CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Wireless Communication is currently the fastest growing segment of the Telecommunication Industry. With the explosion in mobile telephone, Internet and multimedia services, the demand for Wireless Access has been rapidly increasing worldwide. Many new applications have emerged as a result of the transformation of research ideas into concrete systems. Techniques like Orthogonal Frequency Division Multiplexing (OFDM), Turbo coding, Space-Time coding and multi-antenna systems were conceived mainly owing to academic curiosities. Right from Wireless Local Area Networks (WLANs) to cell phones, we are surrounded everywhere by wireless devices.

1.2 WIRELESS CHANNELS: CHALLENGES AND SOLUTIONS

One of the key challenges in studying wireless communications is the amazing breadth of topics that impacts this field. The growing interest for high data rate wireless communications has led communication engineers to develop techniques to provide high speed data communication while trying to keep backward compatibility with the existing systems. They are trying to deploy standards that have been developed at cellular frequencies such as CDMA, TDMA or GSM for high data rate communications. Though there is a
rapid progress in the evolution of sophisticated signal processing techniques and RF technology, wireless applications pose an incredible number of challenges to communication system designers in the design and performance of reliable and robust networks.

In wireless communication, the transmitted signal in the wireless channel suffers not only from additive noise, but also from distortion due to reflection, diffraction and scattering. The net effect on the transmitted signal is time-varying attenuation, delay and phase distortion from multi-path propagation. The received signal is therefore a sum of several delayed and attenuated copies of the transmitted signal. The variation in the received signal’s amplitude due to the time variation of the individual path attenuation and delay is called fading, which degrades the performance and makes reliable high data rate transmissions a greater challenge.

The complex time-varying wireless environment, the limited availability of the radio frequency spectrum, the increasing demand for higher data rates, better quality of service, connectivity in wireless networks, security and higher network capacity call for innovative techniques that improve spectral efficiency and link reliability. The use of multiple antennas at the receiver and/or transmitter in a wireless system promises significant solutions in these measures.

A key feature of Multiple Input Multiple Output (MIMO) systems is the ability to turn multi-path propagation, traditionally a pitfall of wireless transmission, into a benefit for the user (Gesbert et al 2003). Multiple antennas in a communication system serve two important purposes. First, they introduce diversity into the communication system. Secondly, they increase the capacity of communication systems.
In order to mitigate the effects of fading, diversity techniques are used (Biglieri et al 1998). These techniques are commonly classified as time diversity, frequency diversity, spatial diversity and polarization diversity. To obtain independent fading through time diversity, the original data is repeated in time with duration greater than the coherence time of the channel (Rappaport 1996). In frequency diversity, the data is sent on carriers that are spaced by more than the coherence bandwidth of the channel. In spatial or antenna diversity, transmission and reception of information is carried out via multiple antennas placed at appropriate distance in space and suitable processing is done, both at the transmitter and at the receiver.

Many approaches have been studied in order to explore the capacity of MIMO systems. The information theory shows that with $N_T$ transmit antennas and $M_R$ receive antennas ($N_T \leq M_R$), $N_T$ independent data streams have to be transmitted simultaneously in order to achieve the channel capacity. This is the principle of Spatial Multiplexing. The capacity increase due to the use of multiple antennas is studied in detail by Telatar (1995), Narula et al (1996) and later extended by Foschini et al (1998). A system following this approach is the Bell Labs Layered Space-Time (BLAST) architecture proposed by Foschini (1996). It is shown in these works that the capacity of a multiple antenna communication system far exceeds that of a single antenna system.
time, has enabled the feasibility of implementing MIMO systems and the associated signal processing algorithms. Apart from imparting spectral efficiency gains, multiple antennas can also be used to reduce Inter Symbol Interference (ISI) and interference from other users.

The above mentioned advantages will make MIMO, even more popular in the future. Many wireless companies have proposed MIMO based solutions for the implementation of broadband fixed and mobile standards. These standards include IEEE 802.11 and IEEE 802.16. IEEE 802.11a standard uses MIMO architecture, along with OFDM and LDPC coding, where OFDM is capable of providing very high data rate with strong robustness against multi-path delay spread (Nee and Prasad 2000).

The standard IEEE 802.16 specifies the support of MIMO antennas to provide good Non-Line-Of-Sight (NLOS) characteristics through a technology called WiMAX (Andrews et al 2007). Also, MIMO has been incorporated in the Third Generation Partnership Project (3GPP) in standards like Wideband Code Division Multiple Access (W-CDMA), Universal Mobile Telecommunication System (UMTS) and Long Term Evolution (LTE).

In the fourth generation wireless communication systems, the data rate may be as high as 1 Gbps. Space time coding techniques are also employed in conjunction with the MC-CDMA system to achieve very high data rate.

### 1.3 TWO DIFFERENT IMPLEMENTATIONS OF MIMO

In a broader sense, Space-Time Coding and Spatial Multiplexing, the two major implementations of Open Loop MIMO promises to be the attractive solutions for high data rate wireless communication. Essentially,
both these schemes aim at mitigating the detrimental effects of the multi-path fading which is one of the greatest challenges to traditional wireless systems. Increased capacity is achieved by introducing additional spatial channels that are exploited by using Spatial Multiplexing.

The capabilities of MIMO channels can be exploited through various techniques like BLAST-Bell Labs Layered Space-time Architecture, proposed by Foschini et al (1998), Space-Time Block Codes (STBC), proposed originally by Alamouti (1998) and Space-Time Trellis Codes (STTC), proposed by Tarokh et al (1998) and Tarokh et al (1999d). The main objective of Space-Time Coding is to achieve the maximum possible diversity whereas Spatial Multiplexing is employed to achieve a high throughput.

Multiple antennas become a choice to increase diversity, when one needs to compensate the fluctuations in fading channels. Every pair of transmit and receive antennas proves to be a distinct signal path between the transmitter and the receiver. Multiple independently faded replicas of the data symbol can be obtained at the receiver end, by transmitting signals that carry the same information along a number of different paths. For example, in a Rayleigh fading channel with $N_T$ transmitting antenna and $M_R$ receive antenna at high SNR, the average error probability decays as $SNR^{-M_R}$, as compared to $SNR^{-1}$ for SISO system. If the fading across the antenna pairs is independent, for example, an $N_T \times M_R$ MIMO flat fading channel, the diversity gain equals at most $N_TM_R$. By exploiting this diversity, the information capacity of a communication system can be significantly increased. Space-time codes are designed specifically for MIMO systems to provide diversity and coding gain simultaneously.

Another perspective of multiple antennas is that, in a MIMO channel, fading can be exploited to increase the degrees of freedom available
for communication. Consider a high-rate information bit-stream which is divided into a number of independent sub-streams and transmitted over different antennas. If the path gains between the individual transmit-receive antenna pairs, fade independently, then the channel matrix is well-conditioned with high probability. Thus, multiple parallel spatial channels are created and the data rate is increased. This effect known as spatial multiplexing is significant to high signal-to-noise ratio regime where the system is restricted in terms of degrees of freedom. It was proved in Foschini et al (1998) that this scheme offers a theoretical capacity over MIMO Rayleigh fading channels that grow linearly with $\min(N_T,M_R)$. The practical implementations of spatial multiplexing, V-BLAST, Foschini (1996) and its variant D-BLAST (Wolniansky et al 1998) aim at maximizing the data-rate.

1.4 SPACE-TIME CODING FOR MIMO CHANNELS

Space-Time Coding (STC) is essentially a joint design of coding, modulation, transmit and receive diversity and is the generalization of other transmit diversity schemes. The delay diversity scheme by Seshadri and Winters (1994) and the bandwidth efficient transmit diversity scheme by Wittneben (1993) are examples of such schemes.

The two main kinds of STC are STBC and STTC. Space-time block codes operate on a block of input symbols, producing a matrix output whose columns represent time and rows represent antennas. On the other hand, Space-time trellis codes operate on one input symbol at a time, producing a sequence of vector symbols whose length represent antennas. In order to achieve additional coding gain, STBC is combined with channel codes like Convolution Codes (CC), Turbo Convolution (TC) codes, Turbo BCH codes (TBCH), Trellis Coded Modulation (TCM) and Turbo Trellis Coded Modulation (TTCM), each offering different performance and complexity (Liew et al 2000). The key advantage of STTCs over STBCs is that they
provide coding gain along with the provision of full diversity gain, whereas
the main feature of STBC is the provision of full diversity with a very simple
decoding scheme (Sandhu et al 2001).

In summary, an increase in network throughput and spectral
efficiency can be achieved by using multiple antennas at the transmitter and
receiver side in a MIMO system. These additional antennas can be either used
for spatial multiplexing, increasing diversity or a trade-off of both.

1.5  MOTIVATION

Most of the prior research works on space-time codes and spatial
multiplexing have focused on one of the following four aspects:

1. Increase in the rate and diversity of the space-time coded
   system.

2. Applicability of optimal or sub-optimal receivers and evaluation
   of their reliability performance in terms of their error
   probability.


4. Increase in the capacity of the system.

By employing multiple antennas, the capacity of the wireless
channels can be increased. In this research, all possible resources namely
transmit diversity, receive diversity and coding are combined efficiently to
increase the channel throughput, either through concatenation of different
blocks or by combining space-time processing and spatial multiplexing.

With the widespread use of mobile phones and other wireless
devices in every possible scenario of our daily lives, it is mandatory that the
wireless services be robust and compatible. With the introduction of space-
time block coding, the base station can provide reliable communication not only from the mobile user to the base station (receive diversity) but also from the base station to the mobile user (transmit diversity). Receive diversity techniques cannot be typically used for the mobile station as the mobile station has size constraints and it may not be practical to deploy more than a single antenna on it. Furthermore, even if we use multiple antennas at the receiver, we may not get enough separation between the antennas for an effective diversity advantage. To ensure that the fading is independent, the separation between the antennas must be at least $WL/2$, where $WL$ is the wavelength of transmission. For a communication system engineer, space-time codes provide an effective means to bypass this intricacy.

In the above context, it is essential for practical space-time codes and spatial multiplexing architectures to have tolerable performance in fading channels. A fair combination of Space-time coding and spatial multiplexing can be made by considering the rate/diversity/complexity trade-offs, and the benefits of these schemes can be exploited to develop many new systems.

In terms of complexity, STTC is more complex than STBC due to its encoding/decoding methodology. The decoding complexity of STTC increases exponentially as a function of transmission rate and diversity level, whereas in STBC, the detection is based only on linear processing at the receiver.

Layered Space Time (LST) architectures used for multiplexing employ complex ML decoding, with the use of large number of antennas and higher order modulation schemes. However, owing to the nature of LST codes, sub-optimal receivers, like Zero Forcing (ZF) and Minimum Mean Squared Error (MMSE) can be used, thereby reducing the complexity (Tse and Viswanath 2005). Though both LST and STBC can be thought of as good
options for maximization of data rate and diversity gain, they need to be concatenated with other codes to provide coding gain. The conventional channel codes that are opted for concatenation systems are convolution codes and turbo codes.

In fact, STBC provides a high diversity gain with little or no multiplexing gain, whereas LST schemes provide high multiplexing gain and little or no diversity gain. A system that provides a trade-off between the number of transmitted symbols and the achieved diversity can be constructed by combining both LST and STBC. A system combining the benefits of these two techniques for the sake of providing both antenna diversity and spectral efficiency has been proposed by Zheng and Tse (2003).

Combined array processing using space-time trellis codes as component codes was used for achieving very high spectral efficiencies. The drawbacks of these systems such as the requirement of more number of receive antennas and the receiver complexity are taken care in the design of Double Space-Time Transmit Diversity Systems (DSTTD). These systems achieve high data rates and also employ those simple receivers that are used for spatial multiplexing schemes.

Motivated by the aforementioned capabilities of the existing systems, this research is undertaken to derive all the benefits of the existing systems while addressing and providing solutions for the following:

- Can we design a hybrid system that could employ space-time codes both as inner code and outer code and improve the system performance?
• Can we make use of the low complexity receivers that are already being used by the evolved systems?

• How can the benefits of the combined scheme be extracted?

• What is the achievable error rate for the MIMO system when assisted by powerful channel codes along with the hybrid scheme?

1.6 OBJECTIVES

The objectives of the thesis are:

• To combine space-time codes and draw the benefits of these codes to improve the reliability and capacity of the system

• To evaluate the hybrid system performance over a fading channel.

• To investigate the applicability of simple linear receivers that perform group interference suppression.

• To delve into the performance of the coded hybrid system using turbo codes.

1.7 RESEARCH CONTRIBUTION

The key contributions made in this research are summarized below:

• A novel approach called Combined Hybrid Space-Time Code which is a combination of STTC and STBC is proposed. Through this approach, a significant improvement both in
coding gain and diversity gain is achieved when compared to the originally proposed STTC and STBC.

- The performance analysis of the augmented Space-Time Trellis Coded scheme, in terms of joint array processing and space-time block coding is performed for wireless local and metropolitan area networks based on the standard IEEE 802.16. In this scheme, the merits of STTC, STBC and spatial multiplexing are amalgamated to yield coding gain and high data rate.

- Error probability analysis similar to that of Transmit diversity scheme with Trellis coding (Alamouti et al 1998) is carried out to show the coding gain advantage and diversity gain of the scheme.

- The performance results of the coded system using turbo code as outer code and CHSTC as inner code are provided.

1.8 ORGANISATION OF THE THESIS

Chapter 1 gives a brief introduction to the subsequent chapters in this thesis and includes the motivation, objectives and research contribution of the thesis.

In chapter 2, a detailed report of the literature survey carried out to support the work described in the proposal is elaborated. This includes the study and performance comparison of various space-time coding techniques and space-time architectures to bring out the significance of the work in terms of rate, diversity, coding gain and multiplexing gain.
Chapter 3 expounds a novel idea of Hybrid Combination scheme. This is different from other concatenation schemes where the outer code is a single-antenna channel code. The simulation results show that this scheme has a better performance than the conventional space-time codes in terms of coding gain and error performance.

In Chapter 4, an augmented scheme which combines spatial multiplexing and space-time coding are elucidated. Group interference suppression using ZF method and MMSE to suppress the interference between the space-time blocks of the same user is carried out. Performance analysis of Error Probability of this scheme is also carried out.

In Chapter 5, turbo assisted Hybrid Combination scheme is examined. The performance results of the coded system in terms of Bit Error Rate (BER) are provided.

Finally, the conclusions and future scope of the thesis are discussed in Chapter 6.