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INTERFERENCE MITIGATION IN THE VEHICULAR COMMUNICATION NETWORK USING MIMO TECHNIQUES

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Abstract

A vehicular ad hoc network (VANET) is made through implementing the principles of mobile ad hoc networks (MANETs) in the vehicle's domain. With the increasing number of people driving cars and vehicles, there is a corresponding increase in the number of deaths caused by accidents. One of the major challenges in designing a communication system is to overwhelm the impacts of a wireless channel while ensuring high power and spectral efficiencies at the same time. Since the data is transmitted via the wireless medium, the transmitted signal will certainly suffer from the harmful effects of two different factors: mobility and multipath fading. To support communication between vehicles, reliable wireless communication techniques are needed. Multiple input multiple-output (MIMO) technology can improve the transmission process of data to a receiver. Also, it can mitigate the impacts of multipath fading and accomplish reliable high data rate transmission. It is the important factor, producing better performance on two different angles Spatial Multiplexing (SM) and Spatial Diversity (SD). The subject to be addressed is the improved channel reliability of VANET using SM techniques. It is given a significant improvement of Bit Error Rate (BER) performance against traditional methods.

Keywords: ITS, MIMO, Spatial diversity, Spatial multiplexing, VANET.

1. Introduction

The continuous increase in road accidents around the world motivated the evolution of intelligent transport systems (ITS) [1]. Current trends in technology show VANETs, in which vehicles and roads are equipped with wireless communication capabilities in the form of On-Board Units (OBU) in vehicles and Road Side Units (RSU) deployed along roads. These trends aim to increase driver safety on the road, increase road utilization. Its applications can be broadly categorized into road safety applications and value-added services. Safety applications enlist vehicle safety on roads and value-added services include internet access, entertainment, and commercial applications [2, 3]. It has been developed to make these applications feasible, to minimize the risk of accidents, and to improve passenger comfort by enabling vehicles to share different types of data between vehicles themselves V2V or potentially between vehicles, to V2I [1, 4, 5].

VANET designers face a dual challenge, one of which enhances data rate and the other is improving performance without increasing the power or bandwidth. Unfortunately, the available radio spectrum is scarce and should be used effectively. VANET networks have their special characteristics: high node mobility with restricted movements and mobile nodes with ample power, high computing power (e.g., storage and processing), and sufficient space [6]. In a wireless system, the channel plays an important role in determining signal transmission quality. various factors that determine the quality of the wireless system are noise, attenuation, shadowing, and fade through multiple paths which may lead to degrading signal [6, 7].

Significant technologies, like Orthogonal Frequency Division Multiplexing (OFDM), have become a foundation of various standards including wireless local area network (WLANs). MIMO technology can improve system performance [8]. An OFDM can be combined with MIMO for decreasing the impacts of multipath fading and perform reliable high data rate transmission over the wireless channel, through various diversity techniques [5, 6].

Moreover, MIMO and OFDM schemes are considered to be reliable for providing high data rates and are adopted mainly by the 4G wireless network and are most likely to be adopted by the 5G wireless network. MIMO technology is used as a way to meet the demand to increase the capacity of wireless communications systems without increasing transmits power and bandwidth [8, 9].

In this context, this work is going to suggest and implement different possible techniques in VANET environments by exploiting multipath for improving the performance of wireless channel (quality of communication link) in VANET.

2. Related Work

To improve the performance of VANET in fading environments, channel modeling [10-18], mobility modeling [19-25], network topology models [26-31], broadcasting protocols [32-35]. However, many contributions in literature have focused on MIMO techniques to exploit multipath. Giang [36] investigated the performance of a vehicular MIMO system by selecting two out of four available antenna elements at one link-end. Using an adaptive antenna selection algorithm that can keep the channel capacity near to its maximum value at far distances compared to a conventional MIMO system. They can achieve higher capacities than Rayleigh channels.

Saleh and Hasson [37] proposed antenna selection algorithm for making applicable for MU-MIMO VANET. Performance comparison of MU-MIMO with SU-MIMO in realistic urban and highway scenario presented. Comparison has indicated MU-MIMO as a better choice over SU-MIMO in safety applications, as it doubles throughput, reducing end-to-end delay to nearly half. Pollock [38] introduced an applicable low-complexity beam forming scheme with transmit diversity in the high mobility scenario with the aid of location information. A location-aided algorithm is proposed to eliminate the interference and maximize the mobile service of the whole train at the same time . Mohinder [39] and Lozano and Jindal [40] addressed a fundamental problem of VANET: the network capacity. Opens an important direction for future research on understanding VANET networks. Two simple theoretical models to estimate the maximum amount of capacity have been proposed: a packing model and a Markovian point process model. Many simplistic assumptions are presented regarding mobility models and communication models.

3. Methodology

In MIMO communication systems, either M_T or M_R antennas' signals are detected by each receiver antenna. This allows channels of single input and a single output (SISO) to be depicted as matrix $M_T \times M_R$. A frequency flat fading, MIMO channel matrix $M_T \times M_R$, and a specified time might be denoted by Mishkhal et al. [41]:

$$H = \begin{bmatrix} h_{11} & h_{11} & \cdots & h_{1,MT} \\ h_{21} & h_{21} & \cdots & h_{2,MT} \\ \vdots & \vdots & \ddots & \vdots \\ h_{MR1} & h_{MR,2} & \dots & h_{MR,MT} \end{bmatrix} \tag{1}$$

where SISO channel gain is h_{ij} amongst j^{th} transmit antenna pairs and the ith receive antenna. The column j^{th} of H is commonly meant as a spatial signature of the j^{th} transmit antenna across an array of receive antennas. For the case of SISO channels, the distinct channel gains comprising a MIMO channel are generally modelled as zero-mean AWGN. Therefore, the channel amplitudes h_{ij} are randomly Rayleigh Distributed variables. Finally, a receiving signal can be characterized as the subsequent equation [41-49].

$$y = \sqrt{\frac{E_S}{M_T}}\, H\, x + n \tag{2}$$

where vector $M_R \times 1$ of a receiving signal is y , the transmitting signal is x of a vector $M_T \times 1$, the AWGN is a factor $\sqrt{\frac{E_S}{M_T}}$ guarantees that total energy transmitted is E_s. In Fig. 2, assume that a MIMO channel has a rich scattering environment. Each couple of transmitting and receiving antennas can be regarded as parallel sub-channels (SISO channels). Since information is moved over parallel channels, each antenna pair has one channel. The channel capacity increases with increasing the number of transmitting and receiving pairs [50-53]. Multiple antennas can be utilized for diversity by sending redundant data through multiple antennas to enhance performance. Redundancy in data is achieved by transmitting data through spatial streams. It can also be used for multiplexing by transmitting different data through multiple antennas for enhancing capacity beyond Shannon limits [8]. These schemes have been existing for ad-hoc networks with static or slow-moving nodes

[54], however, not for VANETs which are having high node mobility and the varying speed of vehicles. General Flow charts for zero-forcing (*ZF*), minimum mean square error (MMSE), and space-time block coding (STBC) techniques would be depicted below in Fig. 1.

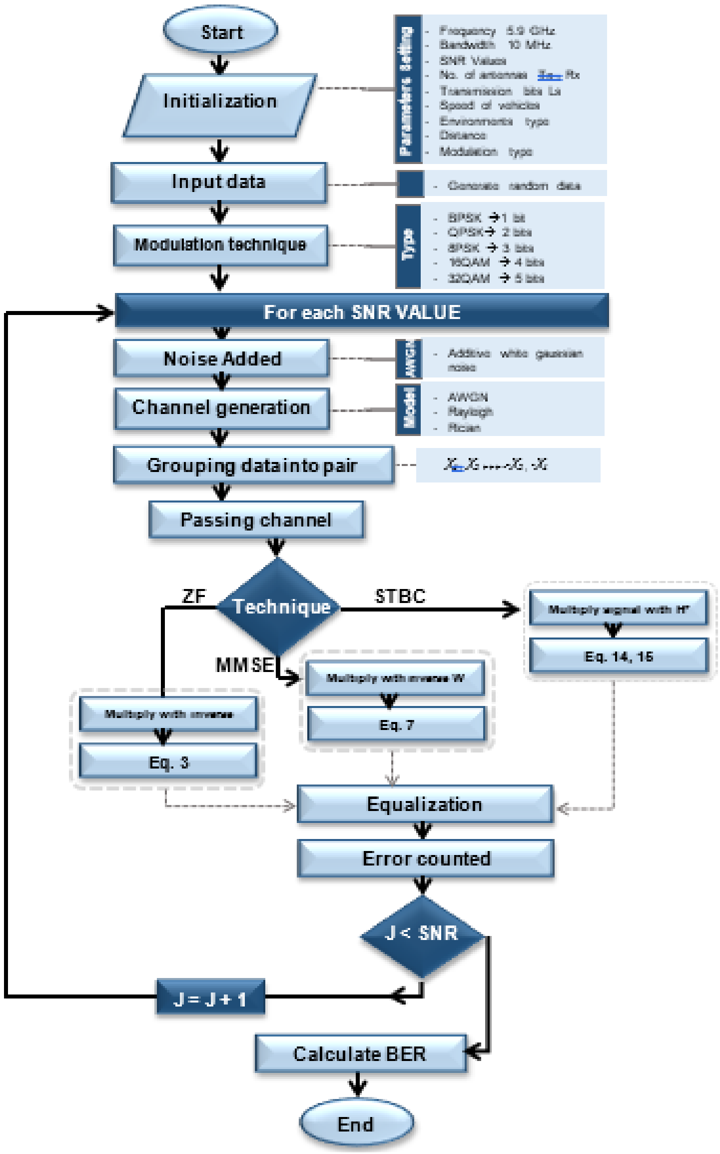

Fig. 1. Flow chart of MIMO techniques.

3.1. ZF technique

Matrix inversion is the simplest, but it is also the least efficient technique. Although the inverse of the matrix is just found for square patterns. Therefore, there is a more comprehensive process associated with a pseudo-inverse matrix that can be applied for squared and no squared forms by multiplying the receiving signal y obtained in

Eq. (2). The interference is eliminated over the pseudo-inverse of the matrix. Consequently, a combiner of *ZF* weight G_{ZF} is obtained by [11, 12, 51]:

$$G_{ZF} = \sqrt{\frac{M_T}{E_s}} H^P = \sqrt{\frac{M_T}{E_s}} (H^H H)^{-1} H^H \tag{3}$$

where a pseudo-inverse matrix is $H^P=(H^H H)^{-1} H^H$ of the channel, and H is the matrix of the channel. Where a complex conjugate transpose is H^H for a channel H. For a matrix 2×2, the $H^H H$ described below [52]:

$$H^H H = \begin{bmatrix} h_{11}^* & h_{21}^* \\ h_{12}^* & h_{22}^* \end{bmatrix} \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}$$

$$= \begin{bmatrix} |h_{11}|^2 + |h_{21}|^2 & h_{11}^* h_{12} + h_{21}^* h_{22} \\ h_{12}^* h_{11} + h_{22}^* h_{21} & |h_{12}|^2 + |h_{22}|^2 \end{bmatrix} \tag{4}$$

As mentioned above, the interference signals are completely overcome by multiplying the signal y obtained of the Eq. (2) by weight G_{ZF} of the *ZF*, providing an estimated vector in the receiver $\tilde{s}$ [51, 54].

$$\tilde{s} = G_{ZF} y = G_{ZF} \left(\sqrt{\frac{E_s}{M_T}} Hs + z \right) = s + G_{ZF} z \tag{5}$$

The major issue of the *ZF* approach is noise amplification. If a matrix $H^H H$ has very small eigenvalues, it might produce very large values in an inverse process that produces samples of noise. *ZF* technique performs diversity gain that is simply M_R-$M_T +1$ [52, 54].

3.2. MMSE technique

An alternative to the *ZF* technique is the MMSE technique, which trying to achieve equilibrium among interference reduction and noise increases through reducing an expected value of a Mean Square Error (MSE), between transmitting *s* vector and a linear combination of the receiving vector $G_{MMSE}\ y$ [50, 54]:

$$E\ \{(s - G_{MMSE} y)^2\} \tag{6}$$

where is G_{MMSE} **is** the combiner weight of MMSE, representing in $M_T \times M_R$ matrix and it is shown below as [54]:

$$G_{MMSE} = \sqrt{\frac{M_T}{E_s}} \left(H^H H + \frac{N_o}{E_s} I_{MT} \right)^{-1} H^H \tag{7}$$

The transmitted power (Energy) is E_s , energy noise is N_o , and the identity matrix ($M_T \times M_T$) is I_{MT}. Estimated vector is $\tilde{s}$ in the receiver is consequently described by [12]:

$$\tilde{s} = G_{MMSE} y = s + G_{MMSE} z \tag{8}$$

As SNR rises to a large value, the MMSE combiner converges to the *ZF* combiner. Nevertheless, in the low value of SNR, it avoids the worst values of the eigenvalues from being inverted [53].

3.3. SBTC technique

In this technique, a sample of the Alamouti STBC technique is sending a 2×2. MIMO likes the MISO situation, suppose that pair of symbols s_1 and s_2 are sent together from antennas one and two in transmitter through the first period, whereas symbols $-s_2^*$ and s_1^* are transferred from antennas one and two through the subsequent period, as shown in Fig. 2. [12].

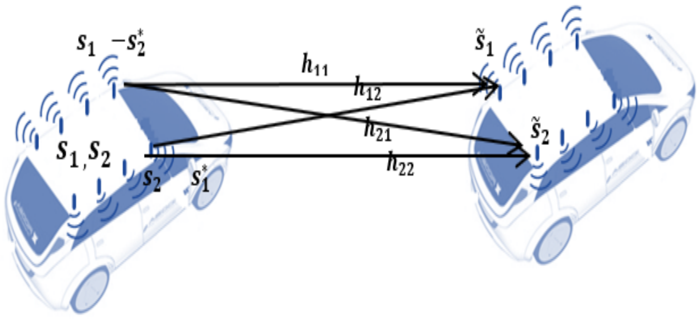

Fig. 2. Alamouti STBC technique with M_T= 2 and M_R = 2.

Suppose a flat fade channel stays constant during dual consecutive periods, so the matrix code of S as follows [23, 53]:

$$S = [s_1 \; -s_2^* \; s_2 \; s_1^* \,] \tag{9}$$

and the matrix of 2×2 channel describes as [48]:

$$H = [h_{11} \; h_{12} \; h_{21} \; h_{22} \,] \tag{10}$$

If y_{11}, and y_{12}, denote to the receiving signals by antenna one at time 1, by antenna one at time 2, if y_{21} , and y_{22} represent the receiving signals by antenna two at time 1, and by antenna two at time 2, separately [49, 54]:

$$[y_{11} \; y_{12} \; y_{21} \; y_{22} \,] = \sqrt{\frac{E_s}{2}}[h_{11} \; h_{12} \; h_{21} \; h_{22} \,][s_1 \; -s_2^* \; s_2 \; s_1^* \,] + [z_{11} \; z_{12} \; z_{21} \; z_{22} \,]$$

$$= \left[\sqrt{\frac{E_s}{2}}(h_{11}s_1 + h_{12}s_2) + z_{11} \; \sqrt{\frac{E_s}{2}}(-h_{11}s_2^* + h_{12}s_1^*) + z_{12} \; \sqrt{\frac{E_s}{2}}(h_{21}s_1 + h_{22}s_2) + z_{21} \; \sqrt{\frac{E_s}{2}}(-h_{21}s_2^* + h_{22}s_1^*) + z_{22}\right] \tag{11}$$

The combiner in a receiver, create as [54]:

$$\tilde{s}_1 = h_{11}^* y_{11} + h_{12} y_{12}^* + h_{21}^* y_{21} + h_{22} y_{22}^* \tag{12}$$

and

$$\tilde{s}_2 = h_{12}^* y_{11} - h_{11} y_{12}^* + h_{22}^* y_{21} - h_{21} y_{22}^* \tag{13}$$

which yields

$$\tilde{s}_1 = \sqrt{\frac{E_s}{2}}\,(\; h_{11} \;{}^2 + |h_{12}|^2 + |h_{21}|^2 + |h_{22}|^2)s_1 + z_1' \tag{14}$$

and

$$\tilde{s}_2 = \sqrt{\frac{E_s}{2}}\,(\; h_{11} \;{}^2 + |h_{12}|^2 + |h_{21}|^2 + |h_{22}|^2)s_2 + z_1' \tag{15}$$

where the noise terms Additive White Gaussian Noise (AWGN) are z_1' and z_2' which are the linear summation of z_{11}, z_{12}, z_{21}, and z_{22}. It is remarked that detection becomes fully decoupled, that is,1 detection of s_1 is independent of s_2 [34]. The modeling process aims to improve the system behaviors and increase its efficiency. The main advantage of the modeling process is to get the optimal solution from the available feasible alternatives. It equipped the decision-maker with a reliable tool to inspect and investigate the Behavior of the studied system without interfering with all its details [3]. The formulated model is usually created to represent a collection of mathematical and logical relationships that consider all the features of the studied problem. It would describe the relationships among variables. The mathematical model is composed of a single or multi-objective function and set of constraints [4].

4. Results

The MIMO techniques are simulated and tested in subsequent sections, with *ZF*, MMSE, and STBC techniques. Furthermore, in terms of BER's performance, these techniques are compared to each other by different transmission categories graphically and numerically.

4.1. ZF performance

The comparison simulation results for the *ZF* technique with M_T = 2 and M_R=2, 3, and 4 are shown in Fig. 3. It can be noticed, the BER of the *ZF* performance with M_T = M_R = 2, (2×2 transmission scheme) is identical to that of SISO. Actually, in the *ZF* technique, co-channel signals interference is completely separated in the *ZF* combiner, but with the cost of noise intensification. Besides, these results are associated with the diversity order of *ZF* provided by M_R–M_T +1. When M_R=M_T, the order of diversity is equal to 1, which is similar to the SISO diversity order. Therefore, the *ZF* technique does not give the benefit of diversity over SISO when M_T=M_R. For instance, at BER=10^{-5}, the performance has improved, if M_R>M_T and for M_R=3 and 4, the improvements are 22.3 dB, and 30.03 dB individually.

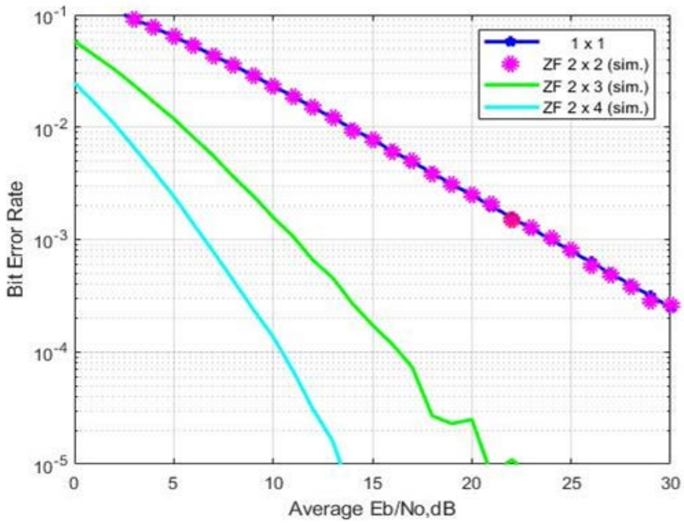

Fig. 3. BER performance of ZF with M_T = 2 and M_R = 2 3, and 4.

The *ZF* with $M_R > M_T$ is also noticed as having the approximation to the performance of the MRC. The BER performance of the *ZF* technique with M_R= 3, for instance, has the same performance as the MRC technique for M_R= 2 (order = 2). This similarity in BER results is because both two techniques have the same order of diversity and rely on the multiplication of the received signal with complex conjugation of channel h^*.

4.2. MMSE performance

Figure 4 illustrates the simulated BER performance of the MMSE technique, at BER=10^{-5}. Figure 4 demonstrates that the BER gain for M_T= M_R= 2 is about 4, 5 dB higher than SISO. The performance improvement in BER is enhanced while utilizing $M_R > M_T$, about 23 dB for M_R= 3 and 31 dB for M_R= 4.

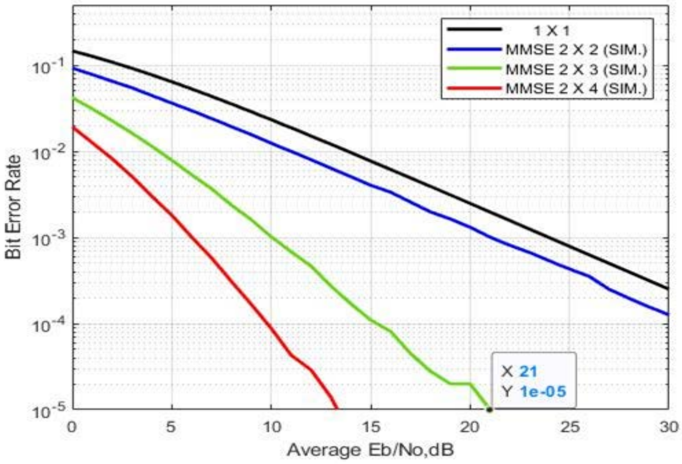

Fig. 4. BER of MMSE with M_T = 2 and M_R =2, 3, and 4.

MMSE technique has greater performance than the *ZF* technique as seen in Figs. 3. and 4. The receiver of the MMSE technique suppresses both noise and interference, while the receiver of the *ZF* technique eliminates just interference. This involves minimizing the mean square error between transferred symbols and estimated symbols at the recipient. Thus, in the presence of noise MMSE technique is superior to the *ZF* technique.

4.3. STBC MIMO performance

As previously outlined, the STBC technique could be utilized for both MISO and MIMO systems. Simulation results of BER performance of STBC are discussed in this section. In the simulation, the STBC receiver is supposed to have a full CSI about the channel and remains consistent over two-time slots for sending two symbol periods. STBC technique with M_T= 2, and M_R= 1, 2, 3 and 4, for STBC (2x1, 2x2, 2x3, and 2x4) Transmission schemes. Figure 5 indicates the gain of STBC. Figure 4 shows the improvement in performance at BER=$10^{.5}$, for M_R=1, 2, 3, and 4 by about 19.7 dB,29 dB,33 dB, and 36 dB, correspondingly.

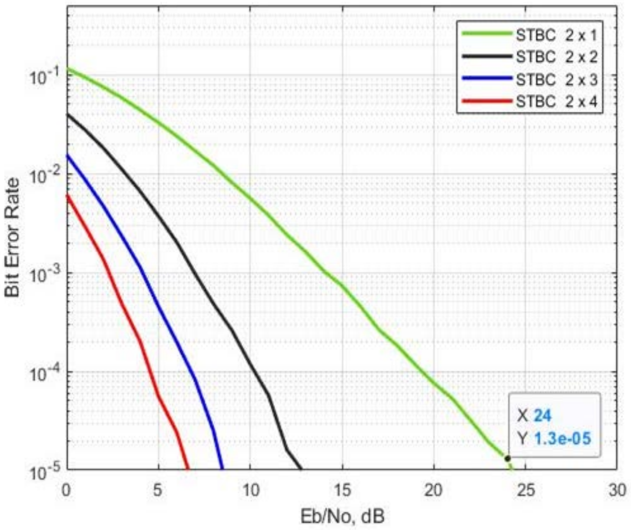

Fig. 5. BER of STBC with M_T = 2 and M_R =1, 2, 3, and 4.

4.4. Performance comparison for MIMO techniques

For all techniques with M_T= 2 and M_R= 2 (2×2 scheme). Figure 6 indicates that *ZF* has the worst results followed by MMSE and STBC techniques, STBC has an improvement in performance than MMSE and *ZF*, at1BER=10-^{5} by about 24.5 dB and 29 dB, separately.

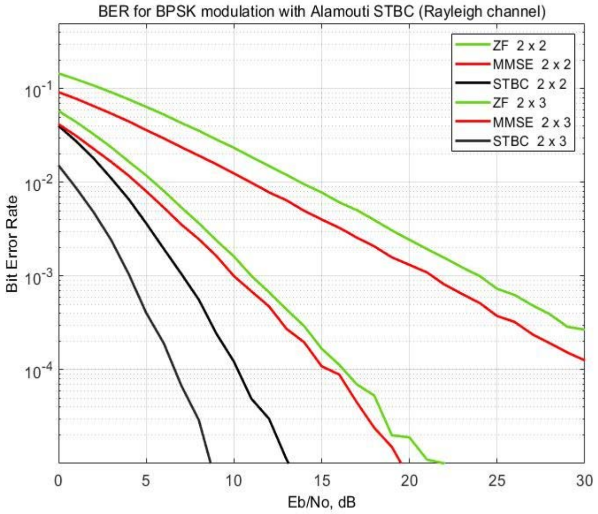

Fig. 6. BER of ZF, MMSE, and STBC with M_T = 2 and M_R = 2, 3.

5. Conclusion

The scattering and multipath fading manifested due to high node mobility and fast-changing topology of VANETs increases errors and deteriorates quality. Path loss, shadowing the loss, and fading losses are significant at 5.9 GHz designated for

VANET. VANET's hybrid architecture, fast node movement, scalability, and no power and space constraint differentiate it from MANET. Due to its unusual characteristics, it is required to be highly efficient, robust, and reliable, in terms of BER and data rates.

To establish efficient communication between V2V, there is a need to overcome some challenges that can affect the efficiency of the communication. A new solution has been proposed to develop Vehicular communication networks using MIMO technology. The proposed solution includes several techniques that improve reliability in the VANET network. It takes into account the main characteristics of such networks. STBC performs best because it offers a diversity gain through coding of a reliable transmission over time and space.

In comparison with MMSE and STBC, the ZF technique was performed with the worst BER output. This is because of noise improvement in the signal received. MMSE has smaller than STBC in BER performance, however, the performance exceeds *ZF* because MMSE could reduce the total error affected by co-channel interference and noise inputs.

General results for all these multiple antennas schemes were to reduce the error rate when the antennas numbers of transmitting and/or receiving are increasing. Further reduction in bit error rate, indicates its benefit in VANET safety applications.

Nomenclatures

$Es.$	Energy transmitted
G_{MMSE}	Combiner weight of MMSE
G_{ZF}	Combiner of ZF
H	MIMO channel matrix
H_P	Pseudo inverse matrix
H_H	Complex conjugate transpose
$\hbar\imath\jmath$	Antenna pair
I_{MT}	Identity matrix
M_T	No antenna at the transmitter
M_R	No antenna at the receiver
N_o	Energy noise
n	AWGN
$s^{\sim}$	Estimated vector
x	Transmitted signal
Y	Received signal

Abbreviations

AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
ITS	Intelligent Transport Systems
MANET	Mobile Ad Hoc Networks
MIMO	Multiple-Input Multiple-Output
MMSE1	Minimum Mean Square Error
OFDM	Orthogonal Frequency Division Multiplexing
OBU	On-Board Units
RSU	Road Side Units

SD	Spatial Diversity
SISO	Single Input Single Output
SNR	Signal-To-Noise Ratio
SM	Spatial Multiplexing
STBC1	Space-Time Block Coding
VANET	Vehicular Ad Hoc Network
WLANs	Wireless Local Area Network
ZF1	Zero-Forcing

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