1.1. Introduction

The advanced mobile phone system (AMPS) is described as the first generation mobile phone network and it was based on analogue radio systems. The second generation (2G) of mobile communications standard: global system for mobile communications (GSM) was preferred by the mobile phone market to deal with increased traffic in the mobile network. Later, third generation (3G) mobile communication network was set up to overcome the drawbacks of 2G mobile communication system. The international telecommunication union (ITU) set a number of requirements for the third generation (3G) cellular network systems that include: code division multiple access (CDMA) 2000, wide-band CDMA and time-division (TD) synchronous CDMA(s-CDMA). In the year 2012, the mobile communications sector has been introduced to the new technology: multiple-input multiple-output (MIMO) systems. The fourth generation (4G) cellular networks are expected to produce substantial solutions with larger throughput.

1.2. Multiuser Detection

Multiuser detection (MUD) is the technique that jointly detects multiple data streams overlapping in both time as well as frequency. It takes the aid of all the active users’ information to detect a single (desired) user data. MUD technique is used in CDMA systems that are widely used in 3G cellular mobile communication systems. In CDMA communication channels, quality of communication is adversely affected by the additive white Gaussian noise (AWGN), and by the interference caused from different users, that are accessing the channel simultaneously, called as multiple access interference (MAI). In early days, the approach followed to deal with MAI was to consider it as AWGN so that the matched receiver filter would be the optimized receiver. Later, the pioneer in mobile communications technology, Sergio Verdu [1] shown that this approach was wrong and derived the optimum minimum error probability receiver [2], [3] to show that the near-far effect could be solved by using the MUD algorithms considering the composition of the MAI.
CDMA systems are known to rely on the spread spectrum (SS) techniques. In SS systems, each of the data bit is multiplied by a wide-band signal termed as spreading sequence or spreading code. This process of multiplying with wide-band signal is known as spreading, and the reverse operation is referred to as de-spreading. The code sequences are pseudo noise (PN) sequences. The autocorrelation property of these spreading codes minimizes the interference such as intra-cell interference, or inter-cell interference. Development of the CDMA technique depends mainly on the spreading sequence properties. When the orthogonal nature of PN sequences are employed, the MAI can be minimized, when time synchronization exists [4].

The conventional detection is the best in AWGN environment which bear the near-far effect in the presence of MAI. If the strength of multiple interfering signals (subscribers) is larger than the strength of the desired user’s signal, deteriorates the filter performance, and the complex power control techniques are necessary to address near-far effect, which is difficult in a real-time application [5].

MUD technique attempts to overcome the CDMA system disadvantage at the receiver by nullifying most of the MAI. S. Verdu [3] proposed an optimum maximum-likelihood (ML) MUD technique. The MUD receivers can be categorized into two main groups: (i) Linear MUD (LMUD) and (ii) successive interference cancellation (SIC) detectors. In the LMUD receiver the transformation is applied to output of the filter to offer improved performance. In SIC detectors estimation of interference will be generated and iteratively removed. Additionally, there are adverse group of methods which deal with the application of the MUD techniques for practical scenarios.

Direct-sequence CDMA (DS-CDMA), a multiple access (MA) technique, has gained considerable attention of mobile communications researchers and used in many cellular and mobile communication systems. Researchers all over the world have explored the prospective benefits of optimum MUD techniques to combat MAI and inter-symbol interference (ISI). Complexity of optimum multiuser detector, based on maximum likelihood (ML) criterion, rise exponentially with more active users [6].
Suboptimal multiuser detectors [7] are the alternatives with identical performance. The decorrelating detector presented in [8] is used to overcome the near-far problem as well as MAI. This decorrelator requires no knowledge of received signal amplitudes but it requires matrix inversion, which increases the computational complexity.

Blind MUD can be used to reduce the ISI and also to improve system throughput [9]-[11]. Subspace-based blind MUD technique is known for its better performance among all the other blind methods [12]. In [13], an improved Subspace-based robust blind MUD technique for synchronous and asynchronous CDMA systems over non-Gaussian channels is presented. A new adaptive algorithm for blind MUD of coherent BPSK signals in DS-CDMA systems operating under non-Gaussian impulsive noise is considered in [14].

1.3. Literature Survey

Multipath fading and shadowing degrades the performance of any wireless communication system which can be mitigated by the diversity combining techniques. Diversity is a technique that combines several copies of information-bearing signal to increase the signal-to-noise ratio (SNR) which is used in many of wireless communication systems. Selection combining (SC), maximal ratio combining (MRC), equal gain combining (EGC), switch and stay combining (SSC) and threshold combining (TC) are the commonly employed receive diversity combining techniques.

In the literature, the Nakagami-$m$ distribution received significant consideration as it offers superior fit for measurement data in diverse multi-path fading environments [15] like Rayleigh, Log-normal or Rician channels. It can also accommodate fading conditions that are more or less severe than that of the Rayleigh fading channel. Nakagami-$m$ fading channel model is frequently encountered in many practical communication systems like cellular mobile communications system [16]. Performance analysis of MUD in synchronous DS-CDMA communication system using decision feedback (DFB) detectors with Nakagami fading in single path is in [17] by deriving the probability of error using lower bounds. Recently, [18] analyzed decorrelator receiver for DS-CDMA system, with RAKE reception and both MRC and SC diversity, through Nakagami fading channel. Performance of digital cellular
systems in a non-selective frequency Rayleigh fading channel with lognormal shadowing, with the effects of white Gaussian noise, in narrow-band impulsive noise and co-channel interference is presented in [19].

Experimental results establish the existence of impulsive noise in outdoor mobile radio communication channels, is due to switching transients or automobile ignition, or as a result of human-made or natural electromagnetic and acoustic interference, and in indoor communication channels [20], [21].

Work of [22] addresses the MUD problem in non-Gaussian channels using Huber and Hampel based estimators. A proposed $M$-estimator based robust MUD technique in non-Gaussian Rayleigh fading channels is presented in [22].

Recently communications researchers have explored the potential benefits of optimization techniques to MUD for DS-CDMA systems [22-27]. In [24], robust MUD technique for DS-CDMA systems by implementing Huber’s $M$-estimator based detector using genetic algorithm (GA) is presented and proved that the detector is robust against heavy-tailed impulsive noise. Particle swarm optimization (PSO) algorithm has applied [25] to detect received data bit.

In [7], the performance of optimum receivers designed to detect signals embedded in impulsive noise is examined. In this work, the impulsive noise is modeled as an infinite variance symmetric alpha-stable random process, and compared it against the performance of four different suboptimum receivers. As a measure of receiver performance, asymptotic expressions for the probability of error for each receiver are derived and compared it to the probability of error calculated by extensive Monte-Carlo simulations.

Design of practical low-complexity DS-CDMA receivers is proposed from the Wiener reconstruction-filter point of view in [10]. These receivers exhibit minimal optimization requirements and near-matched-filter (MF) operational complexity. The results presented in this work suggested that the blind auxiliary-vector receiver compares favorably, both complexity-wise and performance-wise, to MUD such as the minimum output energy (MOE) and the decorrelating receiver.
In the works of [11], a blind multiuser detection technique for array processing and CDMA systems, that does not require knowledge of the array geometry or transmitter signature sequences, is presented. An adaptive algorithm for separating the signal subspace from the noise subspace and an adaptive whitener based on linear prediction is developed, which offers low complexity, fast convergence, and compatibility with shaped signal constellations, near-Wiener steady-state performance, and optimal near-far resistance.

The performance analysis of MUD scheme in a synchronous DS-CDMA system using decorrelating and decision feedback (DFB) receivers over single path Nakagami fading channel is presented in [17]. The lower bounds of the receivers BER are derived to show the performance of DFB receiver over Nakagami fading channels.

In [18], synchronous multiuser receivers that combine antenna diversity, RAKE reception, and a multipath decorrelator for MAI cancellation are analyzed over Nakagami fading channel using MRC. A coherent BPSK modulation scheme employing DS-CDMA is considered in this work.

In [28], the problem of designing a multiuser detector for synchronous CDMA systems is considered, where the signature matrix is subject to structured uncertainties. Based on the framework of robust semidefinite programming (SDP), this work suggested an approximation to the robust multiuser detector that can be obtained as a solution to an SDP, which can be solved efficiently.

The problem of designing a blind multiuser CDMA detector is considered in this work [29]. This work presented a convex formulation for this problem by using the second order cone (SOC) programming.

X. Wang et al [20] developed robust multiuser detection techniques, based on the $M$-estimation method for robust regression, to combat MAI and impulsive noise in synchronous/asynchronous CDMA systems. This work also developed a subspace-based technique for blind adaptive implementation of the robust multiuser detectors.
The work of [30] deals with the problem of MUD in DS-CDMA systems over fading channels with impulsive noise. An $M$-estimator-based structure for noncoherent demodulation of DPSK signals transmitted simultaneously via a CDMA flat-fading channel and embedded in impulsive noise, is proposed and analyzed.

In [8], a robust multiuser detector for combating MAI and impulsive noise in DS-CDMA communication system is considered. This detector is essentially a robust version of the linear decorrelating multiuser detector. The decorrelating detector is robustified based on the Hampel's $M$-estimator.

A new $M$-estimator based structure for non-coherent demodulation of DPSK signals transmitted simultaneously via DS-CDMA flat-fading channel embedded in impulsive noise is proposed in [14]. The gross error sensitivity for the proposed estimator is analyzed and shown that the proposed $M$-estimator based detector performs better when compared to LS, Huber and Hampel estimator based detectors.

The problem of estimating information symbols transmitted through non-Gaussian multipath CDMA wireless channels with a phased array is considered in [31]. This work proposed a new robust estimator based on the Huber's estimator. Researchers of this work also analyzed the estimation accuracy of direction of arrival (DOA) and information signals by Monte Carlo simulations.

A nonlinear $M$-estimation approach is proposed in [32] to solve the MUD problem in asynchronous CDMA systems where the ambient noise is impulsive and the delays are not known. In this work, the unknown delays are treated as nuisance parameters and the transmitted symbols as parameters of interest. This work also analyzed the asymptotic performance of the nonlinear $M$-estimator based detector.

Recently, work of [5] considered the performance of CDMA systems over fading channels with impulsive noise by deriving the closed-form expressions for BER. The performance of linear CDMA detectors, operating in an environment with interference due to non-Gaussian noise and time mismatch is also considered. The MRC and post detection combining (PDC) are used to achieve diversity reception.
A novel adaptive robust multi-user detector for CDMA using a real-coded genetic algorithm (GA) is proposed in [23]. In this work, the GA is used to implement Huber’s $M$-estimator and proved that it is robust against heavy-tailed impulsive noise. It is also shown that the GA approach provides good adaptive impulsive noise rejection capability.

In the works of [24], an evolutionary algorithm, called particle swarm optimization (PSO), to develop a suboptimal MUD strategy. The decorrelating detector (DD) is used as the first stage to initialize the PSO-based MUD. Then, the PSO algorithm is applied to detect the received data bit by optimizing an objective function incorporating the linear system of the DD.

Research work presented in [25] deals with robust blind linear minimum mean square error (LMMSE) detection using the PSO algorithm in the presence of spreading code mismatch. This work shows that the PSO algorithm incorporating the LMMSE detector can significantly improve the BER and the system capacity. A blind LMMSE scheme is also proposed and combined with PSO to form a robust blind detector under spreading sequence mismatch.

By improving binary PSO (BPSO) algorithm and applying it in DS-CDMA system as a MUD algorithm, a BPSO-MUD is proposed in [26], which have significant performance improvements over conventional detection and are easy to be applied in CDMA system.

To reduce computation complexity of the optimal multiuser detector, an algorithm that employs discrete shuffled frog leaping for the multi-user detection problem (DSFLA-MUD) is proposed in [27]. This work proved that the proposed DSFLA-MUD has significant performance improvement over conventional receivers and previous multi-user detectors based on the genetic algorithm (GA) and particle swarm optimization algorithm (PSO) in terms of convergence, capacity of system and near-far resistance.
The multiuser detection of space coded MIMO-CDMA signals in the downlink direction with channel estimation error is investigated in [33]. The performance of the DD under different channel estimation errors, timing errors, and impulsive noise is investigated. A new robust decorrelating detector (RDD) is also proposed which compensates the channel estimation errors by modifying the channel matrix in the system and its performance is superior to that of the DD.

A novel contribution to improve the performance of DD by the addition of a nonlinear clipper in order to eliminate impulsive components is presented in [34]. The system is studied under multipath fading with impulsive noise. It is assumed that the user signals have unequal powers (near/far effect) which make it challenging to determine the threshold in the clipper structure. These cases are studied and it is shown that the proposed robust receiver reduces the impact of impulsive noise by eliminating extreme amplitudes.

Space-time spreading has been employed by [35] to exploit the spatial diversity in MIMO DS-CDMA systems. In this work, the performance of space-time spreading (STS) and transmit diversity in the uplink of a MIMO DS-CDMA system over Nakagami-m fading channels is investigated.

Studies of [36] proposed a generalization of the point-to-point narrowband Bell Labs layered space-time (BLAST) system to a wideband MA system which simultaneously supports multiple users through code spreading. A novel technique for determining the system spectral efficiency (measured in bits per second per Hertz per cell sector) by incorporating the link level results with system level outage simulations is also presented.

Recently, [37] presented a brief survey of numerous MUD techniques which have been developed for optimum MAI cancellation to improve BER, channel capacity and to reduce the computational complexity.

Researcher of [38] describes a successive MUD technique for DS-CDMA systems. In this work a successive MUD scheme is proposed to mitigate the effects of MUI.
The contributory work of [39] derives and analyzes a novel block fast Fourier transform (FFT) based joint detection algorithm. This work compares the performance and complexity of the novel block-FFT based joint detector to that of the Cholesky based joint detector and single user detection algorithms. The novel algorithm can operate at chip rate sampling, as well as higher sampling rates. For the performance/complexity analysis, the time division duplex (TDD) mode of a wideband CDMA (WCDMA) is considered. Moreover, the work proved that the novel method can also be applied to any generic MIMO system.

In the work of [40] a simple and efficient methodology for tuning the input parameters applied to the ant colony optimization MUD (ACO-MUD) in DS-CDMA systems over Rayleigh fading channel is proposed. The performance of the ACO-MUD is analyzed via Monte-Carlo simulations and found better when compared to PSO-MUD.

In the work presented by [41], PSO is applied to solve joint MUD problem in the CDMA systems over multipath Rayleigh fading channel, to reduce the computational complexity. In this proposal, conventional detector is used as the first stage to initialize the PSO algorithm and then time-varying acceleration coefficients are used.

However, the problem of MUD for DS-CDMA systems over shadowed fading channels in the presence of non-Gaussian noise is not considered in the literature. In order to achieve more realistic channel models, the fading and shadowing effects should be considered simultaneously. Many composite channel models such as Rayleigh/lognormal, Rician/lognormal and Nakagami/lognormal were proposed in the literature. With these composite fading models, the performance analysis of communication system under consideration becomes difficult. Another composite model is the GK fading channel which allows the mathematical tractability of system performance analysis. Hence, this work considers the $M$-estimation based multiuser detection technique for DS-CDMA systems on GK fading channel (shadowed fading channel) in the presence of non-Gaussian impulsive noise (modeled by two-term Gaussian mixture model, Middleton Class-A model and Laplace model).
1.4. Objectives of Thesis

- The analysis of multiuser detector for DS-CDMA over fading channels in the presence of impulsive noise.
- The analysis of multiuser detector for MIMO DS-CDMA systems over Nakagami-$m$ fading channels.
- The analysis of multiuser detector for DS-CDMA systems over GK fading channels in the presence of impulsive noise.
- The analysis of PSO and CL-PSO based multiuser detector for DS-CDMA systems in noisy fading channels.

1.5. Contributions of Thesis

In this thesis, the performance analysis of robust multiuser detector for DS-CDMA systems in noisy fading channels is investigated. Further, the performance analysis of robust multiuser detector for MIMO DS-CDMA systems in noisy fading channels is also investigated. Robust MUD technique using PSO is implemented and the performance of PSO-based $M$-decorrelator over noisy fading channels is analyzed.

1.6. Organization of the Thesis

The leftover part of the thesis is developed as: Chapter 1 deals with the introduction and author contributions. Literature review for statistical models of noisy fading channels is provided in Chapter 2. It also explains the impulsive noise models and the corresponding mathematical models for the impulsive noise. Chapter 3 introduces robust MUD in non-Gaussian fading channels. The MIMO channel model and the performance of MIMO DS-CDMA system is provided in Chapter 4. The analysis of PSO and comprehensive-learning (CL) PSO based robust MUD over fading channels is presented in Chapter 5. Finally, conclusions and key results of the thesis are summarized in Chapter 6.
1.7. Summary

This chapter presented the introduction to MUD technique. Literature survey has been conducted and the works of important contributions towards MUD for DS-CDMA systems over fading channels in the presence of impulsive noise is also presented. Further, the issue of MUD for DS-CDMA systems in the presence of combined effects of fading and shadowing along with impulsive noise is also presented. Later, the main objectives and contributions of the research work is discussed. Finally, the organization of the thesis is also presented.