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PAPR Reduction of Waveforms for 5G-6G Communications

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Abstract: ***Orthogonal Frequency Division Multiplexing (OFDM) is a remarkably efficient multicarrier modulation technique. It offers high data rates, high spectral efficiency, reduced complexity, and is resistant to frequency selective fading. Flexible for inter-symbol and inter-frame interference. With all these benefits, OFDM is used in 4G and also meets the requirements of 5G NR. CPOFDM / OFDMA is used for 5G downlink. OFDM is a multi-carrier technique, and one of the main demerit of this technique is high peak-to-average power ratio (PAPR). When PAPR is limited, the power amplifier operates more efficiently and extends the battery life of the device. In this study, we performed various PAPR reduction techniques such as Amplitude Clipping, Selective mapping, and Partial transmit sequences, and compared the simulation results in MATLAB.***

Keywords: OFDM; PAPR; Fifth generation new Radio (5G NR), CP, DFT-s-OFDM, CCDF, CP-OFDM, PTS, SLM

1. Introduction

The fifth generation technology is different from all its predecessors. All the previous generations were primarily concerned with high data rate and spectral efficiency. In 5G different technologies are interconnected and work together at different levels. It is a network that is designed to connect virtually everything including objects, machines and devices. Previous generations were designed with human as end user but now they are beyond human authentication, such as drones and self-drivingcars.

The three main operational scenarios of 5G are Enhanced Mobile Broadband (eMBB), Ultra reliable low latency communication (URLLC), Massive machine type communications. 5G New Radio physical layer multiple access is based on Orthogonal Frequency Division Multiplexing (OFDM-CP) with cyclic prefix supported both on both uplink and downlink. Discrete Fourier transform spread OFDM with Cyclic prefix (DFT-s-OFDM) is supported in the uplink direction. OFDM is one of the most suitable waveforms for wireless communication due to its exceptional multipath combat capability and low complexity Transceiver system. And cyclic prefix help prevent inter symbol interference. In the uplink direction, DFT-s- OFDM is used in both 4G and 5G as it helps to lower PAPR. [1]

OFDM is a multi-carrier technology, and one of the drawbacks of multi-carrier technology is high peak-to-average power ratio. A high PAPR reduces the efficiency of the power amplifier and shortens the battery life of the device. CP-OFDM has a high PAPR, which results in poor performance in the large bandwidth and high frequency bands. Therefore, high PAPR is one of the key challenges for future generations.[1]

Various PAPR reduction techniques are discussed in the literature. Methods such as Clipping and filtering, Tone reservation and Tone injection, Partial Transmit scheme, selected mapping technique, coding techniques, etc. Several hybrid processes that combine the two reduction techniques are also described in research paper. Precoding Partial transmit sequence is an example of a hybrid technique that combines coding and PTS for betterresults.

This paper focuses on three PAPR reduction techniques, Amplitude Clipping Technique, Selective mapping, and Partial transmit sequence technique using MATLAB Software.

This document is organized as follows: Section I is an introduction, Section II is an introduction to the OFDM system, Section III is the peak-to-Average Power Ratio, Section IV is the CCDF, Section V is the PAPR Reduction methods includes Amplitude Clipping, SLM, and PTS, Section VI consist of simulation Results, and Section VII is the Conclusion.

1) OFDM

OFDM is a higher-level form of FDM (frequency division multiplexing) in which the multiplexed frequencies are orthogonal to one another and their spectra overlaps with the adjacent carriers. Cyclic prefix (CP) helps to avoid inter symbol interference (ISI) in the system. In OFDM one of the factors which contributing to orthogonality is the rectangular pulse shape in time domain, and in frequency domain generates a sinc which has a fairly high side lobes. Therefore, there is adjacent channel interference. And that is one of the reasons why adaptive subcarrier bandwidth or variable subcarrier bandwidth and numerology came into existence in 5G NR.

The transmitted OFDM signal, x(n), n ∈ [0, N − 1], can be given as,

$$x(n) = \sum_{r=0}^{N-1} d_r e^{j2\pi\frac{rn}{N}}$$

5G New Radio physical layer is based on Cyclic prefix (CP) with Orthogonal Frequency Division Multiplexing (OFDM) supported both on both uplink and downlink. Discrete Fourier Transform Diffuse OFDM with cyclic prefixes is supported in the uplink direction. DFT spreading means that the spreading signal enters the IFFT block. Therefore, the coherent bonds that can occur are reduced to some extent.

Therefore, if consistent, combining these methods will have no effect. This will also significantly reduce PAPR.OFDM is one of the most suitable waveforms for wireless communication due to its exceptional multipath combat capability and low complexity Transceiver system. And cyclic prefix help prevent intersymbol interference. In the uplink direction, DFT- s-OFDM is used in both 4G and 5G as it helps to lower PAPR.

OFDM is the most popular multi-carrier waveform, and one of the drawbacks of multi-carrier technology are large OoBsidelobes, gives low spectral efficiency and high PAPR. While CP-OFDM, DFT-s-OFDM and for macro uplink OFDM, SC-FDM meet 5G requirements, by 2030, global cellular subscriptions are expected to reach approximately 17.1 billion and M2M (Machine to Machine) 97 billion. Therefore, given the limitations of the OFDM system, other multicarrier waveforms (e.g. FBMC, UFMC, and GFDM) can be considered for 5G beyond generations. [1]

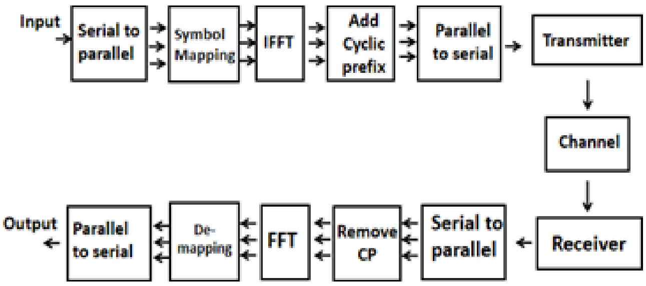

Figure 1: Block diagram of OFDM

2) PAPR

Multi-carrier modulation has emerged as one of the most sophisticated solutions for high symbol rate wireless digital transmission. In Multicarrier waveform, a data stream is divide into different low rate data streams, each one of this is modulated on various subchannels and then it is multiplexed. Multi-carrier modulation has many advantages over single-carrier modulation, but it also has disadvantages. PAPR is one such drawback.

In LTE, PAPR issues are addressed in the uplink direction, but not in the downlink. The main reason is that in the uplink direction, the user device to the base station, the user's battery life is a big issue. Therefore, it is important to reduce PAPR. On the other hand, in the downlink direction, power is not a major constraint and better power amplifiers can be implemented. Therefore, the PAPR issue is not a major issue for base stations, but it is a major issue for user equipment. [2] [4] [5]

The PAPR is the ratio of peaks (marked in blue color fig2) and the average power (marked in green color fig2). Larger number of subcarriers (FFT size) leads to high PAPR means the probability of peak to average power ratio increases with the subcarrier width. The PAPR can be written as:

$$\mathrm{PAPR} = \frac{max|x_n|^2}{E|x_n|^2}$$

Where E [.] denotes the average power or expectation.

In particular, with N subcarriers a baseband OFDM signal has

$$PAPR_{max} = 10\, log_{10} N \ \ (\mathrm{dB})$$

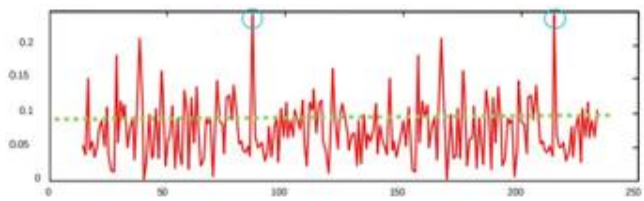

Figure 2: Signal

Ideally, when the signal passes through the High Power Amplifier before being transmitted, the output signal comes out with the same characteristics as the input signal. So, In the linear region, there is no variation in the characteristics of the signal. But practically the performance of the power amplifier is not linear rather it is nonlinear. When the signal is operated at the high input power, the efficiency of the power amplifier is high, and when it is operated in back-off then the efficiency decreases. The power amplifier is linear in the back-off region but the output power is less, which means that the signal or the operation has to be sustained for a longer duration of time in order to send the same number of bits, and also there is a power efficiency loss. So, this effectively results in more lack of battery power of devices. This indicates that the PAPR in OFDM is a vital issue.

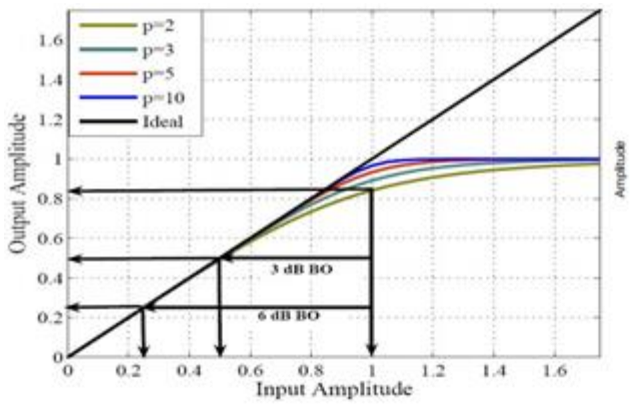

Figure 3: Power Amplifier Characteristics

3) Complementary Cumulative Distribution Function (CCDF)

The Complementary Cumulative Distribution Function is the one of the most commonly used performance indicator for PAPR reduction methods. Mathematically, CCDF can be described using the Probability Density Function (PDF) dataset. The PDF integral is calculated to get the Cumulative Distribution Function (CDF). Then flip the CDF to get the CCDF. It conclude that CCDF is a complement of CDF. [4]

$$\mathrm{CCDF} = 1\text{-}\mathrm{CDF}$$

CCDF measures the efficiency of the PAPR method. The CCDF curve shows how long the signal spends above a certain power level. It is expressed in dB. CCDF gives the probability that the Peak-to-power ratio of a data block is above a given threshold value.[5]

It can be expressed as:

$$\mathrm{CCDF} = \Pr\,(\mathrm{PAPR} > \mathrm{PAPR0})$$

4) PAPR Reduction Methods

Several techniques have been proposed for PAPR reduction of OFDM signals. PAPR reduction methods are classified into two types: signal distortion and signal scrambling.

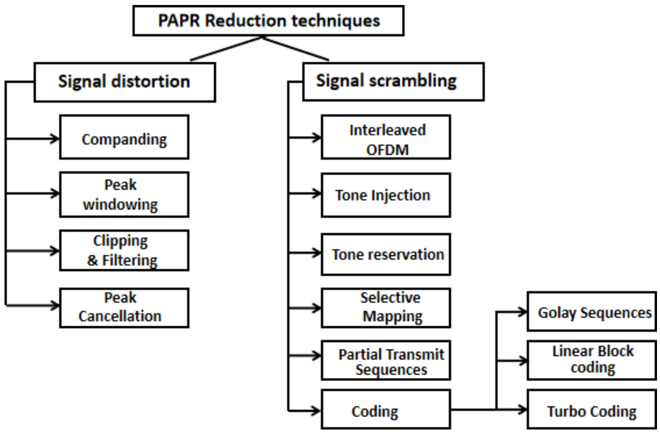

Figure 4: PAPR reduction Techniques

A) Amplitude Clipping

Amplitude Clipping is the simplest and low complexity PAPR reduction scheme that limits the peak value of a broadcast signal to a given level. Filtering can also reduce out-of-band radiation of clipped signals. Clipping and filtering must be repeated to avoid out-of-band noise. Figure 5 shows a block diagram of an iterative C & F technique that uses iterative filtering to avoid regrowth of the OFDM signal.

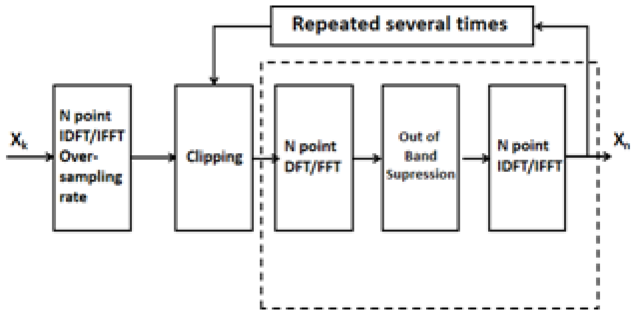

Figure 5: Block diagram of Amplitude clipping technique

Advantages:

- Simple approach and lesscomplex
- Capability of high PAPRreduction
- Side information is notrequired
- No change at receiver side Disadvantages:
- Introducedistortion
- Degrade BERperformance

B) Selected Mapping technique(SLM)

In this technique, the entire set of data symbols is loaded into the subcarriers, then there is a serial to parallel conversion to form a data block, and then the most preferred signal with the least PAPR is selected and transmitted. The basic idea of this technique is based on the phase rotation sequence, the process involves multiplication of data sequence and random phase sequence generated. The selected index is required at the receiver side for the recovery of data block.[3][7]

Figure 6. Shows the detailed block diagram of SLM technique. The original data block is X= [X1, X2……Xu] is multiplied element by element by different phase rotation [B1,B2……Bu], prior to IFFT operation. Then from a large number of different data blocks, the lowest PAPR signal for transmission is individuallyselected.

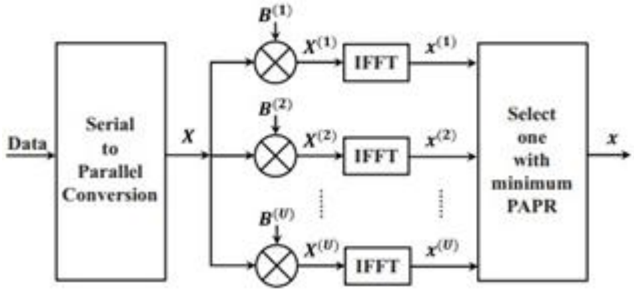

Figure 6: Block diagram of SLM technique

Advantages:

- Nodistortion
- ReducePAPR
- Independent of number ofcarriers
- In terms of PAPR reduction vs. redundancy SLM performs better thanPTS.

Disadvantages:

- Side information isrequired
- Highcomplexity

C) Partial Transmit sequence technique(PTS)

The main idea of PTS is to divide a block of data into non-overlapping sub-blocks with independent rotation coefficients. This rotation factor provides time data in time domain with the smallest amplitude. The basic idea of this technique is to divide the original OFDM symbol data into sub-data, send them through the sub-blocks, and multiply them by different weight values depending on the phase rotation factor until selected the optimal lower PAPR value. [8]

Figure 7. Shows the detailed block diagram of PTS technique. After serial to parallel conversion, the data is partitioned into v sub-blocks [X1,X2,….Xv] without overlapping which are combined to minimize the PAPR. Each carrier in the sub-blocks is multiplied with the same rotation factor. The time domain vector can be composed by IFFT. [7]

$$b(v) = e^{-j\varphi(v)}$$

$$x = \sum_{v=1}^{V} b(v)x(v)$$

There are two important issues that need to be resolved with PTS. The computational complexity of finding the best phase factor and the overhead of the original phase factor as secondary information that must be sent to the receiver to correctly decode the transmitted bitsequence.

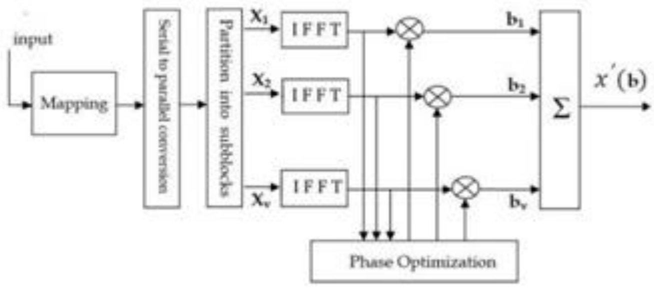

Figure 7: Block diagram of PTS technique

Advantages:
- Nodistortion
- reducePAPR
- In PAPR reduction vs. additional system complexity, PTS is considerably better than other techniques.

Disadvantages:
- Side information isrequired
- Involve complex vector sums at Tx.

2. Simulation Results

The simulation is performed using MATLAB to evaluate the performance analysis of three PAPR reduction methods: Amplitude Clipping, Selected mapping, Partial transmit technique. Figure 8 shows the performance of the CCDF plots of the three methods individually along with the original OFDM, and Figure 9 shows the combined performance for comparison purpose.

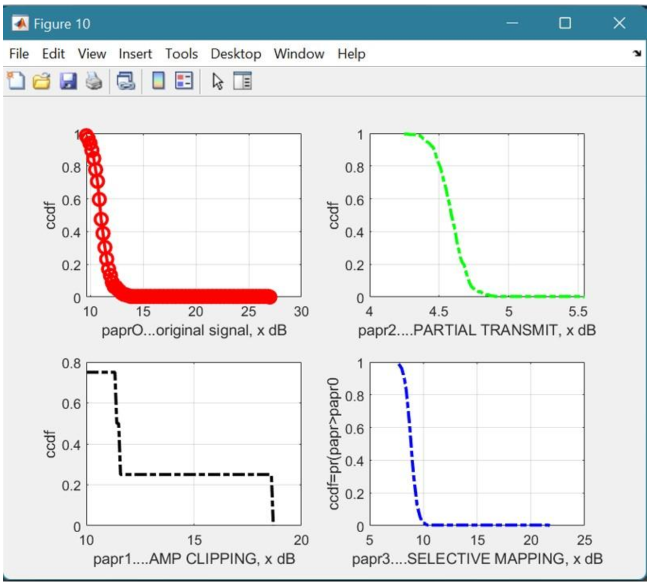

Figure 8: CCDF plots of OFDM, Clipping, PTS, and SLM

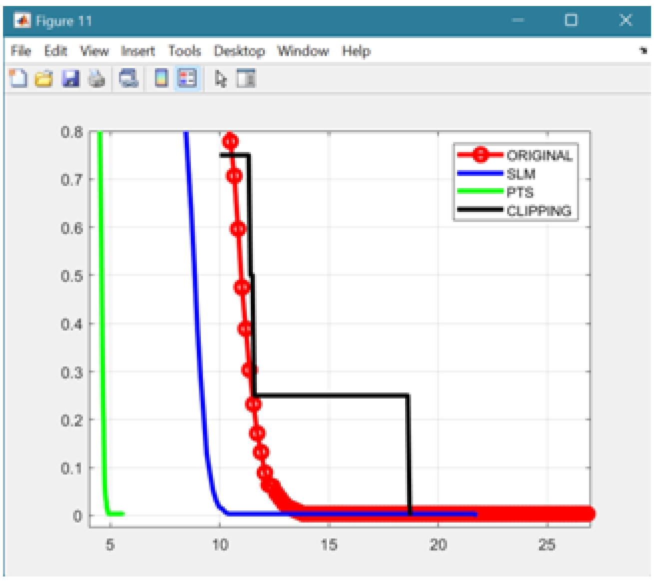

Figure 9: Combined CCDF plots of OFDM, Clipping, PTS, and SLM

Observations from Figure 8 and 9are
1) Clipping technique is the worst among the three techniques.
2) Selective mapped technique is better than clipping but low performance than Partial Transmittechnique.
3) Partial transmit is the best among all the three techniques.

Table 1: Comparison between three PAPR reduction techniques

PAPR Reduction Techniques	Amplitude Clipping	SLM	PTS
PAPR Reduction	Least PAPR reduction	Better than clipping	Better than clipping and SLM
Distortion	Yes	No	No
Power Increase	No	No	No
Complexity	Low	High	High
Data rate loss	No	Yes	Yes
BER Increase	Yes	No	No
Processing at Transmitter	Amplitude Clipping	V-IFFTs	P-IFFTs
Processing at receiver	None	Inverse SLM, Side information separation from received data	Inverse PTS, Side information separation from received data

3. Conclusions

All three methods reduce PAPR, and each method has some advantages and disadvantages, as shown in Table 1. In this paper, clipping simulation, SLM, PTS were shown and compared with the original OFDM. Simulation results show that the SLM and PTS methods are superior to the clipping and filtering methods. The only major problem with these techniques is complexity. From the table it can be observed that there is some BER degradation a compared to original OFDM. The main purpose of the PAPR reduction method is to effectively reduce PAPR without compromising system performance and support low implementation costs.

The disadvantages mentioned are one of the reasons behind the use of DFT-s-OFDM (downlink) in 5G in place of these reduction techniques, as DFT reduces the PAPR. But, when we consider the high data rate requirements for beyond 5G, Keeping the PAPR of DFT-s-OFDM low and improving its spectral efficiency (SE) is a challenge, especially when higher order modulation is not applicable. And Non Orthogonal waveforms can be use for future generations, as they were contending waveforms for 5G suffers from High PAPR. So, In future the effective PAPR reduction techniques can be used in Beyond 5G future generations.

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