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SELECTIVECODEWORD SHIFT (SCS) TECHNIQUE FOR PAPR REDUCTION OF OFDM SYSTEMS

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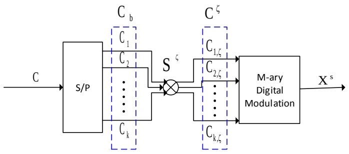
Graphical abstract



Abstract

Peak to Average Power Ratio (PAPR) has been known to be a common problem in Orthogonal Frequency Division Multiplexing (OFDM). The peak value of power signals has contributed to other problems, thus the implementation of OFDM system in many wireless applications has been growing slowly. There are many techniques being discussed to reduce the PAPR in OFDM systems where one of them is reduction through scrambling. In this paper, a technique that is based on scrambling method in order to reduce high PAPR in OFDM system is introduced. This proposed technique is called the Selective Codeword Shift (SCS). The key idea of SCS is to produce a scramble data sequence where the candidate with minimum PAPR will then be selected for transmission. This has shown an improvement in reducing PAPR as compared to original OFDM signals and the conventional Selective Mapping (SLM) technique with 29.5% improvement. This technique also has the advantage of lower computational complexity as compared to conventional SLM where no multiplication of the phase factor involved in the process and no explicit side information was needed to retrieve the transmitted data at the receiver.

Keywords: Peak-average power ratio reduction, scrambling, selective mapping, orthogonal frequency division multiplexing (OFDM) System

1.0 INTRODUCTION

The demand for wireless communication systems has led to the development of efficient, reliable and high speed wireless communication in order to provide people with more sophisticated and ubiquity services. Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier modulation technique which in practical is easier to implement in a digital communications network. This technique gives a significant increase in data rates, robustness in frequency selective fading, high spectral efficiency as well as low computational complexity [1]. Because of these advantages, OFDM has been widely used in the most well-known high data communication standards such as IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMAX) and Digital Video Broadcasting (DVB). However, OFDM systems suffer from a high PAPR problem caused by the nature of the modulation process which involves sinusoid mixing to form signals to be transmitted [2].

There are many techniques being discussed to overcome this problem such as clipping and filtering, coding, Selective Mapping (SLM) and Partial Transmit Sequence (PTS).However, there are some trade off such as computational complexity, bit error rate (BER), data rate, bandwidth and others which have since emerged[3][4][5]. SLM schemes are widely used for the PAPR reduction approach without BER degradation. To obtain a good outcome, they have to deal with high computational complexity which require many inverse fast Fourier transforms (IFFT)[6][7]. As reported by [8], the SLM computational complexity linearly increased as the number of phase sequences increased which corresponded to the number of IFFT block.There are many modified SLM techniques that have been reported but they contained several weaknesses in dealing with both the computational complexity and the PAPR at the same time such as BER degradation [9][10][11]and PAPR reduction performance degradation [7][12].

In this paper, a codeword scrambling called selective codeword shift (SCS) technique is proposed. The proposed technique shows a significant reduction in PAPR while maintaining the BER performance in additive white Gaussian noise (AWGN). It has alower computational complexity as compared to a conventional SLM. This is because this technique eliminates the multiplication of phase factor to the OFDM symbols. In addition to that, the original bits are retrieved by the backward process of the transmitter hence the explicit side information is not required.

2.0 PAPR in OFDM SYSTEMS

The frequency domain symbol of OFDM signal is indicated by $X = [X(0), X(1), \ldots X(N-1))]^T$, where N is the number of subcarriers. The complex time domain of transmitted OFDM signal is given by

$$s(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \cdot e^{j2\pi f_k t}, \quad 0 < t < NT \qquad (1)$$

where $e^{j2\pi f_k t}$ is orthogonal series of sinusoids that is performed by the Inverse Fourier Transform (IFFT). When N signals are added with the same phase in the N-point IFFT stage to produce OFDM symbol, the peak value of the same signals can be very high as compared to the average of the whole system. Basically, PAPR is defined as the ratio between the peak power and its average power,

$$PAPR = 10\log\left\{\frac{P_{peak}}{P_{avg}}\right\} \text{dB} \qquad (2)$$

Mathematically, PAPR is expressed as

$$PAPR = 10\log\left\{\frac{\max|s(t)|^2}{E|s(t)|^2}\right\} dB \qquad (3)$$

where $\max|s(t)|^2$ is the maximum signal power and $E|s(t)|^2$ is the average signal power.

3.0 PROPOSED TECHNIQUE

Base on Eq. 1, it is known that the OFDM signals are the forms of data symbol X_k multiplied with orthogonal sinusoids IFFT $e^{j2\pi f_k t}$. These two components, X_k and $e^{j2\pi f_k t}$are the important parts to determine the PAPR. Data symbol X_k is a sequence of sinusoidal waveform of duration T.

In the conventional SLM technique, alternative OFDM symbol sequences are implemented by multiplication of symbol sequences, $X_k, 1 \le k \le K$ with phase sequences, $P^u = [P^0, P^1, \ldots., P^{U-1}], 0 \le u \le U-1$. Thus, the alternative OFDM symbol sequences are given as

$$X^u = \prod_{k=1}^{K} X_k \otimes P^u, \qquad 0 \le u \le U-1 \qquad (4)$$

Where $\otimes$ denotes the component-wise multiplication of two sequences. The phase sequence, P^u is generated by using complex number magnitude, $P^u = e^{j\varphi_u}$where $\varphi_u \in [0,2\pi]$. Therefore, the OFDM signal in the time domain is written as

$$x^u(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} x^u \cdot e^{j2\pi f_k t} \qquad (5)$$

The transmitted OFDM signals are obtained by

$$s^u(t) = \underset{0 \le u \le U-1}{\operatorname{argmin}} PAPR(x^u(t)) \qquad (6)$$

Obviously, as U increases, the selection of OFDM signal became larger that causedan increase in the number of IFFT block and also computational complexity[8].

In this study, a codeword scrambling PAPR reduction technique is proposed. This technique generates a scramble data sequences by manipulating codeword,C, using the circulant shift. This technique is called the SelectiveCodeword Shift (SCS)(Figure 1).

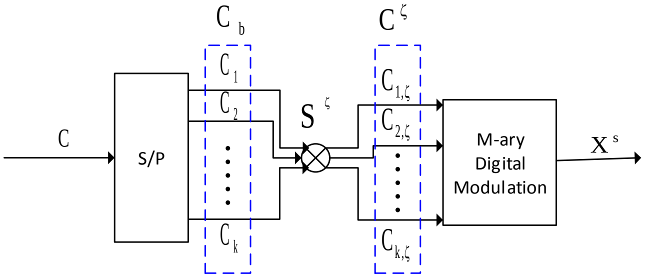


Figure 1 The proposed Circulant shift of codeword sub-blocks for one shift factor

3.1 Proposed Selective Codeword Shift (SCS)

Referring to the block diagram of the proposed technique inFigure 2, binary sequence codeword, C is indicated as C=[c$_1$,c$_2$,....,c$_d$]. The codeword is coded using Quasi-Cyclic Low Density Parity Check Codes (QC-LDPC) where d is the number of coded data bits. For simplicity, code rate 0.5 is used for this work. Coded bits are then divided into sub-block. $C_b = [C_1, C_2, \ldots. C_K]$, where $K = \frac{d}{m}$ is the number of sub-block and $m = \log_2$(M-ary QAM), is the number of bits per symbol. Codeword C in sub-block is represented as

$$C_b = \prod_{k=1}^{K} C_k, \qquad 1 \le k \le K \qquad (7)$$

Table 1 Illustration of Circulant shift of codeword shift for one sub-block.

Sub-block Codeword bits, $C_{k,\zeta}$	4QAM	16QAM	64QAM	128QAM
	$m = 2$ bits	$m = 4$ bits	$m = 6$ bits	$m = 7$ bits
Codeword, $C_{1,0}$,	$[c_1 c_2]$	$[c_1 c_2 c_3 c_4]$	$[c_1 c_2 c_3 c_4 c_5 c_6]$	$[c_1 c_2 c_3 c_4 c_5 c_6 c_7]$
Codeword Shift 1, $C_{1,1}$	$[c_2 c_1]$	$[c_4 c_1 c_2 c_3]$	$[c_6 c_1 c_2 c_3 c_4 c_5]$	$[c_7\ c_1 c_2 c_3 c_4 c_5 c_6]$
Codeword Shift 2, $C_{1,2}$	NA	$[c_3 c_4 c_1 c_2]$	$[c_5 c_6 c_1 c_2 c_3 c_4]$	$[c_6\ c_7 c_1 c_2 c_3 c_4 c_5]$
Codeword Shift 3,$C_{1,3}$	NA	$[c_2 c_3 c_4 c_1]$	$[c_4 c_5 c_6 c_1 c_2 c_3]$	$[c_5 c_6 c_7 c_1 c_2 c_3 c_4]$
Codeword Shift 4, $C_{1,4}$	NA	NA	$[c_3 c_4 c_5 c_6 c_1 c_2]$	$[c_4 c_5 c_6 c_7\ c_1 c_2 c_3]$
Codeword Shift 5,$C_{1,5}$	NA	NA	$[c_2 c_3 c_4 c_5 c_6 c_1]$	$[c_3 c_4 c_5 c_6 c_7 c_1 c_2]$
Codeword Shift 6, $C_{1,6}$	NA	NA	NA	$[c_2 c_3 c_4 c_5 c_6 c_7 c_1]$

*NA= Not Available

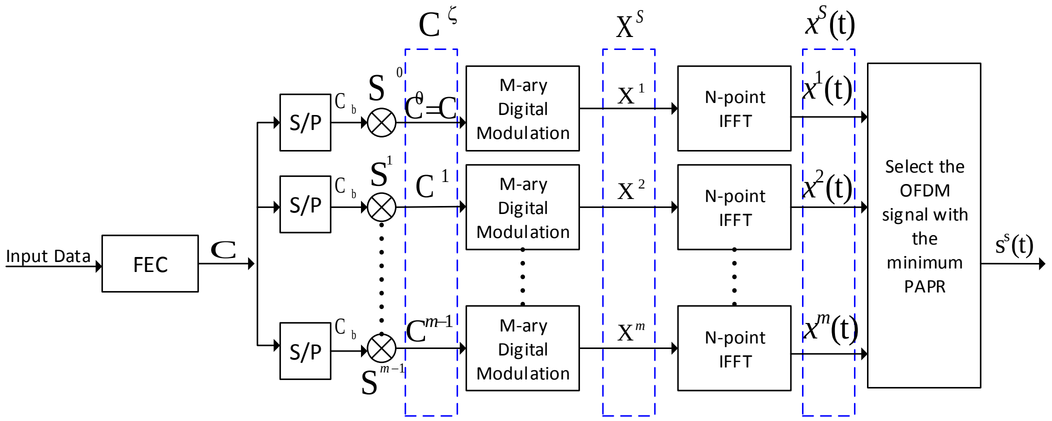


Figure 2 Block Diagram of proposed Selective Codeword Shift (SCS) of OFDM System

where $C_1 = (c_1, \ldots., c_m)$, $C_2 = (c_{m+1}, \ldots., c_{2m})$ and so on until C_K . To generate a number of alternative codewords, C^S, circulant shift (one shift to the right) was applied to every sub-block of the codewords (Figure 1).ζnumber of alternative codeword was produced by the multiplication of every codeword sub-block, C$_b$, with shift factor, S$^\zeta$. The alternative codewords or named as codeword shift is represented as

Table **1** for 4QAM, 16 QAM, 64 QAM and 128 QAM.

Then, the codeword shift sequences were modulated by M-ary digital modulation. The outputs of the symbol sequences are$X^S = [\mathrm{X}_{1,\zeta}, \mathrm{X}_{2,\zeta}, \ldots., X_{K,\zeta}]$.

In the SCS technique, there was no multiplication of phase factor,P^u involved like a conventional SLM (Eq. 4). Thus, this technique is simpler. The OFDM symbol is directly multiplied with orthogonal sinusoid IFFT,$e^{j2\pi f_k t}$.OFDM signal in the time domain is given as

$$x^S(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} \mathrm{X}_k^S \cdot e^{j2\pi f_k t} \qquad 1 \le S \le m \qquad (9)$$

where$S$ is the number of shift factor and the number of OFDM signals outputs. Subsequently, the candidate with minimum PAPR among the S number of OFDM signal outputs was selected for transmission. The block

$$C^\zeta = \prod_{k=1}^{K} C_k \otimes S^\zeta \qquad 0 \le \zeta \le m-1 \qquad (8)$$

Codeword shift sequences become $C^\zeta = [C_1 \otimes S^\zeta, C_2 \otimes S^\zeta, \ldots., C_K \otimes S^\zeta] = [C_{1,\zeta}, C_{2,\zeta}, \ldots., C_{K,\zeta}]$. Circulant shift process for one sub-block is illustrated in

diagram of the proposed technique for OFDM signal transmission is illustrated in Figure 2.

The transmitted OFDM signal was obtained by

$$s^S(t) = \underset{1 \le S \le m}{\operatorname{argmin}}\, PAPR(x^S(t)) \qquad (10)$$

Unlike conventional SLM, the proposed SCS technique does not require explicit side information at the receiver. The side information index of which sequence is selected for transmission were embedded in the codeword block as in Figure 3. The information is in the form of binary bits, $\log_2$(M-ary QAM) . The scrambling indices have to be stored in both the transmitter and receiver. Thus, at the receiver, the bits data were retrieved by the backward process of the transmitter.

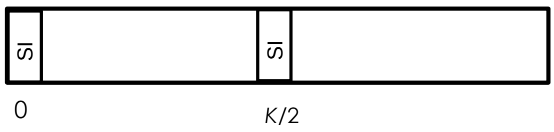


Figure 3 Codeword blocks format with embedded side information

3.2 PAPR Reduction of Proposed SCS

PAPR reduction based on the SelectiveCodeword Shift (SCS) is explained using an example utilizing one sub-block of codeword for 4, 16, 64 and 128 QAM. The black dots in Figure 4, (a), (b), (c) and (d) are the original codeword mapped onto the constellation point or symbol while the red dots are the shifted codeword. The dotted red lines indicate the power of the symbol. It must be noted that each symbol can have a different power. Power symbols are calculated using equation

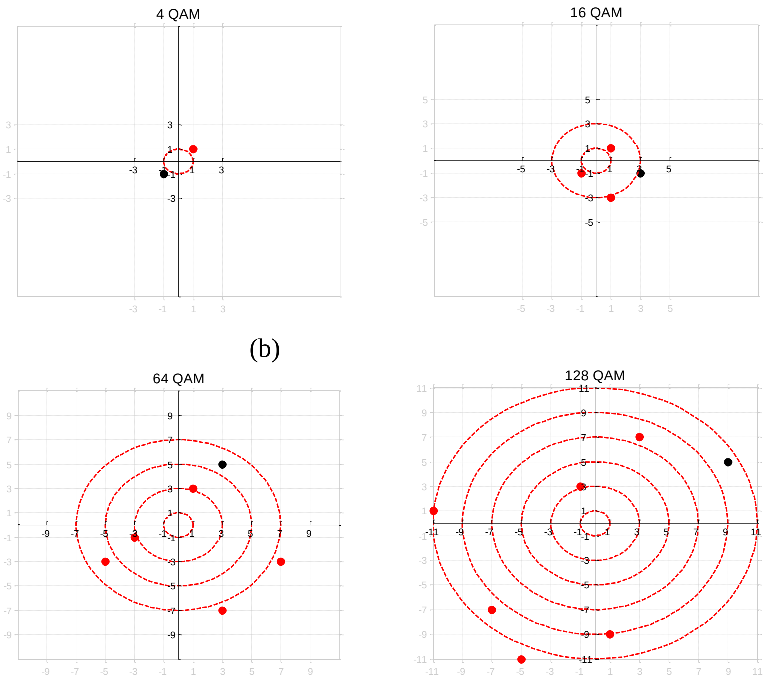
$$X^S_{pow} = \frac{|X^S|^2}{2} \tag{11}$$

As a summary, referring toFigure 4, the farther the symbol from the origin, 0, the larger power value resulted. The number of shifts, the number of OFDM signal outputs and constellations range are summarized and presented in Table 2.

PAPR is calculated as in Eq. 3 where IFFT applies to the OFDM symbol. Here, even though the symbol power has a small value, it does not guarantee a low PAPR. The proposed technique did not disrupt the IFFT process but only concentrated on manipulating codeword, C which produced multiple alternative OFDM symbols, X^S. Unlike conventional OFDM systems which had only one output choice, the proposed technique raised the probabilities of obtaining the minimum PAPR like conventional SLM.

Table 2 Summarization of codeword shift for 4, 16, 64 and 128 QAM

	4 QAM	16QAM	64QAM	128QAM
No. of shift, ζ	1	3	5	6
No. of Outputs, X^S	2	4	6	7
Constellation range	$\pm1, \pm i$	$\pm3, \pm3i$	$\pm7, \pm7i$	$\pm11, \pm11i$



(a) (b)

(c) (d)

Figure 4 Example of codeword shift mapped onto (a) 4 QAM, (b) 16 QAM, (c) 64 QAM and (d) 128 QAM Constellation points

4.0 RESULTS AND DISCUSSIONS

In this section, there are some simulations being conducted to evaluate the PAPR performance using the proposed technique where 10^4 of OFDM signals have been considered to calculate PAPR complementary cumulative distribution functions (CCDF). The input data was randomly generated which produced ½ coding rate of QC-LDPC Codes and IFFT number, N, employed was 128.

Figure 5 compares the CCDF of PAPR for original signals, selective codeword shift (SCS) and selective mapping (SLM) in a 128 QAM OFDM system. For SLM, phase factors, P^{u}, are chosen from $\{\pm 1, \pm j\}$. To make the computational complexity to be equal, the number of *U* in SLM was set to be equal to the number of bits per symbol, *m,* used in SCS. Therefore, the number of IFFT blocks used in both techniques are even. In the graph, it is shown that the SCS technique overcame the original signal and the SLM with 7.4dB which is 29.5% improvement compare to SLM which was only a8.6% improvement. Table 3 summarizes the numerical results of PAPR in Figure 5 at the clip rate of10^{-3}.

The differences between SCS and SLM can be explained by the fact that the SLM phase sequence value is limited to $\{\pm 1, \pm j\}$ range(Eq. 4) in order to generate alternative symbol sequences whereas 128 QAM SCS shifted range is as high as$\{\pm 11, \pm 11i\}$ (Table 2).

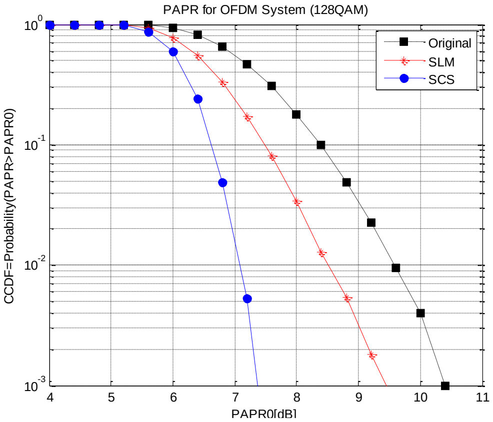


Figure 5 Comparison of the PAPR reduction in 128 QAM

Table 3 PAPR Analysis at Clip rate of 10^{-3}

OFDM System (128QAM, 128IFFT)	PAPR in dB	Improvement (%)
Original OFDM	10.5	-
SLM	9.5	8.6
SCS	7.4	29.5

Figure 6 shows the CCDF of PAPR for original signals and the proposed technique (Selective Codeword Shift-SCS) of 4, 16, 64 and 128 QAM. As shown in the figure, the SCS technique obviously has a significant reduction in 16, 64 and 128 QAM when compared to the original signals. For the SCS technique, a reducing pattern when the number of digital modulation, *m*, increased can be seen. As for original signals, the PAPR value lingered above 10dB regardless of the increasing number of digital modulation. The improvement percentage for 16, 64 and 128 QAM is 13.9%, 19% and 29.5% respectively. Table 4 shows the numerical results of PAPR at clip rate10^{-3}.

It seems possible that these results were due to two reasons. First, more numbers of shifting, S, means more candidate of PAPR value can be chosen at the end of the process (Eq. 10). That explains why 4 QAM has no significant difference as its number of shifts, $\zeta = 1$ (refer Table 2). Second, for 16, 64 and 128 QAM, the PAPR reduction result may be explained by the fact that the new codeword sequences were created in a larger range such as $\{\pm 3, \pm 3i\}, \{\pm 7, \pm 7i\}\}$, $\{\pm 11, \pm 11i\}$ for 16 QAM, 64 QAM and 128 QAM respectively. Therefore, there is a larger space to produce a variety of new alternative symbol sequences according to the number of digital modulation (refer Figure 4 and Table 2).

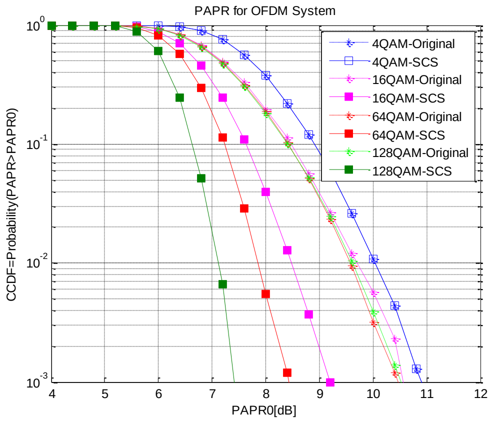


Figure 6 Comparison of the PAPR reduction of 4, 16, 64, 128 QAM OFDM System

Table 4 PAPR Analysis at clip rate of 10^{-3}

OFDM System	PAPR in dB			
	4	16QAM	64QA	128Q
Original	10.9	10.6	10.5	10.5
SCS	10.9	9.2	8.5	7.4
Improvement	0	13.9%	19%	29.5%

As shown in Figure 7, further investigation provides the relationship between numbers of the shift, *S*, and the PAPR CCDF value. In the graph, it is shown that the improvement gradually increased when the number of shifts increased.

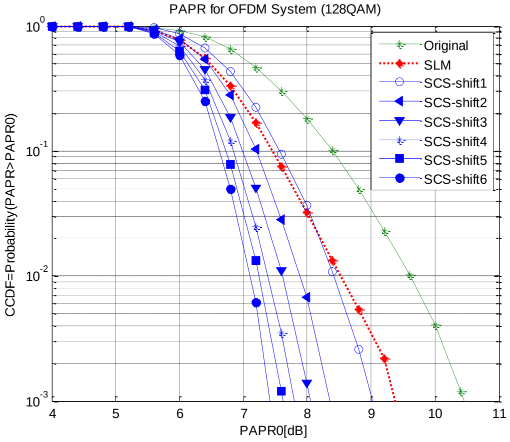


Figure 7 Comparison of number of shift in Selective Codeword Shift

The maximum shift number shows the highest improvement percentage, 28.8%. This finding supports the idea that the more numbers of shifting, S, means more candidates of PAPR value can be chosen at the end of the process. Thus, the minimum PAPR can be obtained (Eq. 10). When comparing to SLM, the SCS technique already overcomes the SLM technique that started from shift 1 with a 13.5% improvement Table 3 summarizes the numerical results of PAPR in Figure 7 at clip rate10^{-3}.

Figure 8 shows a BER performance of the proposed technique and conventional OFDM for additive white Gaussian noise (AWGN) channels. It is shown here that the proposed technique has a similar result as compared to the conventional OFDM which illustrates the robustness of the proposed technique.

Table 3PAPR Analysis at Clip rate of 10^{-3}

OFDM System (128 QAM, 128IFFT)	PAPR in dB	Improvement (%)
Original OFDM	10.4	-
SLM	9.4	9.6
SCS- shift1	9.0	13.5
SCS-shift 2	8.4	19.2
SCS- shift 3	8.1	22.1
SCS- shift 4	7.8	25.0
SCS- shift 5	7.6	26.9
SCS- shift 6	7.4	28.8

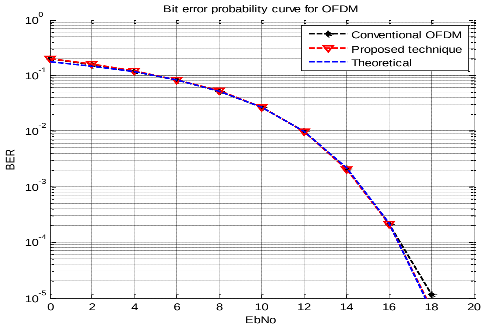


Figure 8 BER performance of the proposed technique

5.0 CONCLUSION

In this paper, a scrambling technique has been proposed to overcome the major problem of OFDM Systems, which is high PAPR. The proposed technique, Selective code word shift (SCS) has shown a significant improvement in reducing high PAPR when compared to original signals and conventional SLM. The PAPR improvement in 128 QAM OFDM system achieved by 29.5% or 7.4 dB as compared to conventional SLM which was only 8.6% or 9.5 dB. However, this technique is only effective for modulation higher than 4 QAM or higher than two bits per symbol. This finding suggests that generally, it is suitable for a high-performance applications system. Besides that, this technique also enjoys an advantage of low computational complexity as compared to the SLM technique in terms of IFFT blocks used. Moreover, no multiplication of phase factor was involved in the transmission process. These advantages contributed to the reduction of cost for the system.

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