CHAPTER 1

INTRODUCTION

Wireless communication is a field that has got its inception about a century ago, when Marconi had successfully demonstrated the first radio transmission. Today, wireless communication occupies the most vibrant area in the communication field. The rapid progress in wireless communication technology has been in the air over the past few decades. The very modern wide spread and successful technology in wireless communication could be witnessed in mobile or cellular communication largely.

Many wireless communication techniques such as Code Division Multiple Access (CDMA), Orthogonal Frequency Division Multiple Access (OFDMA), Multi Input Multi Output (MIMO), MU-MIMO and Ultra Wide Band systems (UWB) have been developed during the past two decades to achieve higher data rate, more robust link quality and more user capacity in equally more rigorous channel conditions. All these systems have their own unique superiority while inducing other drawbacks leading to limited system performance.

Recently, the mobile communication industry is rapidly gliding towards Long Term Evolution (LTE) systems because of the increasing number of smart-phone users and ever-increasing demand for high quality multimedia over wireless (Erik Dahlman et al. 2011). LTE aims to provide improved service quality over 3G systems in terms of throughput, spectral
efficiency, latency, and peak data rate, and MIMO is one of the key enablers of the LTE system for achieving these diverse goals (Lim et al. 2013). The leading carriers and vendors are committed to launching LTE service in the near future and, in fact, one of the major operators Verizon has already initiated LTE service. There are many features in the LTE-Advanced (LTE-A) and it supports up to 3Gbps throughput in downlink. Multi user Multiple Input Multiple Output (MU-MIMO) scheme is one of the key features of LTE-A for achieving a high spectral efficiency (Boccardi et al. 2012). From the initial release (Rel. 8) to the recent release (Rel. 10) the so called LTE-Advanced MU-MIMO techniques have been evolved from their premature form to the more elaborated version.

According to white paper from ERICSON (2013), data traffic levels in mobile networks are increasing very rapidly, that the increase of monthly mobile data traffic in the year 2013 exceeded the total mobile data traffic accounted in the year 2009. Mobile data traffic is expected to grow at a Compound Annual Growth Rate (CAGR) of around 45 percent from 2013 to 2019. This will result in an increase of around 10 times by the end of 2019. Extrapolating this trend indicates that the amount of data-traffic can be expected to increase several hundred times in the longer term. Accommodating all the traffic requirements employable in 5G wireless technology for very high data rates are under discussion.

Finally, the emergence of new data services and applications such as 3D multimedia and high definition video conference, however, creates new challenges to mobile wireless networks. Beyond 4G, radio will require spectrum to support higher data rates and higher capacities. Even if new spectrum is allocated to mobile radio applications, this will be far from sufficient to meet the predicted traffic demands for 2020.
1.1 EVOLUTION OF MOBILE WIRELESS STANDARDS

1.1.1 First Generation Analog Wireless Systems

First generation mobile phones had only voice facility and were based on analog systems. The best known 1G systems were Advanced Mobile Phone System (AMPS), Nordic Mobile Telephone (NMT 450/900), and Total Access Communication System (TACS). With the introduction of 1G phones, the mobile market showed annual growth rate of 30 to 50 per cent, rising to nearly 20 million subscribers by 1990. Other than NMT and TACS, some other analog systems were also introduced in 1980s across the Europe. All these systems offered handover and roaming capabilities but the cellular networks were unable to inter-operate among countries. This happened to be one of the inevitable disadvantages of first-generation mobile networks.

<table>
<thead>
<tr>
<th>Standard</th>
<th>Year of Introduction</th>
<th>Multiple Access</th>
<th>Frequency Band</th>
<th>Modulation</th>
<th>Channel Bandwidth</th>
<th>No. Of Channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMPS</td>
<td>1983</td>
<td>FDMA</td>
<td>824-894</td>
<td>FM</td>
<td>30KHz</td>
<td>832</td>
</tr>
<tr>
<td>NMT 450</td>
<td>1981</td>
<td>FDMA</td>
<td>450-470MHz</td>
<td>FM</td>
<td>25KHz</td>
<td>180</td>
</tr>
<tr>
<td>TACS</td>
<td>1981</td>
<td>FDMA</td>
<td>890-960MHz</td>
<td>FM</td>
<td>25KHz</td>
<td>1000</td>
</tr>
<tr>
<td>NMT 900</td>
<td>1986</td>
<td>FDMA</td>
<td>890-960MHz</td>
<td>FM</td>
<td>12.5KHz</td>
<td>1999</td>
</tr>
</tbody>
</table>

1.1.2 Second Generation Digital Wireless Systems

Second Generation Wireless Systems were introduced in the end of 1980s. Since then, 2-G systems have been using digital multiple access technology such as Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA). In addition, 2G systems offer high
spectrum efficiency, better data services, and more advanced roaming. Further, 2G cellular systems include GSM, digital AMPS (D-AMPS), and Personal Digital Communication (PDC). Of these, GSM is the most successful family of cellular standards deployed in Europe. It includes GSM900, GSM-railway (GSM-R), GSM1800, GSM1900, and GSM400. Due to this, GSM supports around 250 million of the world’s 450 million cellular subscribers, with international roaming in approximately 140 countries and 400 networks. In the United States alone, there were three lines of development in second-generation digital cellular systems. The first digital system, introduced in 1991, was IS-54 (North America TDMA Digital Cellular), of which a new version supporting additional service such as IS-136 was introduced in 1996.

Meanwhile, IS-95 (CDMA One) was deployed in 1993. The US Federal Communications Commission (FCC) also auctioned a new block of spectrum in the 1900 MHz band (PCS), allowing GSM1900 to enter the US market. Meanwhile, in Japan, the Personal Digital Cellular (PDC) system, originally known as JDC (Japanese Digital Cellular) was initially defined in 1990. As years passed, to meet the requirement of increasing data sending over the air interface, General Packet Radio Service (GPRS) was added with the existing GSM system. As a result, GPRS system has been termed as 2.5G, as it provides higher data rate and additional capabilities than 2G.

1.1.3 Third Generation Digital Wireless Systems

Since the standards for developing the networks vary among different parts of the world in 2G systems, a plan for a single global frequency band and standard was formulated by the International Telecommunication Union (ITU) for the Third Generation (3G) digital cellular systems. This standard was named as International Mobile Telephone 2000 (IMT2000). 3G finds application in wireless voice telephony, mobile Internet access, fixed
wireless Internet access, video calls and mobile TV. The most important IMT-2000 proposals are the UMTS (W-CDMA) as successor to GSM, CDMA2000 as the successor to interim-standard ‘95 (IS-95), and Time-Division Synchronous CDMA (TDSCDMA) and UWC-136/EDGE as TDMA based enhancements to D-AMPS/GSM—all of which are leading previous standards towards the ultimate goal of IMT-2000. UMTS, standardized by Third Generation Partnership Project (3GPP), which was first offered in 2001, is a broadband standard for packet-based transmission of text, digitized voice, video, and multimedia at data rates up to and possibly more than 2 Mbps. It provides a consistent set of services to mobile computer and phone users, irrespective of their dwelling in the world.

W-CDMA is the unique competing 3G standard to CDMA 2000. It is also used in Japanese Freedom of Mobile Multiple Access (FOMA) and J-Phone 3G systems. An enhancement to W-CDMA called High Speed Data Packet Access (HSDPC) provides data rates of around 9Mbps.

1.1.4 Fourth Generation Digital Wireless Systems

The ever increasing growth of user demand and the emergence of new technologies in mobile communication systems are reasons for the creation of the fourth generation mobile communication systems. Basically, 4-G mobile system is an Internet Protocol (IP) based network system. In this technology, 4-G network will accomplish new levels of user experience and multi service capacity by integrating all the current existing and future wireless technologies (e.g. IPv6, OFDM, MC-CDMA, LAS-CDMA and Network-LMDS). In terms of functionality, 4G networks are integrated with one core network and several radio access networks. A core interface is used for communication with the core network and radio access networks, and a collection of radio interfaces is used for communication with the radio access networks and mobile users. This kind of integration combines multiple radio
access interfaces into a single network to provide seamless roaming/ handoff and the best connected services. Furthermore, 4G can support at least 100Mbps peak rates in full-mobility wide area coverage and 1Gbps in low-mobility local area coverage. Significantly, 4G will provide solutions for limited bandwidth in 3G when people are moving and uncertainty about the availability of bandwidth for streaming to all users at all times. In short, 4G wireless systems are expected to deliver efficient multimedia services at very high data rates.

**Applications of 4G**

(a) **Virtual Presence:** This means that 4G can provide user services at all times, even if the user is off-site.

(b) **Virtual Navigation:** 4G can provide users with virtual navigation through which a user can access a database of streets, buildings etc.

(c) **Tele-Geo processing Applications:** This is a combination of GIS (Geographical Information System) and GPS (Global Positioning System) in which a user can get the location by querying.

(d) **Tele-Medicine and Education:** 4G will support remote health monitoring of patients. For people who are interested in lifelong education, 4G provides a better platform.

(e) **Crisis Management:** Generally, natural disasters cause unprecedented breakdown in the communication systems. In today's world it might take days or weeks to restore the system. But in 4G it is believed to restore such crisis issues in few hours.
1.1.5 Fifth Generation Digital Wireless Systems

The fluctuations in traffic demand (both in space and time) will be at unprecedented levels in future networks, which result in tremendous stress to wireless operators.

Fifth generation wireless networks (5G Wireless network) is the foremost period of mobile telecommunication standards ahead of current 4G/IMT standards (Yanikomeroglu 2011). 5G will facilitate the affordable provision of very high data rates with virtually ubiquitous coverage. Apart from increased maximum throughput, other benefits expected from 5G wireless techniques are (Saddam Hossain 2013):

1. Improved and innovative data coding and modulation techniques, which include filter bank multi carrier way in schemes.
2. Low battery consumption
3. Lower outage probability
4. Multiple concurrent data transfer paths.
5. More applications combined with Artificial Intelligence (AI) as human life will be surrounded by artificial sensors which could be communicating with mobile phones.
6. Cheaper traffic fees due to low infrastructure deployment cost.
7. Smart beam antenna system.

1.2 MOTIVATION

The advanced signal processing and coding techniques employed in MIMO systems will deliver high data rates and more robust communications.
In MIMO technologies (Kuo et al. 2008) such as Maximum-Likelihood Detection (MLD), and Minimum Mean Square Error (MMSE) detection, the signal processing is associated only at the receivers. In these systems, data streams for different users are transmitted directly into the wireless channel and the individual user’s data are retrieved by employing MIMO signal processing at the receiver. Singular Value Decomposition (SVD) based MIMO techniques include signal pre-processing or precoding before transmission in addition to MIMO signal processing at the receiver. It is also possible to have the MIMO system with signal pre-processing or precoding only, so that a simplified mobile station is devised. In this case, though the mobile station requires the basic front end units, the associated MIMO signal processing at the receivers is greatly reduced. The basic principle of precoding is that if the transmit side knows the channel information, the signal to be transmitted is designed in such a manner to mitigate the adverse effect of the wireless channel. Yet, precoding is not a new concept and has been used in SU- MIMO system to improve SNR at the receiver (Liu et al. 2012). However, the requirement of precoding is necessary in MU-MIMO system to minimize multi user interference. Precoding is performed with the help of downlink Channel State Information (CSI). The requirement of CSI is not essential in SU-MIMO systems but is fundamental for MU-MIMO systems.

In general, the channel information available at the transmitter is referred to as Transmit Channel State Information or CSIT. When CSIT is available at the transmitter, performance of the system can be greatly improved (Paulraj et al. 2003). In MIMO wireless systems, CSIT helps to enhance coverage, to provide significant increase in capacity at all SNRs, to increase the transmission rate, to enhance system reliability and to reduce the receiver complexity. In some popular MIMO systems, such as space time coded systems and BLAST architecture, CSIT is not considered. However,
CSIT is less reliable because of feedback delay and imperfect reciprocity. The information theory has shown that the optimal strategy to maximize the sum rate in MU-MIMO downlink system is Costa’s dirty paper coding (DPC) when full CSIT is available at the transmitter side. Weingarten et al. (2006) has shown that DPC strategy is the optimal precoding strategy not only for sum capacity, but also for the entire capacity region in Broadcast Channel (BC). It has been proved that practical realization of DPC precoding strategy is found to be a difficult task because it requires infinitely long code words and code books.

The non-linear Tomlinson-Harashima Precoding (THP) is another technique which decomposes the MU-MIMO channels into parallel channels by utilizing a successive pre-processing cancellation at the transmit side. Because of nonlinearity of THP in the literature (Windpassinger et al. 2004, Liu & Krzymien 2005, Fung et al. 2007 & Yu et al. 2005) and the combinatorial problem of user order selection, it is impractical to implement THP algorithm for users with multiple receive antennas. Hochwald et al. (2005) showed that Vector Perturbation (VP) can achieve near ideal DPC performance by minimizing the transmit power for each transmitted symbol. The method which requires joint search of optimal perturbation vector based on Sphere Decoding (SD) algorithm, which is a Nondeterministic Polynomial time (NP)-hard problem has been discussed in the literature (Hassibi & Vikalo 2005). The sub optimal low complex linear precoding techniques are proposed by Sampath et al. (2001), Joham et al. (2002), Seaglione et al. (2002), Palomar et al. (2004), Palomar & Barbarossa (2005) and Xu et al. (2006). The transmitter based optimization techniques for MIMO wireless systems have been discussed in the literature (Haustein & Boche 2003, H’osli & Lapidoth 2004, Jafar & Goldsmith 2004, Jongren et al. 2002 & Jorswieck et al. 2004). Precoding design for MIMO wireless has been an active research in the literature (Sampath & Paulraj 2002, Visotsky & Madhow 2001 and Vu
& Paulraj 2006) and is now finding applications in emerging wireless standards (IEEE 2005).

### 1.2.1 Problem Definition

Design of optimum linear precoders to maximize channel capacity, maximize the minimum distance, minimize the Bit-Error Rate (BER), or minimize the Mean Square Error (MSE) etc have been reported in the open literature. Most of the previous researchers in linear precoding design for MU-MIMO systems assumed that perfect Channel State Information (CSI) is available at the transmitter. But in practice, the errors are inevitable in channel estimation process. This erroneous CSI at transmitter degrades the performance, due to difference between the true channel and the erroneous channel used for designing a precoder. Hence, it is necessary to design a precoder to incorporate channel estimation error.

There have been many practical designs that consider imperfect CSIT. Under an independent identically distributed (i.i.d) Rayleigh flat fading assumption, an achievable lower bound and cooperative upper bound for sum rate capacity has been derived to arrive at sum rate loss. Zhang et al. (2008) has derived the closed-form robust designs (including the minimum total MSE design) by assuming that the imperfect CSI, including channel mean and receive correlation information, is available at both ends. Dabbagh & Love (2008) have proposed the MMSE linear precoder design by considering the imperfect CSI at the (Base Station) BS, in which the channel estimation error variance has been incorporated in the system design for multi user wireless communication system. The authors proved that linear MMSE precoder designed by considering channel estimation error outperformed regularized channel inversion precoder. The linear precoding strategy for distributed MIMO systems with partial CSIT has been proposed by Xu et al. (2013).
It is also well known that due to mobility of the vehicle and the time varying nature of the channel, the CSI available at the BS has to be updated. Hence, it is necessary to predict the future CSI to improve the performance of the system. The effect of feedback delay on MIMO systems has been presented in the literature (Ramya & Bhashyam 2007). To compensate the effect of feedback delay, the prediction algorithm is proposed by Kobayashi et al. (2006) and the results are found to be better than the Zero Forcing (ZF) and MMSE methods.

In practical downlink systems, the mobile is often surrounded by the local scatterers and channels from different antennas tend to be uncorrelated, whereas the channels from different base station antennas are often correlated due to limited scattering. The spatial diversity gain, one of the MIMO channel parameters, depends upon the antenna correlation. If the antennas are highly correlated, spatial diversity gain is small and vice versa if the antennas are uncorrelated.

Though some studies in the literature have addressed the imperfect CSI, they do not consider the impact of above three channel parameters, like feedback delay, spatial correlation and the channel estimation error variance as integral part of the system design.

1.2.2 Objectives

Based on the problem outlined in the previous section, attempts have been made in our work to enhance the performance of the MIMO system by incorporating the three channel parameters in the system design. Hence, the objectives of this thesis are:

(i) To derive linear MMSE based precoding matrix with two Dimensional (2-D) prediction by incorporating the channel
estimation error variance, feedback delay and spatial correlation to improve the BER performance.

(ii) To model the prediction error corrected CSI and to use the same in the design of linear MMSE precoder to enhance the performance of outage and BER.

(iii) To optimize MU-MIMO linear precoder with imperfect CSI using Particle Swarm Optimization (PSO) algorithm to enhance the sum rate capacity.

1.3 THESIS OVERVIEW

The background concepts of MIMO's linear precoding technique are discussed in chapter 2. In chapter 3, the design of linear precoder to minimize the MSE at the receiver when the imperfect CSI is available at the receiver is discussed. The channel estimation errors are always inevitable. Due to time varying nature of the channel, the channel at the time of transmission is different from the estimated channel. Therefore the performance degradation due to channel estimation error and feedback delay or velocity of the vehicle should be reduced. Further, transmit channel correlation and/or receive channel correlation often coexist in MIMO wireless communication systems. Hence, it is important to investigate the joint impacts of channel estimation error, feedback delay and channel correlation. The linear MMSE precoder for multi user multiple antenna based system is designed by considering these parameters as integral part of the system design. To compensate the effect of feedback delay, 2- dimensional channel prediction is done. The benefits of the proposed system with channel prediction are evaluated in this system. Significant improvement in Bit Error Rate (BER) performance of the proposed system is obtained upon employing channel prediction.
In chapter 4, the effect of feedback delay or mobility of the vehicle, spatial correlation channel estimation error and prediction error are compensated. Since the prediction error is unavoidable, it is ratified in this chapter by calculating Normalized Mean Square Error of the channel prediction. Then the prediction error corrected CSI is used for linear precoder design. BER performance and outage performance are analyzed. The simulation results prove that the proposed system outperforms the previous system.

In chapter 5, linear precoder to maximize the sum rate capacity under imperfect CSI for MU-MIMO system is considered. Generally, while using uplink and downlink duality, maximizing the sum rate capacity is equivalent to minimizing MSE under perfect CSI for MU-MIMO systems. However, it is shown that, it is not absolutely equal in the case of imperfect CSI, even though duality exists for MU-MIMO system. Hence, the non-convex optimization problem framed for this scenario is solved using the Particle Swarm Optimization (PSO) algorithm. In such simulation, the effect of channel estimation error on the sum rate capacity is examined. Chapter 6 concludes the thesis with a note on future work.