CHAPTER 1 INTRODUCTION

The communication plays an important role in human life. A human can send information in any form such as text, image or video over long distances through a communication system. Modulation is the main argument of all communications. A few decades ago, single carrier based schemes such as Frequency-Division Multiple Accesses (FDMA) [Pietrzyk (2006)] and Time-Division Multiple Accesses (TDMA) [Bahai et al. (2004)] were very popular. Although these were easy to implement, but also provide a limitation like smaller bandwidth, low data rate and so on. Nowadays, single carrier techniques are being replaced by multi-carrier [Fazel and Kaiser (2008)] schemes.

1.1 Need of multi-carrier communication

In general, as the communication traffic [Nee and Prasad (2000)] increases, the spectrum allocation among users becomes very difficult. It implies that wider bandwidth is required to support higher data rate application. The single carrier schemes endure from high complexity equalizer [Bahai et al. (2004)] to mitigate Inter-Symbol Interference (ISI) [Cho et al. (2010)] in the fading [Sklar (2001)] channel. Meanwhile, the multi-carrier scheme does not involve the complexity of channel equalization [Hara and Prasad (2003)]. Figure 1.1 shows the block diagram of transmitter for Multi-Carrier Modulation (MCM) system.

![Figure 1.1: Transmitter of Multi-Carrier Modulation](image)

The information source provides binary information to transmit. It is then coded and fed to mapping block through Serial to Parallel (S/P) scheme. Mapping or modulation block helps to perform digital modulation. The generation of multi-carrier in time domain is done through the Inverse Discrete Fourier Transform (IDFT) [Proakis and Manolakis (2007)] as depicted in Figure 1.1. The working principle of the Fourier transform is to generate different
frequencies for each subcarrier. The concept of guard insertion [Schulze and Luders (2005)] is used to mitigate the Inter-Carrier Interference (ICI) [Zhao and Haggman (2001)]. A Low Pass Filter (LPF) is required to separate out high frequency component. High Power Amplifier (HPA) [Razavi (1998)] strengthens to the amplitude of the desired signal for transmission. At last, Up Conversion (UC) [Bahai et al. (2004)] is performed at the end of the process for converting the multi-carrier signal to a Radio Frequency (RF) [Lathi (1998)] signal. Example of MCM is spread-spectrum communication [Sklar (2000); Proakis and Salehi (2005)] and Orthogonal Frequency Division Multiplexing (OFDM) [Nee and Prasad (2000)]. The main principle of spread-spectrum is band spreading. It can be encrypted by pseudorandom [Papoulis and Pillai (2002)] code which is independent on the information source. The extraction of the original information is done by de-spreading process with the same pseudorandom code.

The year 1949, Pierce produces the spread-spectrum communication in which the idea of Code Division Multiple Access (CDMA) had developed. Nowadays, it is a well known technology in mobile communication. In general, CDMA can be classified in two broad categories, viz. Direct Sequence-CDMA (DS-CDMA) and Frequency Hopping-CDMA (FH-CDMA) [Prasad and Ojanpera (1998)]. The DS-CDMA performs information bandwidth to spread on channel bandwidth. Here, processing gain is the main parameter for band spreading and it is inversely proportional to power density. The dilemma occurs at receiver side when certain user with a high power level masks all other users. In other words, accurate power control is a main challenge in DS-CDMA. During frequency hopping, the signal bandwidth remains unchanged and therefore a particular hopping of frequencies is used in place of band spreading. Hence, on the basis of implementation complexity of a system that DS-CDMA is preferable to FH-CDMA [Fazel and Kaiser (2008)].

A new era of communication emerged when MCM combined with CDMA [Hara and Prasad (2003)]. The allocation of bandwidth can be done by applying different user-specific spreading codes. Through sharing, the symbol rate is reduced between the adjacent sub-channels and also ISI is minimized. The realization of CDMA is possible in multi-carrier through two ways viz. Multi Carrier-CDMA (MC-CDMA) [Chouly et al. (1993)] and Multi Carrier-Direct Sequence-CDMA (MC-DS-CDMA) [Hanzo et al. (2003)]. The MC-CDMA is a combination of orthogonal frequency with code division and it is also called as OFDM-CDMA [Schulze and Luders (2005)]. The MC-CDMA has easy implementation and deal
with parallel transmission of carriers. On the other hand, MC-DS-CDMA has complex nature of the receiver and performs serial communication. Both the schemes have several advantages such as spectral efficiency, high time diversity gain etc. However, there are a few concerns which affect the performance of MCM system. The MC-DS-CDMA suffered from ISI and ICI [Cho et al. (2010)] whereas MC-CDMA affected by Peak-to-Average Power Ratio (PAPR) [Bauml et al. (1996)] problem.

1.2 Orthogonal Frequency Division Multiplexing (OFDM)

The basic principle of OFDM is to divide the entire spectrum into narrowband sub channel through which parallel data are transmitted. In the year 1970, Chang developed first patent of OFDM [Chang (1970)]. The major change observed in 1971 is when DFT replaces banks of sinusoidal generators and the demodulators are suggested by Weinstein and Ebert, which significantly reduces the implementation complexity of OFDM modems [Weinstein and Ebert (1971)]. In the year 1980, Hirosaki designed subchannel-based equalizer for an orthogonally multiplexed system. Using this equalization algorithm in order to suppress both inter symbol and inter carrier interference caused by the channel impulse response or timing and frequency errors are minimized [Hirosaki (1980)]. This suppression is achieved by providing orthogonality among subcarriers. Therefore, OFDM is preferred in many communication systems.

1.2.1 Characteristics

As discussed earlier, OFDM is an evolving multi-carrier technique in the communication system. This is because of several features which attract developers to design various standard applications. The OFDM exhibits numerous advantages over the family of conventional serial modem schemes which are as follows-

- **Implementation complexity**: The complexity is significantly lower comparing to the single carrier system for a specified delay spread [Hanzo et al. (2003)].
- **Robustness against narrowband interference**: An interferer can destroy communication link in single carrier while small number of subcarrier get affected in multicarrier [Liu and Li (2005)].
- **Spectral efficiency**: The behavior of orthogonality accommodated large number of subcarrier in a very narrow spectral region thus increases the spectral efficiency [Hara and Prasad (2003)].
- **Immunity against frequency selective fading**: Each sub-carrier has narrow bandwidth in comparison to overall bandwidth of the signal. It converts a frequency selective fading channel into several nearly flat fading channels [Bahai et al. (2004)].

### 1.2.2 Applications and limitations

The transition from narrowband to broadband is one of the main reasons to advent wireless industries. In recent years multimedia related applications over wireless have motivated various standards. The need of the new standard is basically the outcome of user oriented requirements [Liu and Li (2005)]. The main objective of standard is to provide the specifications of particular system. In fact Institute of Electrical and Electronics Engineers (IEEE) develops several standards for computer and communication technology. The OFDM scheme is used in various standards such as IEEE 802.11a, IEEE 802.16, Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB) and HIPERLAN/2 etc. In present scenario, OFDM is one of the major component in Fourth Generation (4G) mobile broadband standard which is known as Third Generation Partnership Project Long Term Evolution (3GPP LTE) [Hara and Prasad (2003)].

Although the OFDM transmission over mobile communications channels can alleviate the problem of multipath propagation, but recent research efforts have focused on solving a set of inherent difficulties in OFDM system. The various drawbacks in OFDM system is described as below-

- **PAPR**: The transmitted signal of OFDM exhibits a high peak power when added in the same phase at IFFT. When these signals excite the nonlinear characteristics of the HPA, it causes out of band radiation, which further distorts the signals in adjacent bands and in band regions. This high peak power reduces the efficiency of HPA and degrades the performance of the OFDM system. To estimate the distortion which is caused by non-linearity, a well known parameter is used as PAPR [Jones et al. (1994); Bauml et al.(1996)].

- **ICI**: The result of PAPR problem will appear in the form of ICI at the receiver. It decreases the SNR and degrades the BER performance of the OFDM system [Zhao and Haggman (2001)].

- **Symbol Timing Offset (STO)**: It requires proper timing of FFT at receiver; otherwise mismatching arises to detect OFDM symbols [Morelli et al. (2007)].
Carrier Frequency Offset (CFO): The orthogonality is destroyed due to frequency offset arise between carriers. Major cause of CFO is Doppler shift (due to relative motion between transmitter and receiver) [Ronald et al. (2006)].

Adjacent Channel Interference (ACI): Since each subcarrier signal is time-limited for each symbol (i.e., not band-limited), an OFDM signal may occur out-of-band radiation, which causes non-negligible adjacent channel interference [Cho et al. (2010)].

Phase noise: The reason of phase noise is the imperfection matching between transmitter and receiver oscillators. It degrades the system performance [Garcia and Calvo (1998)].

The focus of this thesis is to propose an efficient PAPR reduction method which not only reduce PAPR but also maintain the BER performance and power spectrum. Moreover, one the motive of the proposed scheme is to avoid the need of channel side information. Generally, the combinational methods (serial or parallel structure) of the conventional schemes offer a significant reduction in PAPR but simultaneously increase the computational complexity of the system. Soft computing based scheme provides an alternative approach to reduce the computational load of the system without deteriorating the system performance.

1.3 Need of soft computing

In practice, complexity should be as minimum as possible to support real-time system operations and minimize cost. Therefore, computational complexity reduction is one of the major issues of this research proposal. Fortunately, soft computing schemes viz. Artificial Neural Network (ANN) [Rosenblatt (1958)] and Adaptive Network-Based-Fuzzy Inference System (ANFIS) [Jang (1993)] help to reduce the computational complexity of the system by offering a simple feedforward structure with few fixed parameters.

The soft computing schemes provide inexact solutions to computationally hard tasks. Deviating from the conventional hard computing, soft computing inducts the concept of imprecision and partial truth in dealing with real world problems. Undoubtedly, soft computing concepts are being widely adopted by recent research and applications including power prediction and control in mobile communications system [Haykin (2004)]. Many proposals are available in the literature [Yainashita et al. (2002); Jabrane et al. (2010); Jabrane et al. (2011); Siddiq and Tuama (2011)] to reduce PAPR with smaller computational load through soft computing approach.
1.3.1 Classification and applications

The methodologies used in soft computing are as follows-

- Artificial Neural Network (ANN),
- Fuzzy logic,
- Genetic algorithm,
- Rough set, and
- Hybrid methods.

**Artificial Neural Network:** An ANN [Rumelhart et al. (1986)] is a massively parallel distributed processor made up of simple processing units, which have a natural propensity for storing experiential knowledge and making it available for use. In the year 1943, fundamental building for neural based mathematical model initiated done [McCulloch and Pitts (1943)]. Almost, 72 years have been completed in the research of ANN. The characteristics of ANN like adaptive learning, low energy consumption, parallel processing and fault tolerance [Fauzett (2004)] provide the applications in many areas such as aerospace, health care and communication etc. In this thesis the usefulness of ANN is to reduce the computational complexity involved in proposed PAPR reduction scheme.

**Fuzzy Logic:** The theme of Fuzzy logic [Zadeh (1965)] is to process data linguistically by allowing partial set membership than a crisp set membership or non-membership functions. It is a problem-solving control methodology that lends itself to implementation. Moreover, a selection of rules forms key component of a Fuzzy Inference System (FIS) [Takagi and Sugeno (1985)]. Fuzzy logic finds applications in telecommunication area as channel estimation and equalization [Erman et al. (2009)].

**Genetic algorithm:** These are derivative-free stochastic optimization methods based loosely on the concepts of natural selection and evolutionary processes [Goldberg (1989)]. The applications of genetic algorithm found in searching the routing path of telecommunication network, resources allocation [Liu and Wang (2013)] and channel estimation in OFDM [Hanzo et al. (2003)].

**Rough set:** It is a new mathematical approach to deal with imperfect knowledge. The rough set does not need any preliminary or additional information about data like probability in statistics, grade of membership or the value of possibility in Fuzzy set theory [Casti (1989)].
Hybrid methods: Hybrid methods are the combinational approach of various soft computing schemes. Combining ANN with Fuzzy logic is known as Neuro-Fuzzy model. Various Neuro fuzzy models are available in the literature such as Adaptive Network-Based-Fuzzy Inference System (ANFIS) [Jang (1993)], Co-Active Neuro-Fuzzy Inference System (CANFIS) [Jang (1993)] and subsethood based Fuzzy Neural Network model [Mishra and Zaheeruddin (2010)]. Using a hybrid learning procedure, an input-output mapping can be constructed based on both human knowledge and stipulated data pairs. In this thesis the utility of ANFIS is to provide an alternate approach to reduce PAPR of OFDM system with less offline training time and also it offers computational complexity of the system lower than ANN based PAPR reduction scheme.

1.4 Motivation

In the modern era the requirement of internet, mobile and TV is drastically increasing because in general, human being adopted all such services as common routing life. Nowadays, many wireless services are affected by data traffic management due to a large number of subscribers. Therefore, the data management or simply data rate is the biggest challenge of today’s world. Wireless communication puts a platform for users to perform many tasks simultaneously on the same bandwidth. This can only be possible by using wireless standard such as WLAN, WiMAX etc. These technologies help users to work with high speed even better data security such as net banking transaction, online railway ticket booking, filling of forms and online shopping, etc. On the other hand, TV transmission is also improving to a new level by transforming signals from analog to digital. This can be done by DVB, which now becomes an essential technique for signal broadcasting. It serves many advantages such as number of channels, improvement in picture quality etc.

Presently, OFDM technique is the base of modern wireless and broadband communication. As discussed earlier, OFDM also suffers with a major limitation viz. high PAPR. This drawback decreases the Signal-to-Quantization Noise Ratio (SQNR) of Digital-to-Analog Convertor (DAC), thereby degrades the efficiency of the HPA in the transmitter. Various methods have been proposed in literature to overcome this problem. But the performances of these are limited by several constraints such as BER, spectral spreading, data rate loss, side information and computational complexity etc. There is always a need of efficient schemes which enhance the performance of the modern wireless communication system, one way or other.
In this thesis, the motivation of research work is to propose an efficient scheme to reduce PAPR of an OFDM system. The proposed scheme not only reduces the PAPR of the system, but also maintains the BER performance and spectral spreading. The data rate loss and channel side information should be minimized. Moreover, the computational complexity of the system should be kept as low as possible using soft computing scheme. The performance of the proposed schemes must be analyzed and compared with an existing conventional scheme based on different parameters.

1.5 Objective

The thesis has the following objectives:

- To develop an efficient PAPR reduction scheme for OFDM system using serial and parallel combination of two popular conventional methods viz. Approximate Gradient Project (AGP) and Partial Transmit Sequence (PTS).
- To propose a PAPR reduction scheme which should maintains the data rate (no side information) through combination of AGP and Null sub Carrier Switching (NCS) methods.
- To design an Artificial Neural Network (ANN) based PAPR reduction method to combat the high computational complexity involved in conventional methods through supervised learning algorithm.
- To intend an efficient PAPR reduction technique with fast convergence based on Adaptive Network-Based-Fuzzy Inference System (ANFIS) in soft computing frame.