

High Throughput Vehicular Communication Using Spatial Multiplexing MIMO

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Abstract—Vehicular communication is emerging more and more to make a safer and more comfortable transportation system. To improve road safety and convenient transport facilities, lots of information like traffic congestion, navigation data, traffic status on the road, accident updates need to be shared among vehicles to alert drivers. Only by doing so fully autonomous vehicles can operate in a more feasible way. Sharing information accurately is not an easy task due to the presence of fading in the channel and mobility of the vehicles. Thus a more robust communication system is necessary to make the existing transportation system more efficient. Dedicated Short Range Communication (DSRC) is an existing approach for vehicular communication under the IEEE 802.11p standard yet not feasible to transfer real-time data with the high data rate. In this paper, we propose a modified PHY layer of the existing IEEE 802.11p standard to employ spatial multiplexing MIMO (Multiple Input Multiple Output) for higher throughput while keeping the bit error rate lower than currently what we have now. Spatial multiplexing MIMO can provide high throughput while supporting real-time data transfer in a non-line-of-sight environment. So, this work employed spatial multiplexing MIMO on top of DSRC to achieve improved throughput. The results show that the proposed PHY layer model achieves more than twice throughput compared to the existing model.

Index Terms—MIMO, DSRC, OFDM, ITS, VANET, V2V, V2I

I. INTRODUCTION

Vehicular communication has become more important and gained more attention in the modern networking arena as Intelligent Transportation Systems (ITS) are targeting more on traffic safety. These systems are used to disseminate vital information like real-time information about accidents, traffic congestion, road construction status, and so on to make safer transportation. There are two ways to disseminate information in Vehicular Ad-hoc Network (VANET), which are Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication [6]. These communication frameworks have to be designed in such a way that it becomes cost-effective, more reliable, and faster. These frameworks use DSRC (Dedicated Short Range Communication) as a wireless communication protocol. The U.S. Department of Transportation (DOT) has

estimated that up to 82% of all crashes can be addressed by making a robust paradigm of communication among vehicles through DSRC [1]–[3].

Multipath fading and mobility of vehicles make VANET communication challenging in terms of accuracy and throughput. Several approaches have been introduced to make V2V and V2I communication more efficient. Cooperative communication is a technique that has been used to reduce transmission delay [7] and improve reliability [5], [9] and spectral efficiency [8]. Cooperative MIMO (Multiple Input Multiple Output) is used in [4] to take advantage of MIMO while keeping a single antenna system. A cluster-based adaptive mobile gateway mechanism has been proposed in [10] to achieve high speed inter-vehicular communication. Moreover, Additional Data Transmission (ADT) [11] was employed to improve throughput under the Rayleigh fading channel.

mmWave [12] is also an alternative that can provide high gain in directional beamforming and low interference. As a result, mmWave spectrum on top of DSRC can operate in high bandwidth and the Gbps data rate is expected to be achieved. However, signal distorts and attenuates more while using mmWave due to shorter wavelengths. A novel approach to minimize beam alignment has been proposed in [13] considering high mobility by leveraging DSRC and sensor information. In this approach, relative position information and trajectory estimation are obtained through automotive sensors. Consequently, this information can be exploited to mitigate beam alignment and tracking overhead. But mmWave can only provide limited features in the physical layer. The key challenges for implementing this technology are listed below [12].

- The lack of mmWave vehicular channel model.
- The penetration rate of mmWave V2X-capable vehicles.
- mmWave beam alignment.

Past research has been done to use MIMO in the DSRC standard. MIMO technique was used as a communication paradigm in between RSU (Road Side Unit) and OBU (On Board Unit) in ITS with SDR (Software Defined Radio) technology. SDR technology is used to manipulate and process radio signals for a simple radio transmission system [14]–[16].

Alamouti Space Time Block Code (STBC) as MIMO method was used to utilize diversity gain over antennas [17].

So far, cooperative MIMO and STBC MIMO have been tested for more reliable and high data rate communication. Another form of MIMO is Spatial Multiplexing, which has never been tested for vehicular communication. Therefore, our goal is to propose a PHY layer model in DSRC standard, which includes Spatial Multiplexing MIMO technology and to present maximum achievable throughput.

The rest of the paper is organized as follows: Section II presents the existing vehicular communication standard and scope to use MIMO in it. It also points out channel characteristics for vehicular communication. Section III presents the proposed 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 IV. This section also presents comparative analysis among all the configurations presented in the model. Finally, section VII concludes the paper.

II. MIMO IN VEHICULAR COMMUNICATION

This section demonstrates MIMO as a communication framework in the existing vehicular communication standard. This section also depicts the PHY layer specification in DSRC standard and describes important channel properties specifically for vehicular communication.

A. PHY Layer in Vehicular Communication

The PHY layer in vehicular communication is defined in Dedicated Short Range Communication (DSRC) protocol, which is developed by the automotive industry to use in vehicle-to-vehicle and vehicle-to-roadside communication. 75 MHz dedicated spectrum in the 5.9 GHz band is licensed by the U.S. Federal Communications Commission (FCC) for DSRC communication. DSRC uses Wireless Access for Vehicular Environments (WAVE) standard at the Physical and MAC layer, which is enclosed in IEEE 802.11p [1]–[3]. OFDM (Orthogonal Frequency Division Multiplexing) is a multiple-access technology adopted by DSRC which provides high spectral efficiency, resistance to intersymbol interference due to multipath fading and adaptability for broadband data transmission. The 802.11 working group specified three channel widths for feasible communication which are 5 MHz, 10 MHz, and 20 MHz. DSRC mostly uses 10 MHz channel to neutralize most of the air interference because 20 MHz channel is used by 802.11a standard. The basic parameter for the 10 MHz channel is presented in Table I.

The block diagram of the PHY layer of DSRC is shown in Fig. 1. According to the standard, the frame coming out of the MAC layer is fed into the PHY layer and the first phase of the PHY layer is FEC coding where signal data is encoded by one of the several coding rates. The next phase is Signal Modulation, where the input frame is modulated by modulation techniques like QPSK, 16-QAM or 64-QAM. The third phase in the block diagram is OFDM Modulation,

where the frame from the previous step is modulated using the OFDM modulation technique.

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 μ sec |
| Symbol interval (including GI) | 8 μ sec |

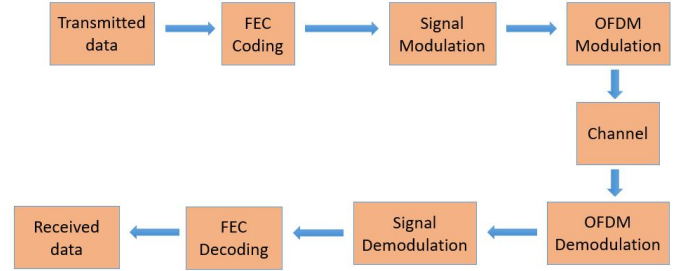


Fig. 1. Block diagram of DSRC PHY layer.

After all the processing, the frame is transmitted out in the channel. At the receiver side, the reverse procedure is applied to get received data bits. We used the same specification to implement our experiment.

B. Vehicular Communication Radio Channel

The performance of vehicular communication depends significantly on the channel properties. Multi-path propagation is one of the major characteristics of the radio channels. It affects the signal when the signal is distorted due to reflection, diffraction or scattering by any object during propagation. This kind of scenario arises in city areas where lots of objects like buildings, traffic light poles, other vehicles are around and mostly non-line-of-sight scenario is observed. Moreover, the mobility of vehicles plays a vital role in changing signal characteristics. Due to relative movement among vehicles and between vehicle and roadside unit, signal frequency changes during propagation which is known as the doppler shift.

We used the MIMO channel model based on channel frequency response to make fading and doppler shift effect to transmitted signals for our approach. Additionally, we used the Additive White Gaussian Noise channel to add noise to the transmitted signal.

C. Multiple Input Multiple Output (MIMO) Communication

The point of MIMO is having more than one antenna at both the transmitter and receiver sides. There are different forms of MIMO techniques available and Spatial Multiplexing is one of them. In Spatial Multiplexing, each transmitting antenna can transmit a completely independent data stream. The advantages of Spatial Multiplexing include data rate increase in proportion to the number of transmit antenna

ports and an increase in bandwidth utilization. Considering the scenario presented in Fig. 2, there can be m transmitting antennas and n receiving antennas. Transmit antenna and receive antenna configuration can be represented as column matrices, and channel can be represented as multidimensional matrix, which is shown in (1).

$$y_{n \times 1} = h_{n \times m} \times x_{m \times 1} + n_{n \times 1} \quad (1)$$

In (1), $x_{m \times 1}$ represents the transmit antenna matrix, $h_{n \times m}$ represents the channel matrix, $y_{n \times 1}$ represents the receive antenna matrix and $n_{n \times 1}$ represents the noise matrix in the channel.

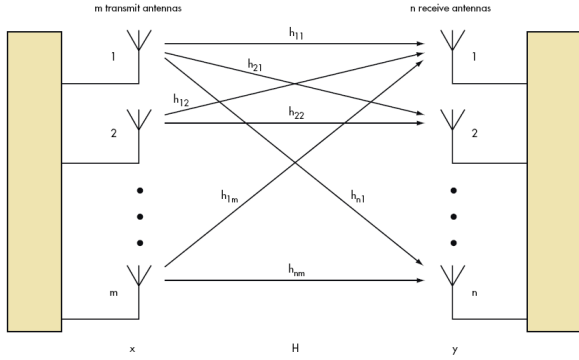


Fig. 2. MIMO Spatial Multiplexing scenario.

At the receiving end, received data may be distorted due to the presence of noise in the channel. So, methodologies need to be used to compensate these noises to get a maximum approximation of transmitted data. There are two well-known methodologies available in Spatial Multiplexing MIMO which are listed below.

- Zero Forcing (ZF).
- Minimum Mean Squared Error (MMSE).

We took 2x2 and 4x4 MIMO configurations into consideration and used both ZF and MMSE equalizers for our approach.

III. EXPERIMENTAL DESCRIPTION

Having multiple transmitting and receiving antennas, MIMO can transfer a large amount of data with a high transfer rate in real-time environment. Applying this feature in DSRC high throughput performance can be achieved. So, we applied MIMO in the DSRC communication standard at the PHY layer. We modified the conventional block diagram of the DSRC system depicted in Fig. 1 for our proposed model.

Moreover, we added a MIMO transmitter in between OFDM Modulation and Channel blocks and also added a MIMO receiver in between Channel and OFDM Demodulation blocks. We added both ZF (Zero Forcing) and MMSE (Minimum Mean Squared Error) functionalities in our experiment. As a modulation technique, we used QPSK in the signal modulation block. As a MIMO configuration, we used 2x2 (two transmitting antennas and two receiving antennas) and 4x4 (four transmitting antennas and four receiving antennas) configurations.

As an FEC error detection and correction scheme, we used 1/3 of coding rates. The block diagram of our proposed model is demonstrated in Fig. 3.

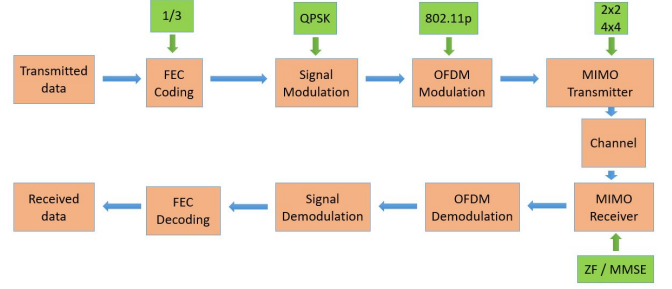


Fig. 3. Block diagram of proposed model.

On the other hand, we designed a baseline experimental model to evaluate the performance of our model. For the baseline model, we used 1x1 (one transmitting antenna and one receiving antenna) MIMO configuration and ZF (Zero Forcing) equalizer at the receiver end. The other specifications stay the same as the proposed model. The block diagram of the baseline model is presented in Fig. 4.

We implemented functionalities of all the blocks depicted in Fig. 3 in the Matlab platform and ran the simulation as a whole package. Our simulation parameters are presented in Table II.

We have considered three metrics to validate our model:

a) *Frame Rate*: Frame rate defines how many frames are received successfully without any error per unit time. It is calculated by the ratio of the number of successful frames at the receiver divided by the total number of frames transmitted during simulation time.

b) *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 simulation time.

c) *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 all our experiments, we used 0.5 ms as a transfer time for each frame to calculate throughput.

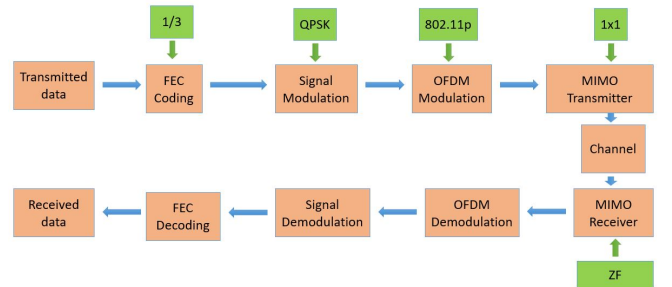


Fig. 4. Block diagram of baseline model.

TABLE II
EXPERIMENTAL SPECIFICATION

| Parameter | Value |
|----------------------------------|--------------------------|
| Modulation type | QPSK |
| Channel model | Rayleigh Fading |
| Doppler Shift | 30Hz & 300Hz |
| Channel Bandwidth | 10 MHz |
| SNR range | 0 - 30 dB |
| CRC code | 24 bit CRC checksum |
| Coding Rate | 1/3 Convolutional Coding |
| FFT length | 64 |
| Number of symbols in each frame | 80 |
| Cyclic Prefix Length | 52 |
| Maximum Number of Bits processed | 2e5 |

We implemented our experimental simulation in the Matlab environment. So, we generated transmission data with the random functionality available there. Convolutional encoding and Viterbi decoding are also available for FEC encoding and decoding respectively, which we used to have 1/3 coding rate. We also used 24 bit CRC (Cyclic Redundancy Check) detector to determine frame error. Moreover, we defined QPSK modulator and demodulator object for our required modulation and demodulation scheme. We also set up OFDM modulator and demodulator object with the specification defined in the IEEE 802.11p standard. After setting up all the parameter we ran our simulation and stored the results for further analysis.

IV. EXPERIMENTAL RESULT AND ANALYSIS

We ran the simulation for the baseline, 2x2, and 4x4 MIMO configurations with both ZF and MMSE equalizers at 30Hz and 300Hz doppler shifts. The BER graph for this experiment is displayed in Fig. 5, 6, and 7. From Fig. 5 it is observed that BER performances for 2x2 and 4x4 configurations are much better than the baseline although 4x4 configuration performs worse than 2x2 configuration. The reason for that is the rank deficiency problem of the channel matrix as the paths connecting transmitting antennas to receiving antennas become similar with the increase of antennas. As a result, BER performance tends to decrease with the increase of antennas.

From Fig. 6 and 7 it is shown that BER performance for 2x2 and 4x4 MIMO configurations at 30Hz and 300Hz doppler shifts are more or less similar but with the increase of SNR value performance at 30Hz turns out a little better than performance at 300Hz for MMSE equalizer.

The frame rate comparison for the baseline, 2x2, and 4x4 MIMO configurations with both ZF and MMSE equalizers at 30Hz and 300Hz doppler shifts are presented in Fig. 8, 9, and 10. From Fig. 8 it is evident that 2x2 MIMO configuration outperforms the baseline, and 4x4 MIMO configuration outperforms the other two configurations. From Fig. 9 and 10, it is shown that the performance of 2x2 and 4x4 MIMO configurations at 300Hz doppler shift is worse than the performance at 30Hz doppler shift. That is because of higher mobility at 300Hz doppler shift distorts signal more than 30Hz.

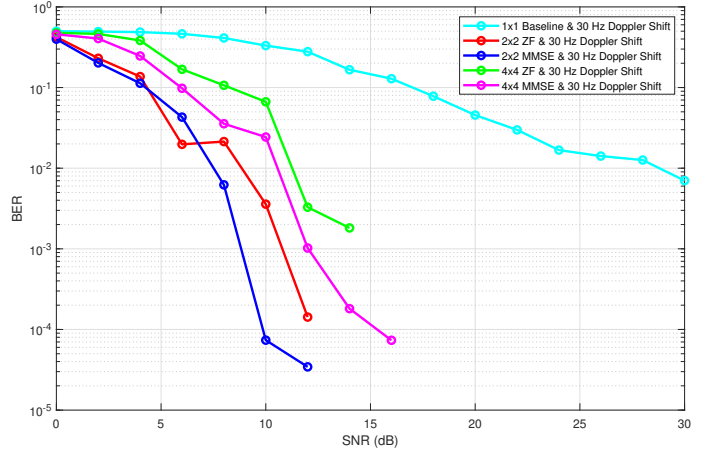


Fig. 5. BER comparison among baseline, 2x2, and 4x4 MIMO configuration with ZF and MMSE equalizer at 30Hz doppler shift.

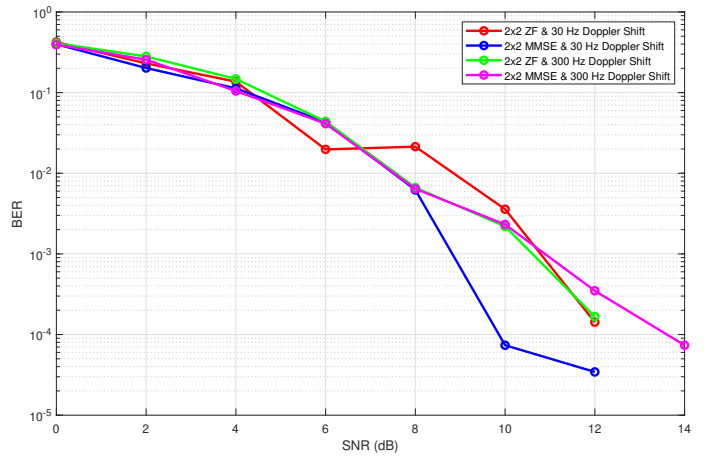


Fig. 6. BER comparison between ZF and MMSE equalizer in 2x2 MIMO configuration at 30Hz and 300Hz doppler shift.

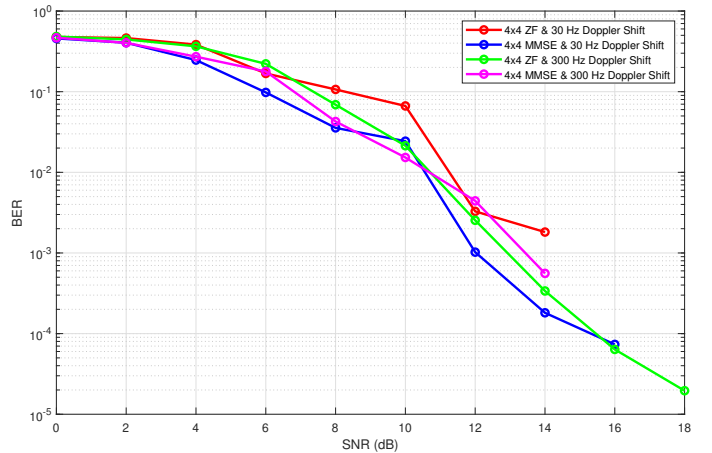


Fig. 7. BER comparison between ZF and MMSE equalizer in 4x4 MIMO configuration at 30Hz and 300Hz doppler shift.

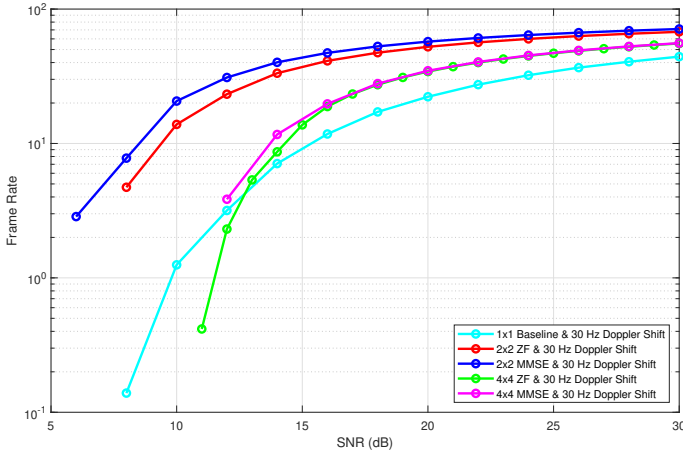


Fig. 8. Frame Rate comparison among baseline, 2x2, and 4x4 MIMO configuration with ZF and MMSE equalizer at 30Hz doppler shift.

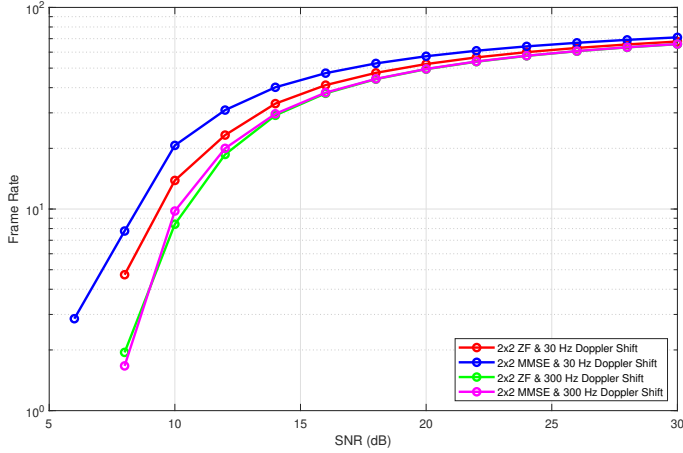


Fig. 9. Frame Rate comparison between ZF and MMSE equalizer in 2x2 MIMO configuration at 30Hz and 300Hz doppler shift.

The throughput comparison for the baseline, 2x2, and 4x4 MIMO configurations with both ZF and MMSE equalizers at 30Hz and 300Hz doppler shifts are presented in Fig. 11, 12, and 13. From Fig. 11 it is observed that throughput for 2x2 and 4x4 MIMO configurations outperform the baseline configuration. Initially, the performance of 4x4 MIMO configuration is worse than the performance of 2x2 MIMO configuration but eventually outperforms with the increase of SNR value. From Fig. 12 and 13, it is shown that the performances for both the 2x2 and 4x4 MIMO configurations are worse at 300Hz doppler shift than the 30Hz doppler shift with both the equalizers. The reason for that is the impact of high mobility in the signal is higher at 300Hz doppler shift than 30Hz.

The overall throughput for the baseline is 1.12 Mbps, and for all the other configuration is presented in Table III. From Table III, it is evident that throughput for 2x2 MIMO configuration is more than twice compared to the baseline. Subsequently, 4x4 MIMO configuration performs more than 1.5 times better than the 2x2 MIMO configuration. The reason behind this is with more antennas transmitter can send more

data to the receiver.

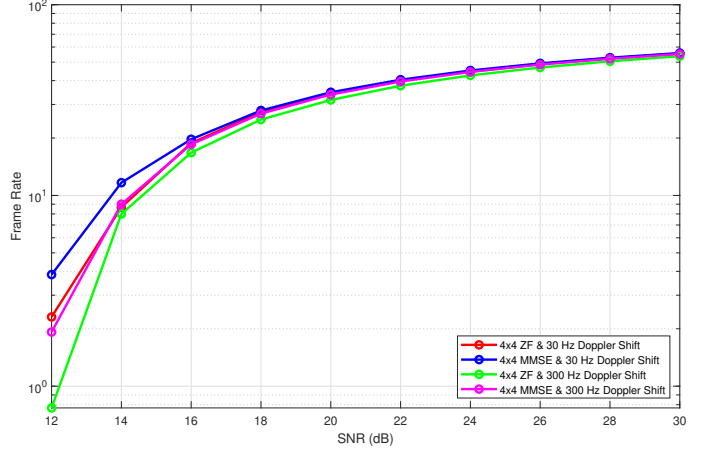


Fig. 10. Frame Rate comparison between ZF and MMSE equalizer in 4x4 MIMO configuration at 30Hz and 300Hz doppler shift.

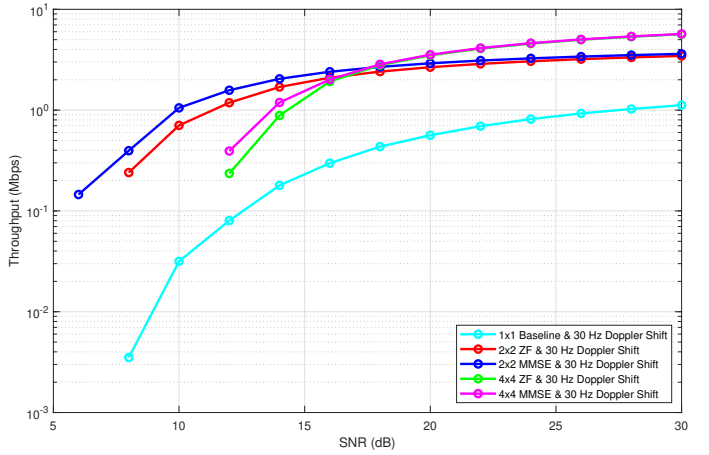


Fig. 11. Throughput comparison among baseline, 2x2 and 4x4 MIMO configuration with ZF and MMSE equalizer at 30Hz doppler shift.

TABLE III
THROUGHPUT COMPARISON

| MIMO Configuration | Doppler Shift (in Hz) | Equalizer | Throughput (in Mbps) |
|--------------------|-----------------------|-----------|----------------------|
| 2x2 | 30 | ZF | 3.45 |
| 2x2 | 30 | MMSE | 3.62 |
| 2x2 | 300 | ZF | 3.34 |
| 2x2 | 300 | MMSE | 3.35 |
| 4x4 | 30 | ZF | 5.66 |
| 4x4 | 30 | MMSE | 5.70 |
| 4x4 | 300 | ZF | 5.48 |
| 4x4 | 300 | MMSE | 5.63 |

V. CONCLUSION AND FUTURE WORK

Researches have been going on in vehicular communication, and several approaches have been proposed to improve efficiency and effectiveness. The existing technology like DSRC can transfer small information with good reliability but fails

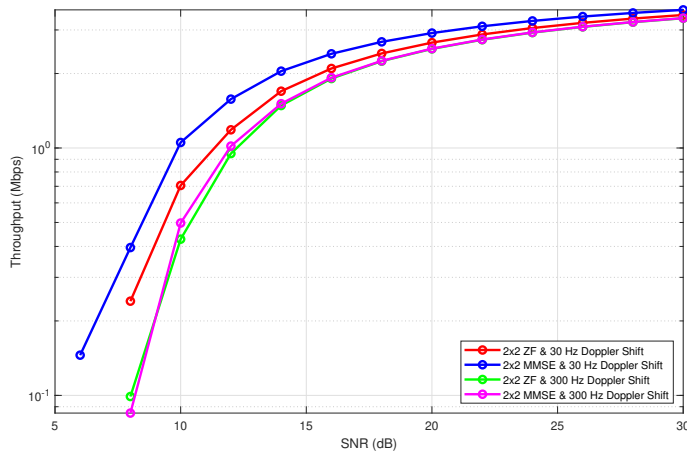


Fig. 12. Throughput comparison between ZF and MMSE equalizer in 2x2 MIMO configuration at 30Hz and 300Hz doppler shift.

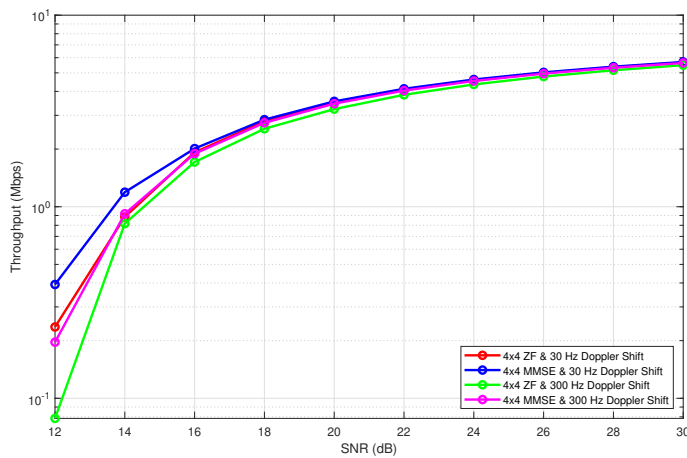


Fig. 13. Throughput comparison between ZF and MMSE equalizer in 4x4 MIMO configuration at 30Hz and 300Hz doppler shift.

to have a high data rate. With the emergence of the smart transportation system, the high data rate will be needed to transfer more data through V2V and V2I infrastructure using the DSRC standard. So, spatial multiplexing MIMO on top of DSRC is proposed to make these communication frameworks more feasible and robust. Our experimental results corroborate the usefulness and efficacy of our proposed model to meet up high-speed data rate requirements in future transportation systems. Also it would be an interesting feature in vehicular communication if motorists and car drivers can communicate using their voice. For making it possible voice data has to be transferred using the same framework and without introducing any new infrastructure. So, our future work includes transmitting voice data over our proposed model and analyze the performance of this voice data.

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