CHAPTER 1

INTRODUCTION

1.1 MOBILE COMMUNICATION SYSTEMS

Mobile communication is one of the rapidly developing key areas in the field of telecommunications and it is envisioned that a huge number of connections will become entirely wireless within the next decade. The term ‘mobile’ has absolutely restructured the communication by introducing new services and applications and created new challenges for the future development of mobile communication systems. In recent days, mobile communication system technologies has enhanced the way of living and become the backbone of the society. According to the recent statistics, the number of mobile phone usage in India is around 900 million and the number of mobile phone users using internet is around 137 million. This rapid growth in mobile phone users demonstrates decisively that mobile communications is a robust, feasible voice and multimedia data transport system.

The worldwide success of mobile communication systems has led to the progress of newer generation systems and standards for numerous other types of mobile communication traffic besides voice calls. The next generation mobile communication systems are being developed to cater high speed data traffic along with voice calls. Initially, the first-generation (1G) mobile stations were based on analog system and had only voice call feature. The Advanced mobile phone system (AMPS) and Nordic mobile telephone (NMT) were first-generation cellular mobile systems. These systems were
replaced by second-generation (2G) digital mobile stations with improved features like voice calls, data and messaging services. The digital AMPS (D-AMPS), global system for mobile communications (GSM), personal digital communication (PDC) and code-division multiple access (CDMA) systems come under 2G cellular mobile systems. The third-generation (3G) system provides multimedia facilities like audio, video and graphics applications. Over 3G mobile stations, video telephony and streaming video can be watched with highest speed up to 2 Mbps. The 3G system also known as Universal Mobile Telecommunications System (UMTS) or IMT-2000 is a set of standards defined by the International Telecommunication Union (ITU). 4G is the fourth generation of mobile communications technology. In addition to voice calls and other features of 3G system, 4G caters mobile ultra-broadband Internet access to smart phones and other mobile devices like IP telephony, video conferencing, gaming, cloud computing and mobile web access. The Long Term Evolution (LTE) and Mobile WiMAX are 4G system standards. The 5G would be the next generation mobile communication standard which is expected after 2020. The evolution of next generation mobile communication systems is illustrated in Figure 1.1.

Figure 1.1 Evolution of next generation mobile communication standards
A typical cellular mobile communication system consist of base stations generally called as towers, mobile stations generally called as mobile phones and a mobile switching centre (MSC). The base station contains many transmitters and receivers connected to transmitting and receiving antennas which simultaneously handles two way communications. The mobile station consists of a transceiver connected to an antenna and control unit. The mobile users communicate each other through base stations by common air interface standard. The voice or data transmission from mobile station to base station takes place through uplink channels. Similarly the voice or data transmission from base station to mobile station takes place through downlink channels. The mobile switching centre centrally coordinates the functions of all the base stations connected to it and connects the whole mobile communication system to public switched telephone network (PSTN). The common air interface standard between mobile station and base station varies for 2G, 3G and 4G mobile communication systems. A cellular mobile communication system is illustrated in Figure 1.2 (Rappaport 2002).

Figure 1.2 A cellular mobile communication system.
1.2 MIMO IN MOBILE COMMUNICATION SYSTEMS

Multiple-Input and Multiple-Output (MIMO) is one of the various forms of smart antenna system. In MIMO, multiple antennas are used at both transmitter and receiver to increase the performance of communication. MIMO technology has grabbed significant attention in recent mobile communication systems since it provides high data throughput and longer range of communication without any increase in bandwidth or change in transmit power. In the past, the performance of mobile communication systems were decreased due to interference caused by natural radio wave phenomenon said to be as multipath. MIMO technology utilizes this multipath phenomenon to increase the system performance and range by implementing multiple antennas connected to smart transmitters and receivers in spatial dimension. MIMO uses spatial diversity by adding more antennas to combine data streams arriving from multipath which efficiently improves the received signal power. A higher speed at the rate of 600 Mbps is achievable by using 3 antennas and a speed of 300 Mbps is achievable by using 2 antennas in the MIMO based systems. Apart from spatial diversity gain which increases coverage and Quality of Service (QoS) the MIMO technology also improves mobile communication system performance through array gain, multiplexing gain and co-channel interference reduction. The array gain increases coverage and QoS by coherently adding transmitted/received signals, multiplexing gain increases spectral efficiency by transmitting independent data streams from different antennas and co-channel interference reduction increases cellular capacity through proper beam forming (Bliss et al 2005).

There are three main categories of MIMO which are diversity coding, precoding and spatial multiplexing. In diversity coding, same data streams are emitted from each transmit antennas with suitable orthogonal coding. Diversity coding increases signal diversity by using independent
fading between multiple antenna links. In precoding, same data streams are emitted from each transmit antennas with suitable gain and phase weighting so that the signal power is increased at the input of the receiver. Precoding improves the received signal gain and reduces multipath fading through constructive addition of received signals at the receiver input. In spatial multiplexing, different data streams are emitted from multiple antennas in the same channel. The receiver efficiently separates these streams through perfect channel state information (CSI).

The MIMO technology has various special cases which are single-input and single-output (SISO), single-input and multiple-output (SIMO) and multiple-input and single-output (MISO). In SISO, the transmitter and receiver have single antenna considered as conventional mobile communication system. In SIMO, the transmitter is equipped with single antennas and receiver with multiple antennas. In MISO, the receiver is equipped with single antenna and transmitter with multiple antennas. The special cases of MIMO are illustrated in Figure 1.3.

![Figure 1.3 Special cases of MIMO](image-url)
1.2.1 MIMO in 3G and 4G Mobile Communication Systems

The rapid growth in internet usage through mobile phones in the past few years has made the mobile service providers to increase their network capacity. The efficiency of spectrum usage can be increased by obtaining new spectrum, restructuring prevailing spectrum, or by hinging on advanced technologies. Obtaining new spectrum licenses and constructing wholly new networks will lead to high capital expenditure and complexity. A robust and less capital expenditure option is to embrace advanced technologies, such as MIMO technology or higher order modulation.

MIMO is the key technology used in third-generation (3G) mobile communication systems which improve capacity, data rates and user experience within the prevailing spectrum and by augmenting the existing network structure. The major advantage of MIMO technology is its cost effectiveness. MIMO in 3G systems plays a phenomenon role in providing higher peak data rates in each version of HSPA+, i.e. 28 Mbps in release 7, 168 Mbps in release 10 and much higher in release 11 also said to be as HSPA+ Advanced. The major 3G applications are telemedicine, global positioning system (GPS), video on demand, mobile TV, video conferencing and location based services (Viera et al 2005).

Two 4G standards Long Term Evolution (LTE) and WiMAX uses key technologies like Orthogonal Frequency Division Multiple Access (OFDMA) and Multiple-Input Multiple-Output (MIMO) to achieve higher peak data rates to cater high bandwidth internet applications. Long Term Evolution Advanced (LTE Advanced) is necessarily an up gradation of LTE. By using $2 \times 2$ MIMO, the LTE Advanced has achieved a peak download data rates of up to 1 Gbit/s and peak upload data rates of up to 500 Mbit/s (Phule & Khazi 2012).
1.3 MULTI-USER MIMO AND ITS CHALLENGES

The rapid development of MIMO systems has increased the data throughput and wide high bandwidth internet applications. The systems that have implemented this MIMO technology are 3G, Long term evolution, LTE Advanced and IEEE 802.11. The latest improvements in mobile communication systems have led to the development of several Multi-User MIMO (MU-MIMO) communication scenarios. A typical MU-MIMO mobile communication system of M users is illustrated in Figure 1.4. The MU-MIMO systems led to the development of next generation mobile communication systems and new standards. The major differences between MU-MIMO and Single-User MIMO (SU-MIMO) systems are, in MU-MIMO system the base station communicates with different mobile stations simultaneously but in SU-MIMO system the base station communicates with single mobile station, in MU-MIMO system the base station implements more number of receivers to increase the throughput of communication without compromising the reliability.

![Figure 1.4 A typical MU-MIMO mobile communication system: M=4](image-url)
The major challenges of MU-MIMO system when compared with SU-MIMO is co-channel or inter cell interference. In order to overcome this drawback, several interference suppression methods have been proposed in the literature for both uplink or multiple access channel (MAC) channel and downlink or broadcast channel. The multiple access interference in MAC channel can be efficiently cancelled at the base station by implementing optimum multi-user detection (MUD) schemes such as Maximum Likelihood MUD, Successive Interference Cancellation MUDs, or Parallel Interference Cancellation MUDs. Similarly the inter cell interference caused in broadcast channel can be overcome by efficient transmission methods. The transmission schemes that are implemented at the base station to minimize the interference in the broadcast channel are Channel Inversion, Block Diagonalization, Dirty Paper Coding (DPC) and Tomlinson-Harashima Precoding (Xiaojie et al 2013).

1.3.1 Mathematical Model for Uplink Multi-User MIMO System

Consider a $M$ user uplink MU-MIMO system with each mobile station and base station are equipped with $N_t$ and $N_r$ antennas, respectively. The multiple access channel for $M$ users is illustrated in Figure 1.5. Let us assume $x_u$, $y_{BS}$ and $H_u$ be the transmit signal from $u_{th}$ user, received signal at the base station and channel gain between the $u_{th}$ user mobile station and base station, where $x_u \in \mathbb{C}^{N_t \times 1}$, $y_{BS} \in \mathbb{C}^{N_r \times 1}$ and $H_u \in \mathbb{C}^{N_r \times N_t}$, $u = 1, 2, ..., M$. The received signal at the base station is expressed as

$$y_{BS} = H_1 x_1 + H_2 x_2 + ... + H_M x_M + n$$ (1.1)

where $n \in \mathbb{C}^{N_r \times 1}$ is the zero-mean circular symmetric complex Gaussian noise random vector (Yong et al 2010).
Figure 1.5 Multiple access channel model for multi-user MIMO system

1.3.2 Mathematical Model for Downlink Multi-User MIMO System

Consider a $M$ user downlink MU-MIMO system with base station and each mobile station are equipped with $N_t$ and $N_r$ antennas, respectively. The broadcast channel for $M$ users is illustrated in Figure 1.6. Let us assume $x$, $y_u$, and $H_u$ be the transmit signal from the base station, received signal at the $u_{th}$ user and channel gain between the base station and $u_{th}$ user mobile station, where $x \in \mathbb{C}^{N_t \times 1}$, $y_u \in \mathbb{C}^{N_r \times 1}$ and $H_u \in \mathbb{C}^{N_r \times N_t}$, $u = 1, 2, ..., M$. The received signal at the $u_{th}$ user is expressed as

$$y_u = H_u x + n_u$$

(1.2)

where $n_u \in \mathbb{C}^{N_r \times 1}$ is the zero-mean circular symmetric complex Gaussian noise random vector at the $u_{th}$ user (Yong et al 2010).
1.4 PROPOSED UPLINK MULTI-USER MISO SYSTEM

In the past few years, after successful implementation of MIMO in existing cellular mobile communication systems, several MIMO scenarios have been studied to improve the system performance. To combat fading and to achieve high download data rates, several analysis have been done in both uplink SIMO and downlink MISO channels. In this scenario, the mobile station with single antenna reduces processing complexity and reduces power consumption; the base station with multiple antennas caters the demand for high data traffic in downlink and simultaneously increases system complexity with more power consumption. Nowadays, Internet applications such as video telephony, video conferencing and gaming services demands high data rates in uplink of cellular systems. In order to increase the data throughput in uplink and reduce the system complexity at base station, an uplink multi-user single output (MU-MISO) system is proposed in this research work. The uplink multi-user MISO system is illustrated in Figure 1.7.
Figure 1.7 An uplink multi-user MISO system

1.4.1 Mathematical Model for Uplink Multi-User MISO System

A $M$ user uplink MU-MISO system with each mobile station equipped with $N_t$ antennas and single antenna in base station is considered. The multiple access channel for $M$ independent users is same as illustrated in Figure 1.5, in which, $x_u$, $y_{BS}$ and $H_u$ be the transmit signal from $u_{th}$ user, received signal at the base station and channel gain between the $u_{th}$ user mobile station and base station, where $x_u \in \mathbb{C}^{N_t \times 1}$, $y_{BS} \in \mathbb{C}^{1 \times 1}$ and $H_u \in \mathbb{C}^{1 \times N_t}$, $u = 1, 2, \ldots, M$. The received signal at the base station is expressed as

$$y_{BS} = h_1 x_1 + h_2 x_2 + \ldots + h_M x_M + n$$

$$= [h_1 \ h_2 \ \ldots \ \ h_M] \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_M \end{bmatrix} + n \quad (1.3)$$

where $n \in \mathbb{C}^{1 \times 1}$ is the zero-mean circular symmetric complex Gaussian noise random vector.
1.5 MULTIUSER DETECTION SCHEMES FOR UPLINK MOBILE COMMUNICATION SYSTEMS

In the uplink of mobile communication systems, the base station implements multiuser detection methods to suppress the multiple access interference that occurs either due to improper transmission schemes or poor channel conditions. The multiuser detection schemes increases the system efficiency by exploiting the available structure of the multiple access interference and channel resources. The multiuser detection schemes in general are of two categories: optimum detection or suboptimum detection. The optimum detection scheme is of less complexity but converges slower whereas the suboptimum detection method converges faster with high complexity. The overloaded systems cannot implement optimum detection methods which needs less convergence time for detection. The suboptimum detection is further classified in to linear and nonlinear detectors. In this section, multiuser detection methods for CDMA systems (decorrelating detection, MMSE detection and parallel interference cancellation detection) and OFDMA systems (parallel interference cancellation) are discussed.

1.5.1 Decorrelating Detector

The natural phenomenon of decorrelating receiver is to totally remove the multiuser interference effects and its term in the received signal. The decorrelating detector is illustrated in Figure 1.8. The main disadvantage of this method is the high noise content in the detected signal. The performance of the decorrelating detector will be optimum when the amplitudes of each user are known at the receiver. The multiple access interference is totally suppressed by taking the product of the received signal with the inverse of the cross correlation matrix. The decision metric used at the decorrelating receiver is given in the Equation (1.4).
\[ \hat{b} = R^{-1}y^{(1)} \]  

(1.4)

This multiuser detection scheme completely retrieves the message signals in a noiseless environment and outperforms the matched filter performance. In a noisy environment the performance of detection scheme can be increased by selecting spreading codes which are closely orthogonal to each other. If all the spreading codes are exactly orthogonal to each other then the effect of noise term can be eliminated. Since the orthogonality of the spreading codes is lost due to multipath channel fading, this ideal consideration cannot be implemented. The system performance will severely degrade during the situation when the spreading codes are highly correlated. In general, the decorrelating detector show better performance at many circumstances and is used for performance comparison with other multiple access interference cancellation schemes.

![Figure 1.8 Decorrelating detector](image-url)
1.5.2 Minimum Mean-Squared Error Detector

The MMSE detector is an advanced linear multiuser detector which is assumed that each user’s signal strength is known at the receiver. The MMSE detector is illustrated in Figure 1.9. The MMSE detector minimizes the mean squared error between the detector output and the original data by using linear transformation. The decision metric used at the MMSE receiver is given by

\[ \hat{b} = [R + \sigma^2 A]^{-1} y^{(1)} \]  \hspace{1cm} (1.5)

The above equation explains that the MMSE detector is generally a trade-off between the conventional and decorrelating multiuser detector. At peak signal to noise ratio which approaches infinity, the term \([R + \sigma^2 A]^{-1}\) from the above equation equals \(R^{-1}\), which results in decorrelating detector. If the signal to noise ratio approaches zero then the term \([R + \sigma^2 A]^{-1}\) tend to zero, which is simply the conventional detector.

Figure 1.9 Minimum mean-squared error detector
1.5.3 Successive Interference Cancellation

The successive interference cancellation and parallel interference cancellation are non linear multiuser detection schemes. In this type of detectors, the final decision metric is formed by means of mapping the conventional detector output nonlinearly. These detectors are also called as decision driven based detectors. From the name itself it implies that these detectors take tentative decision for the multiple access interference estimation. The MAI estimation is used for interference cancellation in the received signal. This interference cancellation method can be implemented through several stages. If the interference cancellation in each stage is done successively then the method is said to be as successive interference cancellation.

In this successive interference cancellation, the MAI interference affected user’s data are detected in a successive manner. In the receiver, the users are categorized corresponding to their received signal power in aspect to find the strongest user. This is done since the strongest user data can be detected with high accuracy. Once the strongest user’s data is detected, the next strongest user will be detected successively on the altered received signal. This process is done without affecting the strongest user and is extended till all the users are detected.

The advantage of successive interference cancellation scheme is less complex in implementation when compared with other kind of multiple access interference cancellation schemes. The major drawbacks of SIC scheme are delay in user detection which increases linearly when there is increase in number of users; when the decision of strongest user detection goes wrong then the poor decision may spread through the detection of other users; ranking procedure has to be made each and every time when the users are changed.
1.5.4 Parallel Interference Cancellation for both Uplink CDMA and OFDMA based Systems

In contrast to the above discussed SIC scheme, the parallel interference cancellation scheme in each stage cancels the multiple access interference in parallel. In general, the parallel interference cancellation is a multistage multiuser detection method. The PIC method is illustrated in Figure 1.10. In each stage at PIC the tentative decision from the previous stage is used for MAI signal estimation. The estimated MAI is subtracted from the received signal and the output is used for MAI estimation in the next stage. When compared with successive interference cancellation scheme the interference cancellation process is much faster in parallel interference cancellation scheme. The initial stage in PIC scheme takes decision statistics from the conventional detector output used in the first stage. In this research PIC scheme is used for MAI suppression in both CDMA and OFDMA based systems. In OFDMA based system the PIC scheme takes the decision statistics from the DFT output after carrier frequency offset compensation.

Figure 1.10 A multistage PIC scheme
1.6 OPTIMIZATION IN MOBILE COMMUNICATION SYSTEMS

High data-rate wireless communications have attracted significant interest due to longevity of communication and establish a substantial research challenge in the context of the emerging wireless standards. The research in MIMO is under progress for next generation wireless communication systems. The study of MIMO signal detection is an attracting research in wireless system. There are numerous challenging issues in MIMO detection; one is the detection of symbols with reduced BER. Once the optimum receiver is designed then the problems are facile. Transmission over a wireless channel has lots of impediment in the received signal like path loss, channel fading, addition of noise and interference from the neighboring channels etc. The use of multiple antennas can palliate these fading effects. MIMO has been used in wireless standards like LTE, WLAN (IEEE802.11) etc. To combat channel fading, high spectral efficiency and good link range, multiple antennas are used in both transmitter as well as in receiver side. MIMO signal detection algorithms like Zero Forcing (ZF), Minimum Mean Square Error (MMSE) and Successive Interference Cancellation (SIC) requires low complexity since they are demand in practical applications. The performances of these algorithms are poor when the signal to noise ratio (SNR) is low. The principles of SIC and Parallel Interference Cancellation (PIC) multi-user detection (MUD) can remove the interference in the iteration manner, but these nonlinear MUD techniques suffer from error propagation (Shaalan et al 2013) due to the error in initial stages.

To achieve satisfactory results Maximum Likelihood (ML) signal detection is used in MIMO systems. Though ML exhibits an optimum performance, the increase in number of antennas increases the computation
complexity exponentially. In order to reduce the complexity this research concentrates on the Evolutionary algorithms (EA) and the possibility of hybrid EA in ML signal detection.

The MIMO technique attracts researchers because the ultimate aim of MIMO is to increase the channel capacity without extra transmit power and frequency band. Evolutionary algorithms have already proved their great ability in the optimization of other research areas like Cryptanalysis, Electromagnetics, Network traffic reduction etc. Evolutionary algorithms also become increasingly popular recently in other domains, ranging from core engineering to computer science; and mathematics to physics. Among these diverse applications, evolutionary algorithms are also applied in wireless communication.

EA like Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and Simulated Annealing have been successfully applied in the field MIMO detection. Though the optimization techniques are applied in these areas to reduce the problem complexity, substantial corpus of theoretical results using hybrid EA are available which offers useful guidelines to solve the complex problems efficaciously. Since ML signal detection involves in complex problem, here we applied a novel hybrid EA named Genetic Swarm Optimisation to reduce the search space/signal constellation effectively even when the number of antennas are increased.

1.7 LITERATURE REVIEW

This section reviews the previous research done in cancelling the interferences introduced in mobile communication systems. The literature review in detail pertaining to the following is done:
- Multiple access interference cancellation in CDMA systems
- Multiple access interference cancellation in OFDMA systems
- Inter antenna interference cancellation in MIMO systems
- MAI and IAI cancellation in MIMO CDMA systems
- MAI and IAI cancellation in MIMO OFDMA systems
- Interference cancellation using optimization techniques in MIMO systems

1.7.1 Multiple Access Interference Cancellation in CDMA Systems

Robler et al (2010) have analyzed matched filter-based soft decision interference cancellation receiver algorithm in downlink of DS-CDMA system. In this research work, the performance of the algorithm was analyzed in multipath channels with square Quadrature amplitude constellations. This paper considers exact power density function for strong residual interference and Gaussian assumption for weak residual interference. The receiver performance is compared with UMTS scenario. This paper concludes that by using this hybrid scheme, bit error rate (BER) is reduced by 80 % for high signal to noise ratio (SNR).

To mitigate multipath and to avoid multipath channel estimation issues in multicarrier CDMA (MC-CDMA) system, a low complexity multicarrier successive interference cancellation (MC-SIC) scheme was proposed by Andrews & Meng (2004). The proposed system improved the capacity of the system in a multipath fading environment. In this work an optimum power control distribution for the system was derived with channel estimation error. The simulated results show that the proposed system
performance in multipath fading environment is comparable to the performance of the system in flat fading channel with reduced channel estimation error.

The major problems in direct sequence CDMA (DS-CDMA) system are near/far effects, fading and multiple access interference caused by other users in the system. A simple multiuser detection scheme was analysed in DS-CDMA system by Pulin & Jack (1994). In this work, a simple successive interference cancellation scheme was analysed in DS-CDMA system with perfect channel estimation. The systems uses coherent BPSK modulation for transmission. A linear correlator is used at the front end of the receiver, where the output of the correlator is used for parameter estimation. The system performance is also analyzed with non coherent M-ary orthogonal modulation. The simulation results show that the performance of simple SIC scheme with coherent and non coherent modulation schemes has low BER in high signal to noise ratio.

To suppress the multiple access interference and inter symbol interference (ISI) in CDMA mobile communication systems, a lesser complexity soft input soft output (SISO) multiuser detector was proposed by Xiaodong & Vincent (1999). In this research work, an asynchronous DS-CDMA system with convolution coding is considered. Iterative interference suppression is used in the receiver; where in each iteration extrinsic information is extracted from detection and decoding stages which are used for successive iterations. The system also incorporates linear MMSE filtering for interference mitigation. The authors conclude that the simulation results of the proposed system show the performance equivalent to single user system at high signal to noise ratio.

interference cancellation (WLPIC) is the multistage MAI cancellation scheme where in every stage the estimation of MAI is weighted by a factor before interference cancellation. Rayleigh fading and diversity channels are considered in this research work. The average signal to interference ratio (SIR) is maximized at the output of each stage to get optimum weights. The optimum weights for each stage are derived in closed form. The authors conclude that this WLPIC scheme show better results compared to matched filter and conventional linear parallel interference cancellation. In CLPIC, the interference is cancelled at each stage without weighting factor. The simulation results show that the system performs well on Rayleigh fading and diversity channels.

1.7.2 Multiple Access Interference Cancellation in OFDMA Systems

Hamid et al (2011) compared filter bank multicarrier (FBMC) with orthogonal frequency division multiple access (OFDMA) in the uplink of a multiple access cellular mobile communications system. The major drawback of OFDMA based mobile communication system is carrier frequency offset (CFO) among multiple users in the system. To overcome the high complexity methods for cancelling the interference due to CFO at base station, FBMC technique is used in the proposed system. The simulation results shows that in FBMC based system near perfect performance is attained without complex interference cancellation techniques at the receiver.

In uplink OFDMA mobile communication systems, each user has different CFO which makes the system more complex to cancel the interference at the receiver. Yucek & Arslan (2006) proposed successive interference cancellation algorithm along with decorrelator for uplink OFDMA system to cancel multiple access interference cancellation and inter carrier interference (ICI). The author concludes that the proposed SIC algorithm with decorrelator suppresses the interference to the maximum and
has very less complexity. The simulation results show that the performance of uplink OFDMA system with SIC and decorrelator has low BER in multipath fading channels.

Manohar et al (2007) proposed a novel interference cancellation scheme for multiuser interference suppression in uplink OFDMA systems. In this proposed interference cancellation scheme, the CFO compensation is done in time domain and the output is fed to DFT operations which are carried out for each user separately. The DFT outputs are used for multistage parallel interference cancellation. This scheme uses soft values of the output obtained from previous stages for parameter estimation for interference cancellation. The proposed MUI cancellation scheme is compared with Huang-Letaief Circular Convolution (HLCC) scheme for analysis. The authors conclude that the multistage LPIC scheme has lesser complexity compared to HLCC scheme for interference cancellation.

A robust multi-access orthogonal frequency division system was proposed by Tsai & Lin (2005) to mitigate multi-access interference due to carrier frequency offset effect. In this work the MAI due to CFO is cancelled by selecting correct set of orthogonal codes. Antisymmetric Hadamard-Walsh code words were used in this system. Normally an OFDM system will be MAI free in the absence of CFO effect, by implementing this proposed scheme, the system was found MAI free even in the presence of CFO. The simulation results show that the proposed system outperforms OFDMA and MC-CDMA systems by selecting correct code selection.

An OFDMA based cognitive radio using convolutional coding was analyzed by Liwen et al (2010). The secondary users who are asynchronized because of random timing effects causes very severe multiple access interference to the well synchronized primary user at the receiver. By knowing the secondary users’ transmitted powers, distance to the primary
user, the multiple access interference is estimated. An error floor prediction method was also proposed by deriving the average probability of error and pair wise error probability for the primary user. This research investigates the trade off among the primary user MAI and secondary users’ performances using simulations.

1.7.3 Inter Antenna Interference Cancellation in MIMO Systems

Boronka & Speidel (2003) presented an efficient multiple-input multiple-output system with Bell Laboratories Layered Space-Time (BLAST) signal detection algorithm. In MIMO systems the data streams from the transmitter are emitted from multiple antennas which causes inter antenna interference (IAI) due to multipath fading and Doppler spread in the channel. To overcome this problem, a convolutional encoder is used at the transmitter which acts as outer encoder, where as QAM mapper is used as inner encoder. The QAM demapper with APP decoder is used at the receiver. In this research work, the performance of the proposed scheme was analyzed for $4 \times 4$, $6 \times 6$, and $8 \times 8$ MIMO systems in fading channels. The complexity of the proposed system is very less compared to MAP detector without BLAST signal detection.

Kumagai et al (2013) proposed a novel adaptive IAI cancellation scheme using joint transmitter and receiver minimum mean square error (MMSE) filtering in single carrier MIMO (SC-MIMO) system. The MIMO channel is transformed to eigen modes for inter antenna interference cancellation and by suitable MMSE power allocation the inter symbol interference is mitigated. The signal to interference noise ratio between eigen modes are narrowed by means of using joint rank adaptation and adaptive modulation. The simulation results confirmed that the proposed adaptive scheme clearly increases the BER performance when compared to conventional eigen modes based single carrier MIMO systems.
Ketonen et al (2011) proposed a two stage receiver for inter symbol interference and inter antenna interference suppression. An uplink single user single carrier frequency division multiple access (SC-FDMA) system is considered in this work. In the first stage sphere detection algorithms are implemented in time domain to cancel IAI and in the second stage minimum mean square error equalization is implemented in frequency domain to mitigate ISI. The authors conclude that the equalizer perform can be further improved through optimized equalizer. The authors also observed significant BER performance in high signal to noise ratio.

A space time block code (STBC) MIMO system with MMSE filtering based turbo frequency domain equalization (FDE) was considered by Wanqiu (2013). The transmit antennas are doubled to achieve high transmit diversity gain. The frequency domain equalization output is fed to soft interference cancellation to suppress inter antenna interference and inter symbol interference. The author considered different channel conditions for performance evaluation of the system. The simulation results show that the BER performance of the proposed system is high compared to the conventional MIMO systems in high signal to noise ratio.

Krishnan & Reddy (2007) proposed efficient signal detection algorithms for MIMO systems. The performance of maximum likelihood (ML) signal detection is high compared to other signal detection algorithms used in MIMO systems. Due to high complexity of ML detection, a modified V-BLAST signal detection is proposed in this paper. The proposed algorithm combines zero-forcing successive interference cancellation (ZF-SIC) scheme with reduced ML search algorithm. On combining these two schemes the performance of the system is comparable to ML detection with less complexity. In this research minimum mean square error (MMSE-SIC) scheme with reduced ML search algorithm is also analyzed. A $5 \times 5$ MIMO
system is considered for the performance evaluation of the proposed algorithms. The simulation output show that the proposed algorithms give better results and the performance of the system is considerably equivalent to ML detection based MIMO system.

1.7.4 MAI and IAI Cancellation in MIMO CDMA Systems

MIMO is a key technology in 3G cellular mobile communication systems. The major 3G standards like High Speed Packet Access (HSPA) and High Speed Packet Access Advanced (HSPA+) uses MIMO with CDMA technology for achieving high data throughput and to overcome fading in multipath channels. Yin et al (2012) proposed an uplink MIMO receiver employing frequency domain equalizer along with partial iterative interference cancellation scheme to suppress inter antenna interference and inter chip interference in 3G systems. The author concludes that this partial interference cancellation scheme has least performance loss compared with non partial interference cancellation scheme.

In the research work of Park & Lee (2008), a multicode MIMO system is considered for analysis. In the receiver less complex two-stage successive interference cancellation detection is implemented. The authors have also presented the transmit power allocation schemes to increase the BER performance for the proposed detection scheme. A two stage power allocation scheme is derived and compared with the joint power allocation scheme. The receiver is designed in such a way it supports both variable and constant power ratio algorithms which reduces the feedback mechanism and its overhead. The author concludes that the variable power ratio scheme and constant power ratio scheme shows similar performance and is equivalent to the two stage power allocation scheme even when the number of antennas are increased both in transmitter and receiver.
The frequency selective fading in MIMO channels introduces interstream interference in CDMA based MIMO systems. To overcome the interstream interference in frequency selective MIMO channels, Hyougyoul et al. (2012) proposed the iterative interstream interference cancellation along with SIMO equalization for enhancing the performance of the proposed system. The authors have also analyzed that the SIMO equalizer is efficient in frequency selective MIMO channels compared to MIMO equalizer. The simulation results show that the proposed interference cancellation scheme with SIMO equalizer shows better performance than linear MMSE equalization. The authors conclude that this scheme can be implemented in any system in frequency selective MIMO channels.

Pritam & Chockalingam (2011) proposed a simple detection method which relies on local neighbourhood search algorithm. The detection method is proposed for uplink multicode multi-antenna direct sequence CDMA systems. The higher order modulation scheme is used in the system. This less complexity detection scheme performs well and shows near performance as that of single user system. The author concludes that this simple, scalable local neighbourhood search detection method can be implemented in any MIMO-CDMA systems for achieving high data throughput.

1.7.5 MAI and IAI Cancellation in MIMO OFDMA Systems

Long term evolution (LTE) is a 4G mobile communication standard. A potential research takes place in this standard to improve the system performance by implementing methods to increase high data rate and to reduce all possible interferences. Wang et al. (2008) proposed a novel thresholded interference cancellation algorithm for uplink LTE multiuser MIMO systems. Conventional cyclic redundancy check (CRC) based interference cancellation scheme consumes more timing for interference
mitigation. In this proposed scheme, by setting optimum threshold the time consumption is reduced with least performance reduction. The research paper gives an idea to set optimum threshold for all modulation and coding schemes. The author concludes that this method can be extended to multiuser MIMO OFDM systems.

Zhang et al (2010) have analyzed the BER performance of MIMO OFDM systems with carrier frequency offset and mainly the errors occurred during channel estimation. The authors have also analyzed the intercarrier interference and interantenna interference caused due to change in residual frequency offsets. The average SINR, bit error rate performance of equal gain combining are derived for analysis. From the analysis, it is shown that the estimation of channel and frequency offset errors are random variables (RV) with zero mean. The statistics of these random variables are clear studied and the reason for system degradation can be analysed using these RVs.

Hammarberg et al (2012) have analyzed the packet based multiuser multiple input multiple output orthogonal frequency division multiplexing uplink system performance and its trade-off with complexity. In this research an iterative receivers consisting of multiuser detector, channel estimator and convolution decoding scheme are considered. The system performance is studied using two suboptimum parallel interference cancellation and one optimum maximum a-posteriori probability (MAP) multiuser detection schemes. Three different channel estimation algorithms are considered for analysis which are optimum joint minimum mean square error estimation, Krylov subspace based MMSE estimation and sub optimum space alternating generalized expectation – maximization (SAGE) estimation algorithms. The authors have inferred that the high complexity algorithms converge faster and the low complexity algorithms converge slower but with similar BER
performance as that of high complexity algorithms. The authors conclude that sub optimum based less complex algorithms are best compared to high complexity and simple receivers.

For MIMO-OFDM multiuser systems, a two stage multiuser interference cancellation framework is proposed by Tang & Heath (2005). To mitigate co-channel interference, reduce asynchronism and cancel inter-carrier interference, time domain equalization is used in the first stage of the receiver. For signal detection and to compensate channel distortion a frequency domain based per tone scalar equalization is used in second stage after time domain equalization in the receiver. The authors have formulated and given a solution for the problem in finding the equalizer coefficients and channel impulse responses after equalization by maximizing the SINR through training based joint optimization. To reduce the system complexity and increase the system performance different variations in maximizing SINR formulation are proposed by the authors. The authors conclude that the proposed methods show high BER and SINR performance and also reduce co-channel interference.

Yin & Cavallaro (2012) proposed a novel inter-symbol interference and inter-antenna interference cancellation scheme for an LTE uplink MIMO system. The scheme increases the system performance with less computation and complexity. The proposed interference cancellation scheme uses time domain equalization and partial interference cancellation apart from frequency domain equalization. This interference cancellation scheme is implemented it on FPGA which resulted in reduced area, low data storage and less feedback latency. The simulation results show the proposed scheme increases the system performance in different channel conditions. The author
concludes that the complexity of the scheme is less compared with long term evolution receiver and also suitable for software defined radio implementation.

Ahrens et al (2007) have presented and analyzed a novel decentralized multiuser detection scheme in uplink MIMO-OFDM systems. This decentralized multiuser detection scheme can be said to be as a promising interference cancellation scheme in next generation mobile communication systems. In centralized interference cancellation approach a joint interference cancellation schemes are in need at the central processing unit where setups like costly optical fibres or radio communication links for point to point transmission have to be implemented for data transmission to the central processing unit. This problem is overcome by this proposed decentralized interference cancellation scheme. The simulation results show that this proposed scheme BER performance outperforms centralized scheme in different channel conditions with less cost.

1.7.6 Interference Cancellation using Optimization Techniques in MIMO Systems

Shaalan et al (2013) proposed a novel Joint Channel Estimation and Partial Parallel Interference Cancellation (PPIC) scheme using Simulating Annealing (SA) or Particle Swarm Optimization (PSO) algorithms. The proposed scheme is mainly for MIMO-SDMA OFDM system. The weights used in the PPIC for multiple interference cancellation are computed by SA and PSO. This scheme is an efficient solution to MUD and MIMO channel matrix estimation in overload scenario. From the simulation results, the adopted PSO-assisted joint channel estimation and PPIC detector outperforms the SA-assisted one in both error performance and channel estimation. Also
the complexity is also reduced in metric evaluation as well as the channel estimation/data detection issue in MIMO SDMA-OFDM systems are done successfully.

Wei et al (2012) proposed a switching detection methods based on multiple-choice knapsack problem (MCKP). Based on the linear relaxation MKCP, the authors have derived Channel Adaptive (CA)-MIMO method. The simulations results reveals that that the lower and upper bounds are tightly matched, the optimal performance evaluation of the CA-MIMO detection without solving the NP-hard MCKP have just acceptable error rate (JAER) specified by the standards, which guarantees the quality of service (QoS) for all users.

Shu et al (2008) proposed an optimal multi-user MIMO linear precoding scheme based on particle swarm optimization which aims at the maximization of the system capacity in multi-user MIMO system. As per the requirements of the simplified function, particle swarm optimization algorithm can be used to search the optimal linear precoding vectors effectively. Based on channel inversion and channel block diagonalization methods, the proposed scheme surmounts the multiuser MIMO linear precoding schemes.

Sayadi et al (2009) proposed genetic algorithm (GA) for novel application of multi objective optimization problems in multi carrier code division multiple access (MC-CDMA) system based on OFDM. In case of time varying channels at every instant of time, the computational complexity of the two linear minimum mean square error (LMMSE) filters are due to be calculated in order to estimate the channel for MUD. They also proposed a hybrid genetic algorithm (HGA) to solve multi objective optimization problems with the combination of the GA having local search (SLS) through
the iterative LMMSE approach for a downlink. There is a trade-off between bit error rate (BER) performance and computational complexity for time-varying channels.

Seyman & Taspinar (2013) proposed the Differential Evolution (DE) algorithm to reduce the search space of the ML detector and reduced the computational complexity of the symbol detection in MIMO-OFDM systems. Also they have compared with heuristic approaches like GA and PSO. From their results, ML algorithm performs better and the computational complexity is extremely high if the system has higher-order modulation constellations. The DE has reduced the BER as well as converges quickly in optimal symbol detection in MIMO-OFDM systems.

1.8 OBJECTIVES OF THE THESIS

The main objective of the thesis is to investigate the performance of multiple access interference and inter antenna interference cancellation techniques in uplink multiple-input single-output mobile communication systems under different channel conditions.

The specific objectives are as follows:

i) To propose a special case of MIMO technology (MISO) in uplink of mobile communication systems. In current scenario, the research in MIMO based mobile communication systems considers uplink SIMO and downlink MISO for advancements. The most of the research is focused on developing new technology to enable high downlink data rate to cater the mobile applications. In this research, by means of implementing MISO i.e. multiple antennas in mobile station and single antenna in base station enables high uplink data
rate caters high bandwidth applications such as video conferencing, IP telephony and interactive gaming etc. This system also reduces the computation complexity in the base station by reducing the number of antennas.

ii) To implement MISO technology in CDMA based mobile communication systems. The advantages of MISO and CDMA join together enable the mobile communication system to handle high data rate and combat channel fading effectively.

iii) To study the major challenges in uplink MISO CDMA systems such as multiple access interferences, inter antenna interferences and its causes. To identify the best interference cancellation techniques to cancel out these interferences.

iv) To investigate the joint multistage weighted linear parallel interference cancellation technique with V-BLAST signal detection technique to suppress MAI and IAI in uplink MISO CDMA system under correlated and uncorrelated Rayleigh channel conditions.

v) To implement the MISO technology in OFDMA based mobile communication systems. OFDMA is the key technology used in 4G wireless communication systems. The combination of MISO with OFDMA enables the end users to upload high data rate and combats frequency selective fading.

vi) To study the major causes of MAI interferences in uplink MISO OFDMA systems in transmitter, channel and RF front end of the base station receiver. To derive the optimum weights for multistage WLPIC scheme and investigate the performance of the WLPIC scheme in the proposed system.
To investigate the joint performance of WLPIC with V-BLAST signal detection in the uplink MISO OFDMA system.

vii) To study the Bit Error Rate performance of the proposed uplink MISO CDMA and uplink MISO OFDMA systems in different channel conditions for various signal to noise ratios through computer simulation.

viii) To propose a novel hybrid algorithm called Genetic Swarm Optimization (GSO) based Maximum Likelihood signal detection in MIMO systems. The new algorithm called GSO-ML reduces the computation complexity in increased search space when the number of antennas is increased in MIMO systems.

1.9 ORGANIZATION OF THE THESIS

Chapter 1 briefs the recent advancements in next generation mobile communication systems using MIMO technology. A new approach of using the MISO technology in uplink of mobile communication systems is proposed. The mathematical model of multiuser uplink MISO system is derived in this chapter. Several issues related to interferences in the MIMO based mobile communication system are discussed. This chapter also gives the overview of several multiple access interference and inter-antenna interference cancellation techniques. A thorough literature survey in the area of interference cancellation in MIMO based CDMA and OFDMA mobile communication systems are presented.

Chapter 2 analyses the performance of uplink CDMA based multiuser MISO system in different channel conditions. The major challenges in the proposed MSIO CDMA systems are presented. The overall system model including transmitter system model, channel model, noise considerations and receiver system model are explained. The performance of
the receiver using multistage parallel interference cancellation technique with V-BLAST signal detection is analyzed. Matlab simulations are carried out for the proposed system and the performance comparison with the conventional interference cancellation techniques is discussed.

In Chapter 3, OFDMA based uplink MISO system is proposed. A thorough study of possible MAI effects and its causes are described. The blocks in transmitter used in the proposed system are explained. The channel and noise considerations for the performance evaluation of the system are discussed. The flow of received signal and its processing methods are explained in detail. The performance analyses of the proposed system using WLPIC scheme with V-BLAST signal detection in various channel conditions are presented. The optimum weights used in multistage WLPIC scheme are derived and explained.

Chapter 4 presents a novel hybrid algorithm called Genetic Swarm Optimization (GSO) and its development in MIMO signal detection. The GSO algorithm is implemented in Maximum likelihood signal detection and its performance analyses and comparison with GA and PSO are discussed.

Chapter 5 reports the conclusion of the thesis.