PAPR OF ORTHOGONAL FREQUENCY DEVISION MULTIPLEXING

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ABSTRACT

Orthogonal Frequency Division Multiplexing (OFDM) is an attractive and promising technique for fourth generation wireless communication. In the OFDM system, orthogonally placed sub-carriers are used to carry the data from the transmitter end to the receiver end. Presence of guard band in this system deals with the problems of ISI and noise is minimized by larger number of sub-carriers. But the large Peak to Average Power Ratio of these signal have some undesirable effects on the system. High Peak to Average Power Ratio (PAPR) is the one of the major drawback of the Orthogonal Frequency Division Multiplexing (OFDM) transmitted signal. This paper tries to analyses the basic principles of OFDM as well as the main advantages and drawbacks, where the high peak-to-average power ratio (PAPR) plays an important role.

Keyword: *- Frequency, Power, System, Signal, Modulation, Multiplexing, Orthogonal and Domain etc.*

1. INTRODUCTION TO OFDM

Orthogonal frequency division multiplexing (OFDM) is a multi-carrier modulation technique with bandwidth efficient signaling schemes for use in high data rate communication systems. Orthogonal frequency division multiplexing (OFDM) is a very promising technique for high-speed data transmission in wireless communication systems due to its robustness against the frequency selective fading channel [1] [2]. Orthogonal Frequency Division Multiplexing is a frequency division multiplexing (FDM) scheme utilized as a digital multi-carrier modulation method. Each sub-carrier is modulated with a conventional modulation scheme (such as QPSK) at a low symbol rate, maintaining total data rates similar to the conventional single carrier modulation schemes in the same bandwidth. Multicarrier transmission splits the high rate data stream into N sub streams of lower data rate. Classical parallel data systems divide the available bandwidth into N non overlapping sub-channels. Each sub-channel is modulated with a separate symbol and then the N sub-channels are frequency multiplexed. Although OFDM has some advantages that make it suitable for fading channels, it presents a high peak to average power ratio (PAPR), which is one of the main disadvantages of OFDM systems [3]. A high PAPR brings disadvantages like an increased complexity of the analog to digital (A/D) and digital to analog (D/A) converters and reduced efficiency of radio frequency (RF) power amplifiers. OFDM signal consists of a number of independent modulated sub-carriers that leads to the problem of PAPR. If all sub-carriers come with same phase, the peak power is N times the average power of the signal where N is the total number of sub-carriers in an OFDM signal.

Thus, it is not possible to send this high peak amplitude signal to the transmitter without reducing peaks. High peak to average power ratio (PAPR) cause unwanted saturation in the power amplifiers, leading to in band distortion and out of band radiation. The high peaks of OFDM signal can be reduced in several ways.

1.1 GENRAL PRINCIPLE OF OFDM

OFDM is a particular type of FDM modulation. The first step in the OFDM system is to convert a serial data stream into a parallel stream and then modulate the symbols, using the quadrature amplitude modulation (QAM) or the phase shift keying (PSK) modulation. The transmitter and receiver can be implemented by means of the IFFT and FFT respectively. After the symbols are modulated the data stream is converted to time domain by means of an IFFT. The length NFFT of the FFT function should be chosen significantly larger than the number of useful sub channels N to ensure that the edge effects are negligible at half the sampling frequency and to ensure that the shape of the reconstruction filter of the digital-to-analog converter (D/A converter) does not affect the significant part of the spectrum.

At the receiver, an FFT of the same length is performed and the N useful coefficients will be extracted from the NFFT spectral coefficients [4]. Figure 2.1 shows a block diagram of an OFDM system. The output signal of the IFFT block is a discrete signal which is processed by the D/A converter. This discrete signal has a periodic spectrum so the D/A converter has to filter it by a low-pass filter in order to eliminate the unnecessary replicas. These filters attenuate the sub-carriers close to the Nyquist frequency, so these sub-carriers should be avoided for data transmission [3].

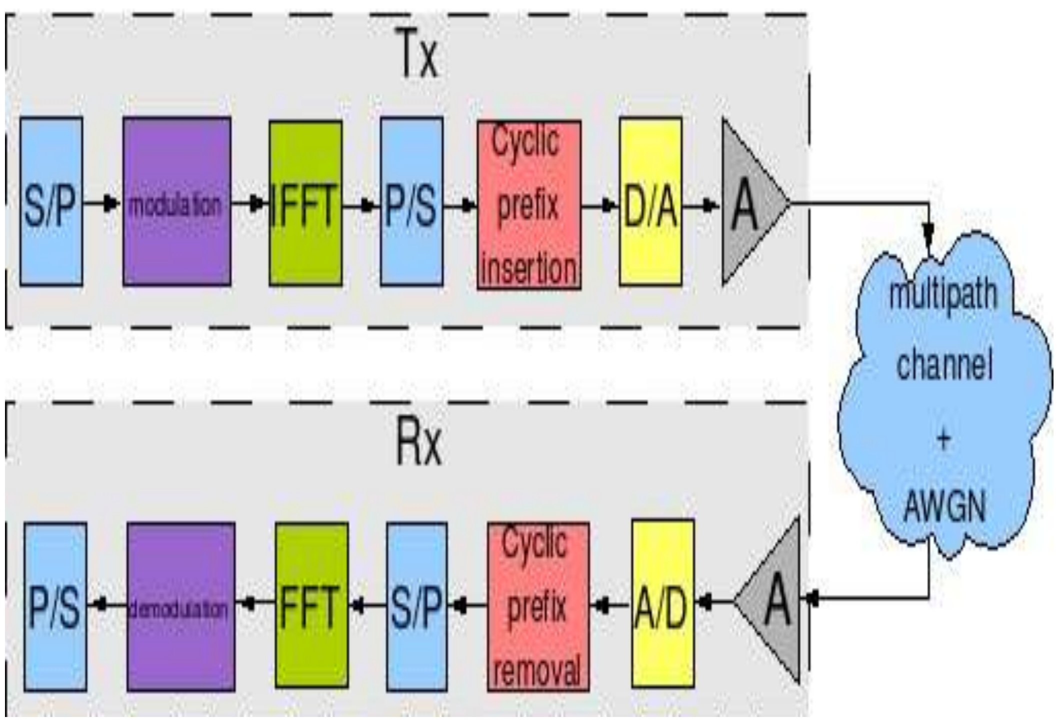

Fig-1: Block diagram of an OFDM system

The signal bandwidth is divided into N small sub channels and the frequency of each sub-carrier is chosen to form an orthogonal set of frequencies, which are known at the receiver. The signal bandwidth is divided into N small sub channels and the frequency of each sub-carrier is chosen to form an orthogonal set of frequencies, which are known at the receiver. This structure with multiple sub channels makes OFDM suitable for multiuser communications, allocating several sub-carriers to each user. Allowing the sub-carriers to overlap reduces the required bandwidth and increases the spectral efficiency. Consider an OFDM system consisting of N sub-carriers. Let us denote a block of N frequency domain sub-carriers as a Vector X, where

$X = [X_0, X_1, X_2 \ldots\ldots\ldots\ldots X_{N-1}]$ denotes the input data in an OFDM block. For an OFDM system each symbol in X is used to modulate a sub-carrier.
Let, f_k, $k = 0,1 \ldots\ldots\ldots N-1$, denote the k^{th} sub-carrier frequency. In the OFDM system, the sub-carriers must be Orthogonal to adjacent sub-carriers, i.e. $f_k = k.\Delta f$, where $\Delta f = 1/(NT)$ and T is the symbol duration. Therefore, the complex envelope of the transmitted OFDM signal is given by

$$x(t) = 1/\sqrt{N}\sum_{K=0}^{N-1} X_k e^{j2\pi k.\Delta f}, 0 \leq t < NT \qquad (1)$$

Where $j=\sqrt{-1}$, Δf is the sub-carrier spacing, and NT denotes the useful data block period. In OFDM the sub-carriers are chosen to be orthogonal ($\Delta f = 1/(NT)$).

The total bandwidth of the OFDM signal is $B = N\Delta f$. Figure 2 shows the OFDM basis functions and how they orthogonally overlap. At the center frequency of each sub-carrier all the rest are zero, so they do not interfere with each other since the receiver calculates the spectrum values at the peak point of each subcarrier; this way Inter carrier interference (ICI) is avoided which is an important advantage of OFDM systems. Because of the frequency selective fading properties

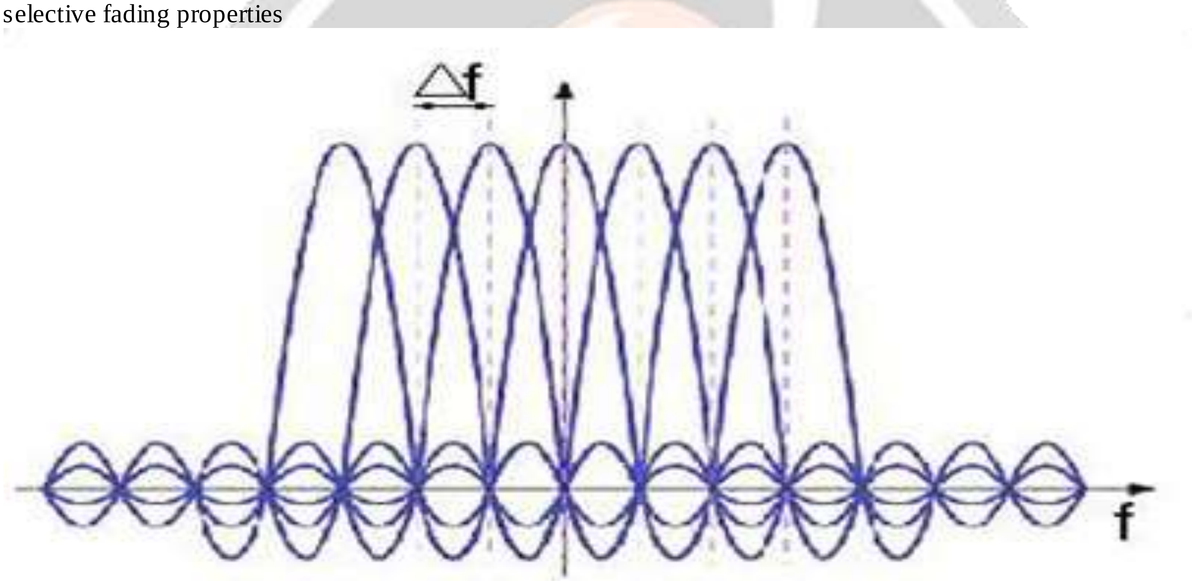

Fig-2: OFDM signal in frequency domain

of wireless channels, some of the sub-carriers of the OFDM signal are enhanced and others suffer fading. If N is large enough, each sub-carrier is narrow compared to the coherence bandwidth of the channel and even under severe fading conditions they suffer flat fading. Although the signal is built in frequency domain, the data transmission takes place in time domain. After shaping the signal, the IFFT block converts it to time domain and produces N output samples, corresponding to the N sub-carriers of the OFDM system and which make a single OFDM symbol. The resulting signal is the sum of all the modulated sub-carriers which form the baseband signal. Figure 3 shows how an OFDM signal looks like in time domain.

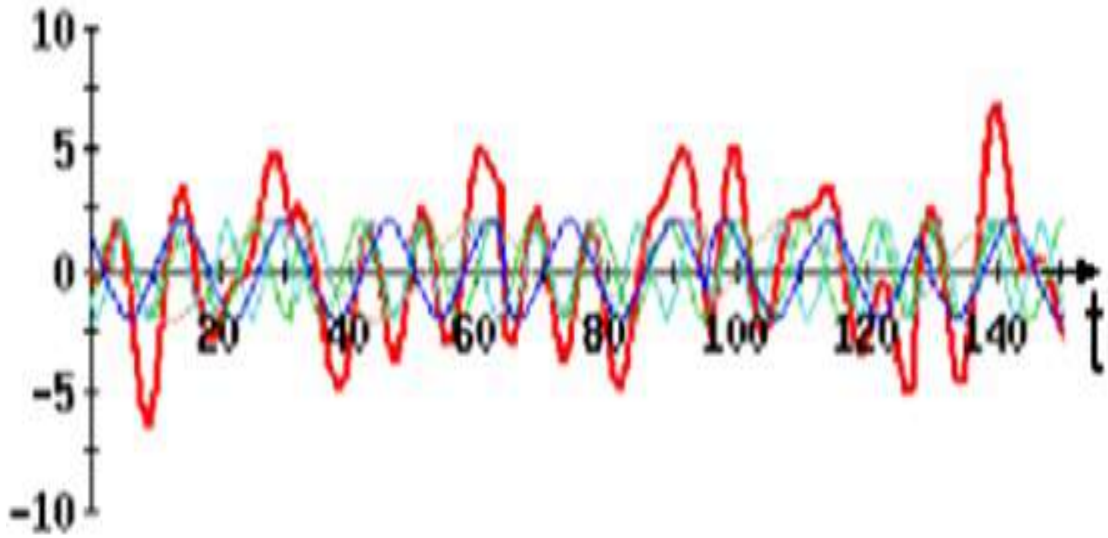

Fig-3: OFDM signal in time domain

The different sub-carriers (blue and green waves) in Figure 3 are added up to form the OFDM signal (red wave). The shape of the red wave has several peaks much greater than the average power. When all the sub-carriers are added up constructively, the resulting power is much higher than the average power of the OFDM signal. This causes a very large peak which increases as the number of sub-carriers increase, leading to a very high PAPR. High PAPR is an important drawback of OFDM systems.

2. ADVANTAGES OF OFDM

Some of the advantages of an OFDM system are as follows:
1. OFDM is computationally efficient to employ the modulation and demodulation techniques by using FFT.
2. The OFDM signal is robust in multipath propagation environment and more tolerant of delay spread.
3. OFDM is more resistant to frequency selective fading than single carrier transmission systems.
4. OFDM system gives good protection against co-channel interference and impulsive parasitic noise.
5. Pilot subcarriers are used in OFDM system to prevent frequency and phase shift errors.
6. It is possible to use maximum likelihood detection with reasonable complexity.
7. OFDM is a good candidate for Cognitive Radio (CR) because of its flexibility and adaptability [5].
8. The Orthogonality preservation procedures in OFDM are much simpler compared to CDMA/TDMA technique in multipath conditions [6].

3. DISADVANTAGES OF OFDM

Some of the disadvantages of an OFDM system are as follows:
1. The OFDM signal suffers from high peak to average power ratios (PAPR) of transmitted signal.
2. OFDM is very sensitive to carrier frequency offset.
3. It is difficult to synchronize when sub-carriers are shared among different transmitters, i.e. accurate frequency and time synchronization is required.
4. More sensitive to Doppler spreads than single-carrier schemes.

4. PEAK TO AVERAGE POWER RATIO (PAPR)

When in time domain all the N sub-carriers are added up constructively, they produce a peak power that is N times greater than the average power of the signal. The PAPR is a figure of merit that describes the dynamic range of the OFDM signal. PAPR is defined as the ratio of the maximum peak power to the average power during an OFDM symbol period. The PAPR of the OFDM signal $x(t)$ can be written as

$$PAPR = \max \left| x(t) \right| / E[\left| x(t) \right|^2] \quad (2)$$

Where E[.] is the expectation operator, i.e. average power.

Basically peak-to-average power ratio (PAPR) is the most popular parameter used to evaluate the dynamic range of the time-domain OFDM signal or signal envelop variation or the crest factor *(CF)* where $PAPR = (CF)^2$. Crest factor is another parameter which is widely used in the literature, and defined as the square root of the PAPR [7].PAPR reduction techniques are concerned with reducing $\max|x(t)|$.However, in practice most systems deal with the discrete-time signals, the amplitude of samples of x(t) is dealt with in many of the PAPR reduction techniques. Since symbol spaced sampling of x(t) sometimes misses some of the signal peaks and results in optimistic results for the PAPR, signal samples are obtained by oversampling *x(t)* by a factor of *L* to approximate the true PAPR better, where L is an integer larger than 2. The L-time oversampled signal can be given by

$$x(n) = 1/\sqrt{N} \sum_{K=0}^{N-1} X_k e^{j2\pi k/LN}, n = 0,1, \dots \dots \dots \dots L-1 \quad (3)$$

The oversampling factor $L = 4$ in a practical OFDM system is sufficient for capturing the peaks [8]. From Eq (3), the L-time oversampled samples can be obtained by performing LN-point inverse fast Fourier transform (IFFT) on the data block X with *(L-1)*. N zero padding. For the discrete time signal, the PAPR can be calculated as

$$PAPR = \max \left| x(n) \right|^2 / E[\left| x(n) \right|^2] \quad (4)$$

Where E(.) denotes the expected value.

PAPR is a random variable because it is a function of the input data, and the input data is of random nature. Therefore PAPR can be calculated by using level crossing rate theorem that calculates the average number of times that the envelope of a signal crosses a given level. Knowing the amplitude distribution of the OFDM output signals, it is easy to compute the probability that the instantaneous amplitude will be above a given threshold and the same goes for power. This is performed by calculating the complementary cumulative distribution function (CCDF) for different PAPR values [9]. From the central limit theorem, for large number of values of N, the real and imaginary values of x(t) becomes Gaussian distributed. The amplitude of the OFDM signal, therefore, has a Rayleigh distribution with zero mean and a variance of N times the variance of one complex sinusoid. The cumulative distribution function (CDF) of the PAPR is one of the most frequently used performance measures for PAPR reduction techniques [10]. The complementary cumulative distribution function (CCDF) is the probability that the PAPR exceeds a certain threshold $PAPR_0$.

$$CCDF(PAPR(x(n))) = Pr(PAPR(x(n))) > PAPR_0 \quad (5)$$

Due to the independence of the N samples, the CCDF of the PAPR of a data block with Nyquist rate sampling is given by

$$P_r(PAPR(x(n)) > PAPR_0) = 1 - (e^{PAPR0})^N \quad (6)$$

This equation assumes that the N time domain signal samples are mutually independent and uncorrelated and it is not accurate for a small number of subcarriers. Therefore, there have been many attempts to derive more accurate distribution of PAPR [11].

In OFDM system the information data is generated and shaped in the Data block, this takes place in frequency domain, then comes the IFFT block and the signal is afterwards in digital time domain. To send the signal through the antenna, it must be first converted to analog time domain by means of an D/A converter and then amplified with an RF power amplifier. After the RF amplifier comes the antenna which sends the signal to the OFDM receiver over the wireless channel. When the amplifier operates in the linear region, as its name indicates, signals are linearly amplified by the same factor. However, when it operates in the saturation region, signals are not amplified any more, they are flattened at the maximum output power of the amplifier. In the OFDM transmitter, the system needs an ideal amplifier which has to work in the linear region in order not to distort the data. The PAPR problem appears when the peaks of the OFDM signal are too large and do not fit in the linear region. In which case they are treated by the saturation region and so they are non linearly modified, causing inter modulation among sub-carriers and out-of-band radiation. To be able to hold these peaks, the operational amplifier (OA) of the transmitter needs a very large dynamic range. Increasing the linear region of an operational amplifier is very expensive and inefficient many a times. If number of sub-carriers increases, the peak power will also increase and so will do the PAPR. If number of sub-carriers is large enough, the actual operational amplifier will not be able to hold the new peak power and it would be necessary to replace it. Besides, the larger the operational amplifiers dynamic range is, the more battery it consumes and since most OFDM systems are power limited, an operational amplifier with a large linear region would consume most of the battery of the system, which is another reason why increasing the dynamic range of the operational amplifier is not a good solution. There are a number of techniques, available in the literature, to deal with the PAPR problem associated with OFDM signals. These techniques include amplitude clipping [12], clipping and filtering [13], tone reservation (TR) [14], tone injection (TI) [14], active constellation extension (ACE) [15], and multiple signal representation techniques such as selective mapping (SLM) [16], partial transmit sequence (PTS) [17], Iterative flipping algorithm [18]. These techniques achieve PAPR reduction at the expense of transmit signal power increase, bit error rate (BER) increase, data rate loss and computational complexity increase [10].

5. CONCLUSIONS

The current status of the research is that OFDM appears to be a suitable technique as a modulation technique for high performance wireless telecommunications. An OFDM link has been confirmed to work by using computer simulations, and some practical tests were performed on a low bandwidth base-band signal. So far only four main performance criteria have been tested, which are OFDM's tolerance to multipath delay spread, channel noise, peak power clipping and start time error. Several other important factors affecting the performance of OFDM have only been partly measured. These include the effect of frequency stability errors on OFDM and impulse noise effects. As one of characteristics of the PAPR, the distribution of PAPR, which bears stochastic characteristics in OFDM systems, often can be expressed in terms of Complementary Cumulative Distribution Function (CCDF) Therefore, it is important and necessary to research on the characteristics of the PAPR including its distribution and reduction in OFDM systems, in order to utilize the technical features of the OFDM.

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