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A hybrid envelope fluctuations reduction approach using multilayer neural network for MIMO-OFDM signals

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Abstract One of the major drawback in multi-carrier signals is large envelope fluctuations i.e., high peak-to-average power ratio (PAPR). The objective of this paper is to propose neural network based active gradient project sequence, a computationally efficient hybrid method to reduce PAPR in multiple-input multiple-output orthogonal frequency division multiplexing system without sacrificing BER performance. In this paper, a neural network based trained module of approximate gradient project scheme (AGP-NN) is combined in parallel with partial transmit sequence method. The Levenberg–Marquardt training algorithm is used to train neural network based AGP module. The simulation results show that the proposed technique not only outperforms other conventional techniques but also offers less computational complexity.

Keywords Multiple-input multiple-output · Levenberg–Marquardt algorithm · Partial transmit sequence · Approximate gradient project

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1 Introduction

The fundamental principle of OFDM system is to use serial-to-parallel transform to allocate the high data rate on orthogonal sub-channels [1]. The multiple-input multiple-output combined with orthogonal frequency division multiplexing (MIMO-OFDM) is an alternative approach to achieve high data rate and high spectrum efficiency against fading environment [2]. The numerous applications viz., IEEE 802.11a (wireless local area network), IEEE 802.16e (WiMAX), Long Term Evolution (LTE), and 4G of wireless communication need a large number of sub-carriers to transmit data symbols [3]. When the large number of data sub-carriers superpose on each other, it will causes a high peak-to-average power ratio (PAPR). The large PAPR signal requires the amplifier with large linear amplification interval; otherwise, it will bring non-orthogonality between sub-channels and out-of-band spectrum interference in MIMO-OFDM system.

From the past few decades, to reduce PAPR in MIMO-OFDM signals various methods have been proposed in literature [4–6]. Besides conventional techniques [7, 8], some hybrid methods [9–12] also attract attention of researchers due to their ability to reduce PAPR substantially, but suffer with high computational complexity. Challenge of the current scenario is to reduce the computational complexity in existing combinational scheme [9, 12].

Fortunately, supervised learning neural network algorithm are being successfully applied to reduce the complexity of OFDM system with better quality of performance and faster convergence [13–15].

One of the efficient combinational approach to reduce PAPR in MIMO-OFDM system is proposed by Pachori [12]. Though this hybrid scheme reduces the PAPR

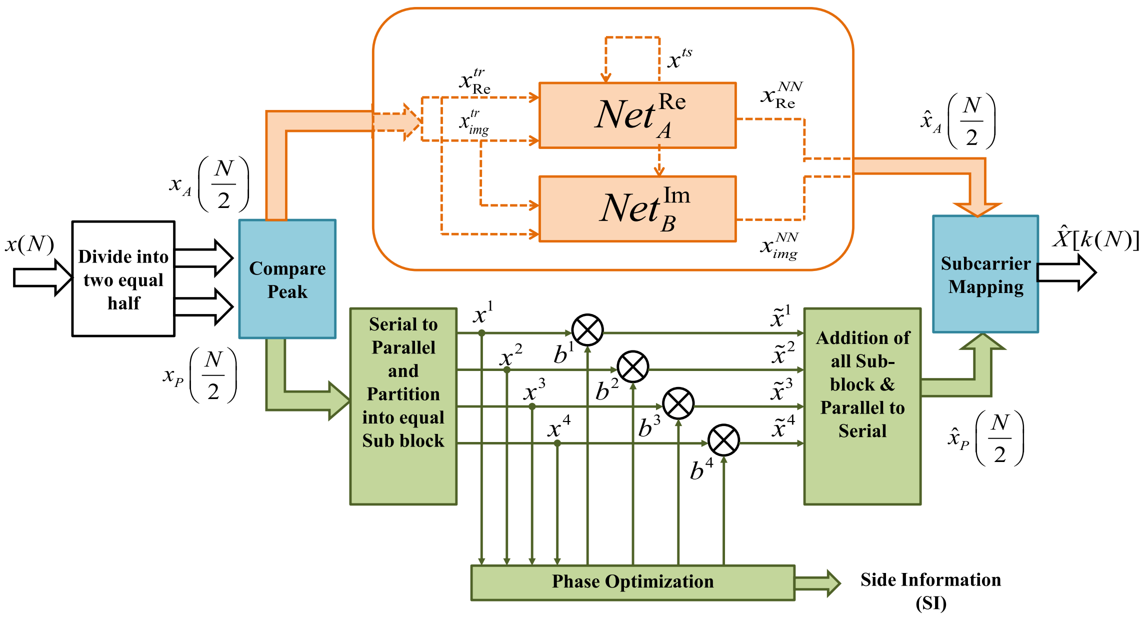

Fig. 1 Block diagram of proposed scheme for MIMO-OFDM $(N_T \times N_R)$ system

significantly without deterioration of BER performance but it requires a large computational complexity. Therefore, the proposed (NN-AGPS) method intelligently combine the neural network trained module of AGP in parallel with PTS scheme. The Levenberg–Marquardt (LM) training algorithm is used to synthesizes the AGP algorithm with much lower complexity. The NN-AGPS method efficiently reduces the PAPR of MIMO-OFDM signals without affecting the bit error rate (BER), while maintaining the same data rate, and providing low in-band ripples and out-band radiations.

The rest of this paper is organized as follows: In Sect. 2, the proposed MIMO-OFDM system model and philosophy of proposed scheme are discussed. In Sect. 3, the computational complexity of the proposed method is evaluated. Simulation results are presented in Sect. 4. Finally, conclusions are drawn in Sect. 5.

2 System model and PAPR formulation

In a multi-carrier OFDM system, the complex time domain transmitted signal x^i for the i-th symbol is given by

$$x^i = \{x^i[0], \ldots, x^i[N-1]\}^T = \frac{1}{\sqrt{N}} \Sigma_{k=0}^{N-1} X_k^i e^{\frac{j2\pi kn}{N}} \tag{1}$$

where N and X_k^i are the number of sub-carriers and complex frequency domain modulated symbol on the k-th sub-carrier at OFDM symbol i, respectively.

Let us consider, a MIMO-OFDM system with configuration $N_T \times N_R$, where N_T and N_R are the number of transmit and receive antennas, respectively. The input data stream for N_T antennas are then mapped into N number of orthogonal symbols.

$$X^{N_T} = X_k^{N_T}, k = 0, 1, \ldots, N \tag{2}$$

The PAPR of L-times oversampled time domain MIMO-OFDM signal samples $x^i(n)$ is defined as

$$PAPR = \frac{1}{E[|x^i(n)|^2]} \max_{0 \le n \le LN-1} |x^i(n)|^2 \tag{3}$$

where $E[.]$ represents the expectation of the signal.

The complementary cumulative distribution function (CCDF) is use to describe the PAPR performance of MIMO-OFDM system and it is defined as the probability of the transmitted signal at given PAPR threshold λ, and is computed as

$$CCDF = 1 - Pr\{PAPR \le \lambda\} = 1 - (1 - e^{\lambda})^N \tag{4}$$

2.1 Philosophy of proposed method

The concept of ACE schemes was developed by Krongold and Jones [21], that has been used to reduce PAPR by appropriate encoding the data symbols using non-bijective constellations. The AGP method, a variant of ACE scheme, modifies and expands the constellation points within allowable region which does not affect the demodulation slicer, and thus, it does not need any side information to be sent [15]. The AGP method substantially reduces PAPR and converges faster relative to other ACE techniques.

In the signal randomization technique, the utilization of different rotation factors can be done to minimize the PAPR of the system. The partial transmit sequence (PTS) method gives better performance among all types of signal randomization PAPR reduction techniques. It exhaustively searches the optimal sub-carrier weighting factor in a set, and brings large computational complexity with the increase of the number of sub-carriers. In the PTS method, V IDFT operations and $[log_2 V]$ bits side information are used to recover the original sequence.

An attempt is made to combine the AGP and PTS schemes for PAPR reduction in MIMO-OFDM system [12]. The major limitation of this approach is the high computational complexity. Recently, artificial neural network (ANN) are efficiently applied across a wide range of problems in MIMO-OFDM system. In [14], to reduce the envelope fluctuation, the multilayer perceptron neural network is employed to synthesis the ACE technique.

In this paper, a new parallel combinational method using neural network (NN) is proposed, which takes the advantages of both the AGP-NN and the PTS methods and avoids their shortcomings in [12]. The key idea of the proposed (NN-AGPS) scheme is to train the AGP module with the LM training algorithm and combined parallel with the PTS scheme. The NN-AGPS method provides a substantial reduction in PAPR with less computational complexity and fast convergence. The NN-AGPS also maintains the same data rate, without affecting the BER performance, and providing low in-band ripples and out-band radiations as well.

2.2 Practical implementation of NN-AGPS method

The block diagram of proposed method for MIMO-OFDM $(N_T \times N_R)$ system is shown in Fig. 1. The LM training algorithm is selected to train the AGP module with low PAPR data patterns. The trained neural network is then

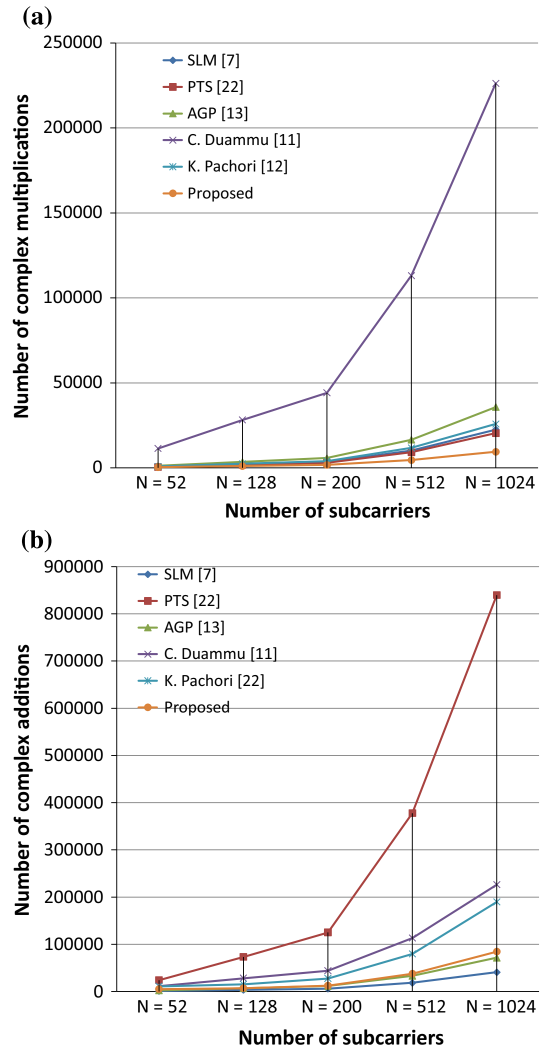

Fig. 2 Computational complexity comparison **a** Complex multiplications and **b** of proposed scheme for MIMO-OFDM (2×2) system

Table 1 Computational complexity comparison and Summary

Operations	Techniques					
	SLM [7]	PTS [22]	AGP [13]	C. Duammu [11]	K. Pachori [12]	Proposed
Wireless local area network (WLAN) IEEE 802.11a						
Complex multiplications	697	593	1261	11492	810	–
Complex additions	1186	24307	2522	11492	11152	–
Integer multiplications	–	–	–	–	–	425
Integer additions	–	–	–	–	–	5323
Worldwide interoperability for microwave access (WiMAX) IEEE 802.16e						
Complex multiplications	3458	3058	5822	44200	3990	–
Complex additions	6115	125359	11644	44200	27911	–
Integer multiplications	–	–	–	–	–	1732
Integer additions	–	–	–	–	–	12495

combined parallel with PTS schemes. The various steps involved in proposed method are given as

- Generate M-ary data symbols $X = X[k], k = 1, \ldots, N$ through quadrature phase shift keying (QPSK) constellation.
- Apply IFFT on data symbols $X[k]$ to obtain $x[n]$.
- Partition the sequence into two equal halves and compare the peak power. Now the highest peak power half sequence must be passed through NN-AGP $x_A(\frac{N}{2})$ and another half is fed to PTS $x_P(\frac{N}{2})$.
- **Neural Network - AGP Module :**
  Use $x_A(\frac{N}{2})$ signals as an input data and pass it through AGP algorithm to get $x_{agp}(\frac{N}{2})$ signals as an output data with reduced PAPR.
  - Split $x_A(\frac{N}{2})$ and $x_{agp}(\frac{N}{2})$ into two sets, viz., the training set $x_{tr}, x_{agp,tr}$ and the test set, $x_{ts}, x_{agp,ts}$.
  - Decompose into real and imaginary parts the original data $x_{tr}(x_{tr}^{Re}, x_{tr}^{Im})$, AGP output $x_{agp,tr}(x_{agp,tr}^{Re}, x_{agp,tr}^{Im})$.
  - Obtain x^{Re} and x^{Im} through training the two separate networks Net_A^{Re} and Net_B^{Im} presenting pairs $[x_{tr}^{Re}, x_{agp,tr}^{Re}]$ and $[x_{tr}^{Im}, x_{agp,tr}^{Im}]$.
  - Test with the values of $\hat{x}_A(\frac{N}{2})$ (test set) to validate the models Net_A^{Re} and Net_B^{Im}.
- **PTS Module:**
  Partition the other half input data block $x_P(\frac{N}{2})$ into V number of sub-blocks given by

$$x_P^v[n] = [x_P^1, x_P^2, \ldots, x_P^{(V)}]^T \tag{5}$$

  where x_P^v is the consecutively located sub-blocks of equal size.
  - Create the phase vector b^v, and optimize the value for minimum PAPR.

$$x_P[n] = \Sigma_{v=1}^{V} b^v x_P^v[n] \tag{6}$$

  where $b^v = e^{j\phi v}, v = 1, 2, \ldots, V$.
  - The corresponding time domain signal with the lowest PAPR vector can be expressed as

$$\hat{x}_P[n] = \Sigma_{v=1}^{V} \tilde{b}^v x_P^v[n] \tag{7}$$

  where

$$[\tilde{b}^1, \ldots, \tilde{b}^V] = arg \min_{\tilde{b}^1,\ldots,\tilde{b}^V} \left(\max_{n=0,1,\ldots,N-1} |\Sigma_{v=1}^{V} b^v x_P^v[n]| \right) \tag{8}$$

- Determine $\widehat{X}_A[k]$ and $\widehat{X}_P[k]$ by applying FFT on $\tilde{x}_A[n]$ and $\tilde{x}_P[n]$, respectively, add all sub-blocks and prepare side information (SI) for receiver.
- Finally, arrange both half sequences i.e., $\widehat{X}_A(\frac{N}{2}), \widehat{X}_P(\frac{N}{2})$ according to their location in original sequence and get the output $\widehat{X}[k(N)]$.
- Send $\widehat{\mathbf{X}}$ to the Alamouti's encoder block [20] of MIMO-OFDM transmitter to improve performance against large delay spread.

3 Complexity analysis

The proposed (NN-AGPS) scheme uses two neural network (Net_A^{Re}, Net_B^{Im}) each with two inputs, two hidden and one output neurons (2:2:1) structure to train AGP module. The activation function used in network is tansig. The complexity of AGP-NN module in terms of number of

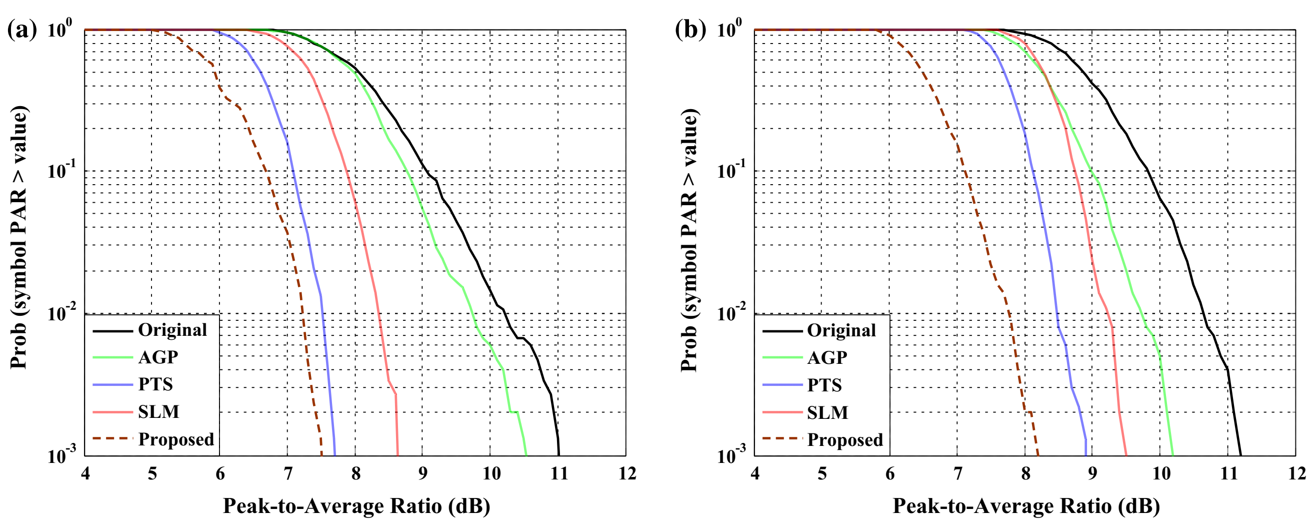

Fig. 3 Comparision of CCDF with subcarriers for MIMO-OFDM (2×1) system **a** Wireless LAN standard and **b** WiMAX standard

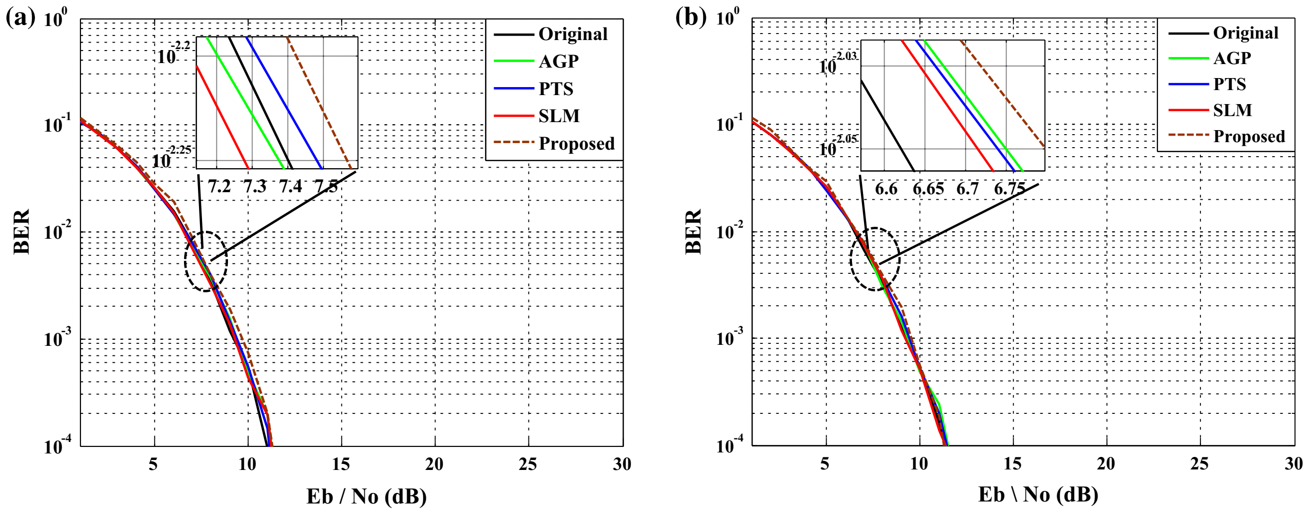

Fig. 4 BER comparision for MIMO-OFDM (2 × 1) system **a** Wireless LAN standard and **b** WiMAX standard

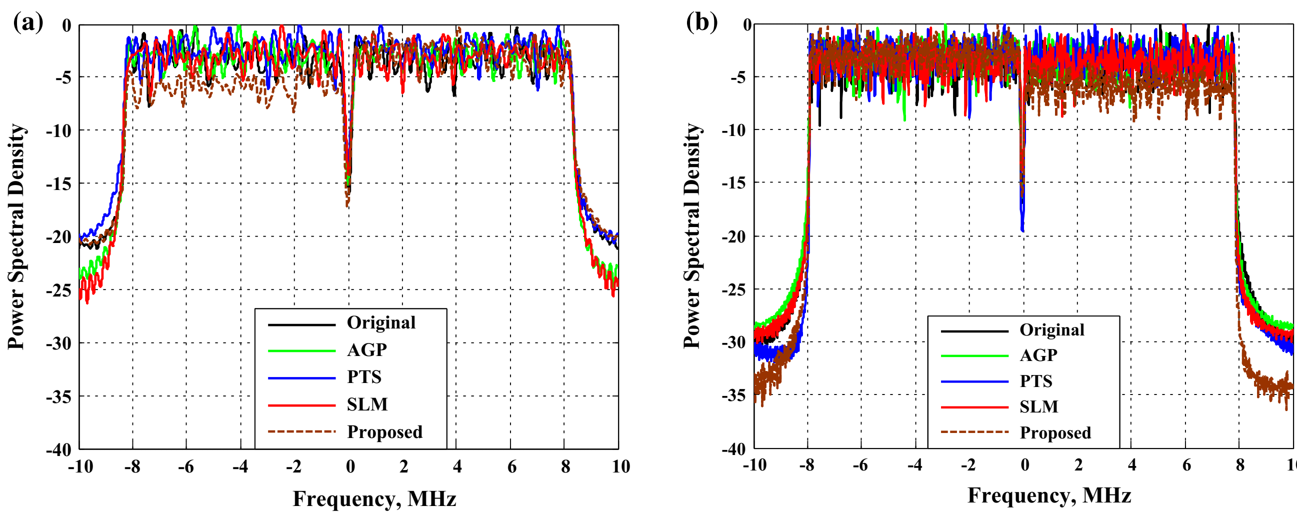

Fig. 5 Power spectrum density comparison for MIMO-OFDM (2 × 1) system **a** Wireless LAN standard and **b** WiMAX standard

integer multiplications and additions for MIMO-OFDM $(N_T \times N_R)$ system are $(14 \times N)$ and $(12 \times N)$, respectively, where N is the number of sub-carriers. The computational complexities of PTS and AGP scheme are evaluated in terms of complex multiplications and additions [9].

The computational complexity comparison between conventional and proposed (NN-AGPS) PAPR reduction techniques are summarized in Table 1. Figure 2 shows the graphical plots of multiplication and addition operations required in various PAPR reduction schemes. The integer additions are two times less complex than complex additions, whereas, integer multiplications are four times simpler than complex multiplications [15].

With this fact, it is evident that the NN-AGPS method not only requires less number of multiplication operations but also achieves a huge reduction (more that 54.2 %)in addition operations as compared to PTS scheme.

4 Results

The IEEE 802.11a (Wireless LAN) and IEEE 802.16a (WiMAX) standards are chosen for validation of the proposed scheme. Simulations have been carried out for 1000 OFDM frames with randomly generated QPSK modulated symbols in MATLAB (R2011a) environment. The IEEE 802.11a (Wireless LAN) system operates in 5 GHz band and supports data rates ranging from 6 to 54 Mbps. The IEEE 802.11a system possesses 48 data, 4 pilot and 12 null subcarriers. Similarly, the IEEE 802.16e (WiMAX) design includes 192 data, 8 pilot and 56 null subcarriers. The

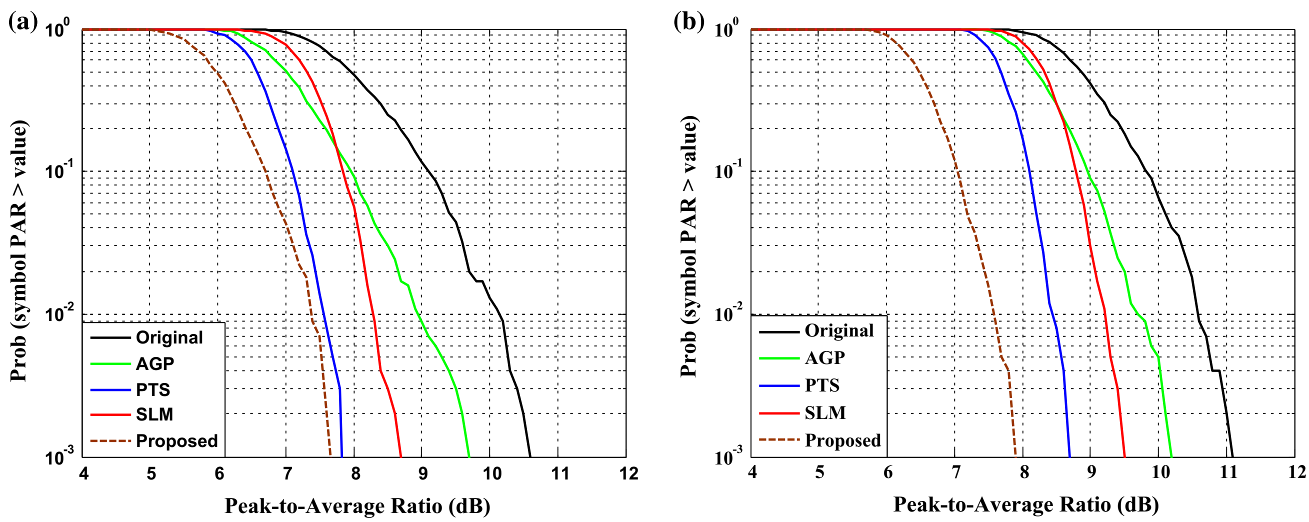

Fig. 6 Comparision of CCDF with subcarriers for MIMO-OFDM (2 × 2) system **a** Wireless LAN standard and **b** WiMAX standard

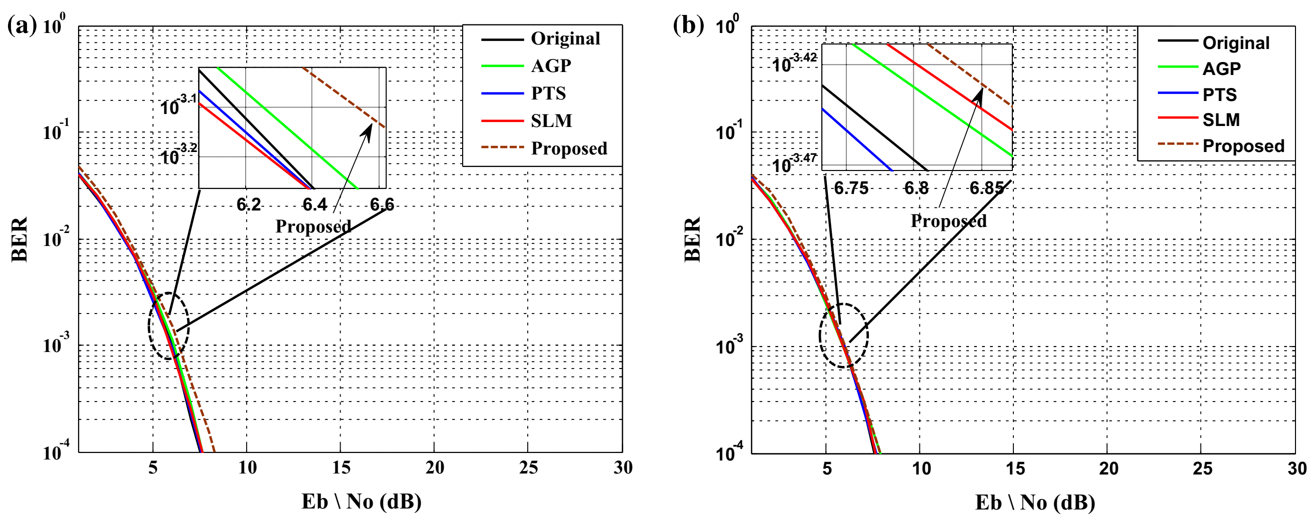

Fig. 7 BER comparision for MIMO-OFDM (2 × 2) system **a** Wireless LAN standard and **b** WiMAX standard

operating frequency of IEEE 802.16e is 2500 MHz. In this paper, the MIMO-OFDM system model with $N_T = 2$ transmit antennas and $N_R = 1, 2$ receive antennas is used for simulation. The number of iterations N_{iter}, sub-blocks V, and candidate sequence M for proposed scheme are initialized as 5, 4, 64 respectively.

Case 1 *MIMO-OFDM* (2 × 1) In Fig. 3, the PAPR performance via complementary cumulative distribution function (CCDF) plots of the proposed scheme along with conventional methods for MIMO-OFDM (2 × 1) system are shown. It can be observed that the PAPR of proposed scheme (≈7.5 dB for wireless LAN, and ≈7.95 dB for WiMAX) which is lower than other conventional techniques such as AGP (≈10.5 dB for wireless LAN, and ≈10.1 dB for WiMAX) and PTS (≈7.8 dB for wireless LAN, and ≈8.72 dB for WiMAX) at 10^{-3} dB CCDF. Figure 4, depicts the BER performance in presence of Rayleigh fading environment of different schemes in MIMO-OFDM systems. It is noticed that the BER performance of the proposed scheme is almost maintained as compared with conventional schemes. Figure 5, shows the in-band ripples and out-bands radiations via power spectral density of the MIMO-OFDM systems for Wireless LAN and WiMAX standards. It can be seen that the in-band ripples of the proposed scheme are not only less than the other techniques but out of band radiations are also smaller as compared to other schemes.

Case 2 *MIMO-OFDM* (2 × 2) As shown in Fig. 6, the PAPR of proposed method for the MIMO-OFDM (2 × 2) system, (≈7.75 dB for wireless LAN, and ≈7.95 dB for WiMAX) is lower than other conventional techniques such as AGP (≈9.8 dB for wireless LAN, and ≈10.2 dB for

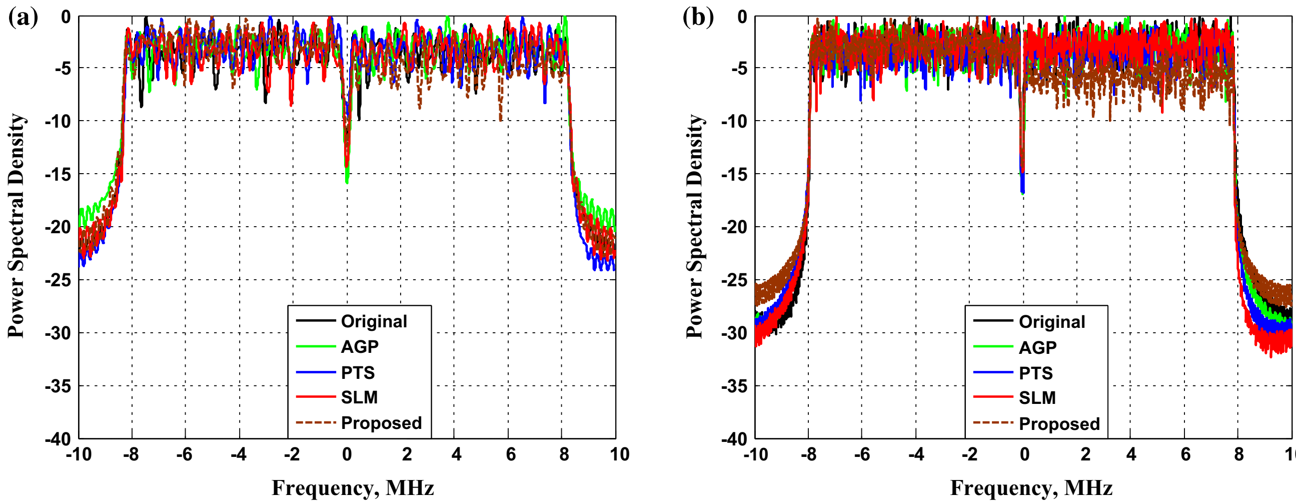

Fig. 8 Power spectrum density comparison for MIMO-OFDM (2 × 2) system **a** Wireless LAN standard and **b** WiMAX standard

WiMAX) and PTS (≈7.9 dB for wireless LAN, and ≈8.8 dB for WiMAX) at 10^{-3} dB CCDF. The BER performance for wireless LAN and WiMAX standards are shown in Fig. 7 and the graphs show that the proposed algorithm maintains its BER as compared to other schemes. Figure 8 shows the power spectrum plots of MIMO-OFDM (2 × 2) system for various schemes and it is also evident that proposed scheme preserves the spectrum for both in band and out of band regions.

The simulation results shown in Fig. 3 and 6 reveals that the PAPR in MIMO-OFDM system through proposed scheme reduces more while using large number of subcarriers. This is an attractive feature of the proposed scheme.

5 Conclusion

In this paper, a combinational of conventional and neural network approach is proposed (NN-AGPS) to reduce the PAPR and computational complexity in MIMO-OFDM system. The proposed (NN-AGPS) method is a combination of AGP-NN module and PTS scheme. The performance of the proposed method is better than other conventional schemes in terms of PAPR reduction, BER performance and out-of-band radiations. The computational complexity of the proposed method is also very less than the other conventional techniques. As the number of sub-carriers increases, the proposed (NN-AGPS) offers better PAPR reduction with low complexity. Therefore, this scheme becomes more efficient for the applications such as digital audio broadcasting (DAB), digital video broadcasting (DVB) and HIPERLAN/2.

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