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PAPR Reduction in Cyclic Prefix OFDM (5G) System using Group Codeword Shifting Technique

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ABSTRACT

Cyclic Prefix Orthogonal Frequency Division Multiplexing (CPOFDM) is a 5G multicarrier waveform that enables high data rates and spectrum efficiency improvements. The primary drawback of CPOFDM is that it has a high peak to average power ratio (PAPR), which is a characteristic of all multicarrier modulation techniques. We study the application of a Group Codeword Shift (GCS) approach to reduce the peak to average power ratio (PAPR) in a CPOFDM system in this article. Additionally, we compared the results of peak to average power ratio (PAPR) reduction with low complexity in CPOFDM using a Group Codeword Shift (GCS) approach, Selective Codeword Shift (SCS), Median Codeword and Conventional CPOFDM.

1. Introduction

Many studies and technique have been proposed to overcome on high PAPR value, by introduce few techniques for reduce the high PAPR value that can be divided into three main approaches [1-5]. First the Signal Scrambling Techniques can be classified as Selective Mapping (SLM), Partial Transmit Sequence (PTS), Selective Codeword Shift (SCS), Interleaving, Tone Reservation (TR), Tone Injection (TI) and Active Constellation Extension (ACE). Secondly the Signal Distortion Techniques can be classified as Clipping & filtering, Companding, Peak Windowing and Envelop Scaling. Thirdly Signal Coding Techniques can be classified as Block Coding and Turbo Coding. On the past research show the potential in PAPR reduction but they had to face with the trade off with some of the problem such as high computational complexity, degrade bit error rate (BER) performance, side information, loss data rates, bandwidth, loss spectral efficiency and distortion. In Block Coding technique it can be divide into two such as Arithmetic coding and Huffman coding, the Arithmetic coding is better on reducing PAPR by 32% compare Huffman only 30.6% [6]. The Clipping & Filtering technique is the

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simplest technique to reduce PAPR and it is depended on clipping level that satisfies the signal to quantization noise ratio (SQNR) [7]. PTS technique is better in reduce PAPR value compare with SLM and Clipping and filtering technique [8].

The Selected Mapping (SLM) technique is multiple phase rotations are applied to the constellation points and the one used that minimizes time signal peak is used and selective mapping involve to generate a large set of vector with lowest resulting PAPR is selected. This technique actual transmit signal lowest PAPR is selected from set of sufficiently different signal which all represents the same information [4,9]. The advantage of SLM such as no distortion is introduced and Independent number of carrier while the disadvantage such as side information and degrade BER performance [10-12]. Due to this disadvantage the combination of SLM and clipping technique been applied to reduce PAPR [5]. The modified of SLM with M-QAM technique improve the PAPR value nearly 3.4dB [8].

In SLM technique it reduces PAPR value but at the same time it compromises the data rate of the system and also the computational complexity. For to choosing which technique that can reduce high PAPR value few criteria need to taking into account such as BER degradation at receiver, data rate loss, computational complexity, power increment in transmitted signal, PAPR reduction capability and bandwidth expansion [13-15]. The Selective Codeword Shift (SCS) technique has shown significant improvement reducing PAPR compared original signal and conventional SLM, however this technique only effective for modulation higher than 4 QAM or higher than 2 bits per symbol. The advantage of this technique are low computational complexity as compared to SLM technique in term of IFFT block used and no multiplication of phase factor involve in transmission process [16,17]. In the SCS technique the codeword is circulant shifting and the time to complete this circulant shifting is longer because the codeword take a long path to travel. The effect of that, the value of PAPR and BER will not reduce so much in SCS technique. In this paper the Group Codeword Shifting (GCS) is propose, the codeword is divided into 2 parts (part A and part B) so it will make a shorter path for codeword to shifting. The value of PAPR and BER is reduce more compare than SCS technique on GCS.

2. Methodology

2.1 Cyclic Prefix Orthogonal Frequency Division Multiplexing (CP-OFDM)

Since January 2016, the 3rd Generation Partnership Project (3GPP) has been working to standardise 5G New Radio (NR), a new Radio Access Technology (RAT) that will ensure the performance, compatibility, and quality of 5G devices and networks under the next-generation global standard. This will enable the realisation of services such as virtual reality, augmented reality, artificial intelligence, self-driving vehicles, and the Internet of Things (IoT). To supply the aforementioned services, a new generation of mobile communication systems will be required, since these systems will be built on more dependable, quick, and even faster interconnection [18].

To support all of the services that the 5G standard is intended to provide, there are three primary problems that 5G NR must address in order to allow a completely networked society: increased data rates, more reliable and low-latency transmissions, and a large increase in the number of devices. These hurdles result in three broad use cases: enhanced mobile broadband (eMBB), which requires extremely high data rates and large bandwidths, e.g., highly mobile UE connected to macrocells; ultra-reliable low-latency communications (uRLLC), which requires extremely high credibility and availability as well as very low latency, e.g., power system automation and factory processes; and massive machine type communications (mMTC), which requires very minimal energy consumption at the UE, high connectivity, and low late[18-20].

In NR Release 15, the 3GPP opted to use CP-OFDM for both downlink and uplink physical-layer radio access [21]. Due to the fact that 5G NR is based on OFDM (as is LTE), it has a benefit in that it enables devices to maintain a low level of complexity and hence inexpensive hardware costs. Furthermore, a single OFDM numerology, defined by subcarrier spacing and cyclic prefix length, is incapable of meeting performance limitations over the necessary frequency range and all suggested deployment alternatives and scenarios. This is why the OFDM numerology must be tailored to the unique service requirements, operation frequencies, and deployment conditions [18,22]. The cyclic prefix (CP) orthogonal frequency-division multiplexing (OFDM) because to its numerous advantages, including effective support for multiple-input multiple-output (MIMO) and granularity in frequency-domain resource allocation [21]. OFDM's well-known drawbacks include a high out-of-band (OOB) power consumption, susceptibility to frequency offset, and a high peak-to-average power ratio (PAPR) [23-25]. A significant drawback of any multicarrier system, including CP-OFDM, is the high peak-to-average power ratio (PAPR), which is caused by the time domain random addition of subcarriers. Consider the following four sinusoidal impulses with varying frequency and phase changes. When the peak amplitudes of the several signals are synchronised at the similar moment, the resultant signal envelope exhibits prominent peaks. Due to the high peaks, the transmitter's power amplifier works in the nonlinear zone, resulting in deformation and spectral dispersion. Additionally, when the number of subcarriers rises, the output power's variation increases as well [26]. Beside that the CP-OFDM, out of band (OOB) emission is highly efficient in the time domain, resulting in the need for time and frequency synchronizations, since the OOB emission created interference with neighbor channels. Due to the fact that restrained synchronization adds additional time (latency) to the system's operation, this higher latency needs increased power consumption [27].

Cyclic Prefix (CP) a duplicate of the Orthogonal Frequency-Division Multiplexing (OFDM) symbol waveform tail injected at the beginning is used to alleviate multipath channel delay spreading and resulting intersymbol interference (ISI). As a result, with adequate time sampling of the received signal and a CP length at least significantly greater than the largest forecast channel delay spread, not simply ISI and yet also Intercarrier Interference (ICI) will be avoided altogether [28,29]. The length of the CP is determined by the wireless channel's impulse response. The choice of CP in cellular systems is determined on the propagation circumstances and cell size. Although its durability in multipath channels, CP-OFDM deployment in wireless transmitters presents certain challenges. CP-OFDM signals utilise CP for a longer period of time than the channel's time spread, resulting in a loss in spectral efficiency [30, 31]. In CP-OFDM, the source symbols are first baseband modulated using one of the modulation standards, such as QAM. The IFFT function is utilized to transfer the modulated symbols X_k, k=0, 1, 2..., N-1 from the frequency domain (FD) to the time domain (TD), resulting in the discrete baseband OFDM signal x (n) [32].

$$x(n) = \frac{1}{\sqrt{N}} \sum_{K=0}^{N-1} X_k e^{j2\pi k \frac{n}{N}} \quad , \; n = 0,1,2, \dots, N-1 \tag{1}$$

where N is the number of subcarriers. The discrete baseband OFDM signal is generated by superimposing the K-samples of the input data symbol on top of N-subcarriers in an orthogonal fashion. In OFDM, executing cycle prefix insertion by placing the last portion of the OFDM signal in front of the OFDM symbol prevents the signal from experiencing inter-symbol interference (ISI). In the alternative side, the OFDM signal is constructed by mixing the N-modulated subcarriers. As a result, when the phases of the samples are comparable, the power of select samples may exceed the average power of the signal. Thus, the PAPR value may be expressed as the rate of the signal's greatest instantaneous power divided by the signal's mean power [32].

$$\mathrm{PAPR} = \frac{|\max\,(n)|^2}{E\{|x(n)|^2\}} \tag{2}$$

where E {.} denotes the average value. Additionally, the complementary cumulative distribution function (CCDF) is frequently used to determine the chance that a PAPR value exceeds a specified threshold value [32].

$$\Pr(PAPR > PAPR_0) = 1 - (1 - \exp\,(-PAPR_0))^{NL} \tag{3}$$

where $PAPR_0$ denotes the threshold value and L is the oversampling factor that converts the discrete time signal to the continuous time signal's characteristic; this is accomplished by embedding (L-1) N zeros in the FD samples [32-34].

2.2 Cyclic Prefix Orthogonal Frequency Division Multiplexing (CP-OFDM) based on GCS

This article proposes a novel approach for PAPR reduction by utilizing a permutation process (circulates shift) to build a scrambled data sequence. GSC is concentrating its efforts on the codeword structure and bit layout as a means of reducing PAPR. GSC generates an alternate codeword with a reduced PAPR by modifying these two factors. Finally, the CP-OFDM signal with the lowest PAPR value will be selected for transmission. The construction of a CP-OFDM signal with N subcarriers begins with the serial-to-parallel conversion of the input data to an information symbol. Then the GCS method been applied and using 64-QAM modulation, the information symbol will be transferred to the constellation point. Finally, the modulated symbol is converted to a CP-OFDM signal using the Inverse Fast Fourier Transform (IFFT) and the cyclic prefix is added before signal enter to the Channel. The entire procedure is depicted in Figure 1, the green circular box contains the code for the GCS approach is the main contribution in this research.

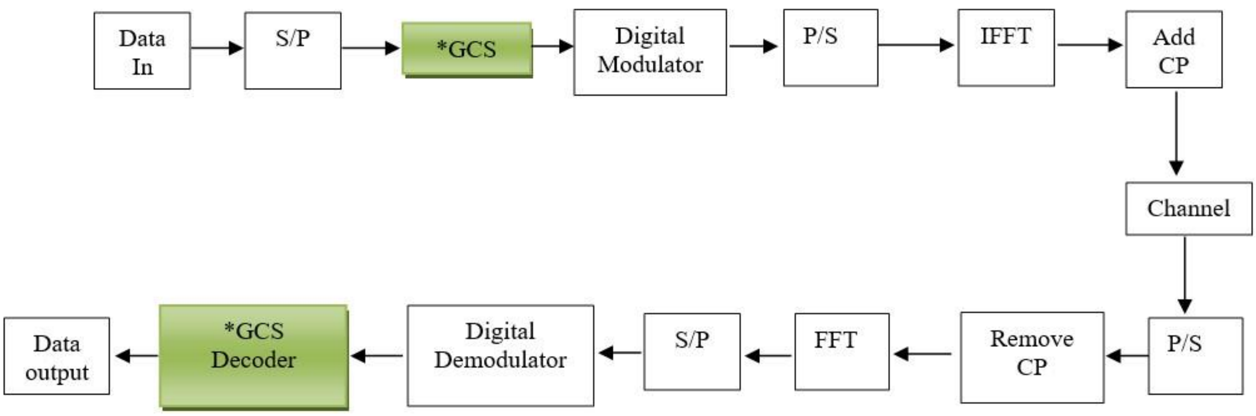

Fig. 1. Block diagram of CP-OFDM GCS

Figure 2 shows the flow chart of overall process involve in reduction of Peak Average Power Ratio and Bit Error Rate by implemented GCS method in CP-OFDM. The first step starts by convert the input data from serial to parallel, then the Group Codeword Shifting method (GSC) will be applied with 64 QAM modulation, and the information symbol will be transferred to the constellation point. The output data will be converted form parallel to serial, then the signal go through IFFT process and cyclic prefix will be added at the signal. Later the PAPR will be calculated and the minimum PAPR will be selected to transmitted, and graph of PAPR will be plot. Signal the lowest PAPR will transmit through the Channel and Additive White Gaussian Noise (AWGN) process happen here. Then the data will convert from parallel to serial and cyclic prefix will be removed from the signal. After removed cyclic prefix data will go through FFT process and data will be convert from serial to parallel, later demodulation and GSC decoding will be applied and lastly the data will be calculated BER and graft of BER will be plot.

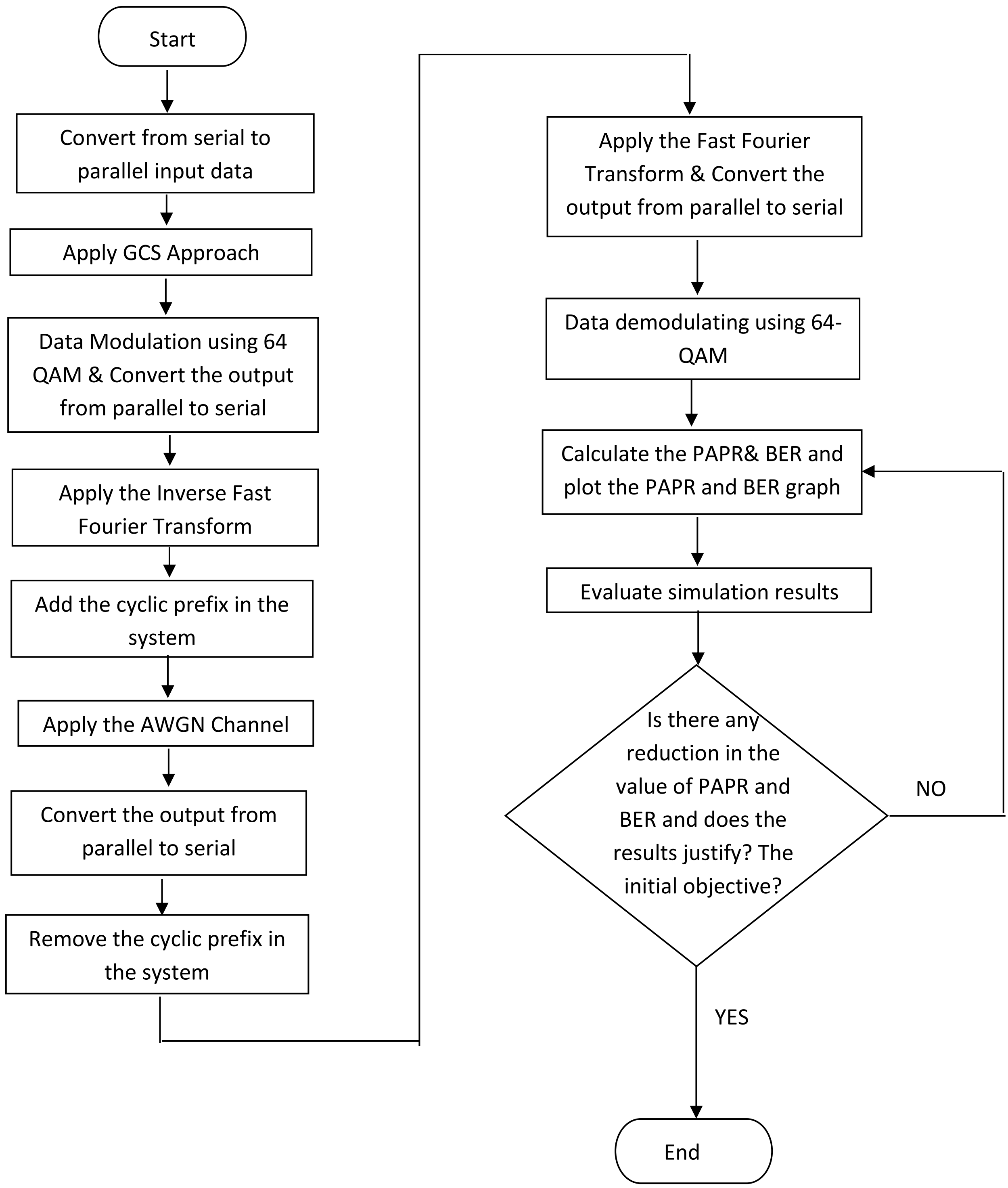

Fig. 2. Flowchart of the simulation process

The Group Codeword Shifting approach is used in this research to produce alternative codewords by modifying the codeword structure and then utilising permutation (circulant shift) to construct a scrambled data sequence for improved PAPR reduction. This Group Codeword Shifting approach is aimed at decreasing PAPR by modifying the codeword and bit structure. By changing these two factors, an alternative codeword with a lower PAPR will be generated.

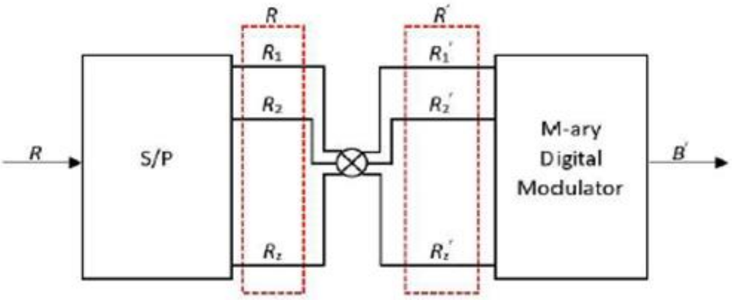

Fig. 3. GCS sub-block

As shown in Figure 3, R represents the binary sequence codeword having r total number of input bits and can be indicated as R = [R_1, R_2, … , 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, … , 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 $R1$ = [$R1$, $R2$, $R3$, , … , Ry], $R2$ = [Ry+1, Ry+2, Ry+3, … , $R2y$] and so on until Rz.

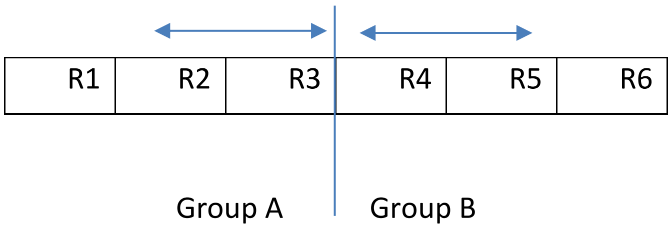

Fig. 4. Group Codeword Shifting structure

The Group Codeword Shifting approach begins by separating the codeword into two group, A and B, as illustrated in Figure 4. The next stage is when the alternative codeword is generated by performing the circulant shift between parts A and B one at a time. By modifying the codeword's structure, you may significantly improve PAPR performance. A shorter codeword distance results in greater PAPR reduction. The advantage of the shifting process in GSC is that it provides the system with the flexibility to send signals with a lower PAPR. Meanwhile, traditional CP-OFDM is inefficient since it generates just a single output signal. Table 1 illustrates the various placements bits of codewords for the numbers of shifting processes for easier interpretation. As a result, the alternate GCS CP-OFDM sent signal is as follows:

$$x'(n) = \frac{1}{\sqrt{N}} \sum_{K=0}^{N-1} R'_k e^{j2\pi k \frac{n}{N}} \quad , \; n = 0,1,2, \ldots ., N-1 \qquad (4)$$

where N is number of CP-OFDM symbol and (kk) is Additive White Gaussian Noise (AWGN) in frequency domain.

To help clarity, Table 1 illustrates the location of bits following a number of shifting processes. Codeword R1, 0 represents the beginning location of the codeword bits. When a shift occurs between parts A and B, the new bit position is indicated by the Codeword R1, 1. R′ = [R1′, R2′..., Rz′] is the new alternative codeword sequence. Lastly, the CPOFDM signal with the smallest PAPR value will be selected for transmission.

Table 1
Bit arrangement of codeword for Group Codeword Shifting Method

Sub-block codeword bits, $R_{z,\delta}$	Position of bits
Codeword, $R_{1,0}$	R1, R2, R3, R4, R5, R6
Codeword shift 1, $R_{1,0}$	R4, R2, R3, R1, R5, R6
Codeword shift 2, $R_{1,2}$	R1, R4, R3, R2, R5, R6
Codeword shift 3, $R_{1,3}$	R1, R2, R4, R3, R5, R6
Codeword shift 4, $R_{1,4}$	R5, R2, R3, R4, R1, R6
Codeword shift 5, $R_{1,5}$	R1, R5, R3, R4, R2, R6
Codeword shift 6, $R_{1,6}$	R1, R2, R5, R4, R3, R6
Codeword shift 7, $R_{1,7}$	R6, R2, R3, R4, R5, R1
Codeword shift 8, $R_{1,8}$	R1, R6, R3, R4, R5, R2
Codeword shift 9, $R_{1,9}$	R1, R2, R6, R4, R5, R3

3. Result and Discussion

The PAPR effectiveness of GCS will be examined in this part via simulation. N = 128 arbitrary input symbols are created in the simulation, then they are all mapped using 64-QAM modulation. Rayleigh channel will be used to broadcast the CP-OFDM signal. To decrease the influence of inter-symbol interference, a cyclic prefix with a length of 1/4 is added to the CP-OFDM symbols (ISI). Table 2 summaries all of the parameters utilized in the simulation method.

Table 2
Simulation parameters for 3rd Generation Partnership Project Long Term Evolution (3GPP-LTE) System [35]

Parameter	Value
Bandwidth (BW)	1.25MHz
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	AWGN

The PAPR effectiveness of original CP-OFDM, SCS, MCS and GCS is depicted in Figure 5. While Table 3 contains the PAPR evaluation results for CPOFDM on SCS, MCS and GCS. At BER = 10^{-3}, the original value of CP-OFDM is 11.20dB; the percentage enhancement for SCS over CP-OFDM is 25.89 percent at 8.30dB; while for MCS is 29.46% enhancement at 7.90db and for GCS, the percentage gain is 41.07 percent at 6.60dB. By altering the codeword structure, taking into account the effect on GCS PAPR effectiveness. Divided codeword structures result in the shortest codeword distance when compared to the intact codeword structures employed in SCS and MCS. The distance between codewords should be reduced as specified in order to get the best PAPR reduction. The benefit of GCS is the shifting process, which allows for the development of new codeword and the system's capacity to send the signal with the smallest PAPR. This is not the case with traditional CP-OFDM, which has a single output signal.

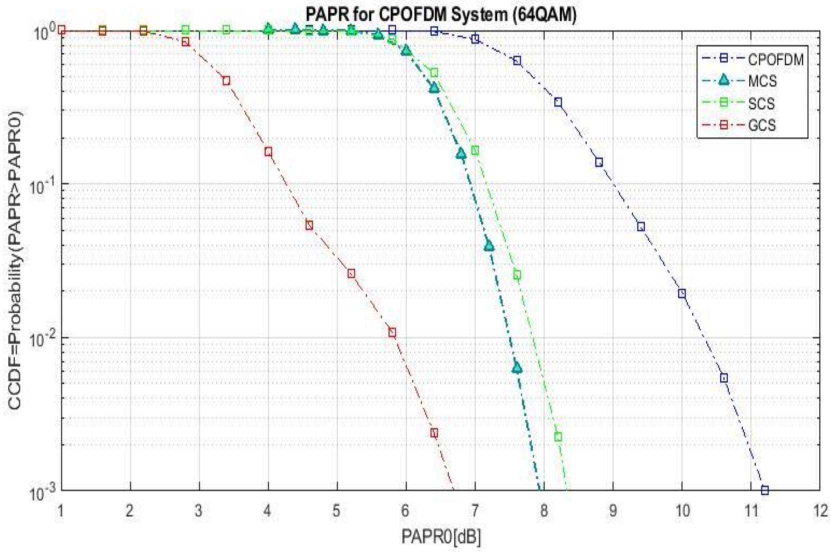

Fig. 5. PAPR performance for GCS, MCS, SCS and Original on CP-OFDM

Table 3
PAPR analysis of GCS, MCS, SCS and Original CP-OFDM (PAPR = 10^{-3})

	PAPR	% of Improvement
Original	11.20	-
SCS	8.30	25.89
MCS	7.90	29.46
GCS	6.60	41.07

The BER effectiveness of original CP-OFDM, SCS, MCS and GCS is depicted in Figure 6. While table 4 contains the BER evaluation results for CP-OFDM on SCS, MCS and GCS. At BER = 10^{-5}, the original value of CP-OFDM is 17.90dB; the percentage enhancement for SCS and MCS over CP-OFDM is 0.28 percent at 17.85dB; and for GCS, the percentage gain is 1.68 percent at 17.60dB. By adjusting the codeword layout in light of its implications on GCS BER efficiency.

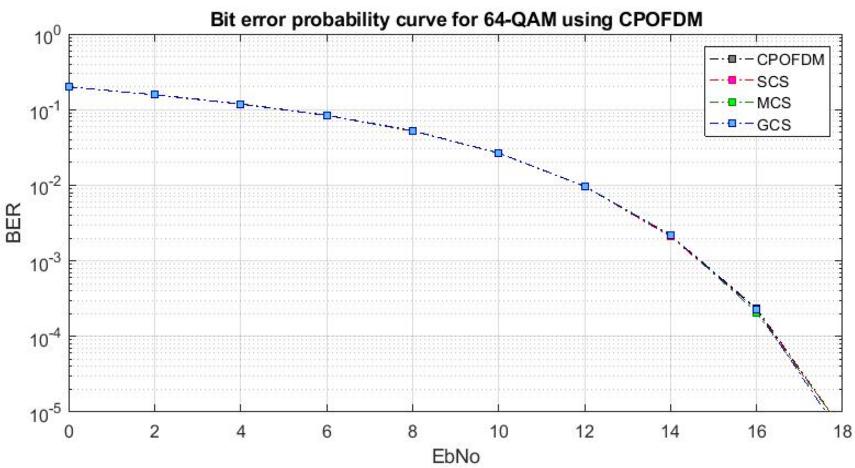

Fig. 6. BER performance for GCS, MCS, SCS and Original on CP-OFDM

Table 4
BER analysis of GCS, MCS, SCS and Original CP-OFDM (BER = 10^{-5})

	BER	% Of Improvement
Original	17.90	-
SCS	17.85	0.28
MCS	17.85	0.28
GCS	17.60	1.68

4. Conclusions

In this research, a GCS approach has been developed to decrease PAPR that the fundamental concern of CP-OFDM systems. The GCS has showed a considerable improvement in minimizing high PAPR when compared with original signal CP-OFDM with 25.45 percent . However, this approach has a constraint that only works for modulation greater than 4 QAM or more than two bits per symbol. The benefit of GCS approach is reduced computing complexity by lowering the utilization of IFFT block in the system comparing with SCS, MCS and original CP-OFDM. The implementations of this GCS approach will be performed at the transceiver. Further study has to be carried out to analyze the PAPR effectiveness of GCS scheme in other modulation approaches for additional applications.

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