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Peak to Average Power Ratio Reduction of OFDM Signals Using Clipping and Iterative Processing Methods

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Abstract

One of the serious problems in any wireless communication system using multi carrier modulation technique like Orthogonal Frequency Division Multiplexing (OFDM) is its Peak to Average Power Ratio (PAPR).It limits the transmission power due to the limitation of dynamic range of Analog to Digital Converter and Digital to Analog Converter (ADC/DAC) and power amplifiers at the transmitter, which in turn sets the limit over maximum achievable rate.

This issue is especially important for mobile terminals to sustain longer battery life time. Therefore reducing PAPR can be regarded as an important issue to realize efficient and affordable mobile communication services.

This paper presents an efficient PAPR reduction method for OFDM signal. This method is based on clipping and iterative processing. Iterative processing is performed to limit PAPR in time domain but the subtraction process of the peak that over PAPR threshold with the original signal is done in frequency domain, not in time like usual clipping technique. The results of this method is capable of reducing the PAPR significantly with minimum bit error rate (BER) degradation.

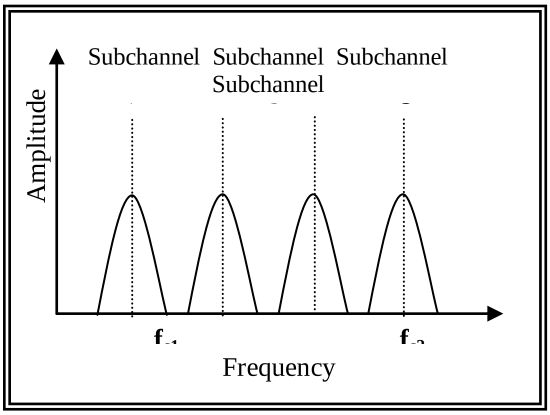
Keywords: OFDM, PAPR Reduction, Clipping Method, Iterative Processing Method.

1. Introduction:

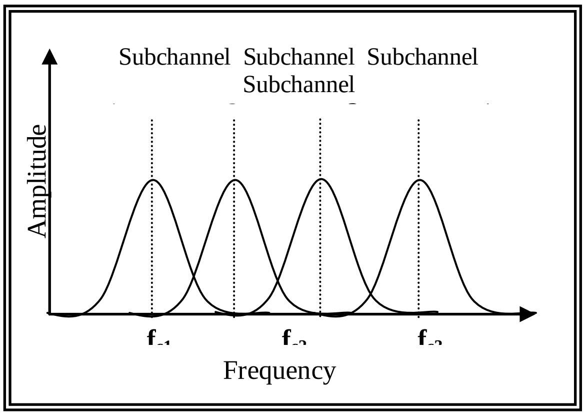
Multi-carrier transmission, also known as Orthogonal Frequency Division Multiplexing (OFDM) or Discrete Multi-Tone (DMT), is a technique with a long history that has recently seen rising popularity in wireless and wire line application. The recent interest in this technique is mainly due to the recent advantage in digital signal processing technology and semiconductor technology. International standards making use of OFDM for high speed wireless communications are already established or being established by IEEE802.11, IEEE802.16, IEEE802.20 and European Telecommunications Standards Institute (ETSI) Broadcast Radio Access Network (BRAN) committees [1]. For wireless application, an OFDM based system can be of interest because it provides greater immunity to multi-path fading and impulse noise eliminates the need of equalizers, while efficient hardware implementation can be realized using Fast Fourier Transform (FFT) techniques.

Unfortunately, one particular major problem with multi carrier signals that is often cited as the major drawback of multi carrier transmission is its large envelope fluctuation, which is quantified by the parameter called Peak to Average Power Ratio (PAPR). Since most practical transmission systems are peak power limited, designing the system to operate in perfectly linear region often implies operating at power levels well below the maximum power available [2]. In practice, to avoid operating the amplifier with extremely large back offs occasional saturation of the amplifiers or clipping in Digital to Analog Converters (DAC) must be allowed. This additional process is a non linear process which creates inter-modulation distortion that increases the bit error rate(BER) in standard linear receiver, and also causes spectral widening of the transmit signal that increase adjacent channel interference to the other users [3].

In this paper an efficient PAPR reduction method for OFDM signals is presented. This method is based on clipping; clipping is introduced to limit the peak power. However, this clipping process does not introduce spectral broadening, as exist in conventional clipping process, because the subtraction to the original signal is processed in frequency domain instead of in time domain and only affects minimum bit error rate (BER) performance degradation. The clipping process is also done iteratively because zero padding operation in frequency domain causes peak growth after converting to the time domain. The iterative processing method gives good results for PAPR reduction and suitable BER performance degradation.



(a) Non-overlapped System



(b) Overlapped System

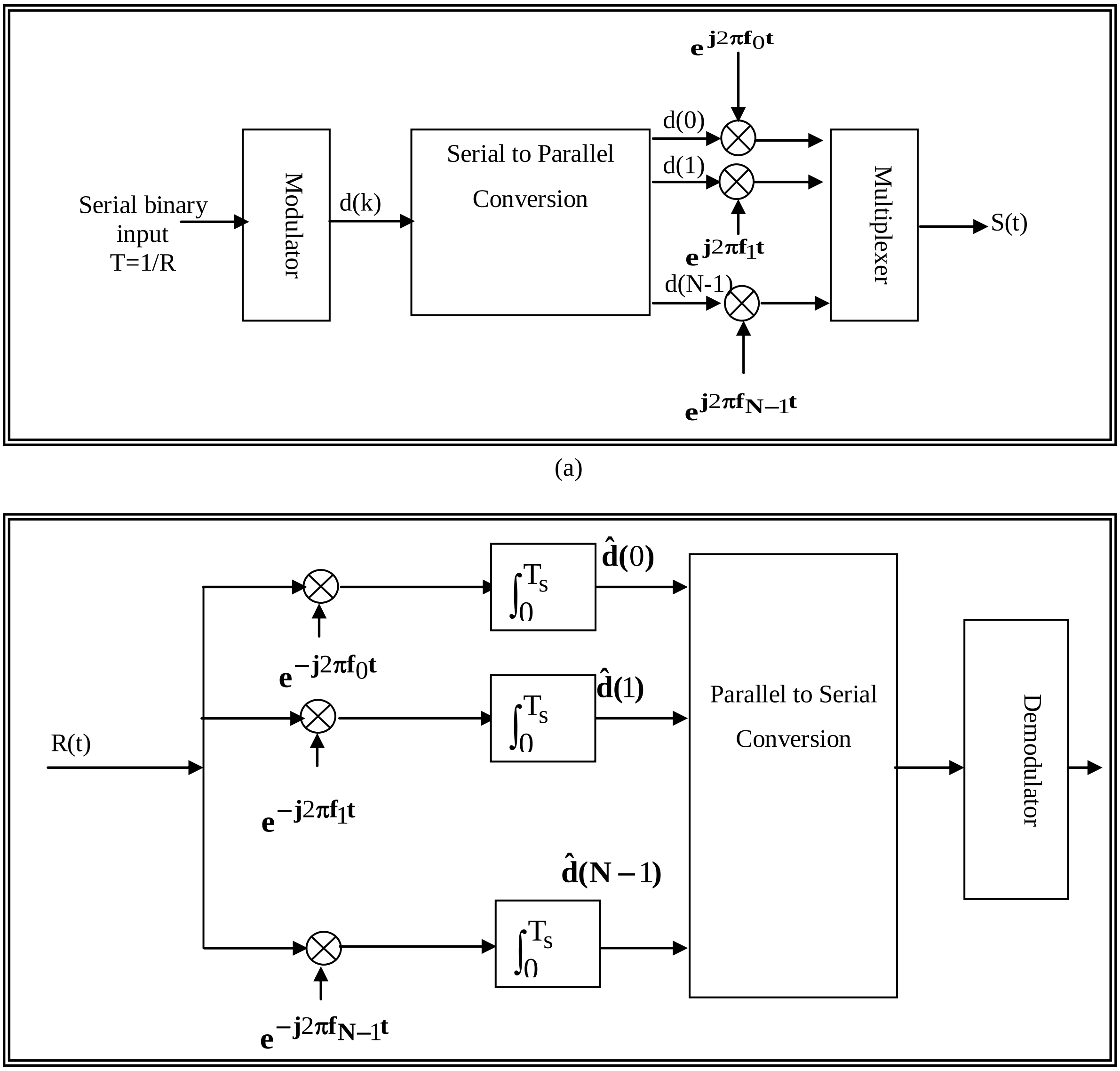
Fig.1. Transmitted Signal Spectrum of FDM System.

2. OFDM System:

Orthogonal Frequency Division Multiplexing (OFDM) system may be viewed as a conventional Frequency Division Multiplexing (FDM) system, as shown in Fig.(1-a). In this arrangement, the spectra of different subchannels do not overlap. In such a system, there is a sufficient guard space between adjacent subchannels to isolate them at the receiver using the conventional filters. This arrangement does not achieve effective use of bandwidth. A much more efficient use of bandwidth can be obtained with a parallel system if the spectra of the individual subchannels are permitted to overlap, as shown in Fig.(1-b). With the addition of coherent detection and the use of subcarrier separated by the reciprocal of the signal element duration, independent separation of the multiplexed subcarriers is possible. If this condition is satisfied then this OFDM system will achieve orthogonality among its consistent subcarriers [4].

Consider the system in Fig.(2). The transmitted spectral shape is chosen so that InterCarrier Interference (ICI) does not occur; that is, the spectra of the individual subcarriers are maximum at their frequency and zero at other subcarrier frequencies. The N serial data elements (spaced by T=1/R where R is the symbol rate) modulate N subcarrier frequencies, which are then frequency division multiplexed. The symbol duration (T_s) has been increased to (NT), which makes the system less susceptible to delay spread impairments [5].

The subcarrier frequencies are separated by the multiples of (1/NT) so that, with no signal distortion in transmission, the coherent detection of a signal element in any subcarrier of OFDM system gives no output for a received element in any other subcarriers. Hence, the N received signal elements, corresponding to the N subcarriers of OFDM system, are said to be orthogonal. So, no further filtering is needed to separate the different subcarriers. In other words, the power density spectrum has a central positive peak at an individual carrier frequency, and zeros at all other subcarrier frequencies [5].



(b)

Fig. 2. Basic OFDM System (a). Transmitter (b). Receiver

3. Implementation of OFDM Using Fast Fourier Transform (FFT):

The main objections to the use of parallel systems are the complexity of the equipment required to implement the parallel system and the possibility of severe mutual interference among subchannels when the transmission medium distorts the signal. System design is greatly reduced by eliminating any pulse shaping and demodulated by using Discrete Fourier Transform (DFT) to implement the modulation process [6].

The transmitted OFDM symbol waveform can be represented as:

$$S(t) = \mathrm{Re}\left\{ \sum_{k=0}^{N-1} d(k) \exp(j2\pi f_k t) \right\} \qquad ...(1)$$

where d(k) is the modulated data symbol, f_k is the subcarrier frequency of k^{th} subcarrier which is equal to $(f_c+k\Delta f)$.

f_c is the carrier frequency, Δf is the subcarrier spacing (bandwidth) equal to (1/NT)
T is the symbol time duration.
N is the subcarriers number.

This expression represents the passband OFDM signal. The equivalent complex baseband notation is given by:

$$S(t) = \sum_{k=0}^{N-1} d(k) \exp(j2\pi k \Delta f\, t) \qquad ...(2)$$

If the signal is sampled at a rate of (T), then (t=nT), and for orthogonality Δf=(1/NT), then equation (2) can be rewritten as:

$$S(n) = \sum_{k=0}^{N-1} d(k) \exp(j2\pi k\, n/N) \qquad ...(3)$$

Equation (3) is exactly the Inverse Discrete Fourier Transform (IDFT) of data sequence d(k). All operations that occur in the transmitter are reversed in the receiver. Further reductions in complexity are possible by using the Fast Fourier Transform (FFT) algorithm to implement the DFT. To eliminate the Intersymbol Interference (ISI) almost completely, a guard time is introduced for each OFDM symbol. The guard time is chosen larger then the expected delay spread such that multipath components from one symbol can not interfere with the next symbol. The guard time could consist of no signal at all. However, the problem of Intercarrier Interference (ICI) would arise. ICI is a crosstalk between different subcarriers, which means that they are no longer orthogonal. To eliminate ICI, the OFDM symbol is cyclically extended in the guard time, which is done by taking symbol period samples from the end of OFDM symbol and appending them to the start of OFDM symbol.

4. Mathematical Formulation of an OFDM Signal and PAPR:

If N is the number of sub carriers in an OFDM, then N distinct mapped QPSK symbols are grouped as a set X={X_1 , X_2 ,….,X_N}. Each value in a set is a complex value. An IFFT of vector X would result in N evenly spaced sample values of an OFDM signal in time domain. If the samples are shown as x={x_1, x_2, …., x_N} then each sample can be derived as [7]:

$$x_k = \sum_{i=1}^{N} X_i e^{j2\pi ki} \qquad ...(4)$$

Each OFDM symbol has time duration T, is relatively very large compared to symbol duration of a single carrier system. Orthogonal condition is attained by maintaining the sub carrier frequency spacing of 1/T. At the receiver end sampling, the received signal and applying FFT followed by de_ mapping can demodulate the OFDM signal. The discrete PAPR of an OFDM signal is defined as [7]:

$$PAPR(x) = \frac{\max(|x_k|^2)}{E\{|x_k|^2\}} \qquad ...(5)$$

where E{.} is the mean of the sequence. The discrete PAPR is a good approximation of exact PAPR if the sampling rate is high enough. This can be assured by over-sampling the OFDM signal before computing discrete PAPR. It has been shown that over-sampling by 4 will make discrete PAPR sufficiently reliable.

5. Clipping Processing Technique:

Clipping method is the simplest way to reduce PAPR. This method is based on clipping the signal, such that the peak amplitude becomes limited to some desired maximum level. This technique is performed by passing the OFDM modems output base band signal through a digital limiting device prior to transmitter stage, as shown in Fig.(3).
The disadvantage of this method is the distortion of the OFDM signal amplitude and this problem can be solved by optimum choice of clipping level for each designed system. This made depending on the analysis of system performance at different clipping level, such that the minimum PAPR with good BER performance can be achieved [2].

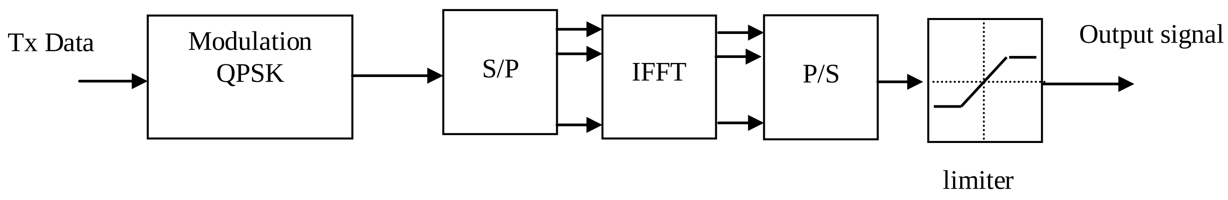


Fig.3. Block Diagram of OFDM Transmitter using Clipping Method.

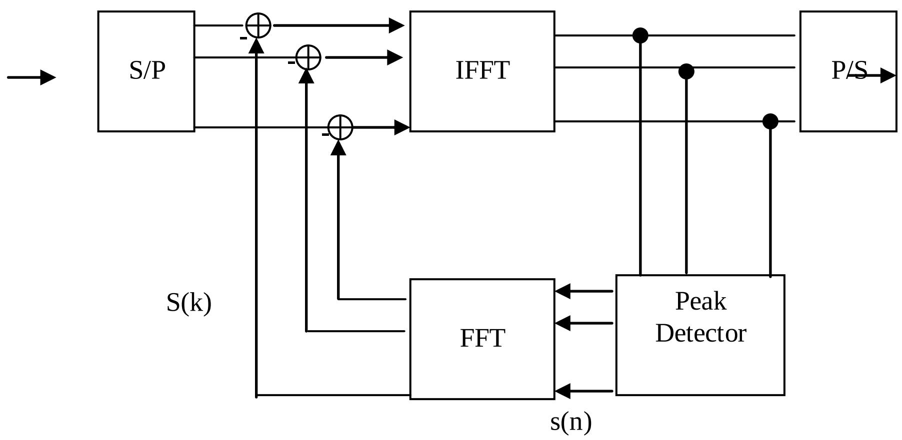


Fig.4. Iterative Processing Structure at the OFDM Transmitter.

6. Iterative Processing Technique:

Fig. (4) shows the transmitter structure of OFDM with iterative processing method. Modulated data are converted from serial to parallel, and then it is transformed to OFDM symbol in time domain by IFFT. The peak power components which exceed permission PAPR in each OFDM are detected by peak detector to obtain s(n). s(n) is defined by:

$$s(n)=\begin{cases} x(n) & |x(n)|\le\lambda \\ x(n)-\dfrac{x(n)}{|x(n)|}.\lambda & |x(n)|>\lambda \end{cases} \quad ...(6)$$

where x(n) is the n^{th} sampling signal in each OFDM symbol and λ is the desired PAPR threshold. Signal s(n) is then FFT to obtain the frequency domain peak cancellation signal S(k) as

$$S(k)=\frac{1}{\sqrt{N}}\sum_{n=0}^{N-1} s(n)\,e^{\frac{-2j\pi kn}{N}}, \quad 0\le k\le N-1 \quad ...(7)$$

The peak cancellation signals S(k) is then subtracted from the input modulated symbols, so that the peak generation is avoided . The target PAPR lower bound can not be attained in single execution, therefore require iteration, as the name implies.

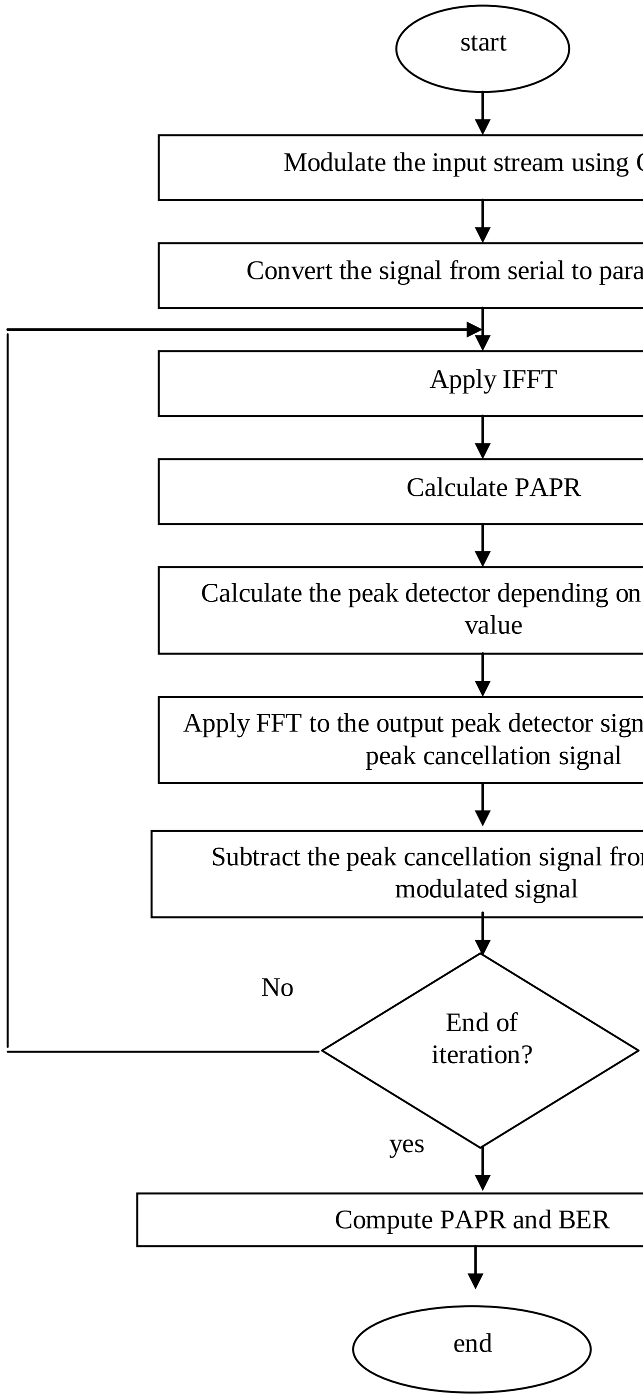


Fig. 5. Flowchart of PAPR Using Iterative Processing.

7. Experimental Results:

Simulation of PAPR reductions using clipping and iterative processing method are carried out using technical (MATLAB) package. Fig.(5) shows flowchart of PAPR using Iterative Processing. PAPR reduction calculation conducted by computer simulation are plotted in Fig.(6), Fig.(7), Fig.(8) and Fig.(9). These graph are generated from 10000 randomly distributed symbols with QPSK modulation and OFDM sub carriers are generated from FFT points of 1024. Fig.(6) shows BER performance degradation using clipping method assuming the channel is AWGN. Fig.(7), Fig.(8) and Fig.(9) show BER performance degradation using iterative processing method for iteration 1, iteration 2, and iteration 3 respectively. BER degradation depends on the iteration time; large iteration caused deep BER degradation compared with clipping method and iterative processing method gives high PAPR reduction compared with clipping method.

Fig.(10) shows comparison of BER performance between different iteration for λ=0.9 of maximum value of OFDM coefficients. It is shown that at BER of 10^{-4} the total degradation is about 4dB after three time iteration.

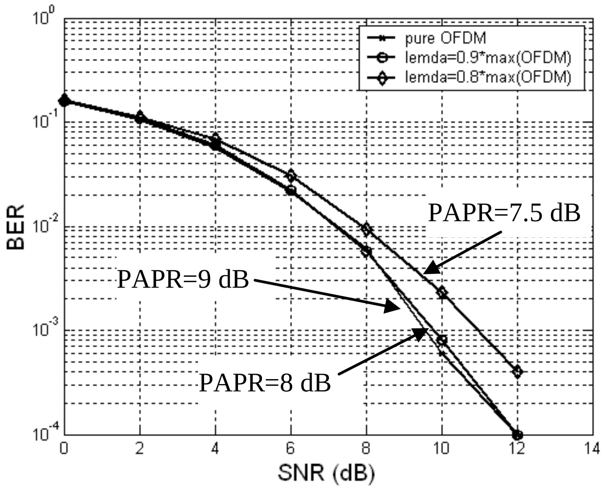


Fig.6. BER Performance for QPSK OFDM with Clipping Method and the Channel is AWGN.

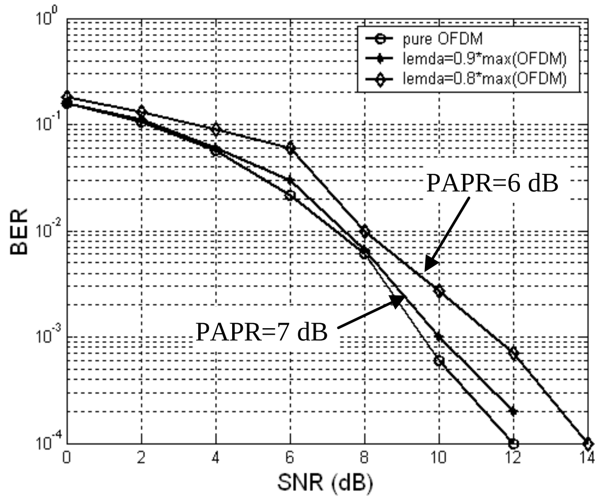


Fig.7. BER Performance for QPSK OFDM with Iterative1.

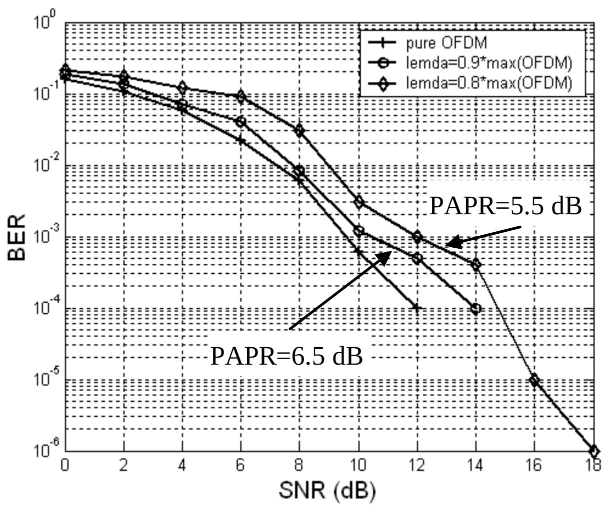


Fig.8. BER Performance for QPSK OFDM with Iterative2.

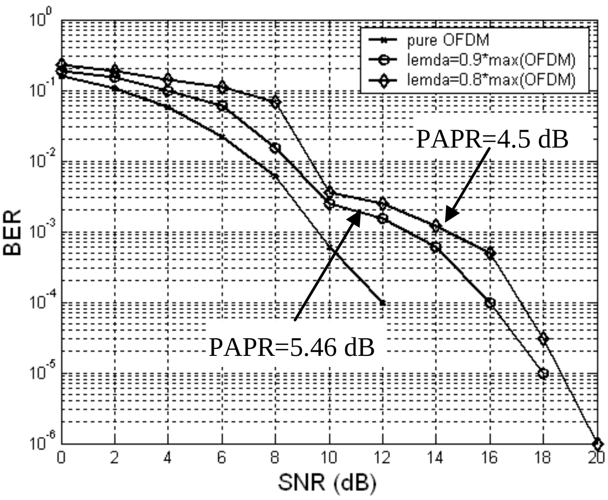


Fig.9. BER Performance for QPSK OFDM with Iterative3.

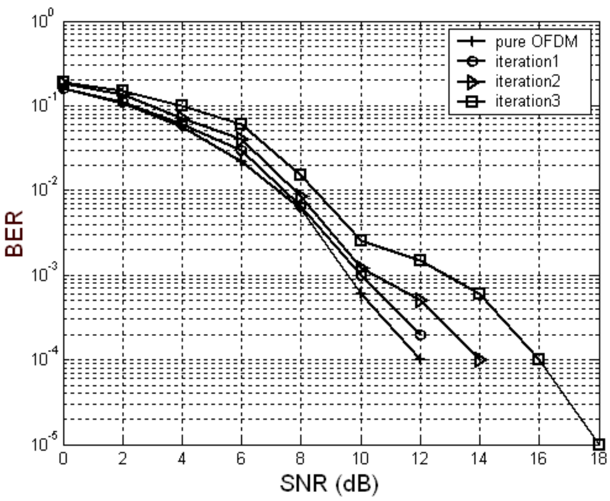


Fig.10. Comparison of BER Performance Between Different Iteration for λ=0.9*max(OFDM).

8. Conclusions:

The following points are concluded from the simulation results:

1- Iterative processing method gives higher PAPR reduction compared with clipping method (i.e., PAPR is about 7.5 dB for clipping method and about 4.5 dB for iterative method when λ=0.8 max(OFDM), therefore there is gain about 3 dB with suitable degradation in BER).

2- Iterative processing method using one iterative gives minimum BER degradation compared with two and three iterative.

3- Iterative processing method using three iterative gives higher PAPR reduction compared with one and two iterative.

4- Threshold value (λ=0.9*max (OFDM)) gives minimum BER degradation compared with threshold value (λ=0.8*max (OFDM)).

5- Threshold value (λ=0.8*max (OFDM)) gives higher PAPR reduction degradation compared with threshold value (λ=0.9*max (OFDM)).

9. References:

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تقليل نسبة القدرة العضمى الى القدرة المعدلة لاشارة مقسم التردد العامودي باستخدام طريقتي التقييم والمعالجة المتكررة

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الخلاصة

احدى المشاكل المهمه في منظومة الاتصالات اللاسلكيه باستخدام التضمين المتعدد التحميل مثل مقسم التردد العمودي المتعدد(OFDM) هي مشكلة نسبة القدرة العظمى الى القدرة المعدلة (PAPR) والتي تسبب تقليل القدرة المرسلة وكذلك تقلل المدى الديناميكي لتحويل (ADC) و (DAC) والتي تودي الى تقليل القدرة المكبرة في الارسال والتي توثر بدورها على معدل المعلومات المنجزة. هذه المشكله مهمه في محطات الموبايل التي تغذي بطارية وبعمر اطول ولذلك تقليل PAPR يعتبر من الامور المهمه التي تزيد كفائة خدمة اتصالات الموبايل.في هذا البحث تم استخدام طريقة فعالة لتقليل PAPR لاشارة (OFDM). هذه الطريقة تستند على التقليم و المعالجة المتكررةلتقليل قيمة PAPR في مجال الزمن ولكن عملية طرح PAPR بعد اجراء التقليم من الاشارة الاصلية تتم في مجال التردد وليس في مجال الزمن كما في طرق التقليم الشائعة.أن النتائج لهذه الطريقة اعطت قدرة على تقليل PAPR مع وجود اضمحلال قليل في قيمة BER.