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OFDM with Low PAPR: A Novel Role of Partial Transmit Sequence

Padmapriya Praveenkumar, Rengarajan Amirtharajan, K. Thenmozhi and John Bosco Balaguru Rayappan
Department of Electronics and Communication Engineering, School of Electrical and Electronics Engineering, SASTRA University, Thanjavur, 613 401, India

Corresponding Author: Padmapriya Praveenkumar, Department of Electronics and Communication Engineering, School of Electrical and Electronics Engineering, SASTRA University, Thanjavur, 613 401, India

ABSTRACT
To tackle "Broadband" applications, high spectral efficiency is the foremost requirement in any wireless domain. Orthogonal Frequency Division Multiplexing (OFDM) promises to be the solution for transmitting and maintaining large amount of data with a high data rate. High Peak-to-Average Power Ratio (PAPR) is the challenging issue with OFDM system. Partial Transmit Sequence (PTS) algorithm is utilized in OFDM system which provides low PAPR and mitigates the out of band radiation in OFDM system. Hence, in this study, a Simulink model of OFDM was built using PTS algorithm to reduce the PAPR. Comparison analysis was carried out for different subcarrier values adopting various modulation schemes and from the graphs plotted, it was observed that there was a reduction in the PAPR value with the increase in the number of subcarriers.

Key words: Orthogonal frequency division multiplexing, partial transmit sequence, algorithm, peak-to-average power ratio, simulink model

INTRODUCTION
OFDM exhibiting robustness towards the fading effects caused by the multipath environment is a commonly adapted modulation scheme in the wireless market (Amirtharajan *et al*., 2010; Praveenkumar *et al*., 2012c). The initiative work of OFDM was successfully carried out by Chang (1966) and was continued by Chang (1970), Saltzberg (1967) and Doelz *et al*. (1957). Weinstein and Ebert in 1971 proposed OFDM as a multicarrier scheme (Cimini Jr., 1985). With increased data rate and large symbol duration, OFDM eradicates the wireless problems like Inter Symbol Interference (ISI), Multipath delay and Inter Carrier Interference (ICI) (Weinstein and Ebert, 1971; Li and Stuber, 2006; Kumar *et al*., 2008). Besides various advantages, the major shortcoming with OFDM is its high PAPR (Arioua *et al*., 2012; Pei-Pei *et al*., 2010; Li and Jr. Cimini, 1998) which limits the system performance.

In 1997, Mullar and Huber explained Partial Transmit Sequence (PTS) algorithm to combat PAPR effectively (Latif and Gohar, 2008; Al-Kebsi, 2008). In PTS, lowest peak power signal among different sequences was transmitted and makes use of non-overlapping sub-block. The phase values are chosen and multiplied with each sub-block. Then the output with the least PAPR value is transmitted (Breiling *et al*., 2001; Jayalath and Tellambura, 2000; Han and Lee, 2004; Yang and Chang, 2003). Another way of employing PTS method is to rule out the phase vector combination which results in a high level of complexity (Nguyen and Lampe, 2008).

Gao and Xie (2009) had determined that the low complexity PAPR reduction schemes can be employed in mobile communication systems. In a study, Petermann *et al.* (2009) and Muller *et al.* (1997), the output of the IFFT block which are the discrete time signals, are transformed to continuous time baseband OFDM (Elahmar *et al.*, 2007; Liu *et al.*, 2006; Thenmozhi *et al.*, 2011, 2012; Kumar *et al.*, 2011) signals using DAC, where the peak power can be increased but a constant average power is maintained.

Jiang and Wu (2008) suggested that the BER performance can be improved using cyclic prefix for band-limited OFDM systems (Praveenkumar *et al.*, 2012a-c). The complexity level in reducing PAPR is based on the sub-block partitioning. There exists a trade-off between the performance measure and the complexity in PTS scheme (Han and Lee, 2005). A new PTS scheme was generated for reducing the computational complexity of IFFTs (Wang and Tellambura, 2006; Sharif *et al.*, 2003).

Reviewing the available literature, it is observed that none of the paper has tried to implement the aforementioned problem in Simulink. Hence, in this study a maiden effort has been attempted to implement OFDM in Simulink using PTS algorithm have been attempted to reduce PAPR and the results are compared for various modulation schemes.

PTS ALGORITHM

The data input block is partitioned into sub-blocks, representing certain portion of the actual information. Then the sub-blocks are passed on to IFFT and multiplied by a corresponding phase value and then added up to get the output signal whose PAPR will be comparatively less.

The sub-blocks are represented as S_b. The phase values can be represented as hP. The data input is given by:

$$I = \sum_{p=1}^{P} s_b \tag{1}$$

Binary Phase Shift Keying (BPSK) or Quadrature Phase Shift Keying (QPSK) or Quadrature Amplitude Modulation (QAM) is used to modulate the input and the modulated signal as input for the proposed block diagram of PTS as given in Fig. 1.

The modulated input is divided into different sub blocks, wherein each subset carries part of the original information. The phase values can be hP1.........hPn and can be chosen from (±i, ±l). The subsets are subjected to IFFT and the outputs are multiplied by the phase value.

Then the desired output can be represented by:

$$o = \sum s_{bP}\ hp_n \tag{2}$$

The Complementary Cumulative Density Function (CCDF) of PAPR with various subcarriers:

$$\text{PAPR} = \frac{\text{Output peak power}}{\text{Average input power}} \tag{3}$$

Table 1: Comparative analysis before and after employing PTS in OFDM

Modulation scheme	PAPR without PTS	PAPR with PTS
Binary phase shift keying (BPSK)	6.125	5.185
Quadrature phase shift keying (QPSK)	8.193	6.640
Quadrature amplitude modulation (QAM)	6.930	6.422

PAPR: Peak-to-average power raho

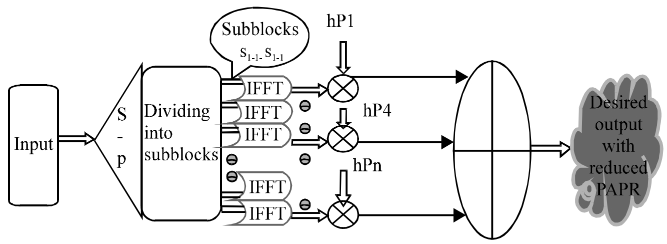

Fig. 1: Block diagram of the proposed method

- Partition the OFDM signal into set of sub blocks
- To reduce PAPR, the sub-carriers in each sub-block are rotated by some phase factor. PTS = OFDM signal×set of phase sequences
- Table 1 provides the reduction in Peak Average Power (PAP) value in dB for various modulation schemes. The PAPR values are measured using displays connected in the Simulink model of Fig. 1, before and after applying PTS algorithm

SIMULINK BLOCK DESCRIPTION

The input data block is divided into sub-blocks of 2, 4 or 8 depending on the subcarriers used. Then the sequence is modulated using BPSK modulator whose output will be in the frequency domain as in Fig. 2. IFFT block is used for frequency to time domain conversion.

The subsystem at the Modulator and demodulator for two subcarriers are shown in Fig. 3 and 4, respectively. It divides the input data sequence into 2 sub blocks and the IFFT of each block is calculated and then the obtained sequence is multiplied with efficient phase factors. The phase factors used are [1 -1]. Then the 2 sequences are added together before transmitting the data through AWGN channel. Similarly for four and eight subcarriers the input data will be divided into four and eight sub-blocks, respectively and the phase vectors used are [1 -j j 1] and [1 -j 1 -1 -1 1 -j 1].

To calculate PAPR:

Mean value = Mean (abs(c).^2)

Peak value = Max (abs(c).^2)

PAPR = 10×log 10 (peak value/mean value)

At the receiver end, for two subcarriers, the two sequences are multiplied by the phase factors of [1 -1] and then the sequences are concatenated using matrix concatenation block.

Similarly the same was carried out for four subcarriers as in Fig. 5 and 6 and for eight subcarriers with various phase values. Then they are passed through OFDM channel.

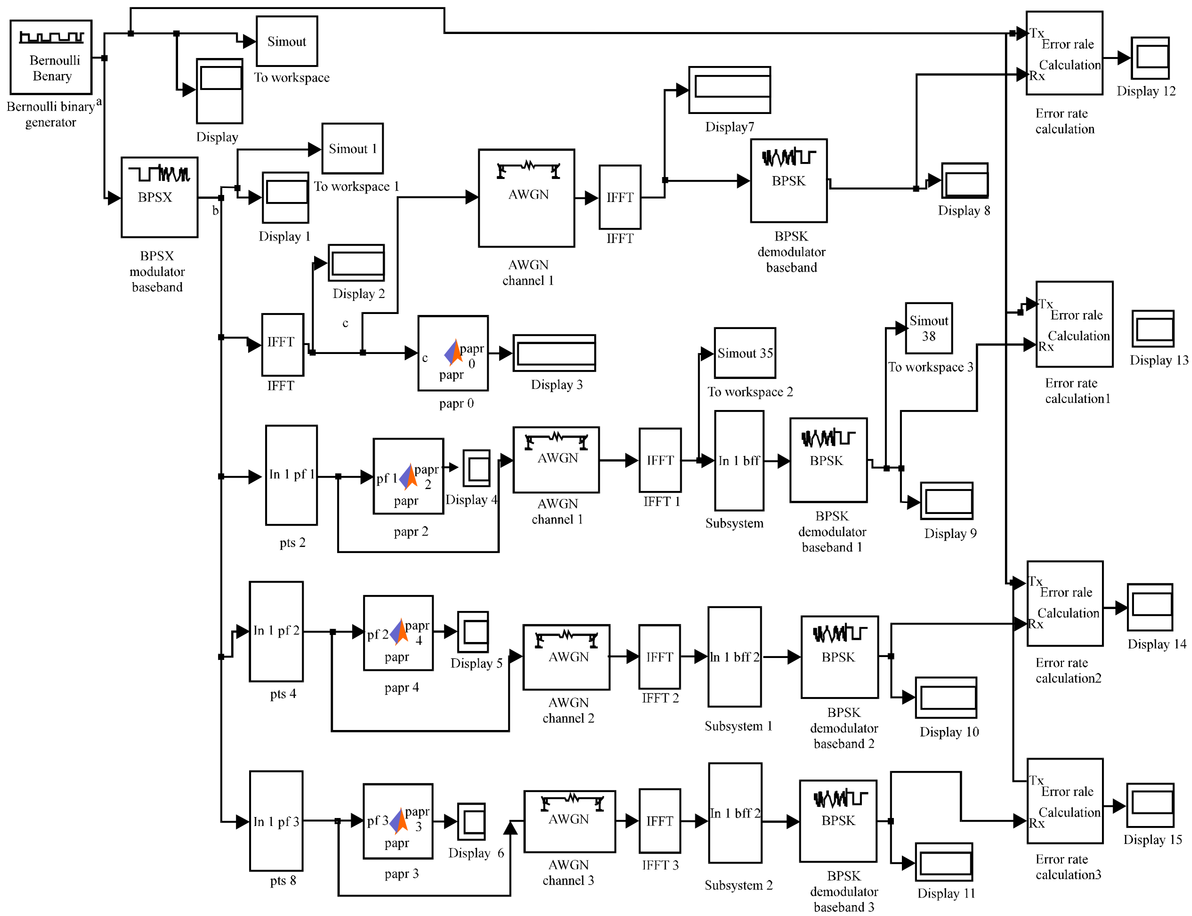

Fig. 2: OFDM simulink model with PTS algorithm

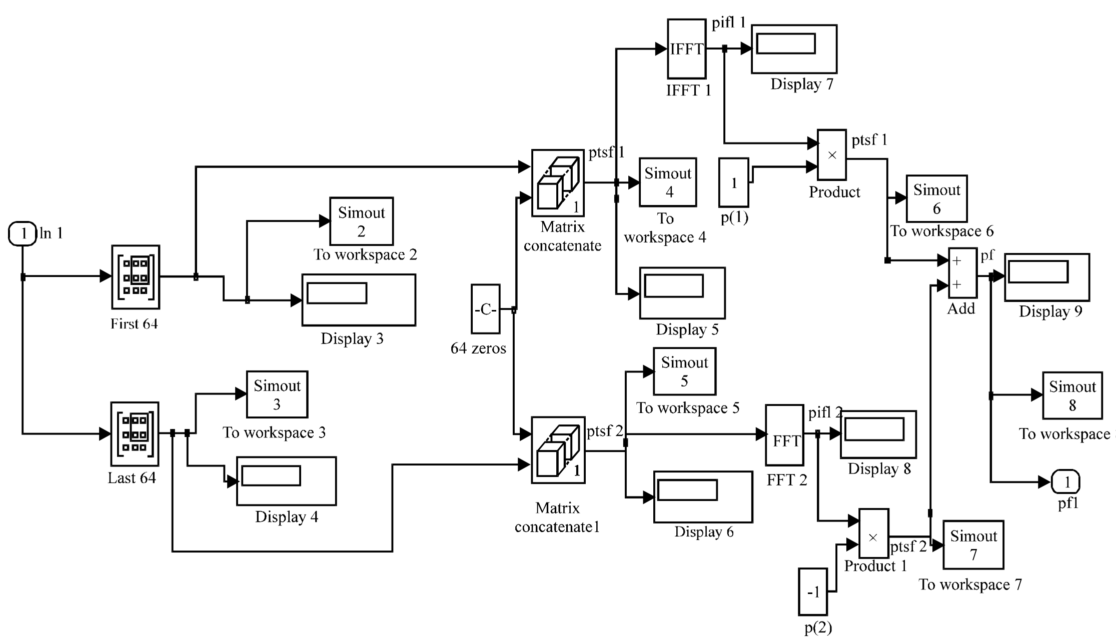

Fig. 3: Subsystem at the transmitter with two subcarriers

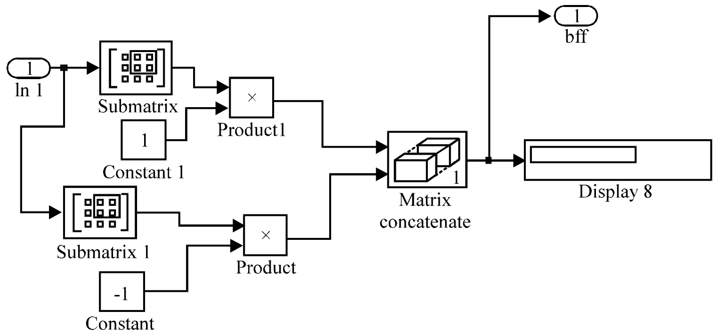

Fig. 4: Subsystem at the receiver with two subcarriers

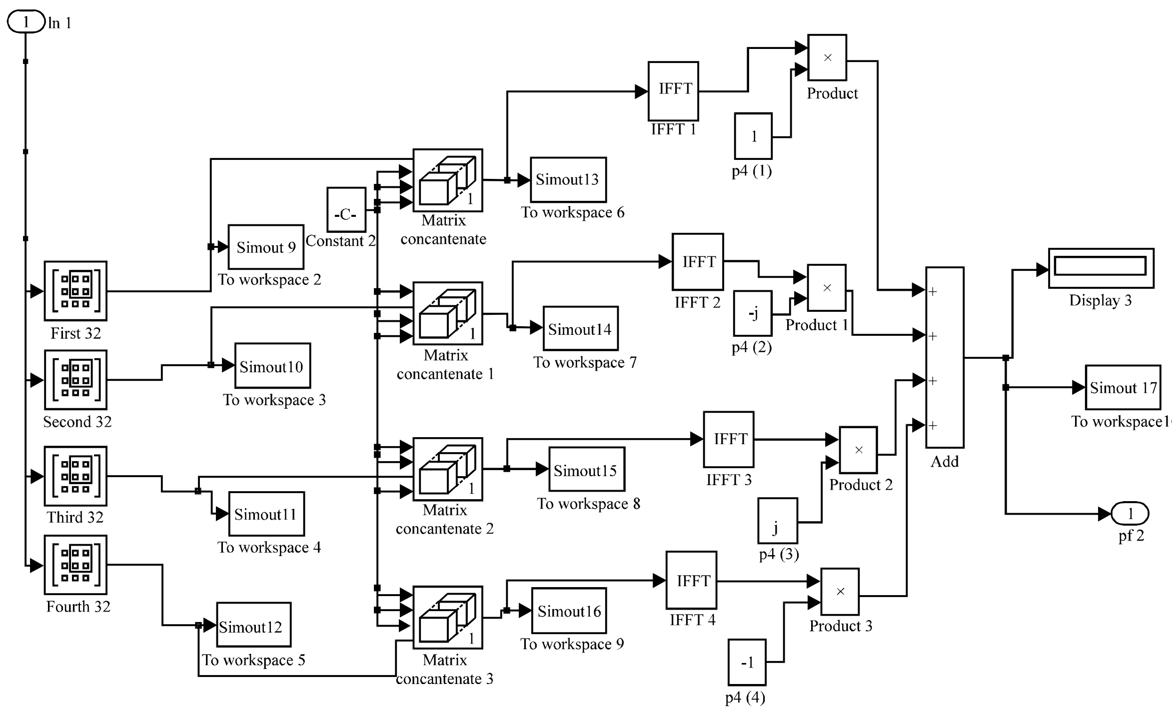

Fig. 5: Subsystem at the transmitter with four subcarriers

RESULTS AND DISCUSSION

The pseudo random input is given to the implemented simulink model and demodulated outputs are plotted in Fig. 7. From the figure it is clear that the output data was decoded correctly using QPSK modulation for the subcarrier values of 2, 4 and 6, respectively.

Figure 8 shows the performance comparison of subcarrier values of 2, 4 and 8 using BPSK modulation in terms of Complementary Cumulative Distribution Function (CCDF) (Han and Lee, 2004; Jiang and Wu, 2008; Latif and Gohar, 2008; Gao and Xie, 2009). There is about 7 dB reduction in PAPR of OFDM signal when the subcarrier value is from 2 to 4 and 10 dB reduction when it is from 4-8 at CCDF of 10^{-1}.

Performance comparison of subcarrier values of 2, 4 and 8 using QPSK modulation in terms of Complementary Cumulative Distribution Function (CCDF) is shown in Fig. 9. There is about 10 dB reduction in PAPR of OFDM signal when the subcarrier value is from 2-4 and there exists 14 dB reduction in PAPR when it is from 4-8 at CCDF of 10^{-2}.

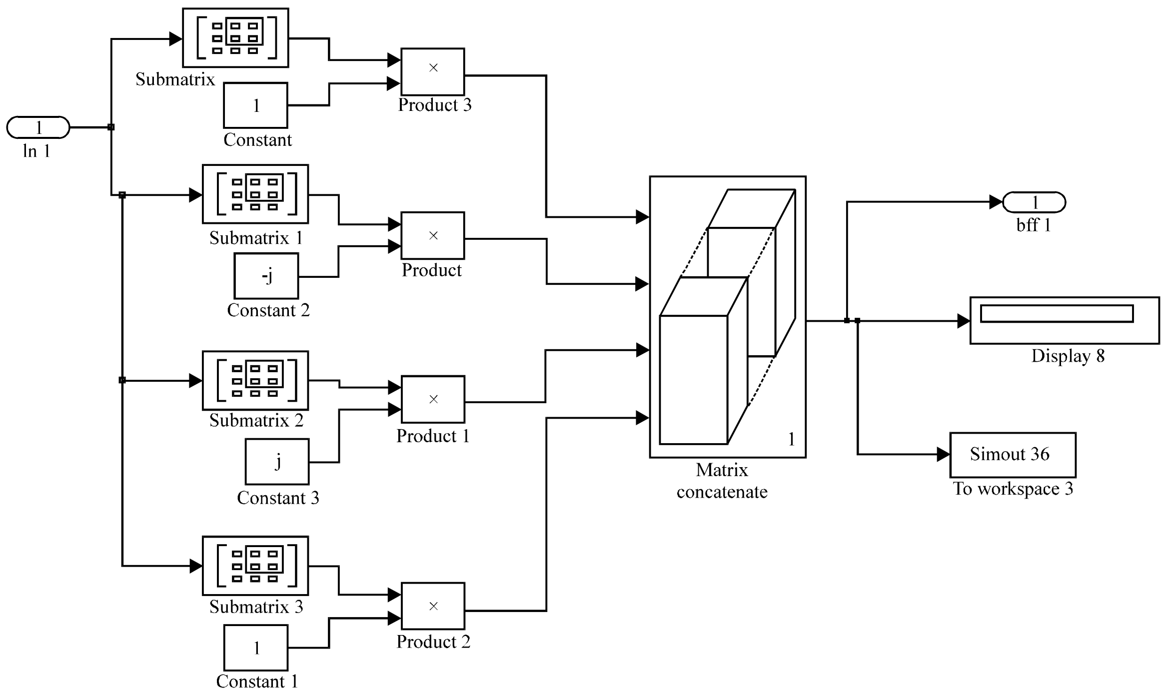

Fig. 6: Subsystem at the receiver with four subcarriers

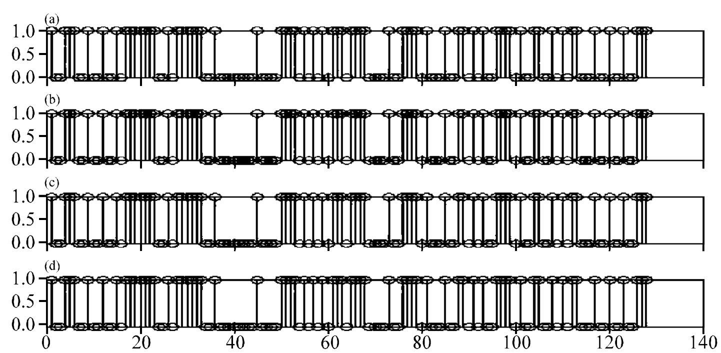

Fig. 7: Comparison between input and the corresponding demodulated Output for various values of subcarriers (a) Input, (b) PTS i* = 2, (c) PTS i* = 4 and (d) PTS i* = 8 using QPSK modulation

From the Fig. 8-10, it is observed that as the number of subcarriers increases there will more reduction in PAPR. This is found to be intact with reported results (Al-Kebsi, 2008; Han and Lee, 2005; Wang and Tellambura, 2006; Nguyen and Lampe, 2008).

Comparison plot of SNR versus BER between BPSK, QPSK and QAM by adapting 2 subcarriers is shown in Fig. 11. From the plot, it is observed that, BER reaches to zero at Eb/No = 15 dB at BER of 10^{-3}, 10^{-6} and 10^{-9} for QAM, QPSK and BPSK, respectively.

Similarly comparison plot of SNR versus BER between BPSK, QPSK and QAM by adapting 4 subcarriers is shown in Fig. 12. From the plot, its observed that BER reaches to zero at Eb/No = 15 dB at BER of 10^{-4}, 10^{-7} and 10^{-10} for QAM, QPSK and BPSK, respectively.

Figure 13 gives the comparison plot of SNR versus BER between BPSK, QPSK and QAM by adopting 8 subcarriers. From the plot, BER reaches to zero at Eb/No = 15 dB at BER of 10^{-3}, 10^{-6}

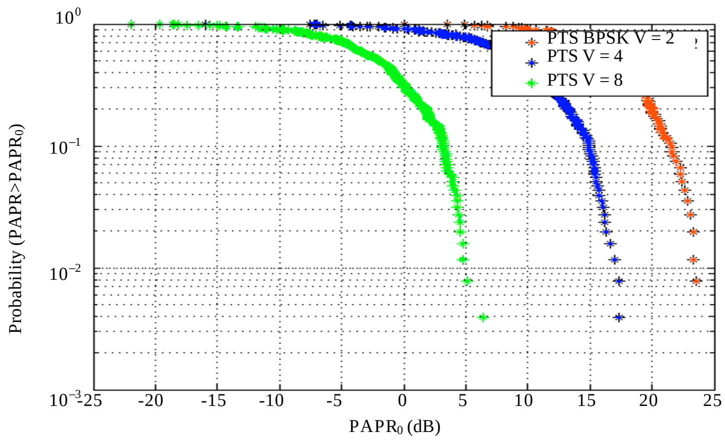

Fig. 8: CCDF plot using PTS in OFDM for various values of Subcarriers using BPSK

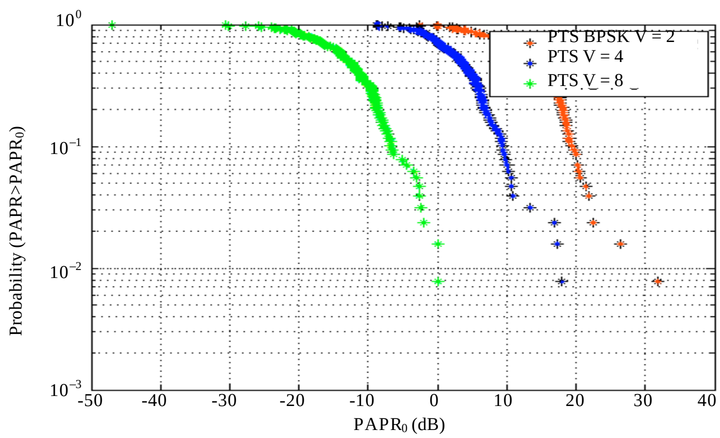

Fig. 9: CCDF plot using PTS in OFDM for various values of subcarriers using QPSK

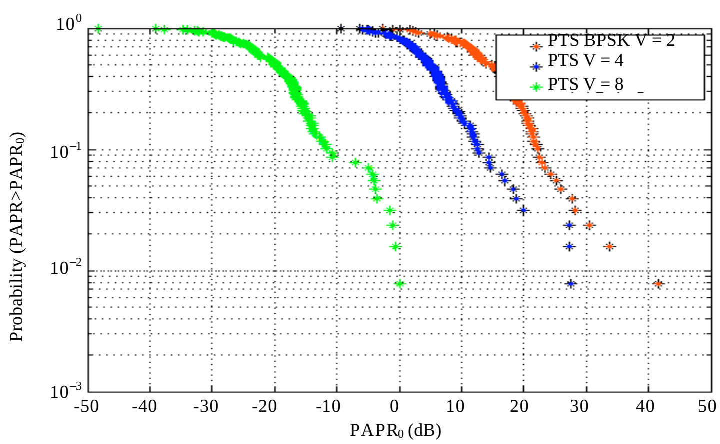

Fig. 10: CCDF plot using PTS in OFDM for various values of subcarriers using QAM

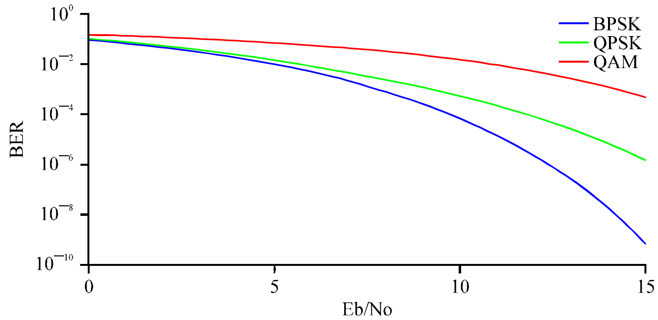

Fig. 11: Comparison between BPSK, QPSK and QAM in OFDM with PTS using 2 subcarriers

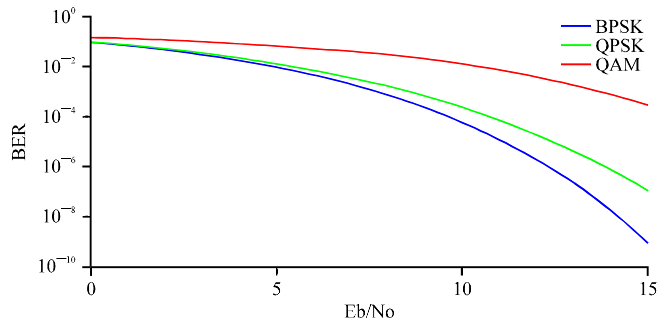

Fig. 12: Comparison between BPSK, QPSK and QAM in OFDM with PTS using 4 subcarriers

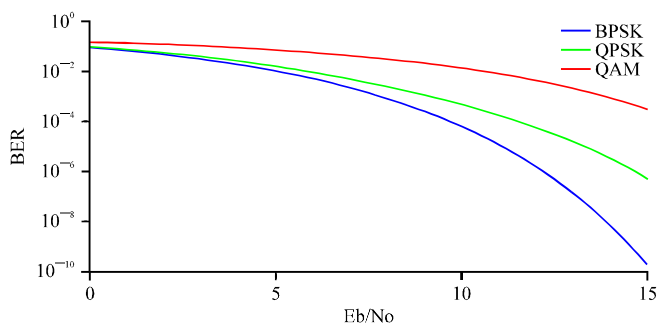

Fig. 13: Comparison between BPSK, QPSK and QAM in OFDM with PTS using 8 subcarriers

and 10^{-10} for QAM, QPSK and BPSK, respectively. From the Fig. 11-13, BPSK outperforms than QPSK and QAM these results are comparable with (Praveenkumar, 2012a). As the number of data becomes larger, compensation is done in the BER (Muller and Huber, 1997; Jayalath and Tellambura, 2000).

CONCLUSION

OFDM has been an attractive Multicarrier modulation scheme for the past decades which offers better spectral efficiency and resilience to multipath distortions. The unresolved problem with OFDM is its high PAPR. The signal subjected to IFFT will become complex in time domain. This time domain signal is Gaussian distributed and so the resultant signal has high peak power. Also the orthogonal sub-carriers combine constructively due to the independence of their phase values leading to an increase in the peak power which results in out-of-band radiation and in-band interference. It affects the performance of the system's ability.

This study analyses Partial Transmit Sequence (PTS) method of PAPR reduction in OFDM system using Simulink model. It provides a comparative study of PTS reduction technique with various values of subcarriers and various modulation schemes like BPSK, QPSK and QAM in terms of Complementary Cumulative Distribution Function (CCDF) and Bit Error Rate (BER). It is observed that Partial Transmit Sequence (PTS) method gives improved PAPR reduction when compared with other PAPR techniques like SLM and Clipping. When the number of subcarriers are increased there will a large reduction in PAPR which in turn increases the complexity of the system. From the results obtained, QPSK provides better PAPR reduction compared to QAM and BPSK. As the phase vector values are increased, better reduction in PAPR is achieved this is evident from the graphs obtained.

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