# Performance of Linear Block Coded Selective Mapping scheme in Reduction of Peak to Average Power Ratio, Cubic Metric, and Block Error Rate in OFDM System

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**Abstract**: ***Orthogonal Frequency Division Multiplexing (OFDM), is a well-known multicarrier modulation scheme. It works very efficiently in reliable data communications. Like any other technique, OFDM encounters some drawbacks, one of which is its high peak to average power ratio (PAPR). High PAPR requires a large power back off in the transmitting amplifier, which results in low power efficiency. Another metric representing the same problem is the cubic metric (CM), which gives a better prediction of the power capability than PAPR. In this paper, the scheme is introduced which combines selective mapping with block coding to reduce the PAPR and improve Block Error Rate (BLER) for OFDM systems. The proposed scheme is compared with the conventional selective mapping PAPR reduction method, which is well known for having a better reduction capability. The comparison is done in terms of Complementary Cumulative Distribution Function (CCDF) of the PAPR of the multicarrier signal. The simulation results show that the proposed scheme can achieve a better PAPR/CM reduction while maintaining the minimum BLER.***

**Keywords***:* Orthogonal Frequency Division Multiplexing (OFDM), Peak to Average Power Ratio (PAPR), Cubic Metric (CM), Block Error Rate (BLER), Selective Mapping, Block Coding.

## 1. Introduction

One of the major disadvantages of orthogonal frequency division multiplexing (OFDM) is the large amplitude variations. In order to reduce the distortion caused by a high power amplifier without setting it to large back-offs, the amplitude variations of the OFDM signal have to be decreased. Peak-to-average power ratio (PAPR) is widely being used to quantify the envelope fluctuations. In fact, many techniques can be found that limit the peak power of the signal and a problem that is usually referred to as PAPR reduction.

In some recent studies, another metric of the envelope variations, known as cubic metric (CM) [1], is being used. The major distortion introduced by the nonlinear amplifier is caused by the third order inter-modulation product which motivates the concept CM.

Recent studies on PAPR and CM shows that, except for large back-offs, CM is more related to the amount of distortion because of nonlinearity than PAPR. The 3GPP standards proposed and adopted the use of CM, as an evolutionary metric [2], [3].

There different PAPR reduction methods are proposed, each one having some advantages and disadvantages over the others. The proposed techniques are divided into two categories: distortion and distortion less techniques. Some examples of distortion techniques are clipping [4] and companding [5]. Distortionless techniques include systematic coding [6], selective mapping [7], partial transmit sequence [8], tone injection/reservation [9] and active constellation extension [10].

Recently, a distortionless technique called selected mapping (SLM) has become more popular because of its efficiency, strong PAPR reduction capabilities and less complexities [10]. In this paper, the block coded selective mapping scheme is proposed which reduces PAPR effectively and simultaneously keeps the block error rate at minimum. Similar to PAPR reduction, the CM reduction is achieved by reducing the root mean square (rms) value of each normalized cubed OFDM symbol for reducing the distortion. Thus, most of the techniques that were originally designed for PAPR reduction can be easily applicable to CM reduction.

## 2. Peak to Average Power Ratio

The PAPR is defined as the ratio of the maximum power occurring in OFDM symbol and the average power of the same OFDM symbol. A major drawback of the PAPR is that it does not consider the secondary peaks of power which affect the power amplifier performance and increases the complexity [4]. If the complex baseband representation of the transmit signal is represented as,

$$x(t) = \sum_{i=1}^{N} S_i \, . \exp(j2\pi f_i t), \qquad 0 \leq t \leq T \qquad (1)$$

The PAPR of signal x(t) is defined as,

$$PAPR = \frac{\max_{0 \leq t \leq T} |x(t)|^2}{\frac{1}{T}\int_0^T |x(t)|^2 dt} \qquad (2)$$

The PAPR (in dB) of the OFDM signal can be defined as,

$$PAPR_{dB} = 10 \log 10 \left(\frac{P_{peak}}{P_{average}}\right) \qquad (3)$$


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Where, $P_{peak}$ is the maximum of power for one OFDM frame and $P_{average}$ is the average power consumed by each frame. PAPR is usually expressed in terms of Complementary Cumulative Distribution Function (CCDF) and is mathematically given by,

$$P(PAPR \geq PAPR_0) = 1 - (1 - e^{-PAPR_0})^N \quad (4)$$

Where, $PAPR_0$ is the clipping level.

When the OFDM signal with high PAPR passes through a non-linear device, the signal will have significant non-linear distortion. To reduce the signal distortion, it requires a linear power amplifier. However, this linear power amplifier has poor efficiency and more cost.

## 3. Cubic Metric

Cubic metric (CM) has been adopted by the 3GPP standard [2] as a parameter to determine power capability of power amplifier because of it is more accurate over a wide range of devices and signals. The cubic metric is defined as a measure of the amount of additional back off needed for a specific signal wave form, relative to the back-off needed for some reference wave form. The CM of a signal is given as [3],

$$CM = \frac{RCM - RCMref}{Kcm} \quad (5)$$

Where,
*Kcm* is an empirical slope factor,
*RCM* is a raw cubic metric, and
*RCM*ref is the raw cubic metric of reference signal.

*RCM* is defined for a signal *x*(*t*) as

$$RCM = 20\log\left(RMS\left(\left(\frac{|x(t)|}{RMS(x(t))}\right)^3\right)\right) \quad (6)$$

Where,
*RMS* is the root mean square value of signal.

## 4. Selective Mapping Technique

In the Selective Mapping technique, the transmitter generates a set of different data blocks which represent the same information as the original data block, and selects the data block with lowest PAPR. We can define the data stream after serial to parallel conversion as,

$$X=[X_0, X_1, \ldots, X_{N-1}]^T \quad (7)$$

Initially each input $Xn^{(u)}$ defined as,

$$X n^{(u)} = Xn\, bn\, (u) \quad (8)$$

Where, b(u) can be written as,

$$b(u) = [b_{u,0}, b_{u,1}, \ldots, b_{u,N-1}]^T, u = 1, 2, \ldots, U. \quad (9)$$

This result in U modified data blocks. All U phase rotated OFDM data blocks represented the same information as the unmodified OFDM data block provided that the phase sequence is known. After applying the SLM technique, the complex envelope of the transmitted OFDM signal becomes,

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n\, e^{j2\pi n \Delta f t} \quad 0 \leq t \leq NT \quad (10)$$

Where, $\Delta t = 1/NT$,
NT is the duration of an OFDM data block.

The output data with the lowest PAPR is selected for transmission. Information about the selected phase sequence should be transmitted to the receiver as side information. At the receiver the reverse operation is performed to recover the original data block. This approach is applicable for all types of modulation with any number of subcarriers. The amount of PAPR reduction for SLM depends on the number of phase sequences *U* and the design of the phase sequences.SLM technique is distortion-less technique. But it has high complexity in design and computation. This complexity can be reduced by using less number of IFFT blocks.

## 5. Linear Block Coding

A block code C of length n with $2^k$ code words is called a linear (n, k) code [6] if and only if its $2^k$ code words form a k-dimensional subspace of the vector space of all n-tuples over the field GF(2). Being a linear vector space, there is some basis, and all codewords can be obtained as linear combinations of the basis. We can designate $\{g_0, g_1, \ldots, g_{k-1}\}$ as the basis vectors. In a nutshell, it means that we can represent the coding operation as matrix multiplication, as we have already seen. We can formulate a generator matrix as

$$G = \begin{bmatrix} g_1 \\ \vdots \\ g_{k-1} \end{bmatrix} \quad (11)$$

Where, G is a k × n matrix.
If $m = (m_0, m_1, \ldots, m_{k-1})$ is an input sequence, then the output is the codeword

$$mG = m_0g_0 + m_1g_1 + \ldots + m_{k-1}g_{k-1} \quad (12)$$

It is observed that the all-zero sequence must be a codeword. Therefore, the minimum distance of the code C is the codeword of smallest weight. A vector space of dimension k embedded in a vector space of dimension n, the set of all n-tuples. Associated with every linear block code generator G is a matrix H called the parity check matrix whose rows span the nullspace of G. Then if c is a codeword, then

$$cH^T = 0 \quad (13)$$

That is, a codeword is orthogonal to each row of H. From this it is observed that,

$$GH^T = 0 \quad (14)$$

There is also associated with each code a dual code that has H as its generator matrix. The dual code is denoted as $C^{\perp}$. If G is the generator for an (n,k) code, then H is the generator for an (n, n-k) code.

## 6. Proposed Scheme

In this section, a detailed description of the proposed scheme is provided to reduce PAPR/CM and BLER. The core of this


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scheme is selective mapping with block encoding approach, in which different coding matrices are used to generate different OFDM symbol. The employed coding matrices are designed such that they will minimize the BLER. For further PAPR or CM reduction, selective mapping is introduced, which reduces PAPR or CM at the cost of some BLER reduction. The block diagram of the proposed scheme is shown in Fig. 1.

At the physical layer, the transmitter partitions the input bit stream data into blocks with fixed size, each of which contains a certain number of bits. These blocks are then attached with CRC bits. Now the numbers of blocks N that can be transmitted over one OFDM symbol are passed through Block Code (BC) units. Let v = [$v_1$, $v_2$ ,……, $v_K$ ] be the vector of original blocks in each OFDM symbol. The BC unit uses the coding matrix for block encoding. Each BC unit encodes the N blocks of v into coded C blocks ($C > N$). Each coded block vector is modulated to a modulation symbol vector After IFFT of these $C$ symbol streams, the transmitter selects the signal with the lowest PAPR or CM for transmission purpose.

The coding matrices employed in the proposed scheme can be previously set and stored in both transmitter and receiver. So the transmitter does not need to transmit the coding matrix. Instead, the receiver will decode the received signal, after fast Fourier transform and symbol demodulating, using the stored coding matrices. After decoding, the cyclic redundancy checks (CRCs) of the decoded bit stream data are examined, and the data that passes the CRC check is selected as the correctly received stream. If none of the decoded bit stream data passes the CRC check, then this bit stream data is discarded at the physical layer without delivering it to upper layers because this data has errors.

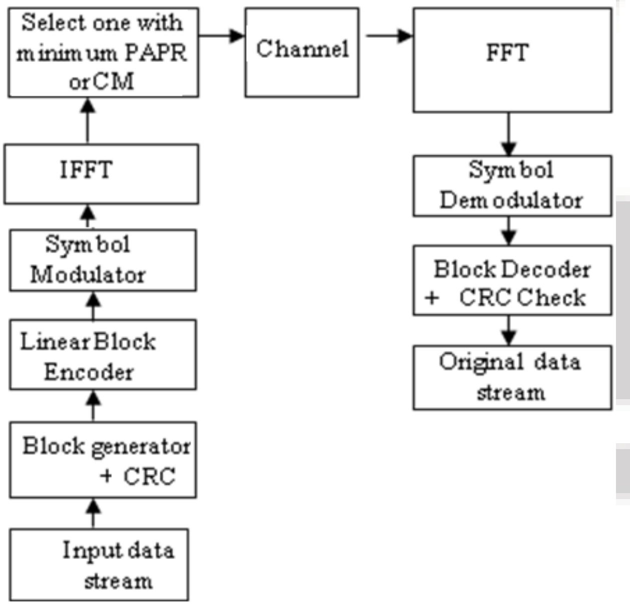


**Figure 1:** Block Diagram of transmitter and receiver of the proposed scheme

## 7. Simulation Results

The Complementary Cumulative Distribution Function (CCDF) is one of the most regularly used parameters, which is used to measure the effectiveness of any PAPR technique. This helps to measure the probability that the PAPR of a certain data block exceeds the given threshold level $PAPR0$, i.e.

$$\text{CCDF (PAPR }(x(t)) = Pr\text{ (PAPR}(x(t)) > PAPR_0) \quad (15)$$

In the first simulation, PAPR is obtained using different phase sequences and coefficient matrices for the Conventional SLM and the proposed Block Coded SLM schemes, respectively. Figure 2 shows the PAPR CCDF performance of the Conventional SLM and the proposed Block Coded SLM schemes. In the simulation, data blocks randomly generated, and the OFDM signal is obtained with16-QAM modulation and IFFT. With this setting, 1000 OFDM signals are simulated and the CCDF performance of PAPR is observed. The simulation results show that the proposed Block Coded SLM scheme achieves a better performance than the Conventional SLM scheme with minimum BLER.

Figure 3 shows the BLER performance of the Block Coded, Conventional SLM and the proposed Block Coded SLM schemes under the additive white Gaussian noise channel and Rayleigh channel condition. The Block Coded SLM is able to achieve minimum BLER. Figure 4 shows BLER performance of C-SLM and BC-SLM of 32 and 64 subcarriers for AWGN and Rayleigh channel.

To overcome the drawback of the PAPR parameter, as discussed in Section 1, the CM is evaluated for the proposed Block Coded SLM scheme. With the same simulation setting, Raw Cubic Metric (RCM) is calculated as described in Section III. The performance results of RCM are shown in Figure 5. It can be seen that the proposed scheme also achieves a better performance when evaluated using the CM.

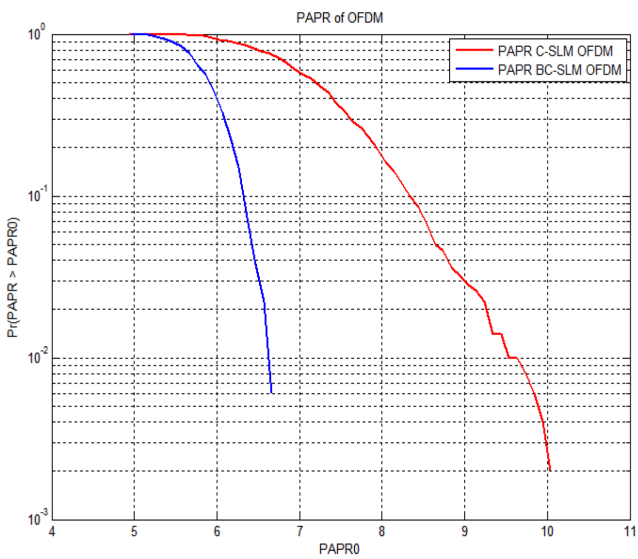


**Figure 2:** PAPR CCDF performance of C-SLM and BC-SLM schemes


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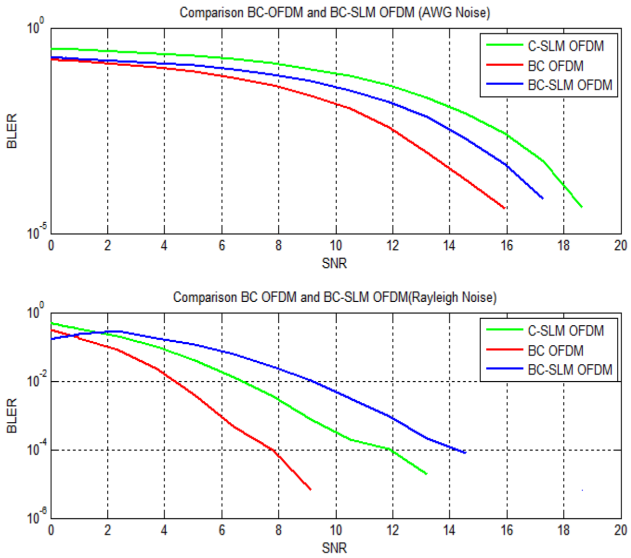


**Figure 3:** BLER performance of BC, C-SLM and BC-SLM for AWGN and Rayleigh noise

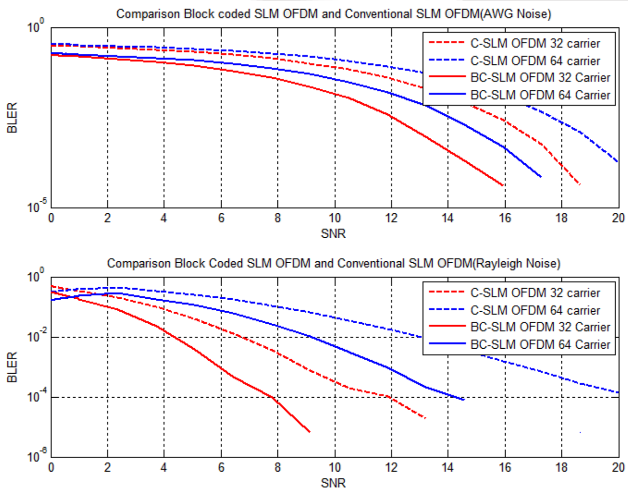


**Figure 4:** BLER performance of C-SLM and BC-SLM for 32 and 64subcarriers

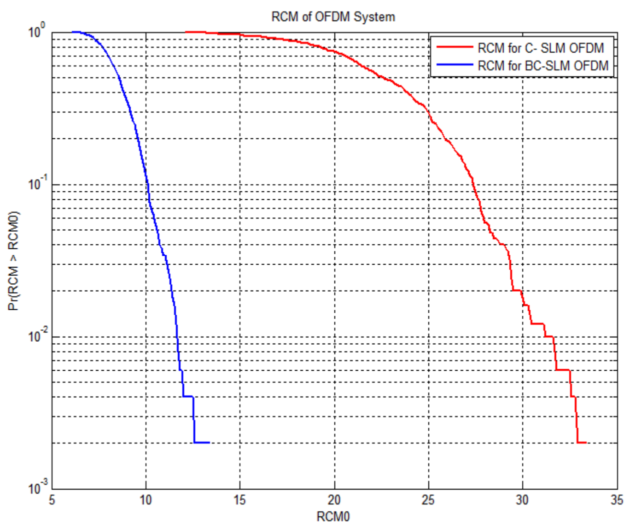


**Figure 5:** CM performance of C-SLM and BC-SLM schemes

## 8. Conclusion

In this paper, a PAPR/CM and BLER reduction scheme based on joint block coding and selective mapping technique is proposed. The PAPR/CM reduction performance and BLER performance are evaluated under different channels by computer simulation. Simulation results state that the PAPR/CM reduction performance is improved compared with selective mapping used only. On the other hand, the BLER of system using proposed scheme is not degraded. This system provides modern wireless techniques to improve the reliability of the communication links.

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