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PAPR Reduction in SLM Scheme using Exhaustive Search Method

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ABSTRACT

Orthogonal Frequency Division Multiplexing (OFDM) is a gifted scheme to accomplish high data transmission for high speed communication systems. Consequently, it is treated as a strong candidate for forthcoming wireless applications. Nevertheless, the foremost drawback of OFDM signal is high Peak to Average Power Ratio (PAPR), which degrades the performance of the primary resources of the communication system. Selective Mapping (SLM) technique is the most familiar to condense the PAPR. However, conventional SLM technique requires many Inverse Fast Fourier Transforms (IFFTs), which surges the computational complexity. Moreover, conventional SLM requires side information, which raises the transmitting power as well as error rate. In this paper, we proposed a novel SLM scheme using exhaustive search method to enhance the PAPR reduction performance, which requires only one IFFT and no side information. In our work (8, 4) extended Hamming code is employed as single error correcting code. The PAPR performance of the exhaustive search SLM and conventional SLM is compared for all possible combination of (8, 4) extended Hamming codes. Numerical results confirmation that the PAPR reduction performance of exhaustive search SLM is superior to that of the conventional SLM.

Keywords: constructive phase, extended Hamming code, exhaustive search, phase sequence, conventional SLM, exhaustive search SLM

INTRODUCTION

OFDM is one of the reputed technologies for higher data rate communication systems. OFDM is recognized as a significant technology for Long Term Evaluation. In OFDM transmission system, N-point IFFT is taken for the transmitted symbols, $[X(k)]_{k=0}^{N-1}$, so as to generate $[x(n)]_{n=0}^{N-1}$, the samples for the sum of N orthogonal subcarrier signals. Therefore, the discrete-time OFDM symbol is expressed as [1].

$$x(n) = \frac{1}{N}\sum_{k=0}^{N-1} X(k)e^{j2\pi n\frac{k}{N}} \quad ; 0 \le n \le N-1 \tag{1}$$

However, when the subcarriers are added coherently, the instantaneous power is more than the average power, which in turn results inter modulation distortion in the transmitted signal [2]. To compute these peak fluctuations, PAPR is the utmost recurrently used metric and expressed as [3].

$$\mathrm{PAPR}[x(n)] = \frac{\max\limits_{0 \le n \le N-1} |x(n)|^2}{E\,|x(n)|^2} \tag{2}$$

where E [·] denotes the expectation operator and x(n) is the transmitted signal defined in (1).

To address this high PAPR issue various schemes, including SLM [4-5], partial transmit sequence (PTS) [6], both SLM and PTS [7], active constellation extension [8], tone injection [9], tone reservation [10], sub-block phase weighting [11], clipping [12], channel coding [13], companding [2], have been suggested. Among these schemes, SLM scheme is the most preferred due to its high PAPR reduction performance. Conventional SLM introduced by Bauml *et al* [4] adopts a bank of IFFTs, resulting additional computational load. Conventional SLM scheme uses parallel signal processing to generate a set of M statistically independent OFDM candidate signals from the same data sequence and the signal with lowermost PAPR is transmitted as illustrated in Fig. 1. The conventional SLM scenario supported with mathematical expressions is summarized as follows.

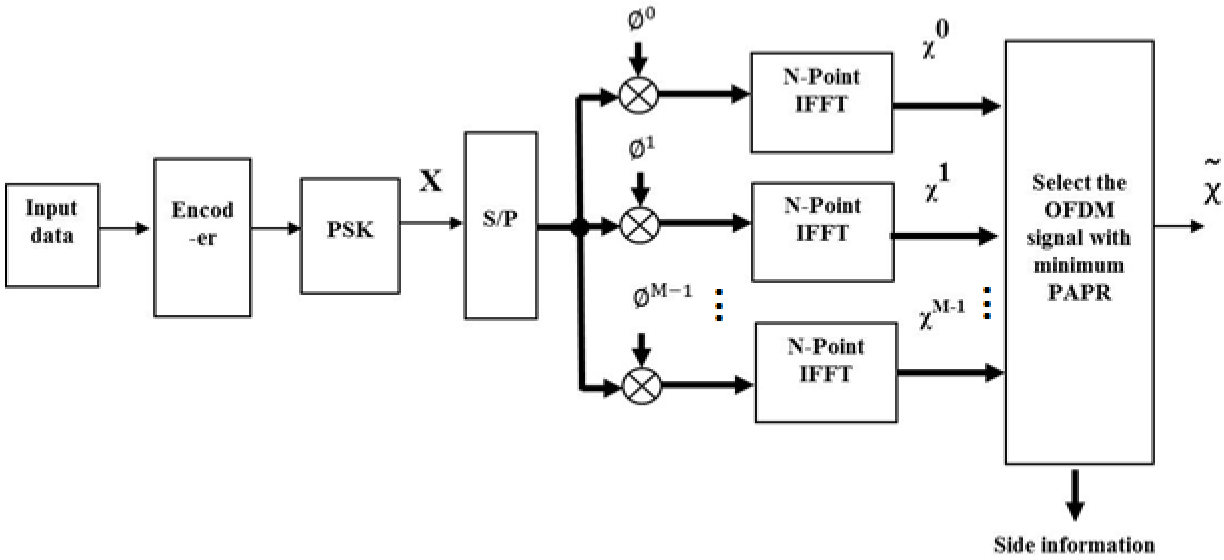

Fig. 1 Architecture of conventional SLM

The input data sequence is subjected to the channel encoder and phase shift keying operation is performed on the output of channel encoder. Then, the modulated data sequence, $X(k)$ is multiplied carrier-wise by the M unique phase sequences $[\emptyset^{m}(k)]_{m=0}^{M-1}$ to produce M unique candidate signals as given by

$$X^{m}(k) = \emptyset^{m}(k) \cdot X(k) \quad ; \; 0 \leq m \leq M-1 \tag{3}$$

The IFFT is applied on each of these modified data sequences to generate M unique OFDM candidate signals $x^{m}(n)$.

$$X^{m}(k) \xleftrightarrow{\text{N−point IFFT}} x^{m}(n) \tag{4}$$

The PAPR of M signals are evaluated and only one presenting the lowest PAPR, $x\widetilde{(n)}$ is adapted for transmission so that the probability of incurring high PAPR can be reduced.

$$x\widetilde{(n)} = \underset{0 \leq m \leq M-1}{\arg\min} \{PAPR[x^{m}(n)]\} \tag{5}$$

Conventional SLM needs to transmit additional $\lceil \log_2 M \rceil$ bits as side information to recover the original sequence at the receiver [14].

It is worth noting that from equation (5), increasing the number of candidate signals M increases the PAPR reduction performance at the cost of M IFFT blocks, which significantly increases the computational complexity. In this paper, we recommended an exhaustive search SLM scheme, which requires single IFFT and no side information.

THE PROPOSED EXHAUSTIVE SEARCH SLM

Exhaustive Search SLM

The architecture of the exhaustive search SLM is depicted in Fig. 2. The input data sequence, $X(k)$ of length N is carrier-wise multiplied with a known phase sequence, $\emptyset^{0}(k)$, of length N to produce an OFDM signal.

$$X(k) \cdot \emptyset^{0}(k) \xleftrightarrow{\text{N−point IFFT}} s^{0}(n)$$

Evaluate the maximum PAPR of the signal, $s^{0}(n)$, Let it be $PAPR^{0}$. Repeat the above step to produce M unique candidate signals using M unique phase sequences $[\emptyset^{m}(k)]_{m=0}^{M-1}$. Then obtain the set of PAPR values for M unique candidate signals as

$$PAPR = \{PAPR^{0}, PAPR^{1}, PAPR^{2}, \ldots, PAPR^{M-1}\}$$

Find the minimum PAPR in the above sequence and choose the corresponding phase sequence. This phase sequence, which is attained from exhaustive search, is called constructive phase. Let $\emptyset^{C}(k)$ be the constructive phase, then the transmitted signal is $X(k)\emptyset^{C}(k)$. At the decoder same phase is fixed to recover the original data sequence as given below.

$$X(k)\emptyset^{C}(k)\emptyset^{c}(k) = X(k), \text{since for PSK } \emptyset^{c}(k)\emptyset^{c}(k) \text{ is always } +1$$

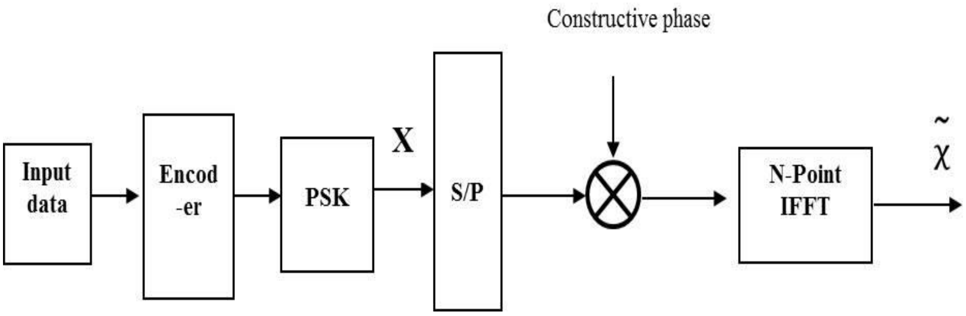

Fig. 2 Architecture of exhaustive search SLM

In conventional SLM scheme, the side information carries the phase sequence details but not about the data sequence. Consequently, side information degrades the performance of the communication resources such as transmission bandwidth, power and error performance. However, the proposed scheme does not involve side information to recover the data sequence, unlike conventional SLM scheme. Hence the proposed scheme is more suitable for high data rate applications. Further, the proposed architecture requires one IFFT block, while conventional SLM method requires M IFFT blocks, to generate M candidate signals. Subsequently, the computational complexity is reduced in the proposed exhaustive search SLM method.

RESULTS AND ANALYSIS

Channel Coding

Owing to frequency selective nature of the communication channel, only one subcarrier is affected in N subcarrier OFDM system. The corresponding subcarrier can be recovered at the receiver using single error correcting channel coding technique. Hamming code is the robust single error correcting channel codes.

A (7, 4) hamming code can be represented as

$$[C] = [P_2\ P_1\ P_0\ d_3\ d_2\ d_1\ d_0\ ] \tag{6}$$

Where,

$d_3\ d_2\ d_1\ d_0$ is the data sequence and $P_2\ P_1\ P_0$ is the parity sequence derived from data sequence.

The generated matrix for the (7, 4) Hamming code is considered as

$$G = \begin{bmatrix} 1 & 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 1 \end{bmatrix} \tag{7}$$

The H matrix is given as

$$H = \begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 & 1 \end{bmatrix} \tag{8}$$

Error Correction

Error correction can be performed using syndrome (S) on the received code (R), which can be characterised as [15]

$$[S] = [R][S]^T$$

Consider a data sequence, $[D] = [0\ \ 0\ \ 1\ \ 0]$

Then codeword, $[C] = [D][G] =. [0\ \ 0\ \ 1\ \ 0] \begin{bmatrix} 1 & 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 1 \end{bmatrix} = [1\ \ 1\ \ 1\ \ 0\ \ 0\ \ 1\ \ 0]$

Let us introduce error in the 5th position, then the received code be $[R] = [1\ \ 1\ \ 1\ \ 0\ \ 1\ \ 1\ \ 0]$

Then

$$[S] = [1\ \ 1\ \ 1\ \ 0\ \ 0\ \ 1\ \ 0] \begin{bmatrix} 1 & 0 & 0 & 1 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 & 1 \end{bmatrix}^T = [0\ \ 1\ \ 1]$$

Since, $[S] = [0\ \ 1\ \ 1]$ is 5th column in H, the error is 5th position of the received code R.

For efficient IFFT operation, it is desired that the number of carriers be in powers of two. Therefore, (7, 4) Hamming code has been converted into (8, 4) extended Hamming code by appending one redundant bit to all the codewords. We consider the redundant bit as 0. The (8, 4) extended Hamming code can be represented as

$$[C] = [0\ P_2\ P_1 P_0\ m_3\ m_2\ m_1\ m_0\ ]$$

PAPR Calculation of OFDM Signal that Employed Extended Hamming Code

Consider a codeword: [0 0 0 0 0 0 0 0] and modulation is PSK.

Then,

X(k) = -1 -1 -1 -1 -1 -1 -1 -1

x(n) = IFFT[x(n)] = 1 0 0 0 0 0 0 0

$|x(n)|^2$ = 1 0 0 0 0 0 0 0

Max. $|x(n)|^2$

Avg. $|x(n)|^2$ $= \frac{1+0+0+0+0+0+0+0}{8} = \frac{1}{8}$

From Eq. 2, PAPR = 8

PAPR in dB = 9.0309

Consider another codeword: [0 1 0 1 1 1 0 1] and modulation is PSK.

Then,

X(k) = -1 1 -1 1 1 1 -1 1

x(n) = 0.25 -0.25 0.25 -0.25 -0.75 -0.25 0.25 -0.25

$|x(n)|^2$ = 0.0625 0.0625 0.0625 0.0625 0.5625 0.0625 0.0625 0.0625

Max. $|x(n)|^2$ = 0.5625

Avg. $|x(n)|^2$ $= \frac{0.0625+0.06250+0625+0.0625+0.5625+0.0625+0.0625+0.0625}{8} = \frac{1}{8}$

From Eq. 2, PAPR = 4.5

PAPR in dB = 6.5321

Correspondingly, PAPR values for all possible codes are evaluated and presented in Table-1.

Table -1PAPR Values for all Possible Codes

Data Sequence	Codeword	PAPR in dB with 0 as MSB	Data Sequence	Codeword	PAPR in dB with 0 as MSB
0000	000 0000	9.0309	1000	110 1000	1.7609
0001	101 0001	6.5321	1001	011 1001	3.0103
0010	111 0010	3.0103	1010	001 1010	1.7609
0011	010 0011	3.9794	1011	100 1011	5.3329
0100	011 0100	1.7609	1100	101 1100	3.0103
0101	110 0101	3.0103	1101	000 1101	1.7609
0110	100 0110	3.9794	1110	010 1110	3.0103
0111	001 0111	3.0103	1111	111 1111	6.5321

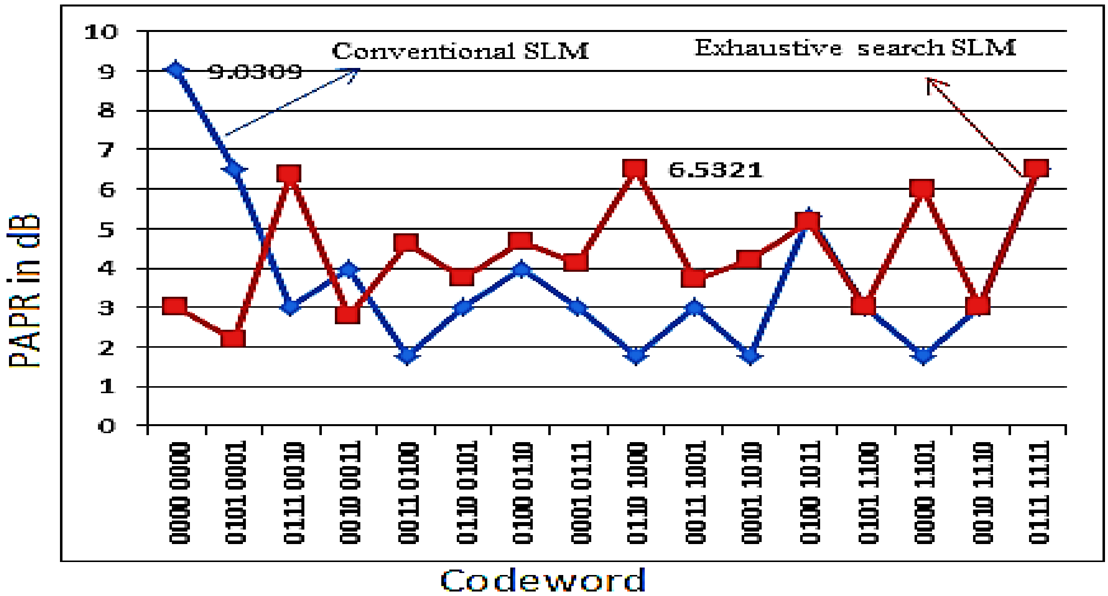

Fig. 4 PAPR values for conventional SLM and exhaustive search SLM with (8, 4) extended Hamming code

Therefore, the set of PAPR values of OFDM signal with extended Hamming code is as
P = {9.0309, 6.5321, 3.0103, 3.9794, 1.7609, 3.0103, 3.9794, 3.0103, 1.7609, 3.0103, 1.7609, 5.3329, 3.0103, 1.7609, 3.0103, 6.5321}.
Similarly, with constructive phase, the set of PAPR values can be obtained as
P_m = {3.0103, 2.1835, 6.3578, 2.7801, 4.6452, 3.7298, 4.6511, 4.1024, 6.5321, 3.7067, 4.2285, 5.1644, 3.0103, 5.9873, 3.0103, 6.5321}.

Fig. 4 presents PAPR values for all possible (8, 4) extended Hamming codes for conventional SLM and exhaustive search SLM scheme. Fig. 4 conformed our proposed scheme provides an effective solution to control the PAPR in OFDM system. It is observed that the maximum PAPR value of the conventional SLM and exhaustive search SLM are 9.0309 dB 6.5321 dB, respectively. Eventually, the gain in PAPR reduction of the proposed scheme is 2.4988 dB, when compared with conventional SLM.

CONCLUSION

In this paper, an exhaustive search SLM scheme is proposed that significantly improves the PAPR performance in OFDM system. In conventional SLM, M unique phase sequences are multiplied with data sequence and parallel IFFT operations are used to generate M unique candidate signal and the signal with minimum PAPR is preferred for transmission. However, in the proposed exhaustive search SLM method, the data sequence is multiplied with constructive phase and then IFFT operation is performed to generate an OFDM signal. The constructive phase is obtained using exhaustive search method and the data sequence can be recovered using the same constructive phase at the receiver. Hence, the proposed scheme does not involve side information to be transmitted and hence the proposed scheme is predominantly suitable for high data-rate applications. Further, the gain in PAPR reduction in exhaustive SLM scheme is 2.4988, when compared with conventional SLM scheme. Even though, our work is emphasis on extended Hamming code, the proposed exhaustive search SLM scheme can be applied to any kind of channel coding technique.

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