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Peak-to-Average Power Ratio (PAPR) Reduction Method using Hybrid Codeword Shifting (CSC+CVMT) in an F-OFDM System

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ABSTRACT

One of the potential technologies for a future wireless network is filtered-OFDM (F-OFDM). The capacity to handle numerous asynchronous sub-band transmissions is necessary in order to accommodate the diversity of services. However, multicarrier transmission systems with multiple subcarriers transmit signals with high Peak-to-Average Power Ratios (PAPR). The high PAPR value, which results in performance degradation and high-power consumption as a consequence of various distortions, therefore constitutes a significant challenge with the F-OFDM system. In order to obtain improved PAPR reduction, the Cluster Scrambling Codeword (CSC) method and its hybrid precoding approach are developed in this paper, which aims to add to this expanding field of research. This novel concept of the bit-data sequence shifting approach can reduce PAPR more effectively than the traditional scheme. In comparison with the conventional F-OFDM system, the simulation results indicate that the hybrid codeword shifting methodology, CSC+CVMT, achieves a 53.84% PAPR improvement at 4.2dB.

1. Introduction

In the new global network system, the wireless communications new generation users are demanding on the high-speed data with low latency which indicates the service efficiency. A phenomenal rate of growth is being experienced by wireless communications, particularly mobile communication systems. The demand for new applications, traffic types, and data services, as well as the growing number of users, place a strain on radio communication systems. Based on current mobile communication system, orthogonal frequency division multiplexing (OFDM) has been widely being applied in various filed as it is well popular for high bandwidth network schematics [1]. The

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OFDM is the digital modulation technique to render high data rate communication that uses encoded digital data onto a number of the orthogonal subcarriers. In other words, OFDM goes by dividing the frequency selective channel into multiple parallel subcarriers. Since the symbol duration is substantially longer than the root mean square (RMS) delay spread of the visible light communication (VLC) wireless channel, this multicarrier modulation not only demonstrates great spectral efficiency but also has inherent resilience against Inter-Symbol Interference (ISI) [2]. In addition, by adapting the frequency selective fading channel into a flat fading channel, OFDM reduces multipath fading. Since an OFDM signal is made up of several independently modulated sub carriers. The transmit signals may encounter large peak values in the time domain throughout an IFFT operation due to the addition of several subcarrier components in an OFDM system. Therefore, it is commonly known that OFDM systems have a larger PAPR than single-carrier systems. The high Peak-to-Average Power Ratio (PAPR) value, however, has a significant negative impact on the performance of OFDM systems.

In recent years, researchers have shown an increased interest on improving the network performance in order to deal with forthcoming demands on wireless communication network system [3]. On the contrary, as a candidate for 5G and 6G system, Filtered Orthogonal Frequency Division Multiplexing (F-OFDM) have been introduced. For F-OFDM system, in order to facilitate diversification in future services beneficial towards growth users' demand on wireless network system and the capability to deal with multiple asynchronous sub-band transmission, multicarrier modulation technique is introduced. At a certain width, the system bandwidth is divided into many sub-bands, and each sub-band is then filtered separately [4]. Seem like F-OFDM system basically using OFDM as its core waveform [5,6], this system will also suffer the same issue which is high PAPR value.

It is highly undesirable for having high PAPR value in the system, since it will degrade system performance which causes by non-linear distortion when passes through power amplifier prior to transmission mentioned by Rateb *et al.,* [7]. This will lead to power deficiency throughout the system. There are studies have been conducted on the method for PAPR reduction on the network system. These techniques can be classified under few categories:

i. coding scheme where it will choose the codewords with minimum value of PAPR for transmission [8-14]
ii. multiple signaling which it will generate signal permutation and minimum peak in envelope be selected to transmit e.g., Partial Transmit Sequence (PTS) and Selective Mapping (SLM) [15-21]
iii. signal distortion scheme is simplest implementation and the signal is distorted before to a high-power amplifier, such commanding, clipping and filtering [22-25]
iv. hybrid technique which is combination of methods in order to have optimal minimum PAPR [26-32]

The main aim of this study is to develop a good algorithm that is required in order to address high PAPR problem with the consideration of signal data rate loss issues. With this aim in mind, this paper presents a new technique to deal with PAPR reduction called as hybrid to Cluster Scrambling Codeword Shifting method. This technique is the combination of two coding methods which are codeword shifting and precoding approach. Cluster Scrambling Codeword (CSC) shifting method is a technique that implementing codeword shifting process without changing the original codeword structure itself. It is feasible to generate alternative codewords with a lower PAPR by manipulating the codeword structure and permutation process, which gives more alternatives for bit position arrangement. While in the precoding approach, a suitable precoding matrix transforms the input symbols into the new symbols before carrying out the IFFT operation. The purpose is to develop alternative candidates by precoding bit sequence techniques that can mitigate high PAPR in the F-OFDM system.

2. Methodology

2.1 Peak-To-Average Power Ratio (PAPR) in OFDM

Studies of PAPR shows the effect towards power consumption efficiency that causes by in-band distortion and undesired spectral spreading. This performance being used by measuring the sensitivity of transmission scheme towards non-linear amplifiers that having a non-constant envelope studied by Cheng *et al.,* [33]. In the direction, to avoid the multicarrier signal's spectral development through intermodulation between subcarriers and out-of-band radiation, which leads to inefficient power conversion, the transmit power amplifier must always be operated in its linear region. The ratio of the peak power to the average signal power within a single IFFT block (one OFDM symbol) is known as the PAPR.

The IFFT of the OFDM modulated subcarriers for signal with N orthogonal subcarriers $x = [x_0,\ x_1,\ \ldots, x_{N-1}]^T$ equation can be implying as

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \,.\, e^{j2\pi f_k t} \tag{1}$$

where X_k is OFDM symbol frequency at f_k and $e^{j2\pi f_k t}$ is IFFT sinusoid. In the meantime, the OFDM system's average signal power was obtained by

$$E = \frac{The\ total\ magnitude\ of\ all\ OFDM\ symbols}{The\ number\ of\ OFDM\ symbols\ (N)} \tag{2}$$

While with provided over a time interval, the complex baseband signal's PAPR mathematical equation is given by

$$PAPR\ (dB) = 10 \log \left[\frac{P_{peak}}{P_{avg}}\right] = 10 \log \left[\frac{max_t |x(t)|^2}{E_t[|x(t)|^2]}\right] \tag{3}$$

where $x(t)$ is amplitude of the complex pass-band signal, $max|x(t)|^2$ is the maximum signal power and $E\ [.]$ is the expectation factor.

A number of research have already demonstrated that the Complementary Cumulative Distribution Function (CCDF) is typically presented for PAPR performance. As the number of subcarriers, N, increases, so does the PAPR CCDF. PAPR performance is measured by determining the probability of a $PAPR$ symbol surpassing the $PAPR_0$ threshold level.

$$CCDF(PAPR) = Prob(PAPR > PAPR_0) \tag{4}$$

2.2 Codeword Shifting Technique

Dealing with the high PAPR problem using Cluster Scrambling Codeword (CSC) shifting. applying the shifting method to the codeword without altering its original codeword's structure. The chance to further enhance this strategy is created by altering the codeword's structure before the shifting process starts. By doing so, more bit placement choices can be evaluated, resulting in alternative codewords with lower PAPR studied by Abd Jabar *et al.,* [34]. By inventing a novel bit sequence methodology that can minimize and is capable of decreasing high PAPR in the F-OFDM system to produce alternative codewords by manipulating the codeword structure and bit shifting. The primary methodological approach is to alter the codeword structure and the permutation process, which is the key to improved PAPR reduction [11].

In furtherance of this hybrid technique, the proposed method of F-OFDM system is shown in Figure 1. The formation for N subcarriers' number of OFDM signal as the input data symbol through the medium of serial-to-parallel block process. At that point, codeword shifting process will take places before the modulating process that mapped the information symbol into constellation point. Subsequently, the modulated symbol will be transformed into an OFDM signal using the Inverse Fast Fourier Transform (IFFT).

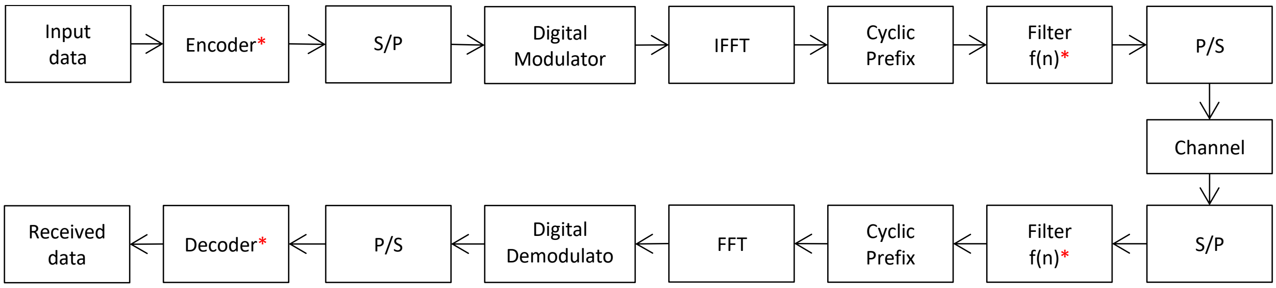


Fig. 1. The proposed F-OFDM system's block diagram

In F-OFDM, a filter is applied to a time domain OFDM symbol to enhance out-of-band radiation of a sub-band signal while keeping the complex domain orthogonality of the OFDM symbols. Therefore, the alternative OFDM transmitted signal given a

$$x'(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} Y'_k W_N^{nk} \quad (5)$$

where Y'_k is the binary shifted codeword sequence of OFDM signal and $W(k)$ is noise in frequency domain.

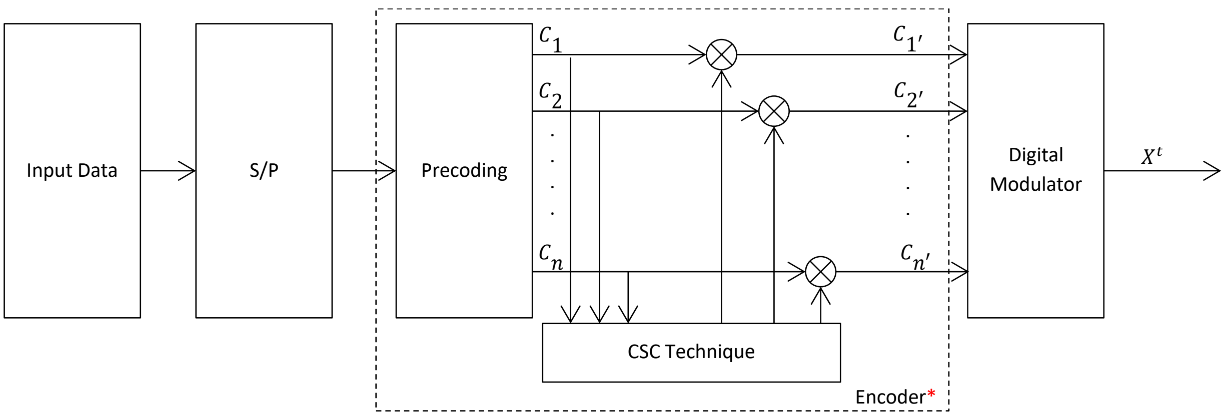


Fig. 2. Block diagram on proposed technique

As in Figure 2, the binary sequence codeword C is represented by the notation $C = [C_1, C_2, \dots, C_z]$, and it has z input bits total. The codeword sequence will be divided into p number of sub-blocks by the serial to parallel converter, indicated by $C' = [C_1', C_2', \dots, C_n']$, and each sub-block will contain r number of bits per symbol where $n = z/r$.

A precoder matrix $\boldsymbol{P}$ creates a new vector Y by precoding the information symbols of length N designate as

$$\begin{bmatrix} Y_1 \\ Y_2 \\ \cdots \\ \cdots \\ Y_{N-1} \end{bmatrix} = \begin{bmatrix} \\ \boldsymbol{P} \\ \\ \end{bmatrix} \times \begin{bmatrix} C_1' \\ C_2' \\ \cdots \\ \cdots \\ C_{N-1}' \end{bmatrix} \quad (6)$$

In this study, the simulation work begins with an OFDM system model using MATLAB and system parameters obtained from the 3GPP-LTE standard described by Mousavi *et al.,* [35]. The proposed method's evaluation will be conducted using the OFDM system that was used in this study as a benchmark. Once the OFDM system has been designed appropriately, the hybrid codeword scrambling technique's performance evaluation for F-OFDM can be done. An outline of the simulations using the MATLAB programming language are carried out is shown in Figure 3. In order to transmit to the channel module, the candidate with the lowest PAPR among all candidates is selected.

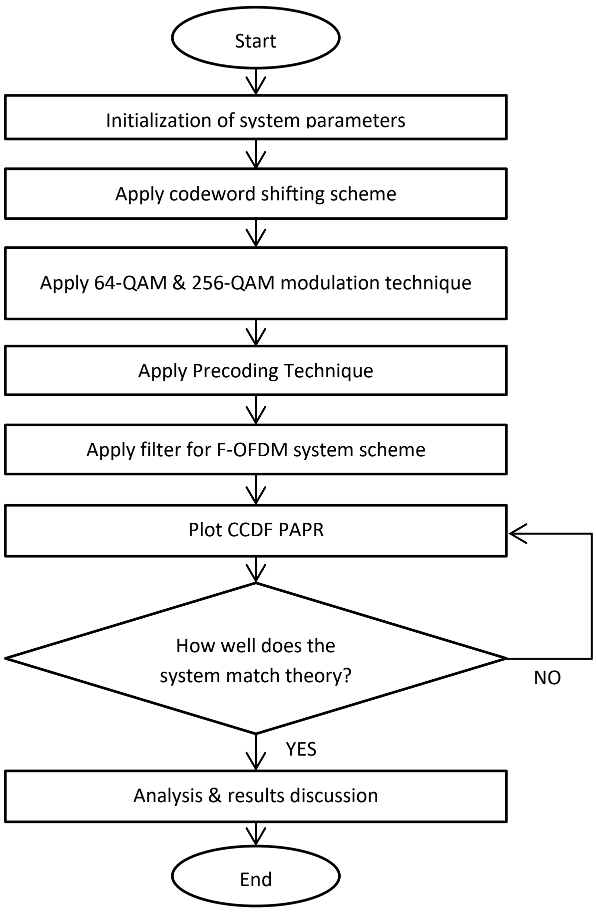


Fig. 3. Flow chart of proposed research method

These were generated using the implementation algorithm, pictured on research flow chart in Figure 3. The process flow was originally designed by specifying the parameter for the entire system. At that point, before the signal is digitally modulated, a codeword shifting technique will be implemented to generate a few of signal candidates. These signals are subsequently multiplied by a precoding matrix. Then, filter is implied for the F-OFDM system.

2.3 Precoding

The PAPR reduction methods based on precoding commonly request for a straightforward linear computation that may be carried out without the need for additional side information. The precoding methods don't need to transmit side information to the receiver [36-38]. Before the IFFT operation, each modulated symbol block will be multiplied by a precoder matrix for the precoding approach as illustrate in Figure 2.

2.3.1 Discrete Hartley Matrix Transform (DHMT)

The transform could well be interpreted as the multiplication of the vector $(p_0, \dots, p_{N-1})$ by an $\boldsymbol{N}$-by-$\boldsymbol{N}$ matrix; thereby, the Discrete Hartley Transform is a linear operator by Baig and Jeoti [39]. Thereabouts, DHMT has frequently been used to precode frequency-domain signals that can alleviate the consequences of deep fading or spectral null effects.

$$p_{a,b} = \frac{1}{\sqrt{N}}\left[cos\left(\frac{2\pi}{N}ab\right) + sin\left(\frac{2\pi}{N}ab\right)\right] \tag{7}$$

2.3.2 Zadoff-Chu Matrix Transform (ZCMT)

The matrix $\boldsymbol{P}$ in the ZCMT precoding methodology is formed using the Zaddoff-Chu (ZC) sequence. A mathematical sequence with the best correlation properties is the ZC sequence, which has the form $z = [z_0, z_1, \dots, z_{L-1}]$ by Baig and Jeoti [40]. The initial root of the ZC sequence has an even length L (where $L = N \times N$) is written by

$$z_k = exp\left(j\frac{\pi}{L}k^2\right) \quad k = 0, 1, \dots, L-1 \tag{8}$$

$$p_{a,b} = \frac{1}{\sqrt{N}}z_{aN+b} = \frac{1}{\sqrt{N}}exp\left(j\frac{\pi}{L}(aN+b)^2\right) \tag{9}$$

2.3.3 Vandermonde-Like Matrix Transform (VLMT)

In linear algebra, a matrix known as a Vandermonde matrix—eponymous for Alexandre-Théophile Vandermonde which is a matrix where each row of the matrix represents the terms of a geometric progression: an $m \times n$ matrix studied by Lundengård [41]. For each element of the precoding matrix in the m row and n column

$$p_{a,b} = \sqrt{\frac{2}{N+1}}cos\left(\frac{\pi}{N-1}ab\right) \quad 0 \le a, b \le N-1 \tag{10}$$

2.3.4 Complex Vandermonde Matrix Transform (CVMT)

Reducing PAPR in OFDM systems can be decreased significantly while using Vandermonde matrices with Chebyshev nodes, as was discovered [29,36]. This technique, which was presented by Md Mahmudul in Ref. [42], substantially reduced PAPR without compromising the extent to which the error performance of the systems is negatively affected.

$$p_{a,b} = \frac{1}{\sqrt{N}} exp\left(-j\frac{\pi}{2N}(N-2a)(N-2b)\right) \tag{11}$$

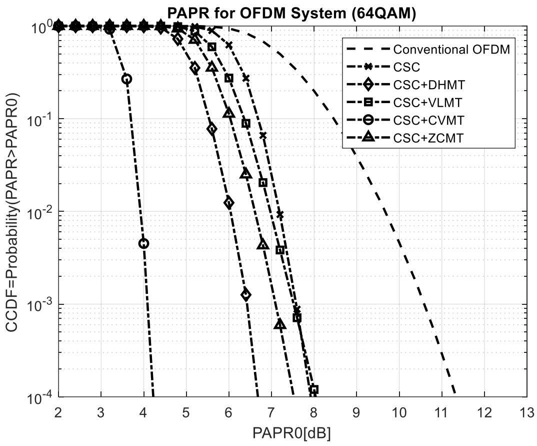
The effectiveness of the Vandermonde-Like Matrix (VLM) for PAPR reduction has been demonstrated through previous studies, and it does not increase computational complexity nor degrade system error performance. Even so, it contains a flaw that causes PAPR reduction performance to decrease as the number of subcarriers increase. The exponential expansion of the numerical condition is one of the Vandermonde matrix's properties. So, these drawbacks may be avoided by placing the nodes on the unit circle where these nodes are restrictedly at linear succession of points. Thereby the, like mentioned by Hasan [42], the Complex Vandemonde Matrix (CVM) that is based on the discovering of unity's roots has been employed to counter the PAPR issue.

3. Simulation Result and Discussion

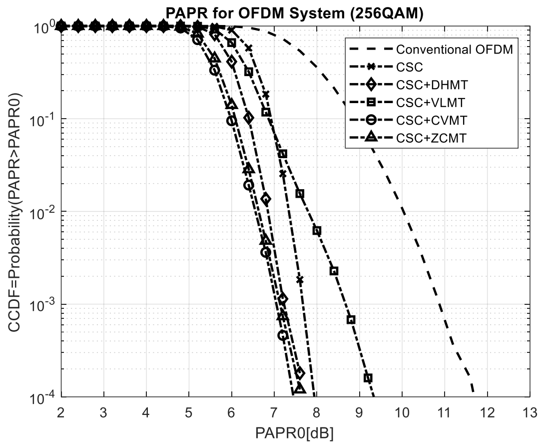
After reviewing related literature, the primary substance of the study is presented in this section where the PAPR reduction performance of hybrid CSC will be evaluated through simulation. In the simulation used in the MATLAB, N random input symbols are generated and they are all mapped using Quadrature Amplitude Modulation (QAM) scheme. As can be seen from the outcomes, Figure 4 looks into the effectiveness of different approaches for reducing PAPR.

Figure 4(a) shows the comparison on PAPR performance between conventional OFDM technique, codeword shifting technique and hybrid techniques (which is modified codeword shifting with precoding) for 64-QAM. It can be seen from the data in Table 1 (reading at 10^{-2} of CCDF PAPR y-axis) that the precoding techniques significantly more PAPR improvement than the conventional OFDM. It can be seen from the data, the ability of hybrid CSC (CSC+CVMT) scheme towards PAPR reduction is the best compared to other precoding schemes. Apparently, CSC+CVMT manage to outperformed the PAPR reduction compared to conventional OFDM method by 58.33% at 4.0dB. Meanwhile, Figure 4(b) demonstrates the PAPR performance of the several codeword shifting algorithms for simulations mapped using 256-QAM modulation. With the proposed method of hybrid CSC+CVMT, the PAPR performance outperformed the conventional OFDM by 35.00% at 6.5dB as shown on Table 1. Higher order modulation offers the potential for better bandwidth utilization and the capacity to deliver higher data rates with a given bandwidth.

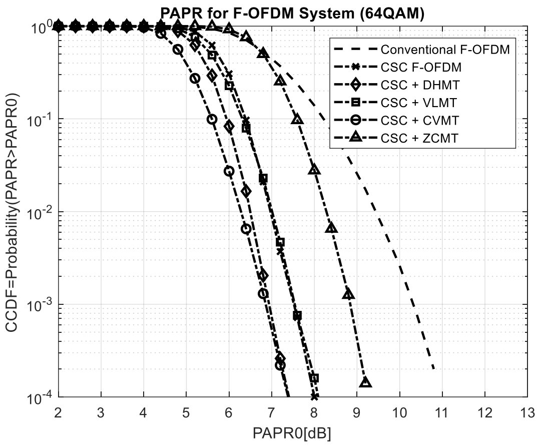
An interesting pattern emerged when analysing the results of OFDM system as shown in Figure 4(a). Instead on Figure 4(c), presents the PAPR reduction of conventional F-OFDM compared to the other techniques. The results obtained shows that there is improvement on PAPR performance when comparing the conventional F-OFDM towards codeword CSC and hybrid CSC methods.



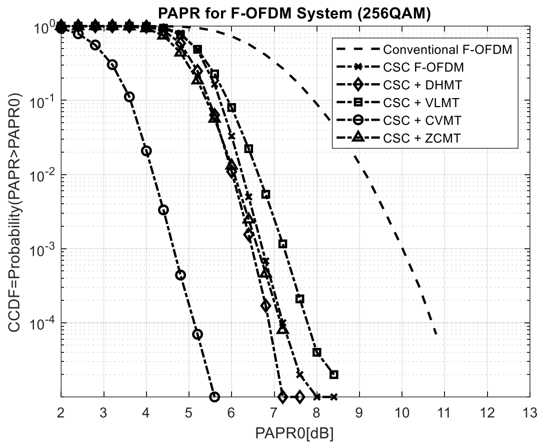
(a) for OFDM 64-QAM



(b) for OFDM 256-QAM



(c) for F-OFDM 64-QAM



(d) for F-OFDM 256-QAM

Fig. 4. PAPR reduction performance between different technique

As shown in Table 1, the PAPR evaluation of precoding methodologies can be compared to the conventional methodology.

As in Table 1, the hybrid CSC+CVMT outperformed by 34.74% at 6.2dB compared to conventional F-OFDM. Furthermore, for Figure 4(d) illustrate the comparison of PAPR performance with proposed methods. The proposed method (CSC+CVMT) considerably out performs the other methods by 53.84% at 4.2dB compared to conventional F-OFDM method as present by data in Table 1. It was found that hybrid CSC (CSC combined with CVMT) performed significantly better for PAPR reduction on both OFDM and F-OFDM systems, which was one of the study's main outcomes.

Table 1
PAPR analysis of precoding techniques vs conventional system

System	OFDM				F-OFDM			
Modulation	64-QAM		256-QAM		64-QAM		256-QAM	
Technique	PAPR (dB)	Improvement (%)	PAPR (dB)	Improvement (%)	PAPR (dB)	Improvement (%)	PAPR (dB)	Improvement (%)
Conventional	9.6	-	10.0	-	9.5	-	9.1	-
CSC	7.2	25.00	7.4	26.00	7.0	26.31	6.2	31.86
CSC + DHMT	6.0	37.50	6.9	31.00	6.5	31.57	6.0	34.06
CSC + VLMT	7.0	27.08	7.8	22.00	7.0	26.31	6.5	28.57
CSC + CVMT	4.0	58.33	6.5	35.00	6.2	34.74	4.2	53.84
CSC + ZCMT	6.5	32.29	6.6	34.00	8.2	13.68	6.1	32.97

4. Conclusions

The main conclusions of this work are drawn together and presented in this section, it has been studied and are shown effective to use the hybrid Cluster Scrambling Codeword (CSC) shifting technique termed CSC+CVMT to address the high PAPR issue in the F-OFDM system. When compared to the conventional OFDM and F-OFDM schemes, this technique can significantly improve the performance of the PAPR value. The simulation results demonstrate that the proposed approach outperforms previous evolutionary algorithms techniques, with a better PAPR reduction of 6.0dB at 34.07% improvement well over conventional F-OFDM system.

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