CHAPTER 1

INTRODUCTION

1.1 GENERAL

The ability to communicate with people on the move has evolved remarkably since Galileo Marconi first demonstrated radio’s ability to provide continuous contact with ships sailing the English Channel in 1897. Since then new wireless communication methods and services have been enthusiastically adopted by people throughout the world. The past decade has seen a surge of research activities in the field of wireless communication due to a confluence of several factors. First, there has been an explosive increase in demand for tether less connectivity, driven so far mainly by cellular telephony but eclipsed soon by wireless data applications. Second, the dramatic progress in very large scale integration (VLSI) technology has enabled small area and low power implementation of sophisticated signal processing algorithms and coding techniques. Third, the success of second generation (2G) systems based on digital multiple access technology such as time division multiple access (TDMA) and in particular, the interim standard (IS-95) code division multiple access (CDMA) [1-5] served low bit rate data communications in addition to voice services. These standards provided a concrete demonstration that good ideas from communication theory can have a significant impact in practice. These trends are expected to continue at an even greater pace during the next decade.

Third generation (3G) mobile communication systems are deployed in several countries enabling new ways to communicate, access information, conduct business and be entertained, liberating users from slow, cumbersome equipment and immovable points of access. This was made possible with multiple access schemes based on multi-carrier modulation (MCM) [6-8] called orthogonal frequency division multiplexing (OFDM). Several studies indicated that only MCM scheme
can support higher data rates suitable for mobile paths. OFDM is the basic MCM scheme that has been introduced and exhaustively studied.

### 1.1.1 OFDM

The available spectrum in OFDM is divided into many carriers, each one being modulated by a low rate data stream. The multiple user access is achieved in OFDM and FDMA by subdividing the available bandwidth into multiple narrow band channels [9-11] and allocating them to the users. However, OFDM uses the spectrum much more efficiently by spacing the channels much closer together with no overhead as in FDMA. This is achieved by making all the carriers orthogonal to one another, thus preventing interference between the closely spaced sub-carriers.

Each carrier in an OFDM signal has a very narrow bandwidth (i.e. 1 kHz), resulting in low symbol rate. This leads to the signal having a high tolerance to multi-path delay spread, as the delay spread must be long enough to cause significant inter-symbol interference (>100ms). Recent advancements in DSP and radio frequency (RF) technologies have enabled OFDM to be very economical and hence a better choice for service providers to compete with wire line carriers in transmitting higher data rates.

OFDM, in spite of all its advantages, has a serious limitation of being sensitive to nonlinear amplification, frequency and phase errors in sub-carriers. Moreover, the mobile community may not be interested in loosing the merits of CDMA and therefore possibilities of integrating CDMA and MCM have been initiated. Researchers have evaluated three different combinations of OFDM and CDMA, namely, multi-carrier direct sequence CDMA (MC-DS-CDMA), multi-tone CDMA (MT-CDMA) and multi-carrier CDMA (MC-CDMA) [12, 13], to arrive at a possible access choice for 4G mobile communication systems.
1.1.2 MC-DS-CDMA

The MC-DS-CDMA transmitter spreads the serial to parallel (S/P) converted data streams using a given spreading code in the time domain. The resulting spectrum of each sub-carrier can satisfy the orthogonal condition with the minimum frequency separation. Usually, the receiver is composed of normal coherent (non-Rake) receivers as it is crucial to have frequency non-selective fading over each sub-carrier. Therefore, without forward error correction among sub-carriers, this scheme can not obtain any frequency diversity gain.

1.1.3 MT-CDMA

The MT-CDMA transmitter spreads the S/P converted data streams using a given spreading code in the time domain so that spectrum of each sub-carrier prior to spreading operation can satisfy the orthogonal condition with the minimum frequency separation. This scheme uses longer spreading codes in proportion to the number of sub-carriers in order to accommodate more users. MT-CDMA receivers can not make the best use of the received signal energy scattered in time domain. Hence, MT-CDMA can not provide the required performance.

1.1.4 MC-CDMA

The MC-CDMA transmitter spreads the original data stream over different sub-carriers [14, 15] using a given spreading code in the frequency domain. Different users share the same frequency band, i.e. the same sub-carriers, at the same time. A fraction of the symbol corresponding to a chip of the spreading code is transmitted through a different sub-carrier. The received signal in the receiver is combined in the frequency domain. Therefore, the receiver can always employ all the received signal energy scattered in the frequency domain. This is the main advantage of the MC-CDMA scheme over other schemes such as MC-DS-CDMA and MT-CDMA.
Block diagram of the transmitter section of MC-CDMA system is shown in the Figure 1.1. The transmitter section consists of an initial modulation scheme. The quadrature phase shift keying (Q-PSK) or quadrature amplitude modulation (QAM) [16] technique is used in most practical situations. It is easy to implement and they are resilient to noise. In QPSK, two bits of information are transmitted in each time slot and there are four possible phases ($\pi/4,3\pi/4,5\pi/4,7\pi/4$) to be allowed for transmission.

![Figure 1.1 Block diagram of MC-CDMA transmitter](image)

Modulated data are spreaded using pseudo noise (PN) sequences for channel separation. Walsh-Hadamard code [17] is one of the PN sequences generally employed for spreading. Walsh-Hadamard code can easily generate orthogonal sequences with zero cross correlation in ideal conditions. However, the correlation between sequences can increase due to delays/shift between them due to practical conditions. Zero cross correlation between the codes, unity dot product of each code and equal number of 1’s and -1’s in each code sequence are some of the major properties of Walsh-Hadamard codes.
Inverse fast Fourier transform (IFFT) operation is performed after modulation and spreading. The spreaded data are summed up and multiplexed before transmitted through the channel. An exact inverse operation of the transmitter is performed at the receiver end and is shown in Figure 1.2. As the first step, the cyclic prefix is removed and fast Fourier transform (FFT) operation is carried out. The FFT operation is performed to obtain the signals in the frequency domain.

![Block diagram MC-CDMA receiver](image)

**Figure 1.2** Block diagram MC-CDMA receiver

Since Walsh-Hadamard code of the user is not known at the receiver section, a search operation is done where the received symbols are correlated to the Walsh-Hadamard codes. The codes with maximum correlation with the received symbols are chosen for despreading to recover the signals.

MC-CDMA signals propagate through multi-path channels with little distortion and signals are not susceptible to delay spreads unlike other schemes. Moreover, the spreading factor can be chosen in such a manner that all the sub-carriers are unlikely to be subjected to deep fade to achieve frequency diversity. Hence, MC-CDMA system has gained more popularity for high data rate transmission in 4G systems.
1.2 NEED FOR PERFORMANCE IMPROVEMENT

Unlike wired channels, which are static and predictable, wireless channels are unpredictable as they are subjected to time-varying impairments [18] such as noise, interference and multi-path propagation. Multi-path causes the transmitted signal to reach the receiver from two or more paths due to refraction and reflection of terrestrial objects such as mountains, buildings etc. As these scattered waves make their way to the receiver, they cause constructive and destructive interference, and phase shifting in the signal [19, 20], which ultimately lead to increased receiver errors.

A proven way to mitigate these effects [21-23] is by employing diversity techniques. In essence, diversity amounts to creating redundancy in the transmitted signal with the expectation that the different transmissions will undergo different fading. This provides the receiver with multiple versions of the same information. Current diversity techniques [24-28] include space (or antenna) diversity, frequency diversity and time diversity. Space diversity uses two or more physically separated antennas to create multiple independent fading channels. Frequency diversity takes advantage of the fact that different carrier frequencies, sufficiently spaced out, will undergo different fading and multi-path characteristics over a channel. In time diversity, signals representing the same information are sent over the channel at different times [29] under different channel fading conditions.

Recent breakthroughs in digital signal processing (DSP) have allowed wireless communication systems to utilise both space and time diversity to address system performance needs by employing multiple-antennas at the transmitter and/or receiver to create a system with independently fading channels. A system employing more than one transmitting and receiving antenna is called a multiple-input, multiple-output (MIMO) system. MIMO systems [30, 31] have been shown to increase the system capacity as the number of transmit and receive antennas increases than single-input, single-output (SISO) systems.
MIMO can be easily realised through space time coding which transmits multiple copies of a data stream across number of antennas. The design of these codes [17] takes into account a trade-off between decoding complexity at the receiver, maximising the information rate and minimising decoding errors. Copies of the signal received through multiple antennas are combined in an optimal way to extract as much information from each of them. This ensures optimal reception of data in a potentially difficult environment with scattering, reflection, refraction and indeed with multi-path problem associated with wireless scenario.

Even though 3G has not emerged in many of the countries, research efforts have already been set on motion to look into fourth generation (4G) systems that can provide data rates of upto 5 Mbps and 10 Mbps in outdoor and indoor environment respectively. By the time 4G services are rolled out in markets, it is predicted that the subscriber population will be many fold higher. The CDMA and OFDM are independently not in a position to meet this demand. An MCM scheme called multi-carrier code division multiple access scheme (MC-CDMA) which has the capability of simultaneously exploiting the advantages of CDMA and OFDM emerged to meet the expectations of 4G systems. Since 2002, the MC-CDMA system has been considered to be one of the candidates [32] as a physical layer protocol for 4G mobile communications.

As wireless communication systems evolve, service quality and capacity are of primary importance. To ensure reliable communication over a mobile radio channel, a system must overcome multi-path fading, polarization and interference. Even as more spectrum is allocated, demand for higher data rate services and steady increasing numbers of users will motivate service providers to seek ways of increasing the capacity of their systems without compromising the quality.

1.3 SCOPE OF THE WORK

The present wireless communication transmission networks require high data transmission capability with improved quality. The search to fulfill this requirement has gone through various stages of 2G and 3G systems to the present
4G systems. MC-CDMA is considered to be a strong contender for this. However, the MC-CDMA systems have their limitations of multi-cell interference and effects of deeply faded sub-carriers. Any solution to improve this aspect of MC-CDMA systems would improve the communications. Site diversity technique is used to enhance the performance of the system by reducing the multi-cell interference.

Initially, maximal ratio combining (MRC) and equal gain combining (EGC) techniques were employed to achieve receiver diversity for performance improvement of MC-CDMA system. MRC technique outperformed EGC technique in improving diversity gain of MC-CDMA system. However, it is ineffective in the downlink of MC-CDMA system.

Subsequently, site diversity is achieved through various types of space time codes to improve the performance of wireless communication system. Space time block codes (STBC) acquires maximum diversity gain to reduce multi-cell interference. The differential space time block codes (D-STBC) functions in a better way than STBC in increasing the system performance even in the absence of channel state information (CSI).

Also, the error rate obtained through D-STBC can be further reduced, provided the space time codes achieve both coding gain as well as diversity gain. This has prompted to develop space time trellis codes (STTC) incorporating error control, modulation and diversity to battle the fading effect. Moreover, the points of constellation with equal probability enhance the performance of STTC codes. The balanced STTC (B-STTC) developed with equal probability of constellation points reduce the error rate in fading environment.

Furthermore, attempts have been made to merge STBC and STTC codes to exploit simultaneously diversity gain and channel efficiency in order to improve the reliability of communication in multi-path fading environments without provoking a bandwidth expansion. The resultant STTC based STBC and STBC based STTC codes proved to be effective in overcoming fading so as to improve the system performance.
However, space time codes were not implemented in MC-CDMA system to improve its performance. Also, space time codes involving D-STBC, STTC, B-STTC and combination of STBC and STTC site diversity techniques are yet to be explored in order to enhance the performance of MC-CDMA system. Further, no attempt has been made so far to apply STBC site diversity technique using multiple antennas at the base and mobile station to improve the performance of MC-CDMA system.

Hence, in the present work, an attempt has been made to improve the performance of MC-CDMA system with multiple antennas at base station and receiver using STBC, D-STBC, STTC, B-STTC and also with the combination of STBC and STTC space time codes.

1.4 OBJECTIVE OF THE WORK

An attempt has been made in the present work to enhance the quality of MC-CDMA system through site diversity technique by employing different space time codes. The following are the set objectives to realise the goal.

- To investigate the performance of MC-CDMA system using STBC and D-STBC site diversity.
- To examine the performance of the system using site diversity technique based on space time trellis code (STTC) and balanced STTC (B-STTC).
- To study the performance of MC-CDMA system under STTC based STBC and STBC based STTC site diversity techniques.
- To evaluate MC-CDMA system’s performance using B-STTC based STBC and STBC based B-STTC site diversity techniques.
1.5 ORGANISATION OF THE THESIS

Chapter 1 provides an overview on MC-CDMA system. The need, scope and prime objectives of the present work and organisation of the thesis are presented in this chapter.

Extensive literature related to the performance improvement of MC-CDMA system and various space time codes for wireless communication system has been critically reviewed and presented in chapter 2. Summary of review of literature is also furnished.

Chapter 3 presents the quality improvement of MC-CDMA system by employing STBC site diversity and D-STBC site diversity techniques. A detailed discussion on the quality expansion with the comfort of simulation results for the system employing STBC and D-STBC are also incorporated.

Site diversity technique for MC-CDMA system using STTC is presented in Chapter 4. Performance analysis and discussion with the assistance of simulation results is clearly presented. Further, the system performance with B-STTC site diversity and comparison of STTC and B-STTC site diversity are also included in this chapter.

Chapter 5 deals with the STTC based STBC site diversity technique to MC-CDMA system. Mathematical analysis of the system is also lucidly presented. Finally the simulation results and performance comparison with complete discussion is concisely provided. Further, STBC based STTC site diversity technique for the system is presented along with simulation results and a meticulous comparison of performance is incorporated in this chapter.

Chapter 6 represents the system analysis with B-STTC based STBC and STBC based B-STTC site diversity technique. Also the mathematical model representing the proposed system is devised and presented. Finally a discussion on
the simulation results and the performance comparison is tersely offered for the system.

Chapter 7 concludes the thesis by emphasizing the major conjecture of the study. A summary of research contribution and the scope for future studies are also incorporated in this chapter.