CHAPTER 1

INTRODUCTION

1.1 Basic Principle of OFDM

Future broadband wireless communication systems require high-speed data rate transmissions through severe multipath propagation channels. Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier transmission technology for wireless digital communication systems because of its high-speed data rates, high spectral efficiency, high-quality service and robustness against narrow band interference and Frequency Selective (FS) fading. OFDM is an efficient modulation that splits a single signal into various low data rate subcarriers. This scheme allows simultaneous transmission of data without interference from each other.

This modulation technique has a wide variety of applications in both wired and wireless communication systems such as Asymmetric Digital Subscriber Line (ADSL) and Very High Speed Digital Subscriber Line (VDSL) broadband access, Power Line Communication (PLC), modems, digital TV, Wireless Local Area Network (WLAN) radio interfaces, digital radio systems and Ultra-Wide Band Personal Area Networks (UWB-PAN). International standards making use of OFDM for high speed wireless communications are established by IEEE 802.11, IEEE 802.16, IEEE 802.20, and European Telecommunications Standards Institute (ETSI) Broadcast Radio Access Network (BRAN). OFDM signals can easily adapt to severe channel conditions without complex time-domain equalization with high bandwidth efficiency. OFDM is an attractive technique for its robustness against narrow band channel interference, Inter Symbol Interference (ISI) and FS channels. However, the OFDM transmitted signal suffers from two major problems, i.e., high Peak to Average Power Ratio (PAPR) and Carrier
Frequency Offset (CFO). High PAPR is one of the most significant problems in OFDM, when the independent phases of subcarriers combine constructively. A High PAPR reduces the system efficiency and increases the system complexity. Many PAPR reduction methods have been discussed in the literature. Several techniques, however, increase the Bit Error Rate (BER) while trying to decrease the PAPR.

1.1.1 Orthogonality

Conceptually, OFDM is a specialized Frequency Division Multiplexing (FDM), the additional constraint is that all the carrier signals are orthogonal to one another. In OFDM, the sub-carrier frequencies are chosen so that the subcarriers are orthogonal to each other, meaning that cross-talk between the subchannels is to be eliminated and inter-carrier guard bands are not required. This will simplify the design of both the transmitter and the receiver unlike conventional FDM, a separate filter for each sub-channel is not to be needed. The orthogonality requires the sub-carrier spacing $\Delta f = k / T_u$ Hz, where $T_u$ is the useful symbol duration, and $k$ is a positive integer, typically equal to 1.

Therefore, with $N$ sub-carriers, the total pass band bandwidth can be written as,

$$ B = N \cdot \Delta f \ (Hz) \quad (1.1) $$

The orthogonality allows high spectral efficiency, with a total symbol rate near the Nyquist rate for the equivalent baseband signal (i.e., near half the Nyquist rate for the double-side band physical pass band signal). Almost the whole available frequency band could be utilized. OFDM has a nearly 'white' spectrum, giving electromagnetic interference properties on other co-channel users.

The waveform of subcarriers in an OFDM transmission is illustrated in Figure 1.1. The figure indicates the spectrum of carriers significantly, over the
other carrier. In the frequency domain, each transmitted subcarrier results in a sinc function spectrum with side lobes that produce overlapping spectra between subcarriers. As a result subcarrier interference arises except at orthogonally spaced frequencies. At orthogonal frequencies, the individual peaks of subcarriers will line up with nulls of the other subcarriers. This overlap of spectral energy does not interfere with the system’s ability to recover the original signal. Thus the receiver multiplies the incoming signal by the known set of sinusoids to recover an original set of bits sent. The $N$ equally spaced subcarriers will be orthogonal, if the frequency separation between subcarriers is $\Delta f = \frac{1}{NT_s}$, where $T_s$ is symbol duration, and $N$-point Inverse Fast Fourier Transform (IFFT) is performed. Under these conditions, the subcarriers will have a sinc waveform frequency response.

![Figure 1.1 Frequency Spectrums of Orthogonal Subcarriers of an OFDM Signal](image_url)
As mathematically, orthogonality of two signals, $\psi_k(t)$ and $\psi_l(t)$ over period $T$ can be expressed as,

$$\lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} \psi_k^*(t) \psi_l(t) dt = 0 \quad (1.2)$$

The use of orthogonal subcarriers which allows more subcarriers per bandwidth resulting in an increase in spectral efficiency. In the perfect OFDM signal, orthogonality prevents interference between overlapping carriers. In FDM systems, any overlap in the spectrums of adjacent signals will result in interference. The frequency spectrum of one carrier exhibits zero-crossing at the central frequencies corresponding to all other carriers. At these frequencies, the Inter-Carrier Interference (ICI) is to be eliminated, although the individual spectra of subcarriers overlap. It is well known; orthogonal signals could be separated at the receiver by correlation techniques. Therefore, the receiver acts as a bank of demodulators, translating each carrier down to baseband, the resulting signal then integrated over a symbol period to recover the data. If the other carriers all beat down to frequencies which, in the time domain mean an integer number of cycles per symbol period, then the integration process results in a zero contribution from all these carriers.

### 1.1.2 OFDM System Model

The block diagram of the IEEE 802.11a OFDM system is shown in Figure 1.2. In this system, the input data stream is converted into $N$ parallel data streams each with symbol period $T_s$ through a serial to the parallel convertor. When the parallel symbol streams are generated, each data stream would be modulated and carried at different center frequencies. Then the $N$ data symbols are mapped to bins of an IFFT. An IFFT transforms converts the frequency components of the spectrum into the time domain OFDM symbols, adds a prefix and transmits the resulting signal over the communication channel.
This method of insertion of Guard Interval (GI) is used for frequency hopping and Radio Frequency (RF) convergence. GI in OFDM system is used to remove ISI which is introduced between consecutive OFDM symbols. The delay spread of multipath channel causes ISI in OFDM symbols. A guard band interval with no signal transmission could be used to remove ISI entirely, but it can produce ICI because of higher spectral components which occur due to quick change of waveform.
The GI can be used in two ways: Zero Padding (ZP) and Cyclic Extension (CE). CE has been extended in two ways - Cyclic Prefix (CP) or Cyclic Suffix (CS). In CP, small part or portion of transmitted symbols is taken and repeated as the prefix of transmitted symbol. By prefixing of OFDM symbol, ISI is removed. The CP insertion is shown in Figure 1.3.

In ZP top and the bottom portion of the transmitted symbols are filled with zeros as shown in Figure 1.4.

![Figure 1.4 OFDM Symbols with ZP](image)

At the receiver, the GI is removed on a fading channel. After the serial-to-parallel conversion, the OFDM sub-channel demodulation is implemented by using Fast Fourier Transform (FFT). The received OFDM symbols generated by the FFT are to be demodulated at the receiver.

### 1.1.3 IEEE 802.11a OFDM System Overview

An 802.11a OFDM carrier signal is the sum of one or more OFDM symbols each comprising of 52 orthogonal subcarriers, with baseband data on each subcarrier independently modulated using Quadrature Amplitude Modulation (QAM). Figure 1.5 illustrates the generation of OFDM signal process. This composite baseband signal is used to modulate an RF carrier. In an OFDM system, the input data bit stream has been encoded with
convolutional coding and Interleaving. Based on the modulation scheme each data stream is divided into groups of "n" bits and converted into complex numbers representing the mapped constellation point.

The 64-QAM constellation (6 bits/symbol) can have a bit rate of 54 Mbps while a Quadrature Phase Shift Keying (QPSK) constellation (2 bits/symbol) may only be 12Mbps. Then 52 subcarriers of the IFFT block are loaded. 48 subcarriers contain the constellation points which are mapped into frequency offset indexes ranging from -26 to +26, skipping the 4 Pilot and zero subcarriers. There were 4 Pilot subcarriers inserted into frequency offset index locations -21, -7, +7, and +21. A zero subcarriers are Null or DC subcarrier and are not to be used; it contains a 0 value. When the IFFT block is loaded, the IFFT is computed, giving a set of complex time-domain samples representing the combined OFDM subcarrier waveform.

**Figure 1.5 OFDM Signal Generation Process**
A 0.8\(\mu\)s duration GI is then added to complete the OFDM symbol, the beginning of the OFDM waveform. This will produces a single OFDM symbol with the duration of 4\(\mu\)s in length. The process is repeated to create additional OFDM symbols for the remaining input data bits.

The timing parameters associated with the IEEE 802.11a signal is illustrated in Table 1.1.

**Table 1.1 IEEE 802.11a Parameters**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total subcarriers (N_{ST})</td>
<td>52</td>
</tr>
<tr>
<td>Data subcarriers (N_{SD})</td>
<td>48</td>
</tr>
<tr>
<td>Pilot subcarriers (N_{SP})</td>
<td>4 (subcarriers -21, 7, 7, 21)</td>
</tr>
<tr>
<td>Subcarrier Frequency Spacing (F_{SP})</td>
<td>312.5 KHz (20MHz/64)</td>
</tr>
<tr>
<td>Symbol Interval Time (T_{SYM})</td>
<td>4 (\mu)s ((T_{GI} + T_{FFT}))</td>
</tr>
<tr>
<td>Data Interval Time (T_{DATA})</td>
<td>3.2(\mu)s ((1/F_{SP}))</td>
</tr>
<tr>
<td>Guard Interval (GI) Time (T_{GI})</td>
<td>0.8(\mu)s ((T_{FFT}/4))</td>
</tr>
<tr>
<td>IFFT/FFT Period (T_{FFT})</td>
<td>3.2(\mu)s ((1/F_{SP}))</td>
</tr>
<tr>
<td>Signal Symbol Time (T_{SIGNAL})</td>
<td>4(\mu)s ((T_{GI} + T_{FFT}))</td>
</tr>
<tr>
<td>Preamble (T_{PREAMBLE})</td>
<td>16(\mu)s ((T_{SHORT} + T_{LONG}))</td>
</tr>
<tr>
<td>Short Training Sequence (T_{SHORT})</td>
<td>8(\mu)s ((10xT_{FFT}/4))</td>
</tr>
<tr>
<td>Long Training Sequence (T_{LONG})</td>
<td>8(\mu)s ((T_{GI2} + 2xT_{FFT}))</td>
</tr>
<tr>
<td>Training symbol GI (T_{GI2})</td>
<td>1.6(\mu)s ((T_{FFT}/2))</td>
</tr>
<tr>
<td>FFT sample size</td>
<td>64</td>
</tr>
</tbody>
</table>
1.1.4 BWA

Broadband Wireless Access (BWA) has emerged as a promising solution for last mile access technology to provide high-speed internet access in the residential as well as small and medium-sized enterprise sectors. At this moment, cable and Digital Subscriber Line (DSL) technologies provide broadband service in these sectors. But the practical difficulties in deployment have prevented them from reaching many potential broadband internet customers. Currently, many areas throughout the world are not under broadband access facilities. Even many urban and suburban locations may not be served by DSL connectivity as it can only reach about three miles from the central office switch. On the other side, many old cable networks do not have return channel which will prevent to offer internet access and many commercial areas are often not covered by the cable network. However with BWA, these difficulties can be overcome. Because of its wireless nature, it can be faster to deploy, easier to scale and more flexible, thereby giving it the potential to serve customers who are not to be served or not satisfied by their wired broadband alternatives.

IEEE 802.16 standard for BWA and its associated industry consortium, Worldwide Interoperability for Microwave Access (WiMAX) Forum promise to offer high data rate over large areas to a large number of users where broadband is unavailable. This was the first industry-wide standard that could be used for fixed wireless access with substantially higher bandwidth than most cellular networks. The first version of the IEEE 802.16 standard operates in the 10–66GHz frequency band and requires Line of Sight (LOS) towers. Later the standard extended its operation through different Physical Layer (PHY) specification to 2-11 GHz frequency band enabling Non Line of Sight (NLOS) connections, which require techniques that efficiently mitigate the impairment of fading and the multipath.
The advantage of OFDM technique, the PHY can provide robust broadband service in the hostile wireless channel. The OFDM based PHY of the IEEE 802.16 standard had been standardized in close cooperation with the ETSI High-Performance Metropolitan Area Network (HIPERMAN).

1.1.5 OFDM Transmission in Wireless Channel

In wireless communications, the signal transmitted from the source typically will experiences attenuation, scattering, reflection and refraction before it reaches the destination. These effects are usually modelled as one or several values are known as the channel response which is to be convolved with the transmitted signal. The response of the channel between the transmitter and the receiver is not fixed but varies with time and frequency.

![Multipath Propagation](image)

**Figure 1.6 Multipath Propagation**

The bandwidth upon which the channel response could be assumed flat is known as the coherence bandwidth of the channel. If the data is transmitted at high symbol rates, the bandwidth of the signal becomes wide and may exceed the coherence bandwidth of the channel. This will distorts the signal
and leads to ISI. ISI degrades the signal in two ways. First, previously transmitted symbols interfere with the current symbol. The second part of the current symbol energy was lost as it will cause ISI for subsequent symbols. To eliminate ISI, equalization can be employed. The equalizer is an adaptive digital filter with a certain number of taps. The weights of the taps in the equalizer are designed such that, the combined response of the channel and equalizer is a constant value (flat) within the signal bandwidth. Equalizers suffer from a number of limitations. By finding the optimum weight of each tap is a complicated process which increases exponentially as the length of the filter increases. Moreover, these weights are calculated from a noisy estimate of the channel response, and hence the estimation error will be higher when compared to the single tap filter needed for flat channel. Another limitation is equalizers which have been designed with a maximum length. Such equalizers will perform poorly, if the channel response is longer than the equalizer’s length. To eliminate the need for multi-tap equalizers, it has been proposed in the 1960s that the data be split into parallel streams. If the number of streams is large enough, the bandwidth of each stream will become less than the channel coherence bandwidth and hence, each stream experiences a flat channel response. These streams will be modulated using separate orthogonal carriers known as subcarriers. The subcarriers must be fitted within the bandwidth allocated for transmission but must be far enough so that they do not interfere with each other. The minimum spacing between the subcarriers are found to be $1/T$, where $T$ is the symbol duration after splitting the data into parallel streams in OFDM system.

The transmitted OFDM wireless signal faces various obstacles and surfaces of reflection, as a result of the received signals from the same source reach at different times. It gives rise to the formation of echoes which affect the other incoming signals. Some of the reflections arrive almost at the same time, and their combined effect is shown in Figure 1.6. Depending on the
phase difference between the arriving signals, the interference can be either constructive or destructive, which causes a very considerable observed difference in the amplitude of the received signal even over very short distances. In other words, moving the transmitter or the receiver even a very short distance can have a dramatic effect on the received amplitude, even though the path loss and shadowing effects may not have changed at all.

1.1.6 OFDM Advantages

The main advantages of the OFDM technique are listed below:

**Robustness against FS Fading Channel with Simple Channel Equalization**

In single carrier (SC) based systems, adaptive equalization techniques with relatively extra cost are required to compensate for the channel effect. Such techniques of channel equalization become very hard difficult and achieve inferior performance when the symbol period becomes shorter with increasing data rates due to an increase in the number of adjacent symbols affected by a single fade. In contrast, in a multicarrier system, the entire available bandwidth is divided into narrow band subcarriers. Therefore, each subcarrier experiences its flat fading channel which can be simply equalized using the linear single tap equalizer.

**High Spectral Efficiency**

The orthogonality among the subcarriers of OFDM based systems eliminates ICI between adjacent subcarriers. Moreover, the OFDM system produces high spectral efficiency by allowing the overlap between adjacent orthogonal subcarriers. The orthogonality between subcarriers is maintained by carefully selecting the spacing between the subcarriers.
1.2 PAPR Reduction Techniques

1.2.1 PAPR of OFDM Signal

OFDM signal consists of same independently modulated sub-carriers which can give a peak when added with same phases. PAPR occurs due to a large dynamic range of OFDM symbol waveforms. High PAPR in OFDM essentially arises because of IFFT pre-processing.

As long as the signal swing is limited to the dynamic or linear range, input and output are linearly related as shown in Figure 1.7. But in OFDM system, a swing of instantaneous power is very high compared to mean. So, it will cross over into the non-linear range where amplification is non-linear. As amplification is non-linear, all the OFDM orthogonality is lost, and then there will be extreme ICI. So, high PAPR in OFDM results in amplifier saturation, thus leading to ISI.

Figure 1.7 Characteristics of HPA
From the Central Limit Theorem (CLT), the time-domain OFDM symbol has been approximated as a Gaussian waveform. The amplitude variations of the OFDM modulated signal can, therefore, be very high with less probability as compared to the high probable mean value of the amplitude. This high-value amplitude is a result of an addition of phases of the subcarriers together.

For these variations to accommodate PA, it should have a large linear range under which it can amplify the highest value of the amplitude peak and average amplitude value. Coherent addition of $N$ signals of the same phase produces a peak value which is $N$ times the average signal. The time domain representation of OFDM signal and the frequency spectrum of OFDM signal are illustrated in Figure 1.8 and Figure 1.9 respectively.

![Figure 1.8 Time Domain Representation of OFDM Signal](image-url)
The complex representation of OFDM signal $x(n)$ is given by,
\[
x(n) = \sum_{k=0}^{N-1} X(k) w_N^{nk} \quad n = 0,1,\cdots,N - 1
\] (1.3)

Where,

$w_n$ is a twiddle factor

The PAPR for OFDM signal is to be defined as the ratio between the maximum power and the average power for the envelope of a baseband complex signal $x(n)$, i.e.,

\[
PAPR\{x(n)\} = \frac{\max |x(n)|^2}{E[|x(n)|^2]}
\] (1.4)

Where, $E[.]$ denotes the expectation operator.

Figure 1.9 OFDM Frequency Spectrum
1.2.2 Selection Criteria for PAPR Reduction Techniques

The selection criteria of the PAPR reduction are to find the approach that can reduce PAPR effectively while maintaining good performance in the aspects discussed next.

High PAPR reduction capability

This primary factor has been considered in selecting the PAPR reduction technique which has few harmful side effects such as in-band distortion and OBR.

Low average power

Although high average power also can reduce PAPR, it requires a larger linear operation region in HPA and thus resulting in degradation of BER performance.

Low implementation complexity

Generally, complex techniques exhibit better PAPR Reduction ability. However, for practical implementation, both time and hardware requirements for the PAPR reduction should be minimal.

No bandwidth expansion

The bandwidth expansion directly results in the data code rate loss due to Side Information (SI). Moreover, when the SI is received in error unless some ways of protection such as channel coding are employed. Therefore, when channel coding to be used, when the loss in data rate is increased due to SI. Therefore, the loss in bandwidth due to SI should be avoided or at least be kept minimal.
No BER performance degradation

The aim of PAPR reduction is to obtain the better system performance including BER than that of an original OFDM system. Therefore, an increase in BER at the receiver should be paid more attention in practice.

1.2.3 CCDF of the PAPR

The Complementary Cumulative Distribution Function (CCDF) of the PAPR is an important measure for PAPR reduction techniques. It denotes the probability that the PAPR of an OFDM symbol exceeds a given peak threshold. By implementing the CLT for a multi-carrier signal with a large number of sub-carriers, the real and imaginary part of the time domain signals have a mean of zero and a variance of 0.5 and follow a Gaussian distribution. So Rayleigh distribution is followed for the amplitude of the multi-carrier signal, whereas a central chi-square distribution with two degrees of freedom to be followed by the power distribution of the system.

The Cumulative Distribution Function (CDF) of the amplitude of a signal is given by,

\[
F(PAPR_o) = 1 - \exp(-PAPR_o) \tag{1.5}
\]

The CCDF of the PAPR can be given by,

\[
\Pr(PAPR \geq PAPR_o) = 1 - F(PAPR_o) = 1 - \left[ 1 - \exp(-PAPR_o) \right] \tag{1.6}
\]

Where, PAPR_o is a peak threshold.
Figure 1.10 CCDF for OFDM Signal with Various Subcarriers

PAPR is also measured for a different number of $N$ up to 1024 subcarriers using randomly generated data bits with 64 ary QAM OFDM and the result is shown in Figure 1.10. It has been observed that as the number of subcarrier increases, PAPR value also increases. Therefore, the PAPR depends upon the number of data considered in OFDM system.

1.2.4 Overview of PAPR Reduction Schemes

PAPR reduction techniques vary according to the needs of the system and are dependent on various factors. PAPR reduction capacity, increases in power in transmit signal, loss in data rate, the complexity of computation and increase in the BER at the receiver end are various factors which were taken into account before adopting a PAPR reduction technique of the system. Many techniques have to be suggested for PAPR reduction, with different levels of success and complexity. Figure 1.11 shows the classification of
PAPR reduction techniques. Numerous techniques have been proposed and optimized in the literature to reduce the PAPR of OFDM signals. These techniques are classified into three major categories: signal distortion techniques, probabilistic techniques, and coding techniques.

Several techniques have been proposed to reduce the PAPR, such as clipping, coding, peak windowing, and Tone Reservation (TR) and Tone Injection (TI) techniques. But, most of these methods are unable to achieve a large reduction in PAPR with low complexity, with low coding overhead, without performance degradation, and transceiver will symbol handshake.

In the first reduction, the signal distortion technique, which introduces distortion to signals and causes reputation in an action including clipping, clipping and filtering, windowing, peak cancelling, pre-distortion or companding. Signal pre-distortion techniques based on companding are to reduce the PAPR has been proposed by several authors using different companding techniques such as μ-Law, exponential, modified exponential and linear companding. Clipping is simple and effective and causes In Band Radiation (IBR) and increased BER. The companding transforms better than clipping as they reduce distortion significantly.

Different coding techniques have been proposed for signal scrambling, which can be classified into various schemes with an explicit SI including linear block codes, and multiple signal representations such as Selective Mapping (SLM) and TR, Partial Transmit Sequence (PTS), and interleaving schemes. These schemes give an ease of modification, at an increased overhead, search complexity, and data loss. The various schemes were proposed without SI includes block coding, Hadamard transform method, Dummy Sequence Insertion (DSI) method, Golay complementary codes, Reed-Muller codes, etc. The signal scrambling technique may not be affecting
the system performance, but it has an overhead of increased complexity and needs to perform an exhaustive search to find best codes and to store large lookup tables for encoding and decoding. It does not support error correction. As a result, TR offers a distortion-less technique that effectively reduces the PAPR without SI, but BER increases. Coding can also be used to reduce the PAPR by selecting applicable code words that minimize the PAPR of the transmitted signal. Error control SLM is an effective, and there is no need for SI but, complexity will be increased.

![Figure 1.11 Classification of PAPR Reduction Techniques](image)

Figure 1.11 Classification of PAPR Reduction Techniques
The signal distortion techniques, including clipping and filtering, peak windowing and companding, will distort the OFDM signals before PA to reduce PAPR. These techniques can reduce PAPR to a high level, but result in signal distortion, which leads to worse BER performance.

As the high PAPR appears randomly, probabilistic techniques focus on the lower probability of high peaks of OFDM signals. The principle of these techniques is that the different scrambling sequences are weighted to original OFDM signals to optimize phase sequences. Therefore, one combination between OFDM signal and phase sequence that has minimum PAPR is selected to be transmitted. The probability of high peaks occurrence is to be reduced through this way and then PAPR is also reduced. The performance comparison of PAPR reduction techniques is summarized in Table 1.2.

Table 1.2 Performance Comparisons between PAPR Reduction Techniques

<table>
<thead>
<tr>
<th>PAPR Reduction Techniques</th>
<th>Parameters</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Distortion</td>
<td>Power Increase</td>
<td>Data rate loss</td>
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<tr>
<td>Clipping and Filtering</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Selective Mapping (SLM)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Partial Transmit Sequence (PTS)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Block coding</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
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<td>Interleaving</td>
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<td>Yes</td>
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<td>Active Constellation Extension</td>
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<td>No</td>
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<tr>
<td>(ACE)</td>
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<tr>
<td>Tone Reservation (TR)</td>
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<td>Tone Injection (TI)</td>
<td>No</td>
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</table>
1.3 Need for the Study

PAPR occurs when the different subcarriers are out of phase with each other in a multicarrier system. At each instant, they are different on each other at various phase values. Due to the presence of a large number of independently modulated subcarriers in an OFDM system, the peak value of the system can be very high as compared to the average of the whole system. The OFDM signal consists of some independently modulated sub-carriers which will give a large PAPR when it is added up coherently. So OFDM signal has a very huge PAPR, which is very sensitive to the nonlinearity of the HPA.

Therefore, RF PAs will be operated in a very extent linear region. Otherwise, the signal peaks get into nonlinear region of PA causing Inter-Modulation Distortion (IMD) among the subcarriers and Out of Band Radiation (OBR). Thus, the PAs can be operated with large power back-offs. On the other hand, this leads to a very inefficient amplification and expensive transmitters. Thus, it is highly desirable to reduce the PAPR.

1.4 Problem Statement

Due to the parallel transmission of several symbols, the duration of the symbol is increased leading to a reduction in the effects of ISI arising from the dispersal of multipath propagation. Moreover, OFDM essentially converts an FS channel into some sub-channels that exhibit approximately flat fading. Thus, they are all orthogonal to one another within the entire symbol duration. This technical issue can be provided with OFDM owing to the use of an IFFT on the transmitter side of a system. The size of the IFFT have been chosen carefully where; the OFDM based large IFFT size is more robust to multipath dispersion owing to an increase in the symbol period, albeit with higher susceptibility to frequency offset Therefore, balances between computational complexity and performance have to be considered.
Discrete Hartley Transform (DHT) is particularly attractive for the processing of real signals. Fourier transform always implies a complex processing and the phase carry fundamental information, while Hartley transform is a real trigonometric transform. In this research work, the proposal is made on combining DHT and Walsh-Hadamard Transform (WHT) based weighted OFDM system that can lower hardware system complexity and reduce PAPR.

1.5 Objectives of the Study

The objectives of the study are:

- To propose a new low complexity transform called combined DHT and WHT.
- To analyse the system performance of low complexity transform based OFDM.
- To design a low complexity transform based OFDM with modified weighted factor to achieve lower PAPR.
- To propose a low complexity transform based SLM-OFDM to improve better PAPR reduction performance.

1.6 Methodology of the Study

Most of the PAPR reduction schemes have been achieved considerable OFDM transmission impairments, albeit with the expense of one or more of either a data rate loss, high computational complexity or BER degradation. In this research work, a new low complexity transform is proposed on OFDM which is an alternative approach to mitigating OFDM transmission impairments.

The study is to improve the performance of OFDM system. A new low complexity transform called combined DHT and WHT into a single
orthonormal unitary transform is proposed in OFDM system to achieve significant BER performance and considerable PAPR reduction. When compared with FFT scheme, this proposed scheme could reduce computational complexity by half.

1.7 Limitation of the Study

This section addresses the main drawbacks which exist in OFDM systems, as follows:

Most of OFDM transceivers employ inverse IFFT and FFT to perform modulation and demodulation in transmitter and receiver, respectively. The FFT/IFFT becomes one of the most critical modules in OFDM transceivers. The rapidly increasing demand of OFDM based applications for wireless broadband communications makes processing speed an important major consideration in FFT architecture design. Accordingly, if we would like to design a DFT-OFDM transceiver with lower power consumption or computational complexity an efficient FFT processor design is important. Once the FFT algorithms have been chosen, the computational complexity of FFT is being decided. However, IFFT/FFT is not the only orthogonal basis for OFDM systems.

Another limitation of OFDM is the high PAPR of the transmit signal which occurs due to the summation of many subcarriers modulated signals. A high PAPR requires a wide dynamic range for the High Power Amplifier (HPA) at the transmitter, or more commonly the Power Amplifier (PA) needs to be backed off to accommodate high peaks. As a results, significant reduction of the transmission power which leads to very low power efficiency. It is, therefore, preferable to reduce the PAPR of the signal.
ODFM is sensitive to the time and frequency offsets in the transmitter and receiver. In the OFDM system, the carrier frequency mismatch between the transmitter and local receiver oscillators, and the Doppler shift, due to mobility, may destroy the orthogonality among the subcarriers leading to ICI, which degrades the performance of such a system.

Synchronization is needed all the time to maintain communication. To support orthogonality between subcarriers, time and frequency synchronization is necessary. If the system loses synchronization, the orthogonality of the subcarriers is affected, and ICI and ISI are to be increased, which in turn decrease the system throughput.

1.8 Organization of the Thesis

The thesis is organized as follows:

**Chapter 2 on Review of Literature** includes a survey on different OFDM schemes using PAPR reduction techniques, and their performance is analyzed.

**Chapter 3 on Proposed Low Complexity Transform** describes the algorithm. The proposed transform is implemented using IDHT via WHT and proved to achieve better complexity reduction than the conventional DHT.

**Chapter 4 on Proposed Transform Based OFDM System** deals with low complexity transform using IDHT via WHT. The proposed transform is applied on OFDM system and system performance is analyzed with the conventional OFDM system.

**Chapter 5 on Proposed Transform Based Weighted OFDM System** deals with proposed transform based OFDM with and without weighted function and their performance regarding CCDF and BER are analyzed.
Chapter 6 on Proposed SLM Based Weighted OFDM presents the SLM method with low computational complexity called low complexity transform based SLM has been proposed which employs the combined Inverse DHT (IDHT) via WHT at the transmitter. This method can reduce the computation complexity relatively with keeping the better PAPR reduction performance.

Chapter 7 on Conclusions and Scope for Further Study gives the overall conclusion of the research work which explains the merits of the proposed work over the existing work, and also presents the future work.