Chapter-1

Introduction

1.1 Next Generation Wireless Communications

In recent years, broadband wireless data networks are driving the development of telecommunication industry. Beyond 3G (B3G) wireless systems e.g. 3GPP Long Term Evolution (LTE), LTE advanced, IEEE 802.16m etc. are expected to provide a variety of multimedia services in a wide range of wireless and mobile environments. To use the scarce bandwidth resource of the wireless channel, it is necessary to design channel access control techniques for a large population of users (potentially hundreds of mobile stations). To meet the strong demand for broadband multimedia services by both nomadic and mobile users, it is important to increase the bit rate of future mobile communication systems. To enhance the system capacity, novel technologies or new concepts for improving system capacity are indispensable. In this thesis, we propose some multiple access schemes using Orthogonal Frequency Division Multiplexing (OFDM), which can improve the throughput performance of the system for the 4^{th} generation (4G) wireless communications.

The arrival of the IEEE standard 802.16 Wireless Metropolitan Area Network (WMAN) marks the start of the era where broadband wireless access (BWA) is coming onto stage. It brings great challenges to today's wired broadband with great merits, such as low cost for installation and maintenance. This standard also makes long-range wireless network communication (up to 40 km) a reality and might provide an alternative or complement to 3G. All these promising features of 802.16 standards lead to a great market in the future.

Broadband wireless can be described as a continuum of co-existing and overlapping technologies that enable high-speed wireless communications e.g. Wi-Fi, WiMAX, 3G and Ultra-Wideband (UWB) technologies. These are necessary to form the global wireless infrastructure needed to deliver high-speed communications and Internet access worldwide. WiMAX works best for computing platforms, such as laptops, while 3G is best for mobile devices like PDAs and cell phones. UWB offers very short range connectivity, perfect for the

home entertainment environment or wireless USB. In short, each technology is important for different reasons.

The next generation wireless system will provide convergence of multimedia services such as speech, audio, video, image and data. This implies that a future wireless terminal will be able to connect to different networks in order to support various services by guaranteeing high speed data. The rapid increase in the number of wireless mobile terminal subscribers and users of wireless local area networks (WLAN) and wireless local loops (WLL) highlights the importance of wireless communications. The wireless communication systems of the future are likely to require considerably higher data rates and reliability than today. As high data rate services such as video transmission and other data services become popular, the demands on the networks providing these services will increase. It is therefore very important to find a suitable transmission technique with high spectral efficiency and robustness to various distortions. The design of wireless systems has focused on increasing the reliability of the air interface as well as increasing the spectral efficiency. The advantages of multi-carrier modulation on one hand and the flexibility offered by the spread spectrum technique on the other hand have motivated us to investigate the combination of both techniques called Multi-Carrier Code Division Multiple Access (MC-CDMA) and Multi-Carrier Direct Sequence Code Division Multiple Access (MC-DS-CDMA).

1.2 Role of OFDM in Wireless Communications

OFDM is a special case of multicarrier modulation where a high-rate data stream is divided into several low-rate sub-streams. These sub-streams are modulated on different sub-carriers [Nee'00]. By using a large number of sub-carriers, a high immunity against multipath dispersion can be provided since the useful symbol duration T_s on each sub-stream will be much larger than the channel time dispersion. Hence the OFDM offers multiple access and signal processing benefits that have not been available in previous modulation methods, and allows wireless networks to pack high spectral efficiency into relatively small spectrum bandwidths.

The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions — for example, attenuation of high frequencies in a long copper wire, narrowband interference and frequency-selective fading due to multipath without complex equalization filters. Channel equalization is simplified because OFDM may

be viewed as using many slowly-modulated narrowband signals rather than one rapidly-modulated wideband signal. The low symbol rate makes the use of a guard interval between symbols affordable, making it possible to handle time-spreading and eliminate intersymbol interference (ISI). This mechanism also facilitates the design of single frequency networks, where several adjacent transmitters send the same signal simultaneously at the same frequency, as the signals from multiple distant transmitters may be combined constructively, rather than interfering as would typically occur in a traditional single-carrier system.

OFDM is a bandwidth efficient scheme, reduces the affects of intersymbol interference (ISI) and can be implemented efficiently by fast Fourier transform (FFT) algorithms. However, by using cyclic prefix, redundancy is introduced which reduces the spectral efficiency. It is also sensitive to frequency and time synchronization errors. Another disadvantage of OFDM is its high peak-average power ratio (PAPR). Multiple symbol encapsulated OFDM (MSE-OFDM) provides a flexible way of OFDM system design such that two major disadvantages of OFDM system i.e., sensitivity to frequency offset and high peak-to-average power ratio (PAPR), can be handled at the same time. MSE-OFDM scheme can be used to either improve the bandwidth efficiency for static channels or to improve the robustness to synchronization errors and the PAPR reduction for mobile channels.

1.3 Motivation for the Thesis Work

One of the main issues involved in the development of broadband wireless communication systems is the choice of multiple access technology to efficiently share the available scarce bandwidth among a large number of users. Spectral efficiency is of primary concern in the design of future wireless communications systems. Since the resources (such as time, frequency and code) in the wireless networks are limited, it is critical for wireless network designers to utilize these resources efficiently and effectively. The future demands on high data rate and mobility require the design of new air interfaces for next generation of mobile radio systems, which require high spectral and system efficiency, flexibility in data rates and robustness. The multiple access schemes proposed in the literature have addressed some of these issues, but not all. This motivated us to explore new hybrid multiple access schemes.

It is expected that no single existing multiple access technique would be able to satisfy the severe transmission criteria in 4G systems, and properly designed hybrid multiple access schemes for different environments would solve the problem of fair and efficient spectrum allocation in multi-user environments. Multicarrier approach offers several advantages including robustness in fading and interference, frequency diversity and non-contiguous bandwidth operation. Due to these advantages, multicarrier techniques have been proposed for the next generation wireless systems. Therefore, we decided to explore some OFDM based multiple access schemes in this thesis.

Multi-carrier modulation and multi-carrier spread spectrum are today considered potential candidates to fulfill the requirements of next generation high speed wireless multimedia communications systems because of their spectral efficiency and flexibility. OFDM has been widely deployed in digital audio broadcasting (DAB), digital video broadcasting (DVB), wireless local area networks (WLAN), wireless metropolitan area networks (WMAN) and is considered a potential candidate for the 4G mobile communications. The MC-CDMA and MC-DS-CDMA schemes reduce MAI due to an FDMA scheme at subcarrier level and also exploit the diversity gain offered by spread spectrum technique. Hence they give better performance than OFDM or CDMA schemes in frequency selective channels.

MSE-OFDM is a bandwidth efficient OFDM, which improves the bandwidth efficiency, provides more robustness to carrier frequency offset and lower peak-to-average power ratio (PAPR) for mobile channels. The advantages of MSE-OFDM motivated us to explore multiple access schemes using this bandwidth efficient scheme.

1.4 Objectives of the Thesis Work

The objective of this thesis is to study OFDM based multiple access schemes for 4G wireless communication. The research work deals with following aspects related to the topic.

- Study of the existing multiple access schemes.
- Proposing a new multiple access scheme using variable time slots, spreading factors and number of subcarriers for LTE and other applications. The aim has been to explore and assess a new multiple access technique for broadband wireless access. The system parameters e.g. spreading factor, number of time slots, number of subcarriers etc. are optimized to get a suitable application for 4G communication.
- Study of MSE-OFDM, a bandwidth efficient OFDM scheme and its analysis in presence of frequency and timing errors.
- Application of MSE-OFDM for multiple access. New multiple access schemes using MSE-OFDM have been proposed. Analysis of MAI in the proposed schemes due to multiple users has also been reported.

1.5 Contributions Made in This Thesis

The overall contributions of the thesis are summarized below:

I. A hybrid multiple access scheme TD-MC-CDMA is proposed for both downlink and uplink using TDMA, CDMA and OFDMA for 4G applications, which can support users with multiple data rates. This scheme gives better performance than OFDMA and is found to accommodate more number of users in a given bandwidth.

II. Performance analysis of MSE-OFDM, a bandwidth efficient OFDM scheme in presence of synchronization errors. Analytical results are obtained and extensive simulations are carried out. The experimental results are found to match analytical expressions closely.

III. New multiple access schemes have been proposed using MSE-OFDM. Their BER performances have been analyzed and studied in simulated environment and found to be better than the conventional OFDMA.

1.6 Overall Thesis Organization

The thesis has six chapters: the introductory chapter, the review chapter, three contributory chapters and last chapter is the concluding chapter. In Chapter-2, we present an in-depth review of the multiple access schemes used currently for different standards. We also compare the different schemes and describe the requirements of next generation wireless networks.

Chapter-3 presents a new multiple access technique TD-MC-CDMA, which can be used for future wireless communication systems e.g. LTE advanced and IEEE802.16m. This is a combination of the existing techniques TDMA, CDMA and OFDMA and uses variable time slots, spreading factors and number of subcarriers to support different data rates for different classes of users. This scheme can be used for integrating the existing technologies, can provide better performance, better spectral efficiency, bandwidth scalability and can support different types of services e.g. audio, video, internet, ISDN, multimedia etc.

In Chapter-4, we study and analyze a Multi-Symbol Encapsulated Orthogonal Frequency Division Multiplexing (MSE-OFDM) scheme. MSE-OFDM is a bandwidth efficient OFDM scheme, where a number of OFDM symbols are grouped together as a frame and protected by one single cyclic prefix. There are two different implementations of the MSE-OFDM scheme, the CP-reduced MSE-OFDM, which is designed to improve the bandwidth efficiency for static channels and FFT-sized reduced MSE-OFDM, which improves the PAPR and robustness to frequency offset for mobile channels. The effects of interchannel interference (ICI) and intersymbol interference (ISI) on the performance of MSE-OFDM systems are analyzed. Expressions for probability of error for MSE-OFDM in presence of ICI and ISI are derived. Both analysis and simulation results are presented for the MSE-OFDM system and are found to be almost identical.

Chapter-5 presents new multiple access schemes named as MSE-OFDMA. In MSE-OFDMA, OFDM symbols of different users are taken in one frame and protected by one cyclic prefix. Thus better spectral efficiency is obtained as compared to conventional OFDMA, where each OFDM symbol uses one cyclic prefix. Smaller FFT blocks are used reducing the number of subcarriers for each block, thus reducing the FFT size. When the

number of subcarriers is reduced, keeping the bandwidth constant, the relative frequency offset becomes smaller, so the system becomes more robust to synchronization errors. The PAPR also reduces due to smaller number of subcarriers.

The last chapter i.e. Chapter-6 contains our major conclusions. All the proposed schemes are summarized in this chapter. We also indicate future work scope in this area.