Performance Evaluation of PAPR in OFDM System Using Median Codeword Shift and Hybrid Median Codeword Shift Method

Mohd Danial Rozaini, Azlina Idris, Darmawaty Mohd Ali, Ezmin Abdullah

Abstract - **Orthogonal Frequency Division Multiplexing (OFDM) is the solutions to the current demand for a system having high data rate, capable to improve spectral efficiency and have the immunity against frequency selective fading. However, high peak to average power ratio (PAPR) is the major issue faced by every multicarrier modulation technique including OFDM systems. This paper presents a Median Codeword Shift (MCS) method, which is based on Selective Codeword Shift (SCS) scheme, to overcomes the PAPR problem in OFDM system. The manipulation of codeword structure and permutation process is the key to achieve better PAPR reduction in MCS method. In addition, the hybrid version of MCS is also being proposed by combining MCS with companding technique to further improve the PAPR performance. The simulation results show that MCS overcomes conventional OFDM and SCS with 24% improvement and 0.5 dB difference from SCS. The hybrid MCS also managed to achieve outstanding result with average of 74.4% improvement with tolerable degradation in BER performance.**

Index Terms — **Codeword, Companding, Median Codeword Shift (MCS), Orthogonal Frequency Division Multiplexing (OFDM), Peak-to-Average Power Ratio (PAPR).**

I. INTRODUCTION

ORTHOGONAL Frequency Division Multiplexing (OFDM) is the multicarrier modulation technique and become prominent technology for wireless communication system to meet the demand of higher data rate. Many wireless applications utilized OFDM in their system due to its unique features such as high spectral efficiency, immune against Inter Symbol Interference (ISI) and robustness to multipath fading. As a multicarrier modulation scheme, the OFDM signal comprises of several independently modulated subcarriers. Due to the summation of the subcarrier via Inverse FastFourier Transform (IFFT) operation, the transmit OFDM signal will have a very high PAPR. Having a large PAPR will cause the complexity of analog-to-digital converter (ADC) and digital-to-analog converter (DAC) to increase and at the same time will decrease the power efficiency of radio frequency (RF) amplifier [1][2].

A number of techniques have been developed to address the issue of high PAPR. Generally, PAPR reduction method can be classified into three major categories; signal distortion, multiple signalling technique and probabilistic, and coding technique [3][4]. Companding, clipping and filtering, and peak windowing are the example of signal distortion method while selected mapping (SLM) [5], partial transmit sequence (PTS) [6] and selective codeword shift (SCS) [7-11] are the example of multiple signalling technique and probabilistic method. Block coding, convolutional coding and concatenate coding are three methods that being placed under coding technique.

Multiple signaling is a technique that focus on permutation of multicarrier signal and the signal with lower PAPR value will be selected for transmission while probabilistic technique is focusing on modification of certain parameters in OFDM signal and optimize them to achieve better PAPR reduction [3]. These techniques can achieve significant PAPR reduction without introducing distortion effect. However, transmission of side information is crucial in these method, thus it will lead to date rate loss. A new scheme under multiple signaling and probabilistic technique, SCS proposed in [7-11] managed to outperform conventional SLM in terms of PAPR reduction and computational complexity. The SCS concept is to implement the shifting process to the codeword in order to produce alternative codeword having a lower PAPR values.

In recent years, researchers have explored a new way to deal with PAPR problem by proposing a hybrid technique [3][12][13][14]. The combination of two or more method will produce a new hybrid scheme having a better PAPR reduction but at the same time it also inherit the weaknesses. For instance, SLM reduces the PAPR but at the same time, it compromise the computational complexity and data rate of the system. Therefore, certain factors such as PAPR reduction capability, power increment in transmitted signal, BER degradation at the receiver, data rate loss, computational complexity and bandwidth expansion must be considered when choosing a specific PAPR reduction method [3].

This manuscript is submitted on 30.10.2018 and accepted on 14.12.2018.
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Companding is the common method used in hybridization due to its simplicity as compared to other methods. The idea of companding technique was inspired from speech processing algorithm Mu-law [15]. Companding transformation is a straightforward process where high amplitude OFDM signal will be compressed and low amplitude signal will be amplified in order to preserve the average power by utilizing non-uniform quantization function [16][17][12]. This method is proven as an effective solution for PAPR problem with less implementation complexity. However, companding scheme suffer from poor BER performance at the receiver [3][13].

This paper proposed a new scheme called the Median Codeword Shift (MCS) to deal with high PAPR problem. The methodological approach of MCS is to generate alternative codeword by altering the codeword structure followed by shifting process. MCS offered better PAPR reduction as compared to SCS without affecting the BER performance. A hybrid version of MCS is proposed by merging it with companding technique to further improved PAPR reduction than the original MCS. Simulation result shows that hybrid MCS achieved an acceptable trade-off between PAPR reduction and BER degradation.

II. PAPR IN OFDM SYSTEM

The formation of OFDM signal for N number of subcarriers begin with the conversion of input data into information symbol via serial-to-parallel process. Then, modulating process will be conducted using 64-QAM and mapped the information symbol into the constellation point. Finally, Inverse Fast Fourier Transform (IFFT) will transform the modulated symbol into an OFDM signal. These whole process is illustrated in Fig 1.

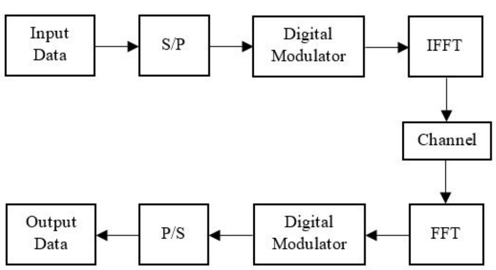

Fig 1: Block diagram of OFDM transceiver system

Mathematically, OFDM signal can be expressed as [7]:

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

where N indicates the number of subcarriers while T is the symbol duration. PAPR in general is a ratio between peak power of OFDM signal and its average power [7]

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

Therefore, PAPR of OFDM signals $b(t)$ in (1) can be written as [7]:

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

where $E|b(t)|$ is referring to average power. The performance of every PAPR reduction method can be analyzed statistically using complementary cumulative distribution function (CCDF). CCDF represents the probability PAPR of OFDM symbol that surpasses the threshold level $PAPR_0$ [14].

$$CCDF(PAPR_0) = P_r(PAPR > PAPR_0) \qquad (4)$$

III. COMPANDING SCHEME: MU-LAW AND A-LAW

Essentially, mechanism of companding techniques can be divided into two parts, compressing the signal amplitude in the transmitter and expanding it back at the receiver end. Compression of OFDM signal using Mu-law can be performed using the following function [18]:

$$G(x) = \operatorname{sgn}(x)\frac{\ln(1+\mu|x|)}{\ln(1+\mu)} \qquad (5)$$

where $\operatorname{sgn}(\cdot)$ is signum function and μ is the compression parameter with standard value of 255 [19]. The expansion function for Mu-law is given as [18]:

$$G^{-1}(x) = \operatorname{sgn}(x)\frac{1}{\mu}\left((1+\mu)^x - 1\right) \qquad (6)$$

Compression of OFDM signal using A-law can be performed using the following function [18]:

$$G(x) = \operatorname{sgn}(x)\frac{A|x|}{1+\log(A)} \quad , \quad |x| < \frac{1}{A} \qquad (7)$$

$$G(x) = \operatorname{sgn}(x)\frac{1+\log(A|x|)}{1+\log(A)} \quad , \quad \frac{1}{A} \le |x| \le 1 \qquad (8)$$

where A is the compression parameter and its standard value is 87.6 [19]. The expansion function for A-law is given as [18]:

$$G^{-1}(x) = \frac{|x|(1+\ln(A))}{A} \quad , \quad |x| < \frac{1}{1+\ln(A)} \qquad (9)$$

$$G^{-1}(x) = \frac{\exp(|x|(1+\ln(A)) - 1)}{A} \quad , \quad \frac{1}{1+\ln(A)} < |x| < 1 \qquad (10)$$

IV. MCS AND HYBRID MCS

A new PAPR reduction method is proposed in this paper by using permutation process (circulant shift) in order to generate a scramble data sequence. MCS is focusing on the codeword structure and the bits arrangement as the way to reduce PAPR. By manipulating this two parameters, MCS will produce an alternative codeword having a lower PAPR. This whole restructuring and shifting process took place between serial-to-parallel and digital modulator as shown in Fig 2.

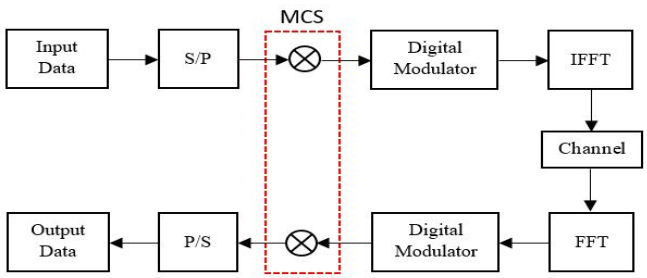

Fig 2: Block diagram of MCS technique

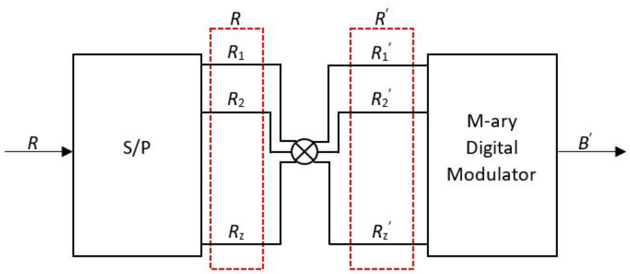

Fig 3: MCS sub-block

As shown in Fig 3, R represents the binary sequence codeword having r total number of input bits and can be indicated as $R = [R_1, R_2, \ldots, R_r]$. The serial to parallel converter will divide the codeword sequence into z number of sub-block denoted by $R = [R_1, R_2, \ldots, R_z]$ and each sub-block will have y number of bits per symbol where $z = r/y$. Therefore, the representation for codeword for each sub-block can be written as $R_1 = [R_1, R_2, R_3,, \ldots, R_y]$, $R_2 = [R_{y+1}, R_{y+2}, R_{y+3}, \ldots, R_{2y}]$ and so on until R_z.

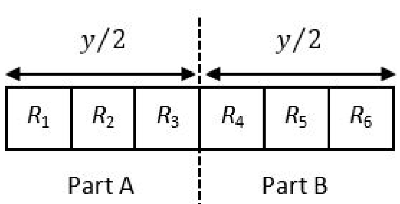

Fig 4: MCS codeword structure

The first step performed by MCS is altering the structure of the codeword by dividing it into two parts, part A and part B as shown in Fig 4. The second step is the one that will generate the alternative codeword by implementing the circulant shift to both part A and part B one at a time. For example, when part A is performing shifting process, part B will remain in idle state. When part A has completed the shifting process, part B will undergo the same process and this time around, part A will be in idle state. Both part A and B will go through δ number of shifting, where

$$\delta = (y/2) - 1 \tag{11}$$

Table 1: Bit arrangement of codeword for MCS technique

Sub-block codeword bits, $R_{z,\delta}$	**Position of bits**
Codeword, $R_{1,0}$	$R_1, R_2, R_3, R_4, R_5, R_6$
Codeword shift 1, $R_{1,1}$	$R_3, R_1, R_2, R_4, R_5, R_6$
Codeword shift 2, $R_{1,2}$	$R_2, R_3, R_1, R_4, R_5, R_6$
Codeword shift 3, $R_{1,3}$	$R_1, R_2, R_3, R_6, R_4, R_5$
Codeword shift 4, $R_{1,4}$	$R_1, R_2, R_3, R_5, R_6, R_4$

To get better understanding, the position of bits after δ number of shifting process is show in Table 1. The initial position of the codeword bits is represented by Codeword $R_{1,0}$. When the shifting process took place in part A, its new bit position will be represented by Codeword $R_{1,1}$ and $R_{1,2}$ while Codeword $R_{1,3}$ and $R_{1,4}$ is for part B. The new alternative codeword sequence can be expressed as $R' = [R_1', R_2', \ldots, R_z']$ and the alternative OFDM symbol sequences can be written as:

$$B' = \prod_{x=1}^{z} R_x' \cdot \beta(t) \tag{12}$$

where $\beta(t)$ is M-ary QAM digital modulation. Therefore, the transmitted signal for alternative OFDM signal are given as below:

$$b'(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} B_k' \cdot e^{j2\Pi f_k t} \tag{13}$$

Finally, the alternative OFDM signal with lowest PAPR value will be chosen for transmitted. For the hybrid MCS method, the companding process is performed after the IFFT as shown in Fig 5.

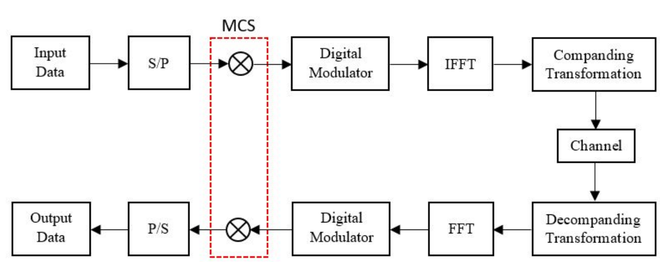

Fig 5: Block diagram of hybrid MCS technique

The alternative OFDM signal $b'(t)$ in (13) will undergo companding transformation (compression process) before the signal goes through the channel. The new companded alternative OFDM signal can be written as:

$$\overline{B}(t) = \prod_{x=1}^{z} b_x{}'(t) \cdot \tau \tag{13}$$

where τ is companding transformation. Thus, for i number of companded alternative OFDM signal, the transmitted signal is obtained by:

$$\bar{b}^i(t) = \arg\min_{1 \le i \le z} PAPR\left(\bar{B}^i(t)\right) \tag{14}$$

V. RESULTS AND DISCUSSION

In this section, the PAPR and BER performance of MCS and hybrid MCS will be evaluated through simulation. In the simulation, $N = 128$ random input symbols are generated and they are all mapped using 64-QAM modulation. The OFDM signal will be transmitted over AWGN channel. To minimize the effect of inter-symbol interference (ISI), cyclic prefix with the length of $1/4$ is add to the OFDM symbols. All the parameter used in the simulation process are summarized in Table 2.

Table 2: Simulation parameters for 3rd Generation Partnership Project Long Term Evolution (3GPP-LTE) System [20]

Parameter	Value
Bandwidth (BW)	1.25 MHz
Sampling frequency	1.92 MHz
Sampling time	5.208×10^{-7} sec
IFFT size	128
Used subcarrier	76
Modulation technique	64 QAM
Cyclic prefix length	$1/4$
Channel model	Rayleigh Fading
Compression parameter, μ	255
Compression parameter, A	87.6

A. PAPR and BER Performance for MCS

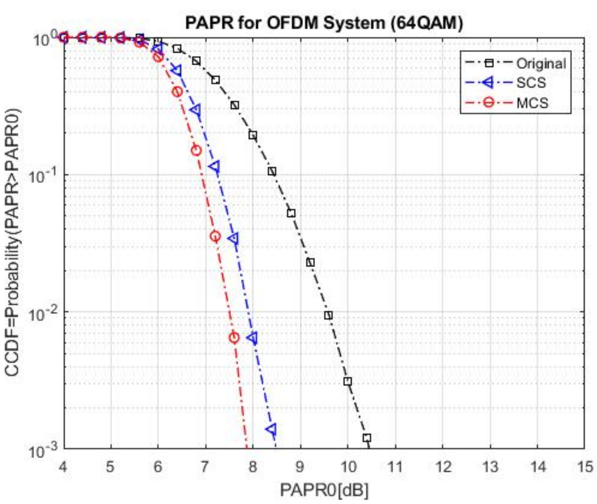

Fig 6: PAPR performance for MCS

Table 3: PAPR analysis of SCS and MCS

	PAPR (dB)	Improvement (%)
Conventional OFDM	10.4	-
SCS	8.4	19.2
MCS	7.9	24.0

Fig 6 shows the comparison of PAPR performance between conventional OFDM, SCS and MCS. It is apparent from the data in Table 3 that MCS managed to outperform SCS with 24% improvement at 7.9 dB while SCS only achieved 19.2% improvement at 8.4 dB. Altering the structure of the codeword has a significant impact on MCS PAPR performance. Divided codeword structure has lower the codeword distance compared to unaltered codeword structure that were used in SCS. As mentioned in [21], lower codeword distance will lead to better PAPR reduction. The advantage of shifting process in MCS is that it can generates an alternative codeword and gives flexibility to the system to choose signal with lower PAPR to be transmitted. This situation does not happened in conventional OFDM because it has only one output signal.

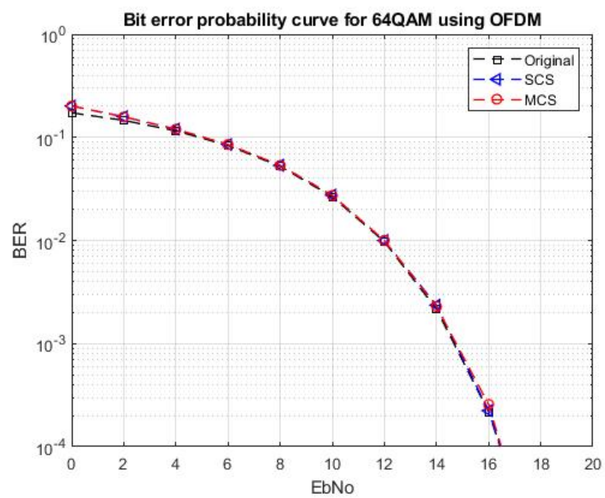

Fig 7: BER performance for MCS

Table 4: BER analysis of SCS and MCS

	BER (dB)	Degradation (%)
Conventional OFDM	16.4	-
SCS	16.4	0
MCS	16.4	0

The BER performance for conventional OFDM, SCS and MCS are shown in Fig 7. It is shown here that MCS has the same BER performance with conventional OFDM and SCS. Interpretation of BER analysis in Table 4, indicates that MCS has the immunity against fading channel.

B. PAPR and BER Performance for Hybrid MCS

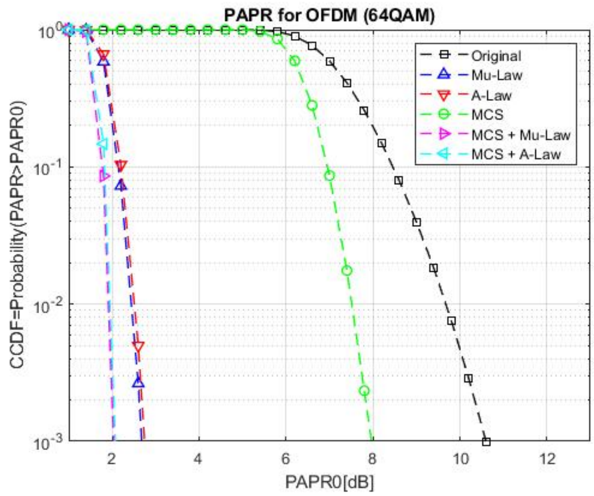

Fig 8: PAPR performance for hybrid MCS

Table 5: PAPR analysis of MCS and hybrid MCS

	PAPR (dB)	Improvement (%)
Conventional OFDM	10.61	-
Mu-law	2.66	74.93
A-law	2.75	74.08
MCS	7.91	25.45
MCS + Mu law	2.00	81.15
MCS + A law	2.05	80.68

Fig 8 shows an overview of PAPR performance of conventional OFDM, companding technique, MCS along with its hybrid version. From the data in Table 5, it can be clearly seen that the Mu-law and A-law have significantly reduced the PAPR with 74.93% and 74.08% improvement respectively as compared to MCS with 25.45% improvement. The huge differences between companding technique and MCS in terms of PAPR performance can be explained by the compression process perform by Mu-law and A-law itself. The basic principal of companding technique is to compress the high peak power signal while maintaining the low power signal. Referring to (2), PAPR value is directly proportional to the peak power signal. Therefore, when the peak power is reduce the PAPR value will be lower. On the other hand, MCS only depends on the manipulation of codeword to gain better PAPR performance. The combination between MCS and companding methods are proven to be effective to further reduced the PAPR with 74.72% improvement for MCS-Mu-law and 74.08% for MCS-A-law respectively as compared to MCS. This improvement is driven by the compression process that were implemented to the alternative codeword and as a result a much lower PAPR value can be achieved.

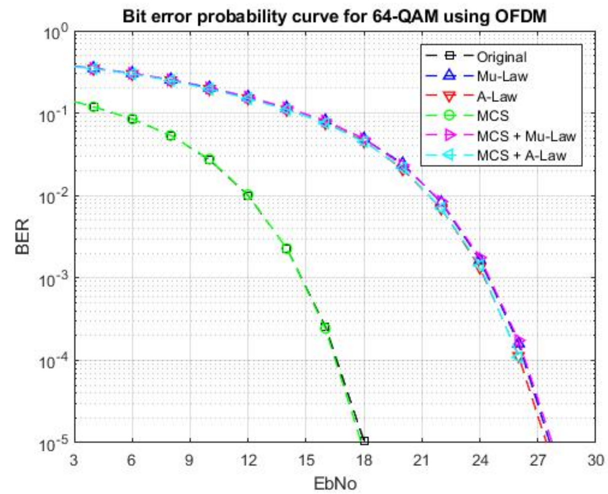

Fig 9: BER performance for hybrid MCS

Table 6: BER analysis of MCS and hybrid MCS

	BER (dB)	Degradation (%)
Conventional OFDM	17.8	-
Mu-law	21.8	22.47
A-law	21.4	20.22
MCS	17.8	0
MCS + Mu-law	21.8	22.47
MCS + A-law	21.4	20.22

Fig 9 represents the BER performance for conventional OFDM, companding technique, MCS and hybrid MCS. As expected, the degradation in BER performance when companding technique is implemented to the system is inevitable with 22.47% and 20.22% for Mu-law and A-law respectively. This result may be explained by the fact that expansion process at the receiver amplified the large signal a long with their noise and this will cause the introduction of in-band noise and out-band interference [13][22]. However, it can be seen here that hybrid MCS managed to maintain the BER performance without any further degradation. With an average of 74.4% improvement in PAPR reduction and 21.4% degradation in BER performance, it can be conclude that hybrid MCS has a good trade-off between the two parameters.

Table 7: MCS and hybrid MCS system performance

	PAPR (db)	BER (dB)
MCS	7.90	16.4
MCS + Mu-law	2.00	21.8
MCS + A-law	2.05	21.4

Table 7 shows the overall system performance for both MCS and hybrid MCS in terms of PAPR reduction and BER degradation. The combination of MCS and Mu-law gives a better PAPR reduction as compared to the combination between MCS and A-law with a slight difference of 0.05 dB. However, when it comes to BER performance, combination between MCS and Mu-law produces approximately 2% higher degradation as compared to combination between MCS and A-law.

VI. CONCLUSION

In this paper, the high PAPR issue in OFDM system has been dealt with the new proposed method called MCS. Simulation results revealed that MCS can fulfill it purpose with 24% improvement as compared to conventional OFDM system and at the same time maintaining its BER performance. Not only that, MCS also managed to outperform SCS with 4.8% improvement in PAPR reduction. The combination of MCS and companding technique offer better PAPR reduction with an average of 74.4% improvement in exchange to an acceptable percentage of degradation in BER performance.

ACKNOWLEDGMENT

We are grateful to the Faculty of Electrical Engineering, Universiti Teknologi MARA (UiTM) Shah Alam, Selangor for providing the insight and expertise that greatly assist this research.

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