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PAPERS

Investigation of error performance in network coded MIMO-VBLAST wireless communication systems

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Paper aims to enhance the performance of bit error rate (BER) in wireless communication based on the multiple-input multiple-output (MIMO) system of vertical Bell laboratories layered space-time (VBLAST) algorithm. The VBLAST algorithm uses zero-forcing (ZF) and the minimum mean square error (MMSE) to evaluate the BER of wireless communication. MIMO VBLAST techniques function as an adaptive filter and can minimize the interference and multipath fading in the received signal of the channel. Physical layer network coding (PNC) is a new technique used to exploit the spatial diversity of the MIMO VBLAST system to improve the throughput and performance of wireless communication. The bit-error-rate (BER) of proposed VBLAST MIMO with PNC with binary phase-shift keying (BPSK) and quadrature phase-shift keying (QPSK) modulation over the additive white Gaussian noise and Rayleigh fading channel are analyzed. The performance of both BPSK and QPSK modulation in two and four antennas are compared. From the simulation results, it was found that the proposed scheme MIMO VBLAST PNC has a 45.2 % higher BER performance compared to the traditional MIMO scheme with an increase in the BER using MMSE and ZF respectively in both two and four antennas.

K e y w o r d s: multiple input multiple output, vertical Bell laboratories layered space-time, zero forcing, minimum mean square error, physical layer network coding

1 Introduction

The development of wireless network and the high demand from users in wireless communication in previous years presents a challenge in the communication industry especially in improving the performance of the network. However, wireless communication still has challenges and problems in achieving a better network to provide better performance in term of quality and quantity [1]. The current performance of wireless communication still has a gap in achieving the vision of the communication industry.

The transmitted signal will face the danger of fading effect such as interference and noise by passing through the fading channels. This makes the signal distorted and the receiver will not be able to retrieve the original signal.

Multiple input multiple output (MIMO) system is a system which applies multiple antenna at the input and output. It is very famous because it can enhance the data rate and reduce the effect of fading channels [2]. To transmit the data, MIMO applies multiple antennas at transmitter and receiver. To achieve better network throughput, multiple antennas are applied. Traditional MIMO system is said to be efficient compared with single input single output (SISO) of the traditional scheme, with because of its higher spectral efficiency. The usage of spectrum can be optimized in MIMO system. Thus, the higher amount of data can be transmitted with few errors.

In these terms, the number of transmit antenna must be equal to or greater than the number of receiver antenna. Thus, this paper discussed the techniques used to increase the data reliability in wireless communication by enhancing the throughput in wireless communication using various detection techniques of MIMO VBLAST, cooperative communication and physical layer network coding.

These various detection techniques are adopted into a channel of wireless communication to achieve a low BER performance hence improving the overall performance of wireless communication.

Multiple input multiple output (MIMO)

MIMO is a system which applies many antennas for input and output for the signal transmission. By using MIMO technology, we can introduce spatial diversity which can overcome the degradation of multipath propagation.

MIMO exploits the multipath effect of propagation signal to achieve better throughput. With the ability to improve the performance reliability of wireless network system, MIMO is also known as a smart antenna.

MIMO is utilized in helping to mitigate the fading channel and interference [3]. The rate of the data can

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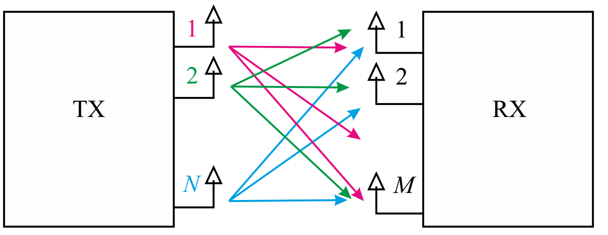

Fig. 1. Multiple input multiple output channel model

be enhanced by using the spatial multiplexing in MIMO system. Figure 1 shows a model of a MIMO channel.

Vertical Bell laboratories layered space-time (VBLAST)

Zhang *et al* proved that by applying VBLAST code, the property of multiplexing can be fully used. In coherent MIMO optical wireless communication (OWC) systems, the higher data rate can be achieved [4]. The research, based on the channel capacity of coherent MIMO OWC channels showed that the gain of multiplexing could be used in MIMO OWC systems [5]. In MIMO system, there is not only VBLAST but also diagonal Bell laboratories layered space-time (D-BLAST) system. But, DBLAST is a complicated system compared with VBLAST system. Thus, DBLAST is not used commonly and VBLAST is preferable because of its simplicity and availability in obtaining the highest rate of data compared to DBLAST.

VBLAST is utilized in a MIMO system to improve the performance of wireless communication. VBLAST is a technique used to produce a better spectral efficiency without the need for optimizing the bandwidth of the system [6].

In VBLAST system, the data from the users are divided into so many parallel data streams. The rate of data transmission is directly proportional to the number of antennas which applied in the system. The data rate of the system can be improved by applying the scattered wireless channel in VBLAST system. The strongest signal with high signal-to-noise ratio (SNR) can be estimated in the VBLAST system. By using nulling process in the network, the signal can be applied for estimation which can diminish the effect of error rate and signal interference in the system.

There are few layers of the parallel stream in the transmitter scheme of VBLAST. These layers allow for spatial diversity and spectral efficiency enhancement. In processing the signal, the strongest signal will be detected and eliminated due to the interference. Next, this technique will continue to process the signal until it detects the weakest signal.

However, VBLAST technique has few disadvantages toward the system. In order to deal with the nulling process of interference, the number of receive antennas must be the same as or greater than the number of transmit antenna [7]. Two types of VBLAST techniques will be discussed in this paper; namely zero-forcing (ZF) and minimum mean square error (MMSE).

ZF and MMSE are a type of equalizer that is used to mitigate the inter-symbol interference (ISI) effect of the multipath fading channel. The equalizer is usually placed at the baseband of the receiver. Both ZF and MMSE are adaptive filters used to filter out the noise of the surrounding to achieve optimal filtering. The adaptive filter will cancel out the noise which is overlapping with the signal at the same frequency region. ZF reduced the ISI of the system to zero under the noise-free condition while the MMSE reduced the value of mean square error and did not completely cancel out the ISI effect but diminished the effect of the noise and ISI at the receiver [8].

Based on the analysis done in [9], it is shown that the detection techniques of ZF and MMSE combined with the successive interference cancellation (SIC) improved the performance of MIMO. By comparing MMSE with ZF, MMSE has better BER performance compared to ZF. Both performance of ZF and MMSE in MIMO channel increase as the number of antennas for transmitter and receiver increases.

Physical layer network coding (PNC)

Cooperative communication refers to a system in which the transmitted signal will transmit to a node and then send to the destination. Cooperative communication is used as exploitation for spatial diversity in wireless communication. Cooperative communication usually combined with MIMO system to produce a better throughput performance. In this paper, the method of amplifying and forward (AF) will be discussed. In the relay of the system, the signal contained interference and noise will be transmitted from the source.

From this relay node, the signal will be amplified and then sent to another node for the combination of the information sent by the transmitter. By using the relay, multiple signal can be sent, and a better throughput can be made although the amplified signal in the node contained noise and interference. The AF method of cooperative communication can reduce the bit error rate of the transmitted signal.

In the research paper done in [10], the research is based on a simple cooperative communication to evaluate the performance of the AF method in a MIMO system. Hence, it is shown that the scheme of MIMO VBLAST

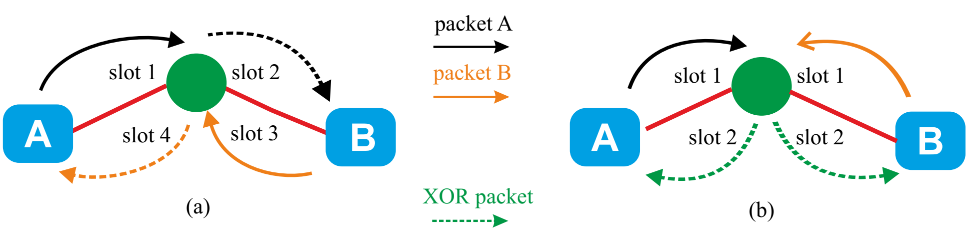

Fig. 2. Block diagram of different time slots for transmission scheme.

cooperative communication has better BER than the traditional scheme of MIMO VBLAST. Thus, it can be concluded that using a relay node in the MIMO can reduce multiple signals at a node without the use of multiple antennas.

PNC is applied onto two-way relay channel (TWRC). The exploitation of interference and noise are used as an opportunity in boosting the system throughput [11]. PNC used TWRC as the node in transferring the signal. In a none-coded network scheme, four slots are required in transmitting the signal. PNC used fewer time slots, which are two slots. The reduction in each of the time slot for transmitting is a great advantage for PNC as it can help in improving the throughput of the system as well as the system capacity.

In the simulation to investigate MIMO PNC based on VBLAST detection, it is stated that the TWRC can help in achieving double the spectral efficiency in transmitting signal. Thus, most of the current wireless network is a combination of PNC and MIMO in order to improve the spectral efficiency [12]. According to [13], a physical layer network coding with multiple antennas, with the application of TWRC in PNC, a high and low SNR can be easily approached through the method. With only the usage of MIMO, the channel capacity of the wireless network can be increased. Adding PNC to the system allowed a greater increase than MIMO.

Figure 2 shows the block diagram of different time slots for a transmission scheme in conventional bi-directional relay and PNC relay [14].

In Fig. 2, by using a conventional bi-directional relay, there will be four time slots to exchange the messages while using PNC, it will be two time slots only.

There are two phases in PNC two-way relay model. In phase 1, the users will send the messages to the relay in first time-slot. In the second time slot which is the phase 2 of PNC, the messages from relay will extract their original information signals. XORed messages will give redundancy which will transmit together with the original messages which will be applied for error correction and detection.

2 Analysis of MIMO with PNC

In this research paper, for MIMO physical layer network coding with VBLAST detection, the performance of MIMO VBLAST and MIMO VBLAST PNC are proposed and compared. The system is assumed to have Rayleigh fading channel and the results are evaluated through BER performance. The results showed the combined system with PNC have better performance than a system without PNC. Sorted VBLAST PNC outperformed VBLAST PNC and linear ZF PNC. Hence, through this simulation it is proved that PNC has a greater advantage on wireless communication [15].

Monte Carlo simulations for the MIMO PNC are explored to compare the analytical result from the research paper of MIMO physical layer network coding with VBLAST Detection. In the research, Monte Carlo is suitable to be used in the second physical layer as the results show that BER results meet the requirement of theory for Monte Carlo simulation. It is proof in the simulation that when the value of k for Monte Carlo simulation is equal to one, VBLAST PNC has the same result as MIMO NC. However, when the value of k is smaller or greater than one the BER shows a small value which indicates that VBLAST PNC help in improving the performance of wireless communication [16].

According to research done by Khani and Chen, by using packet redundancy the throughput of wireless communication can be improved. The method of combining the PNC and MIMO is advantageous in spatial multiplexing gain of the system by using diversity method. In the simulation, both BPSK and QPSK modulation are used to compare which modulation is better for the performance of the system using PNC and MIMO. It is evaluated that BPSK modulation is better than QPSK in term of Packet Error Rate (PER).

Moreover, the simulation is done based on MMSE and ZF. The performance for PNC MMSE is slightly better than PNC ZF in the same SNR aspect. However, it is proven that PNC MMSE and ZF have better BER than traditional MMSE and ZF.

Hence, it is showed through this research that the combination of MIMO with PNC produced a good result in BER analysis with SNR. Thus, wireless communication can be used PNC for its application in different areas such as power minimizing.

3 System model

In this paper, two modulation techniques are discussed, namely; BSPK and QPSK. The performance of BPSK modulation and QPSK modulation with ZF-based VBLAST detection technique and MMSE-based VBLAST detection technique will be compared.

3.1 Binary Phase Shift Keying (BPSK)

In BPSK, the encode bit from the source in the form of the binary number 1 and 0 will be mapped into the transmission symbol 1 and -1 respectively. The phase shift for BPSK are 0 or 180 degrees with every bit interval. BER performance of BPSK can be determined as shown in (1).

$$BER_{BPSK} = Q\left(\sqrt{\frac{2E_b}{N_o}}\right), \tag{1}$$

E_b is the energy per bit and N_o is noise power spectral density ratio. $\frac{E_b}{N_o}$ is an important parameter in data transmission. It is a normalized signal-to-noise ratio (SNR) measure, also known as the "SNR per bit".

3.2 Quaternary Phase Shift Keying (QPSK)

For the modulation technique of QPSK, the phase shift for every bit interval are 45, 135, 225 or 315 degrees. The encoded bit of QPSK is the same as BPSK which consist of a binary number of 1 and 0, mapped into a transmission bit of 1 and -1 respectively. BER performance for QPSK is estimated using (2).

$$BER_{QPSK} = Q\left(\sqrt{\frac{2E_b}{N_o}}\right) \tag{2}$$

Hence, the average probability error rate for modulation of BPSK and QPSK in MIMO system based on Rayleigh fading channel according to [1] is as shown in the (3) and (4)

$$P_{av(BPSK)} = \frac{1}{2}\left(1 - \sqrt{\frac{SNR}{SNR+1}}\right) \tag{3}$$

$$P_{av(QPSK)} = \frac{1}{2}\left(1 - \sqrt{\frac{SNR}{SNR+1}}\right) \tag{4}$$

This technique of modulation is applied in the MIMO VBLAST scheme. Figure 3 shows the block diagram of the MIMO VBLAST simulation.

The simulation is started by randomly generating a source signal of the system. Modulation and demodulation techniques of BPSK and QPSK are used. The BER of the system will be determined by calculating the error in the number of bits of the system. Based on [8], (5) shows the MIMO channel equation used in the simulation.

$$\begin{bmatrix} y_1 \\ y_2 \\ \cdot \\ \cdot \\ y_r \end{bmatrix} = \begin{pmatrix} h_{1,1} & \cdot & \cdot & h_{r,1} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ h_{1,t} & \cdot & \cdot & h_{t,r} \end{pmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ x_t \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \cdot \\ \cdot \\ n_t \end{bmatrix} \tag{5}$$

This matrix can be simplified into (6)

$$\overline{y} = H\overline{x} + \overline{n} \tag{6}$$

where, $\overline{y} = r$ dimensional received antenna,
$\overline{x} = t$ dimensional transmitted antenna,
$\overline{n} =$ noise matrix,
$H =$channel matrix

In this MIMO system, Rayleigh fading channel is used as the system channel and additive white Gaussian noise (AWGN) is the channel noise. AWGN has the mean of zero and variance of σ. The value of variance used in the simulation is 0.0025. There are two detection techniques of MIMO VBLAST discussed in the paper, which are ZF and MMSE.

ZF is used to invert the frequency response of the channel. ZF can be used to completely remove interference in the wireless communication. ZF will inverse the channel received data from the source and restore back the signal channel before demodulation process. By referring to [12], in order to satisfy the condition for ZF to reduce ISI effect under noise condition, the equation for ZF is considered as

$$W = H^H \left(H^H H\right)^{-1} \tag{7}$$

For MMSE to minimize the error, equation (8) is used:

$$E\left\{[W_{y-x}]\,[W_{y-x}]^H\right\} \tag{8}$$

As proposed by Tikhonov ordinance [12], to satisfied the condition of $WH = I$, the matrix of W is applied in the MIMO VBLAST channel equation.

$$W = \left[H^H H + N_o I\right]^{-1} H^H \tag{9}$$

where N_0 is considered as $\frac{1}{SNR}$.

Successive interference cancellation (SIC) method is applied with both ZF and MMSE to remove the interference at the next symbol until all the symbol at the receiver is detected completely. Figure 4 shows the interference cancellation process in the ZF-SIC.

For ZF with SIC, (7) is the algorithm that will be used for substituting into the equation for SIC. Considering a wireless system that has two antennas for both transmitter and receiver, (10) shows the algorithm for ZF-SIC [17] and [18].

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = (H^H H^{-1})^H \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} \tag{10}$$

For MMSE, (11) will be applied for the simulation of SIC to determine the error in the channel which is based on [14].

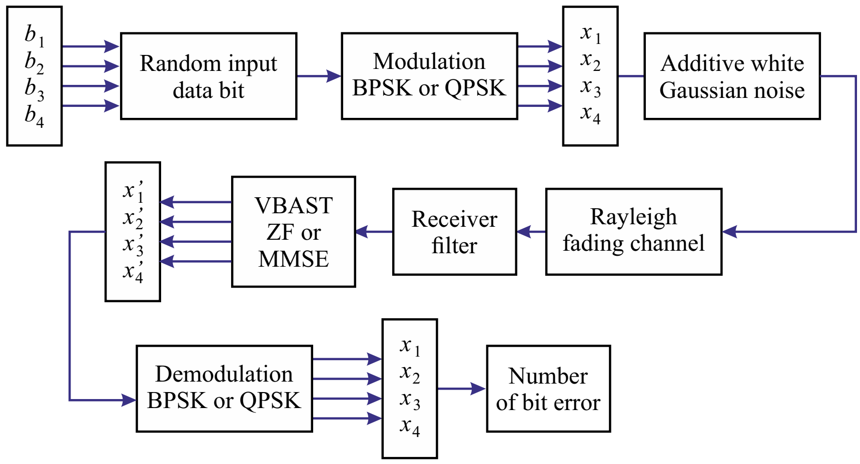

Fig. 3. Block diagram of MIMO VBLAST simulation

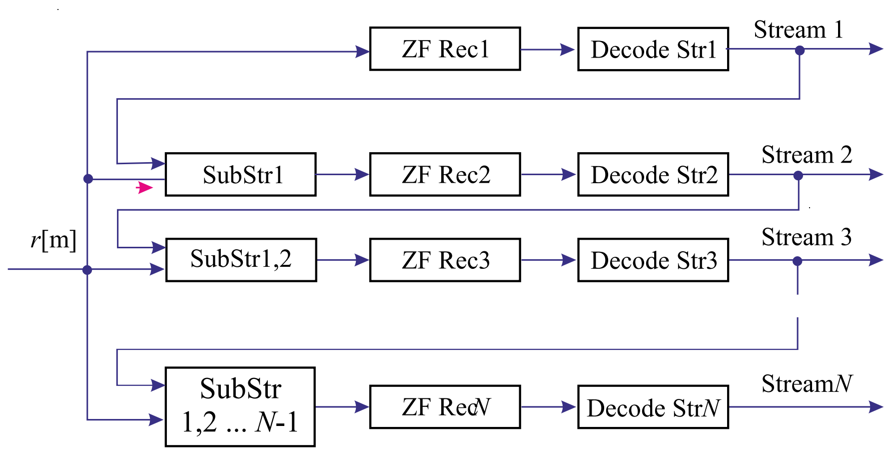

Fig. 4. ZF-SIC detector: SubStr - Substract stream, Rec N-Receiver - N

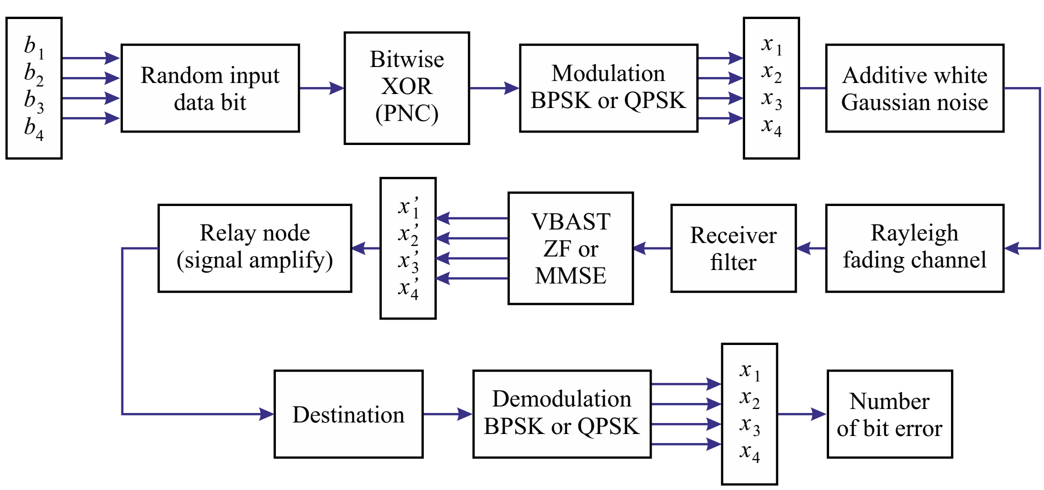

Fig. 5. Block diagram of MIMO VBLAST cooperative communication

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = (H^H + N_0 I) H^{-1} x^H \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} \tag{11}$$

To estimate signal for x_1, the value for x_2 will be subtracted from the wireless network system.

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} y_1 - h_{12}x_2 \\ y_2 - h_{22}x_2 \end{bmatrix} = \begin{bmatrix} h_{11}x_1 + n_1 \\ h_{21}x_1 + n_2 \end{bmatrix} \tag{12}$$

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} h_{11} \\ h_{22} \end{bmatrix} x_1 + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \tag{13}$$

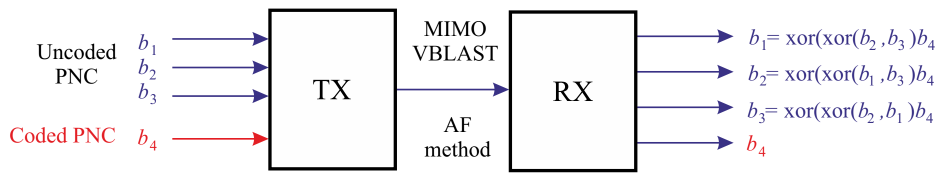

Fig. 6. Physical layer of network coding scheme.

$$r = Hx_1 + n \tag{14}$$

$$\widehat{a}_1 = \frac{H^H r}{H^H H} \tag{15}$$

Figure 5 shows the block diagram of a MIMO VBLAST cooperative communication.

As shown in Fig 5, cooperative communication is one of the techniques used in the wireless communication that uses a relay in the channel to improve the throughput [19].

MIMO VBLAST technique [20] will be applied at the source before transferred to the first relay. The received signal at the first relay will be amplified and forwarded to the second relay. In the same time slot, a signal from the source will be transmitted to the destination. From the second relay, the received signal from the first relay will be transmitted to the destination. The transmitted signal from the second relay will be applied on a maximal ratio combining (MRC) [21] before forwarding to the destination to calculate for bit error. The proposed PNC scheme is applied by implementing a bitwise XOR operation. The proposed scheme required both coded and non-coded PNC data for the source signal [22].

In VBLAST PNC scheme, the channel coefficient matrix can be eliminated by using QR decomposition as: $H = QR$, where the matrix Q is an unitary matrix and R is an upper triangular matrix in (5). Independent non-zero entries are included in R. The received signal Y is multiplied with Q^H (superscript H denote the conjugate transpose of a matrix), then (16) can be expressed

$$w = Q^H Y = RX + N' \tag{16}$$

where the new noise $N' = Q^H N$ has the same distribution as N. Then, N' does not need to be separated and N without any confusion. The scalar form of W is

$$w_1 = r_{1,1}x_1 + r_{1,2}x_2 + n_1 \tag{17}$$

$$w_2 = r_{2,2}x_2 + n_2 \tag{18}$$

From (18), x_2 can be detected by hard decision,

$$\widehat{x}_2 = sign\left(\frac{w_2}{r_{1,1}}\right) = sign\left(x_2 + \frac{n_2}{r_{1,1}}\right) \tag{19}$$

In (19), the hard decision is taken. After the second layer signal x_2 has been detected, the first layer of PNC can be applied by the help of $\widehat{x}_2$. This result is the VBLAST PNC scheme as follows. Rewriting w_1 in (17) as,

$$w_1 \backslash r_{1,1} = x_1 + kx_2 + \left(\frac{r_{1,2}}{r_{1,1}} - k\right) x_2 + \frac{n_1}{r_{1,1}} \tag{20}$$

where k is an integer which can be the focus for eliminating the effect of signal error propagation. k can be described as

$$k = [real\,(r_{1,2} \backslash r_{1,1})] \tag{21}$$

Then, the cancellation step: canceling the fractional interference part $\left(\frac{r_{1,2}}{r_{1,1}} - k\right) x_2$. Then, the soft estimation of $x_1 + kx_2$ as

$$\widetilde{x_1 \oplus x_2} = \frac{w_1 - (r_{1,2} - kr_{1,1}\widehat{x_2})}{r_{1,1}} \tag{22}$$

Simplified decision rule is performed [23], when $k \neq 0$, for each dimension (real part or imaginary part) signal, the estimation of $x_1 \oplus x_2$ is

$$\widehat{x_{1,r}x_{2,r}} = \begin{cases} \text{sign}(|real\widehat{x_1x_2})| - k & \text{when } k > 0 \\ \text{sign}(-|real\widehat{x_1x_2})| - k & \text{when } k < 0 \end{cases} \tag{23}$$

when $k = 0$, adopting the VBLAST network coding scheme to detect the target signal $x_1 \oplus x_2$. Figure 6 shows the physical layer of the network coding scheme.

In the theory of VBLAST system, the order of diversity in the second layer should be smaller than in the first layer by assuming the clean interference cancellation [24]. However, in practice, the orders of the diversity in both first and second layer should be the same. It is because the propagation error can be detected erroneously second layer signal.

This proposed PNC scheme utilized the used of four antennas for transmitting and receiving. There are three antennas at the transmitter which are the uncoded $PNC\,(b_1, b_2, b_3)$, while one antenna is a coded $PNC\,(b_4)$ as expressed in (24).

$$b_4 = b_1 \oplus b_2 \oplus b_3 \tag{24}$$

This uncoded and coded PNC data will be transmitted and modulated by using BPSK or QPSK modulation. Coded PNC data carry redundant data in the channel. The signal will be added into MIMO VBLAST system by adding on additive white Gaussian noise and Rayleigh fading channel. MIMO VBLAST system will used the

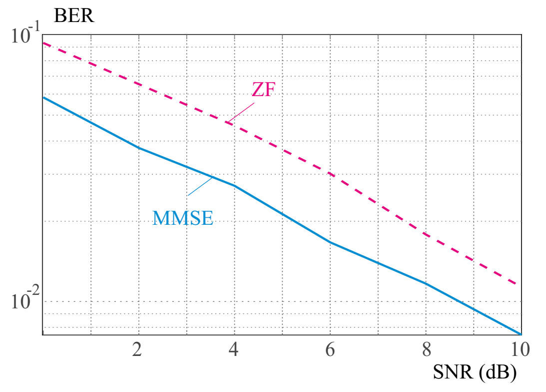

Fig. 7. BPSK modulation of ZF and MMSE MIMO VBLAST for $T_x = R_x = 2$

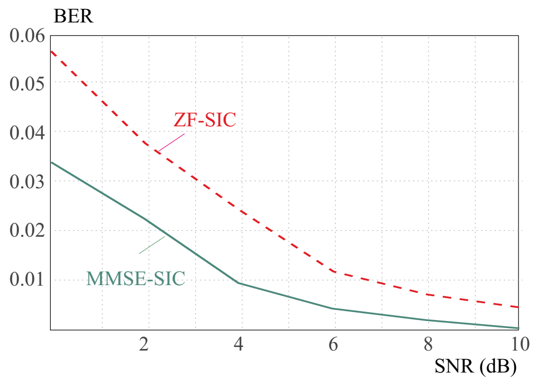

Fig. 8. BPSK modulation of ZF-SIC and MMSE-SIC MIMO VBLAST for $T_x = R_x = 2$

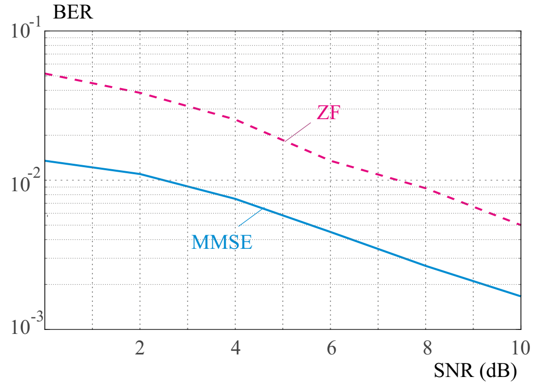

Fig. 9. BPSK modulation of ZF and MMSE MIMO VBLAST for $T_x = R_x = 4$

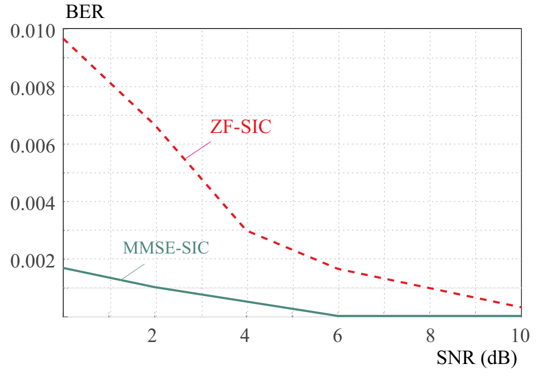

Fig. 10. BPSK modulation of ZF-SIC and MMSE-SIC MIMO VBLAST for $T_x = R_x = 4$

techniques of ZF and MMSE as mentioned in the Part 3.3 of this chapter. After the decoding process is done successfully at the receiver by using ZF, MMSE and SIC, the signal will be demodulated by using BPSK or QPSK demodulation process. The coded PNC carry redundant data to increase the transmit signal. The extraction for the signal received at the destination are expressed in (25-27), [25] b_1 packet extraction by PNC packets at the receiver,

$$b_1 = b_4 \oplus b_2 \oplus b_3 \tag{25}$$

b_2 packet extraction by PNC packets at the receiver,

$$b_2 = b_4 \oplus b_1 \oplus b_3 \tag{26}$$

b_3 packet extraction by PNC packets at the receiver,

$$b_3 = b_4 \oplus b_1 \oplus b_2 \tag{27}$$

After the extraction of the signal at the destination, the error performance will be calculated based on (3) and (4).

4 Results and discussions

4.1 Simulation of BPSK and QPSK in MIMO VBLAST

in this section.

Table 1 shows the simulation parameter of MIMO VBLAST. Figure 7, 8, 9 and 10 show the simulation results for BPSK modulation of ZF, MMSE, ZF-SIC and MMSE-SIC of two and four antennas for both transmitter and receiver respectively.

Table 1. Simulation Parameters of MIMO VBLAST

Parameter	Value
Number of Transmitter Antennas	2 and 4
Number of Receiver Antennas	2 and 4
Number of Bits	6000
Modulation Techniques	BPSK and QPSK
Channel	AWGN and Rayeligh
SNR (dB)	0-10 dB
Receiver Algorithm	ZF, MMSE, SIC

In Fig. 7 and Fig. 8, the BER results of BPSK modulation for ZF and MMSE MIMO VBLAST in two-transmitters and two-receiver system are presented. From the simulation results, The MMSE technique has better BER performance than ZF technique and MMSE-SIC outperforms the ZF-SIC. It was also found out that MMSE-SIC has the best BER compared to ZF, MMSE and ZF-SIC. The results show that a combination of the receiver algorithm with SIC outperformed the traditional receiver algorithm.

In Fig. 9 and Fig. 10, the BER results of BPSK modulation for ZF and MMSE MIMO VBLAST in four transmitters and four receivers system are presented.

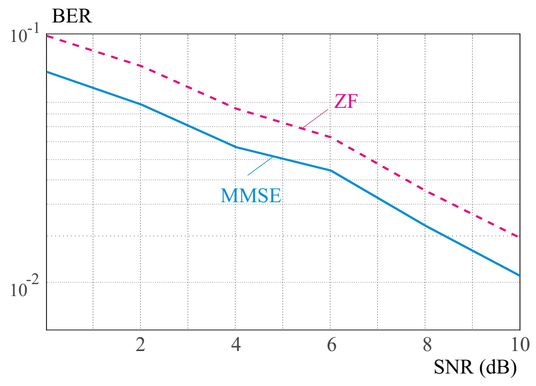

Fig. 11. QPSK modulation of ZF and MMSE MIMO VBLAST for $T_x = R_x = 2$

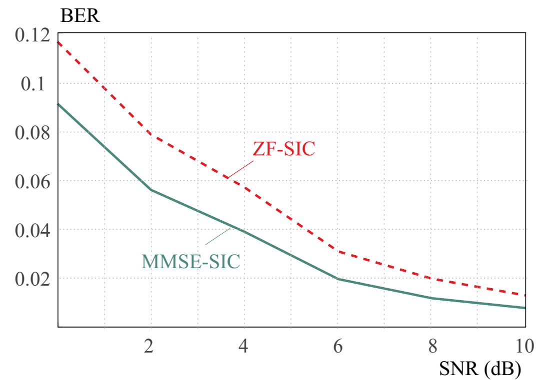

Fig. 12. QPSK modulation of ZF-SIC and MMSE-SIC MIMO VBLAST for $T_x = R_x = 2$

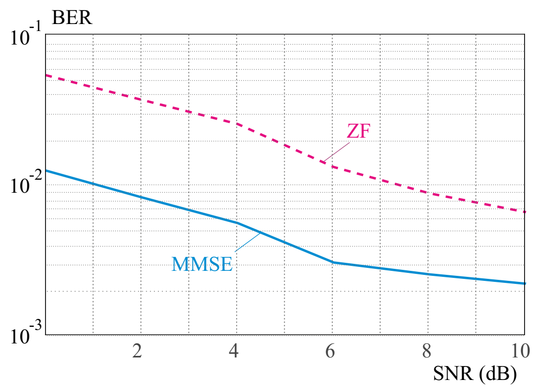

Fig. 13. BPSK modulation of ZF and MMSE MIMO VBLAST for $T_x = R_x = 4$

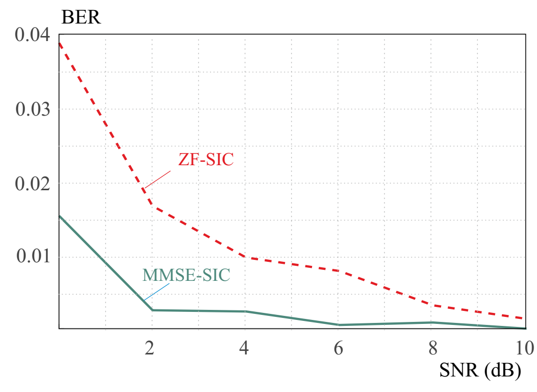

Fig. 14. QPSK modulation of ZF-SIC and MMSE-SIC MIMO VBLAST for $T_x = R_x = 4$

Table 2. BER performance for BPSK and QPSK modulation in MIMO VBLAST

SNR		2 dB	6 dB	10 dB
BPSK	1	7.15×10^{-2}	1.12×10^{-2}	1.17×10^{-3}
$T_x = 2$	2	4.20×10^{-2}	4.00×10^{-3}	6.67×10^{-4}
$R_x = 2$	3	3.56×10^{-2}	5.33×10^{-3}	1.67×10^{-4}
	4	1.93×10^{-2}	1.00×10^{-3}	5.00×10^{-4}
BPSK	1	3.33×10^{-2}	5.33×10^{-3}	5.00×10^{-4}
$T_x = 4$	2	9.16×10^{-3}	1.52×10^{-3}	3.33×10^{-4}
$R_x = 4$	3	8.51×10^{-3}	3.33×10^{-4}	9.99×10^{-5}
	4	2.16×10^{-3}	5.00×10^{-5}	2.52×10^{-5}
QPSK	1	1.03×10^{-1}	2.23×10^{-2}	3.67×10^{-3}
$T_x = 2$	2	7.43×10^{-2}	1.66×10^{-2}	2.67×10^{-3}
$R_x = 2$	3	9.02×10^{-2}	1.32×10^{-2}	6.67×10^{-4}
	4	6.93×10^{-2}	7.67×10^{-3}	3.33×10^{-4}
QPSK	1	6.93×10^{-2}	1.42×10^{-2}	1.17×10^{-3}
$T_x = 4$	2	2.96×10^{-2}	4.83×10^{-3}	6.67×10^{-4}
$R_x = 4$	3	4.73×10^{-2}	2.83×10^{-3}	1.83×10^{-4}
	4	1.65×10^{-2}	5.00×10^{-4}	9.99×10^{-5}

1-ZF, 2-MMSE, 3-ZF-SIC, 4-MMSE-SIC

As can be seen from Fig. 9 and Fig. 10, MMSE technique has better BER performance than ZF technique and MMSE-SIC outperforms the ZF-SIC. It was also found out that MMSE-SIC has the best BER compared to ZF, MMSE and ZF-SIC.

The results show that a combination of receiver algorithm with SIC outperformed the traditional receiver algorithm. And four transmitters and four receivers system with MMSE-SIC has the best BER performance than four transmitters and four receivers system with ZF-SIC, two transmitters and two receivers system with MMSE-SIC, ZF-SIC, MMSE and ZF techniques.

In Fig. 11, Fig. 12, Fig. 13 and Fig. 14, the BER results of QPSK modulation for ZF, MMSE, ZF-SIC and MMSE-SIC in MIMO VBLAST with two and four transmitters and receivers system are presented.

From the result shown in Fig. 11 and Fig. 12, the simulation shows that MMSE-SIC gives better BER performance compared to ZF, MMSE, and ZF-SIC in two transmitters and two receivers system with QPSK modulation in MIMO VBLAST system. It can also be seen that MMSE has better performance than ZF at high SNR. MMSE acts as ZF works the best when the simulation is free of noises at low SNR.

QPSK modulation of ZF and MMSE MIMO VBLAST for $T_x = R_x = 2$

From the result shown in Fig. 13 and Fig. 14, the simulation shows that MMSE-SIC gives better BER performance compared to ZF, MMSE, and ZF-SIC in four

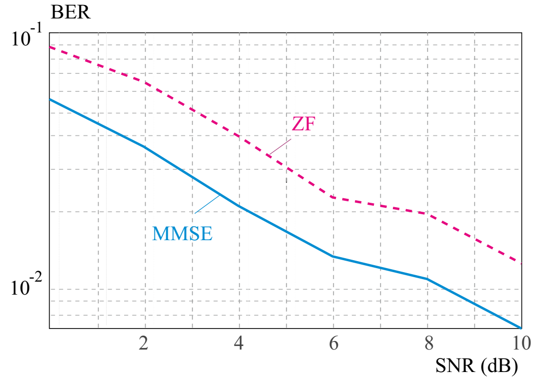

Fig. 15. BPSK modulation of ZF and MMSE MIMO VBLAST with PNC for $T_x = R_x = 2$

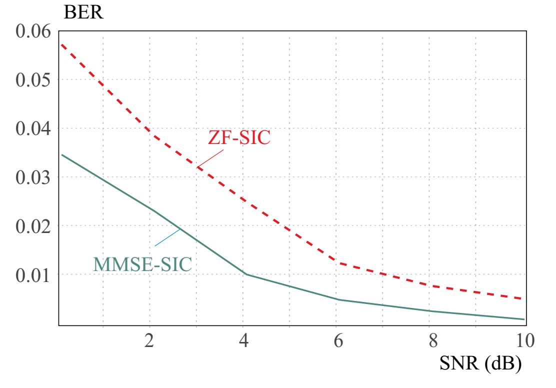

Fig. 16. BPSK modulation of ZF-SIC and MMSE-SIC MIMO VBLAST with PNC for $T_x = R_x = 2$

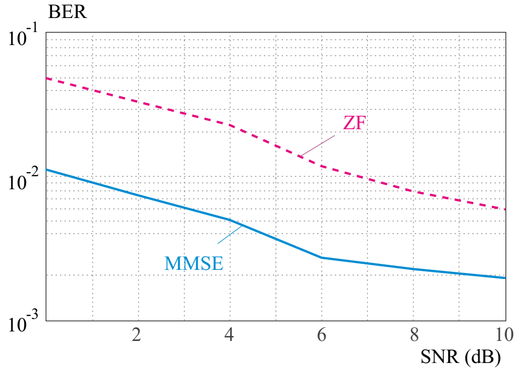

Fig. 17. BPSK modulation of ZF and MMSE MIMO VBLAST with PNC for $T_x = R_x = 4$

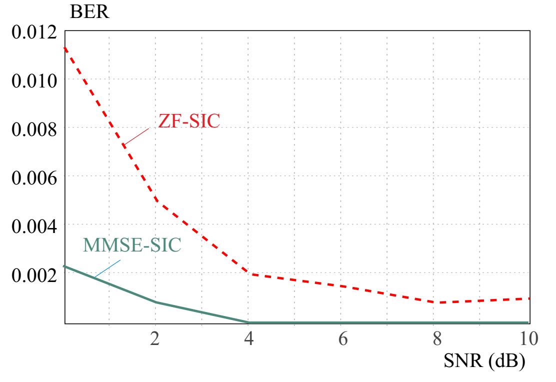

Fig. 18. BPSK modulation of ZF-SIC and MMSE-SIC MIMO VBLAST with PNC for $T_x = R_x = 4$

transmitters and four receivers system with QPSK modulation in MIMO VBLAST system. It was also found that MMSE acts as MRC has lower BER performance compared to ZF. Moreover, simulation results proved that increasing number of antenna can reduce the BER with increasing SNR.

Table 2 shows the comparison of the BER performance for SNR value for both transmitter and receiver antennas with two and four antennas respectively.BER performance in BPSK has better than the QPSK.

According to Tab. 2 , for the value of ZF with BPSK at four transmitters and four receivers system at SNR equal to 10, the values of BER is 5×10^{-4} but with QPSK is 1.17×10^{-3} which is very different.

From Tab. 2, as the number of antennas increases, the value of BER performance decreases. Hence, the BER of wireless communication of MIMO VBLAST gives better performance as the number of antennas at the transmitter and receiver increases. The value of BER decreases as the number of antennas increases. This shows that as the number of antennae increases, wireless communication gives better throughput.

There are differences in the BER value for the modulation of BPSK and QPSK. SIC work principle is to cancel out the interference of the channel continuously by using a successive symbol. When each of the interference is canceled out, there will be less interference at the receiver, hence minimizing the effect of ISI at the receiver. It can be concluded that the combination of SIC with MMSE and ZF gives lower BER compared to ZF and MMSE. It can also be seen that as the value of SNR increases, the value for BER performance decreases.

From the simulation results, it was found that the BPSK has a lower BER compared to QPSK. Hence, BPSK modulation gives better performance compared to QPSK in terms of BER for wireless communication. In BPSK, the number of modulation is two while QPSK is four. This is because the BPSK has two levels of bits which is 0 and 1 while QPSK has four levels of modulation for bits which is 00, 01, 10 and 11.

4.2 Simulation of BPSK and QPSK in MIMO VBLAST with PNC

Table 3 shows the simulation parameters of proposed MIMO VBLAST with PNC technique.

Table 3. Simulation Parameters of MIMO VBLAST with PNC

Parameter	Value
Number of Transmitter	2 and 4
Number of Receiver	2 and 4
Number of Bits	6000
Modulation Techniques	BPSK and QPSK
Channel	AWGN and Rayeligh
SNR (dB)	0-10 dB
Receiver Algorithm	PNC (ZF,MMSE,ZF-SIC)

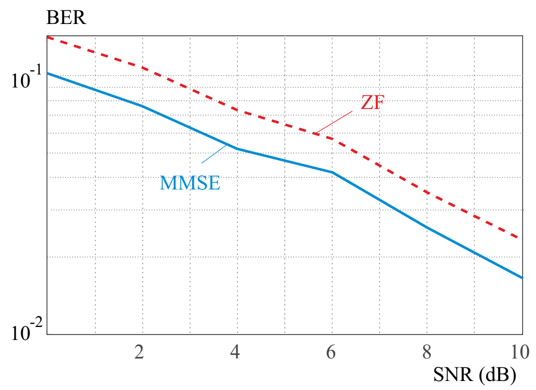

Fig. 19. QPSK modulation of ZF and MMSE MIMO VBLAST with PNC for $T_x = R_x = 2$

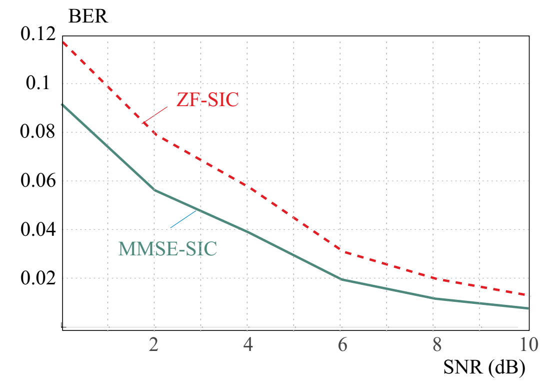

Fig. 20. QPSK modulation of ZF-SIC and MMSE-SIC MIMO VBLAST with PNC for $T_x = R_x = 2$

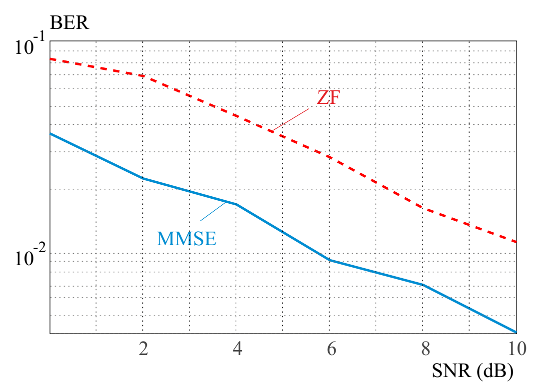

Fig. 21. QPSK modulation of ZF and MMSE MIMO VBLAST with PNC for $T_x = R_x = 4$

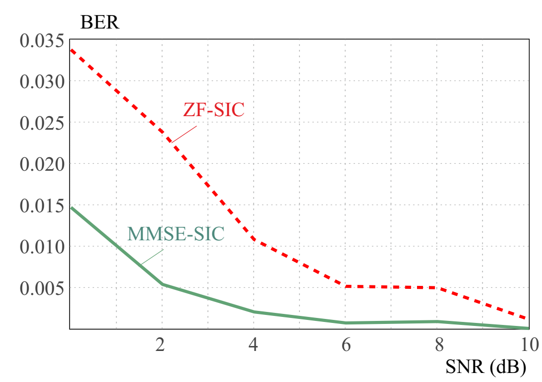

Fig. 22. QPSK modulation of ZF-SIC and MMSE-SIC MIMO VBLAST with PNC for $T_x = R_x = 4$

Table 4. BER performance for BPSK and QPSK modulation in MIMO VBLAST with PNC

SNR		2 dB	6 dB	10 dB
BPSK	1	8.92×10^{-2}	2.95×10^{-2}	7.17×10^{-3}
$T_x = 2$	2	5.47×10^{-2}	1.87×10^{-2}	3.33×10^{-3}
$R_x = 2$	3	3.47×10^{-2}	5.53×10^{-3}	1.67×10^{-4}
	4	1.97×10^{-2}	2.33×10^{-3}	9.98×10^{-5}
BPSK	1	3.47×10^{-2}	5.53×10^{-3}	1.67×10^{-4}
$T_x = 4$	2	1.97×10^{-2}	2.33×10^{-3}	8.99×10^{-5}
$R_x = 4$	3	3.47×10^{-3}	5.54×10^{-3}	1.67×10^{-4}
	4	1.97×10^{-3}	2.33×10^{-3}	8.99×10^{-5}
QPSK	1	9.02×10^{-2}	1.30×10^{-2}	6.67×10^{-4}
$T_x = 2$	2	6.93×10^{-2}	7.67×10^{-3}	3.33×10^{-4}
$R_x = 2$	3	3.47×10^{-2}	5.50×10^{-3}	1.67×10^{-4}
	4	1.97×10^{-2}	6.67×10^{-4}	8.99×10^{-5}
QPSK	1	5.83×10^{-2}	9.54×10^{-3}	8.91×10^{-4}
$T_x = 4$	2	4.62×10^{-2}	6.17×10^{-3}	8.99×10^{-4}
$R_x = 4$	3	1.53×10^{-2}	1.33×10^{-3}	6.67×10^{-4}
	4	1.33×10^{-2}	1.33×10^{-4}	6.48×10^{-5}

1-ZF, 2-MMSE, 3-ZF-SIC, 4-MMSE-SIC

Figure 15 and Fig. 16 show the simulation result for BPSK modulation of ZF and MMSE with proposed MIMO VBLAST PNC with the number of antennas of two for both transmitter and receiver respectively. From Fig. 16 and Fig. 17, it is seen that the MMSE in proposed MIMO VBLAST PNC has the lowest number of BER at 10 dB. This followed by ZF in PNC.

Figure 17 and Fig. 18 show the simulation result for BPSK modulation of ZF and MMSE with proposed MIMO VBLAST PNC with the number of antennas of four for both transmitter and receiver respectively. It is seen that MMSE-SIC in proposed MIMO VBLAST PNC has the best BER performance than ZF-SIC, MMSE and ZF. Moreover, the proposed MIMO VBLAST with PNC produced better BER compared to the traditional MIMO VBLAST.

Figure 19 and Fig. 20 show the simulation result for QPSK modulation of ZF and MMSE with proposed MIMO VBLAST PNC with the number of antennas of two for both transmitter and receiver respectively.

From Fig. 19 and Fig. 20, one can see that proposed MIMO VBLAST with PNC produced better BER compared to the traditional MIMO VBLAST.

Figure 21 and Fig. 22 show the simulation result for QPSK modulation of ZF and MMSE with proposed MIMO VBLAST PNC with the number of antennas of four for both transmitter and receiver respectively.

It can be observed in Fig. 21 and Fig. 22 that MMSE-SIC in proposed MIMO VBLAST PNC which is with the cooperative network has the lowest BER.

Table 4 shows the BER of MIMO VBLAST with PNC with $T_x = R_x = 2$ and $T_x = R_x = 4$ for both BPSK and QPSK modulation techniques.

From Tab. 4, at SNR of 10 dB, the BER value for ZF with BPSK modulation at two transmitters and two receivers, is 7.17×10^{-3} while the BER for ZF at four transmitters and four receivers is 1.67×10^{-4}. The simulation results show that as the number of antennas in the channel increases, the BER decreases. By increasing the number of antennas at the source and destination, the spatial diversity of signal to the relay node the will be increased. Thus, the BER of the channel can be reduced. We can say the higher antenna system has better error performance.

The differences between ZF and ZF-SIC value shows that the BER performance of wireless communication using PNC gives superior performance compared to the traditional ZF. This analysis is same as for MMSE and MMSE-SIC. The MMSE-SIC is one of the best techniques in terms of BER compared to ZF, MMSE and ZF-SIC in both two and four antennas including BPSK and QPSK modulation techniques as well.

MIMO VBLAST and proposed VBLAST with PNC are due to the utilization of a relay node in the channel. Table 4 shows that the MMSE-SIC in proposed MIMO VBLAST with PNC has the lowest number of BER at 10 dB. This followed by ZF-SIC, MMSE and ZF in proposed technique. Thus, MIMO VBLAST with PNC produced better BER compared to the traditional MIMO VBLAST. It can also be concluded that the proposed MIMO VBLAST PNC works 45.2 % average BER better in a wireless communication compared to the traditional method of MIMO VBLAST.

5 Conclusion

In this paper, a MIMO system based on two VBLAST techniques; namely the ZF-based and MMSE-based technique, were investigated. The performances of both ZF-based and MMSE-based techniques were compared to see which of the method gives a better improvement in term of BER of wireless communication. By combining the MIMO VBLAST with PNC, it was found that the BER performance of wireless communication can be increased as the PNC is a technique that carries redundant data by using diversity in the channel. It can also be concluded from the simulation results that MMSE has better performance compare to ZF. The proposed scheme PNC with MIMO VBLAST has 45.2% superior performance than the traditional MIMO scheme. For future work, the improvement in the performance of wireless communication can be further investigated by using PNC modulation and VBLAST.

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