OFDM PAPR REDUCTION USING HYBRID PARTIAL TRANSMIT SEQUENCES BASED ON CUCKOO SEARCH ALGORITHM

A
THESIS
Presented to the Faculty of Engineering and Technology of the Department of Electronics and Communication Engineering, Punjabi University, Patiala towards the partial fulfillment of requirement for the award of the degree of

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IN
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Submitted by

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CERTIFICATE

This is to certify that this thesis entitled, “OFDM PAPR REDUCTION USING HYBRID PARTIAL TRANSMIT SEQUENCES BASED ON CUCKOO SEARCH ALGORITHM” embodies the work carried out by Mr. Maninder Singh under my supervision and that it is worthy of consideration for the award of the M.Tech. degree.

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DECLARATION

I hereby affirm that the work presented in this thesis is exclusively my own and there are no collaborators. It does not contain any work for which a degree/diploma has been awarded by any other University/Institution.

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MANINDER SINGH

ABSTRACT

The past decade has seen many radical changes and achievements in the field of wireless communication. Applications of wireless communication have grown swiftly in the recent past. This rigorous growth lead to more throughput over wireless channels along with increased reliability. But still the bandwidth demands are endless and increasing day by day. Today we need to constantly work towards achieving reliable wireless communication with high spectral efficiency, low complexity and good error performance results.

Orthogonal frequency division multiplexing (OFDM) technique is a promising technique in this regard as it offers high data rate and reliable communications over various fading channels. But the main drawback of OFDM is the high peak to average power ratio (PAPR).

In this thesis the technique to reduce the PAPR using Cuckoo Search Algorithm in multicarrier modulation system is presented. Simulation results show that the proposed scheme considerably outperforms the conventional system.

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List of Abbreviations

ACE	: Active Constellation Extension
BPSK	: Binary Phase Shift Keying
CCDF	: Complementary Cumulative Distribution Function
ICI	: Inter Carrier Interference
ISI	: Inter Symbol Interference
IDFT	: Inverse Discrete Fourier Transform
IFFT	: Inverse Fast Fourier Transform
ISI	: Inter Symbol Interference
MCM	: Multi Carrier Modulation
OFDM	: Orthogonal Frequency Division Multiplexing
PAPR	: Peak to Average Power Ratio
PTS	: Partial Transmit Sequence
QAM	: Quadrature Amplitude Modulation
QPSK	: Quadrature Phase Shift Keying
TI	: Tone Injection
TR	: Tone Reservation
SLM	: Selected Mapping
SNR	: Signal-to-Noise Ratio

List of Publications

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Chapter 1

Introduction

The demand of extraordinary data rate services has been increasing very promptly and there is no slowdown in sight. We know that the data transmission contains both wired and wireless medium. Often, these facilities require very reliable data transmission above very severe environment. Most of these transmission schemes experience much degradation such as huge attenuation, noise, multipath, time variance, interference, nonlinearities and necessity meet the finite restrictions like power limitation and cost factor. One physical layer method that has gained a lot of admirations due to its robustness in dealing with these impairments is multi-carrier modulation method.

In multi-carrier modulation, the most frequently used method is Orthogonal Frequency Division Multiplexing (OFDM); it has become very general in wireless communication. Unfortunately the main disadvantage of OFDM transmission is its large wrapping fluctuation which is quantified as Peak to Average Power Ratio (PAPR). Since power amplifier is used at the transmitter, so as to function in a perfectly linear area the working power must lies underneath the available power. For decrease of this PAPR lot of algorithms have been established. All of the methods has some sort of benefits and drawbacks [1]. Clipping and Filtering is one of the simple method in which some part of transferred signal undergoes into distortion. Also the Coding arrangement decreases the data amount which is undesirable. If we deliberate Tone Reservation (TR) system it also allows the data rate loss with additional probable of increasing power. Again the methods like Tone Injection (TI) and the Active Constellation Extension (ACE) having a criteria of increasing power will be unwanted in situation of power constraint environment. If we go for the Selected Mapping (SLM) and Partial Transmit Sequence (PTS) system, the PTS method has additional complexity than that of SLM method. This Selected Mapping is one of the promising method due to its simplicity for implementation which familiarizes no distortion in the transmitted signal. It has been designated first in [2] i.e. to be recognized as the traditional SLM method. This method has one of the disadvantage of sending the additional Side Information (SI) index along with the transmitted OFDM signal. Which can be evaded using a special method described in [3].

Main reasons for this limitation were the complexity of real time Fourier Transform and the linearity required in RF power amplifiers. However since 1990s, OFDM is used for wideband data communications over mobile radio FM channels, OFDM has many benefits over single carrier systems. The circuit complexity of OFDM is significantly lower than that of a single carrier system with equalizer. When the transmission bandwidth exceeds coherence bandwidth of the channel, resultant distortion may cause intersymbol interference (ISI). Single carrier systems resolve this problem by using a linear or nonlinear equalization. The problem with this approach is the complication of effective equalization algorithms

It divide available channel bandwidth into subchannels [4]. By choosing the subchannel bandwidth smaller than the coherence bandwidth of the frequency selective channel, the channel seems to be almost flat and no equalization is required. Also by inserting a guard time at the beginning of OFDM symbol during which the symbol is regularly extended, intersymbol interference (ISI) and intercarrier interference (ICI) can be completely eliminated, if the interval of guard period is properly chosen. In single frequency networks, transmitters instantaneously broadcast at the same frequency, which bases intersymbol interference. Moreover, in relatively slow time fluctuating channels, it is probable to significantly enhance the capacity by adapting the data rate per subcarrier according to the signal-to-noise ratio (SNR) of that particular subcarrier. Another use of OFDM over single carrier systems is its strength against narrowband interference because such interference affects only a slight percentage of the subcarriers. Beyond all these advantages, OFDM has some problems compared to single carrier systems. Two of the difficulties with OFDM are the carrier phase noise and frequency offset. Carrier phase noise is affected by limitations in the transmitter and receiver oscillators. Frequency offsets are created by differences between oscillators. Doppler shifts, or phase noise introduced by nonlinear channels [5]. There are two negative effects caused by a carrier frequency offset in an OFDM system. One is the drop of signal amplitude since sinc (.) functions are shifted and no longer appraised at the peak, and the other is the introduction of ICI from the other carriers. The latter is caused by the damage of orthogonality between the subchannels. Compassion to phase noise and frequency offsets rises with the number of subcarriers and with the constellation size used for subcarrier modulation. For single carrier systems, frequency and phase noise offsets only give degradation in the receiver SNR, rather than introducing ICI. The most important disadvantage of OFDM systems is that highly linear RF amplifiers are needed. An OFDM signal consists of a number of individually modulated subcarriers, which can give a large Peak-to-Average Power Ratio (PAPR) when added up coherently. When N signals are added with the same phase, they generate a peak power that is N times the average power. To escape nonlinear distortion, highly linear amplifiers are essential which cause a severe decrease in power efficiency. Several methods are explained in the literature in order to solve this problem.

1.1 OFDM Transmission Theory

The basic principle of OFDM is to split input data stream into a number of lower rate streams that are transferred simultaneously over a number of subcarriers, the transmission rate is slower in parallel subcarriers, a frequency selective channel seems flat to each subcarrier. ISI is reduced almost completely by adding a guard interval at the beginning of each OFDM symbol. However, instead of using an empty guard time, this interval is filled with a cyclically extended version of the OFDM symbol. This method is used to avoid ICI. In MCM, input data stream is distributed into lower rate substreams, these are used to modulate few subcarriers. The spacing among these subcarriers is large enough such that individual spectrum of subcarriers do not overlap. Therefore the receiver uses a band pass filter tuned to that subcarrier frequency in order to demodulate the signal. In OFDM, subcarrier spacing is kept at minimum, while still preserving the time domain orthogonality between subcarriers, even though the individual frequency spectrum may overlap. The least subcarrier spacing should equal to 1/T, where T is the symbol period. An OFDM symbol in baseband is defined as:

$$x(t) = \sum_{i=-\frac{\mathrm{N}}{2}}^{\frac{\mathrm{N}}{2}-1} a_{i+\frac{N}{2}} \exp\left(j\frac{2\pi i t}{\mathrm{T}}\right) s(t) \qquad 0 \le t \le \mathrm{T}$$

where, $a_{i+N/2}$ denotes the complex symbol modulating the i-th carrier, *s(t)* is the time window function defined in the interval [0,T], N is the number of subcarriers, and T is the OFDM symbol period. Subcarriers are spaced $\Delta\mathrm{F} = 1/\mathrm{T}$ apart. The correlation coefficient between the subcarriers may be defined as:

$$\rho_{kn} = \frac{1}{\mathrm{T}}\int_{0}^{T} \exp\left(j\frac{2\pi kt}{\mathrm{T}}\right)\exp\left(-j\frac{2\pi nt}{\mathrm{T}}\right)dt$$

As can be seen from (1.1)

$$\rho_{kn} = \begin{Bmatrix} 1, & n = k \\ 0, & n \neq k \end{Bmatrix} \tag{1.1}$$

Therefore, OFDM signal of the form (1.1) satisfies the condition of mutual orthogonality among subcarriers in the symbol interval. In order to obtain the data modulating the *k-th* subcarrier OFDM symbol should be down converted with a frequency of *k*/T, and then integrated over the symbol period [4]. Then above operation may be shown as:

$$\text{Resultant Signal} = \frac{1}{\mathrm{T}}\int_0^T \exp(-j\frac{2\pi kt}{\mathrm{T}})\sum_{i=-N/2}^{N/2-1} a_{i+N/2}\exp\left(j\frac{2\pi it}{\mathrm{T}}\right)dt \tag{1.2}$$

$$\frac{1}{T}\sum_{i=N/2}^{N/2-1} a_{i+N/2}\ \frac{1}{T}\int_0^T \exp\left(-j\frac{2\pi kt}{\mathrm{T}}\right)dt \tag{1.3}$$

Using (1.2) and (1.3) together

Resultant signal=$a_{k+N/2}$ considering the sequential transmission of symbols, the baseband signal at the OFDM modulator output can be expressed as:

$$x(t) = \sum_{n}\sum_{i=-\frac{N}{2}}^{\frac{N}{2}-1} a_{i+\frac{N}{2},n}\exp(j\frac{2\pi i(t-n\mathrm{T})}{\mathrm{T}})s(t-n\mathrm{T})$$

Where,$a_{i+N/2,n}$ represents the data modulating the *i-th* carrier of the n-th OFDM symbol. The *n*-th OFDM symbol is transmitted in the time interval [*n*T, *n*T+T]. Assuming that the windowing function *s(t)* is nonzero only in [0,T] interval, if N samples are taken from *x(t)* at time instants {*n*T+*k*T/N, *k*=0…N-1}, the result will be [4]:

$$y[k] = x(nT + \frac{k\mathrm{T}}{\mathrm{N}})$$

$$= \sum_{n}\sum_{i=-\mathrm{N}/2}^{\mathrm{N}/2-1} a_{i+\frac{\mathrm{N}}{2},n}\exp(j\frac{2\pi i(n\mathrm{T}+kT/\mathrm{N}-nT)}{T})s(n\mathrm{T}+k\mathrm{T}/\mathrm{N}-n\mathrm{T})$$

$$= \sum_{i=-\mathrm{N}/2}^{\mathrm{N}/2-1} a_{i+\frac{N}{2},n} \exp(j\frac{2\pi ik}{\mathrm{N}}) s\left(\frac{kT}{\mathrm{N}}\right) \qquad 0 \leq k \leq \mathrm{N}-1 \tag{1.4}$$

It can be seen from (4) that, N samples reserved from n-th OFDM symbol at a rate of N/T can be achieved by taking N-point inverse Discrete Fourier Transform (IDFT) of the input data $a_{k,n}$, k=0…N-1, weighted by the window function *s(t)* at the sampling time instants

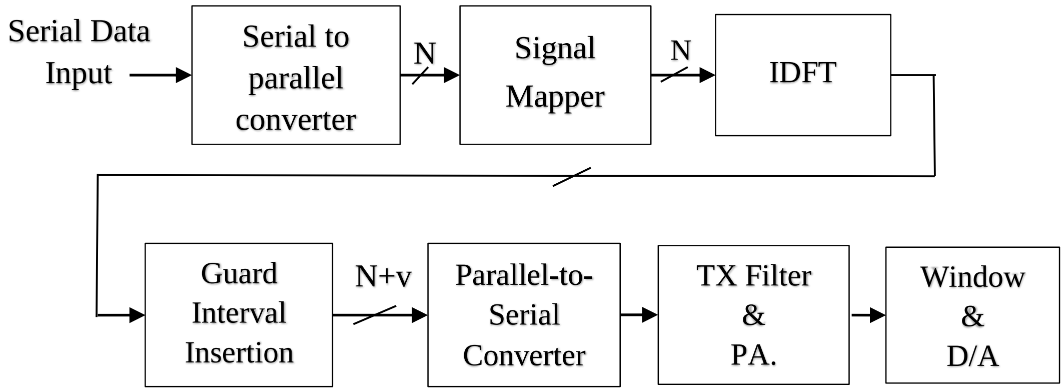

Figure 1.1 Block Diagram of an OFDM Transmitter.

The serial input data stream is distributed into frames of N_f bits. These N_f bits are arranged into N groups, where N is the number of subcarriers. The number of bits in each of the N groups determines the constellation size for that particular subcarrier. For example, if all the subcarriers are modulated by QPSK then each of the groups consists of 2 bits, if 16-QAM modulation is used each group holds 4 bits. This scheme is called as *fixed loading*. However, this is not the only way of distributing input bits among the subchannels. N_f bits could be distributed among subcarriers according to the channel states. Therefore, one of the subcarriers can be modulated with 16-QAM whereas another one can be modulated with 32-QAM, etc [6]. The former subcarrier consists of 4 bits and the latter subcarrier resides of 5 bits. This scheme is named as *adaptive loading*. OFDM can be considered as N independent QAM channels, each having a different QAM constellation but each operating at the same symbol rate 1/T. After signal mapping, N complex points are obtained. These multiple points are passed over an IDFT block. Cyclic prefix of length v is added to the IDFT output in order to combat with ICI and ISI. After Parallel–to- Serial conversion, windowing function is applied. The output is fed into a Digital-to-Analog converter efficient at a frequency of N/T. Finally transfer filter is applied in order to deliver necessary spectrum shaping before power enlargement.

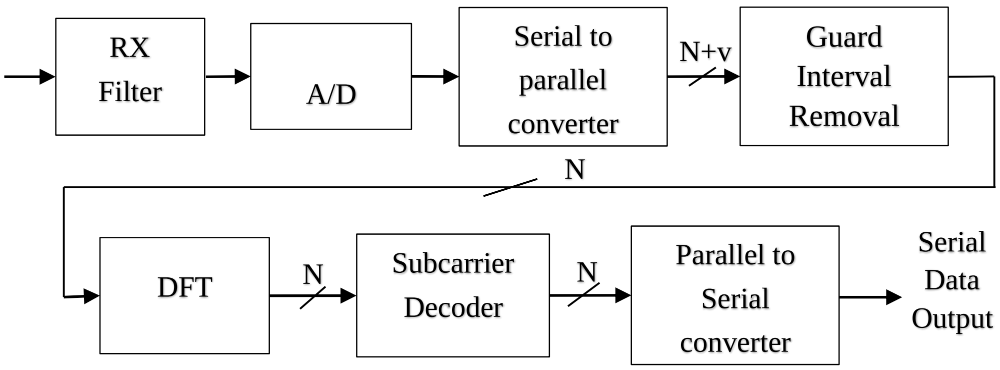

Figure 1.2 Block Diagram of an OFDM Receiver.

The receiver implements inverse processes of the transmitter. Received signal is delivered through a receive filter and an Analog-to-Digital converter operating at a frequency of N/T. After these down converting and sampling processes, cyclic prefix is detached from the signal and a DFT operation is achieved on the resultant complex points in order to demodulate the subcarriers. Subcarrier decoder translates obtained complex points to the corresponding bit stream.

1.2 System in OFDM

Orthogonal frequency division multiplexing (OFDM) [7, 8] transmission scheme is a type of multichannel system which avoids the usages of the oscillators and band limited filters for each sub channel. The OFDM technology was first conceptualized in the 1960s and 1970s. The main idea behind the OFDM is that since low-rate modulations are less sensitive to multipath, the better way is to send a number of low rate streams in parallel than sending one high rate waveform. It divides the frequency spectrum into sub-bands small enough so that the channel effects are constant (flat) over a given sub-band. Then a classical IQ (In phase Quadrature phase) modulation (BPSK, QPSK, M-QAM, etc) is sent over the sub-band. If it designed correctly, all the fast changing effects of the channel disappear as they are now occurring during the transmission of a single symbol and are thus treated as flat fading at the receiver.

The basic principle of OFDM is to split a high-rate data stream into a number of lower rate streams that are transmitted simultaneously over a number of subcarriers. These subcarriers are overlapped with each other. Because the symbol duration increases for lower rate parallel subcarriers, the relative amount of dispersion in time caused by multipath delay spread is decreased as well as we can use the available bandwidth more efficiently as shown in figure 1.3.

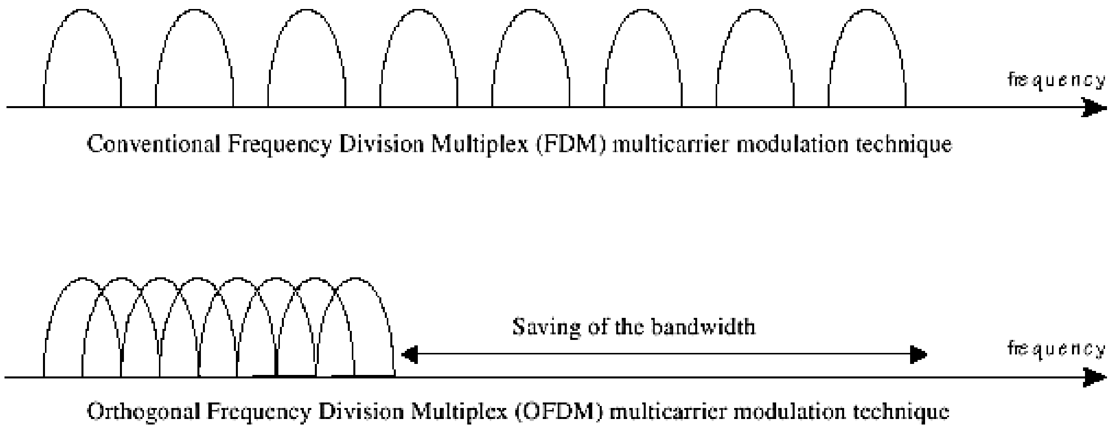

Fig. 1.3 Comparison of the bandwidth utilization for FDM and OFDM.

Figure 1.1 and 1.2 shows a general OFDM system. The transmitter first converts the input data from a serial stream to parallel sets. Each set of data contains one information bit for each carrier frequency. Then, parallel data are modulated to the orthogonal carrier frequencies. The IFFT (Inverse Fast Fourier Transform) converts the parallel data into time domain waveforms. Finally, these waveforms are combined to create a single time domain signal for transmission.

The receiver basically performs the inverse of the transmitter by first separating the data into parallel streams. Then, the FFT (Fast Fourier Transform) converts these parallel data streams into frequency domain data [9]. The data are now available in modulated form on the orthogonal carriers. Demodulation down-converts this information back to the baseband. Finally, this parallel data are converted back into a serial stream to recover the original signal.

OFDM faces several challenges. The key challenges are ISI due to multipath-use guard interval, large peak to average ratio due to non-linearity of amplifier; phase noise problems of oscillator, need frequency offset correction in the receiver. Inter-symbol interference (ISI) is eliminated almost completely by introducing a guard time in every OFDM symbol. Large peak-to-average power ratio (PAPR) which distorts the signal if the transmitter contains nonlinear components such as power amplifiers (PAs). The nonlinear effects on the transmitted OFDM symbols are spectral spreading, inter modulation and changing the signal constellation. In other words, the nonlinear distortion causes both in-band and out-of-band interference to signals. Therefore the PAs requires a back off which is approximately equal to the PAPR for distortion-less transmission. This decreases the efficiency for amplifiers. Therefore, reducing the PAPR is of practical interest.

1.2.1 OFDM Transmission Technique

If a high data rate is transmitted over a frequency-selective radio channel with a large maximum multi-path propagation delay τ_{max} compared to the symbol duration, an alternative to the classical SC approach is given by the OFDM transmission technique. The general idea of the OFDM transmission technique is to split the total available bandwidth B into many narrowband sub-channels at equidistant frequencies. The sub-channel spectra overlap each other but the subcarrier signals are still orthogonal. The single high-rate data stream is subdivided into many low-rate data streams for the sub-channels. Each sub-channel is modulated individually and will be transmitted simultaneously in a superimposed and parallel form [10]. An OFDM transmit signal therefore consists of N adjacent and orthogonal subcarriers spaced by the frequency distance Δf on the frequency axis. All subcarrier signals are mutually orthogonal within the symbol duration of length TS, if the subcarrier distance and the symbol duration are chosen such that TS = 1 Δf. For OFDM-based systems, the symbol duration T_S is much larger compared to the maximum multipath delay τ_{max}. The k-th unmodulated subcarrier signal is described analytically by a complex valued exponential function with carrier frequency $k\Delta f$, $\widetilde{g_k}(t)$, $k = 0, \ldots, N - 1$.

$$\widetilde{g_k}(t) = \begin{Bmatrix} e^{j2\pi k \Delta f t} & \forall t \epsilon [0, T_s] \\ 0 & \forall t \epsilon [0, T_s] \end{Bmatrix} \tag{1.5}$$

Since the system bandwidth B is subdivided into N narrowband sub-channels, the OFDM symbol duration T_S is N times larger than in the case of an alternative SC transmission system covering the same bandwidth B. Typically, for a given system bandwidth, the number of subcarriers is chosen in such a way that the symbol duration TS is sufficiently large compared to the maximum multi-path delay τ_{max} of the radio channel. Additionally, in a time-variant radio channel, the Doppler spread imposes restrictions on the subcarrier spacing Δf. In order to keep the resulting Inter-Carrier Interference (ICI) at a tolerable level, the system parameter of the subcarrier spacing Δf must be large enough compared to the maximum Doppler frequency f_{Dmax}. In [18] the appropriate range for choosing the symbol duration.

$$4\tau_{max} \leq T_s \leq 0.03\frac{1}{f_{Dmax}}$$

The duration T_S of the subcarrier signal $\widetilde{g_k}(t)$ is additionally extended by a cyclic prefix (so-called guard interval) of length T_G, which is larger than the maximum multi-path delay τ_{max} in order to avoid ISI completely which could occur in multipath channels in the transition interval between two adjacent OFDM symbols [11].

$$g_k(t) = \begin{cases} e^{j2\pi k\Delta f t} & \forall t\epsilon[-T_G, T_s] \\ 0 & \forall t\epsilon[-T_G, T_s] \end{cases}$$

The guard interval is directly removed in the receiver after the time synchronization procedure. From this point of view, the guard interval is a pure system overhead. The total OFDM symbol duration is therefore $T = T_S + T_G$. It is an important advantage of the OFDM transmission technique that ISI can be avoided completely or can be reduced at least considerably by a proper choice of OFDM system parameters. The orthogonality of all subcarrier signals is completely preserved in the receiver even in frequency-selective radio channels, which is an important advantage of OFDM. The radio channel behaves linearly and in a short time interval of a few OFDM symbols even time-invariant. Hence, the radio channel behavior can be described completely by a Linear and Time Invariant (LTI) system model, characterized by the impulse response *h(t)*. The LTI system theory gives the reason for this important system behavior that all subcarrier signals are orthogonal in the receiver even when transmitting the signal in frequency-selective radio channels. All complex-valued exponential signals (e.g., all subcarrier signals) are Eigen functions of each LTI system and therefore Eigen functions of the considered radio channel, which means that only the signal amplitude and phase will be changed if a subcarrier signal is transmitted over the linear and time-invariant radio channel. The subcarrier frequency is not affected at all by the radio channel transmission, which means that all subcarrier signals are even orthogonal in the receiver and at the output of a frequency-selective radio channel. The radio channel disturbs only amplitudes and phases individually, but not the subcarrier frequency of all received sub-channel signals. Therefore all subcarrier signals are still mutually orthogonal in the receiver. Due to this important property, the received signal which is superimposed by all subcarrier signals can be split directly into the different sub-channel components by a Fourier transform and each subcarrier signal can be restored by a single-tap equalizer and demodulated individually in the receiver. At the transmitter side, each subcarrier signal is modulated independently and individually by the complex valued modulation symbol $S_{n,k}$, where the subscript n refers to the time interval and k to the subcarrier signal number in the considered OFDM symbol. Thus, within the symbol duration time interval T the time continuous signal of the n-th OFDM symbol is formed by a superposition of all N simultaneously modulated subcarrier signals.

$$s_n(t) = \sum_{k=0}^{N-1} S_{n,k} g_k(t - nT)$$

The total time-continuous transmit signal consisting of all OFDM symbols sequentially transmitted on the time axis is described by Eq. (1.6):

$$s(t) = \sum_{n=0}^{\infty} \sum_{k=0}^{N-1} S_{n,k} e^{j2\pi k \Delta f (n-nT)} \frac{rect[(2(t-nT)+T_G-T_S)]}{2T} \tag{1.6}$$

The analytical signal description shows that a rectangular pulse shaping is applied for each subcarrier signal and each OFDM symbol. Due to the rectangular pulse shaping, the spectra of all the considered subcarrier signals are sinc-functions which are equidistantly located on the frequency axis, e.g., for the k-th subcarrier signal, the spectrum is described in Eq. (1.7)

$$G_k(f) = T.sinc[\pi T(f - k\Delta f)] \tag{1.7}$$

The typical OFDM spectrum shown in figure 1.4 consists of N adjacent sinc functions, which are shifted by Δf in the frequency direction.

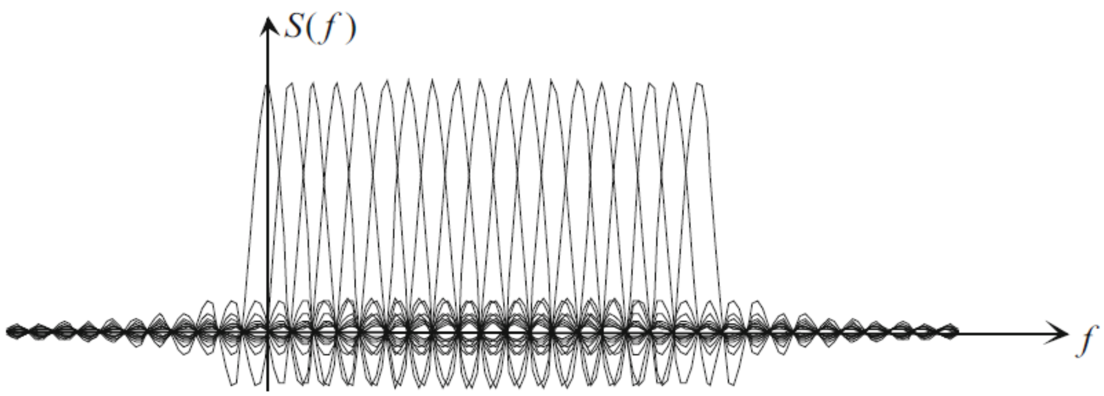

Figure 1.4 OFDM spectrum which consists of N equidistant sinc functions.

The spectra of the considered subcarrier signals overlap on the frequency axis, but the subcarrier signals are still mutually orthogonal, which means the transmitted modulation symbols $S_{n,k}$ can be recovered by a simple correlation technique in each receiver if the radio channel is assumed to be ideal in a first analytical step

$$\frac{1}{T_s}\int_0^{T_s} g_k(t)g_l^*(t)dt = \begin{Bmatrix} 1 & k = l \\ 0 & k \neq l \end{Bmatrix} \tag{1.8}$$

$$S_{n,k} = \frac{1}{T_s}\int_0^{T_s} s_n(t)g_k^*(t)\,dt = \frac{1}{T_S}\int_0^{T_s} s_n(t)e^{-j2\pi k\Delta f t}dt \tag{1.9}$$

Where $g_k^*(t)$ is the conjugate complex version of the subcarrier signal$g_k(t)$. Eq. (1.10) shows the correlation process in detail:

$$Corr = \frac{1}{T_s}\int_0^{T_s} s_n(t)g_k^*(t)\,dt = \frac{1}{T_S}\int_0^{T_s} \sum_{m=0}^{N-1} S_{n,m}g_m(t)g_k^*(t)dt \tag{1.10}$$

$$\sum_{m=0}^{N-1} S_{n,m}\frac{1}{T_s}\int_0^{T_s} g_m(t)g_k^*(t)\,dt = \sum_{m=0}^{N-1} S_{n,m}\delta_{m,k} = S_{n,k}$$

In practical applications, the OFDM transmit signal $s_n(t)$ is generated as a time discrete signal in the digital baseband. Using the sampling theorem while considering the OFDM transmit signal inside the bandwidth $B = N\Delta f$, the transmit signal must be sampled with the sampling interval $\Delta t = 1/B = 1/N\Delta f$. The individual samples of the transmit signal are denoted by $s_{n,i}$, $i = 0, 1 . . . N-1$ and can be calculated as follows (see Eq. (6)

$$s(t) = \sum_{k=0}^{N-1} s_{n,k}e^{-j2\pi k\Delta f t}$$

$$s(i\Delta t) = \sum_{k=0}^{N-1} s_{n,k}e^{-j2\pi k\Delta f i\Delta t}$$

$$s_{n,i} = \sum_{k=0}^{N-1} s_{n,k}e^{j2\pi ik/N} \tag{1.11}$$

The individually modulated and superimposed subcarrier signals are transmitted in a parallel way over many narrowband sub-channels. Thus, in each sub-channel, the symbol duration is large and can be chosen much longer than the maximum multi-path delay of the radio channel [12]. In this case, each sub-channel has the property to be frequency non-selective.

1.2.2 Advantages of OFDM

The Orthogonal Frequency Division Multiplexing (OFDM) transmission arrangement is an attractive technology. It has the following benefits [5]:

- OFDM is computationally effective by using FFT methods to implement the modulation and demodulation purposes.
- By separating the channel into narrowband flat fading sub channels, OFDM is more resistant to frequency selective fading than single carrier schemes.
- By using acceptable channel coding and interleaving, the symbols lost can be recovered, due to the frequency selectivity of the channel.
- OFDM is a bandwidth effectual modulation system and has the benefit of mitigating ISI in frequency selective fading channels.
- Channel equalization becomes simpler than by using adaptive equalization methods with single carrier schemes.
- In conjunction with differential modulation, there is no need to implement a channel estimator.
- Delivers good protection against co-channel interference and impulsive parasitic noise.
- OFDM can simply adapt to severe channel situations without complex time domain equalization.
- It removes Inter Symbol Interference (ISI) over the use of a cyclic prefix.
- OFDM is less sensitive to sample timing offsets than the single carrier schemes.
- OFDM offers greater immunity to multipath fading and impulse noise.
- OFDM makes effectual use of the spectrum by allowing overlap.
- OFDM removes the need for equalizers.

1.2.3 Disadvantages of OFDM

The Orthogonal Frequency Division Multiplexing (OFDM) transmission arrangement is an attractive technology but has the following drawbacks [13]:

- OFDM is additional sensitive to carrier frequency offset and drift than single carrier schemes, due to leakage of the Discrete Fourier Transform (DFT).
- OFDM is sensitive to frequency synchronization difficulties.

- It is sensitive to Doppler Shift.
- The OFDM signal has a noise like amplitude with a very large dynamic range; therefore it necessitates RF power amplifiers with a high Peak-to-Average Power
- Ratio (PAPR). • The high PAPR increases the complication of the Analog-to-Digital (A/D) and Digital-to-Analog (D/A) converters.
- The high PAPR also lowers the productivity of power amplifiers.

1.3 PAPR Reduction Technique

Several PAPR reduction techniques have been proposed in the literature [14]. These techniques are divided into two groups. These are signal scrambling techniques and signal distortion techniques.

1.3.1 Signal Scrambling Technique

1.3.1.1 Tone reservation

The main idea of this method is to keep a small set of tones for PAPR reduction. This can be originated as a convex problem and this problem can be solved accurately. Tone reservation method is based on adding a data block and time domain signal. A data block is dependent time domain signal to the original multicarrier signal to minimize the high peak. This time domain signal can be calculated simply at the transmitter of system and stripped off at the receiver. The amount of PAPR reduction depends on some factors such as number of reserved tones, location of the reserved tones, amount of complexity and allowed power on reserved tones [13]. This method explains an additive scheme for minimizing PAPR in the multicarrier communication system. It shows that reserving a small fraction of tones leads to large minimization in PAPR ever using with simple algorithm at the transmitter of the system without any additional complexity at the receiver end. Here, N is the small number of tones, reserving tones for PAPR reduction may present a non–negligible fraction of the available bandwidth and resulting in a reduction in data rate. The advantage of TR method is that it is less complex, no side information and also no additional operation is required at the receiver of the system.

1.3.1.2 Block coding

The fundamental idea is that of all probable message symbols, only those which have low peak power will be chosen by coding as valid code words for transmission. No introduction of distortion to the signals. If there have N subcarriers, they are represented by $2N$ bits using QPSK modulation and thus 2^{2N} messages. Using the whole message space corresponds to zero bits of redundancy. Using only half of the messages corresponds to one bit of redundancy. The remaining message space is then divided in half again and this process continues until N bits of redundancy have been allocated which corresponds to a rate one-half code for N carriers. Large PAPR reduction can be achieved if the long information sequence is separated into different sub blocks, and all sub block encoded with System on a Programmable Chip (SOPC).

1.3.1.3 Interleaving

The notion that highly correlated data structures have large PAPR can be reduced, if long correlation pattern is broken down. The basic idea in adaptive interleaving is to set up an initial terminating threshold [15]. PAPR value goes below the threshold rather than seeking each interleaved sequences. The minimal threshold will compel the adaptive interleaving (AL) to look for all the interleaved sequences. The main important of the scheme is that it is less complex than the PTS technique but obtains comparable result. This method does not give the assurance result for PAPR reduction.

1.3.1.4 Selective Level Mapping

The simple idea of this method is first produce a number of alternative OFDM signals from the original data block and then transmit the OFDM signal having least PAPR. But data rate loss and complexity at the transmitter side are two simple drawbacks for this method.

1.3.1.5 Tone injection

Tone Injection (TI) technique is based on general additive method for PAPR reduction. Using an additive method achieves PAPR reduction of multicarrier signal without any data rate loss. TI uses a set of equivalent constellation points for an original constellation points to reduce PAPR. The main idea behind this method is to increase the constellation size. Then, each point in the original basic constellation can be mapped into several equivalent points in the extended constellation, since all information elements can be mapped into several equivalent constellation points [2]. These additional amounts of freedom can be utilized for PAPR reduction. The drawbacks of this method are; need to side information for decoding signal at the receiver side, and cause extra IFFT operation which is more complex.

1.3.2 Signal Distortion Technique

1.3.2.1 Clipping and Filtering

This is a humblest method used for PAPR reduction. Clipping means the amplitude clipping which limits the peak envelope of the input signal to a prearranged value [16].

$$x_c(n) = f(x) = \begin{cases} -A & x[n] \quad \leq A \\ x[n] & x[n] \quad < A \\ A & x[n] \quad \geq A \end{cases} \tag{1.12}$$

where, A is the pre-specified clipping level. Nevertheless this method has the following disadvantages:

- Clipping bases in-band signal distortion, resulting in Bit Error Rate performance degradation.
- It also causes out-of-band radiation, which executes out-of-band interference signals to neighboring channels. This out-of-band radiation can be reduced by filtering.
- This filtering of the clipped signal leads to the peak regrowth. That means the signal after filtering process may exceed the clipping level identified for the clipping operation.

So we came to recognize that this clipping and filtering method has some sort of distortion throughout the transmission of data [7].

1.3.2.2 Peak Windowing

The peak windowing method proposes that it is possible to remove large peaks at the cost of a slight amount of self-interference when large peaks arise less frequently. Peak windowing reduces PAPRs at the cost of increasing the BER and out-of-band radiation. It offers better PAPR reduction with better spectral properties. In peak windowing method we multiply large signal peak with a specific window, for example; Gaussian shaped window, cosine, Kaiser and Hamming window. In view of the fact that the OFDM signal is multiplied with several of these windows, consequential spectrum is a convolution of the original OFDM spectrum with the spectrum of the applied window. Thus, the window should be as narrow band as possible, conversely the window should not be too long in the time domain because various signal samples are affected, which results an increase in bit error rate (BER).

1.3.2.3 Envelope Scaling

In the Envelope Scaling technique PAPR is reduced by scaling the input envelope for some subcarriers before they are sent to IFFT. The key idea of this scheme is that the input envelope in some sub carrier is scaled to achieve the smallest amount of PAPR at the output of the IFFT. Thus, the receiver of the system doesn't need any side information for decoding the receiver sequence. This scheme is appropriate for QPSK modulation; the envelopes of all subcarriers are equal.

1.4 Cuckoo Search Algorithm

Cuckoo are fascinating birds, not only because of the beautiful sounds they can make, but also because of their aggressive reproduction strategy. Some species such as the ani and Guira cuckoos lay their eggs in communal nests, though they may remove others' eggs to increase the hatching probability of their own eggs. Quite a number of species engage the obligate brood parasitism by laying their eggs in the nests of other host birds (often other species). There are three basic types of brood parasitism: intra specific brood parasitism, cooperative breeding, and nest takeover. Some host birds can engage direct conflict with the intruding cuckoos [17]. If a host bird discovers the eggs are not owns, they will either get rid of these alien eggs or simply abandon its nest and build a new nest elsewhere. Some cuckoo species such as the New World brood- parasitic Tapera have evolved in such a way that female parasitic cuckoos are often very specialized in the mimicry in colour and pattern of the eggs of a few chosen host species. This reduces the probability of their eggs being abandoned and thus increases their productivity.

For simplicity in describing Cuckoo Search, we now use the following three idealized rules:

- Each cuckoo lays one egg at a time, and dumps its egg in a randomly chosen nest;
- The best nests with high-quality eggs will be carried over to the next generations;

- The number of available host nests is fixed, and the egg laid by a cuckoo is discovered by the host bird with a probability $p_a \in [0,1]$. In this case, the host bird can either get rid of the egg, or simply abandon the nest and build a completely new nest.

As a further approximation, this last assumption can be approximated by a fraction p_a of the n host nests are replaced by new nests (with new random solutions).

For a maximization problem, the quality or fitness of a solution can simply be proportional to the value of the objective function. Other forms of fitness can be defined in a similar way to the fitness function in genetic algorithms.

For the implementation point of view, we can use the following simple representations that each egg in a nest represents a solution, and each cuckoo can lay only one egg (thus representing one solution), the aim is to use the new and potentially better solutions (cuckoos) to replace a not-so-good solution in the nests. Obviously, this algorithm can be extended to the more complicated case where each nest has multiple eggs representing a set of solutions. For this present work, we will use the simplest approach where each nest has only a single egg. In this case, there is no distinction between eggs, nest or cuckoo, as each nest corresponds to one egg which also represents one cuckoo.

When generating new solutions x^{t+1} for, say, a cuckoo i, a Levy fight is performed.

$$x_i^{(t+1)} = x_i^{(t)} + \alpha \oplus Levy(\lambda) \tag{1.13}$$

Where $\alpha > 0$ is the step size which should be related to the scales of the problem of interests, in most cases, we can use $\alpha = O(L/10)$ where L is the characteristic scale of the problem of interest. The above equation is essentially the stochastic equation for a random walk. In general, a random walk is a Markov chain whose next status/location only depends on the current location (the first term in the above equation) and the transition probability (the second term). The product $\oplus$ means entry wise multiplications [17]. This entry wise product is similar to those used in PSO, but here the random walk via Levy right is more efficient in exploring the search space, as its step length is much longer in the long run.

The Levy right essentially provides a random walk whose random step length is drawn from a Levy distribution which has an infinite variance with an infinite mean.

$$\text{Levy} \sim u = t^{-\lambda}, \qquad (1 < \lambda \leq 3) \qquad (1.14)$$

Here the steps essentially form a random walk process with a power-law step-length distribution with a heavy tail. Some of the new solutions should be generated by Levy walk around the best solution obtained so far, this will speed up the local search. However, a substantial fraction of the new solutions should be generated by far field randomization and whose locations should be far enough from the current best solution, this will make sure that the system will not be trapped in a local optimum.

1.5 Organization of Thesis

Chapter 1 includes introduction to OFDM technique and PAPR in OFDM and its reduction. In chapter 2, we review the previous research papers of PAPR reduction in Multicarrier modulations, which is followed by solutions that are familiarized to PAPR reduction theory, their working. First, we quickly review the PAPR reduction parameters and design consideration, theory to implementation, to have design a PAPR reduction. Chapter 3 provides background information on design consideration of PAPR reduction and introduces our proposed architecture of PAPR reduction using cuckoo search. In chapter 4, we recall results of proposed PAPR reduction using cuckoo search technique. In last the conclusion and summary of achievements followed by future work.

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Chapter 2

Literature Survey

This chapter focuses on the critical points of current knowledge including substantive findings as well as theoretical and methodological contributions to a thesis topic under consideration.

2.1 Literature Survey

T. Wattanasuwakull et al (2005) [18] introduced the reduction of peak-to-average power ratio (PAPR) of the orthogonal frequency division multiplexing (OFDM) signal by using a method of tone reservation and tone injection. To reduce the peak of the OFDM signal, method is based on the reservation of some tones that are not used to carry data symbols. It replaces the appropriate chosen tones that carry data symbols with the dummy symbols. Data symbols, which are carried by replaced tones, are carried by reserved tones. The magnitude of the signal constellation of the dummy symbols must be larger than that of the original OFDM symbol so that the positions of the replaced tones can be easily detected by the receiver. There is no need to send any side information. The proposed method with proposed iterative search algorithm is an efficient scheme to reduce the PAPR of the OFDM signal with low complexity. However, it retards data rate and increases a little average power of the transmitter due to the dummy symbols that replace some tones and the usage of larger signal constellation

I. Hosseini et al. (2006) [8] defined a novel algorithm for PAPR reduction of an OFDM system, based on a companding scheme. In this method a compressing polynomial is appended to the IFFT block at the transmitter and at the receiver the FFT block is combined with a reverse expanding function where the iterative Jacobi's method is used for solving equations. This method entails less complexity at the transmitter in comparison with other PAPR reduction algorithms. It also requires less increase in SNR for the same BER compared to other companding methods. A tradeoff between complexity and performance can set the order of compressing polynomial and the number of iterations for the proposed algorithm at the receiver

W. Luqing et al (2006) [11] derived the active constellation extension (ACE) technique is a lossless (in terms of throughput) peak-to-average power ratio (PAR) reduction technique that adaptively extends the signal constellation while ensuring that the minimum distance between any two constellation points does not decrease. However, this technique increases the average transmit power, an adaptive-scaling algorithm for the implementation of ACE. It is based on the clipping and filtering technique, uses only the peak samples of clipping noise to reduce PAR. Simulation results show that the proposed algorithm has better PAR reduction, lower complexity and smaller BER than the previously proposed Smart Gradient-Project ACE

M. Sandell et al (2007) [19] analyzed lattice reduction for MIMO decoding and investigates how different parameters affect the complexity. Lattice reduction is a promising technique and a common approach to implementing it is to use the LLL algorithm, shows that how the complexity of the LLL algorithm depends on such parameters as the number of antennas, SNR, channel correlation and channel matrix column sorting. Both real- and complex-valued versions are considered and complexity-performance trade-offs are also studied.

N. LaSorte et al (2008) [20] depicted that the development of Orthogonal Frequency Division Multiplexing from a historical perspective, major research milestones are noted that contributed to modern-day OFDM. These contributions include the use of discrete Fourier transforms replacing the analog implementation and addition of cyclic extensions to ensure orthogonality among the sub-channels. Also, channel equalization algorithms to suppress inter-symbol interference and inter-carrier interference, channel estimation through the insertion of pilot tones among data blocks, peak-to-average power ratio reduction, and synchronization techniques are discussed.

A. Ghassemi et al (2009) [6] defined that the major drawbacks of orthogonal frequency division multiplexing (OFDM) is sensitivity to carrier frequency offset (CFO) caused by a mismatch between the transmitter and receiver oscillators. CFO destroys the orthogonality of the subcarriers and introduces intercarrier interference (ICI), reducing the system performance. Previously, tone reservation (TR) was considered for reducing the peak interference-to-carrier ratio (PICR) and shown to provide significant PICR reduction. In this paper, we use sub matrices of the inverse fast Fourier transform (IFFT) and fast Fourier transform (FFT) to reduce the number of variables in the optimization to efficiently compute the optimal tones. Performance results are presented which demonstrate that the proposed algorithm yields PICR performance similar to that with the previous TR technique

J. W. Choi et al (2009) [14] defined two simple orthogonal frequency-division multiplexing (OFDM) mean-delay estimation schemes, i.e., a channel impulse response (CIR)-based scheme and a differential scheme, which are applicable for adaptive algorithms including improved channel estimation and fast handover. Instead of time-domain processing which requires additional inverse fast Fourier transform (IFFT), the mean delay can be obtained in the proposed CIR-based scheme using the estimated frequency-domain CIR. When cell-specific preamble sequences are employed, the mean delay can also be estimated without CIR estimation in the proposed differential scheme using cross correlation of differentially correlated received signals, enabling further complexity reduction and performance improvement when the CIR estimation is not sufficiently accurate.

M. Itagaki et. al. (2010) [21] gave a theory that in cellular systems, multi-user multi-input multi-output (MIMO) multiplexing can increase the number of simultaneous users per cell; however co-channel interference (CCI) from other cells limits the number of users/cell (defined as the cellular capacity). The well-known zero-forcing detection (ZFD) and minimum mean square error detection (MMSED) are computationally efficient detection methods, but their diversity order decreases as the number of users increases. The multi-user signal detection method which has the full diversity order and less complexity is required in order to enhance the cellular capacity and introduce the lattice reduction (LR) aided ZFD and MMSED to the uplink multi-user MIMO using orthogonal frequency division multiplexing (OFDM) and investigate the uplink cellular capacity. LR using Lenstra-Lenstra-Lovasz (LLL) algorithm is a promising technique to improve the performance of ZFD and MMSED, LR aided ZFD and MMSED can obtain larger uplink capacity than conventional ZFD and MMSED at the cost of relatively low increase of computational complexity.

P. Phoomchusak et al (2011) [22] described a cross-layer design of adaptive tone reservation for PAPR reduction technique with throughput constraint for multi-user OFDMA systems is proposed. A tone reservation (TR) is an efficient technique to reduce the PAPR, which is the main problem in OFDMA systems. In order to reduce the PAPR with satisfied throughput requirement of the OFDMA systems, the cross-layer design between a resource allocation and a PAPR reduction is proposed, a non-selected tone resulted from the optimal subcarrier allocation algorithm, based on the subcarrier's channel gain approach, will be used as a reserved tone. The tradeoff between PAPR and throughput requirement is evaluated by determining the optimal number and position of reserved tone. Performance evaluation of the proposed technique is presented to prove its benefits.

Jun Hou et al (2012) [23] defined the main drawback of orthogonal frequency division multiplexing (OFDM) systems is the high peak-to-average power ratio (PAPR), which leads to performance degradation and power inefficiency. Tone injection (TI) is a distortion less technique that can reduce PAPR efficiently without incurring data rate loss or extra side information. However, optimal TI requires an exhaustive search over all combinations of possible constellations, which is an NP-hard problem. Suboptimal algorithms, achieving different tradeoffs between the PAPR reduction and complexity, have thus been developed. In this paper, a novel parallel tabu search algorithm for TI. Simulation results show that the proposed algorithm achieves significant PAPR reduction while maintaining low complexity.

L. Fety et al (2012) [24] stated that in radio mobile communication, antenna array structure at the reception is used to perform interference cancellation and equalization, introduce a reception structure where a spatial filter is split between a set of coefficients applied to received signals and a set of coefficients applied to reference signal (pilots symbols). Instead of trying to find this set of filter coefficients, the approach is based, for rank reduction reasons, on the projection of these coefficients on a discrete Fourier basis. In order to avoid a trivial solution, two constraints on filter coefficients are proposed, related algorithms are developed and simulation results are compared.

2.2 Problem Formulation

It has been concluded that PAPR reduction is of main concern in present communication systems. A higher PAPR means the system requires large linearity range for the analog circuitry used. This causes expensive system elements, higher power consumption and lower efficiency. The orthogonal frequency division multiplexing (OFDM) signals require the use of power amplifiers that behave linearly up to peak envelop power of the transmitted signal. Thus its reduction techniques play an important role for the better performance of OFDM system. Low bit error rate, high spectral efficiency, less computational complexity, easy implementation are the major factor that influence the development of PAPR reduction technique. A swarm based technique for PAPR reduction in OFDM can be developed.

2.3 Objectives of Thesis

Objective of thesis is to evaluate the performance of an OFDM system in the presence of Cuckoo Search Algorithm as the method to reduce PAPR. We will use Cuckoo Search Algorithm for reducing PAPR of Partial Transmit Sequence (PTS) OFDM system, which [6] would allow achieving solution with reduced computational burden and try and evaluate the resultant system performance with and without Cuckoo Search. The software used will be – MATLAB R2013a. The main objectives are summarized as follows:-

- To simulate the conventional OFDM system without PAPR reduction in MATLAB.
- To use PTS technique in the conventional OFDM system to reduce PAPR.
- To simulate the conventional Cuckoo search algorithm.
- To use combine the Cuckoo search algorithm with PTS technique to reduce the PAPR of the conventional OFDM system more efficiently and quickly.
- To compare the proposed OFDM system with the conventional OFDM system with and without PTS.

2.4 Research Methodology

MATLAB (matrix laboratory) is a numerical computing environment and fourth-generation programming language. Developed by Math Works, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, and Fortran. In this work, we will use **MATLAB version 8.1** released under the name MATLAB R2013a, for the computations and the final results.

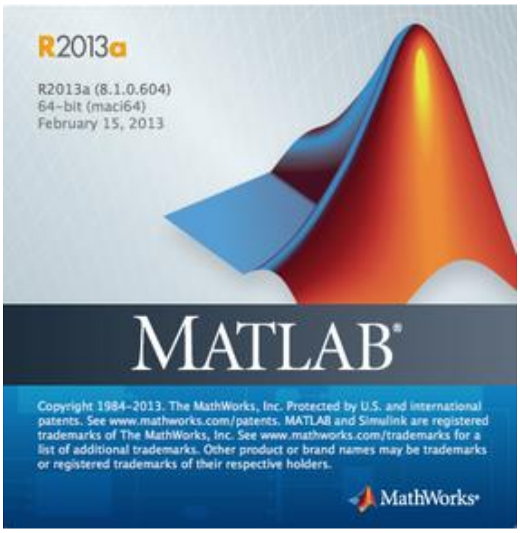

Fig. 2.1: MATLAB R2013a.

Chapter 3

Design and Implementation

In this chapter, we provide an insight of the actual system used in our simulations. Also the techniques and the software used in the course of the work are discussed in the forthcoming sections.

Orthogonal frequency division multiplexing (OFDM) offers high data rate and reliable communications over fading channels. But the major disadvantage of OFDM is the high peak to average power ratio. Our objective is to develop a technique to reduce the PAPR in multicarrier modulation system using cuckoo search algorithm.

3.1 Cuckoo Search Implementation

[Step 1] **Initialization**

Objective function $f(x), x = (x_1, x_2, \ldots x_d)$

[Step 2] **Generate initial host**

Generate initial population of n host nests x_i $(i = 1,2, \ldots n)$

Get a cuckoo randomly by levy flights.

Evaluate its quality fitness F_i.

Choose a nest among n randomly.

[Step 3] **Find the best solution**

If $(F_i > F_j)$ replaces j by the new solution;

End

A fraction (P_a) of worse nests is abandoned and new ones nests are built;

Keep the best solutions or nest with quality solutions;

Pass the current best to the next generation.

$$G = G + 1$$

3.2 System Model

The transmitter system used in our result simulations is shown in figure 3.1.

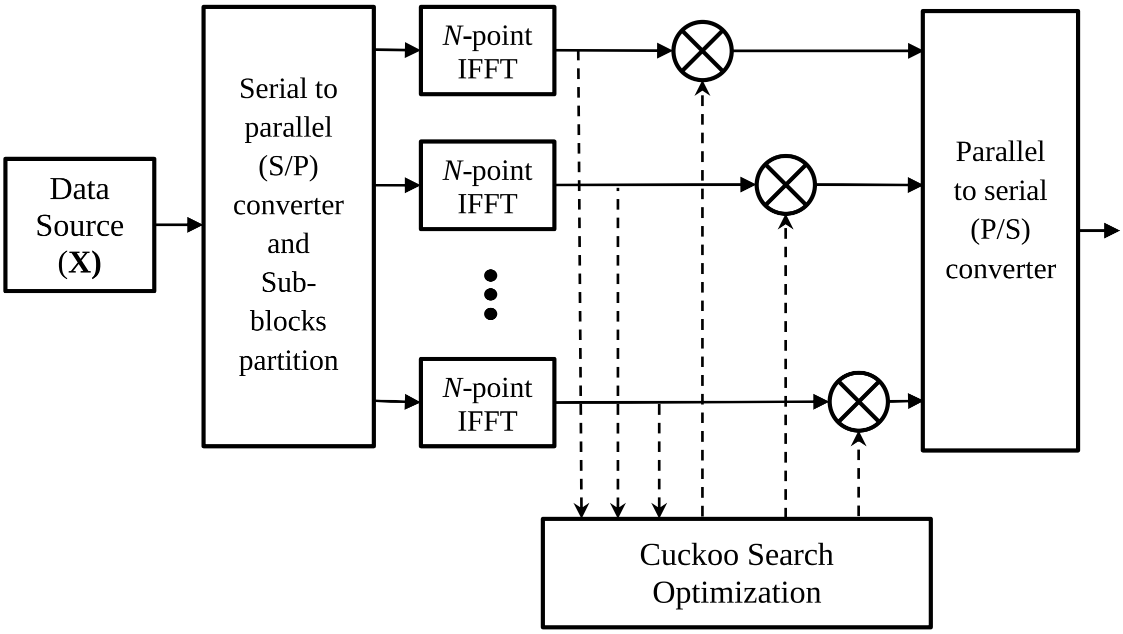

Figure 3.1 Transmitter.

The functional block diagram of a multicarrier modulation system with PTS scheme is shown in Figure 4.1. The data source block **X** is partitioned into M disjoint sub-blocks X_m, where m = 1, 2... M, such that,

$$\mathbf{X} = \sum_{m=1}^{M} X_m \tag{3.1}$$

Here, it is assumed that the sub-blocks X_m consist of a set of subcarriers of equal size N. The partitioned sub-blocks are converted from the frequency domain to the time domain using *N*-point IFFT. Due to IFFT being a linear transformation, the representation of the block in the time domain is given by,

$$\mathbf{x} = \text{IFFT}\{\sum_{m=1}^{M} X_m\} = \sum_{m=1}^{M} \text{IFFT}\{X_m\} = \sum_{m=1}^{M} x_m \tag{3.2}$$

The goal of the PTS is to form a weighted combination of the M time-domain partial sequences x_m by a phase vector $\mathbf{b} = [b_1, b_2 ... b_M]$ to minimize the PAPR, which is given by,

$$\mathbf{x}' = \sum_{m=1}^{M} b_m x_m \tag{3.3}$$

To minimize the peak power of $\mathbf{x}'$, we need to generate appropriate phase shifts b_m, such that it would result in lower PAPR. Letting $b_m = e^{j\varphi_m}$, where φ_m can be chosen freely within [0, 2π) can be expressed as,

$$\mathbf{x}' = \sum_{m=1}^{\mathrm{M}} e^{j\varphi_m} \mathrm{x}_m \tag{3.4}$$

The main objective here is to design a phase vector **b** that minimizes the PAPR. PAPR reduction with the PTS technique is related to the problem of minimizing max ($\mathbf{x}'$) subject to $0 \leq \varphi_m \leq 2\pi$, $m = 1, 2, \ldots,$ M. However, it is equivalent to an exhaustive search for a combinatorial optimization problem, which requires an enormous amount of computations to search all over possible candidate phase vectors and thus incurs a huge computational burden.

In this thesis we used Cuckoo Search Algorithm to search for the optimum phase vector **b** that would result in lower PAPR value for the system described above. As shown in figure 3.1, if the system follows the dashed line path then the Cuckoo Search Algorithm will optimize the system by generating appropriate phase vector **b**, by minimizing the fitness function given by,

$$PAPR = \frac{\max_{m=0}^{M-1} |\mathbf{x}'|}{\sigma^2} \tag{3.5}$$

where, σ^2 is the average power of the transmitted signal.

Chapter 4

Simulation Results

In this chapter the techniques described in previous chapters are used and the resultant system performance is evaluated using MATLAB R2012a.

4.1 Parameters Setting for MATLAB Simulations

The following Table 4.1 illustrates the parameter name and value used for MATLAB simulation of the system model described in previous chapters. Parameter description is given along with.

Table 4.1: Parameter Settings for Simulation.

Parameter	Description	Value
availableSubBlocks	Sub-Block size	2, 4, 8, 16
OFDMBlocks	Input bits	availableSubBlocks * 10^5
numSubCarriers	No. of subcarriers	128, 256, 512
M	Constellation Size	16-QAM
m	Bits/Symbol	$\log_2(M) = 4$
PAPRdB	PAPR in dB	4 to 14
fitnessFunc	Fitness Function	@(x) max(abs(x(1)^2)) ./ mean(x(1))
numOfNests	Number of Nests	10
maxIterations	Max Iterations	5

4.2 System performance (CCDF vs. PAPR)

Figures 4.1 to 4.3 illustrates the CCDF vs. PAPR performance of the system described in previous chapter. The parameter settings for the system model and the Cuckoo Search (CS) algorithm are given in Table 4.1. The only difference being in the number of subcarriers (128, 256, and 512) used. In each simulation the number of sub-blocks are varied from 2, 4, 8 and 16, whereas the number of possible phase shifts are varied from 0 to 2π. The phase shift values between 0 and 2π are obtained using CS algorithm.

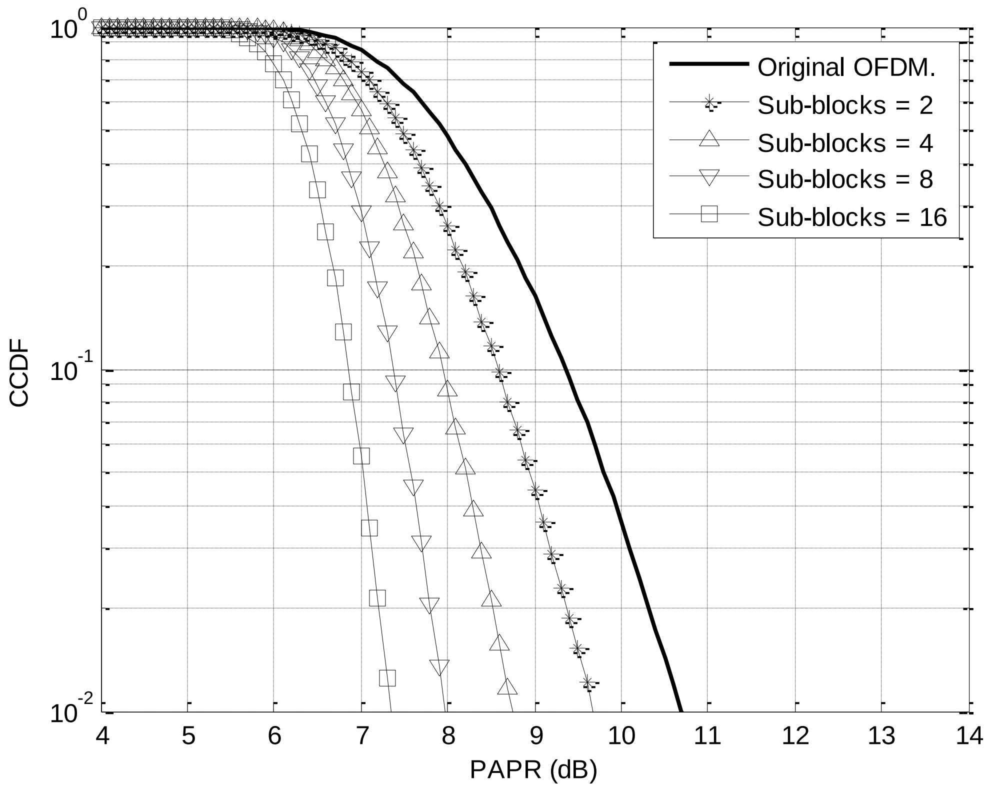

Figure 4.1 System performance for N=128 and 16-QAM.

Figure 4.1 illustrates the system performance (CCDF vs. PAPR) for underlying 16-QAM modulation and N=128 subcarriers. It can be seen that by increasing the number of sub-blocks PAPR reduces significantly. At CCDF of 10^{-2} PAPR is 9.7 dB for 2 sub-blocks, 8.8 dB for 4 sub-blocks, 7.9 dB for 8 sub-blocks and 7.35 dB for 16 sub-blocks. Moreover, a reduction of about 1.0 dB with respect to the original OFDM (without sub-blocks or rather 1 sub-block) is achieved if compared with PAPR of 2 sub-blocks.

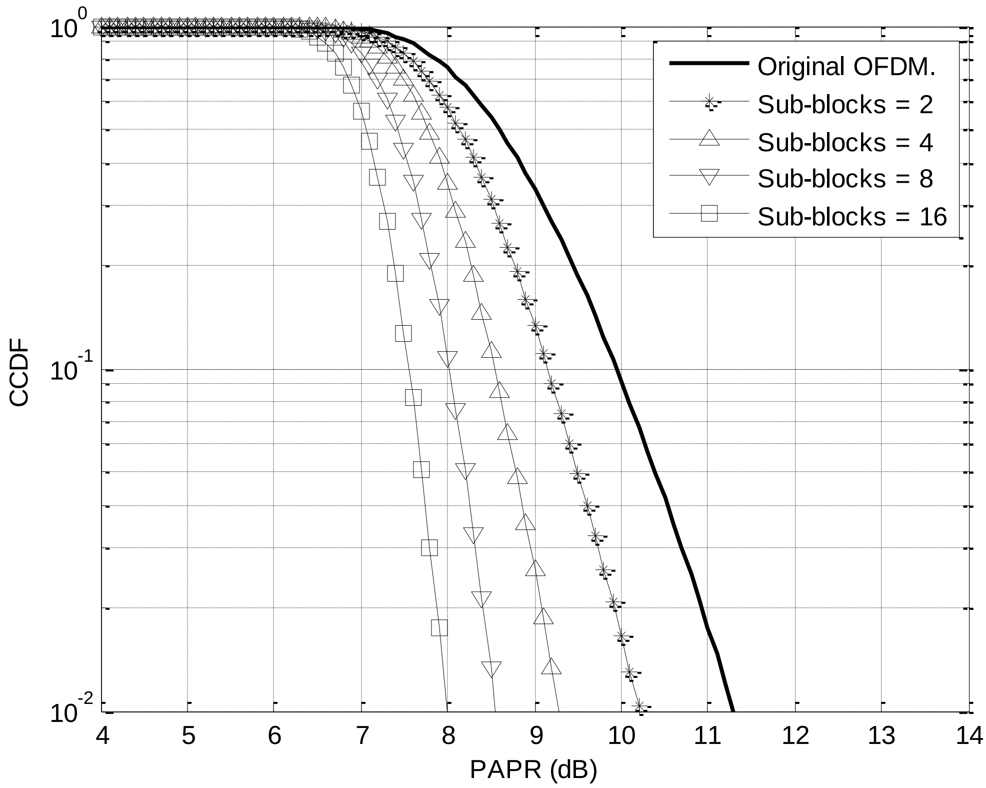

Figure 4.2 System performance for *N*=256 and 16-QAM.

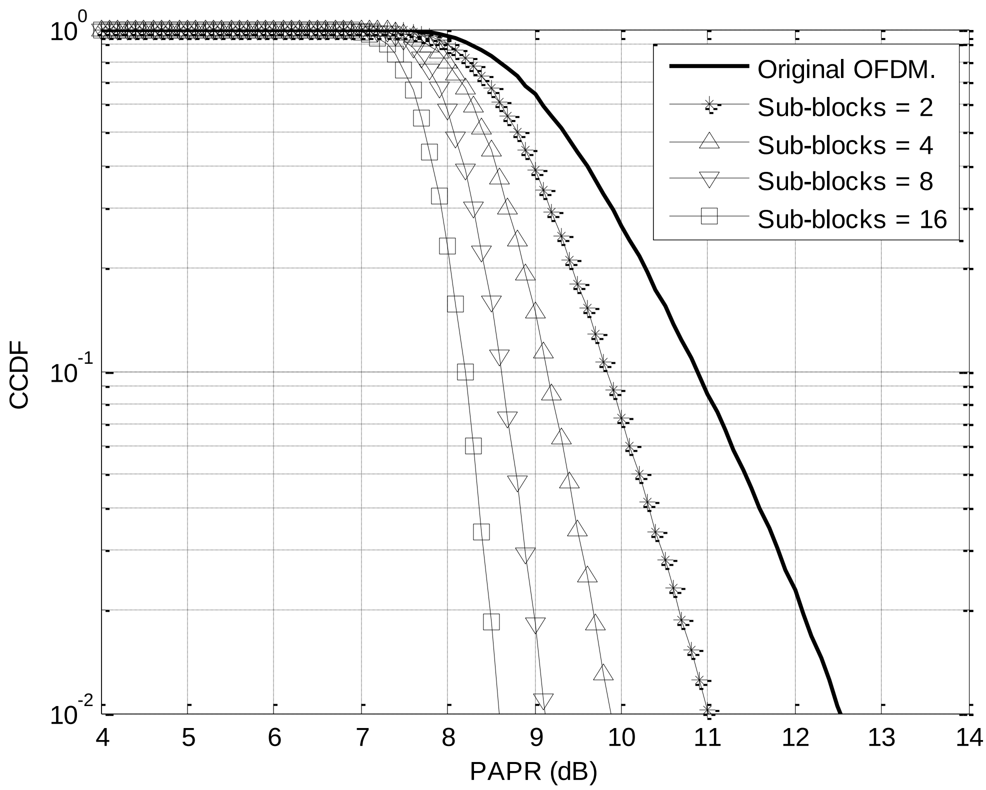

Figure 4.3 System performance for *N*=512 and 16-QAM.

Figure 4.2 illustrates the system performance (CCDF vs. PAPR) for underlying 16-QAM modulation and N=256 subcarriers. It can be seen that by increasing the number of sub-blocks PAPR reduces significantly. At CCDF of 10^{-2} PAPR is 10.2 dB for 2 sub-blocks, 9.3 dB for 4 sub-blocks, 8.65 dB for 8 sub-blocks and 7.97 dB for 16 sub-blocks. Moreover, a reduction of about 1.1 dB with respect to the original OFDM (without sub-blocks or rather 1 sub-block) is achieved if compared with PAPR of 2 sub-blocks.

From the above figures (4.1 and 4.2) it can be noted that there is significant improvement with increase in the number of sub-blocks.

Figure 4.3 illustrates the system performance (CCDF vs. PAPR) for underlying 16-QAM modulation and N=512 subcarriers. It can be seen that by increasing the number of sub-blocks PAPR reduces significantly. At CCDF of 10^{-2} PAPR is 11 dB for 2 sub-blocks, 9.9 dB for 4 sub-blocks, 9.15 dB for 8 sub-blocks and 8.6 dB for 16 sub-blocks. Moreover, a reduction of about 1.5 dB with respect to the original OFDM (without sub-blocks or rather 1 sub-block) is achieved if compared with PAPR of 2 sub-blocks.

4.3 Effect of Subcarriers on System performance

With increase in the number of subcarriers the system performance degrades as shown in figures 4.4 & 4.5 given below. These figures illustrates the CCDF vs. PAPR performance of the system described in previous chapters. The parameter settings for the system model and the CS algorithm are identical to the settings summarized in previous section 4.1. The only difference being in the number of subcarriers N (128, 256, and 512) used. In each simulation the number of sub-blocks are varied from 2, 4, 8 and 16, whereas the number of possible phase shifts are varied from 0 to 2π. The phase shift values between 0 and 2π are obtained using CS algorithm.

Figure 4.4 illustrates the system performance (CCDF vs. PAPR) for underlying 16-QAM modulation, for 2 & 8 sub-blocks and for subcarriers N=128, 256, & 512. It can be seen that for the same number of sub-blocks if we decrease the number of subcarriers, then the PAPR reduces significantly. At CCDF of 10^{-2} and sub-blocks = 2, PAPR is 11 dB for 512 subcarriers, 10.2 dB for 256 subcarriers and 9.7 dB for 128 subcarriers.

Similarly, at CCDF of 10^{-2} and sub-blocks = 8, PAPR is 9.15 dB for 512 subcarriers, 8.55 dB for 256 subcarriers and 7.95 dB for 128 subcarriers.

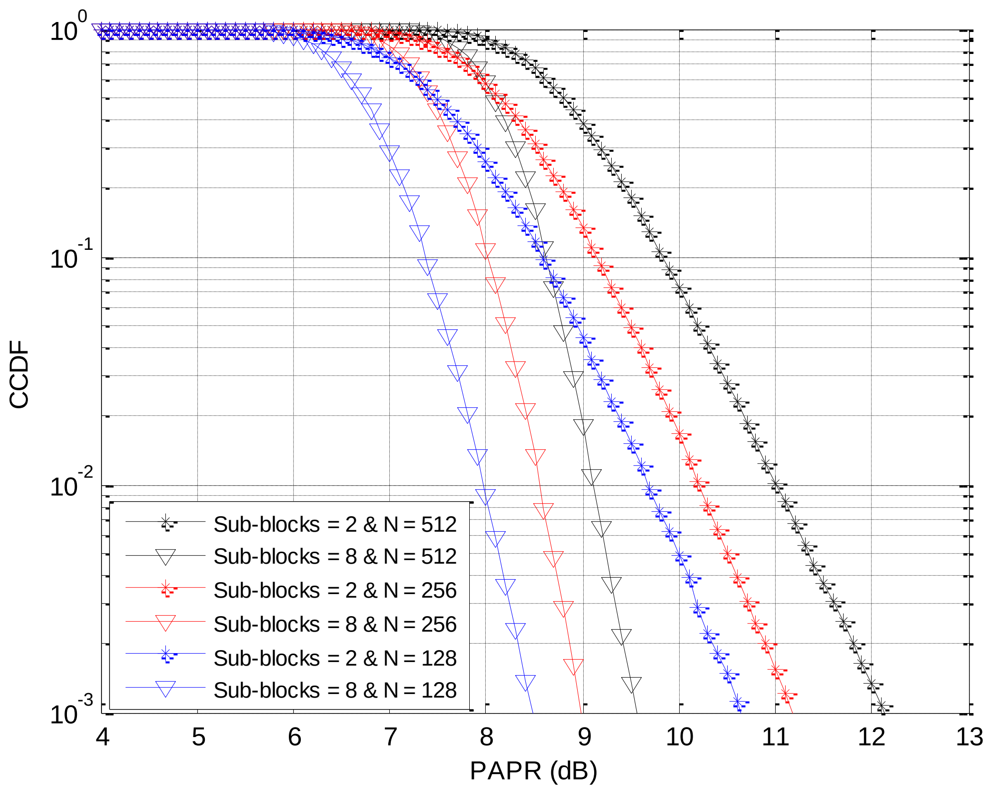

Figure 4.4 System performance for 2 & 8 sub-blocks, various *N* and 16-QAM.

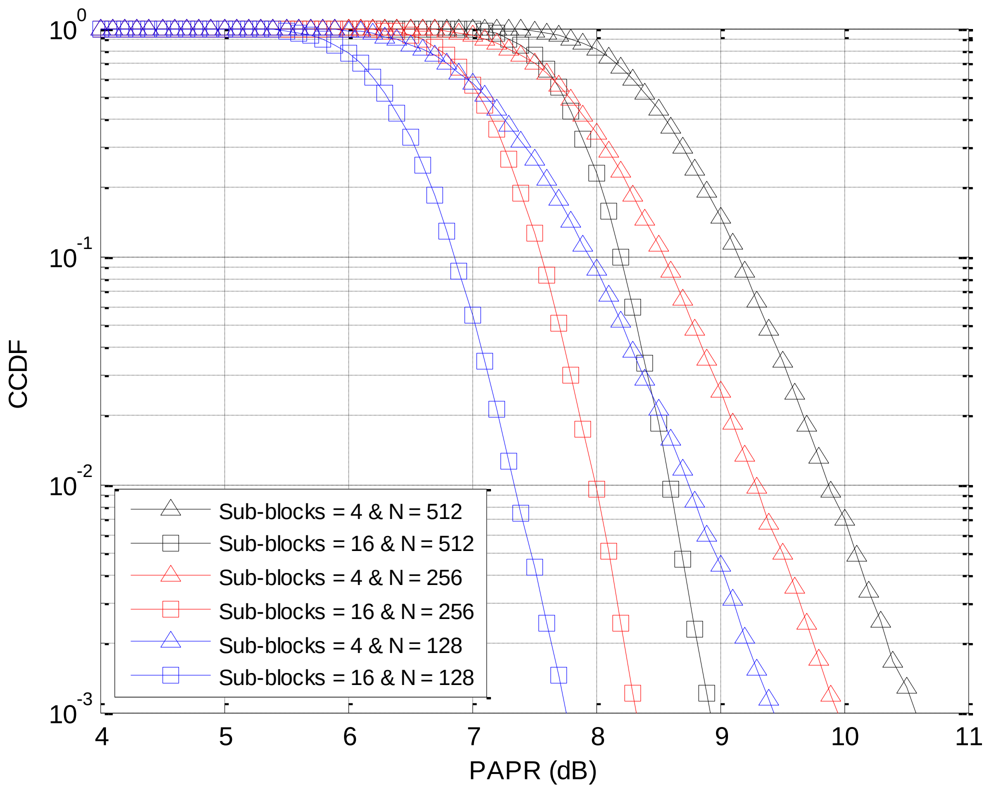

Figure 4.5 System performance for 4 & 16 sub-blocks, various *N* and 16-QAM.

Figure 4.5 illustrates the system performance (CCDF vs. PAPR) for underlying 16-QAM modulation, for 4 & 16 sub-blocks and for subcarriers N=128, 256, & 512. Here also we see that for the same number of sub-blocks if we decrease the number of subcarriers, then the PAPR reduces significantly. At CCDF of 10^{-2} and sub-blocks = 4, PAPR is 9.9 dB for 512 subcarriers, 9.3 dB for 256 subcarriers and 8.75 dB for 128 subcarriers.

Similarly, at CCDF of 10^{-2} and sub-blocks = 16, PAPR is 8.6 dB for 512 subcarriers, 8.0 dB for 256 subcarriers and 7.35 dB for 128 subcarriers.

From the above simulation results we can say that by using the CS Algorithm we are getting the desired type of results with much less computational complexity. In the original system without CS Algorithm we would get same type of results but with higher computational complexity and different values too (those values would be more accurate than the values obtained using CS Algorithm).

4.4 Comparison with GA

The above results are compared with Genetic Algorithm block coding (GA) technique. Genetic Algorithm block coding technique is distortion less method and is combination of partial transmit sequence and dummy sequence insertion methods. It takes apart the original signal into two parts and select the part having minimum PAPR. The following Table 4.2 illustrates the parameter values used for GA system. Parameter description is given along with.

Table 4.2: Parameter Settings for GA.

Parameter	Description	Value
numSubBlocks	Sub-Block size	2
numSubCarriers	No. of subcarriers	64
PAPRdB	PAPR in dB	3 to 10
Tx	Transmit Antennas	2
Rx	Receive Antennas	1

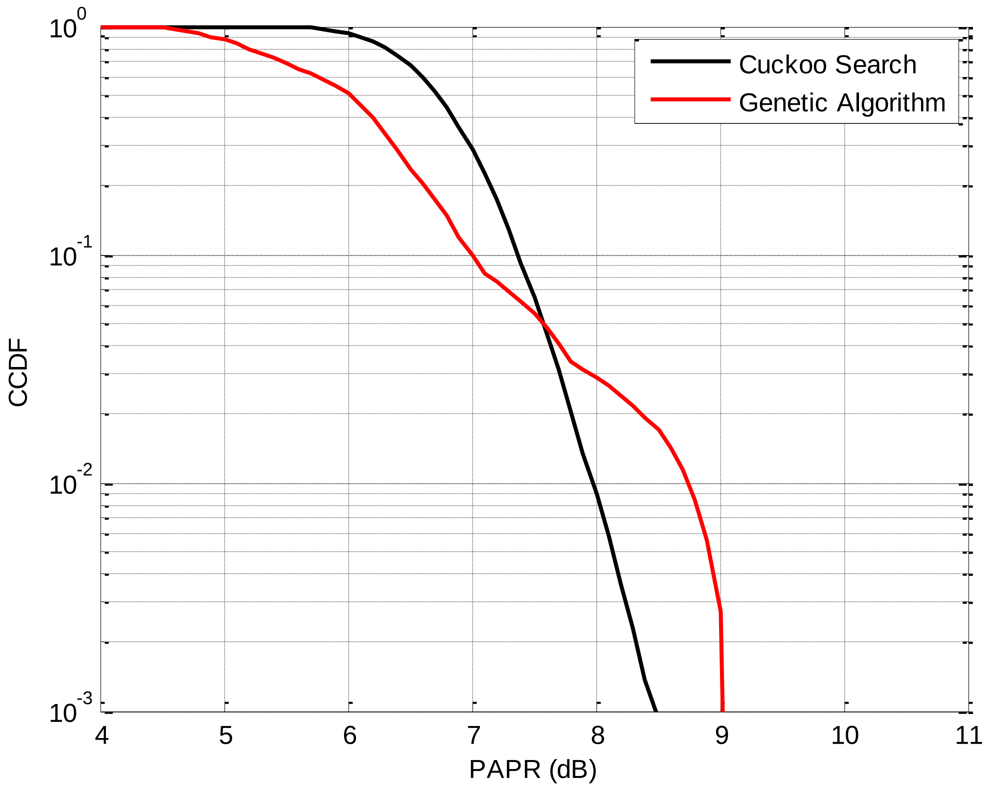

Figure 4.6: Comparison of CS (128 sub-carriers) with Genetic Algorithm technique.

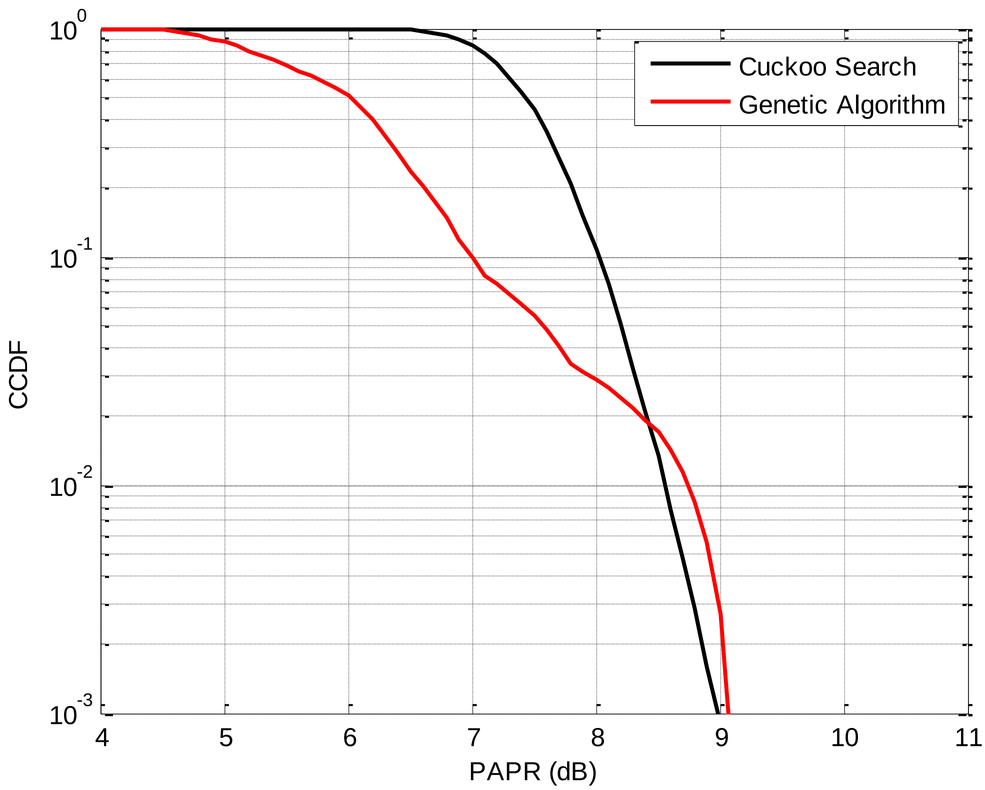

Figure 4.7: Comparison of CS (256 sub-carriers) with Genetic Algorithm technique.

Figures 4.6 and 4.7 compare the system performance (CCDF vs. PAPR) for CS and GA schemes, the only difference being the number of subcarriers used for CS, 128 in Fig. 5.6 and 256 in Fig. 5.7. The number of sub-blocks used are 4 in both the cases (CS and GA), for both figures (4.6 and 4.7).

From figure 4.6, it can be seen that for the same number of sub-blocks (2) and same number of subcarriers (64), the PAPR obtained using CS is less than that obtained with GA system. At CCDF of 10^{-2}, PAPR is 8.1 dB for CS and 8.7 dB for GA system, thereby having an improvement of 0.6 dB. At CCDF of 10^{-3}, an improvement of 0.6 dB is seen, with PAPR of 8.4 dB for CS and 9 dB for GA system.

Figure 4.7, compares the GA system used in figure 5.6 with CS (having 256 subcarriers). It can be seen that even with more number of subcarriers (64), the PAPR obtained using CS is nearly equal to that obtained using GA system.

4.5 Summary

In this thesis the use of CS Algorithm to reduce PAPR in OFDM systems has been proposed. Simulations were conducted and show that the performance of the proposed system provided almost the same PAPR statistics as that of the optimal system (like that in case of GA), while maintaining a low computational load. Results show the effectiveness of the proposed method in reducing the computational complexity of the calculation algorithm. The proposed technique provides a practical and economical approach toward solving the difficulty of high PAPR in OFDM systems.

Conclusion

OFDM is a multicarrier modulation scheme which plays an important role in long distance communication. One of its biggest challenges in OFDM is the peak to average power ratio (PAPR) which is ratio of maximum power of given OFDM symbol to the average power of that OFDM symbol. Many techniques were proposed to reduce the PAPR problem. Recently some techniques based on swarm intelligence were proposed which include particle swarm optimization (PSO), artificial bee etc. Cuckoo Search optimization is also one of the swarm intelligence techniques. So, this algorithm has been implemented to tackle the PAPR problem in OFDM systems.

The simulation results shows that CS is an effective method to reduce the PAPR problem. This method reduces the probability of having PAPR value. Simulation Results are compared with GA coding technique. Also effect of changing various simulation parameters such as subcarriers, sub-blocks is studied. By changing simulation parameters, system performance changes in terms of PAPR values and probability of PAPR values.

5.1 Future work

PAPR is a problem of OFDM systems and bio inspired algorithm i.e. Cuckoo Search algorithm to reduce the problem of PAPR has been used. It has effectively reduced the probability of having PAPR. Reduction in PAPR of OFDM systems can also be achieved with the help hybrid bio inspired algorithm such as particle swarm optimization genetic algorithm (PSOGA), ant colony genetic algorithm, ant colony algorithm. Cuckoo Search can also be combined with other techniques to reduce the PAPR problem.

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