communication standard is presented in Fig. 1. The IEEE 1609.2 standard is defined for Security Services, IEEE 1609.3 is defined for Network Services like WAVE Short Message Protocol (WSMP), and IEEE 1609.4 standard is defined for Channel Switching. [8] Safety service messages are transferred using single hop link via WSMP to have bandwidth efficiency. Whereas, other service packets are transferred using multi hop communication links via other protocols like Transmission Control Protocol (TCP), User Datagram Protocol (UDP), and Internet Protocol version 6 (IPv6). The SAE J2735 standard defines message formats for safety messages which are called Basic Safety Message (BSM). The channel congestion control, power, and transmission rate requirement for BSMs are handled by SAE J2945.1.

The spectrum from 5.850 GHz to 5.925 GHz in the 5.9 GHz band was specified by the Federal Communications Commission (FCC) in the United States for DSRC communication. There are seven 10 MHz channels available in the spectrum with a 5 MHz guard band which is shown in Fig. 2. Among all the channels, channel 178 is the Control Channel (CCH) and the other channels are Service Channels (SCH). Channel 178 is used for service advertisement purposes, Channel 172 is used for safety services and other channels are used for non-safety services.

From Fig. 1 it is understood that the safety services use WSMP protocol and other services use IPv6 protocol. Basically, it can be chosen whether a service wants to be run over IPv6 or WSMP. Before actual data exchange happen WAVE Service Advertisement (WSA) messages are exchanged which contain the necessary information for the communication that will take place. Based on the WSA information the communicating device switches to that particular SCH. The WSA frame format is shown in Fig. 3. WSA contains the service information that is offered. In the frame format, the WAVE Routing Advertisement field is used for the services which require IPv6 protocol that means non-safety services.

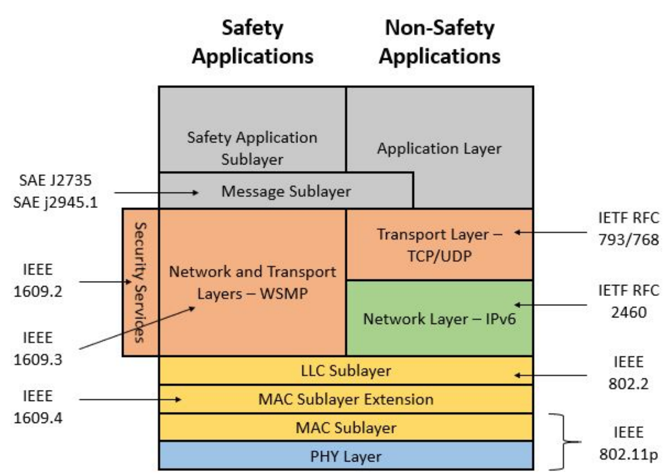

Fig. 1. Protocol Stack of DSRC Standard in United States.

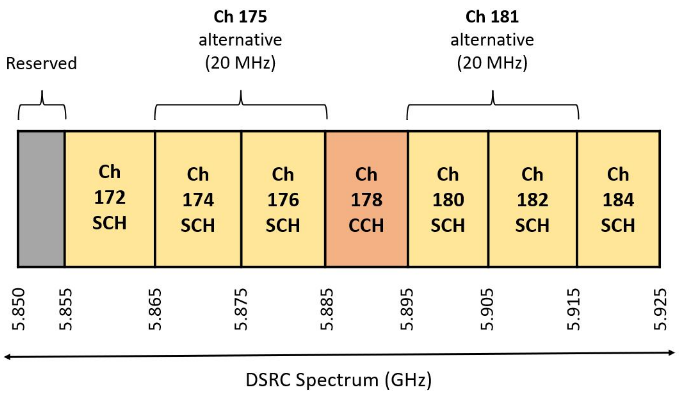

Fig. 2. Channelwise DSRC spectrum division in United States.

Fig. 3. WAVE Service Advertisement frame format.

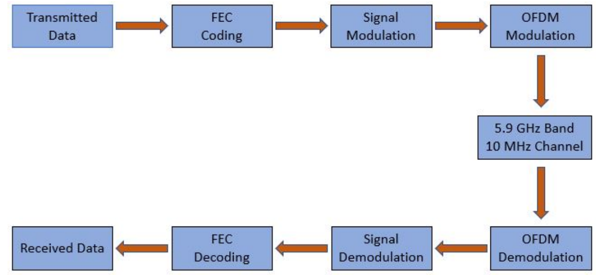

Fig. 4. Block Diagram of DSRC PHY layer.

TABLE I
OFDM CHANNEL CHARACTERISTICS FOR 10 MHz CHANNEL

Parameter	Value
Number of Data Subcarriers	48
Number of Pilot Subcarriers	4
Number of Total Subcarriers	52
Subcarrier Frequency Spacing	156.25 KHz
Guard Interval (GI)	1.6 μsec
Symbol Interval (including GI)	8 μsec

A. PHY Layer in V2X Communication

The block diagram of the existing DSRC PHY layer model is shown in Fig. 4. According to this figure, the sending device produces the transmitted data and pushes it to the PHY layer. Then the transmitted data goes through the FEC Coding segment where transmitted data is coded using one of the coding schemes. This helps to reduce the bit error rate during transmission. After that, the coded data goes through the Signal Modulation segment. This segment prepares the coded data to send over air medium. Next, the modulated data goes through the OFDM Modulation segment. This segment prepares the modulated data to avoid interference caused by multipath fading in the air medium. Then, the OFDM modulated data is sent in the 10 MHz channel. On the receiver side, similar demodulation and decoding techniques are applied to the received data to get the best approximation of the sending data. The OFDM specifications for the 10 MHz channel are presented in Table I.

B. Radio Channel for V2X communication

FCC specified 75 MHz spectrum in the 5.9 GHz band for V2X communication. As mentioned in section II, the 75 MHz spectrum is divided into seven 10 MHz channels. There are two major channel characteristics that impact the signal most. They are doppler effect and multipath fading. Doppler effect happens when the signal is distorted by changing the position of vehicles and roadside units. Multipath fading happens when the signal is distorted due to reflection, diffraction, or scattering by objects on the way to the receiver.

We designed our experiment in such a way that, the transferring signal has the effect of random channel noise, multipath fading, and doppler effect. We used an Additive White Gaussian Noise (AWGN) channel model to generate random channel noise. We specified certain doppler value and added in our experiment so that it can make a significant impact on the signal. Path delay was calculated according to the channel specific value of sampling frequency and delay spread. Moreover, we added rayleigh fading impact on the channel by using randomized path gain, path delay, and sampling frequency.

III. SELECTIVE MIMO IN V2X COMMUNICATION

MIMO is a technique of achieving diversity gain using more than one antenna to make the communication performance better. The diversity gain can be achieved via two major types of MIMO which are Transmit Diversity (TD) and Spatial Multiplexing (SM). TD transmits the same data over multiple antennas to achieve less error in the data to get more reliable communication rather than having more throughput. On the other hand, SM transmits different data over multiple antennas to achieve a high data rate by lightly considering the data error rate. TD is more suitable for safety services and SM is more suitable for non-safety services. We used these two types in a selective way in our experiment. As mentioned in section II, the type of service can be known to both the sender and receiver from WSA message. The service and routing information in the WSA message are different for safety and non-safety services. Based on this information, the right type of MIMO can be selected beforehand for effective communication. If a safety service is to be offered we are going to select TD MIMO otherwise we are going to select SM MIMO. That's how our proposed model is organized.

IV. EXPERIMENTAL DESCRIPTION

TD MIMO can be used to improve bit error rate and SM MIMO can be used to improve data rate. We employed both the MIMO techniques in a selective fashion to achieve a better bit error rate or data rate when it is required. The block diagram of our proposed PHY model is presented in Fig 5.

We modified the general block diagram of the DSRC PHY layer model shown in Fig 4 and added two new blocks. One is the MIMO transmitter in between OFDM Modulation and

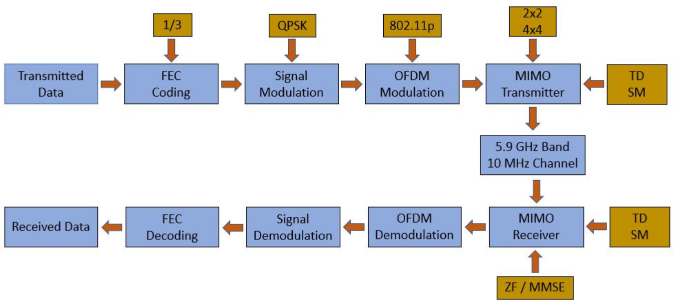

Fig. 5. Block diagram of the proposed model.

Channel blocks at the transmitter side and the other one is the MIMO receiver block which is added in between Channel and OFDM Demodulation blocks at the receiver side. We used two MIMO configurations, one is 2x2 (two transmitting antennas and two receiving antennas) configuration and the other one is 4x4 (four transmitting antennas and four receiving antennas) configuration. We evaluated both the configurations for both the TD and SM MIMO types. We used 1/3 convolutional coding scheme in the FEC Encoding and FEC Decoding blocks. Moreover, we used the QPSK modulation scheme in the Signal Modulation and Signal Demodulation parts. We configured OFDM Modulation and OFDM Demodulation parts based on the IEEE 802.11p specifications. In the MIMO Receiver block, we used two well known linear signal equalization methods which are Zero Forcing (ZF) and Minimum Mean Squared Error (MMSE). We implemented functionalities for all the blocks presented in Fig 5 in the Matlab environment and ran the simulation as a complete package. We recorded the simulation results and presented them in the next section. The simulation parameter values are shown in Table II.

We evaluated our proposed model based on two metrics which are given below.

a) Bit Error Rate (BER): BER is defined by the number of error bits are received per unit time. It is calculated by the ratio of the number of error bits at the receiver divided by the total number of bits transmitted during the simulation time.

b) Throughput: Throughput is defined by the total number of frames successfully received, divided by the total time over which the transmission is being held. Throughput is expressed in Mbps, which refers to channel capacity as well. In our experiments, we used 1 ms as a transfer time for each frame to calculate throughput.

TABLE II
EXPERIMENTAL SPECIFICATION

Parameter	Value
Modulation Type	QPSK
Channel Model	Rayleigh Fading
Doppler Shift	300Hz
Channel Bandwidth	10 MHz
SNR Range	0 - 30 dB
CRC Code	24 bit CRC Checksum
Coding Rate	1/3 Convolutional Coding
Maximum Number of Bits Processed	2e5

V. EXPERIMENTAL RESULT AND ANALYSIS

According to the proposed model in the experimental description section, we ran our simulation for Conventional DSRC, Transmit Diversity, and Spatial Multiplexing (both ZF and MMSE equalizers) settings. We ran our simulation for all the configurations at 300 Hz doppler shift. Fig. 6 and 7 displays the BER comparison among Conventional DSRC, TD, and SM (both ZF and MMSE equalizers) configurations. It is observed from Fig 6 and 7 that, the BER performance for TD is much better than the Conventional DSRC and SM for both 2x2 and 4x4 configurations. In addition, TD has 10 dB and 15 dB gain compared to Conventional DSRC for 2x2 and 4x4 configurations respectively. The reason behind that is, the data that is transferred in Conventional DSRC is transmitted via two antennas and four antennas for 2x2 and 4x4 configurations using TD. That's why the bit error rate becomes lower. On the other hand, the BER performance for SM is slightly poorer than Conventional DSRC. That is because completely different data is transmitted via two antennas and four antennas for 2x2 and 4x4 configurations respectively that is transferred using Conventional DSRC. So, noise affects the data a little more than Conventional DSRC.

The throughput comparison among Conventional DSRC, TD, and SM (both ZF and MMSE equalizers) is demonstrated in Fig. 8 and 9. From Fig 8 and 9, it is evident that throughput for TD and SM (both ZF and MMSE equalizers) are significantly higher than Conventional DSRC for both 2x2 and 4x4 configurations. In addition, throughput for SM (both ZF and MMSE equalizers) is slightly higher than TD. The reason behind this is TD transmits the same data using multiple antennas with less error. The throughput increases for TD more than Conventional DSRC with the increase of SNR because of less error during transmission. Subsequently, SM transmits different data using multiple antennas in a 2x2 or 4x4 configuration. That's why the throughput for SM (both ZF and MMSE equalizers) is much higher than Conventional DSRC even though the bit error rate is higher in SM.

The final throughput for all the configurations are presented in Table III.

TABLE III
THROUGHPUT COMPARISON

MIMO Configuration	Methodology	Throughput (in Mbps)
1x1	Conventional DSRC	2.62
2x2	TD MIMO	3.81
	SM MIMO using ZF Equalizer	3.95
	SM MIMO using MMSE Equalizer	4.12
4x4	TD MIMO	4.35
	SM MIMO using ZF Equalizer	5.33
	SM MIMO using MMSE Equalizer	6.02

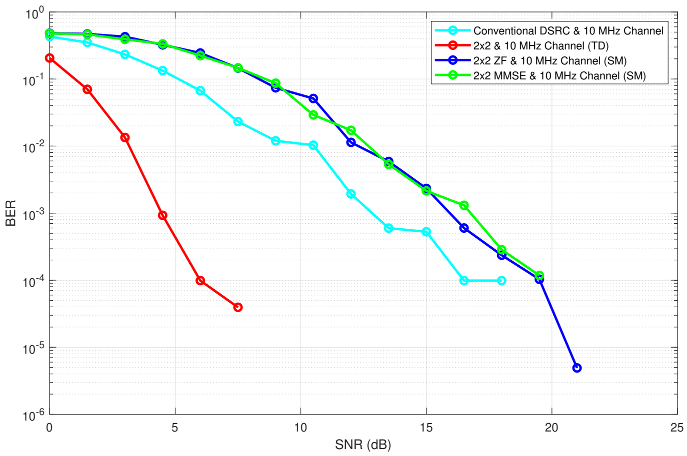

Fig. 6. BER comparison among Conventional DSRC, 2x2 TD MIMO, 2x2 SM MIMO with ZF equalizer, and 2x2 SM MIMO with MMSE equalizer at 300 Hz doppler shift.

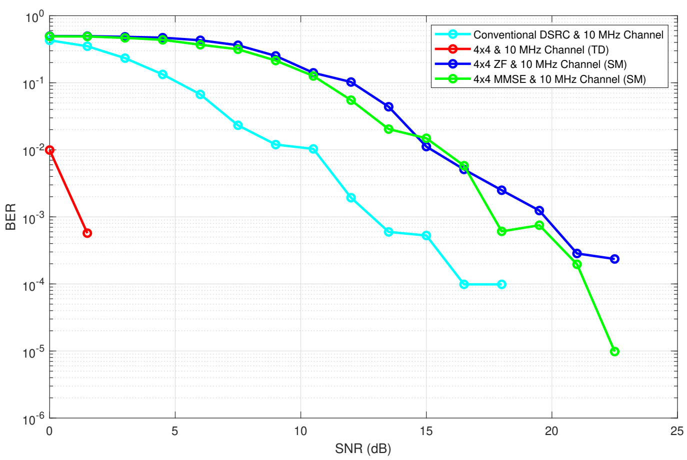

Fig. 7. BER comparison among Conventional DSRC, 4x4 TD MIMO, 4x4 SM MIMO with ZF equalizer, and 4x4 SM MIMO with MMSE equalizer at 300 Hz doppler shift.

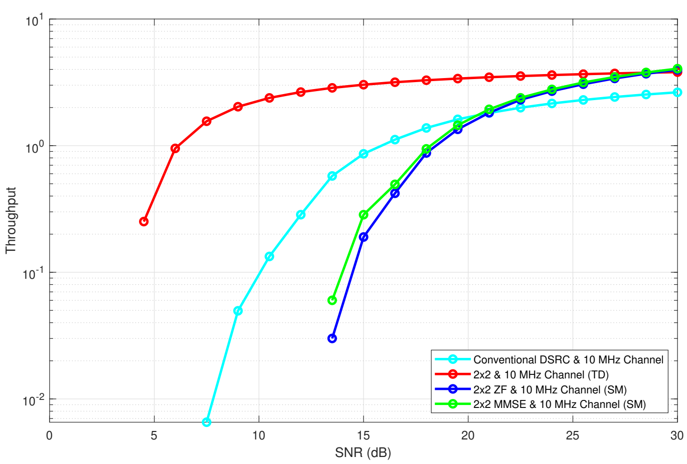

Fig. 8. Throughput comparison among Conventional DSRC, 2x2 TD MIMO, 2x2 SM MIMO with ZF equalizer, and 2x2 SM MIMO with MMSE equalizer at 300 Hz doppler shift.

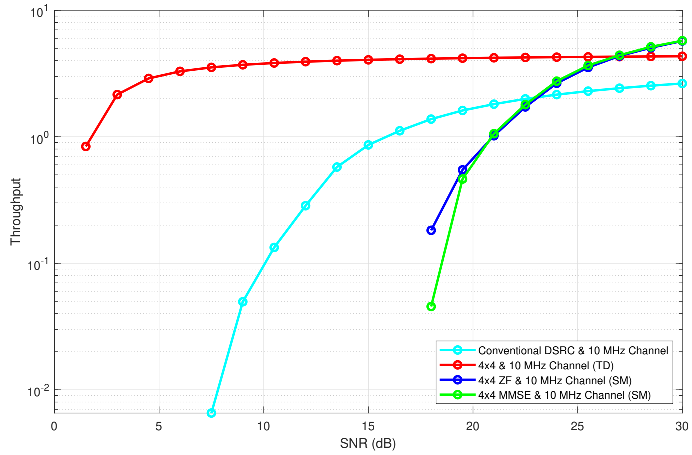

Fig. 9. Throughput comparison among Conventional DSRC, 4x4 TD MIMO, 4x4 SM MIMO with ZF equalizer, and 4x4 SM MIMO with MMSE equalizer at 300 Hz doppler shift.

From Table III it is obvious that throughput for TD MIMO is 1.5 times and 1.7 times better compared to Conventional DSRC for 2x2 and 4x4 configurations respectively. In addition, SM MIMO using ZF equalizer performs 1.5 times and 2 times better compared to Conventional DSRC for 2x2 and 4x4 configurations respectively. Moreover, SM MIMO using MMSE equalizer performs 1.6 times and 2.3 times better compared to Conventional DSRC for 2x2 and 4x4 configurations. Nevertheless, the performance of SM MIMO (both ZF and MMSE equalizers) is better compared to TD MIMO for both 2x2 and 4x4 configurations.

VI. Conclusion

Transmit Diversity (TD) MIMO and Spatial Multiplexing (SM) MIMO have their own advantages and drawbacks. Vehicular Communications have particular scenarios where both the MIMO types can be a good fit. Subsequently, better performance in terms of bit error rate and data rate can be obtained for safety and non-safety services respectively. A modification in the PHY layer is proposed in this work for the enhanced vehicular communication framework which could be helpful to improve road safety and make the car journey more enjoyable. This kind of communication framework is going to be necessary in near future as the need for increased safety and entertainment facility is on the rise. Our experimental results corroborate that, selecting the right MIMO type based on the required vehicular service can improve the service performance significantly. Moreover, we are trying to explore Low Density Parity-Check (LDPC) code in the context of vehicular communication. Our future work includes checking the compatibility of LDPC in the DSRC framework. Our curiosity also grows on how would be the performance of LDPC in terms of reliability and data rate if included in the existing DSRC standard.

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