CHAPTER 1

INTRODUCTION

1.1 MOTIVATION

Wireless communications, which has been growing enormously in the recent years, is an emerging field. This rapid expansion of wireless services has fueled the evolution of wireless communication systems from the first-generation to fourth-generation systems. It also supports multidimensional high-speed wireless communications, which leads to an increase in demand for high capacity wireless networks in many applications, such as wireless local area networks (WLANs), and worldwide interoperability for microwave access (WiMax). Moreover, the demand for high-speed mobile wireless communications is also rapidly growing.

Orthogonal Frequency Division Multiplexing (OFDM) technology is a key technique for achieving high data capacity and spectral efficiency requirements in the present, as well as in the future broadband wireless communication systems. OFDM is capable of combating inter symbol interference (ISI) by translating broadband frequency selective channel into a number of parallel narrow band channels. Also, OFDM is used in numerous wireless transmission standards such as Digital Audio/Video Broadcasting (DAB/DVB), WiMAX and WLAN. WLAN standards such as, IEEE 802.11a provides data rate of 2Mbps whereas, the OFDM based WLAN standards such as IEEE 802.11 b/g provides data rate of 54 Mbps. However, future wireless communication systems will require WLANs with data rates of greater than 100 Mbps.
As for as cellular mobile applications are concerned, 2G (second generation) Mobile phones provide very low data rates ranging from 9.6 kbps up to 14.4 kbps and the cost is high. Due to this low data rate, 2G mobile phones are unable to provide the useful services like internet access, computing, and multimedia communications. Hence, the objective of formulating 3G (third generation) and 4G (fourth generation) mobile network is to provide high data rate to support services such as video communication and high speed internet access. To achieve this, OFDM plays a vital role in designing the physical layer of fourth generation mobile systems. A single Moving Picture Experts Group (MPEG-2) encoded video stream of good quality, needs 6 Mbps to 8 Mbps while, an MPEG-2 High-Definition Television (HDTV) stream needs 20 Mbps of continuous transfer rate. Hence, there is a need to improve the spectral efficiency and data capacity of OFDM systems in WLAN applications and mobile networks. This forms the foundation to focus on OFDM systems.

Multiple Input Multiple Output (MIMO) systems transmit multiple data streams in parallel from different antennas which results in a linear increase in system capacity. MIMO systems do not increase bandwidth in order to increase system capacity. They simply exploit the spatial dimension by increasing the number of unique spatial paths between the transmitter and receiver. Since MIMO systems provide spatial diversity, the Bit Error Rate (BER) performance is high and thus achieves good quality of service (QoS). The combination of OFDM with MIMO is considered to be one of most promising techniques for future wireless communication systems (Jian Xu et al 2006, Hassen Karaa et al 2007). Therefore, MIMO-OFDM combines OFDM and MIMO technique is capable of achieving spectral efficiency and increased capacity. This technique is proposed to be used in newer WLAN standard IEEE 802.11n. On the other hand, multiuser MIMO-OFDM systems allow different users to transmit through the same subchannel, which
introduces multi access interference (MAI). Further analysis is required to improve the system performance of multiuser MIMO-OFDM systems.

1.2 OFDM SYSTEM – A SURVEY

The basic idea of OFDM is to divide the available spectrum into several subchannels so that, the information symbols are transmitted in parallel on the subchannels over the wireless channel. This allow to design a system supporting high data rates while maintaining symbol durations much longer than the channel’s delay spread. By doing so, each subchannel experiences almost a flat fading, and the effects of the multipath channels are reduced.

OFDM overcomes most of the problems with both Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA). Since the subcarriers are orthogonal, they are arranged very close to each other and also no need for the users to be time multiplexed as in TDMA. Thus there is no overhead required at the receiver’s side. Whereas in TDMA there is an overhead associated with the change over between users due to time slotting on the channel. The orthogonality of the carriers means that, each carrier has an integer number of cycles over a symbol period. Due to this, the spectrum of each carrier has a null at the center frequency of each of the other carriers in the system. As a result there is no interference between the carriers, allowing them to be spaced as close as theoretically possible. This overcomes the problem of overhead carrier spacing required in FDMA.

Each carrier in an OFDM signal has a very narrow bandwidth, in other terms, it has very low symbol rate, leading to a high symbol period. Hence, the delay spread must be very long to cause significant ISI. And so,
OFDM signal has very high tolerance to multipath delay spread. OFDM requires very accurate frequency synchronization between the receiver and the transmitter to maintain the orthogonality among the subcarriers. Carrier frequency offsets (CFO) are typically caused by mismatched transmitter and receiver oscillators or by Doppler shift due to movement. The small deviations in carrier frequency and CFO lead to Inter Carrier Interference (ICI) in OFDM systems.

1.2.1 OFDM Modulator and Demodulator

A schematic diagram of an OFDM system is shown in Figure 1.1. Firstly the transmitter converts the input data from a serial stream to parallel sets. Based on the constellation size, these parallel data are further mapped into corresponding symbols using signal mapper. And then an inverse Fourier transform converts the frequency domain symbols into samples of the corresponding time domain representation of these symbols. Since inverse fast Fourier transform (IFFT) generates samples of a waveform with frequency components satisfying orthogonality conditions, it is used as an OFDM modulator. Next the time domain signals are transmitted through the channel. The receiver receives the time domain signal and performs fast Fourier transform (FFT) operation to obtain the corresponding frequency domain components. The magnitudes of these frequency components correspond to the original data. Finally, the parallel to serial block converts this parallel data into a serial stream to recover the original input data.
1.2.2 Advantages of OFDM System

- Achieves high spectral efficiency by efficiently using the spectrum (allowing spectrum overlap).

- By dividing the channel into narrowband flat fading subchannels, OFDM is more resistant to frequency selective fading and ISI than single carrier systems.

- Channel equalization becomes simpler.

- It is possible to use maximum likelihood decoding with reasonable complexity.

- It is computationally efficient by using IFFT and FFT techniques to implement the modulation and demodulation functions respectively.

- Less sensitive to sample timing offsets than single carrier systems.
1.2.3 Disadvantages of OFDM System

- OFDM signal exhibits a high Peak-to-Average Power Ratio (PAPR), since the OFDM signal is the superposition of a large number of modulated subcarrier signals.
- It is more sensitive to CFO and carrier frequency drift than single carrier systems.

1.3 LITERATURE SURVEY AND PROBLEM STATEMENTS

In this thesis, various techniques like PAPR reduction, CFO estimation and correction, adaptive modulation, Adaptive Resource Allocation (ARA) and MAI cancellation have been studied extensively and their performances have been analyzed.

1.3.1 PAPR Reduction Techniques for OFDM Systems

The OFDM technique transforms a frequency-selective fading channel into a large number of flat-fading subchannels (subcarriers) which leads to easy subchannel equalization, less ISI, high data rate and easy symbol decoding. Due to the large number of subcarriers, OFDM systems have a large dynamic signal range with a very high PAPR. Also, it is very sensitive to nonlinear effects due to high PAPR.

Ochiai and Imai (2002) performed the digital clipping on the OFDM signals sampled at the Nyquist rate. In this technique, PAPR reduction is not significant enough and provides out of band radiation. Hence, to achieve the additional PAPR reduction, he combined selected mapping and clipping technique as a new technique. The PAPR reduction capability will be considerably enhanced if the oversampled OFDM signal is digitally clipped and filtered. In practice, digital clipping has three problems they are:
1) In-band distortion - which causes significant performance penalty.

2) Out-of-band radiation, which reduces the spectral efficiency.

3) Peak re-growth after D/A conversion.

Wang et al (2003) proposed an A-law companding technique to reduce PAPR with low complexity. In this method, the PAPR of OFDM signals is reduced by increasing the average power of signals while keeping the peak unchanged, but this reduction in PAPR may be very limited under certain BER performance constraints.

Huang et al (2004) investigated the performance of four typical companding schemes, namely, linear symmetric transforms, linear non-symmetric transforms, non-linear symmetric transforms and non-linear non-symmetric transforms. These methods alleviate the aforementioned problems in digital clipping. Specifically, compared with the clipping-filtering method, linear non-symmetric transforms may improve SNR significantly. The four companding schemes mentioned above outperform the A law and μ law companding techniques. The PAPR reduction may be achieved by proper selection of the companding parameters. Though these techniques provide significant PAPR reduction, it fails to achieve the good BER performance.

Jiang et al (2004, 2005) proposed a new nonlinear companding technique, called “exponential companding” to reduce the PAPR of OFDM signals. It can effectively transform the original OFDM signals into uniform-distributed signals without changing the average power level. Unlike the A-law companding scheme, which mainly focuses on enlarging small signals, exponential companding schemes adjust both small and large signals without bias so that it is able to offer better performance in terms of PAPR reduction.
Tao Jiang et al (2007) proposed a PAPR reduction technique based on the non linear companding scheme. Nonlinear companding schemes transform the amplitude or power of the original Multi Carrier Modulation (MCM) signals into uniform distribution, which can reduce the PAPR. This technique can effectively reduce PAPR for different modulation formats and subcarrier sizes without any increase in complexity and bandwidth expansion. These schemes also have the advantage of maintaining a constant average power level in the nonlinear companding operation. But a non linear companding scheme fails to maintain a good BER performance.

Slimane Ben (2007) proposed a PAPR reduction technique for the OFDM systems based on signal precoding technique. In this signal precoding technique, each data block is multiplied by a precoding matrix prior to OFDM modulation and transmission. This precoding matrix is designed such that the PAPR of the OFDM signal is as low as possible adding extra subcarriers. The PAPR reduction is done in the frequency domain. This method is data independent and thus avoids the block based optimization. It also works with an arbitrary number of subcarriers. Since the precoding matrix is orthogonal, it can maximize the BER performance than the aforementioned techniques.

In this precoding technique, extra subcarriers are required to design a precoding matrix. Hence this technique needs extra overhead to reduce PAPR. The PAPR reduction depends upon the number of extra subcarriers added to the original subcarriers. The PAPR performance of this technique gets degraded for the higher data rate modulation schemes. To alleviate this problem, extra overhead needs to be increased. This leads to a reduction in spectral efficiency. Therefore a new PAPR reduction technique to achieve both good PAPR reduction and BER performance is required for the OFDM systems.
1.3.2 Adaptive Modulation with CFO

The OFDM systems can suffer from CFO (Leke and Cioffi 1998). Carrier Frequency error in the transmission due to synchronization errors and Doppler shift result in a loss of orthogonality between the subcarriers. There are two deleterious effects caused by CFO, one is degradation of SNR and the second is introducing ICI (Ma et al 2003). Beek et al (1997) analyzes the effects of CFO for the OFDM systems. The effect of SNR due to CFO has been analyzed in Jungwon Lee et al (2006). Due to this SNR degradation the performance of BER is poor. Also the orthogonality among OFDM subcarriers are destroyed and eventually leads to ICI among subcarriers. CFO of only 1 - 2% of the subcarriers spacing results in the effective SNR which is limited to 20 dB.

Adaptive modulation technique can be employed to mitigate the deep fading effect, if the channel state information (CSI) is available at the transmitter (Keller and Hanzo 2000, Chung and Goldsmith 2001, Yue Rong et al 2006). Conventionally CSI is estimated from average SNR. The performance of adaptive modulation technique depends on the accurate estimation of CSI. But in practice the CFO will make the estimated CSI to deviate from the actual CSI. This imperfect estimated CSI will reduce the spectral efficiency greatly. Hence an accurate estimation technique and correction techniques are required in adaptive modulation OFDM systems.

1.3.3 ARA Algorithms for OFDM Systems

An ARA algorithm with proportional rate constraints has been proposed by Shen et al (2005). In this algorithm the subchannel and power assignment are handled separately using root-finding method. The subchannel allocation and power allocation is performed separately in this algorithm. Hence the number of variables in the objective function is almost reduced by
half. Furthermore, the base station has to rapidly assign the optimal subchannel and power as the wireless channel changes. Hence low-complexity suboptimal algorithms are preferred for cost-effective and delay-sensitive implementations. This strictly maintains proportional rate among users to achieve high QoS. It provides less system capacity since some subchannels are unused.

Computationally efficient loading algorithm for OFDM systems in a time varying wireless channel has been proposed by Jiho Jang et al (2003). It is aimed at the maximization of data rate under the constraint of total transmit power and target BER. The algorithm which is based on the water-filling approach is known as an optimal solution to maximize data rate under the constraint of total transmit power. In this algorithm, the water-filling power allocation is not fully performed. Instead, by adjusting only the water-filling level needed in the water-filling power allocation, transmit power and number of bits for each subchannel is adapted with low computational complexity. The total number of loaded bits in an OFDM symbol can be maximized.

Wong et al (2004) algorithm is almost similar to Shen et al (2003) algorithm with minor difference such as efficient use of unallocated subchannels and employing low complexity power allocation algorithm. While the root-finding method addresses the problem of proportional ARA in a multiple-user environment, the nonlinear equation available in Shen et al (2003) algorithm takes a lot of computations. This bottleneck is eliminated by removing the exponent, thus the equation becomes linear and much easier to solve. The linear method proposed by Wong et al (2004) does this by relaxing the adherence to the proportionality constants. This algorithm maximizes the sum capacity by efficiently utilizing the unused sub channels, but it fails to maintain the proportional rate among users and thus results in poor QoS.
Mohmmad Anas et al (2004) separated the total users into two types. Both users are differentiated on the basis of required data rate and BER criteria and referred as Guaranteed Performance (GP) user and Best Effort (BE) user. Applications that require guaranteed QoS, such as bounded BER, and a guarantee on the throughput, are called GP services. On the other hand, applications which are less sensitive to instantaneous variations in available bandwidth and do not require guarantees on the throughput, are called BE services. Due to equal power distribution for the BE users, this algorithm provides lower system capacity. Hence there is a need for a new ARA algorithm for multiuser OFDM systems.

1.3.4 ARA Algorithms for MIMO-OFDM Systems

The use of multiple antennas to communicate with many users simultaneously is especially charming in WLAN environments such as IEEE 802.11 n. MIMO technology constitutes a breakthrough in wireless communication system design. It offers a number of benefits that help meet the challenges posed by both the impairments in the wireless channel, as well as resource constraints. In addition to the time and frequency dimension that are exploited in conventional SISO (Single-Input Single-Output) wireless system, the spatial dimension is also exploited. Also Guoliang Shen (2004) presents that MIMO-OFDM provides spatial diversity, combat multipath environment, increases link reliability and reduces receiver complexity in wireless multiuser broadband systems. So MIMO-OFDM is the competitive choice for future broadband wireless communication systems.

Jian Xu et al (2006) have dealt with the problem of ARA in multiuser MIMO-OFDM systems under various constraints. In this algorithm, MIMO channel matrix is converted into SISO channel matrix using Frobenious norm criteria. Due to equal power and subchannel distribution,
this algorithm provides less system capacity. Hence there is a need for improved resource allocation algorithm for multiuser MIMO-OFDM.

1.3.5 Precoding with ARA Algorithms for MIMO-OFDM Systems

The primary objective of the coding technique is to maximize the system capacity with zero multiuser interference for the downlink multiuser OFDM systems. This coding technique is mainly used where a base station with multiple antennas, communicate simultaneously with many users. Dirty-paper coding technique (DPC) is the first described coding technique for the Gaussian interference channel by Costa (1983). The key idea of DPC is to pre-cancel the interference at the transmitter using perfect CSI and complete knowledge of the transmitted signals. Costa identified the interference as dirt and his signal as ink; his idea is not to oppose the dirt, but to use a code that aligns itself as much as possible with the dirt. It has been shown that the sum capacity is also maximized using DPC (Caire et al 2003). But it is difficult to implement in practice. Consequently, several practical near-DPC techniques (Hassen Karaa et al 2007, Samardzija and Mandayam 2003, Peel et al 2005) based on the concept of precoding have been proposed to maximize the system capacity. These techniques offer tradeoffs between complexity and performance.

Both optimal and suboptimal ARAsuch as subchannel allocation, power allocation, bit loading and adaptive modulation techniques for MIMO-OFDM systems have been discussed (Cheong Yui Wong and Roger 1999, Suodong Zhang 2004, Zhenping Hu et al 2004 and Peeraponpong Uthansakul 2006). But in all these papers, the sharing of a subchannel by more than one user haven’t been considered i.e. MAI is not into consideration. In Chengkang Pan et al (2005), a different resource allocation method is considered, but for the removal of MAI, DPC technique is used.
An alternative to implementing DPC is Block Diagonalization (BD) (Spencer et al 2004), which supports multiple stream transmission as well. The basic concept of BD consists of using special transmit vectors that ensure zero interference between users. The resulting multiuser MIMO channel matrix has a block diagonal form so that each user can apply a standard point-to-point MIMO receiver. Moreover, if adaptive transmission is jointly optimized for all users in a multiuser environment, power and spectral efficiency can be significantly enhanced due to the multiuser diversity which provides another degree of freedom (Zhang and Letaief 2005).

In Shiping Duan et al (2003) and Seijoon et al (2006), BD with water-filling power allocation method has been used to increase the system capacity. However, it lacks in BER performance and frequency diversity is not considered. So BD with Water-filling power allocation algorithm provides less system capacity with zero MAI. Hence new algorithms are required for resource allocation and MAI cancellation.

1.4 OBJECTIVES OF THE THESIS

The primary objectives of this thesis are

- To device a new PAPR reduction technique to achieve a better PAPR reduction and acceptable BER performance of the OFDM systems.
- To develop an adaptive modulation technique with CFO correction algorithm to maximize the spectral efficiency of the OFDM systems
- To device a new ARA algorithm for the multiuser SISO-OFDM and multiuser MIMO-OFDM systems
  - To maximize the system capacity in terms of minimum user capacity and sum capacity.
• To achieve fairness among the users.
• To achieve good BER performance.

➢ To develop a new ARA algorithm to improve the system capacity of multiuser MIMO-OFDM systems with zero MAI.

1.5 PROPOSED METHODOLOGIES

In this thesis, five different techniques have been proposed to improve the system performances of the OFDM systems, which are given below

• A novel efficient PAPR reduction technique has been proposed with low complexity to achieve the good PAPR reduction and acceptable BER performance.

• Adaptive modulation with CFO correction for OFDM systems has been proposed to maximize the spectral efficiency.

• A Novel ARA algorithm for multiuser OFDM has been proposed to maximize system capacity and to achieve good QoS. This proposed algorithm jointly achieves guaranteed performance to GP users with good QoS and also maximizes the sum capacity for BE users.

• An efficient ARA algorithm for multiuser MIMO-OFDM systems has been proposed to improve the system capacity.

• A novel BD with ARA for multi user MIMO-OFDM systems has been proposed to maximize the system capacity with zero MAI.
1.5.1 Proposed PAPR Reduction Technique

To achieve both the PAPR reduction and acceptable BER, a novel efficient PAPR reduction technique has been proposed in this thesis. In this proposed technique, a better reduction in PAPR is achieved by combining precoding technique with non linear companding transform technique. The PAPR reduction is done in both time (companding) and frequency (precoding) domain. Since the precoding matrix is orthogonal, it can maximize the BER performance better than the companding transform techniques. Also the side information is not required in this proposed technique. Hence the complexity is considerably reduced. This proposed technique provides significant PAPR reduction with low overhead of 10%. Simulation results show that the PAPR reduction of the proposed technique is better than the precoding and companding techniques. Also it provides better BER performance than the existing techniques.

1.5.2 Proposed Adaptive Modulation with CFO Correction Technique

Adaptive modulation with CFO correction algorithm has been proposed to maximize the spectral efficiency of the OFDM system. In this proposed algorithm, the CFO is estimated and corrected before the CSI estimation. CFO is estimated using the ML estimator and the direct correction method has been employed to cancel the estimated CFO. This algorithm selects the modulation technique (constellation size M) adaptively based on the new CSI. Hence this proposed algorithm provides better spectral efficiency than the fixed modulation techniques and conventional adaptive modulation techniques available in literature.
1.5.3 Proposed ARA Algorithm for SISO-OFDM System

An efficient ARA algorithm for multiuser OFDM has been proposed to maximize system capacity and to achieve good QoS. In this proposed algorithm, two types of users: Guaranteed Performance (GP) and Best Effort (BE) users are considered. Both users are differentiated on the basis of required data rate and BER criteria. For subchannel assignment, the suboptimal subchannel allocation algorithm proposed by Shen et al (2005) is modified to provide services to GP users. The suboptimal subchannel allocation algorithm proposed by Wong et al (2004) is modified to provide services to BE users. To achieve good QoS, GP users are given priority in assigning subchannels to that of BE users. While assigning subchannel it is assumed that total available power at BS is equally distributed among the subchannels. Adaptive bit loading algorithms proposed by Jiho Jang et al (2003) is modified for power allocation which is the low complexity power allocation algorithm. GP users are considered first to allocate power so as to satisfy their data rate requirements and then allocate the rest of the power among the subchannels of BE users using the adaptive bit loading algorithm. This proposed resource allocation algorithm jointly achieves guaranteed performance to GP users with good QoS and also maximizes the sum capacity for BE users. It also provides better minimum user capacity and sum capacity compared to the existing algorithms.

1.5.4 Proposed ARA Algorithm for MIMO-OFDM System

In this thesis, the algorithm proposed by Shen et al (2003) is modified for MIMO environment. This algorithm maintains proportional rates among users. Since this method maintains strict proportionality there are some unallocated subchannels which decrease the sum capacity. The algorithm proposed by Wong et al (2004) is also modified suitably for MIMO environment. Even though this approach utilizes the unallocated subchannels
efficiently it fails to maintain the proportionality among the users. This may affect the users who require strict QoS. The algorithm proposed by Mohammad Anas et al. (2004) for SISO OFDM system is modified to MIMO-OFDM system using Frobenious norm criteria. Since the equal power allocation is performed for BE users, this algorithm provides less sum capacity. Hence the proposed algorithm for SISO OFDM system has been modified suitably for the multiuser MIMO-OFDM systems. The performance of this proposed algorithm is analyzed with existing resource allocation algorithm for multiuser MIMO-OFDM systems. This algorithm provides better minimum user and sum capacity than the existing and modified algorithms. Since this method utilizes the low complexity power allocation algorithm, it provides less complexity than the existing algorithms.

1.5.5 **Proposed BD with ARA Algorithm**

Two algorithms have been proposed in this thesis to increase the system capacity and BER performance with zero MAI. BD with optimal power and subcarrier allocation is performed with the constraint of total power to maximize the minimum user capacity and sum capacity. BD with adaptive bit loading and power allocation has been done to achieve the target BER with the constraint of data rate and BER performance. These proposed algorithms provide better system capacity and BER performance than the existing algorithms.

1.6 **ORGANIZATION OF THE THESIS**

The thesis is organized as follows: chapter 2 highlights the existing PAPR reduction techniques for OFDM systems and analyses the performances of new proposed PAPR reduction technique. The performances of adaptive modulation techniques for OFDM systems with CFO have been analyzed and discussed in chapter 3. A literature review of different resource
allocation algorithms and a proposed novel ARA algorithm for multiuser SISO-OFDM systems are provided in chapter 4. In chapter 5, the performance of proposed ARA algorithm for multi user MIMO-OFDM systems has been discussed and their results have been analyzed with existing resource allocation algorithms. In Chapter 6, various coding techniques to maximize the system capacity with zero MAI for multiuser MIMO-OFDM systems and proposed BD with ARA algorithms are analyzed. Conclusion, suggestions for improvement and possible extension of this thesis are discussed in chapter 7.