Approach to reduce PAPR in Orthogonal Frequency Division Multiplexing Technique

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Abstract: Orthogonal Frequency Division Multiplexing (OFDM) is an efficient and attractive modulation technique that can be considered as the heart of all major wireless communication applications used as well as in development today. OFDM is an advanced version of Frequency Division Multiplexing (FDM) technique that separates the channel bandwidth into multiple narrow sub-bands in order to transfer information. With the progress of advance communication field there should be high data rate along with power efficiency and lower Bit Error Rate (BER). Due to advent of Internet of Things (IoT), Artificial Intelligence (AI), 5G and other network demanding technologies network congesting scenarios are becoming common and because of interfering channels noise is observed caused by adjacency of communicating devices. So, the fulfillment of current as well as future demand of high data rate and greater power efficiency are very much essential. These requirements are achieved very well with OFDM technique but at the cost of high Peak to Average Power Ratio (PAPR). High PAPR leads to in band distortion and Out of Band radiation along with power inefficiency while using practical power amplifier at the transmitter. This paper presents a review of OFDM and analysis of a technique for PAPR reduction. Additionally, the scopes and challenges in PAPR reduction have been documented which describes clipping technique to reduce PAPR through MATLAB simulation models.

Keywords: OFDM, BER, ISI, OOB radiation, CFO, PAPR reduction.

1. Introduction

With mammoth development in the field of communication, high data rates and greater bandwidth have become highly demanding in addition to both power efficiency and lower Bit Error Rate (BER). Single carrier system can fulfil the demand of enhance data rate but with compromising signal distortion and higher cost due to presence of frequency selective environment. While considering an advance step towards the multi-carrier modulation system it is possible to get higher data rates in a time dispersive channel without compromising the bit error rate performance of the system. To achieve better performance while applying multi-carrier modulation scheme, it is desirable to make the sub-carriers to be orthogonal to each other which is better termed as Orthogonal Frequency Division Multiplexing (OFDM), which is one of the most commonly deployed technologies of the present time **(Vishal Ghode, 2021**). OFDM is a specialized version of Frequency Division Multiplexing scheme, used as a digital multi-carrier modulation method to encode digital data on multiple sub-carrier frequencies. Numerous closely spaced orthogonal sub-carriers are used to carry data on several parallel data streams or sub-channels. Each sub-carrier is modulated with a conventional modulation scheme at a lower symbol rate, maintaining the total rate similar to conventional single-carrier modulation schemes in the same bandwidth. The bandwidth of each sub-channel is small enough as compared to frequency selective channel to turn a single wideband channel into 'n' number of parallel flat fading channels. Thus, OFDM does not suffer from frequency selective fading, and it enables parallel transmission. But OFDM suffers from high Peak to Average Power Ratio (PAPR). High PAPR significantly degrades the system performance. So, PAPR reduction is very much important for application of OFDM **(A. B. Kotade, 2018)**.

This paper therefore represents a review of OFDM technology and analysis of Amplitude Clipping, which is used for PAPR reduction in OFDM. Additionally, the scopes and challenges in PAPR reduction have been documented with Amplitude Clipping technique through simulation models. The remaining paper is structured as follows. In section II, the system modelling of OFDM system is presented. Section III depicts an overview of adoption of OFDM for 5G technology and provides certain setbacks as well. Section IV documents PAPR reduction techniques in OFDM technology and provides simulation results of clipping to reduce PAPR. Section V concludes the proposed work with sagacity to future scopes.

2. System Modelling

OFDM is a spectrum efficient digital modulation scheme in which the complete channel bandwidth is divided into multiple sub-carriers that are mutually orthogonal to each other. Orthogonality gives the sub-carriers a valid reason to be closely spaced, even partially overlapped, without interfering each other. Due to its various advantages like high spectral efficiency, robustness to channel fading, immunity to interference etc., OFDM is widely used in digital audio and video broadcasting, referred to as 'DAB' and 'DVB' respectively.

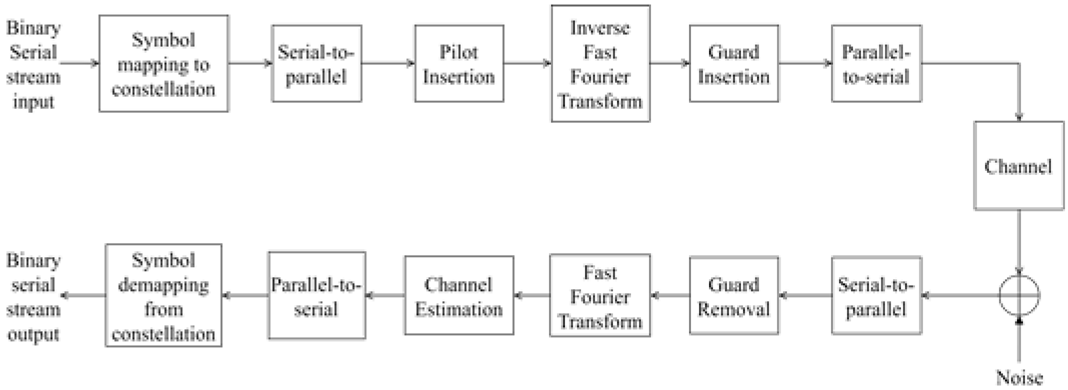


Fig.-1: Orthogonal Frequency Division Multiplexing (OFDM) system block diagram

Fig.-1 represents typical OFDM system block diagram. The first stage is symbol mapping that performs one-to-one mapping of binary data input to a complex valued number, representing a point on the constellation. Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), Quadrature Amplitude Modulation (QAM) or such type of other conventional modulation scheme can be used in this stage. Similarly symbol de-mapping in receiver, converts complex valued numbers on the constellation into corresponding binary data depending upon its phase and amplitude values. In the second stage, the serial to parallel converter converts serial OFDM sequence to parallel sequence to load them onto the sub-carriers. Correspondingly, at the receiver parallel to serial converter converts received parallel OFDM sequence to serial sequence to get it back into its original form. At the third stage, pilot insertion inserts pilot carrier into the OFDM symbol. These pilot carriers do not carry any information and this are complex valued numbers; representing a point on the constellation. These pilot carriers are used to correct the frequency and timing error of OFDM symbols. In the receiver counterpart, channel estimation stage, pilot carriers are used to indicate where actually the OFDM symbol begins. In fourth Stage, Inverse Fast Fourier Transform (IFFT) generates the time domain OFDM samples by multiplexing symbols on different sub-carriers. Multi-carrier signal *x(t)* is defined as —

$$x(t) = \sum_{k=0}^{N-1} X(k) e^{j2\pi kFt} \tag{1}$$

where, *X(k)* = k^{th} symbol, *F* = fundamental frequency, *N* = total number of symbols. Let, total bandwidth = *B*, so *F=B/N*, and maximum frequency component of x(t) is

$$f_{max} = \frac{B}{2} \tag{2}$$

Now, if *x(t)* is sampled at Nyquist rate, then sampling rate = $2f_{\max} = B$ and sampling interval $T = \frac{1}{B}$, resulting in the n^{th} sampling instant to be $nT = \frac{n}{B}$. So,

$$x(t) = \sum_{k=0}^{N-1} X(k) e^{j2\pi kFt} \tag{3}$$

$$\Rightarrow x(nT) = \sum_{k=0}^{N-1} X(k) e^{j2\pi kFnT} = \sum_{k=0}^{N-1} X(k) e^{j2\pi k\left(\frac{B}{N}\right)\left(\frac{n}{B}\right)} \tag{4}$$

$$\Rightarrow x(n) = \sum_{k=0}^{N-1} X(k) e^{\frac{j2\pi nk}{N}} \tag{5}$$

Equation (5) is the equation of n^{th} OFDM sample that is generated by N-point IFFT of N number of symbols without using of local oscillators **(A. K. Jagannatham, 2012)**. Since, as can be observed in equation (5), the function is no longer dependent on any constant sampling interval, *T*, hence *x(nT)* is transformed to *x(n)*, i.e., a discrete time function. The next stage is guard interval insertion that adds a cyclic prefix at the front of each OFDM symbol to mitigate the effect of Inter Symbol Interference (ISI).

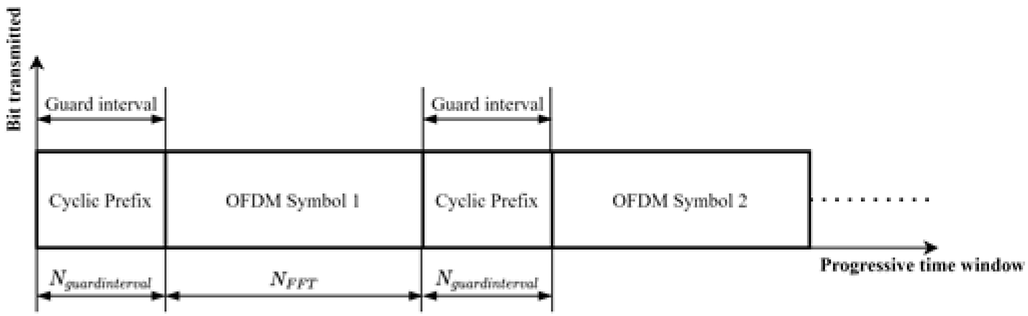


Fig.-2: A sequence of OFDM symbols with cyclic prefix in time domain

Fig.-2 illustrates a sequence of OFDM symbols with cyclic prefix guard interval at beginning. Guard removal removes the cyclic prefix from the OFDM symbols because it gets affected by Inter Symbol Interference (ISI) during transmission **(A. K. Jagannatham, 2016)**. Sixth stage is parallel to serial conversion; this stage converts the OFDM symbols with guard interval into the serial sequence of OFDM symbols to transmit through the channel. In the receiver, OFDM waveforms are transformed into the parallel form **(Drakshayini M N, 2016)**.

3. Implications of use of OFDM in 5G technology

OFDM is the most proficient technology for 4G standard. OFDM has outpaced all other technologies because of its numerous merits. Apart from the merits, there are some demerits also. The main drawback of using OFDM is that, it cannot be highly preferred for the use in 5G technology. The main difference between 5G and its previous generations that lies in the fact that 3G and 4G technologies are focused on high mobility to be an afterthought.

Moreover, in 5G communication, the higher mobility is treated as an integral part of the communication systems. OFDM faces many challenges in the aspect of its adoption in wireless communication system. One of the biggest problems in OFDM is high Peak to Average Power Ratio (PAPR), that significantly reduces the system performance, spectral efficiency and power efficiency.

Firstly, PAPR generates non-linear distortion, Out of Band (OOB) emission and PAPR also increases Bit Error Rate (BER). Now, with the use of cyclic prefix or guard band, near about 10% of the bits are repeated that decreases spectral efficiency **(P. Lavanya, 2019)**. Secondly, the carrier and timing synchronization are challenging tasks without which OFDM signal suffers from Carrier Frequency Offset (CFO) and that leads to Inter Carrier Interference (ICI). The significant Out of Band noise is introduced in these systems, that pick-up interference from nearby channels. Because of these significant drawbacks, it does not appear that OFDM would be able to continue to serve as a proficient candidate for 5G communication.

4. PAPR reduction

PAPR stands for Peak to Average Power Ratio and it is mathematically defined as —

$$PAPR = \frac{P_{peak}}{P_{average}} \qquad 6$$

where P_{peak} represents peak output power and $P_{average}$ represents average output power of a sample in transmission of OFDM symbol.

An OFDM signal consists of many individual sinusoidal sub-carriers. When these sinusoids are aligned in phase at the IFFT input and are added coherently, the OFDM signal can have large amplitude resulting in a high PAPR at the IFFT output. The large peak amplitude of the OFDM signal is due to *N*-subcarriers, and it is *N* times that of a single carrier system. When these large peaks with high PAPR exceed the saturation region of power amplifier used at the transmitter and/or receiver, the OFDM signals suffer from non-linear distortion, Out of Band radiation and also Inter Modulation Interference among OFDM sub-carriers. Due to this, Bit Error Rate (BER) increases at the receiver end **(A. E. Jayati, 2019)**. Although the use of power amplifiers with a large saturation region can reduce distortion or BER, but it leads to high equipment cost and high battery power consumption **(K. Mhatre, 2015)**. To deal with this problem, several algorithms have been implemented for reduction of high PAPR such as Clipping, Coding, Partial Transmit Sequences, Selective Mapping and Tone Reservation.

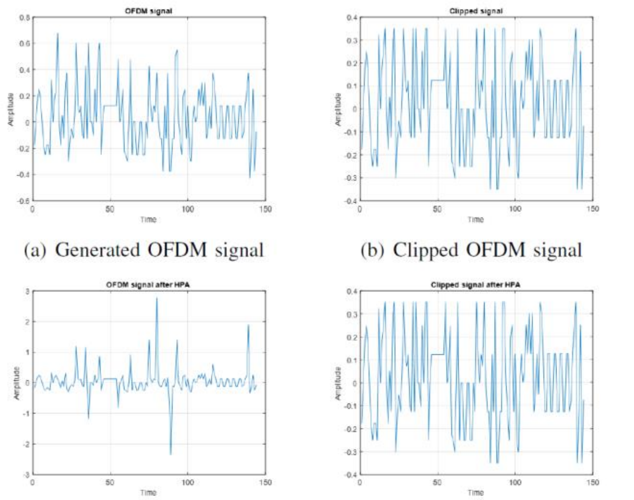
Amplitude Clipping with High Power Amplifier (HPA), technique for reduction of PAPR is presented in this paper. Amplitude Clipping is one of the simplest and one of the most cost-effective techniques for PAPR reduction. In order to limit the peak envelope of the IFFT output signal, the values higher than the pre-defined set of values, such that the threshold value, are clipped and the rest of the values, such that the values less than the threshold value, are passed through the channel in an undisturbed manner. The threshold value can be determined depending upon the dynamic operating region of the High Power Amplifier (HPA) **(Kaur, S., 2017)**.

Let, $x_c(n)$ is clipped version of IFFT output $x(n)$ and A is the threshold value, so

$$x_c(n) = \begin{cases} x_c(n), & x_c(n) \leq A \\ A, & x_c(n) > A \end{cases} \qquad 7$$

Equation (7) can be used to define the mathematical function for clipping.

During amplitude clipping distortion is considered to be another source of noise. Clipping causes in band signal distortion which results in BER performance degradation **(A. Y. Jaber, 2015)**. But this problem can be solved by limiting the number of sub-carriers which are capable enough to overcome frequency selective fading of time dispersive channel, by repeating the process of filtering and clipping till the desired amplitude level is achieved to improve Bit Error Rate (BER).



(a) Generated OFDM signal
(b) Clipped OFDM signal
(c) Non-clipped OFDM signal after HPA+noise
(d) Clipped OFDM signal after HPA+noise

Fig.-3: Simulation result

For the above proposed idea, the corresponding simulated results can be observed in the above figure. Here, it can be observed that the effect of High-Power Amplifiers on the generated OFDM signal which is shown in figure 3(a). For a non-clipping system, the OFDM signal produces a high PAPR as can be observed in figure 3(c). But the same signal when applied with a clipping system, as shown in figure 3(d), produces a signal with much lower PAPR which is a very desirable condition for operation of systems with lower threshold and tolerance value. This allows safer operation of equipment even with lower power electronics. As for the effect of clipping on the original signal, there is very negligible change in the signal as can be compared between figure 3(a) and figure 3(b). Hence, this can be conclusively stated that, the objective of this paper to reduce PAPR in an OFDM system is fulfilled.

5. Conclusion

This paper presents an overview of Orthogonal Frequency Division Multiplexing technique, with an eye toward issues such as technological ideologies, the problem OFDM faces due to PAPR, its applicability in 5G standard and PAPR reduction technique with the aid of simulations. OFDM serves as a proficient technology in

4G but high PAPR questions it application in 5G with enhanced data rates. PAPR reduction is a challenging task and almost all available technique of PAPR reduction has some setbacks. The presented PAPR reduction technique employing clipping suffers from BER, but it is simple and cost efficient that strengthens its applicability and hence it can be served as one of the best candidates for its employability. The application of clipping technique can also be verified in Orthogonal Frequency Division Multiple Access (OFDMA). The acknowledgement reduced BER in clipping can be solved in suitable error control coding that will enhance the system's liability.

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