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Modified PHY Layer for High Performance V2X Communication using 5G NR

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***Abstract*—People are increasingly relying on vehicular communities for a more safe and comfortable day-to-day car journey. So, expectation from vehicular technology is increasing more from time to time. As a result, vehicular technology is expected to support infotainment services to the traveler. Hence, the requirements for entertainment services need extra capacity along with safety services. One of the important pieces in the channel capacity is throughput. The existing IEEE 802.11p standard with the support of Dedicated Short Range Communication (DSRC) might not fulfill the required capacity in the coming days. To achieve that required throughput DSRC protocol needs to evolve. However, Multiple Input Multiple Output (MIMO) and 5G NR has the potential to improve throughput while maintaining the existing PHY layer specifications defined in the Wireless Access for Vehicular Environments (WAVE) standard. We propose a modified PHY layer of the DSRC protocol to integrate MIMO and 5G NR to enhance the existing data rate. Our experimental results show that the combination of MIMO and 5G NR can boost the throughput to 6.5 times better compared to MIMO enabled existing framework while keeping the BER (Bit Error Rate) as the same or in some cases below the combination of MIMO and DSRC.**

***Index Terms*—V2X, VANET, ITS, DSRC, MIMO, 5G NR, IEEE 802.11p, OFDM, bit error rate, throughput**

I. Introduction

Nowadays vehicles use various wireless technologies. Communication through Vehicle-to-Everything (V2X) framework offers a mechanism for vehicles to connect with Vehicular Ad-Hoc Network (VANET) while driving. V2X consists of two entities, one is communication between two vehicles which is referred to as Vehicle-to-Vehicle (V2V) communication and the other one is communication between vehicle and road-side infrastructure which is referred to as Vehicle-to-Infrastructure (V2I) communication. A robust V2X communication can increase road safety by reducing accidents, traffic congestion, traffic violation, and many more.

The communication framework, called the Intelligent Transportation System (ITS), was proposed by the US Department of Transportation (DOT) which can work using V2X communication [1]. ITS is one form of VANET which offers various infotainment services through various applications [2], [3]. the Dedicated Short Range Communication (DSRC) protocol established by IEEE 802.11p [4] is used by ITS. Services such as Electronic Toll Collection (ETC) system [5], [6] have been provided by ITS. Now, due to the increased demand, VANET needs to provide non-safety services like media streaming, web browsing, mobile gaming, voice over IP along with safety services like Global Positioning System (GPS), warning messages, traffic monitoring system, parking payments [1], [3] etc. DSRC needs a more stable and effective infrastructure in order to provide these aforementioned services so that it can cope with the increased data rate.

Different approaches have been proposed to meet up the demand. Cluster Based Adaptive Mobile Gateway Management Mechanism (CMGM) using 3G/4G networks [7] was proposed to improve throughput, low latency, and reduce power consumption. WAVE-based Hybrid Coordination (W-HCF) function was proposed as an extension to the IEEE 802.11p MAC protocol to improve the Quality of Service (QoS) of non-safety services while keeping bandwidth available for safety services [3]. Additional Data Transmission (ADT) scheme was also introduced in [8] to provide improved data rates under the rayleigh fading channel. Multiple Input Multiple Output (MIMO) can be another option in this regard [9], [10]. Orthogonal Space-Time Block Codes (OSTBC) is one type of MIMO which was used in [6], [11] to improve the bit error rate and throughput compared to the conventional system. Spatial Multiplexing is another form of MIMO which was employed in [12] to further improve throughput, frame rate, and bit error rate.

Up to this point, these above improvements might not be capable to meet up with the increased demand. 5G is the new radio specification developed by the Third Generation Partnership Project (3GPP) which could be a solution to boost the data rate even more. The authors in [13] tried to combine 5G NR with V2X communication and their theoretical calculation suggests that 5G NR-V2X has the capability to perform better than the 802.11bd standard in terms of latency and data rate. A Semi-persistent Scheduling (SPS) approach was adopted in [14] to combine cellular networks with the V2X framework for 5G NR utilization. They were able to improve reliability and latency by varying Transmission Time Interval (TTI) and Sub-carrier Spacing (SCS). A truck platooning application was experimented in [15] to exploit the capabilities of 5G

NR in V2X communication. The approaches mentioned in [14], [15] mostly work in line-of-sight scenario. So far 5G NR combined with MIMO technology has not been explored in the context of vehicular communication. So, we integrated 5G NR along with Spatial Multiplexing MIMO while keeping other DSRC specifications as the same for further improvement in the non-line-of-sight scenario. We compared our simulation result with the 5.9 GHz radio output to analyze our model.

The rest of the paper is organized as follows: Section II presents the existing vehicular communication standard and details about MIMO. It also points out channel characteristics for vehicular communication. Section III presents 5G NR specifications that were used in our experiment. Section IV presents the integration of MIMO and 5G NR in the PHY layer model and experimental specification for every single portion. It also describes how simulation has been done in the Matlab environment. Then all the experimental results are demonstrated in section V. This section also presents comparative analysis among all the configurations presented in the experiment. Finally, section VI concludes the paper.

II. MIMO and V2X Communication Details

A. Multiple Input Multiple Output (MIMO)

Because of its high reliability and spectral efficiency for the same resources, MIMO is a very important technology in the context of wireless communication. In MIMO, to transmit data, more than one antenna is used. Subsequently, to minimize error and get the best estimate of transferred data, data obtained at each antenna at the receiving side is combined. Zero Forcing (ZF) and Minimum Mean Squared Error (MMSE) are two well-known equalization strategies available to minimize error at the receiving end. There are also different types of MIMO available and one of them is Spatial Multiplexing. Each transmitting antenna can transmit a totally independent data stream in the Spatial Multiplexing MIMO. As a consequence, a linear improvement in bandwidth capacity [16] can be offered by Spatial Multiplexing MIMO. The key three main benefits of MIMO technology are that it operates in the Non-Line-of-Sight (NLOS) scenario, that it operates in the real-time communication medium, that it greatly enhances system throughput.

B. PHY Layer in V2X Communication

In V2X communication, Dedicated Short Range Communication (DSRC) defines specifications for each layer. The IEEE 802.11p Wireless Access for Vehicular Environments (WAVE) standard at the PHY layer is used by DSRC. To battle against intersymbol interference caused by multipath fading, it also uses Orthogonal Frequency Division Multiplexing (OFDM). Three channel widths are defined by the 802.11 group for OFDM protocol which are 5, 10, and 20 MHz. since 802.11a and other WiFi standards use 20 MHz bandwidth, DSRC uses 10 MHz bandwidth to cancel out much of the channel interference. Table I presents the basic parameter for 10 MHz bandwidth [17].

The block diagram of the PHY layer of V2X communication is shown in Fig. 1. The diagram illustrates the flow of data through the framework. First, to encode the user bits for successful decoding at the receiving end, transmitting data is passed via the Forward Error Correction (FEC) module. The encoded data in the Signal Modulation module is then modulated using either BPSK, QPSK, 16-QAM, or 64-QAM modulation techniques. Then, for multiplexing purposes, modulated data is sent to the OFDM Modulation module. After that, the data is sent via a specified channel to the receiver. Finally, the reverse procedure is performed at the receiving end to get the original transmitted error-free data. According to the same specification mentioned in this section, we implemented our experimental setup.

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

C. Radio Channel for V2X communication

75 MHz of licensed spectrum in the 5.9 GHz band is allocated by the U.S. Federal Communications Commission (FCC) for V2X communication [17]. This spectrum is divided into a 5 MHz guard band of seven 10 MHz channels. Channel characteristics greatly influence the signal in the air medium. Multipath fading and the doppler effect are the two major characteristics. In a non-line-of-sight scenario during propagation, multipath fading is defined as a distortion in the signal due to reflection, diffraction, or scattering by any component. So, multipath fading can generate rayleigh distribution to have rayleigh fading on a particular channel model. Furthermore, doppler effect is defined as the effect on the signal due to the change of relative position of transmitter and receiver.

We defined our MIMO channel model in a way to make both fading and doppler effect on the transmitted signals in our experiment. We determined the delay spread based on cyclic prefix length and estimated path delay based on the delay spread and sampling frequency. Subsequently, we used the path delay, sampling frequency, and randomized path gain to have a rayleigh fading feature in our channel model. In addition, we added certain doppler value in the channel model to have a considerable amount of change in our signal which should happen in real scenarios where vehicles move pretty fast. We also used an Additive White Gaussian Noise (AWGN) channel model to make an effect of random channel noise on the signal.

III. 5G NR in V2X Communication

5G is the fifth generation communication technologies defined by the wireless community. Third Generation Partnership Project (3GPP) developed new radio access technology for the air interface. 3GPP defined two frequency ranges, operating bands, channel bandwidths with detailed specifications in its

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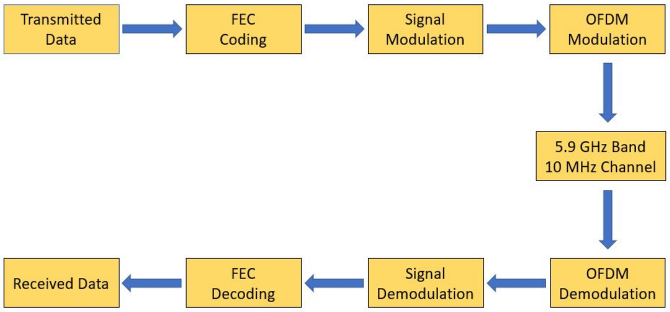

Fig. 1. Block diagram of DSRC PHY layer.

latest release [18], [19]. The first frequency range FR1 goes from 410 MHz up to 7125 MHz and the second frequency range FR2 goes from 24250 MHz up to 52600 MHz. We used two frequency sets from FR1 in our experiment. The frequency sets are shown in Table II.

There are different channel bandwidths available for the FR1 frequency range. Among them, we used 20 MHz, 50 MHz, and 80 MHz bandwidths in our experiment. The basic parameters for these three bandwidths are shown in Table III. We used the same specifications in our experimental simulation.

IV. Experimental Description

MIMO can transmit more data using multiple antennas rather than a single antenna. We used Spatial Multiplexing MIMO to get the maximum performance from our proposed model. We included this form of MIMO in the traditional DSRC structure. So, we modified the block diagram presented in Fig. 1 and added two more blocks. We added MIMO Transmitter block in between OFDM Modulation and Communication Channel blocks in the transmitter side. On the receiver side, we added a MIMO Receiver block in between Communication Channel and OFDM Demodulation blocks. Our proposed model is shown in Fig. 2. For the FEC Coding part, we used 1/3 convolution coding scheme. As a modulation technique, we used QPSK modulation. In the OFDM Modulation part, we used the IEEE 802.11p specified standard. In addition, we used 2x2 (two transmitting antennas and two receiving antennas) configuration and 4x4 (four transmitting antennas and four receiving antennas) configuration in the MIMO Transmitter and MIMO Receiver parts. We also used ZF (Zero Forcing) and MMSE (Minimum Mean Squared Error) methods to equalize the received data. As a communication radio, we used three different frequency bands which are 5.9 GHz, 3.6 GHz, and 4.7 GHz. The 5.9 GHz is the regular frequency band that has been used for vehicular communication. 3.6 GHz and 4.7 GHz frequency bands are the 5G new radio which we used in our experiment to increase the communication performance. Moreover, we used 10 MHz channel specifications from the 5.9 GHz frequency band in our experiment. We also used 20 MHz, 50 MHz, and 80 MHz channel specifications from 3.6 GHz and 4.7 GHz frequency bands in our experiment.

TABLE II
5G Operating Bands

NR Band Index	Operating Band	Duplex Mode
n48	3550 MHz - 3700 MHz	TDD
n79	4400 MHz - 5000 MHz	TDD

TABLE III
OFDM channel characteristics for 20, 50 and 80 MHz channels

Channel Bandwidth	Parameter	Value
20 MHz	Subcarrier Frequency Spacing	15 KHz
	Number of Symbol per Subframe	14
	Number of Resource Block	22
	FFT Length	2048
	Cyclic Prefix Length	144
50 MHz	Subcarrier Frequency Spacing	30 KHz
	Number of Symbol per Subframe	28
	Number of Resource Block	27
	FFT Length	2048
	Cyclic Prefix Length	144
80 MHz	Subcarrier Frequency Spacing	60 KHz
	Number of Symbol per Subframe	56
	Number of Resource Block	22
	FFT Length	2048
	Cyclic Prefix Length	144

We designed our experiment in the Matlab environment and implemented all the functionality in each block presented in Fig. 2. We executed our experiment as a whole package and recorded the results for further analysis which is demonstrated in the next section. The values for our simulation parameters are shown in Table IV.

We have considered two metrics to validate our model:

a) Bit Error Rate (BER): BER defines how many 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.

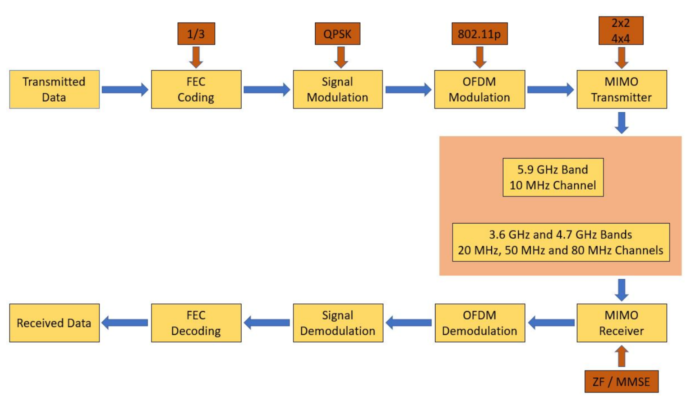

Fig. 2. Block diagram of proposed model.

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TABLE IV
EXPERIMENTAL SPECIFICATION

Parameter	Value
Modulation Type	QPSK
Channel Model	Rayleigh Fading
Doppler Shift	300Hz
Channel Bandwidth	10 MHz, 20 MHz, 50 MHz and 80 MHz
SNR Range	0 - 28 dB
CRC Code	24 bit CRC Checksum
Coding Rate	1/3 Convolutional Coding
Maximum Number of Bits Processed	2e6

V. EXPERIMENTAL RESULT AND ANALYSIS

We ran our experimental simulation for four different channel specifications (10 MHz, 20 MHz, 50 MHz, and 80 MHz) at a doppler shift of 300 Hz and for two MIMO configurations (2x2 and 4x4). The BER comparison of 10 MHz and 20 MHz channels using both 2x2 and 4x4 MIMO configurations are shown in Fig. 3 and 4 respectively. From Fig. 3 and 4 it is observed that the BER performance for 20 MHz channel is slightly better than 10 MHz channel for both 2x2 and 4x4 MIMO configurations. The reason for that is 20 MHz channel has 1.6 times more guard band compared to the 10 MHz channel. In addition, The performance using MMSE equalizer is almost the same as ZF equalizer in both the channels for both the configurations. That is because of having the same FFT size while using both the equalizers on the same channel even though FFT size in 20 MHz channel is bigger than 10 MHz channel.

The BER comparison of 10 MHz and 50 MHz channels using both 2x2 and 4x4 MIMO configurations are shown in Fig. 5 and 6 respectively. From Fig. 5 and 6 it is observed that the BER performance for 50 MHz channel is the same as 10 MHz channel for both 2x2 and 4x4 MIMO configurations due to more noise available in the channel compared to 20 MHz and 80 MHz channels even though 50 MHz channel has 4.5 times more guard band than 10 MHz channel. In addition, The performance using MMSE equalizer is almost the same as ZF equalizer in both the channels for both the configurations. The reason for that is 50 MHz channel has a bigger FFT size for both the equalizers compared to 10 MHz channel but both the equalizers use the same FFT size in the corresponding channel.

The BER comparison of 10 MHz and 80 MHz channels in both 2x2 and 4x4 MIMO configurations are shown in Fig. 7 and 8 respectively. From Fig. 7 and 8 it is observed that the BER performance for 80 MHz channel is slightly better than 10 MHz channel in both 2x2 and 4x4 MIMO configurations. The reason for that is 80 MHz channel has 6.6 times more guard band compared to the 10 MHz channel. In addition, The performance using MMSE equalizer is almost the same as ZF equalizer in both the channels for both the configurations. That is because of having the same FFT size on the respective channel while using both the equalizers even though FFT size in 80 MHz channel is bigger than 10 MHz channel.

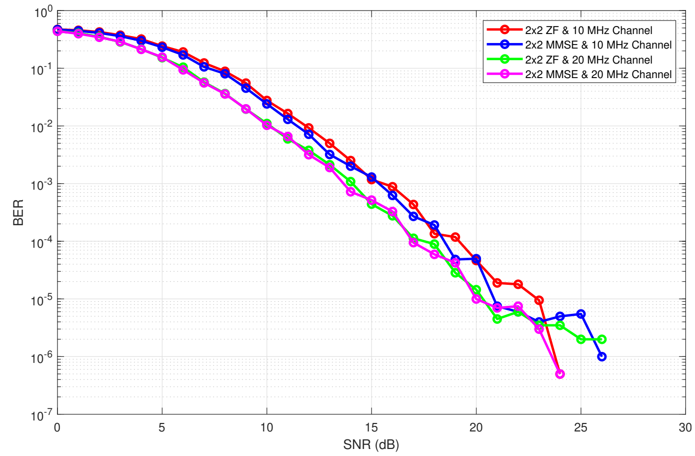

Fig. 3. BER comparison between 10 MHz and 20 MHz channels in 2x2 MIMO configuration using ZF and MMSE equalizers at 300 Hz doppler shift.

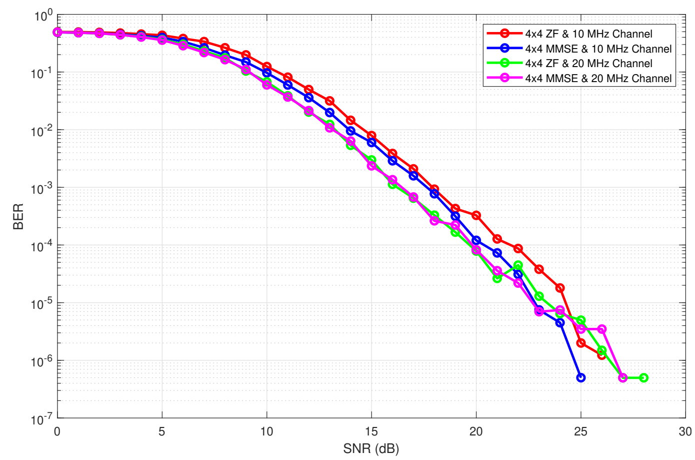

Fig. 4. BER comparison between 10 MHz and 20 MHz channels in 4x4 MIMO configuration using ZF and MMSE equalizers at 300 Hz doppler shift.

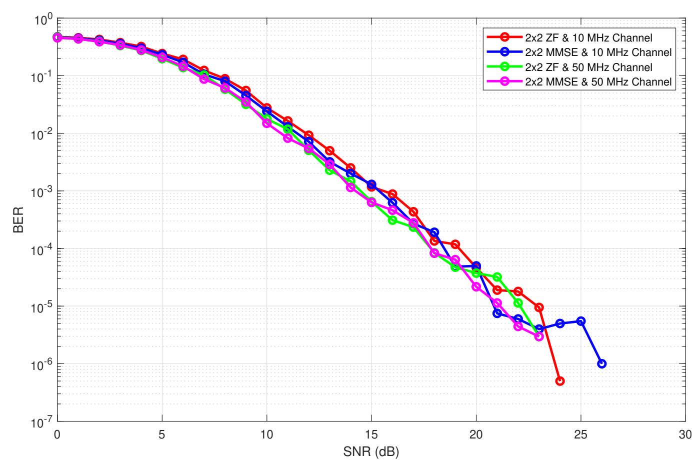

Fig. 5. BER comparison between 10 MHz and 50 MHz channels in 2x2 MIMO configuration using ZF and MMSE equalizers at 300 Hz doppler shift.

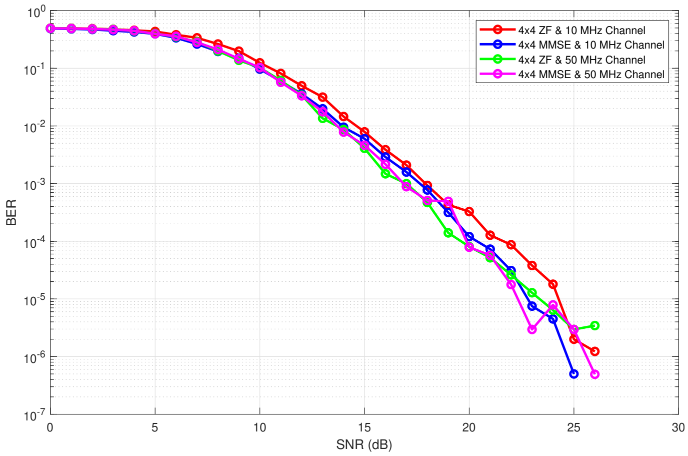

Fig. 6. BER comparison between 10 MHz and 50 MHz channels in 4x4 MIMO configuration using ZF and MMSE equalizers at 300 Hz doppler shift.

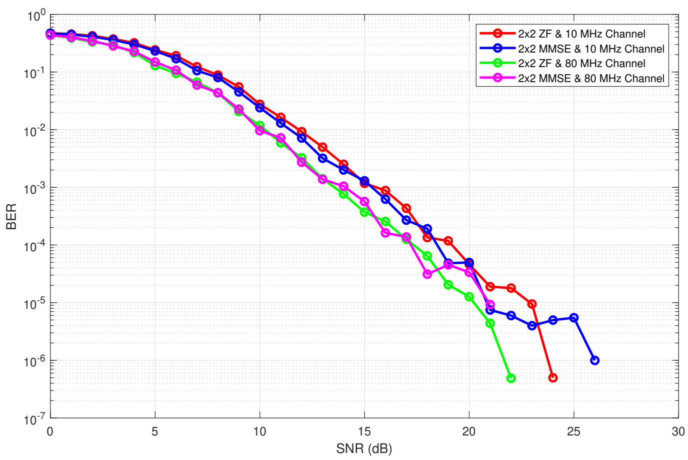

Fig. 7. BER comparison between 10 MHz and 80 MHz channels in 2x2 MIMO configuration using ZF and MMSE equalizers at 300 Hz doppler shift.

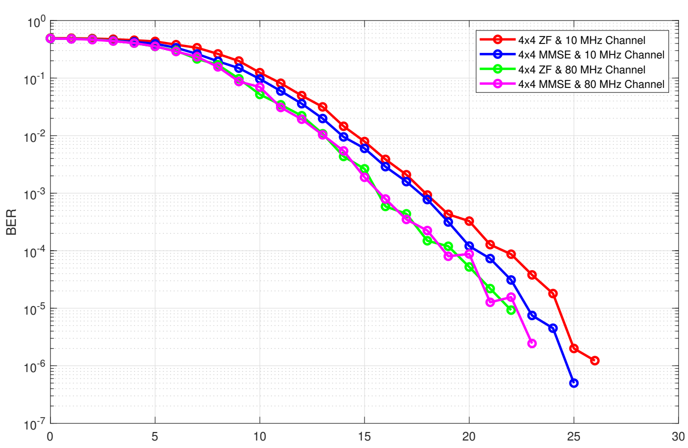

Fig. 8. BER comparison between 10 MHz and 80 MHz channels in 4x4 MIMO configuration using ZF and MMSE equalizers at 300 Hz doppler shift.

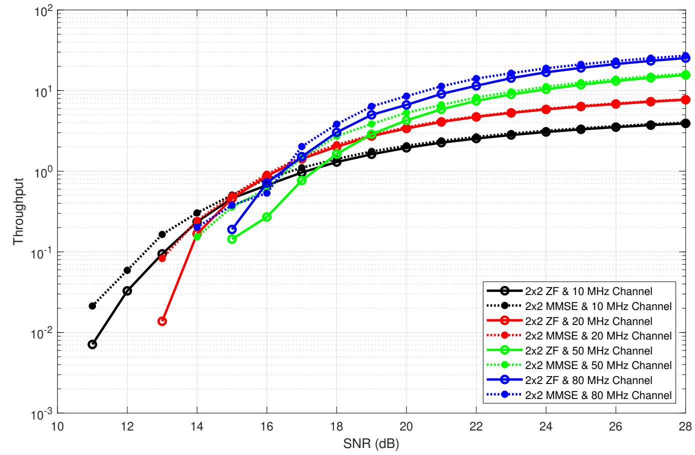

Fig. 9. Throughput comparison among 10 MHz, 20 MHz, 50 MHz, and 80 MHz channels in 2x2 MIMO configuration using ZF and MMSE equalizers at 300 Hz doppler shift.

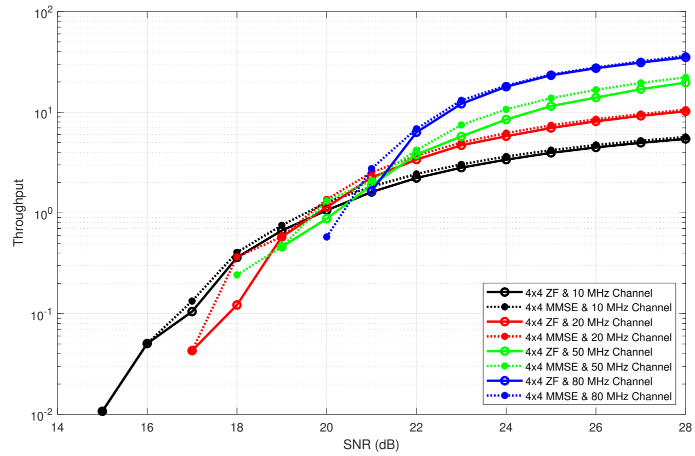

Fig. 10. Throughput comparison among 10 MHz, 20 MHz, 50 MHz, and 80 MHz channels in 4x4 MIMO configuration using ZF and MMSE equalizers at 300 Hz doppler shift.

The throughput comparison among 10 MHz, 20 MHz, 50 MHz, and 80 MHz channels for 2x2 and 4x4 MIMO configurations with both the ZF and MMSE equalizers are shown in Fig. 9 and 10 respectively. From Fig. 9 and 10 it is evident that the data rate at 20 MHz channel is higher than 10 MHz channel, the data rate at 50 MHz channel is higher than both the 10 MHz and 20 MHz channels, and the data rate at 80 MHz channel is higher than the other three channels. The reason for that is with larger bandwidth more data can be transferred within the same time frame. Also, larger bandwidth provides a larger guard band and FFT size which helps to minimize error and increase frequency resolution accuracy during transmission.

The final throughput for both 2x2 and 4x4 MIMO configurations in all four channels are recorded for both the equalizers at the end of the simulation which are presented in Table V. From Table V is it evident that the throughput for MMSE equalizer is better than the ZF equalizer in all the combinations of MIMO configurations and bandwidths because MMSE takes signal noise into consideration while estimating received signal. It is also obvious that throughput in 4x4 MIMO configuration increases significantly compared to 2x2 MIMO configuration in all four bandwidths for both the equalizers since 4x4 MIMO configuration includes more data streams in between the transmitter and the receiver.

TABLE V
THROUGHPUT COMPARISON

MIMO Configuration	Bandwidth	Throughput (in Mbps) using ZF Equalizer	Throughput (in Mbps) using MMSE Equalizer
2x2	10 MHz	3.92	4.01
	20 MHz	7.71	7.79
	50 MHz	15.60	16.16
	80 MHz	25.30	27.07
4x4	10 MHz	5.43	5.68
	20 MHz	10.23	10.60
	50 MHz	19.70	22.24
	80 MHz	35.13	36.38

However, the throughput in 20 MHz channel using 2x2 and 4x4 MIMO configurations are almost 2 times better compared to 10 MHz channel for both the equalizers. Subsequently, the throughput in 50 MHz channel using 2x2 MIMO configuration is 4 times better than 10 MHz channel for both the equalizers. On the other hand, throughput in 4x4 MIMO configuration in 50 MHz channel is more than 3.5 times better compared to 10 MHz channel for both the equalizers. In addition, the throughput in 80 MHz channel using 2x2 and 4x4 MIMO configurations are 6.5 times better compared to 10 MHz channel for both the equalizers.

VI. CONCLUSION

A change in the existing DSRC standard is imminent in the near future to fulfill the user requirements. Hence, researches have been going on to satisfy the increasing desire of vehicle users. The combination of MIMO and DSRC can provide certain improvements whereas 5G NR can achieve a significant rise in throughput on top of MIMO. Our experimental results corroborate that, the combination of MIMO and 5G NR is feasible as it does not need any new infrastructure. In addition, 5G NR does not cause additional data loss. Moreover, our proposed model keeps the enhanced data rate in high mobility non-line-of-sight scenarios. As a result, our suggested approach seems feasible and efficient to meet up the increased demand. Subsequently, our curiosity grows more on the frequency bands in the 5G NR suite especially the 28 GHz band. Also, we have an interest in reliability augmentation as well. So, our future work consists of finding compatibility of 28 GHz in the context of vehicular communication and reliability improvement using the existing DSRC standard.

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