1. INTRODUCTION

1.1. INTRODUCTION

Wireless communication systems and standards have been developing rapidly with evidences of significant growth in the areas of mobile and wireless access networks and applications. The high data rate demand from the customers paved the way for developing higher generation wireless standards. The fourth generation (4G) wireless standard that outperforms the 3G and 2G families of standards is already developed. A new wireless evolution started since the first generation (1G) system which was first introduced in early 80’s, followed by the second generation (2G) system that started in 1992, and third generation (3G), which was developed in the subsequent years. First generation wireless standard was completely analog with limited data rate. The introduction of 2G systems created a huge revolution in the cellular industry where the subscribers increased drastically because of the distinguished features provided by 2G technology.

The third generation (3G) systems are designed for multimedia communication. Communication is enhanced with the transmission of both voice and data. At the same time, access to information and services on public and private networks is achieved by the higher data rates. The 4G systems aim at providing a wide variety of new services, from high quality voice to high definition video and increasing data rate. The additional features of 4G wireless systems include faster and reliable transmission, more economical than previous generations. It employs fully packet switching and makes use of internet protocol version 6 (IPV6).

Long term evolution (LTE) is a wireless standard which can provide high data rates up to 100Mbps. WiMAX-2 and LTE-Advanced (LTE-A) are the current 4G wireless standards which are designed to provide data rates of about 1Gbps. Orthogonal frequency division multiplexing (OFDM) has become a very important multicarrier scheme to support these 4G wireless standards to achieve high data rates as the interference is almost negligible in OFDM. Currently, fifth generation (5G) wireless standards also make use of OFDM to improve the spectral efficiency and to achieve high data rates.
1.2. PRESENT STATE-OF-ART

The growing demand for multimedia services and high data rates from the customers, now at present, need transmission techniques which are efficient [1]. As discussed in sec. 1.1, the use of 4G technology provides very high data rates and good quality of service to the customers. Hence the objective of the fourth generation wireless systems is to provide high data rates and a wider range of services, such as voice communications, videoconferencing, and high-speed internet access. A technical challenge in designing a wireless system is to overcome the effects of the wireless channel, which is characterized as having multiple transmission paths and as being time varying. Providing high quality of service (QOS) to users and alleviating the fading of signals require high spectral efficiency and it should be improved with proper link with high reliability.

Orthogonal frequency division multiplexing (OFDM) system is one of the prominent multicarrier modulation techniques which meet these demands. It is a strong candidate for supporting the 4G technology and an attractive technique for achieving high bit data rate in wireless communications. In addition, it can provide multipath delay tolerance and power efficiency. The ability of OFDM systems to mitigate the effects of multipath propagation along with flexible receiver made it suitable for some of the important wireless technologies like IEEE 802.11 wireless local area networks (WLANs). It also finds its application in wireless broadcasting applications such as digital audio broadcasting and terrestrial digital video broadcasting (DVB-T). The introduction and discussion about OFDM in detail is made in sec. 1.3.1.

1.3. MULTI-CARRIER TRANSMISSION

To overcome the frequency selective fading of wideband channel that is experienced by single carrier transmission, multiple carriers are used for achieving high data rates [2]. The single carrier scheme is not suited for high data rate wireless transmission as it needs a high complexity adaptive equalizer to avoid inter symbol interference (ISI) particularly in time variant channel.

Now we introduce the basic block diagram of a multicarrier transmission scheme in Fig. 1.1. The wideband signal is divided into $N$ narrowband subchannels. The frequencies of subcarriers say $f_0, f_1, ..., f_{N-1}$ are applied to the multipliers at the
transmitter and receiver sections respectively. The different input symbols $x_0(t), x_1(t), \ldots, x_{N-1}(t)$ are applied in parallel form to the corresponding encoders.

![Block diagram of a multicarrier transmission scheme](image)

At the receiver side, outputs of the channel are split and then multiplied with the frequencies of subcarriers $f_0, f_1, \ldots, f_{N-1}$ which are used at the transmitter side. After passing through a section of low pass filters and corresponding decoders, the final demodulated outputs $y_0(t), y(t), \ldots, y_{N-1}(t)$ are obtained.

However, in conventional multicarrier technique, the implementation complexity increases as it involves more encoders/decoders and higher quality filters as the number of subcarriers increases. So the concept of OFDM which is an important classification of multicarrier transmission scheme is introduced now.

### 1.3.1. Introduction to OFDM

The mobile radio channel is characterized by multipath signal reception. The signal received not only contains a direct line-of-sight (LOS) radio wave, but also a large number of reflected radio waves that reach the receiver at different instants of time. Delayed signals arrive as the result of reflections from human made structures such as buildings or from natural terrains such as hills, mountains, forests, etc. These reflected waves interfere with the direct wave and causes inter symbol interference (ISI). It results in degradation in the performance of the system. A wireless system should be designed in such a way as to minimize this interference.

The design of multimedia broadband wireless communication system requires adaptive equalizers at the receiver. The working of these equalizers requires compact
and low cost hardware which is really a challenging task because of the many practical difficulties that are encountered.

To overcome this type of multi-path fading environment with low complexity in broadband wireless communication system, OFDM is an excellent multicarrier modulation technique [3]. OFDM is a parallel data transmission scheme which avoids the use of complex equalizers.

OFDM is a multicarrier transmission scheme where in a single data stream is divided into a number of subcarriers. The special feature of OFDM is that it can be employed as a modulation technique or multiplexing technique. In a multicarrier system like OFDM, only a small percentage of subcarriers will be affected. Error correction coding can be employed to correct a few erroneous subcarriers. In a classical parallel data system, the total frequency band is divided into a number of non-overlapping sub-channels. Each sub-channel is modulated and all the divided sub-channels are frequency multiplexed. Even though it appears to prevent spectral overlap of channels to mitigate inter channel interference, it leads to inefficient use of the available spectrum [4].

To avoid this wastage of available bandwidth, multicarrier parallel data transmission with overlapping sub-channels is used to eliminate impulsive noise and multipath distortion. This technique uses the available bandwidth effectively and hence the spectrum efficiency will increase.

Figure 1.2: Concept of OFDM signal, (a) conventional multicarrier technique (b) orthogonal multicarrier technique
The difference between conventional non-overlapping and the overlapping multicarrier modulation technique is represented in Figures 1.2(a) and 1.2(b) respectively. By employing the multicarrier modulation technique, more bandwidth is saved. To realize this scheme, the crosstalk must be reduced between the subcarriers and this is possible only when the orthogonality is maintained between the different subcarriers.

Signals are orthogonal if they are independent with respect to each other. Orthogonality is the property that allows multiple information signals to be transmitted over a common channel and received without any interference. The subcarriers in OFDM are spaced closely without loss in the orthogonality. OFDM attains orthogonality in the frequency domain by allocating each information signal to a different subcarrier. The baseband frequency of each subcarrier is selected as an integer multiple of the symbol rate which results in all the subcarriers to be orthogonal to one another.

![Figure 1.3: Spectra of (a) OFDM sub-channel (b) OFDM signal](image)

The spectrum of individual data of the sub-channel is shown in Fig. 1.3(a). Fig. 1.3(b) shows the spectrum of the OFDM signal in frequency domain. Each OFDM subcarrier possesses a sinc shaped frequency response. The sinc shape has a narrow main lobe with various side lobes slowly degrading in the magnitude. Each subcarrier exhibits peak at the centre frequency and the nulls evenly spaced. The orthogonality property is followed here as the peak of each carrier corresponds to the nulls of other subcarriers. So, at the centre frequency of each subcarrier, cross talk is alleviated from other subcarriers.
1.3.2. Characterization of OFDM signals

Let a block of $N$ symbols $X = \{X_k, k = 0, 1, \ldots, N - 1\}$ be formed with each symbol modulating one of a set of subcarriers $\{f_k, k = 0, 1, \ldots, N - 1\}$ with $N$ denoting number of sub-carriers. The $N$ subcarriers are selected to be orthogonal such that the following relations are satisfied.

\[
\begin{align*}
    f_k &= k\Delta f \\
    \Delta f &= \frac{1}{NT_s}
\end{align*}
\]

Here $T_s$ is the symbol period. The transmitted OFDM signal is obtained by taking the IDFT of $X_k$ which is represented as

\[
x(n) = \frac{1}{N} \sum_{k=0}^{N-1} X_k \exp(j2\pi f_k n), \ n = 0, 1, \ldots, N - 1
\]

Figure 1.4: Block diagram of (a) OFDM transmitter (b) OFDM receiver

The block diagrams of OFDM transmitter and receiver are represented in Fig. 1.4 as specified in [52]. Now we describe the respective blocks in the transmitter and receiver sections.
Modulator: The serial data is given as input to the modulator which modulates using different digital modulation techniques like binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), and quadrature amplitude modulation (QAM). A modulation scheme is a mapping of data symbols to in-phase and quadrature constellation termed as IQ constellation. The number of bits that can be transferred corresponds to the relation given by

\[ m = \log_2 M \]  

Here \( M \) represents the number of points in the constellation or signal state space diagram. The transmission bandwidth does not depend on increase in the number of constellation points. When the number of points is increased, it enhances the spectral efficiency. However, the probability of error increases due to the increase in the number of constellation points [5]. Hence there is a trade-off between spectral efficiency and error probability. Depending on the application, an appropriate modulation scheme must be selected.

Figure 1.5: Constellation diagrams for QPSK, 16-QAM and 64-QAM schemes
The constellation diagrams for QPSK, 16-QAM and 64-QAM modulation schemes are illustrated in Fig. 1.5. For QPSK scheme, the number of constellation points are \( M=4 \). Hence QPSK scheme can be represented with \( m=2 \) bits. The number of constellation points generated for 64-QAM scheme is \( M=64 \). Hence \( m=6 \) for 64-QAM scheme. The positions of the constellation points always give the important information about the magnitude and phase of the respective points. In BPSK and QPSK, only phase information is required as the amplitude is constant and in QAM scheme, both the magnitude and phase information are required.

**Serial to parallel (S/P) converter:** The serial to parallel converter converts the incoming serial data into parallel form. This S/P block is required to generate parallel data to be transmitted. It is shown in Fig. 1.6 where the serial block of input data \([X_0,X_1,\ldots,X_{N-1}]\) is converted to parallel block.

![Serial to Parallel Converter Diagram](image)

**Inverse fast Fourier transform (IFFT):** In the transmitter portion of OFDM the OFDM symbols are constructed by mapping the input bits on the in-phase and quadrature-phase components of the digital modulation scheme employed according to the number of subcarriers in the OFDM signal. To transmit them, the signal must be represented in time domain. This is accomplished by computing IDFT of the signal using very efficient inverse fast Fourier transform (IFFT) algorithm [52]. The outputs of IFFT as shown in Fig. 1.4(a) are \( x_0,x_1,\ldots,x_{N-1} \) in parallel form. The multicarrier signal consists of linearly modulated subchannels and the right side of (1.3) corresponds to sum of samples of the digital modulation scheme.
**Addition and removal of cyclic prefix (CP):** It is the requirement of a wireless system to compensate for the effects of wireless channel. The received signal is the sum of several versions of the transmitted signal with different delay and attenuation and hence ISI occurs.

The conventional way to mitigate the ISI is to utilize time domain equalizers. But these equalizers are difficult to realize in practice because of their complexity which increases with the ISI length.

In OFDM systems, the bandwidth is divided into $N$ subcarriers which results in the symbol rate $N$ times lower than that of single carrier transmission. This lower symbol rate makes OFDM naturally immune to ISI caused by multipath signal propagation. To eliminate ISI totally, a guard time is inserted for each OFDM symbol. The guard time is chosen to be higher than the delay spread such that multipath versions of the same symbol do not interfere with the next symbol. This insertion of guard time is illustrated in Fig. 1.7.

![Figure 1.7: Addition of cyclic prefix](image)

Here $T$ denotes the OFDM symbol time and $T_g$ denotes the guard time and the total time is $T + T_g$. The next problem is the occurrence of inter carrier interference (ICI) which results from the cross talk between successive subcarriers.

![Figure 1.8: Occurrence of ICI due to crosstalk between subcarriers](image)
Figure 1.8 represents the occurrence of ICI due to the cross talk between two symbols in path 2. Path 1 shows that the waves in first and second symbol are orthogonal to each other.

The process of mitigating the ICI in multipath propagation is shown in Fig.1.9. Here the OFDM symbol is cyclically extended in the guard time.

This ensures that the delayed replicas of the OFDM symbol possess an integer number of cycles in the FFT interval as long as the guard time is larger than the delay. This results in the mitigation of ICI for the multipath signals which have lesser delays than the guard time.

**Parallel to serial (P/S) converter:** It converts the parallel incoming data into serial form. The output of P/S converter as shown in Fig.1.4(a) is $x(n)$.

**Digital to Analog converter (DAC):** It used in the transmitter portion of OFDM to convert the incoming digital OFDM signals to analog signals and the output is $x(t)$.

**RF amplifier:** The function of RF amplifier is to amplify high frequency radio frequency (RF) signals and drives the antenna. As shown in Fig. 1.4(a), its output is $s(t)$ which is transmitted through a wireless channel.

**RF Receiver:** At the OFDM receiver input as shown in Fig.1.4(a), the input to the RF receiver is the received signal $s(t)$ combined with additive white Gaussian noise. It is denoted as $r(t)$. The output of the RF receiver $\tilde{x}(t)$ is given as input to the ADC.
Analog to digital converter (ADC): It is used in the OFDM receiver section to convert the incoming analog signals to digital form for further processing. Its output is $\hat{x}(n)$ that is given to the serial to parallel converter after removing cyclic prefix. The S/P converter produces the output $\hat{x}_0, \hat{x}_1, \ldots, \hat{x}_{N-1}$ in parallel form.

Fast Fourier transform (FFT): It is employed in the receiver section to transform the OFDM symbols in time domain into frequency domain. FFT algorithms namely the decimation in time (DIT) and decimation in frequency (DIF) are used to find the DFT of a sequence at a faster rate by reducing the number of complex additions and complex multiplications. It produces the output $\hat{X}_0, \hat{X}_1, \ldots, \hat{X}_{N-1}$ in parallel form.

Demodulator: The function of demodulator in the OFDM receiver section is to demodulate and generate the original input data at the output of the receiver. The demodulator produces the output required digital output data after taking $\hat{X}_k$ as the input from parallel to serial converter.

Now, the advantages of OFDM are summarized as follows:

- OFDM is an efficient technique to minimize the multipath effects.
- Bandwidth efficiency is more as it employs overlapping subcarriers which are orthogonal in frequency domain.
- The use of IFFT and FFT algorithms in the transmitter and receiver sections respectively improves the speed of computation of IDFT and DFT making the system efficient.
- System capacity can be improved significantly by adapting the data rate per subcarrier.

1.4. INTRODUCTION TO OFDM-OQAM SYSTEM

This section introduces orthogonal frequency division multiplexing with offset quadrature amplitude modulation (OFDM-OQAM) system, its advantages and description. An OFDM system uses a rectangular window which results in high out-of-band radiation. The use of rectangular window in time domain in OFDM system in high mobility scenarios is suggested by E. Pieker in [53]. Also, the data transmission rate of OFDM system is decreased by adding the cyclic prefix. To enhance the spectral efficiency and improve the data transmission rate in digital broadcasting systems, OFDM-OQAM system has gained more importance.
Unlike OFDM-QAM, OFDM-OQAM system allows the effective utilization of pulse shaping. In addition, these systems yield high spectral efficiency as the cyclic prefix is not required. On the other hand, the inter symbol interference can be avoided without cyclic prefix in OFDM-OQAM system. Also, this system is less sensitive to carrier frequency offsets. The carrier offsets problem occurs due to the mismatch of the carrier frequency of local oscillators employed in transmitter and receiver. Moreover, the OQAM-OFDM system is able to compensate for the channel distortions and cope with residual timing offsets with suitable adaptive equalizer as suggested in [29]. Timing offsets generally occur when the transmitter and receiver do not have a common time reference.

1.4.1. Description of OFDM-OQAM system

The basic OFDM-OQAM transmitter block diagram is shown in Fig. 1.10. The serial data is given as input to the modulator which modulates and maps the symbols based on offset QAM.

![Diagram of OFDM-OQAM transmitter](image)

Figure 1.10: Basic OFDM-OQAM transmitter

The serial to parallel converter splits the serial data into parallel form to obtain real and staggered imaginary data. Next the real and imaginary frequency domain symbols are transformed into time domain by using IFFT. The time domain symbols are inputted to the filter banks having the specified impulse response. More elaborate details about the impulse response of the prototype filter are discussed in chapter 4. The outputs of these filter banks are summed up and
converted into serial form by a P/S converter. Then the digital signal is converted into analog form by digital to analog converter, passed through a power amplifier which amplifies the low power analog signals into high power signals suitable for transmitting over the wireless channel.

Figure 1.11 illustrates the block diagram of a OFDM-OQAM receiver. The transmitted signal $s(t)$ combined with additive white Gaussian noise $n(t)$ which is represented as $r(t)$ is given as input to the input to carrier recovery block. After multiplying with local oscillator, it is converted from RF to IF. The local oscillator signal must be synchronous with the transmitter carrier. It is followed by a coherent detector where the feed forward loop has a phase locked loop (PLL). The PLL forms the important block of carrier recovery unit [54]. It produces an output signal whose phase is proportional to the phase of the input signal.

The timing recovery unit is connected as a feedback circuit after the ADC [55]. The feedback path has a timing error detector which detects any delay in the received digital signal. Next, it has a numerically controlled oscillator (NCO) which generates a synchronous, discrete time discrete valued waveform.

Figure 1.11: Basic OFDM-OQAM receiver with carrier and time recovery
The output of the carrier recovery circuit is given as input to the Analog to digital converter. After getting converted to digital form by ADC, the serial to parallel converter converts the serial data to parallel form. As specified in the transmitter section, the data is passed through the filter banks and then FFT operation is performed which uses DIT or DIF algorithms to find the DFT of the incoming data at a faster rate by decreasing the number of complex operations. Then it is passed through the equalizer which compensates the effects of the channel in frequency domain and hence ISI gets eliminated. Finally, the symbols are passed through the demodulator which demodulates the incoming serial symbols and original symbols are retrieved.

1.5. PROBLEM DEFINITION

In the previous sections, we have seen many characteristics and advantages of OFDM and OFDM-OQAM systems. Despite many advantages, the performance limitations of OFDM based systems are the carrier frequency offsets and peak to average power ratio (PAPR) of the signal transmitted. Carrier frequency offsets occur due to mismatch of the local oscillator frequency used at the transmitter and the receiver. This leads to synchronization errors that destroy the orthogonality among the subcarriers and cause ISI.

Next, high PAPR is a technical challenge in OFDM that occurs due to the summing of the carriers together which in turn causes the peak power to increase.

- A larger value of PAPR enhances the complexity of analog to digital and digital to analog converters and decreases the efficiency of RF power amplifier [6].
- The high PAPR is also responsible for in-band distortion and out-of-band radiation when the signal is passed through a non-linear device like a transmitter power amplifier.
- If \( x(t) \) is the transmitted signal, the PAPR of the transmitted OFDM signal is obtained by taking the ratio of maximum power to the average power.

It is defined as

\[
PAPR = \frac{P_{\text{max}}}{P_{\text{avg}}} = \frac{\max ||x(t)||^2}{E[||x(t)||^2]} \tag{1.4}
\]
Here $P_{max}$ represents the peak power and $P_{avg}$ denotes the average power and $E[.]$ denotes the expectation operator.

- If $y(n)$ is the received signal, the PAPR of the received OFDM signal is obtained by taking the ratio of maximum power to the average power.

  It is defined as

  $$PAPR = \frac{P_{max}}{P_{avg}} = \frac{\max_{n} |y(n)|^2}{E[|y(n)|^2]}$$  \hspace{1cm} (1.5)

  Now we describe two illustrative examples of measuring PAPR in the following paragraphs.

**Illustrative example 1:**

Consider the scenario of calculation of PAPR at the transmitter and receiver in the testing of wide band CDMA (WCDMA) devices. Here both peak and average powers of the devices are calculated and their ratio is considered as PAPR. The PAPR must be carefully calculated so that it does not exceed the limits specified by the manufacturer. The operation of the power amplifier is also analyzed.

**Illustrative example 2:**

Next consider the measurement of PAPR in testing Wireless LAN devices. Here also PAPR is calculated at the transmitter and receiver and seen that the calculated values do not exceed the threshold limits. The power amplifiers are designed to work at or near the saturation region for satisfactory performance of the device.

**1.5.1. Significance of reducing PAPR**

The high PAPR requires system components which have wide linear range to compensate variations in the signal. So, a high PAPR results in OFDM to be sensitive to non-linear distortion caused by the transmitter power amplifier which decreases the performance of the system. The transfer characteristics of the transmitter power amplifier are represented in Fig. 1.12. The power amplifier has a linear region which is confined. After the linear region, the scalar relation is lost and the amplifier enters in the saturation region. For signals with large PAPR, the operating point should transfer to the left there by keeping the amplification linear. This results in reduction in average input power and this is known as input power back off (IBO) [56].

This IBO is defined mathematically as

$$IBO = 10 \log_{10}(\frac{P_{sat}}{P_{avg}})$$ \hspace{1cm} (1.6)
Here \( P_{\text{sat}} \) represents the saturated power. The fig.1.12 clearly shows both the linear region and the saturation region. The dashed line represents the ideal linear response and the solid line represents the actual response of the amplifier. Most wireless systems make use of high power amplifier (HPA) in the transmitter to achieve required transmit power. HPA is generally made to work at or near the saturation region to attain maximum efficiency of output power. The high PAPR induces non-linear distortion in the communication channels. If HPA is not made to work in the linear region with large power back-off, the out-of-band power exceeds the specified limits. Hence it is always necessary to concentrate on developing efficient algorithms to reduce PAPR in order to obtain the satisfactory performance of the system.

![Figure 1.12: Transmitter power amplifier transfer characteristics](image)

1.5.2. Non-linearity and power amplifier models

Multicarrier modulated signals like the OFDM signal are more sensitive to the non-linearity of the power amplifier. Hence precise models for the characteristics of the power amplifiers must be specified [56].

If the input to the power amplifier is given as

\[
x(t) = |x(t)|e^{j\phi(t)}
\]

(1.7)
where $|x(t)|$ and $\Phi(t)$ are the amplitude and phase of the input signal respectively, the output of the power amplifier is given by

$$y(t) = G[|x(t)|]\exp\{j[\Phi(t) + \Phi(|x(t)|)]\}$$

(1.8)

where $G[.]$ and $\Phi[.]$ represent the amplitude/amplitude and amplitude/phase conversions respectively. $G[.]$ shows the effect of non-linearity on the amplitude $|x(t)|$ and $\Phi[.]$ shows the effect of non-linearity on the phase $\Phi(t)$.

The most popular power amplifier model is the Saleh’s traveling wave tube amplifier (TWTA) model as specified in [56] that is expressed as

$$G[|x(t)|] = \frac{\alpha_a|x(t)|}{1 + \beta_a|x(t)|^2}$$

(1.9)

and

$$\Phi[|x(t)|] = \frac{\alpha_\phi|x(t)|}{1 + \beta_\phi|x(t)|^2}$$

(1.10)

where $\alpha_a$, $\beta_a$, $\alpha_\phi$ and $\beta_\phi$ are the parameters that control the characteristics of amplitude/amplitude and amplitude/phase conversions. This TWTA model incorporates increased non-linearity.

1.6. SINGLE CARRIER FDMA (SC-FDMA) SYSTEM

The complexity of an SC-FDMA system is equal to that of orthogonal frequency division multiple access (OFDMA) but it has less PAPR because it contains a single carrier. This enhances the efficiency of RF power amplifier and the output power from a mobile terminal. 3G long term evolution (LTE) is further strengthened by third generation partnership project (3GPP) and is a good wireless standard to meet the customer requirements in the coming years. These standards along with WiMAX and mobile broadband wireless access support 4G technology for achieving high mobile data rates. As SC-FDMA is a strong candidate in the 3GPP-LTE, focus is made on developing PAPR reduction algorithms in SC-FDMA system in detail in chapter 5.

1.7. RESEARCH GOAL

One of the bottlenecks in OFDM, OFDM-OQAM and SC-FDMA systems is high PAPR of the transmitted signal. It is very essential to carry out research to develop efficient techniques for decreasing PAPR in these techniques. Hence our research goal is to reduce PAPR in these systems and increase the performance of the system. On the other hand, the computational complexity of the proposed system must also be
decreased and it also requires much attention. The efficient algorithms for reducing PAPR in OFDM, OFDM-OQAM and SC-FDMA are discussed in detail in chapters 3, 4 and 5.

1.8. ORGANIZATION OF THE THESIS
The thesis report is organized as follows:

Chapter 1 provides clear and concise introduction about the importance of OFDM system in present day scenario. It also provides brief introduction about OFDM-OQAM and SC-FDMA systems. This chapter introduces the main technical challenge of high PAPR and the importance of reducing high PAPR.

The literature survey of various PAPR reduction methods developed by different authors is carried out in chapter 2. The drawbacks and shortcomings of these methods are also discussed. Then the motivation for doing the research work and objectives are explained briefly.

Chapter 3 discusses about the PAPR reduction in OFDM signals by employing optimized partial transmit sequence (O-PTS) scheme with low complexity. It is seen that the proposed O-PTS scheme performs much better than conventional PTS scheme in decreasing PAPR. To validate the simulation results, analytical expressions are derived for the proposed scheme. The expression for the total complexity for the proposed technique is also derived.

The reduction of PAPR using alternative signal (AS) algorithms is presented in chapter 4. First the OFDM-OQAM system is characterized and some useful relations are formulated. Then, we suggest three algorithms namely individual AS (AS-I), combined AS (AS-C) and modified AS with sequential optimization (MAS-S). The complexity calculations are also shown for the proposed algorithm.

Reduction in PAPR of SC-FDMA signals by employing DFT spreading techniques using Gaussian pulse shaping is discussed in chapter 5. We first introduce about the basic SC-FDMA system. Then the three DFT spreading techniques namely Localized Frequency Division Multiple Access (LFDMA), Distributed Frequency Division Multiple Access (DFDMA) and Interleaved Frequency Division Multiple Access (IFDMA) are presented. Discussion is then made about pulse shaping using raised cosine and Gaussian filters. The PAPR reduction performance of the DFT
spreading techniques using Gaussian pulse shaping is compared with that of raised cosine pulse shaping.

Chapter 6 discusses about the simulation results for the algorithms developed in chapters 3, 4 and 5. The simulation and analytical results are plotted for O-PTS technique first by considering the required simulation parameters. The simulation results are compared with that of analytical results and it is seen that the analytical results nearly match the simulation results. Then the simulation results are plotted for MAS-S algorithm developed in chapter 4 and compared with that of AS-I and AS-C algorithms. Finally, the simulation results are plotted for DFT spreading techniques using the two pulse shapings discussed in chapter 5 and their PAPR reduction performance is compared.

The summary and conclusions of the proposed works are presented in chapter 7. This chapter also quantifies the important results obtained. The PAPR reduction performances of the proposed techniques are compared with that of the conventional techniques. Also, the scope for carrying out future work is also discussed in this chapter.

In the coming chapter, the extensive literature survey of various PAPR reduction techniques proposed by different authors is carried out. Then discussion is made about the motivation and objectives for carrying out the research work.