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A Novel ZCS-Clipping Precoding Technique for PAPR Reduction using DCT-OFDM in Vehicular Channels

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Abstract

IEEE 802.11p defines an international standard for wireless access in vehicular environments. It is normally designed for operating at high user mobility. Thus, decreasing the signal bandwidth to 10 MHz in IEEE 802.11p makes the communication more efficient for the vehicular channel. Furthermore, the Orthogonal Frequency Division Multiplexing (OFDM) methodology is commonly used to mitigate the Inter-Symbol Interference (ISI) occurred over a wireless channel. However, the OFDM suffers from certain drawbacks including higher system complexity due to the generation of the peak to average ratio (PAPR). The objective of this study is to reduce the high PAPR resulted from adapting the OFDM system to vehicular networks. In this paper, we propose a novel precoding Zadoff-Chu Sequence (ZCS) combined with the Clipping technique for PAPR reduction in OFDM based on the Discrete Cosine Transform (DCT). The proposed technique which is based on precoding the constellation symbols of the vehicular channels with DCT succeeds to decrease the PAPR ratio up to 4dB for 64 subcarriers.

Keywords: *Vehicular Networks, Zadoff-Chu Sequence, Peak to Average Ratio, Discrete Cosine Transform, Clipping Technique*

1. Introduction

Intelligent Transportation Systems (ITS) is a major research topic that results from the huge development of both the number of transportation systems and the user's need for technological services [1-3]. The ITS provides a vital direct communication among vehicles themselves and with roadsides within their vicinity, taking the form of Vehicle-to-Vehicle (V2V) and Vehicle-to-Roadside (V2R) respectively. According to the IEEE organization, several studies have been investigated to standardize the communication through IEEE 802.11p. For instance, the Medium Access Control (MAC) specifications are inherited from the IEEE 802.11e whereas the PHY layer specifications come from the IEEE 802.11a using its OFDM modulation [4, 5]. This modulation is mainly utilized to cope with the needed high data rates as well as to challenge the selective frequency channels of vehicular networks.

One of the primary drawbacks of the IEEE 802.11p transmission is the fast-changeable radio channel specifications due to the vehicular nodes high mobility. As a consequence, an efficient OFDM channel technique should be adjusted to overcome the IEEE 802.11p problems. OFDM system encodes digital data on multiple carrier frequencies (*i.e.*, subcarriers). This powerful method is applied on popular schemes for wideband digital communication such as Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB), DSL Internet access, and 4G mobile communications. High speed data rates, high spectral efficiency, high quality service, and robustness against narrow-band interference are the main

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privileges offered by the utilization of OFDM [6, 7]. Typically, the OFDM eliminates the Inter-Symbol Interference (ISI) effect by inserting a guard interval and cyclic prefix. Moreover, it moderates the frequency selectivity of the multipath channel by simplifying the channel equalizer functionalities [8]. Nevertheless, the PAPR effect is still one of the major obstacles in the transmitted OFDM signal [9].

In order to enhance the transmission quality of the OFDM signal over vehicular channels, the PAPR of this signal should be controlled. The ramification of having high PAPR can lead to distortion in electrical devices such as digital-to-analog (DAC) /analog-to-digital (ADC) converters, and nonlinear impacts on the vehicular OFDM signal [10]. Numerous techniques have been introduced to resolve the high PAPR including constellation shaping [11], companding transform [12], clipping and filtering [13, 14], Walsh-Hadamard transform [15], Partial Transmit Sequence (PTS) and selective mapping [16].

In this paper, we present a hybrid technique, namely Zadoff-Chu Sequence-Clipping-Discrete Cosine Transform (ZCS-C-DCT) for reducing the high PAPR resulted in the OFDM vehicular channels. This combination is based on the DCT/IDCT transform. The effect of the PAPR reduction on the bit-error rate (BER) has been experimentally investigated. Through the simulation results, we observe that the proposed combination succeeds to reduce the PAPR without affecting the system BER.

The rest of this paper is organized as follow: Section 2 reviews the related work concerning enhancing the vehicular channels and the usage of ZCS mechanism. The basics of the OFDM system, the main characteristics of channels in vehicular networks and the PAPR problem have been described in Section 3. In section 4, we explain the proposed Clipping-ZCS technique based on DCT/IDCT to enhance the PAPR in vehicular networks. Experimental results and simulation analysis are illustrated in Section 5. Finally, Section 6 concludes the presented work.

2. Literature Review

In vehicular networks, researchers pay attention to the intensification of the signal transmission range over vehicular channels. They aspire to overcome the common vehicular channel challenges such as shadowing by other vehicles, lack of stationary and high Doppler shift. These key characteristics have absolute influence on the reliability and robustness of the transmitted signal. In [17], authors acquaint a general study to address different vehicular channel measurements over distinct environments. This study kept an eye on the major channel features (*e.g.*, delay and Doppler spreads) with an immersed focus on the IEEE 802.11p standard. The existing vehicular channel models and their main properties are also discussed.

Besides ensuring the safety applications, recent studies emphasis on the vehicular communication technologies in an effort to improve the efficiency of transportation systems. The important issues for the channel measurement in a vehicle-to-vehicle (V2V) environment have been addressed in [18]. Authors classified the channel measurement over V2V networks based on many criteria include carrier frequencies, antennas positions, direction of vehicles motion, and selectivity of frequencies. A tone reservation method is used by Bachir *et al..*. to reduce the PAPR in the vehicular OFDM signal [19]. This proposed method utilizes the Conjugate-Gradient algorithm which rely on the Polak-Ribiere direction search [20, 21]. Unfortunately, the tone reservation method suffers from slow convergence speed since it requires the transmitter and receiver to agree on the number and position of the used subset of subcarriers which is called peak reduction tones [22]. In addition, this method increases the searching complexity as well as the bandwidth wastage due to the unused subcarriers.

On the other side come the precoding techniques which are considered the most effective methods for the PAPR augmentation in OFDM systems. The Zadoff-Chu Transform (ZCT) is, one of the most attractive precoding techniques, applied to radio signals in order to reduce the cost and complexity of the radio's power amplifier [23, 24]. A ZCT pre- and post-coding is utilized to decrease the PAPR for OFDM systems over wireless networks[25]. This proposed scheme is based on carrying out the ZCT in two ways one for pre-coding and another for post-coding. On one hand, the precoding ZCT reshape the ZCT matrix row and reform the constellation symbols before the IFFT. On the other hand, the post-coding ZCT reshape the ZCT matrix column and execute the transform after the IFFT. Another proposed work that is based on using the ZCT to analyze the PAPR effect is presented in [26, 27]. The difference between [26] and[27] is that the first considers the ZCT row-wise pre-coder while the second depends on Selected Mapping technique (SLM) to abate the PAPR in an OFDM system. Both works succeed to offer substantial performance gain in a fading multipath channel. Finally in [28], another PAPR reduction mechanism is anticipated that includes the use of the ZCT based on distributed OFDM uplink system.

3. Vehicular OFDM Overview

3.1. Classical OFDM

The OFDM is a modulation formation that has been approved by many wireless and telecommunications standards such as 802.11a, 802.11n, and WiMAX. Although the OFDM is known to be more complicated, it supports some advantages in terms of data transmission [29]. Specifically, it provides high data rates even when the spectrum bandwidth is limited as the case in vehicular networks.

In OFDM, a signal consists of a number of closely spaced modulated carriers known as subcarriers. These subcarriers can be modulated in any form and transmitted to the destination. However, the receiver should demodulate the OFDM subcarriers in order to be able to receive the whole signal successfully. Moreover, the signal can be received without the expected interference, as the subcarriers are orthogonal to each other. This can be achieved by having the carrier spacing equal to the reciprocal of the symbol period.

The baseband signal is firstly passed through Serial-to-Parallel (S/P) converter which generates a complex vector of size N (*i.e.*, number of subcarriers). Generally, an OFDM signal with N subcarriers is formulated as follow:

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

Where X_k represents the generated data symbols to create a complex value vector $X = [X_0, X_1, \dots, X_{N-1}]$ is in the frequency domain. The complex value X_k usually carries the k^{th} subcarrier and it is known as the input symbol sequence. Typically, the OFDM signal is produced by summing all the N modulated subcarriers which are separated by $1/NT_s$ in the frequency domain. $T_s$is the sampling period which results in a continuous time baseband $x(t)$. Finally, $f_k = k\Delta f$and $\Delta f = 1/NT_s$ for N OFDM subcarriers.

In the conventional OFDM, the generated subcarriers from equation (1) are then passed through an Inverse Fast Fourier Transform (IFFT). The various advantages of the OFDM allow for this method to be involved in several wireless systems. One of the main advantages of OFDM systems is being immune to the frequency selective fading channels. This is because OFDM normally affects the channels using flat fading by dividing the channel into multiple narrowband sub-channels. The channel division leads to simplified channel equalizers. Besides, OFDM is more resilience to the inter-symbol interference by reducing the data rate transferred on each sub-channel.

Unfortunately, an OFDM signal has a relatively high large dynamic range known as peak to average power ratio.

3.2. Vehicular Channel Characteristics

The wide advent of the dependable vehicular communication systems calls for the design of accurate propagation models that cope with all relevant vehicular scenarios. The major goal is to achieve safer and efficient transportation along with providing robust connectivity at adequate data rates. High Doppler shifts, inherent non-stationary, and shadowing by other vehicular nodes are considered the key obstacles in vehicular channels. These factors have a great influence on the transmitted data packet. Recently, the well-known IEEE 802.11p standard [5, 30] has gained considerable attention in vehicular networks. This standard is directed to the Vehicle-to-Vehicle, Vehicle-to-Roadside communications and applications as well as it operate on the 5.9 GHz frequency band. Several vehicular users can gather data about road traffic and disseminate the collected data among each other using the IEEE 802.11p standard. Such provided data and applications aim to prevent accidents through event-triggered messages.

In vehicular networks, the channels can be exposed to fading due to the variation of the received signal power and time delays. Moreover, the vehicular high mobility can lead to a significant number of relevant scatters which consequently affects the transmitted data quality [17]. Thus, the utilization of the OFDM modulation is vital to support robust and efficient signal and achieve moderate data rate transfer. Nevertheless, appropriate PAPR reduction techniques should be operated to enhance the output behavior of the vehicular channel propagations.

3.3. OFDM-PARP Properties

As we mentioned above, the OFDM splits the transmitted data over orthogonal subcarriers in which each subcarrier is modulated at a low rate [6]. Although, the OFDM has several attractive features that make it suitable for high data rates transmission, it suffers from some obstacles such as the high PAPR.

PAPR is defined to be the relationship between the maximum power of a given transmitted OFDM sample and the average power of the OFDM symbol itself [31]. In a multicarrier system, different subcarriers can be out-of-phase with each other which leads to the high PAPR phenomenon. The reason behind this is that the variation of these subcarriers at each instant with respect to each other. As a consequence, the peak value of the system will suddenly shoot up to be very high compared to the average of the whole system which is known as the PAPR effect.

Based on equation (2), the PAPR of an OFDM signal $x(t)$ can be expressed as:

$$PAPR = 10\log_{10}\frac{P_{Max}}{P_{avg}} \qquad (2)$$

Where $P_{Max} = max|x(t)|^2$ represents the maximum power of an OFDM sample. And

$P_{avg} = \frac{1}{T}\int_0^T |x(t)|^2 \, dt$ is the mean value of the OFDM signal power.

The presence of high PAPR values is undesirable as it results in several grim consequences includes higher power consumptions which reduce the signal efficiency. Furthermore, it may affect the linearity of the analog circuits which leads to the utilization of costly devices. As a result, a reasonable PAPR value can be achieved by limiting the input OFDM sequence to a smallest subset.

4. The Proposed Model

4.1. Conventional ZCS Technique

A Zadoff-Chu Sequence (ZCS) or Frank-Zadoff-Chu Sequence (FZCS) [32, 33] is described as a complex mathematical sequence that when applied to a digital signal can enhance the constant-amplitude output signal. As a result, the cost and complexity of the radio's power amplifier are reduced. In addition, the ZCS has the optimum property that their periodic autocorrelation function is zero for all the time shifts except for the zero shifts.

Generally, a ZCS[33] of length N_{zc} is defined as in equation (3):

$$a(n) = \begin{cases} e^{\frac{j2\pi r}{N_{zc}}\left(\frac{k^2}{2}+qk\right)}, & \text{for } N_{zc} \text{ is even} \\ e^{\frac{j2\pi r}{N_{zc}}\left(\frac{k(k+1)}{2}+qk\right)}, & \text{for } N_{zc} \text{ is odd} \end{cases} \quad (3)$$

Where $k = 1, 2 \ldots N_{zc}$ and $j = \sqrt{-1}$ is an imaginary number. Finally, q and r are integers relatively prime to N_{zc}.

Assume that $L = N_{zc} \times N_{zc}$, and then a ZCS matrix A of size ${N_{zc}}^2$ can be estimated by reshaping the ZCS as follows:

$$A_{x,y} = \begin{pmatrix} a_{00} & a_{01} & \cdots & a_{0(N_{zc}-1)} \\ a_{10} & a_{11} & \cdots & a_{1(N_{zc}-1)} \\ \vdots & \vdots & \ddots & \vdots \\ a_{(N_{zc}-1)0} & a_{(N_{zc}-1)1} & \cdots & a_{(N_{zc}-1)(N_{zc}-1)} \end{pmatrix} \quad (4)$$

Here, the kernel of the ZCS is obtained by $k = xN_{zc} + y$, where x and y represent the rows and columns of variables of matrix A respectively. Consequently, the ${N_{zc}}^2$ elements of the ZCS can fill the kernel of the matrix A.

4.2. Clipping-DCT Technique

Typically, the clipping technique is applied over discrete frequency components in order to reduce the power by setting a max-level for the transmitted signal. However, the use of clipping only suffers from severe drawbacks including the negative effect on the BER performance due to the in-band distortion & the disturbance of adjacent channels due to out-of-band radiation.

In this subsection, we briefly review the clipping technique based on the DCT/IDCT transform [34, 35]. The DCT helps to transform a digital signal from the spatial domain to the frequency domain. According to Figure 1, a new OFDM symbol s_m enters the clipping-DCT block by firstly converting it to a frequency domain signal S_m using the DCT transform with length N, such that:

$$S_m = DCT(s_m) \quad (5)$$

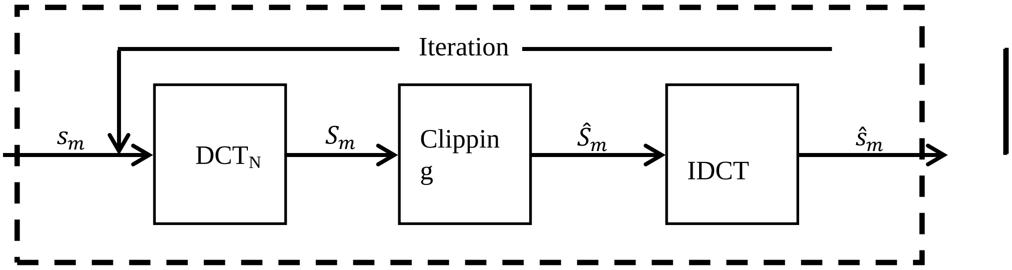

Figure 1. Clipping-DCT Block

Afterwards, the number of iterations m is predefined according to an estimated clipping ratio (CR). This ratio is calculated in each iteration as in equation (6):

$$CR = \sqrt{PAPR_{\max}} = \frac{C_m}{\frac{1}{\sqrt{N}} \left\| s_m \right\|_2} \quad (6)$$

Where s_m is the input OFDM symbol and C_m represents the clipping level in the m^{th} iteration. The generated OFDM symbol S_m is passed through a clipping operation in an effort to enhance the PAPR ratio. The clipped symbol $\hat{S}_m$ can be obtained using the following equation:

$$\hat{S}_m(i) = \begin{cases} C_m e^{j\theta_m i}, & \left|S_m(i)\right| > C_m \\ S_m(i), & \left|S_m(i)\right| \le C_m \end{cases} \quad (7)$$

Such that$1 \le i \le N$, and θ_m is the phase of the $S_m(i)$ at iteration$m$.

Finally, the clipped OFDM symbol $\hat{S}_m$ is re-converted into time domain using equation (8):

$$\hat{s}_m = IDCT(\hat{S}_m) \quad (8)$$

4.3. Hybrid ZCS Transform Based on Clipping DCT

In the previous subsection, we have discussed the basic issues concerning the classic ZCS transform. The ZCS is a powerful pre-coding technique that is applied to radio signal in order to reduce the PAPR results due to the OFDM system. Additionally, the clipping-DCT technique (as in Figure 1) also helps to lessen the system complexity as well as achieves better performance.

However, we propose a hybrid ZCS-C-DCT scheme which combines the popular pre-coding ZCS technique with the clipping-DCT/IDCT transform [34]. This novel scheme is projected to the vehicular channels to diminish the PAPR of the OFDM signal. Our scheme considers a transmitted signal between a transmitter V_x (*i.e.*, a vehicle) and a receiver R_x (*i.e.*, a roadside). The primary objective is to extend the signal transmission range and avoid distortion due to multipath fading and scatters.

According to Figure 2, a vehicle V_x commences by sending a digital signal to a roadside R_x within its coverage area. This input signal (I_s) is divided into parallel narrow subcarriers which are passed through the mapper block. The parallel sequence is mapped using a suitable format (e.g. QPSK or M-QAM). Then, the ZCS sequence is implemented to transform the mapped data S as in the following equation:

$$S' = AS \tag{9}$$

Afterwards, the time domain signal is obtained through the IFFT using equation (1). Then, a produced complex-value time domain subcarriers are re-shaped to serial format. Later on, we perform the clipping-DCT operation [34], and then the resulted digital signal is converted to analog signal using the DAC process.

As abovementioned, the vehicular channel is normally operating using the IEEE 802.11p standard which operates on the DSRC/WAVE [1, 5, 18]. The enhanced signal is passed through the vehicular spectrum in its way to the receiver, which is re-converted again to digital format through the ADC. After the serial-to-parallel (S/P) operation, the FFT is applied to produce the OFDM subcarriers.

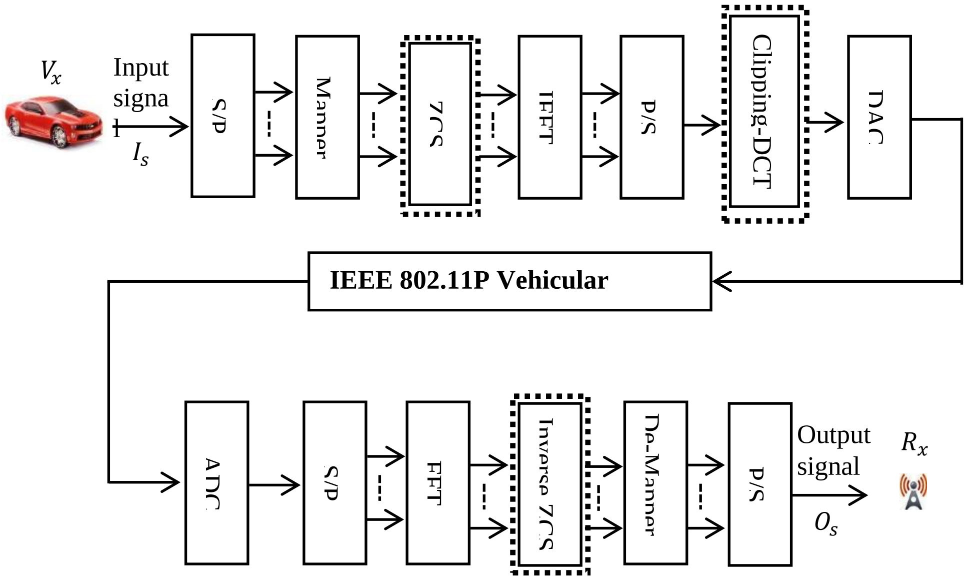

Figure 2. The Proposed ZCS with Clipping-DCT Transform

At the receiver side, the inverse ZCS transform is carried out in an effort to decrease the high PAPR. Accordingly, the received symbols are demodulated and converted to a signal channel using the parallel-to-serial (P/S) block as to be received by the roadside.

In short, the main steps of our proposed scheme are summarized as follows:

Step 1: After generating the data S from the mapper, the ZCS transform is applied.

Step 2: The $\grave{S}$ is converted to time domain using IFFT block.

Step 3: Calculate the CR and execute the clipping DCT.

Step 4: Pass the signal through the vehicular channel.

Step 5: Finally, extract the received OFDM subcarriers and re-convert it to serial data to be received byR_x.

5. Simulation Results and Analysis

In vehicular networks, the IEEE802.11p is a specific standard which is modified for different vehicular scenarios. Boosting the radio signal quality over vehicular-to-roadside environment is our main concern. As a consequence, several extensive simulations have been carried out using MATLAB in order to evaluate the performance of the proposed OFDM ZCS-C-DCT system.

Thereby, we set the allocated bandwidth for the tested channel to 10MHz as to ensure that the cyclic prefix length (*i.e.*, 16 samples) corresponds to a larger tolerable excess delay (*i.e.*, 6 μs). According to[18], a total number of 64 subcarriers are used for the vehicular channel whereas only 52 subcarriers are utilized for data transmission due to the presence of the guard band requirements. Finally, we consider a distance of 480 m between the transmitter V_x and the receiver R_x as well as a data transmission rate ranges from 3 to 27 Mbps.

Table 1 shows the parameters of OFDM signal that we used in our experiment to control the PAPR over the vehicular channels. Here, three M-QAM modulations have been considered in our simulation stated as 16-, 64- and 256-QAM.

Table 1. Experimental Parameters

Parameters	Assigned Value
Number of subcarriers	64
M-QAM modulation	16, 64, 256
Oversampling factor	4
FFT/IFFT length	64
Number of OFDM frames	100
High Power Amplifier (HPA) parameter	2

Figure 3 shows the complementary cumulative distribution function (CCDF) comparison of the PAPR distribution when 16-QAM is used. We compare the proposed scheme with the Walsh-Hadamard [15] and the classical OFDM [29]. The PAPR of our scheme is reduced by 3 and 4 dB compared to the other schemes.

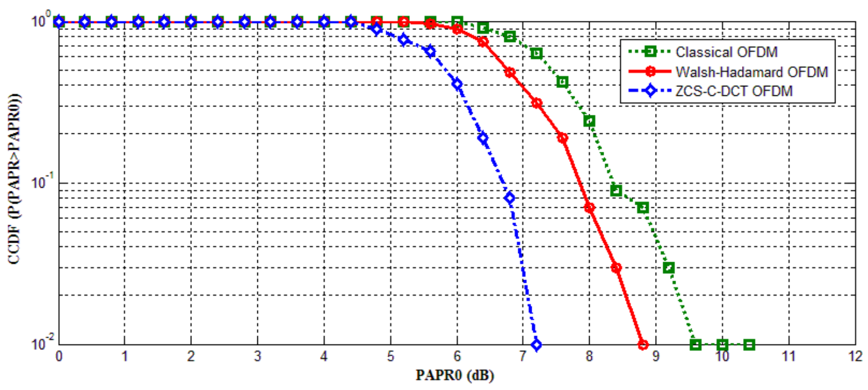

Figure 3. The CCDF Function for PAPR with 16-QAM

Another CCDF comparison of PAPR is illustrated in Figure 7. A tick of rate 10^{-1} is used with the 64-QAM to decrease the resulted PAPR to be 7.6, 8.4, and 11.6 dB respectively, for the ZCS-C-DCT, Walsh-Hadamard, and classical OFDM. Similarly, Figure 5 shows the PAPR due to applying the proposed ZCS-C-DCT with

256-QAM. Based on the executed experiments, we observe that our scheme is able to decrease the PAPR resulted from using the OFDM method in vehicular channels.

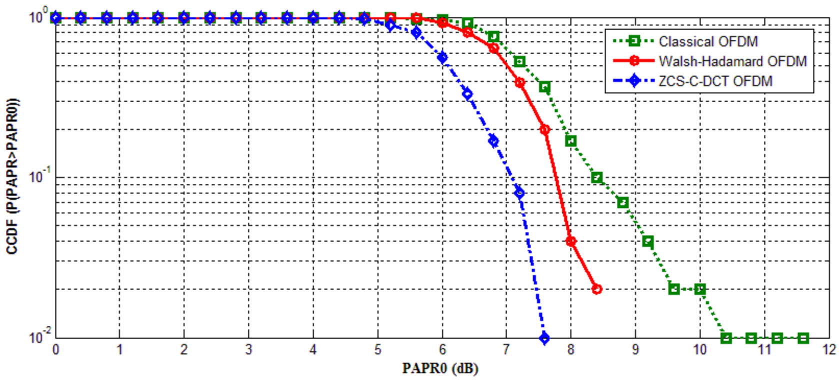

Figure 4. PAPR's CCDF using the ZCS-C-DCT with M=64

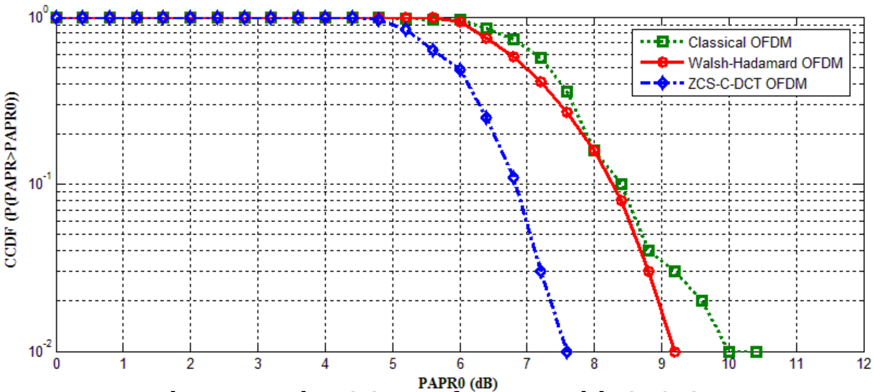

Figure 5. The CCDF of PAPR with 256-QAM

6. Conclusion

In this paper, we introduce a novel Zadoff-Chu Sequence (ZCS) combined with the clipping (C) technique. Our scheme aims to lessen the high PAPR over vehicular channel based on DCT/IDCT transform. Dependent upon the experimental results, the proposed scheme improves the performance of the vehicular OFDM system especially in vehicle-to-roadside environment. In addition, it can be shown that the increasing value of the PAPR has been decreased by 3 to 4 dB when compared with the conventional OFDM system and the Walsh-Hadamard system. Consequently, the proposed ZCS-C-DCT scheme succeeds to achieve better signal transmission quality by reducing the PAPR accompanied with the OFDM utilization.

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