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PERFORMANCE OF ADAPTIVE OFDM SCHEME FOR BROADBAND POWER LINE COMMUNICATION SYSTEM WITH NEURAL NETWORK BASED CHANNEL PREDICTION

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ABSTRACT

Broadband Power Line Communication (BPLC) is a popular technology that utilizes the existing power line networks for the transmission of information. The power line channel is affected by multipath propagation. The BPLC system performance is degraded due to multipath propagation and the noise in the channel. One of the promising approaches to mitigate the problem is to implement a proper modulation technique. Adaptive OFDM (AOFDM) method can potentially aid to achieve high data rates in Broadband Power Line Communication system. To realize this potential, the transmitter needs accurate Channel State Information (CSI) for the upcoming transmission frame. This paper proposes an Adaptive OFDM scheme with an optimal approach of Exponential Effective SNR Mapping (EESM) on prediction of the BER over all subcarriers. A channel prediction scheme using Neural Network is also presented for OFDM system to select a suitable Modulation and Coding Scheme (MCS) for the BPLC channel realization. The proposed method of Adaptive OFDM enhances the system throughput about 8% and reduces the feedback overhead compared to the conventional schemes in BPLC system. The results show that the proposed adaptive algorithm with neural network channel prediction scheme can achieve a considerable improvement in the processing time over the conventional method.

KEYWORDS: Broadband Power Line Communication (BPLC)

I. INTRODUCTION

The Broadband power line communication (BPLC) is the popular wired network technology that utilizes power lines for the transmission of voice, video and data services. The channel properties degrading the performance of high speed communication over power line are noise, attenuation and multipath propagation [1]. Multi-carrier modulation scheme has been adopted as the technology of BPLC standards [2]. Orthogonal Frequency Division Multiplexing has been a major candidate for BPLC systems due to its robustness to multipath, selective fading and different kinds of interference. Its inherent characteristics make it possible to provide high data rate services, such as multimedia services [3]. In an OFDM based system, the channel performance may be highly fluctuating across the subcarriers and varies from symbol to symbol. In fixed modulation scheme the error probability is dominated by the OFDM subcarriers with highest attenuation resulting in a poor performance. The spectral efficiency of OFDM systems can be effectively enhanced by an adaptation scheme that allocates power and determines modulation and coding level adaptively to the time varying Power line channel [4]. This problem can be mitigated if different modulation schemes are employed for the individual OFDM subcarriers. In adaptive modulation, different parameters including data rate, transmit power, instantaneous BER, constellation size and channel code or scheme can be adjusted according to the channel conditions. This will substantially improve the performance and data throughput of an OFDM-BPLC system [5]. We propose the method of Exponential Effective SNR Mapping (EESM) which is a simple mapping method used when all the subcarriers of a specific group are modulated using the same Modulation and Coding Scheme (MCS) level [6].

In this paper, group adaptive method employed to reduce the complexity. In group adaptive OFDM, all subcarriers in a symbol are split into blocks of adjacent subcarriers referred as groups. The choice of the modulation to be used by the transmitter for its next OFDM symbol is determined by the channel quality estimation. In addition a selective modulation approach is suggested for each group of subcarrier to enhance the throughput of the system. By using the channel state information (CSI), spectral efficiency in various OFDM systems can be effectively enhanced by adaptation schemes [7]. An Artificial Neural Networks (ANNs) based prediction scheme is proposed and trained to predict channel condition so as to perform adaptive transmission. The performance is evaluated with the proposed Neural network based channel prediction scheme for Adaptive OFDM system. The rest of the paper is organized as follows. In section II the system model is described along with the proposed concept of grouped subcarriers for adaptive OFDM system and its performance is discussed. Section III presents the channel prediction scheme using Neural network based adaptive OFDM system for Broadband power line communication. Finally results are discussed in section IV and conclusion is made in section V.

II. DESCRIPTION OF THE PROPSED SYSTEM

A. Channel Model

Power lines are not designed for communication purpose, so the channel properties are significantly differ from conventional communication channels such as coaxial, twisted pair and fiber cables. The most influencing properties of this channel for high speed communication are signal distortion due to frequency dependant cable loses, multipath propagation and noise [4]. A multipath PLC channel model [3] with Additive White Gaussian Noise (AWGN) is considered for performance evaluation of the BPL system.

B. OFDM System

Orthogonal Frequency Division Multiplexing (OFDM) is considered as the transmission scheme for Broadband power line communication by most researchers. This multi-carrier transmission technique performs well in multipath and frequency selective channels. In OFDM systems single high rate data stream is divided into multiple low rate data streams that modulate multiple orthogonal subcarriers by means of Inverse Fast Fourier Transform (IFFT). In this way the symbol rate on each sub channel is greatly reduced, and hence the effect of inter symbol interference (ISI) due to channel dispersion caused by the multipath delay spread is reduced. The system block diagram is shown in Figure 1.

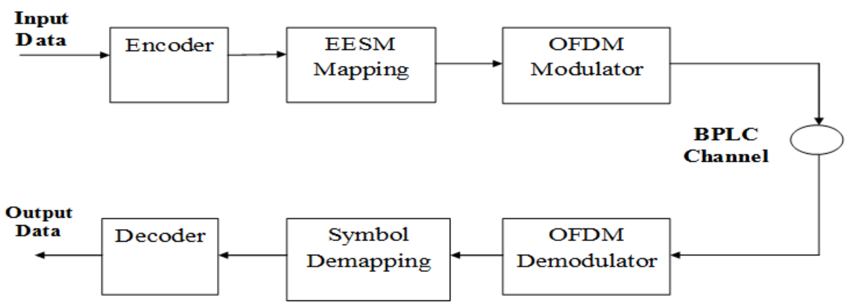

Figure 1: Block Diagram of BPLC-OFDM System

C. Exponential Effective SNR Mapping (EESM)

Exponential Effective SNR Mapping (EESM) is used to map the instantaneous values of SNR to the corresponding Bit Error Rate (BER) value. EESM is a simple mapping method used when all the subcarriers of a specific system are modulated using the same Modulation and Coding Scheme (MCS) level single value that is a good predictor of the actual BER [6]. In case of multi-carrier transmission the set of subcarrier SNRs are mapped with the help of EESM formula into a scalar instantaneous effective SNR value. An estimate of the BER value is then obtained, using the effective SNR value from basic AWGN performance. The EESM method estimates the effective SNR using the following formula

$$\gamma_{eff} \equiv EESM\,(\gamma,\beta) \equiv -\beta \cdot \ln\left[\frac{1}{N}\cdot\sum_{i=1}^{N} e^{-\gamma/\beta}\right] \qquad (1)$$

Where, γ is a vector $[\gamma_1, \gamma_2,., \gamma_N]$ of the per-subcarrier SNR values, which are typically different in a frequency selective channel. β is the parameter to be determined for each Modulation Coding Scheme level, and this value is used to adjust EESM function to compensate the difference between the actual BER and the predicted BER. Figure 2 shows the OFDM bit error performance plot under the AWGN channel and power line channel condition for the modulation schemes 4 QAM, 16 QAM, and 64 QAM. The AWGN performance curve act as the reference curve for mapping the BER achieved at real time BPLC channel. To obtain β value, several realizations of the channel have to be conducted using a given channel model. Then BER for each channel realization is determined using the simulation. Using the AWGN reference curves generated previously for each MCS level, BER values of each MCS is mapped to an AWGN equivalent SNR. These AWGN SNRs for n realizations can be represented by an element vector SNR_{AWGN}. Using a particular β value and the vector γ of subcarrier SNRs, an effective SNR is computed for each realization. For n realizations, we get a vector of computed effective SNRs denoted by Γ_{eff}..

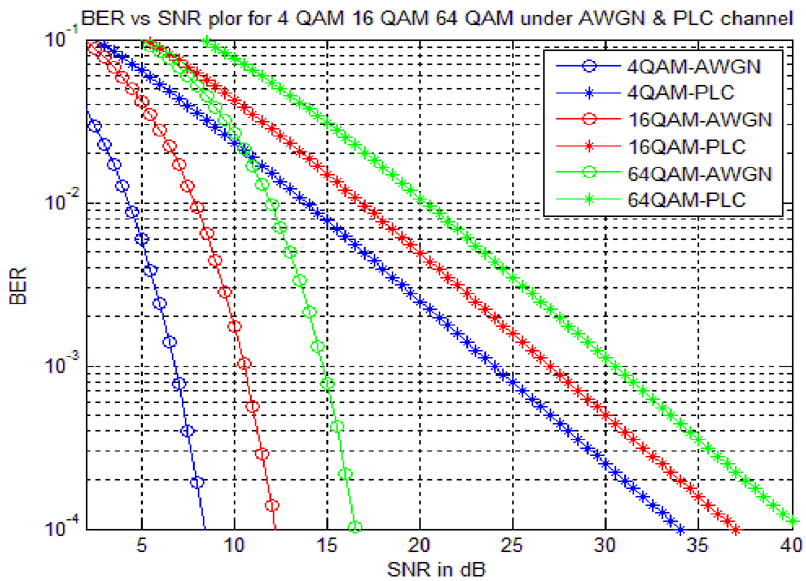

Figure 2

The goal is to find the best possible β value that minimizes the difference between computed and actual effective SNRs:

$$\beta = \arg\min(\beta) \left\| SNR_{AWGN} - \Gamma_{eff}(\beta) \right\| \quad (2)$$

Table 1 shows the calibrated β value for 4 QAM coded & uncoded, 16 QAM and 64 QAM modulation schemes under PLC channel. The switching threshold for activating different modes can be determined by extensive simulation of the fixed mode modulation system. The switchingalgorithm used for the adaptive modulation schemes are presented in Table 2

Table 1: Calibrated Beta Value for Different Modulation Schemes

Modulation	Code Rate	β
4 QAM	1/2	3.8
4 QAM	3/4	4.5
4 QAM	-	6.4
16 QAM	-	8.5
64 QAM	-	12.6

Figure 3 shows the throughput performance of EESM adapted OFDM system. For fixed system there is a limit in throughput achievement even if the SNR value increases. But in case of EESM adapted system, the MCS scheme switches from one to another based upon the SNR improvement so that higher throughput is achieved. Here in this figure the colored lines show the fixed system throughput where the black circular marked line shows the adapted throughput enhancement.

Table 2: Switching Threshold for EESM Adapted System

Mode	Modulation	Thresholds
1	4QAM	SNR≤15dB
2	4QAM(1/2)	15dB<SNR≤21dB
3	16QAM	21 dB<SNR≤28dB
4	64QAM	SNR>28dB

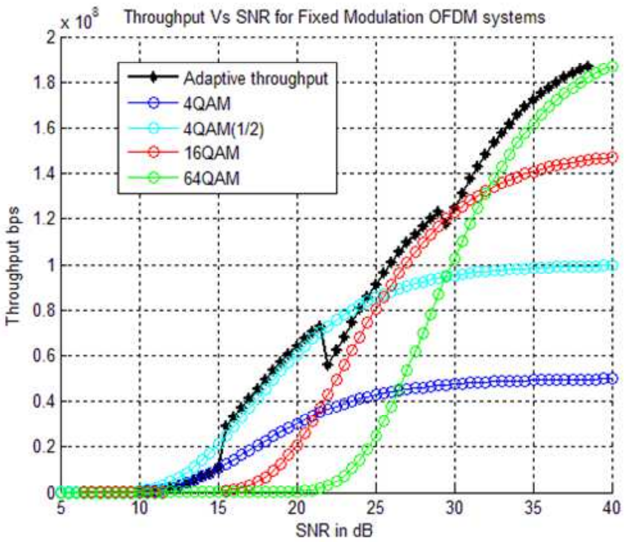

Figure 3: EESM Throughput Performance Comparison over Conventional OFDM System

D. EESM Selective Modulation Scheme

The traditional EESM abstracts all the received SNR vectors into a single vector known as effective SNR. This method of abstraction may be accurate but affects the throughput performance to a certain level. So as to enhance the throughput performance further, the concept of grouping of subcarriers shall be considered. The idea is to group the received SNR vectors into three different groups namely A, B, and C. Group A consists of the SNR vectors of best strength. Group B consists of SNR vectors of good strength and Group C comprises of the SNR vectors of weakest strength. Here it should be noted that the groups are made up to the appropriate FFT sizes at the transmitter. Now for each group the EESM concept is applied and a separate effective SNR is being calibrated and then reported to the transmitter. The transmitter then decides an appropriate MCS for each group. Group C may be a no transmission mode however if necessity arises the same group shall be utilized and assigned with the lowest order modulation. The following Figure 4 shows the concept of EESM based grouping of subcarriers.

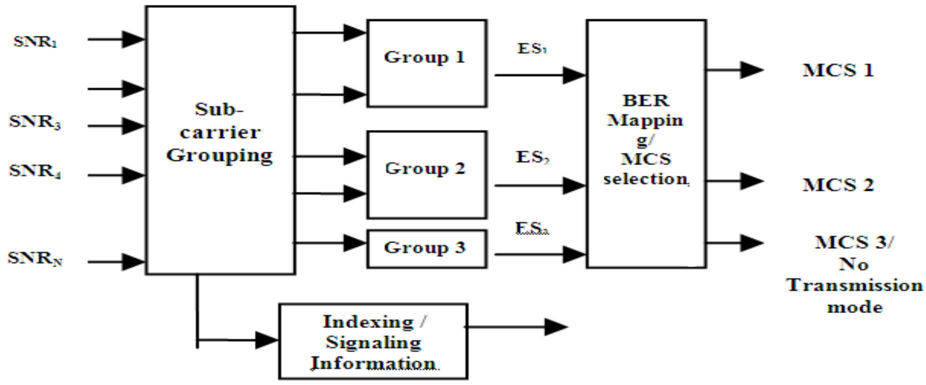

Figure 4: Grouping of Subcarriers for EESM Selective Modulation

In the proposed EESM selective modulation scheme the transmitter has to be intimated the subcarrier indexing information and SNR threshold of each group so that the transmitter shall perform the unequal constellation assignment to each group. Hence a practical reduced feedback scheme is considered. Practical Feedback Design based OFDM Adaptive Communications over Frequency Selective Channels [8] has been incorporated here. The traditional OFDM systems report 4 to 6 bits per subcarrier, where the proposed scheme reports only the indexing information in 2 bits per subcarrier.

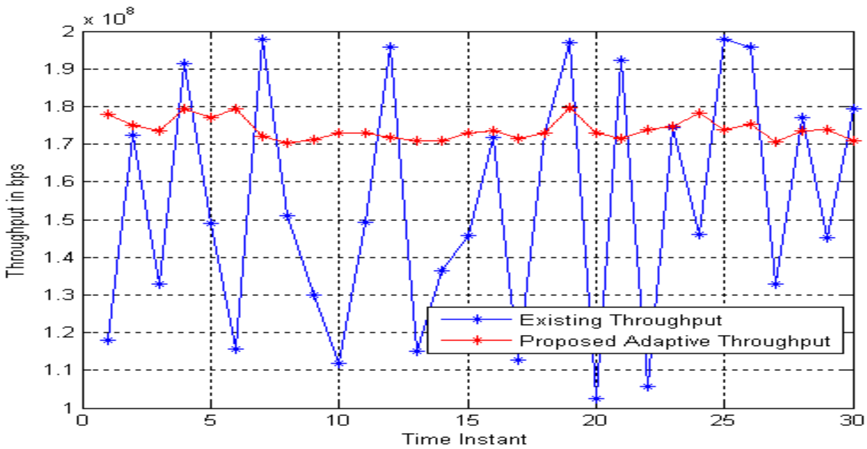

Figure 5: Throughput Performance Comparison Traditional EESM vs. EESM Selective Modulation

Figure 5 shows the throughput performance comparison between EESM equal modulation scheme and EESM selective modulation scheme for 30 time instants. It is observed that an average throughput of 175 Mbps can be achieved through the proposed EESM selective modulation procedure, while the traditional EESM equal modulation gave a throughput of 150 Mbps. Hence the proposed EESM selective modulation scheme gives a better throughput performance compared to the traditional EESM procedure Figure 6shows the feedback overhead reduction in bits by grouping of subcarriers over the conventional instantaneous SNR feedback scheme for OFDM system with subcarriers 52, 128, 256, 512, 1024, 2048 respectively. In conventional scheme for each instantaneous subcarrier a feedback overhead of 4 to 6 bits is sent, whereas in grouping of subcarriers an overhead of 2 bits are intimated to the group with predefined threshold. The results show that, there is a 50% reduction in the overhead compared to the conventional feedback scheme and also it reduces the control channel bandwidth utilization.

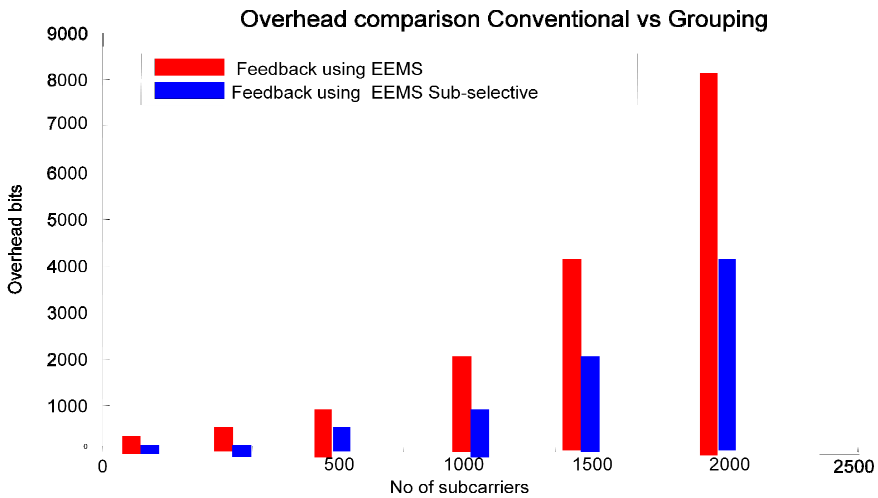

Figure 6: Feedback Overhead Reduction Traditional vs. EESM Selective Modulation

II.CHENNEL PREDICTION USING NEURAL NETWORK

The channel prediction is to use past and present channel samples to predict future samples to estimate the channel state information (CSI). The Artificial Neural Networks (ANNs) [9] have been successfully applied to a number of scientific and engineering fields in recent years for the application of function approximation, system identification and control, image processing, time series prediction etc. Neural network performance is highly dependent on its structure. The interaction allowed between the various

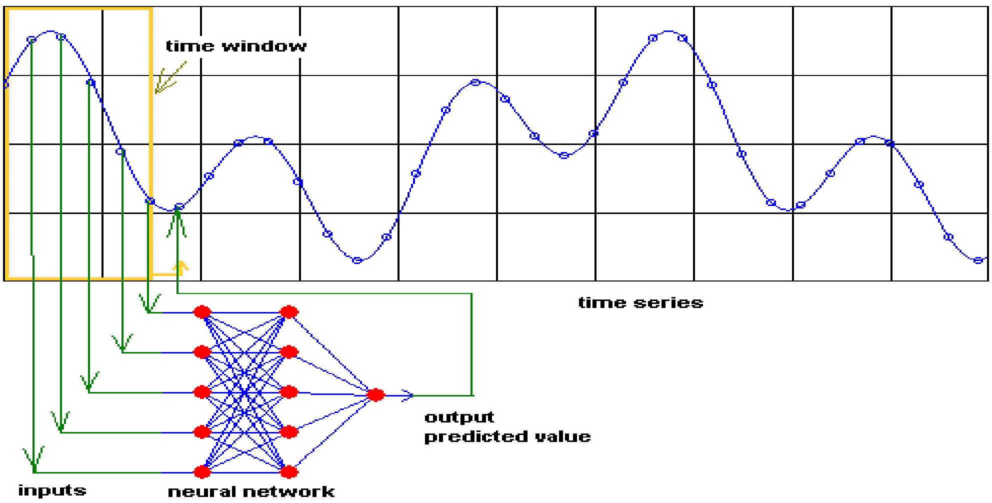

Figure 7: Time Series Prediction Neural Network

Nodes of the network is specified using the structure. An ANN structure is not unique for a given problem, and there may exist different ways to define a structure corresponding to the problem. Depending on the problem, it may be appropriate to have more than one hidden layer, feed forward or feedback connections, or in some cases, direct connections between input and output layer. Time-series forecasting is an important research and application area [10]. The basic function of the Time series prediction neural network is shown in Figure 7.

A. Adaptive OFDM Implementation in a Neural Network

This section discusses the techniques used to develop the Neural network and training it to perform EESM based adaptation. The network structure for EESM adaptation consist of two stages in which the stage 1 computes the Effective SNR value and the stage 2 decides the best MCS based on effective SNR. The network specifications are listed as follows in the Table 3 and Table 4.

Table 3: Stage 1 Network: Effective SNR Calibration

Slab No	Slab Type	Transfer Function	No. of Neurons
Slab 1	Input	Tansig	(N) No of subcarriers
Slab 2	Hidden	Tansig	300
Slab 3	Hidden	Tansig	300
Slab 4	Hidden	Tansig	300
Slab 5	Output	Tansig	1

Table 4: Stage 2 Network: EESM MCS Selection

Slab No	Slab type	Transfer Function	No. of Neurons
Slab 1	Input	Tansig	1
Slab 2	Hidden	Tansig	30
Slab 3	Hidden	Tansig	30
Slab 4	Hidden	Tansig	30

Figure 8 shows the grouping of 128 subcarriers with three group levels as A,B, and C. Group A is the better group with an FFT size of 52 subcarriers and group B is the good group with an FFT size of 52 subcarriers and group C is of no transmission. If the necessity arises group C shall be also utilized. Here we propose a Radial Basis Function model Neural network for the OFDM-BPLC system.

B. Radial Basis Function Networks

Radial Basis Functions (RBF) are embedded in a two layer neural network, where each hidden unit implements a radial activated function. The output units implement a weighted sum of hidden unit outputs. The input into an RBF network is nonlinear while the output is linear. Finding the RBF weights is called network training.

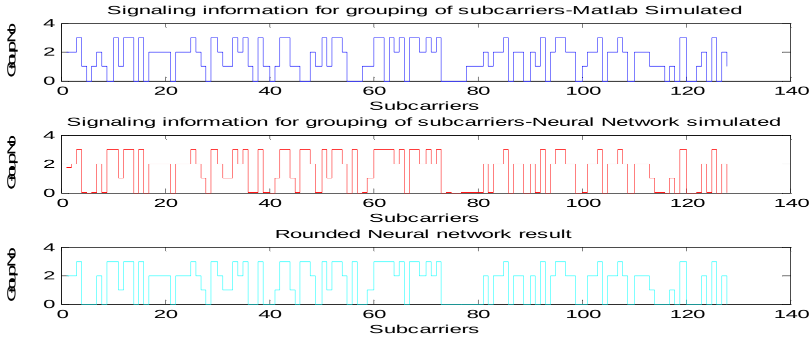

Figure 8: Signal Information for EESM Selective Modulation

C. Training Algorithm

By means of training, the Neural network model the underlying function of a certain mapping. In order to model such a mapping we have to find the network weights and topology. There are two categories of training algorithms, supervised and unsupervised. Radial Basis networks (RBF) are used mainly in supervised applications. In a supervised application, we are provided with a set of data samples called training set for which the corresponding network outputs are known. In this case the network parameters are found such that they minimize a cost function

$$\min \sum_{i=1}^{Q} (Y_k(X_i) - F_k(X_i))^T (Y_k(X_i) - F_k(X_i)) \quad (3)$$

WhereQ is the total number of vectors from the training set, ( ) *i k* X Ydenotes the RBF output vector and ( ) *i k* X F represents the output vector associated with the a data sample *i* X from the training set. In unsupervised training the output assignment is not available for the given set. Orthogonal least squares using Gram-Schmdt algorithm is proposed. An adaptive training algorithm for minimizing a given cost function is a gradient descent algorithm. Back propagation adapts iteratively the network weights considering the derivatives of the cost function with respect to those weights. The grouping of subcarriers with the EESM algorithm is trained for the underlying function of the neural network model.

IV. SIMULATION RESULTS AND DISSCUSSIONS

The performance of the purposed system with Radial Basis Network is evaluated through simulation and the simulation parameters are tabulated in table 5.

Table 5: Simulation Parameters

Channel	Power Line Channel
Input Sample time period	0.1 millisecond
Path Delay	10^{-6} to 0 second
Number of Subcarriers	52, 112, 512, 1024
Adaptation algorithm	EESM
Modulation schemes used	4 QAM, 16 QAM, 64 QAM
Coding scheme used	Convolution Coding
Simulation Environment	Matlab 2009b
Neural Networks Model	Radial Basis Network

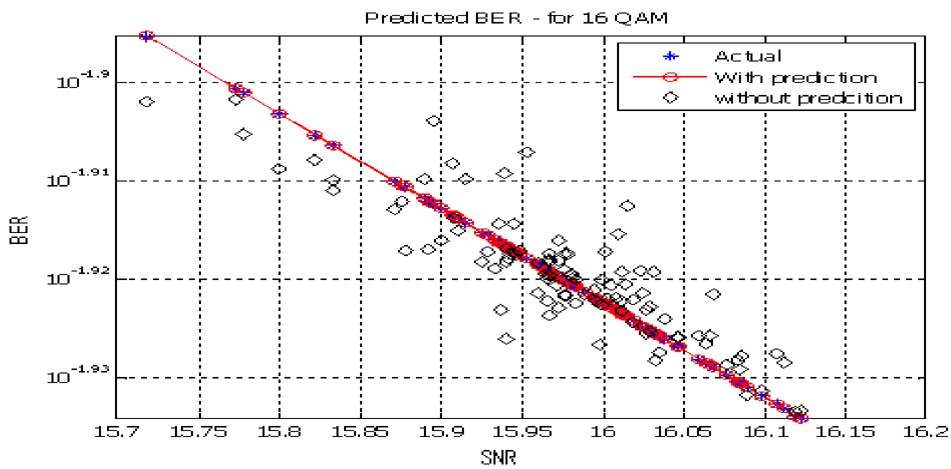

Figure 9: EESM BER Performance with and Without Prediction

Figure 9 shows the BER performance of the EESM algorithm with and without prediction. It is observed that prediction scheme aid the BER performance of the system being improved to a great extent.

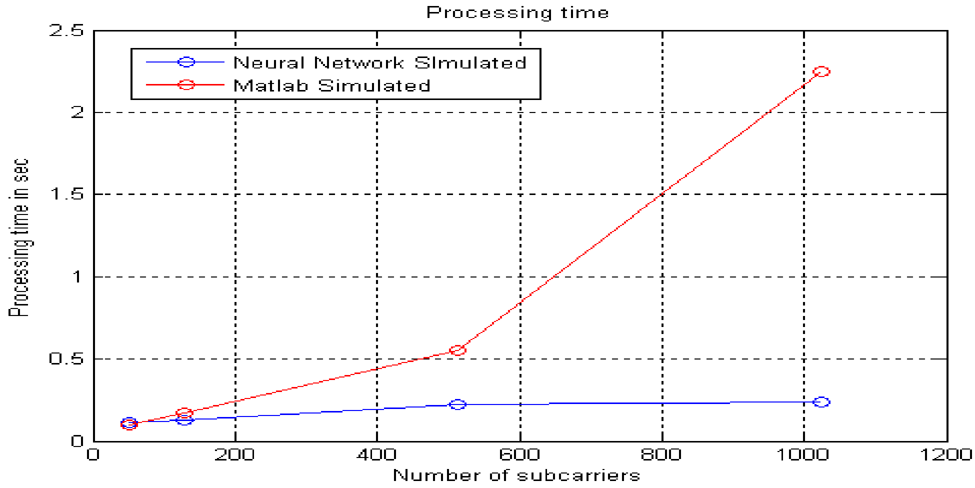

Figure 10: Total Processing Delay

Figure 10 shows the total processing delay of EESM algorithm by the Neural networks. The computation using conventional method (with feedback) using MATLAB simulation for channel prediction takes a processing time of 2.31 seconds while Neural network based EESM channel prediction takes 0.26 seconds thus proving a fast adaptation.

V. CONCLUSIONS

The BPLC system with adaptive OFDM scheme is considered and the adaptive algorithm selects a suitable MCS for the current channel realization which renders high throughput. The adaptation has been performed for 4 different MCS orders 4 QAM ½ convolution coded, 4 QAM, 16 QAM, & 64 QAM keeping a target Bit Error Rate of 10^{-2}. The throughput performance comparison has been shown for EESM equal and selective constellation with traditional systems. The proposed EESM selective modulation method for OFDM enhances the system throughput about 9% compared to the conventional EESM scheme in OFDM-BPLC system. It is observed that since the process is nonlinear, the system takes more time for computation. A Neural network based channel prediction scheme is proposed and the EESM algorithm for adaptive OFDM has been trained for BPLC. On comparing with the conventional channel estimation method, the result shows that the proposed Neural network based channel prediction scheme minimize the processing time from 2.31 seconds to 0.26 seconds and provide a fast adaptation.

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