Advances in Wireless and Mobile Communications.
ISSN 0973-6972 Volume 10, Number 2 (2017), pp. 271-283

http://www.ripublication.com

Investigations on MIMO Broadband Power Line Communication System with Joint Precoding under Impulsive noise Scenario

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Abstract

Multiple Input Multiple Output (MIMO) technique has been employed for Broadband Power Line Communication (BPLC) to increase the reliability and enhance the performance. The system performance is degraded due to impulsive noise. Aiming at this problem, Tomlinson-Harashima Precoding (THP) has been analyzed to alleviate the effect of various instances of impulse noise that is exhibited using Middleton's class A Noise Model and the effect of asynchronous impulse interference. In this paper, we propose a joint precoding approach of THP in combination with Zero forcing (THP-ZP) and Minimum Mean Square Error (THP-MMSE). The MIMO BPLC system performance is investigated for different types of MIMO configuration under impulsive noise scenario. The simulation results and analysis show that the proposed joint precoding scheme effectively improves the Bit Error Rate of the MIMO-BPLC system.

Keywords: BPLC, Multiple Input Multiple Output (MIMO), Minimum Mean Square Error (MMSE), Precoding, Tomlinson-Harashima Precoding (THP), Zero Forcing (ZF)

1. INTRODUCTION

Broadband Power Line Communication (BPLC) is a popular technology that utilizes the existing power line networks for the transmission of information. The present BPLC mainly focus on Single Input Single Output (SISO) system, which uses signals that are coupled differentially between phase and neutral wires for communication [1]-[3]. Multiple Input Multiple Output (MIMO) technology is applied in BPLC systems by using more than two conductors or wires to carry information. The input data streams are de-multiplexed and transmitted over different pair of conductors to enhance the throughput significantly[4]-[6]. But the measurement results prove that due to the small distance between the conductors or wires in the indoor MIMO-BPLC system causes interference and limits the channel capacity [5], [7], [8]. Among the various noises in BPLC, the impulsive noise causes severe signal distortions and degrades the Bit Error Rate (BER) performance [9].

To overcome this problem, one important approach is to adopt an appropriate precoding scheme at the transmitter to implement channel decoupling and to improve the performance of MIMO-BPLC systems. Various schemes have been proposed in literature such as the Zero-forcing (ZF), the Minimum Mean Square Error (MMSE) and the Successive Interference Canceller (SIC).In previous works, the literature describe ZF precoding is the basic precoding scheme that makes use of matrix inversion with full channel state information. In ZF, as the transmitted signal is detected with the pseudo-inverse of the channel matrix to reduce the channel effects. Alternatively, the MMSE precoding considers the effect of interference along with noise and hence it display better performance than ZF precoding [10], [11]. On the other hand, there has been significant research on Tomlinson-Harashima precoding (THP) scheme with wireless communications but they have not demonstrated its effect with the BPLC for varying noise effects [12], [20].

To improve the system performance further, a novel joint precoding scheme is considered in this paper using Tomlinson-Harashima Precoding in combination with Zero Forcing and MMSE algorithm. The performance is investigated for SISO, 2x2 MIMO and 3x3 MIMO systems using OFDM with 16 QAM and 64 QAM modulations under impulsive noise scenario.The rest of the paper is organized as follows. Section 2 describes the model along with the proposed joint precoder for MIMO-OFDM system. Section 3 presents the joint precoding scheme using THP in combination with ZF and MMSE. Finally, simulation results are discussed in section 4 and conclusion is made in section 5.

2. MIMO BPLC CHANNEL MODEL AND SYSTEM

A.MIMO Power Line Channel Model

In this paper the BPLC is considered with MIMO technique and the configuration for typical in-home networking that is being identified as a potential candidate for home and local area networking. For MIMO configuration, we assumed single phase three-wire power system with wires P referring phase, N denoting neutral and PE displaying protective earth. The block diagram of the MIMO-BPLC is shown in Fig. 1 and the dotted line signify that a coupling between the wires as defined by the multi-conductor transmission-line theory. This coupling facilitates the reception of signals at all the receiving ports from a single transmitter port.

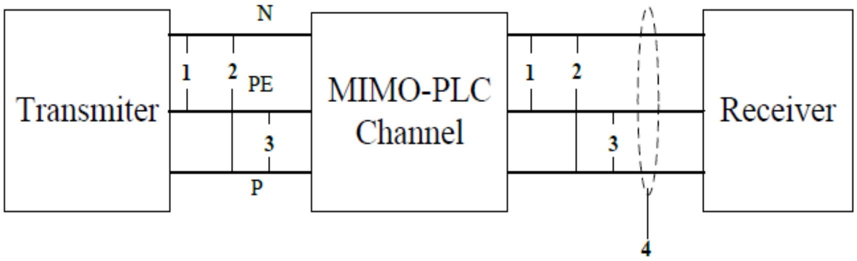

Fig.1 Schematic of MIMO BPLC System

The multi path channel model developed by Zimmermann and Dostert for BPLC system [13] is extended to MIMO-BPLC model as described in [14], which includes the transmit ports of order M and N receiver ports. Considering 3 transmit ports and 3 receiver ports, the link between transmit port $M_1$and receiver port $N_1$is represented as Stream 1, N_2 as Stream 2 and N_3 as Stream 3 respectively.

B. Impulsive Noise Model

The impulsive noise is caused by switching transients in the power line network and the suitable model for these impulsive noises for MIMO-BPLC system is Middleton's class A noise model [15]. In Middleton's Class A noise model, A refers to the impulsive index and it is used to define the average number of impulses through the unit length interval. The Middleton's model is the comprehensive power line model as it combines the effect of additive impulse noise and white Gaussian noise. The effect of impulsive noise over the OFDM system in the wireless radio communication is studied in [16]. Since the impulsive noise in MIMO radio communications is different from that of MIMO BPLC, the former is not applicable to analyze the effect of impulsive noise on BPLC systems. To analyze the noise effects on MIMO BPLC, it is assumed that the background noise as additive white Gaussian noise with mean zero and variance σ^2 and the impulsive noise i_k is as given in [19]

$$i_k = b_k g_k \tag{1}$$

where b_k is the impulsive noise arrival and g_k refers to the white Gaussian process. Eq.(1), describes the impact of transmitted symbol being affected by impulsive noise with a probability of b_k and random amplitude g_k . For instance, a_k is the transmitted signal, and then the received signal is given by

$$r_k = a_k + n_k \tag{2}$$

where n_k is the noise given by

$$n_k = w_k + i_k \tag{3}$$

Sub. Eq. (1) in Eq. (3), we obtain,

$$n_k = w_k + b_k g_k \tag{4}$$

C. MIMO-OFDM system

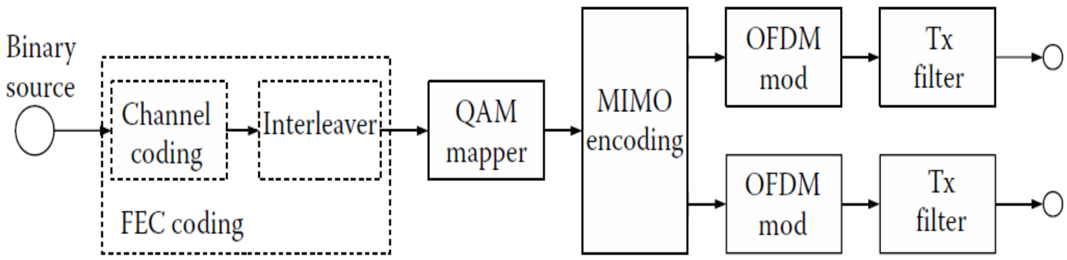

Fig.2 MIMO-OFDM System in the Transmitter

In BPLC OFDM system, the complete channel is divided into various sub-channels. As, we also consider MIMO based BPLC with OFDM, the system consist of transmitting ports of order m_T and receiving ports of order m_R. The input data from the random signal generator is mapped into m_T complex constellation sequences and it is given by S_i (k, 1), S_i (k, 2)…S_i (k, L), where i=1,…, m_T and L refers to the number of subcarriers. In addition, the data stream (d) from the transmitter *k* has to be sent is defined as follows

$$d_k = \begin{pmatrix} d_1 \\ \vdots \\ \vdots \\ d_L \end{pmatrix} \tag{5}$$

where d_k is composed by complex values. Each transmitter ports are considered as transmitter station and have its own transmit filter

$$B_k = \begin{pmatrix} b_{11} & \cdots & b_{1M} \\ \vdots & \ddots & \vdots \\ b_{1N} & \cdots & b_{NM} \end{pmatrix} \tag{6}$$

In the matrix we have all the coefficients among all M wires at the transmitter station and all components of the data stream N. These filters are called as precoding filters which allow us to make a linear filtered version of the transmitted signal. So that we can obtain the following transmitted vector

$$x_k = B_k d_{k,} \;\; x_k \in \mathbb{C}^{[M+1]} \tag{7}$$

Each station transmits the signal to the corresponding receiver port and it is clear that this signal also arrives at the other receiving ports as interference signal. The MIMO channel involved in our system is between *i* transmitter ports and the *k* receiver ports.

$$H_{ki} = \begin{pmatrix} h_{11} & \cdots & b_{1N} \\ \vdots & \ddots & \vdots \\ h_{1M} & \cdots & b_{MN} \end{pmatrix}, H_{ki} \in \mathbb{C}^{[N+M]} \tag{8}$$

The values in the matrix display the gain of the channel among various port pairs, namely, NN, NP and NPE. Each pair station user has a different channel. The channel between the station k and user k is the channel carrying the desired signal. The channel between station i and user k, where i is different from k carries the inter-channel interference. For instance, H_{kk} refers to the channel carrying the desired signal and H_{ki} refers to the channel carrying the interference signal. As we see in the figure, the block diagram shows how the transmitted signal travels through the system. Firstly, the data stream d_k passes through the transmitted filter B_k, so we obtain x_k the linearly filtered version of d_k.

$$x_k = B_k d_k \ , x_k \mathrm{C}^{[N+M]} \tag{9}$$

Now, x_k travels by the channel until arrive at the user. As we see in the figure, user is going to receive one desired signal and −1 interference signal. Thus for the user k, we have the next receiving signal

$$y_k = \sum_{i=1}^{k} H_{ki} x_i + n_k, \ x_k \mathrm{C}^{[N+1]} \tag{10}$$

Rewriting Eq. (10) by means of the desired signal, asynchronous impulse interference and the Middleton's class A noise impulse,

$$y_k = H_{kk} x_k + \sum_{\substack{i=1 \\ i \neq 1}}^{K} H_{ki} x_i + n_k \tag{11}$$

Using Eq. (9) in Eq. (11), we attain:

$$y_k = H_{kk} B_k d_k + \sum_{\substack{i=1 \\ i \neq 1}}^{K} H_{ki} x_i + n_k \tag{12}$$

where, $H_{kk} B_k d_k$ is the desired Signal,

$\sum_{\substack{i=1 \\ i \neq 1}}^{K} H_{ki} B_i d_i$ is the asynchronous impulse interference and n_k refers to the impulse noise.The last step in this block diagram is the application of received filter when the received signal applied at each user end. If we apply the received filter at the received signal we obtain this equation:

$$d_k = A_k y_k = A_k H_{kk} B_k d_k + \sum_{\substack{i=1 \\ i \neq 1}}^{K} A_k H_{ki} B_k d_k + A_k n_k \ , \ d_k \mathrm{C}^{[N+1]} \tag{13}$$

3. JOINT PRECODING SCHEME

In MIMO BPLC based systems with spatial multiplexing, as seen in Eq. (13), the independent data streams is the main source of asynchronous impulse interference as the system undergoes parallel transmission. Under these circumstances, the conventional stand alone precoding schemes, namely, zero-forcing (ZF) and minimum mean square error (MMSE) precoding and the system without precoding fail to deliver the desired BER performance. It is also shown in [10], [11], [18], [19] that the system performance degrades with suitable noise considerations. The solution can be obtained with Tomlinson-Harashima precoding (THP) where appropriate signal conditioning is carried out at the transmitter section [20]. THP has been one the promising precoding schemes in wireless communication as the successive pre-cancelation structure makes it to outperform the linear precoding schemes[12]. Hence, in this paper an attempt is made to make use of the THP to effectively cancel the interference due to asynchronous impulse that sources from other data streams. In addition, a novel joint precoding technique is proposed to improve the system performance by combining THP with the ZF criterion (THP-ZF) and employing the THP with MMSE precoding (THP-MMSE) for MIMO channel with impulsive noise.THP make use of nonlinear signal processing technique at the transmitter section with the assumption that perfect knowledge of channel sate information (CSI) that helps the ZF or MMSE for interference cancelation at the receive side.

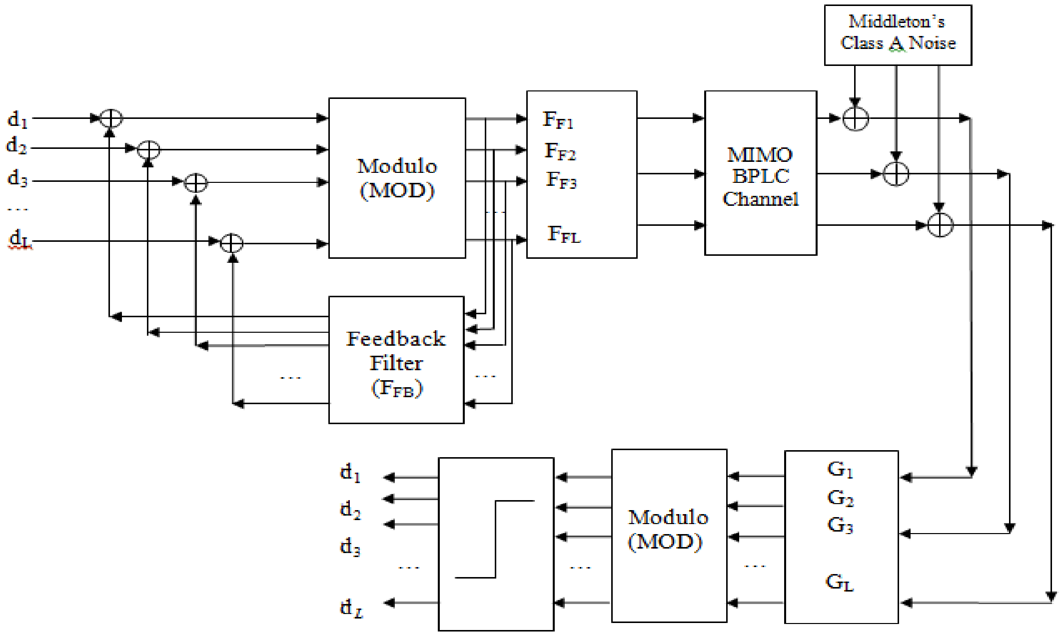

Fig.3 Proposed THP for MIMO-BPLC system

The MIMO-BPLC system described in Fig.3 is standard system using THP precoding. In this section we will analyze the THP-ZF precoding and THP-MMSE precoding. With THP-ZF precoding and with perfect CSI at the transmitter port, the THP transmit filter consist of a feedback filter (F_{FB}), modulo operator (MOD) and forward filter (F_F). The data symbols that transmitted are denoted as 'd' and the precoded symbol is given by 'x'. The received signal vector is given in Eq. (12) and '*r*' refers to the outcome of the receive filter, then the detected signal can be denoted as '$\hat{d}$' and the data for user '*k*' is given by as $\widehat{d_k} = r_k\left(H_k\, x_k + n\right)$ with THP-MMSE precoding and with perfect CSI at the transmitter port, the detected signal is given by $\hat{d}_k = G_k\left(H_k\, F_{FL} + n_k\right)$.

4. PERFORMANCE EVALUATION

Considering the physical constrains in the BPLC system, we assumed the transmitter and receiver ports as 2 or 3 for the simulation of the proposed system model. Also, the transmission characteristics of the MIMO- BPLC channel and noise model (Middleton's class A noise model) are used to meet the standards of MIMO BPLC system.

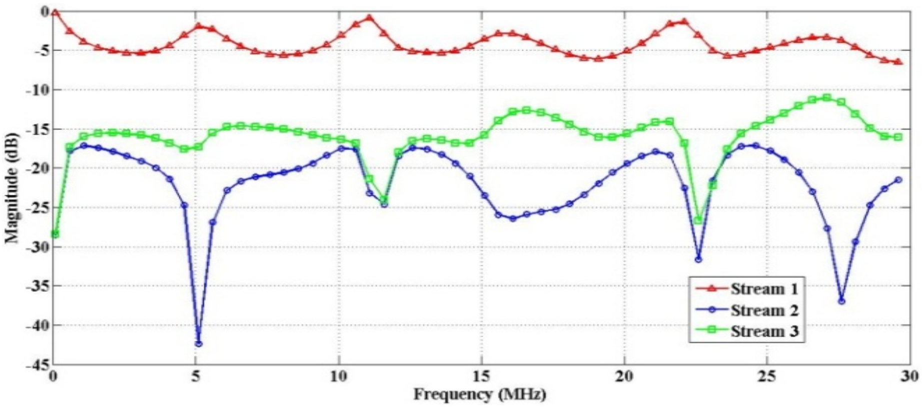

Fig.4 Transfer function of MIMO-BPLC system

As mentioned in the MIMO channel model we considered 3 transmit ports and 3 receiver ports, where the link between transmit port M_1 and receiver port N_1 is represented as Stream 1, N_2 as Stream 2 and N_3 as Stream 3 respectively. The transfer function of the MIMO-BPLC channel is shown in Fig.4 which demonstrates the response for 3 different streams over a frequency range of 0 to 30 MHz. The performance comparison of the proposed system is analyzed in terms of Bit Error Rate (BER) for Tomlinson-Harashima precoding (THP) in combination with Zero Forcing (ZF) and MMSE.

Table 1: Simulation parameters

Parameter	**Details**
Bandwidth	30 MHz
Channel Model	Multipath MIMO BPLC Channel
Impulsive Noise model	Middleton's class A noise model
Precoding Schemes	THP, THP-ZF, THP-MMSE
Modulation scheme	16 QAM, 64 QAM
MIMO Channel Matrix	1x1 (SISO), 2x2 and 3x3
No. of OFDM Tones	1024
Spacing between Tones	15.625 kHz
Cyclic Prefix Length	16
Simulation Tool	Matlab 2013b

This investigation is based on the systems of SISO, 2x2 MIMO and 3x3 MIMO using OFDM with 16 QAM and 64 QAM modulations. The simulation parameters used in conjunction with the proposed system is shown in Table 1. The system is simulated on MATLAB platform to verify the Bit Error Rate performance and to analyze the advantage of the proposed joint precoding scheme. Also the system performance is investigated for 16 QAM modulation under Low, Medium and High impulsive noise scenario using Middleton's class A noise model.

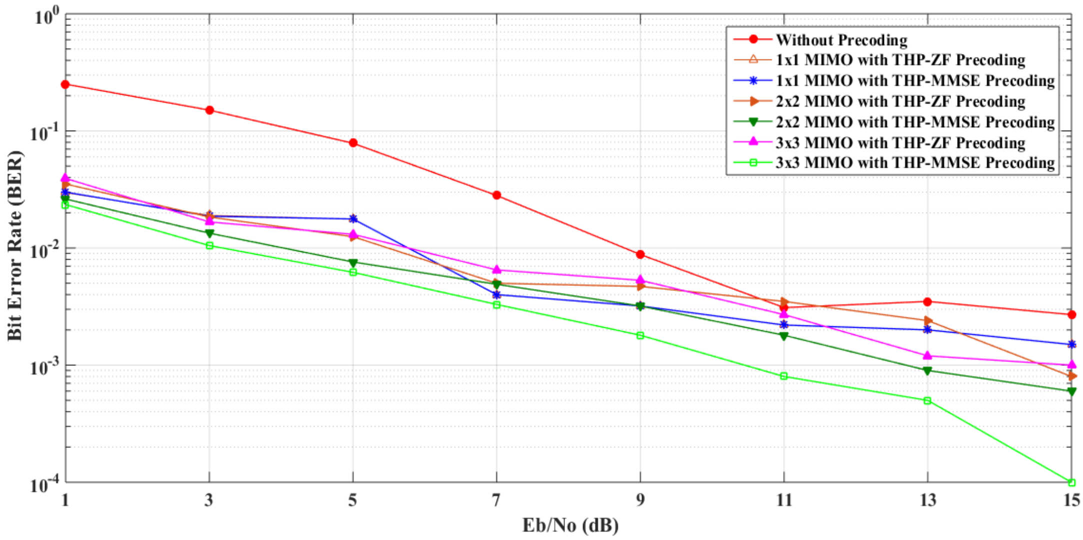

Fig.5 BER performance for 16 QAM under low impulsive noise index (A=0.1)

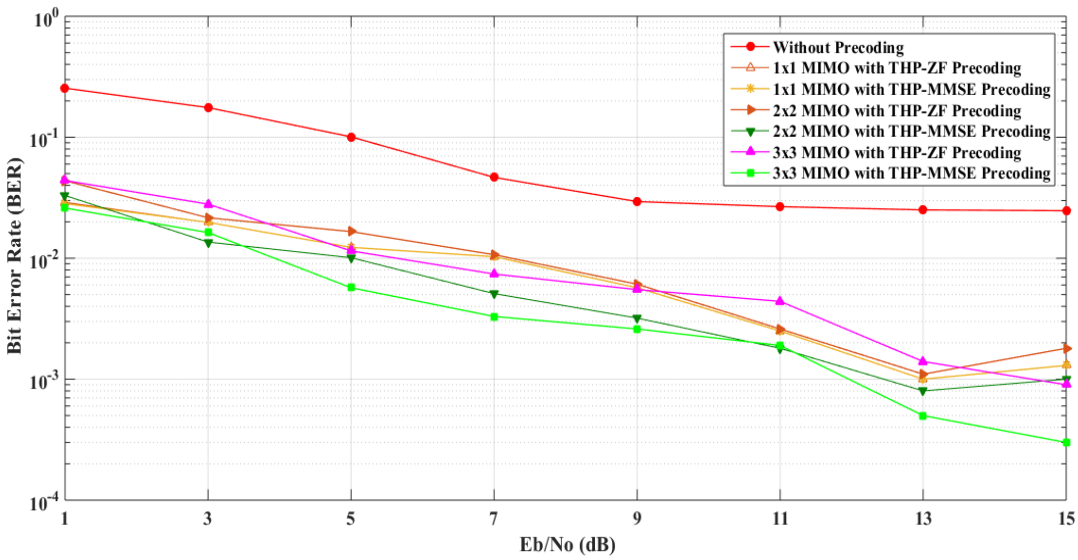

Fig.6 BER performance for16 QAM under medium impulsive noise index (A=0.5)

The impulsive index A is the average number of impulses during a unit length interval. For the simulation we have chosen the value of impulsive index A as 0.1, 0.5, and 0.8 for the impulsive noise scenario low, medium and high respectively [9], [15], [16] and the simulation results are show in Fig.5, Fig. 6 and Fig. 7, respectively.

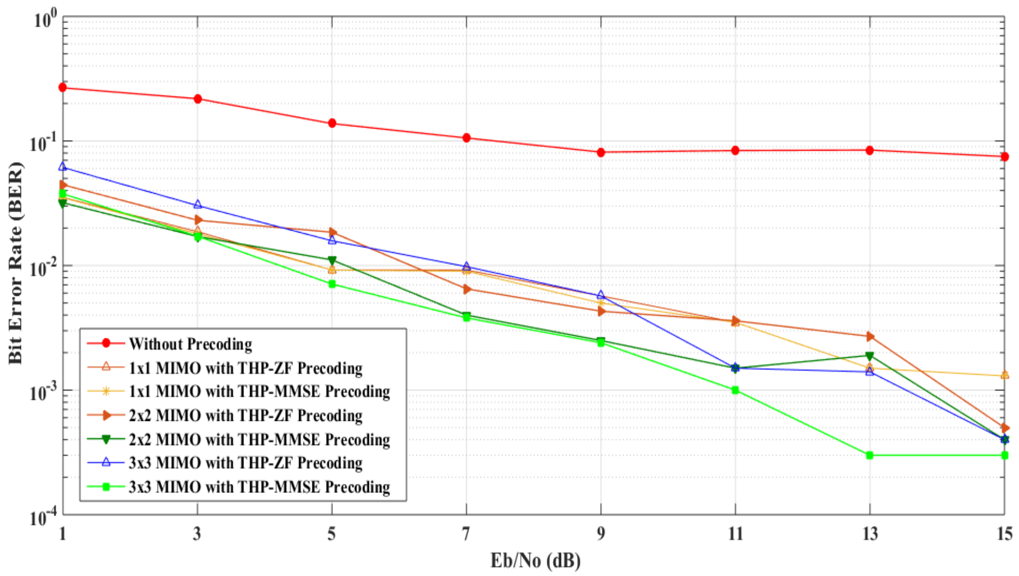

Fig.7 BER performance for 16 QAM under high impulsive noise index (A=0.8)

The mean performance comparison of the results for different type of MIMO system and precoding schemes with 16 QAM modulations are tabulated in Table 2. From the results of 16 QAM scheme under various impulse noise it could be inferred that the precoding using THP and MMSE is effective for high impulse noise environments. As seen from Fig. 5, the effect of precoding is less effective at low impulse environment as compared to the profile of curves in Fig. 6 and Fig. 7, where the impulse noise is relatively medium and high.

Table 2: Mean performance comparison for 16 QAM with various impulsive index

Modulation Scheme16 QAM				
System Description		**BER**		
		A=0.1	**A=0.5**	**A=0.8**
SISO without Precoding		0.1170	0.0760	0.0584
SISO	THP-ZF	0.0088	0.0091	0.0094
	THP-MMSE	0.0088	0.0090	0.0092
2 x 2 MIMO	THP-ZF	0.0092	0.0116	0.0115
	THP-MMSE	0.0065	0.0076	0.0078
3 x3 MIMO	THP-ZP	0.0095	0.0114	0.0140
	THP-MMSE	0.0053	0.0063	0.0077

From the comparison table, the numerical results shows that the proposed THP-MMSE precoding scheme provide the improved performance with 3x3 MIMO configurations under all impulsive noise scenario.

The simulation results for Bit Error Performance of the proposed joint precoder with 64 QAM under impulsive noise index for SISO, 2x2 MIMO and 3x3 MIMO systems are depicted in Figures 8, 9 and 10.

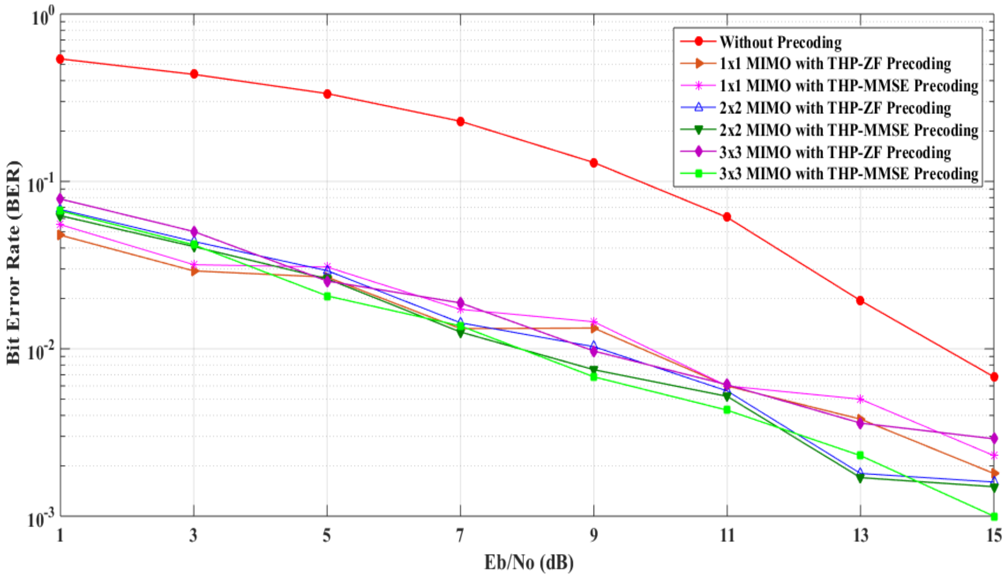

Fig.8 BER performance for 64 QAM under low impulsive noise index (A=0.1)

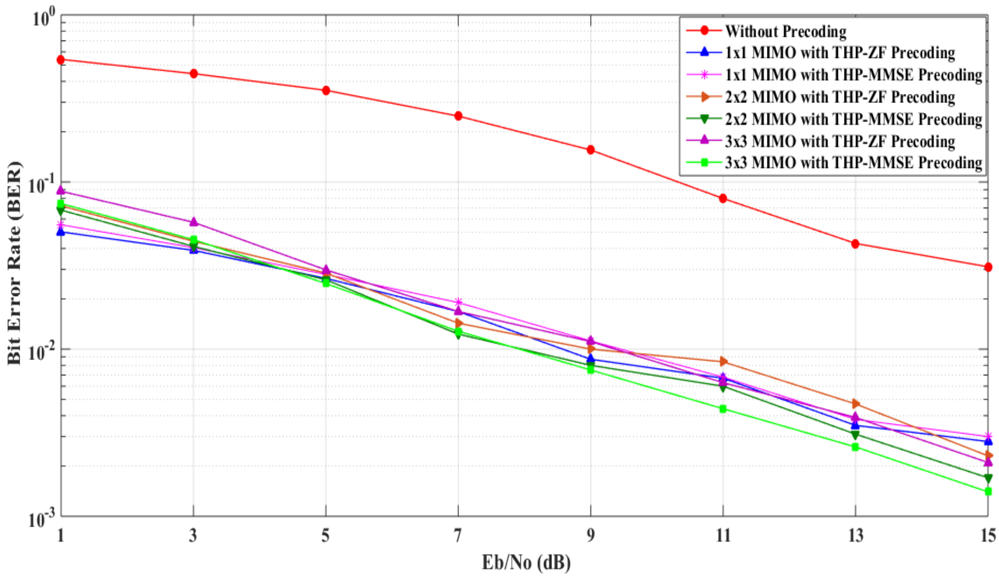

Fig.9 BER performance for 64 QAM under medium impulsive noise Index (A=0.5)

The results of without precoding and the joint precoding schemes THP-ZF and THP-MMSE approach for 64 QAM, are tabulated in Table 3. The BER performance enhancement is achieved with the proposed THP-MMSE precoding scheme under different impulsive noise scenarios.

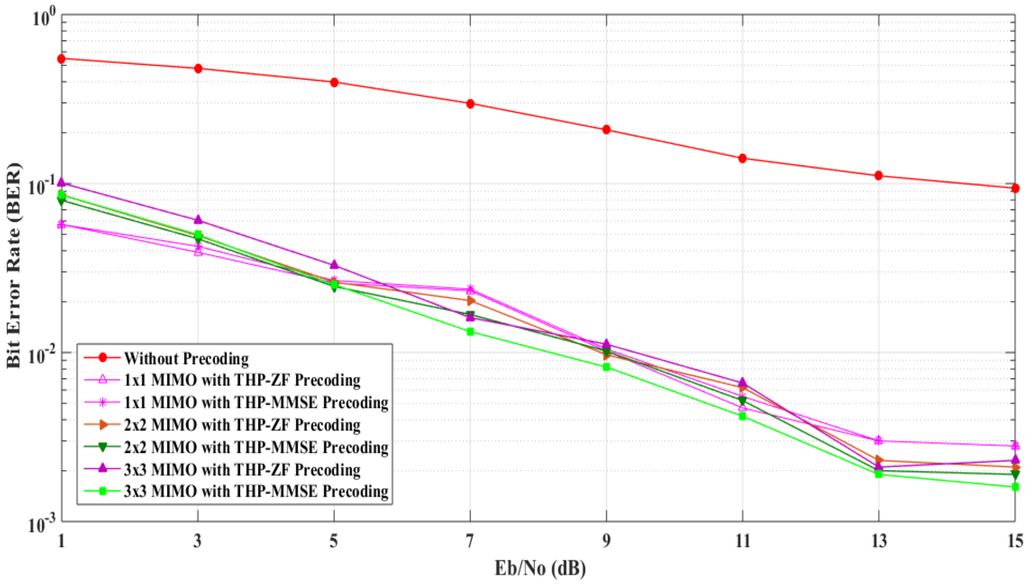

Fig.10 BER performance for 64QAM under high impulsive noise index A=0.8

Table 3: Mean performance comparison for 64QAM with various impulsive index

Modulation Scheme 64 QAM				
System Description		**BER**		
		A=0.1	**A=0.5**	**A=0.8**
SISO without Precoding		0.1951	0.2108	0.2535
SISO	THP-ZF	0.0217	0.0171	0.0185
	THP-MMSE	0.0175	0.0186	0.0191
2 x 2 MIMO	THP-ZF	0.0194	0.0205	0.0224
	THP-MMSE	0.0175	0.0185	0.0208
3 x 3 MIMO	THP-ZF	0.0217	0.0239	0.0258
	THP-MMSE	0.0175	0.0192	0.0211

5. CONCLUSION

In this paper, the effect of impulsive noise with different magnitudes (High, Medium and Low) and occurrence rates in OFDM-based MIMO BPLC was studied with joint precoding scheme to improve the Bit Error Rate (BER) of the system.The prominent nonlinear precoding technique Tomlinson-Harashima precoding (THP) is formulated in combination with the conventional Zero-Forcing (ZF) and Minimum Mean Square Error (MMSE) methods. The performance of the proposed precoding scheme is investigated for SISO, 2x2 MIMO and 3x3 MIMO systems using OFDM with 16 QAM and 64 QAM modulations. The results evaluated for a targeted BER of 10^{-2} reveals that the proposed joint precoding scheme has good performance over the other schemes for BPLC systems. In addition, the numerical results show that 3x3 MIMO systems with the proposed joint precoding THP-MMSE achieves improvement of 95.4%, 91.7% and 86.8% in terms of BER under the high, medium and low impulsive noise scenarios respectively than the existing scheme without precoding.

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