# Eliminate the Effects of Clipping Technique on the SER performance by Recovering the Clipped Part of the OFDM Signal

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**Summary**
The simplest and most effective method to reduce PAPR might be the clipping and filtering [1], but the error performance of clipped OFDM signal is degraded due to the distortion of the original signals. The simplest and most effective method to reduce peak to average power ratio (PAPR) might be the clipping and filtering, but the error performance of clipped Orthogonal Frequency Division Multiplexing (OFDM) signal is degraded due to the distortion of the original signals. This paper suggests a simple solution to eliminate the degradation in the SER performance that caused by clipping the OFDM signal at the transmitter side by copying the clipped part of the OFDM signal and provide it to the receiver to recover the original signal. The delay in receiving the signal will be calculated to insure the receiver will be able to recognize and recover the clipped part of the original signal very well. With this proposed method there is freedom to use low clipping ratio (CR) and therefore it is easy to get efficient PAPR reduction. But it is better to choose the appropriate CR to avoid wasting the bandwidth by minimizing the amount of the copied part of the clipped signal.

***Key words:***
*Clipping Ratio, SER, PAPR, EVM, Power Amplifier, A/D converter.PAPR.*

## 1. Introduction

The basic premise of a multicarrier modulation scheme is to break a wideband channel into multiple parallel, typically, orthogonal narrowband channels. OFDM has many well documented advantages including resistance to multipath fading and high data rates [1, 2]. OFDM is an effective transmission technique for high data rate transmission in impulse noise and multipath fading environments. OFDM has been employed in diverse wired and wireless applications. For instance, in digital audio and video broadcasting [3], digital subscriber lines using discrete multitone [4], the wireless LAN systems, such as, IEEE 802.11, HIPERLAN and MMAC [5], wireless broadband services [6] and also is a strong candidate for next generation cellular systems [7]. One of the limitations of using OFDM is the high peak-to-average power ratio (PAPR) of the transmitted signal. A large PAPR leads to disadvantages such as increased complexity of the analog to digital converter (A/D) and reduced efficiency of the radio frequency (RF) amplifier. If power amplifiers are not operated with large linear-power back-offs, it is impossible to keep the out-of-band power below imposed limits. This leads to very inefficient amplification, expensive transmitters and causing intermodulation among the subcarriers and undesired out-of-band radiation. The Analog to Digital converters and Digital to Analog converters are also required to have a wide dynamic range which increases complexity. The PAPR reduction techniques are therefore of great importance for OFDM systems. To reduce the PAPR different techniques were proposed. These techniques can be categorized into the following, clipping and filtering [8], coding [9], phasing [10], scrambling [11], interleaving [12], and companding [13]. Coding is the most widely used technique. Selective mapping has been used [14] to reduce PAPR. However this resulted in a loss of data during decoding. Partial transmit sequence (PTS) is another method that is based on scrambling. Compared to the previous method, this method is more effective. In the PTS scheme, sub-carriers are partitioned into many blocks and each block is multiplied by a constant phase factor (codes) [15]. But this greatly reduces the number of carriers. In [16], PAPR reduction is achieved by deliberately introducing a limited number of errors to the forward-error correction (FEC) encoded input bits. This approach suffers receiver performance degradation. Each of these above mentioned solutions had some problems that are yet to be solved. The clipping signal scheme is relatively simpler than others. The performance of the clipping scheme is superior to that of the windowing

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signal scheme in OFDM system, because the windowing technique distorts all signals, but the clipping technique distorts small portion signal where the peak power exceeds the maximum permitted power. The simple concept behind this is to clip the power peaks that go beyond a predetermined level. Clipping has been thought to introduce error. But it actually depends on careful selection of clipping level [17]. This paper will focus on the clipping signal technique and it will propose a simple method to recover the clipped part of the original OFDM signal to improve the SER performance. The remainder of the paper is organized as follows. Section 2 presents the simulation model. Section 3 presents the simulation results. Lastly, the conclusions are presented in Section 4.

## 2. Simulation Model

A baseband OFDM symbol can be generated in the digital domain before modulating on a carrier for transmission. To generate a baseband OFDM symbol, a serial of digitized data stream is first modulated using common modulation schemes such as the phase shift keying (PSK) or quadrature amplitude modulation (QAM). These data symbols are then converted from serial-to parallel (S/P) before modulating subcarriers. Subcarriers are sampled with sampling rate $N/T_s$, where $N$ is the number of subcarriers and $T_s$ is the OFDM symbol duration. The frequency separation between two adjacent subcarriers is $2\pi/N$. Finally, samples on each subcarrier are summed together to form an OFDM sample. In OFDM, a block of N symbols, $\{y_n,\ n=0,1,\ldots,N-1\}$ is formed with each symbol modulating one set of $N$ subcarriers, $\{f_n=0,1,\ldots,N-1\}$. The $N$ subcarriers spacing is chosen to be orthogonal, that is $f_n = n\Delta f$, where $\Delta f = 1/NT_s$. Thus the complex envelope of the transmitted OFDM signal is represented by

$$x(t) = \sum_{n=0}^{N-1} y_n e^{j2\pi f_n t} \quad 0 \le t \le NT \qquad (1)$$

This Matlab simulation will focus in the 2k mode of the OFDM-DVB-T standard. This particular mode is intended for mobile reception of standard definition DTV. The transmitted OFDM signal is organized in frames. Each frame consists of 68 OFDM symbols. Four frames constitute one super-frame. Each symbol is constituted by a set of 1705 subcarriers in the 2k mode. The specific numerical values for the OFDM parameters for the 2k mode are given in Table 1. A simple AWGN channel is used as channel model.

TABLE I
SIMULATION PARAMETERS

| Parameters | Values |
|---|---|
| Channel Bandwidth | 7.61 MHz |
| Carrier frequency | 91 MHz |
| Modulation scheme (Mapping scheme) | 16QAM, 64QAM, and 256QAM |
| FFT Size (NFFT) | 2048 |
| Number of subcarriers | 1705 |
| Useful symbol duration ($T_U$) | 224 µs |
| Cyclic prefix or guard time Δ | 1/8 |
| Guard Time ( $T_g$ =(1/8)* $T_U$ ) | 28 µs |
| Total symbol duration ($T_U$+Δ) | 252 µs |
| Carrier spacing (1/ $T_U$) | 4.46 KHz |
| Number of OFDM symbols in frame | 68 |

The OFDM system model used in this work is shown in Figure 1, a digital nonlinearity is introduced at the transmitter and an equalization block at the receiver. The proposed method to improve the SER performance by copying the clipped OFDM signal as shown in figure 1 is performed after the clipping process.

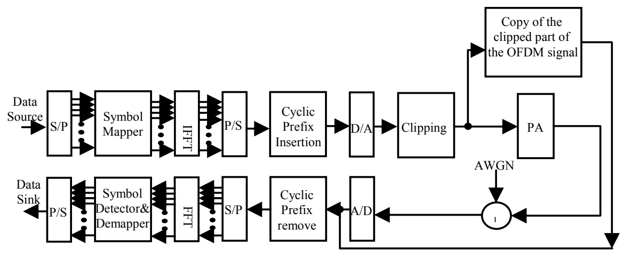



Figure 1: OFDM system block diagram and the proposed solution

Deliberate clipping might be the simplest method to reduce PAPR. This method limits the samples' amplitudes of the input OFDM signal to a predetermined value. If the digital OFDM signals are clipped directly, the resulting clipping noise will all fall in-band and cannot be reduced by filtering. To address this aliasing problem, in this simulation, the OFDM signal is oversampled by a factor of 8. Then, the real valued bandpass samples, $x$, were clipped at amplitude $A$ as follows:

$$y = \begin{cases} -A, & \text{if } x < -A \\ x, & \text{if } -A \le x \le A \\ A, & \text{if } x > A \end{cases} \qquad (2)$$

Although the PAPR is moderately high for OFDM, high magnitude peaks occur relatively rarely and most of the transmitted power is concentrated in signals of low amplitude. Therefore, the statistical distribution of the PAPR should be taken into account. PAPR is independent of modulation used. One way to avoid nonlinear distortion is to operate the amplifier in its linear region. Unfortunately such solution is not power efficient and thus not suitable for battery operated wireless communication applications. Minimizing the PAPR before power amplifier allows a higher average power to be transmitted for a fixed peak power, improving the overall signal to noise ratio at the receiver. It is therefore important to minimize the PAPR. The recovering process will be performed at the receiver side after A/D converter to avoid any reduction in the efficiency of the analog-to-digital. The PAPR of a continuous-time OFDM signal cannot be computed accurately by sampling the signal at Nyquist rate. Hence oversampling is essential to produce accurate PAPR estimates. As mentioned before discrete time domain OFDM signal in this simulation is oversampled by a factor of 8. The variation of the envelope of a multi-carrier signal can be defined by the peak to average power ratio (PAPR) which is given by:

$$PAPR = \frac{\mathrm{Max}\left\{ \left|x(t)\right|^2 \right\}}{\mathrm{E}\left\{ \left|x(t)^2\right| \right\}} \qquad (3)$$

At the transmitter side, the invertible clipping method reduces the amplitude dynamics, and thus the PAPR of the signal that has to be amplified. This result is presented in Complementary Cumulative Distribution Function (CCDF) a term which is defined as follows:

$$CCDF\big(PAPR(x)\big) = \mathrm{Prob}\big(PAPR(x) > PAPR0\big) \qquad (4)$$

This function represents the probability that the PAPR of the OFDM signal exceeds the threshold PAPR0. This invertible clipping method allows reducing the PAPR of the OFDM signal. The implementation of deliberate clipping is quite simple and effective in PAPR reduction, but larger clipping ratio results in the severe SER performance degradation. Unfortunately, clipping generates a spectral regrowth (the so called spectral shoulders) on the spectrum of output signal, widening its frequency support. Thus, parasitic frequencies appear in the adjacent channels. Filtering after clipping is therefore compulsory to limit this spectral regrowth and, finally, to assure a good system performance. A cyclic prefix (CP) is then appended to minimize interblock interference and aid the frequency domain equalizer at the receiver. Digital-to-analog (D/A) conversion and analog filtering are performed. The clipping process is characterized by the clipping ratio (CR), defined as the ratio between the clipping threshold and the root-mean square (rms) level of the OFDM signal. However, Clipping is a nonlinear process that leads to distortion. Without filtering, clipping causes out-of-band radiation. Digital filtering is present to control out-of-band radiation.

$$\mathrm{CR} = \frac{\mathrm{CL}}{\mathrm{rms\ level}} \qquad (5)$$

where CL is the Clipping Level and CR is the clipping ratio. The CR in this simulation has different values depends on modulation schemes. Clipping the OFDM signal before amplification is a simple and typical method for the PAPR reduction [18]. Figure 2 exhibits the concept of the proposed method of copying the clipped part of the original OFDM signal in enlarged-time domain. The original signal $y = x(t_n)$ at time $t_n$ is clipped by the threshold value $A$ to the clipped signal. The copied signal that will be provided to the receiver side is equal to: $y\_copy(t_n) = \pm\, x(t_n) - (\pm\, A)$
where: $t_n = 0{:}T_s$, and $n = 0{:}\ [T_s/(1/Sp)]$, and $T_s$ is the total OFDM symbol period, and $Sp$ is the simulation period. The recovered OFDM signal at the receiver side is the received signal plus to the copied signal as follows:
$y\_recov(t_n) = y\_copy(t_n) + y\_r,$
where $y\_r$ is the received signal and can be defined as :
$y\_r = y$+AWGN

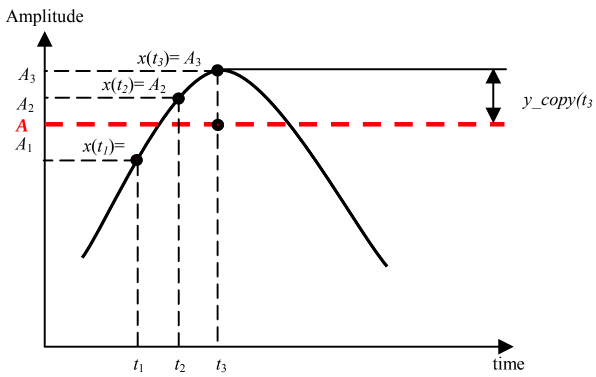



Figure 2: The clipped OFDM signal and copied signal

To understand the proposed method of recovering the original signal, figure 3 illustrates the details of copying the clipped part of the OFDM signal and then using it to recover the original signal at the receiver side.

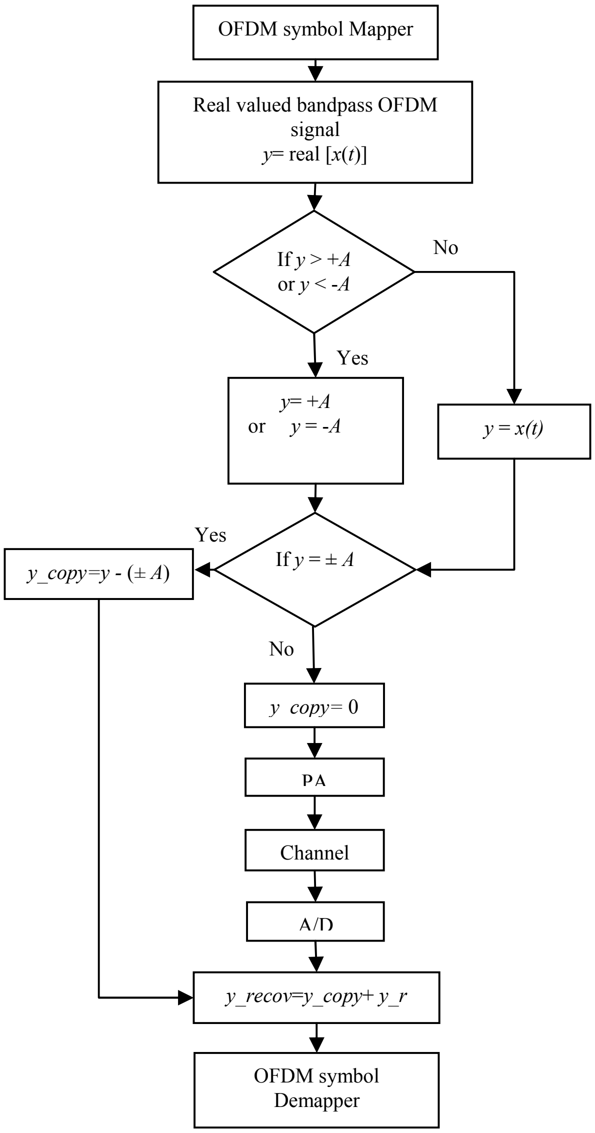



Figure 3: The proposed method to recover the clipped OFDM signal

## 3. Results and Discussion

When using the clipping scheme, the phase information of the signal is completely transmitted, and the amplitude of the signal is clipped if the power of the signal exceeds the maximum permitted power. If using ideal power control to counteract the influence of wireless channel in systems and not considering other factors (such as frequency set-off), the received signal amplitude also shows as the same as the original signal plus to AWGN. Although PAPR is very large for OFDM especially for large number of subcarriers as in this simulation, high magnitude peaks occur relatively rarely and most of the transmitted power is concentrated in signals of low amplitude.

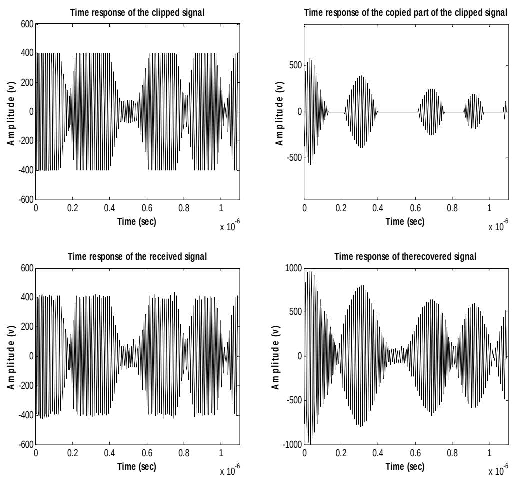
Table 2 shows the percentage of the clipped samples of the original OFDM signals at different CR values for various modulation schemes. The higher the clipping ratio, few OFDM samples will be clipped. So it is important to choose the CR carefully to get a good reduction in the PAPR without degrade the performance of SER. But with this proposed method of recovering the clipped part of the original signal, it is possible to clip the signal hardly or in other word using small CR without degrading the SER performance.

TABLE II: PERCENTAGE OF THE CLIPPED OFDM SAMPLES AT DIFFERENT CLIPPING RATIO VALUES

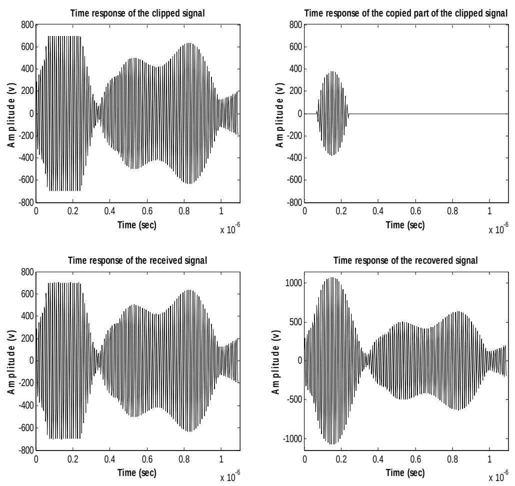
| Clipping Ratio (CR) | Modulation scheme | Percentage of clipping % |
|---|---|---|
| 1.35 | 256-QAM | 16.41 |
| | 64-QAM | 16.37 |
| | 16-QAM | 15.28 |
| 2.75 | 256-QAM | 0.99 |
| | 64-QAM | 0.86 |
| | 16-QAM | 0.80 |

The most important thing that should be considered in this proposed recovering method is appropriate choosing of the CR value. In this proposed method, a low Clipping Ratio (CR) will achieve a significant PAPR reduction, and improve the SER performance, but the price is increasing in the amount of the copied signal which is in fact a redundancy in the transmitted data.

Figure 4 (a and b) shows the clipped signal, copied signal and the recovered signal at different CR values.




(a)




(b)

Figure 4: Time response of the clipped, copied, received, and recovered signal of OFDM-256QAM at two different clipping ratio CR (a) CR=1.2, (b) CR=2.3

Figures 5, 6, and 7 show the ability of the proposed method to improve the performance of the SER. It is easy to note that the improvement in the SER of the recovered OFDM signal at different CR values is better than the SER performance of the conventional clipped OFDM signal and it shows superior performance compared to the normal or unclipped OFDM signal. The proposed method was tested with different modulation schemes such as 16, 64, and 256QAM, and in all schemes the performance of the SER at low CR values is better than that with high CR values. This is because in the hard clipping, more peaks will be clipped and this means more copies of clipped parts of the original signal will be transmitted as information data to the receiver to recover the original signal, and this is the disadvantage of using low CR in this proposed method because it causes redundancy in the transmitted data and wastes the available bandwidth. So it is better to choose appropriate CR to get the advantage of this proposed method without any sacrificing in the bandwidth.

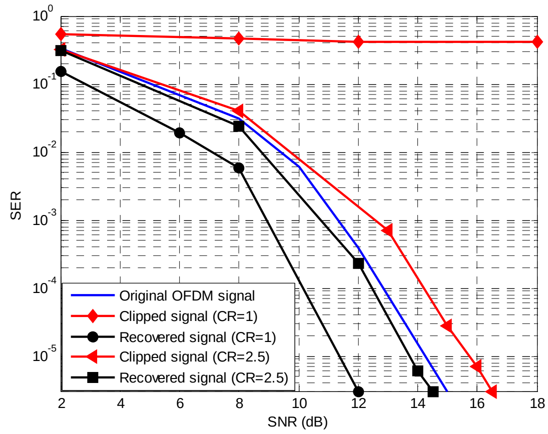



Figure 5: SER performance of the original, clipped, and recovered OFDM signal using proposed method of OFDM -16QAM

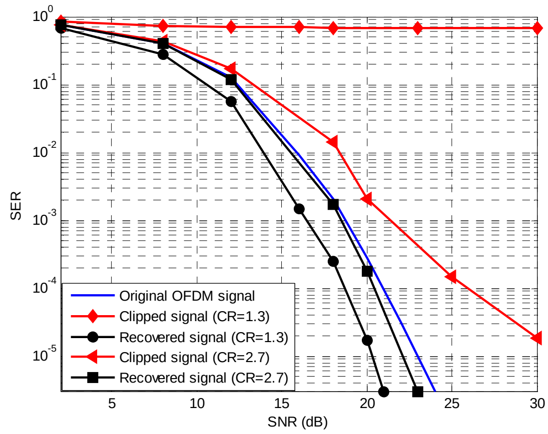



Figure 6: SER performance of the original, clipped, and recovered OFDM signal using proposed method of OFDM -64QAM

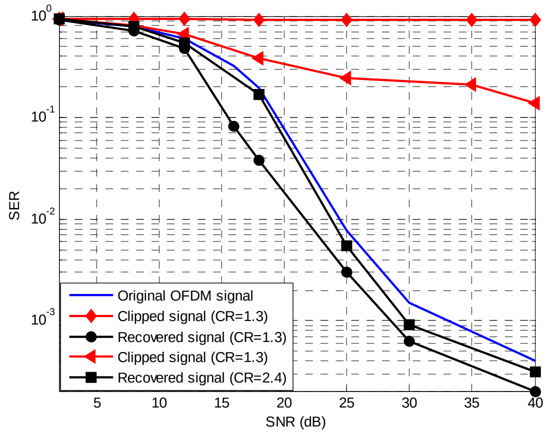



Figure 7: SER performance of the original, clipped, and recovered OFDM signal using proposed method of OFDM -256QAM

Crosscorrelation function was measured between the transmitted and received signals. Maximum peak of this function showed the time delay between the lead and lag signals. Figure 8 shows the maximum peak of the crosscorrelation function equal to 63. There is a delay produced in this simulation system was generated from the reconstruction filtering process, the reconstruction filter produced the delay that was enough to impede the reception and caused the slight difference between the transmitted signal and the received signal. For this system, the delay produced by the reconstruction and demodulation filters is about:

$$T_d = \frac{63}{SP} = 7.0314\times10^{-9} \text{ sec}$$

where $SP$ is the simulation period = $4\times f_c$

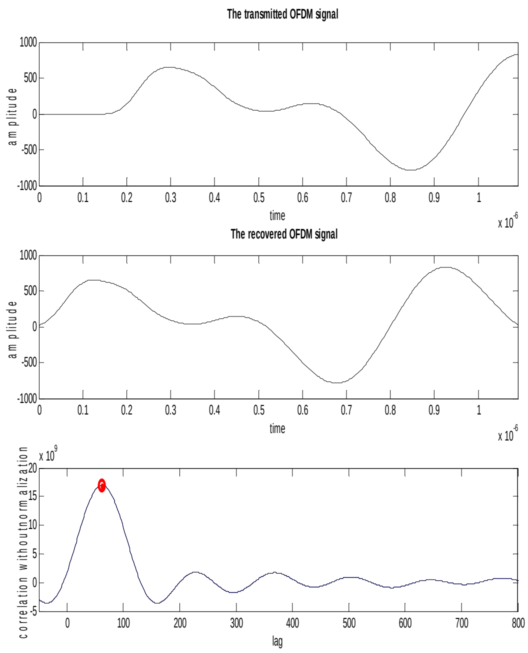



Figure 8: Crosscorrelation of the transmitted and recovered signals

With the proposed method of recovering the clipped part of the original signal, it is possible to use low CR to achieve a good PAPR reduction, but the value of CR depends on the order of the modulation scheme. Figures 9, 10, and 11 show the CCDF of the normal and the recovered OFDM signals at different CR with different modulation schemes. The improvement in PAPR at the probability of $10^{-3}$ is listed in table 3 at different CR values.

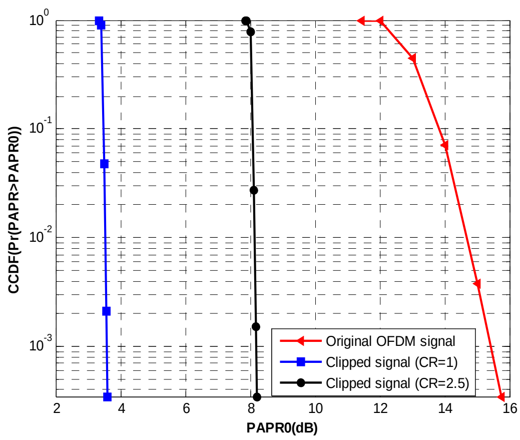



Figure 9: CCDF of PAPR for normal and clipped OFDM signal at different CR with 16-QAM

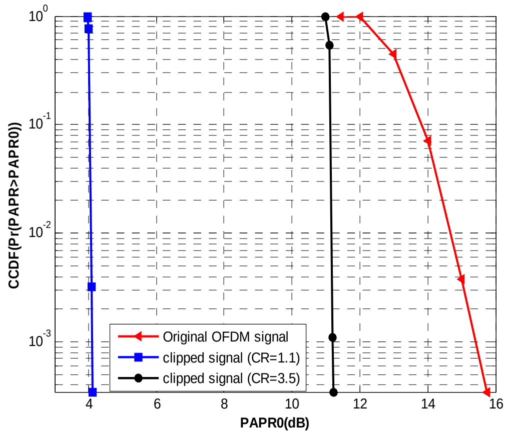



Figure 10: CCDF of PAPR for normal and clipped OFDM signal at different CR with 64-QAM

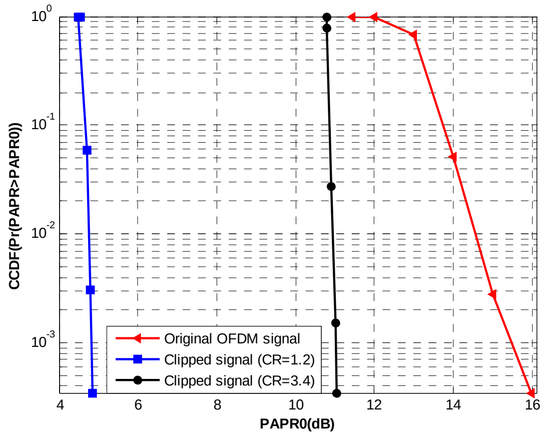



Figure 11: CCDF of PAPR for normal and clipped OFDM signal at different CR with 256-QAM

TABLE 3: PERCENTAGE OF THE CLIPPED OFDM SAMPLES AT DIFFERENT CLIPPING RATIO VALUES

| Reduction in the PAPR at the probability of $10^{-3}$ compared to the normal OFDM with: | | | | | |
|---|---|---|---|---|---|
| 16-QAM (dB) | | 64-QAM (dB) | | 256-QAM (dB) | |
| CR=1 | CR=2.5 | CR=1.1 | CR=3.5 | CR=1.2 | CR=2.5 |
| 7.24 | 11.86 | 4.22 | 11.31 | 4.47 | 10.66 |

The measurement is carried in a channel with different distortion which has different SNR. Error vector magnitude (EVM) is far greater than SER. In the case of high SNR, SER is nearly equal to zero which could not fully characterize signal distortion of system. Obviously, it is incapable to pursuit perfect system, while EVM still has high enough value which contains more information and could characterize the imperfection of system. The proposed recovering solution in figure 13 shows small value of EVM at low SNR values better than the normal OFDM system in figure 12.

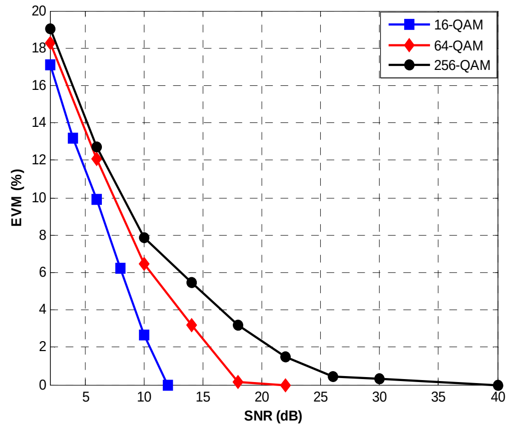



Figure 12: EVM-SNR of different types of normal (unclipped) OFDM signal

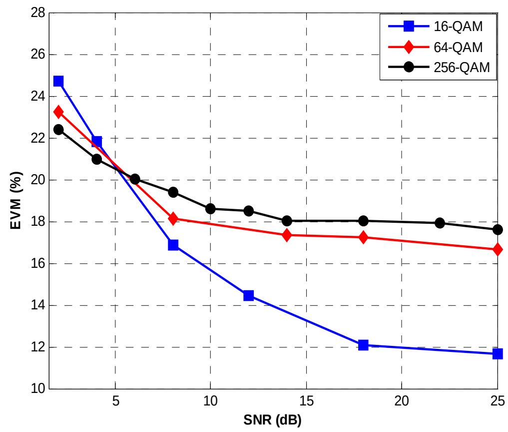



Figure 13: EVM-SNR of different types of conventional clipped signal with CR=1.1

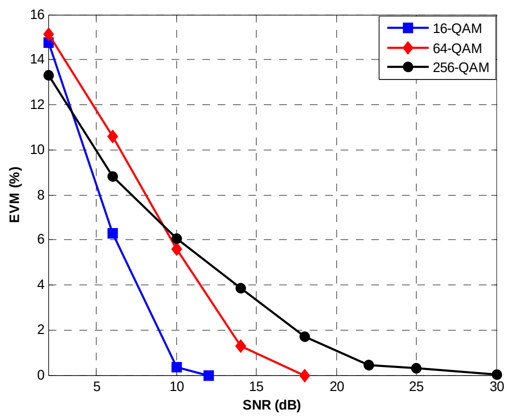



Figure 14: EVM-SNR of different types of recovered signal with CR=1.1

## 4. Conclusion

The proposed method to recover the original signal by copying the clipped part of the original signal at the transmitter side and then provide this copied signal to the receiver as information data. The numerical results show the ability of this method to eliminate the clipping noise and improve the SER performance compared to the conventional clipped signal and even better than the SER performance of unclipped OFDM system. It is possible to use low CR with this proposed method to get efficient PAPR reduction. But it is important to make appropriate selecting of the CR to minimize the amount of the transmitted copies of the clipped parts of the original OFDM signal to avoid wasting the valuable bandwidth.

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