Parameter Estimation of Adaptive Receiver for MC-CDMA

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بسم الله الرحمن الرحيم

In the Name of ALLAH

The Most Gracious and the most Merciful

Declaration

Certified that the work contained in this thesis

Parameter Estimation of Adaptive Receiver for MC-CDMA System

is totally my own work and no portion of the work, referred in this thesis, has been submitted in support of an application for another degree or qualification of this or any other institute of learning.

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Lastly, I dedicate this thesis to my family, especially to my mother, father, brothers, sister and all the little angles in the home. All of them are always a big source of prayers for me.

Dedication

This Thesis is dedicated to

Prophet Muhammad (P.B.U.H), the greatest reformer of the world;

To my

Beloved Parents, brothers and sister for their lot of prayers for me;

To all the teachers

From School to University, they are a beacon of guidance;

To all the friends

Great support, and for giving me the joyful moment of their life.

Table of contents

List of figure

List of flow charts

Flow Charts..Page No.

List of Tables

List of Abbreviations

1. MUD: Multi user Detection
2. MC-CDMA: Multi Carrier Code Division Multiple Access
3. STBC: Space Time Block Codes
4. NCA: Non-Conventional Algorithms
5. CA: Conventional Algorithms
6. GA: Genetic Algorithm
7. PSO: Particle Swarm Optimization
8. BER: Bit Error Rate
9. SNR: Signal to Noise Ratio
10. LMS: Least Mean Square
11. RLS: Recursive Least Square
12. TDMA: Time Division Multiple Access
13. FDMA: Frequency Division Multiple Access
14. MT: Multi Tone
15. EC: Evolutionary Computing

Abstract

A communication system is consist of the transmitter, channel and receiver. Multiple antenna is used at transmitter side to implement MIMO system for the efficient use of the bandwidth. Channel estimation is also a challenging research area with many new techniques for estimation of channel behavior.

The receiver is also very important part of the communication system. Selection of the algorithm at receiver side is one of the intersecting area for research. These algorithms improve various parameter of the receiver like signal to noise ratio (SNR), bit error rate (BER) and the convergence rate of the system.

In this research work, parameters of the receiver are under observation. The adaptive receiver is used at receiver side, which keeps observing the behavior of the channel and adjusts its weights according to that. This adjustment of the weights helps the receiver to keep the bit error rate as low as possible.

However, the calculation of the weights require some adaptive algorithm. In past, many techniques were used to calculate these weights like steepest decent algorithms (SDA), least mean square (LMS) and recursive least square error (RLS). These algorithms belong to conventional algorithms and often stuck in the local minima.

In this research work, the above said problem is solved with the help of non-convention algorithms like genetic algorithms (GA) and particle swarm optimization (PSO). These algorithms are nature based evolved. These algorithms do not stuck in the local minima, and can find the optimal point in less number of cycles. This saves the time and reduces the computational complexity of the system. These algorithms show a remarkable efficiency as compared to the conventional algorithms.

1. Chapter 1:- Introduction to Communication System

1. Chapter 1:- Introduction to Communication System

1.1 Introduction

A communication system consists of transmitter, channel through which the signal travel (it could be wired or wireless) and the receiver side.

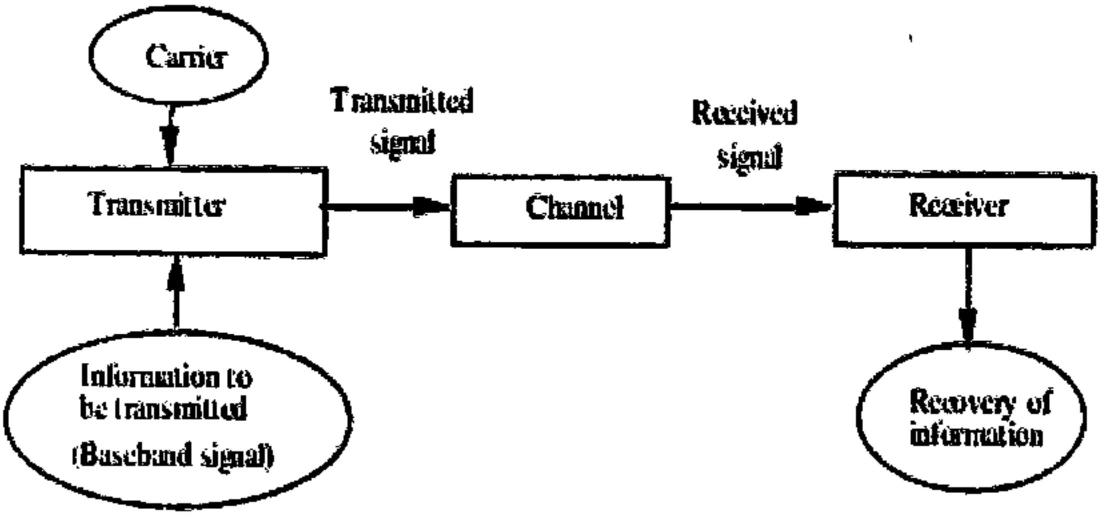

Figure 1: Communication System

Figure 1 shows the system model of the communication system. This is the block diagram of the system. At transmitter side, the base band signal is transmitted over the carrier. This signal travels through the channel. A channel is the medium, by which the signal passes. A channel could be wired or wireless. The public switched telephone network (PSTN) is example of the communication system having the wired channel and the mobile network (GSM) is the example of the wireless channel. Adaptive receiver is used at receiver side. This receiver tunes its weights to minimize the bit error rate (BER). There are many algorithms which can calculate the optimal values of these weights. To utilize the complete bandwidth, transmit antenna diversity is applied. This transmit antenna diversity can be achieved by multiple access. Time division multiple access (TDMA), frequency multiple access (FDMA) and code division multiple access (CDMA) are used for this purpose. Among them, CDMA is more efficient than the others. CDMA scheme has many types like wideband code division multiple access (WCDMA) and multicarrier code division multiple access (MC-CDMA).

1.2 Multi carrier code division multiple access (MC-CDMA)

The transmitter side can be designed by using time division multiple access (TDMA), frequency division multiple access (FDMA) and code division multiple access (CDMA). These techniques have different advantages and disadvantages. However CDMA is better than TDMA and FDMA. The reason behind this is, that CDMA uses the frequency and time slot at the same time using codes. This give rise to the concept of frequency reuse. CMDA system can accommodate more user as compared to the other systems. The code division multiple access (CDMA) is a multiplexing technique which accommodate a number of users simultaneously and asynchronously access a channel by modulating and spread their information –bearing signals with pre-assigned signature sequences.

Recently, CMDA is considered to be the best solution in mobile radio communication. Because it provides higher capacity to accommodate the user over the conventional schemes like TDMA and FDMA. In 1993, a mixture of the code division and orthogonal frequency division multi access (OFDMA) was proposed, with some variants. These techniques were multi carrier code division multiple access (MC-CDMA), direct sequence multi carrier code division multiple access (DS-MC-CDMA) [1] and multi tone code division multiple access (MT-CDMA).

Multi-Carrier Code Division Multiple Access (MC-CDMA) is a multiple access scheme used in OFDM-based telecommunication systems, allowing the system to support multiple users at the same time over same frequency band.

MC CDMA is relatively new technique, which is hot topic for research in the field of the communication technology [2]. Aim of research is to improve its performance over the multipath. MC CDMA is a form of DS CDMA, but our code sequence is Fourier transformation of the Walsh Hadamard Sequence [3].

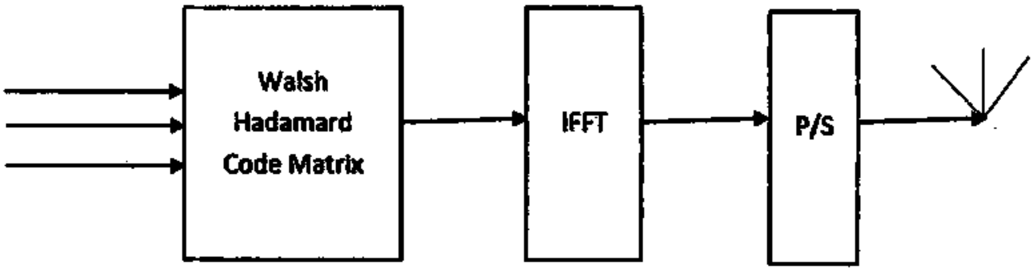

Figure 2: Multi Carrier Code Division Multiple Access

1.2.1 Codes of MC CDMA

The MC-CDMA can be implemented by using various code schemes.

1. Maximal length (ML)
2. Gold Codes
3. Walsh Codes
4. Kasami Codes

1.2.2 Walsh Codes

These codes are perfectly synchronized and orthogonal to each other. The Walsh codes also give shield against the multiuser interference (MI), due to its orthognality in the codes. The simplest Walsh code of 2 X 2 matric is given below.

$$A = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \quad (1)$$

The element of column 1 (1, 1) and column 2(1,-1) are orthogonal to each other. These codes can be extended to n-th number by using the recursive techniques. As shown in equation (2).

$$A_n = \begin{bmatrix} A_{n-1} & A_{n-1} \\ A_{n-1} & -A_{n-1} \end{bmatrix} \quad (2)$$

The Walsh codes are used here as the spreading code [4]. Its every column and row is orthogonal to every other column and row respectively. Walsh codes can be implemented by using the Hadamard matrix, which is square matrix and given in Equation 2.

1.3 Space Time Block Codes

Alamouti's scheme is the basis for implementation of the space time block coding (STBC) techniques. These codes are used for the implementation of multi input and multi output (MIMO) systems [5]. These schemes are used to attain maximum available bandwidth and to achieve higher data rates of the communication technology [6]. These codes can be explained graphically and mathematically as shown in figure 2.

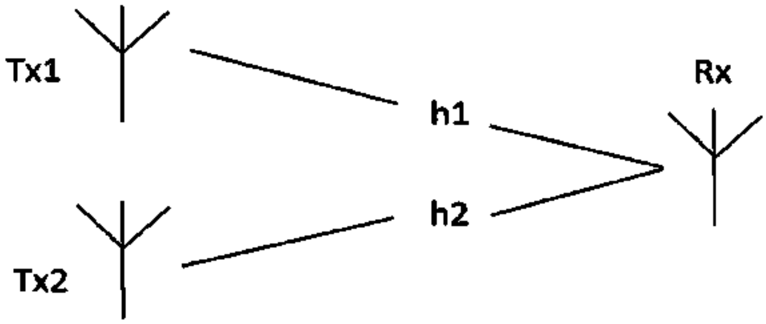

Figure 3: Alamouti for 2 X 1 System

Tx1 and Tx2 are the transmitting antenna and Rx is the receiving antenna. While channel coeffient are h_1, h_2.

This system can be described in matrix form, as shown in equation (3)

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad (3)$$

Where

$$H = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \quad (4)$$

represent the complex conjugate. Y_1 and Y_2 are the received signal, and H is orthogonal matrix of order 2 X 2. X_1 and X_2 are the transmitted signal [7]. The additive noise is represented by n1 and n2. For achieving maximum antenna diversity, these codes are made orthogonal [8]. This scheme provide same diversity as maximal ratio receiver combining (MRRC) can be improved for the nth number of receiver antenna and transmit antenna with some modification in the mathematical form [9].

1.4 Rayleigh Fading Channel

The transmitted signal arrives at the receiver side by reflecting from many paths. This multipath arrival gives rise to the change in amplitude, phase and angle of arrival. These factor fluctuate the transmitted signal parameter. This reflection is due to obstacle and many other things between the transmitter and receiver station. This multipath arrival has advantages and disadvantages. The advantage is that, due to multiple reflections the transmitted signal arrives at the receiver station. However, the disadvantage is that, due to reflection, it fluctuates the signal properties [10]. This makes decision to be sensitive, when the received signal is being estimated. Such multipath fading channels are often classified into slow fading/fast fading and frequency-selective flat fading channels.

The delay in the arrival signal at receiver side from multi path, consists of unpredictable manner and can only be estimated statistically. When the transmitted signal face large number of reflections, a central thermo can be applied to the model. This model is complex-valued Gaussian random process. When the mean of complex value Gaussian model take zero, then it is Rayleigh fading channel.

1.4.1 Types of Fading Models:

To mitigate the effect of the fading channel, a model of the fading channel is used. Some fading channel are listed below.

1. Rayleigh Fading model (Clarke's Model, Young's model)
2. Rician Fading model
3. Nakagami Fading model
4. Weibull Fading model
5. Log-Normal Shadowing model

1.5 Noise

The communication system consist of the transmitter, channel and receiver. There is another parameter called noise, which reduces system efficiency badly. The noise in the communication is due to many factors. Figure (4) shows the addition of noise to a communication channel. Noise cancellation is also a major issue in communication system. There are many types of noise in the communication system like Gaussian noise, uniform noise etc. In this communication model, Additive White Gaussian Noise (AWGN) is used. Following subsections explain AWGN and its effect on communication channel.

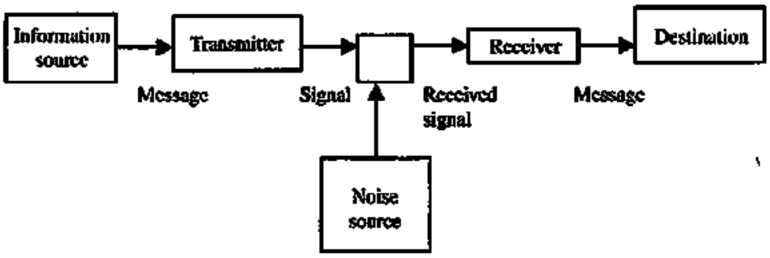

Figure 4: The Communication System with Noise

1.5.1 Additive White Gaussian Noise (AWGN) Channel

In any communication systems, the transmitted signal undergoes some noise disturbances. This noise reduces the power of the baseband signal, which results in the hard estimation of the transmitted signal. The signal to noise ratio (SNR) is the measure of the disturbance in the baseband signal. SNR is given by

$$SNR_{dB} = 10 \log \frac{\text{Power of Sgnal}}{\text{Power of Noise}} \quad (5)$$

1.5.2 Effects of SNR

The AWGN channel affects the signal in uniform manner. SNR is equally effective on all the frequency ranges and amplitude of transmitted signals. More precisely, we can say that, the AWGN disturbs only the amplitude level of the transmitted signal. Since this noise is due to many factors, involving the transmitter and receiver station hardware as well along with the noise in the environment from which the transmitted signal is traveling [11]. That's why, this noise cannot be removed completely. The effect of this noise can be minimized to various optimal point , by using different estimation schemes like least mean square (LMS) or some non-conventional algorithms like genetic algorithm (GA) and particle swarm optimization (PSO) etc. one more addition to mitigate this effect is to use the receiver adaptively.

$$y(t) = \text{Trnasmitted Signal}\,\big(x(t)\big) + AWGN(n(t)) \tag{6}$$

Here $x(t)$ is the transmitted signal and n(t) is the noise (AWGN Channel).

$$\text{Noise(AWGN)} = \text{Received Signal}\,\big(y(t)\big) - \text{DesiredSignal}\,\big(x(t)\big) \tag{7}$$

1.6 Adaptive Receiver

In communication system, the disturbance in the transmitted signal depends upon many factors. These factors include multipath fading and the noise in the environment. Disturbance due to the fading channel can be mitigated upto some extent, however the problem of noise cannot be removed completely. To overcome this problem, the receiver can be implemented as the adaptive receiver.

The adaptive receiver is a receiver, which adapts itself with the channel or the plant, from which it under goes. The receiver does so by doing feedback [12] to the input. The output is compared with the input, which gives the possible error in the signal. This error is fedback and the input is adapted accordingly. This adaptive behavior helps to overcome the errors due to channel.

This process is more generalized, rather than looking for the change in the channel. More precisely, the coefficients of channel are always kept on changing with respect to time and many other conditions. This causes many problems in estimation of the transmitted signal. The adaptivity of the receiver can overcome the channel behavior which results in the optimal minimized value of disturbance or error in the transmitted signal. Figure 5 is representing the working mechanism of the adaptive receiver.

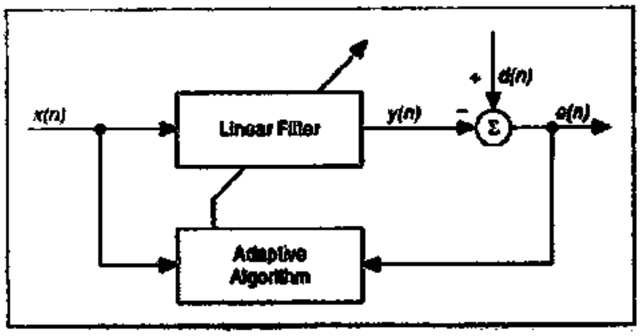

Figure 5: Adaptive Filter

2. Chapter 2: Literature Review

2.1 Literature Review

The demand of high data rate is going to be extensive day by day due to modern multimedia services & wireless internet etc. The barrier to such demand is inter symbol interference (ISI) and scattered fading channels. A special treatment is required for solution of such issues while detecting data at receiver. One way to resolve fading channels issue is to use adaptive equalizer. Another way is to use multicarrier transmission in which more than one carrier is used for [1] transmission. This idea was further improved by Chang [2] [3] with new technique namely Orthogonal Frequency Division Multiplexing (OFDM). The performance of this system was analyzed by Saltzberg [4] for scattered channels. He highlighted that reduced crosstalk between neighboring channels instead of ideal individual channels. OFDM is a form of multicarrier modulation in which available bandwidth is split into number of orthogonal flat frequency channels.

Another communication technique is Code Division Multiple Access (CDMA) introduced by Leonoid in 1957. In CDMA, the data is extended uniformly on the available Bandwidth with the help of locally generated code. CDMA got good attention in the last era.

CDMA is used with different types of multicarrier modulation techniques for improving data rate. One of the famous CDMA based method is Multicarrier CDMA (MC-CDMA), introduced [5] in 1993. In MC-CDMA, the data spreads in frequency domain with the help of user specific codes. Another variation is Direct Sequence Code Division Multiple Access (DS-CDMA), that has been adopted in future generation networks like 4G, MotoA4, [6] etc. These are affective wireless technologies for supporting high data rate, convergence rate [7] etc. Moreover, in multi carrier systems an increased number of users can be accommodated very affectively as compared to single carrier systems [8].

One common quality in all above mentioned systems is fulfillment of high data rate. But as this demand goes extensive, then receiver becomes complex as discussed initially. Akhtman [9] analyzed Minimum Mean Square Error (MMSE) channel estimation for OFDM and MC-CDMA by proposing new version of MMSE which is less complex. Similarly, a low complexity MMSE detector is proposed on the basis of power allocation techniques to amplify users for best available performance track [10]. Three different low complexity spatial frequency/time domain MMSE based multiuser detectors are proposed for minimizing the complexity of receiver in [11]. The complexity of receiver was minimized by scheduling the down linking of data [12].The disadvantage of former scheme is that this burdens receiver. However, previously discussed schemes work without scheduling down linking of data.

Another solution is to implement the receivers adaptively with the help of adaptive algorithms. The commonly used adaptive algorithms are classical algorithms that are based on sequential search which makes it computationally heavy. The solution of it is to use of modern computational intelligence techniques. Brief background of computational intelligence techniques is given as under.

In 1950, Turing published his test of computer intelligence, referred to as the Turing test. This was the first computational intelligence application. This thesis focuses on a sub branch of artificial intelligence (AI), namely computational intelligence. Computational intelligence is the study of adaptive mechanism to facilitate intelligent behavior in changing and complex environments. These mechanisms include those artificial intelligence paradigms that exhibit an ability to learn or adapt to new situations, abstract, to generalize, associate and discover.

The demand of high data rate in wireless communication is increasing tremendously due to frequent usage of multimedia applications. This leads to the development of wireless communication system with huge data rate for as many users as possible [13] [14]. This trend is seen over last two decades. It seems that "global information village" is the demand of next generation wireless networks [15]. In order to support this idea, the user services will vary from Pico-cellular to global size. Hence, there is a key requirement of the time for the development of bandwidth efficient and robust wireless communication systems. Orthogonal Frequency Division Multiplexing (OFDM) is one of the famous multi carrier techniques that has got good attention over the past two decades [16] [17]. Below is the brief discussion on evolution of wireless networks.

2.2 Evolution of wireless networks

There is a lot of research and achievements on wireless networks during the last 100 years due to which users are enjoying multimedia services now-a-days. The growth in mobile communication increased gradually. In 1960-70, it was not feasible to facilitate whole population with wireless communication. In 1970, the development of solid state radio frequency hardware was the starting era of wireless communication [18] . The historical development in the field of digital signal processing has played a key role in the progress of modern digital communication systems.

Many researchers have categorized the evolution of mobile communication into pre period, pre-cellular period and cellular period [19]. The era before 1900 AD falls in pioneer period. In this era, James Clark introduced the electromagnetic waves, later, Heinrich Rudof Hertz demonstrated the existence of such waves. Similarly, the wireless telegraph was also invented by Gugelielmo Marconi in this era.

In 1920, many applications of wireless telegraph started. The pre-cellular period started when Detroit police started using wireless telephone system in 1932. The wireless communication was started for commercial usage after the end of World War II. The first commercial usage of wireless communication was started in 1946 at Bell Telephone Laboratories. This system used three channels at 150 Hz band. This system worked with manual telephone exchange initially which was converted to automated telephone exchange later in 1948.

There is a list of developments in wireless communication which was collectively named as mobile radio telephone. These systems are also referred as zero generation (0G) systems as they are predecessors of cellular systems. Few of the developments of this era include Mobile Telephone System (MTS), Push to Talk (PTT), Advanced Mobile Telephone System (AMTS) and Improved Mobile Telephone Services (IMTS). These systems could not facilitate its subscribers due to huge number of users in large coverage area. In order to overcome this problem, cellular systems was introduced with key feature of using low power transmitter of small coverage area, cell splitting to increase capacity, frequency reusability and handoff control [20].

The above concept of cellular systems is considered as the start of cellular period. The cellular period is still held on due to huge demand services provided by cellular systems. In this era many standards of mobile radio communication have been developed in wireless systems. There was still a lot of space for the development of new standards. However, these new systems are distinct to each other in terms of services. For example; voice, video and data, technology usage and existence period. Some other parameters include like multi access technique, channel bandwidth, frequency band and modulation methods. These systems are categorized in to generations on the basis of above parameters. They are called 1G, 2G, 3G and 4G networks [21]. However, 5G is the future of these network generations.

2.2.1 First Generation (1G) Mobile standards

1G was analog cell phone standards that were designed in 1970s. This was physically deployed in 1980s and continued until replaced by the 2G digital phones. The voice telephone services were only provided in 1G network which uses the Frequency Division Multiple Access (FDMA) for resource sharing. The Advanced Mobile Phone System (AMPS) and Nippon Telephone and Telegraph (NTT) are some of 1G systems developed in Europe and Germany. The systems developed in 1979 used 600 frequencies modulated duplex channel in 800 MHz band. The systems of 1G network were incompatible with one another due to different communication protocols and frequencies. Some of the drawbacks of 1G network include lack of roaming facility; limited number of users was supported due to FDMA.

2.2.2 Second Generation (2G) Mobile Standards

In order to overcome the disadvantages of 1G network new generation of cellular communication was evolved named as 2G networks.

The 2G services were based on standards like Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA). The services provided by these networks include Personal Communication Services (PCS). The Global System for Mobile (GSM) is most popular and successful standard of 2G networks based on Time Division Multiple Access (TDMA). The GSM was first deployed in Germany in 1981. GSM supports eight time slotted users for each 200 KHz radio channels. GSM is one of the hugely adopted cellular standards all over the world which accommodates huge number of user along the roaming facilities.

2.2.3 Third Generation (3G) Mobile Standard

The 2G networks is not able to facilitate the users for the services like high quality audios, videos, games, web browsing, etc. These all services demands high data rate from the network. The demand of high data rate initiate a research activity in 1995 with results of new mobile standard named as 3G network. 3G Networks offers all the services to its user mention at start. There are total three multiplexing techniques that are standardized in 3G networks. This includes Direct Sequence (DS)-CDMA, Multi Carrier (MC)-CDMA and DS-CDMA- Time Division Duplexing (TDD).

2.2.4 Fourth Generation (4G) Mobile Standards

A 4G network is considered as fastest available wireless communication network. It provides end to end IP based solution. The data, voice and multimedia services can be accessed by all the users anytime and anywhere with high data rates as compared to prior ones [22]. Some of the key features of 4G networks are: It is a full IP based integrated network of all nodes, capable of 100 Mbps and 1Gbps indoor and outdoor data rates. However, a 4G network is still a multicarrier and packet switching communication network [23] [24].

2.3 Multiple Access Techniques

It is seen that the major development in data communication is in high data rate. There are various kinds of multiple access techniques like FDMA, TDMA, CDMA, and WCDMA which were designed for achieving the high data rate with maximum number of users. However, the focus of CDMA techniques is to accommodate more number of users as compared to FDMA and TDMA. WCDMA is a CDMA based standard used in 3G network [25].

The DS-CDMA and WCDMA faces the common problem of frequency selective multipath fading. Such type of issue arises in indoor and urban environment. This problem arises as the number of users increase. The frequent change in amplitude of signal for short period of travelled distance or time is known as fading. The reason behind it is the combination of multipath waves on receiver antenna for received signal. These received signals may vary a lot in phase and amplitude as compared to original signal [26] [27].

Therefore, fading may be of many types depending upon signal and channel parameters [28]. In categories; flat fading, the bandwidth of signal is less than bandwidth of channel or delay spread is less than symbol period. In frequency selective fading, the issue arises, if bandwidth of signal is more than bandwidth of channel or delay spread is greater than symbol period. Similarly, there is another category of fading on the basis of Doppler shift. The fast fading on the basis of Doppler shift arises due to high Doppler spread; if coherence time is less than symbol duration, and lastly, channel varies fastly than baseband signal variation [29]. The slow fading arises due to low Doppler spread, if coherence time is greater than symbol period and lastly, if channel variations is slower than baseband signal variations.

The above discussion shows that frequency selective multipath fading arises due to narrowband signals. These signals are less sensitive to frequency selective multipath fading and inter symbol interference. Therefore, Multicarrier techniques like OFDMA and MC-CDMA are suggested for 4G mobile communication as well as 5G [30].

Another enhancement to the multicarrier communication is Multiple Input and Multiple Output (MIMO) system utilizes more than one antenna on both transmitters and receivers. This technology got good attention in Beyond 3rd Generation (B3G) wireless networks [31] [32] [33] [34] [35] due to the fact of maximum utilization of limited bandwidth [36]. Multi carrier MIMO was recommended by Jagan Nathan by imposing two constraints in order to reduce the receiver complexity [37]. The first constraint was on the number of sharing users with respect to base station antennas. Secondly each user was forcedly employed beam forming by constraining covariance matrix of transmitter to be rank one [38]. The channel estimation method for multi user for multi carrier MIMO was investigated in [39]. They used Least Mean Square (LMS) error criteria in order to estimate multi path gain coefficients, carrier phase offset and transmission time delay. The drawback of purposed scheme was due to multiple parameters computation at receiver, due to which receiver becomes complex. The research done by Steiner [40] and Jorswieck [41] showed that multi carrier systems are of key importance in fulfilling the high data rate demand of future generation networks like B3G, 4G, 5 G etc.

The Alamouti's [6] Space Time Block Coding (STBC) is suggested for different flavors of Code Division Multiple Access (CDMA) based systems in [42] [43] [44]. The research showed that Alamouti's code are the only STBC's that achieve full rate .The high speed codes are studied by Vahid for improvement in BER [44] [7]. The recently invented two layered space time coding [45] [46] [47] [48]mechanism may be observed on multi carrier systems for attractive BER. The use of high data rate STBC's in Alamouti scheme is one of the key requirement of time in multi carrier system. Now a day's, researchers propose layered coding mechanisms that are more orthogonal with respect to single layered codes. The benefit of such scheme is that they improve the BER of the system at the cost of complexity .The multi carrier code division multiple access (MC-CDMA) scheme is recommended for MIMO technology [49] [50]. Orthogonal frequency-division multiple access (OFDMA) is another multi carrier system that works by encoding data on multiple frequencies. OFDMA [51] is a popular scheme for wideband digital wireless communication. This is used in applications such as digital televisions, audio broadcasting, 4G mobile communications, etc.

The Space Time Block Coding (STBC) is preferred for the Batch processing systems in [52] [53]. The batch processing is one of the affective methods in order to reduce the computation complexity of receiver. In batch processing system, the data is assembled in batch before computation begins. One of the key requirements of batch processing system is the calculation of inverse auto-correlation matrix of the received signal. The user configuration and channel coefficients are not static, so this increases the computational complexity. There are chances that filter vector length is large which burdens the receiver as it results in too many computations. It is difficult to find out the inverse auto correlation matrix accurately, there for it is recommended to implement the receiver adaptively [54]. The adaptive receivers are implemented via adaptive algorithms with classical algorithms, evolutionary algorithms and swarm optimization due to their recursive adaptive mechanism [55].

2.4 Computation Intelligence

Computational intelligence [56] is a branch of artificial intelligence [57] [58] which deals with study of adaptive mechanism for facilitation of complex and changing environments. As many problems are not well defined mathematically, but they can be compared with some other problems that are clearly defined. The conventional models also often fall short to grip vagueness, noise and the presence of frequently changing situation. Computational Intelligence is solver for such complicated problems. Computational Intelligence includes evolutionary computation [59] fuzzy logic, swarm intelligence, etc. Here the focus is only on the role of evolutionary computation, fuzzy logic and swarm optimization [60] for multiuser detection in multiuser systems. Such schemes may improve the convergence rate and BER of multiuser receivers.

2.5 Evolutionary Computing

Evolutionary Computing (EC) is a family of stochastic search techniques that mimic the natural evolution proposed by Charles Darwin in 1858. It is a new vibrant area of investigation which uses ideas of biological evolution to solve computational problems. A computational problem often requires system to be adaptive. Evolution is an optimization process that aims to improve the ability of an organism to survive in dynamically changing environments. EC is considered as a problem solving computer system that makes use of evolutionary processes i.e. natural selection, survival of the fittest, reproduction as the core component of computational system. Natural selection emphasis that the plants and animals are the result of adaptation according to the environment. Organism adaption level helps us to measure the fitness of an organism. Survival of the fittest describes the strength of one to survive, which will eventually enhances the capability of reproduction and propagation of their genotype. EC searches parallel in search space [61] [62] [63]. The aim to improve one's ability to survive makes EC an optimization process. Meanwhile the selection operation reduces the diversity in population and on the other hand the variation and mutation affects the increase in diversity of population, which results in solution quality and convergence rate.

The algorithms based on evolutionary principles are the techniques behind evolutionary computation. These algorithms are applicable for searching optimal solution to a problem. There may be a number of possible solutions to a problem in a search algorithm and finding the best / optimal out of these many solutions in a certain limited time can be challenging. Evolutionary Algorithm (EA) is a stochastic search based subset of EC that is also known as EC algorithms. It is considered that, the intelligence as a kind of capability of an entity to adapt it to ever changing environment, it can consider evolutionary algorithms as a subdivision of soft computing. EA is a generic based meta-heuristics that gives an optimized solution to a problem by improving a candidate solution in an iterative manner. The mechanism of EA is inspired by biological evolution i.e. reproduction, mutation, recombination and selection. Being an optimization algorithm, EA should be analyzed to calculate convergence rate, increase in quality of evolved solution and to find computational requirement. Up till now, there is no proposed general framework to analyze EA's general form. However specific variations exist which are focused on investigation along two lines that are theoretical and empirical. Theoretical approach focuses on finding the mathematical truth for algorithms that will be valid on broad domain of applications. However, empirical approach evaluates performance of an implementation in that specific domain. Having their own merits and demerits, in practice, both should be used as complementary means to design and tune an algorithm [64]. EC works better for discontinuous, non-differentiable, multimode and noisy problems. EC does not require information on continuing the slope of function, which makes EC, converges faster than classic optimization algorithms. On other side, the performance of EC is stable with more number of variables which make it difficult to apply to the problems with large dimensions. The evolutionary computation [64] [65] involves continuous and combinatorial optimization situations. Its algorithms can be considered global optimization methods with complex optimization or stochastic optimization character. Evolutionary computation uses iterative method of problem solving, such as growth or development in a population. Further, the population is selected in a steered random search using corresponding processing to reach at desired solution.

2.5.1 Swarm Intelligence (SI)

Swarm intelligence [66] originated from the study of swarms of social organisms. Particle swarm optimization (PSO) is one of the swarm intelligence based algorithm. PSO is a global optimization approach, modeled on the social behavior of bird flocks.

2.5.2 Genetic Algorithm

The father of original genetic algorithms was John Holland, who worked it a lot in 1970.Genetic algorithms are nature evaluation schemes [67]. Genetic algorithms are nature inspired techniques, which are used to find the optimum solution of any problem. This algorithm is having wide application to almost every field of engineering and science. Usually these algorithms are used for non-linear and undertaken problems. By undetermined problems mean the problems which have no exact or deterministic solution. But the solution lies in the optimization of some variable of that problem.

This algorithm is based on the concept of "best candidate will survive". This concept is based on the behavior of human, struggle for the maximum point of their struggle and the behavior of the genes of the human being [68]. This can be related as, that offspring of best generation result is better than that generation or equal to their parents.

2.5.2.1 Terminology of Genetic Algorithms

1) **Initial Population:** - The initial population is problem dependent initial possible candidate solution. This population is created randomly. The initial population is under the limits of the constraints of the problem. More randomize the initial population, more possibilities to find out the optimal point.

2) **Chromosome**: - The group of the initial population, which contains the set of possible solution, known as candidate solution is known as the chromosome. This chromosome can be a row or column of the initial population.

3) **Genes**: - The particle of the chromosome is called gene. A gene alone is nothing for the evolution of the problem, but a set of genes, forming the chromosome is candidate solution of that problem. The number of chromosome and number of genes of a chromosome are problem dependent variables. Their values change from problem to problem.

4) **Fitness Function**: - Fitness function is the function which gives is the value of the fitness of the chromosome. By the fitness it is meant that, how the best or worst the chromosome is? The genetic algorithm can be used for finding the minimum or maximum (optimal point) of the given problem. The selection of best or worst chromosome is problem dependent. This value of the fitness function for respecting chromosome is just a tag of that chromosome. Which is used to identify its standing among all the possible candidate solutions.

5) **Sorting**: - After getting the fitness tag, all the candidate solution (chromosomes) are sorted depending on their fitness value. After sorting, the candidate solution are arranged in the descending or ascending order.

6) **New Generation**: - Based on the sorting, the desired chromosomes are kept, while remaining chromosomes are discarded. After discarding the undesired chromosomes, new generations are created.

7) **Cross Over**: - It is the method to create new offspring's form the initial population. The initial population is known as the parents and new generated offspring's are known as the offspring or children of that generation [84]. The cross over can be single point, scattered, geometry or stochastic based. Single point cross over is shown in the figure 5. With the change in cross over operator, the performance of the algorithm also varies. Multi point cross over is shown in figure 6.

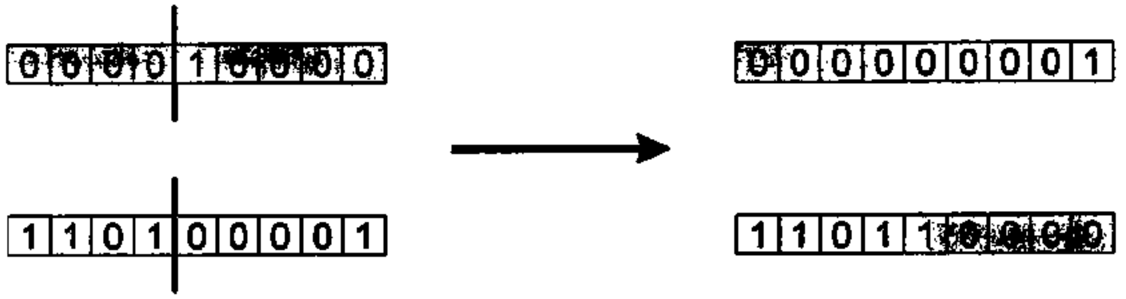

Figure 6: Single Point Cross Over

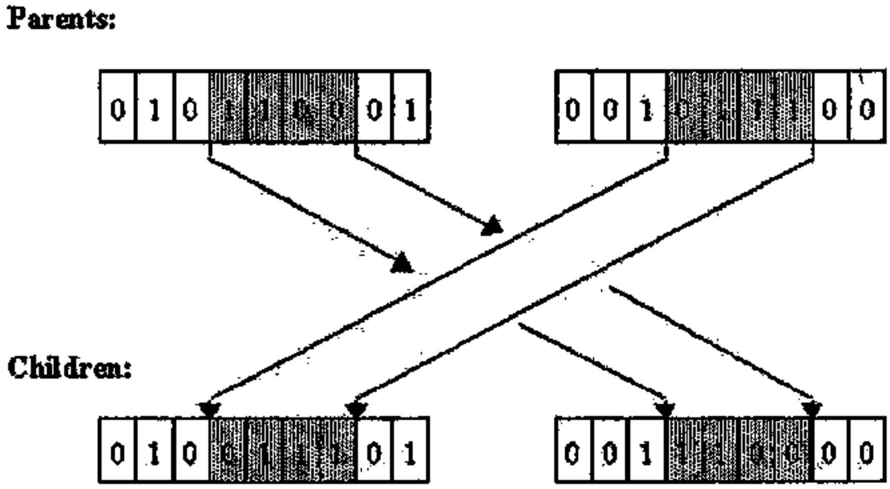

Figure7: Multi Point Cross Over

8) **Mutation**: - As the meaning of the mutation mean "to deface something". Same concept is used in the genetic algorithm. This is another operator of GA. This operator also plays a vital role for achieving the optimal point. In this scheme, the value of a gene is changed to its opposite value. This means that, the value of gene is defaced. Which gives the better solution to achieve optimal point of the given problem. However, care is taken that, the gene should not go beyond the limits of the given problem. This operator has also many types, which can alter the optimization of the system. Gaussian mutation, uniform

mutation, adaptive mutation are some different types of the mutation. The figure 7 is showing the mutation operator.

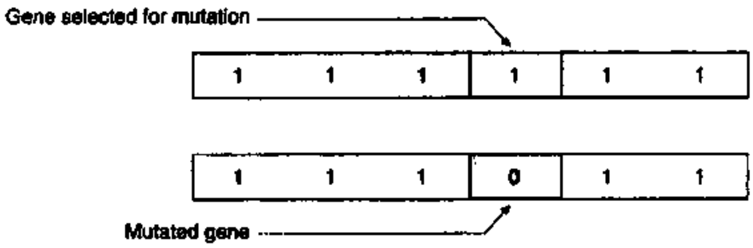

Figure 8: Mutation Operator

9) **Stopping Criteria**: - Cross over generation and mutated generation are again passed form fitness function. The stopping criteria is based on the two factors.

- The required fitness value is achieved
- The number of cycles

If the required value of the fitness is achieved, the process of generating population, cross over and mutation is stopped, regards less the number of cyclic. But if there is danger of unstoppable process based on this criteria, the stopping criteria is set on the number of cycles. The stopping criteria can be used as both, based on fitness value and number of cycles or iteration. The flow chart of the genetic algorithm is given blow.

2.5.2.2 Flow Chart of Genetic Algorithm

Flow chart of genetic algorithm is shown in figure 6.

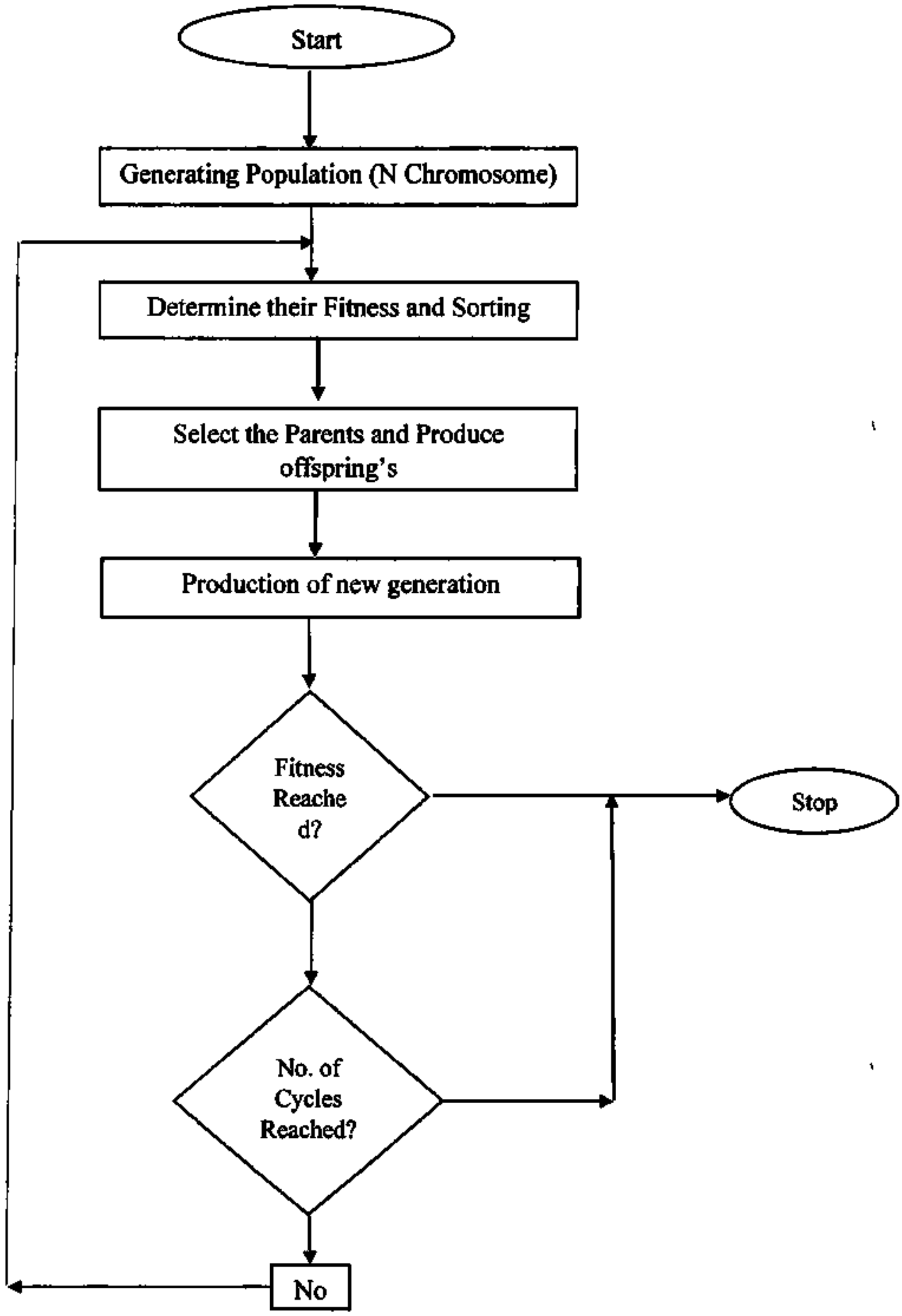

Figure 9: Genetic Algorithm Flow Chart

2.5.3 Particle Swarm Optimization

Particle swarm optimization is based on the idea of searching mechanism of birds for food. The behavior of the flock is adapted to find the optimal point. The idea of particle swarm optimization was given by the Eberhart and Kennedy in 1995 [69]. This scheme is inspired from the social model of the birds flock and fish schooling.

In Particle swarm optimization (PSO) all the particles are subjected to the search space of the given problem. Every particle undergoes its evaluation, which evaluates its current position. Initially all particles are at rest [70]. Then each particle determines its own movement by using some aspects of history, like current position and best location and compares its self with the other member of the flock [71].

Particle Swarm Optimization is the nature inspired technique based on the behavior of birds flock or fish schooling. This algorithm is very helpful for finding out the optimal point of the non -linear system. The main concept used in this algorithm to enhance individual [83] intelligence, which result in the rise of overall intelligence of the system. Initially the individual intelligence got more importance or weight as compared to combined intelligence of the whole flock. Gradually combined intelligence got more weight as compared to the individual intelligence.

PSO algorithm can be described by using following rules as shown in figure 4.

1. Separation: avoid collisions with nearby flock mates
2. Alignment: attempt to match velocity (speed and direction) with nearby flock mates
3. Cohesion: attempt to stay close to nearby flock mates

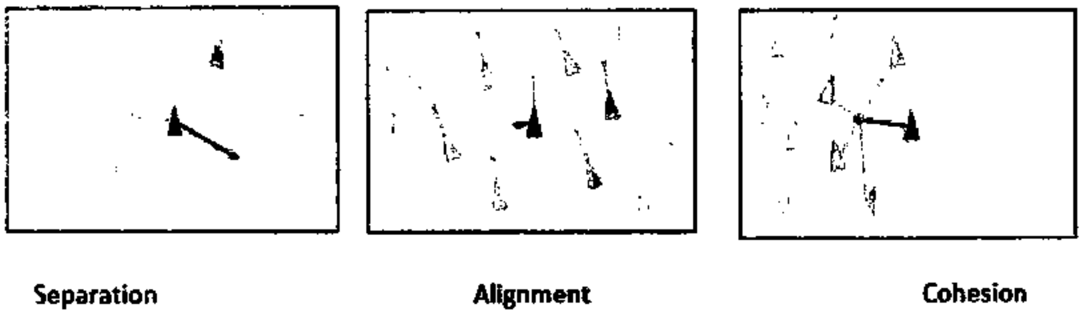

Figure 10: Particle Swarm Optimization

2.5.3.1 Flow Chart of PSO

The flow chart of PSO is shown in figure 7.

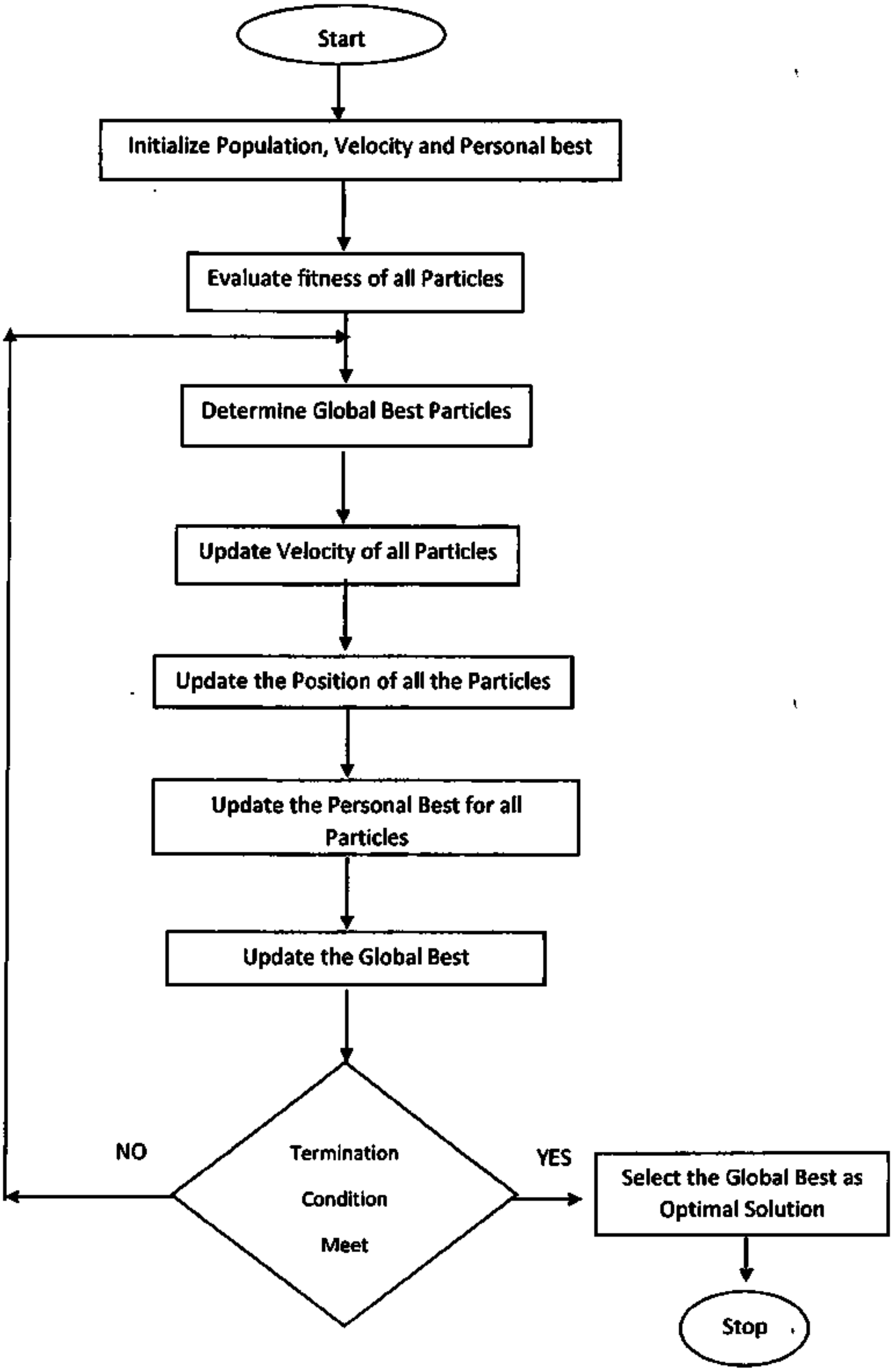

Figure 11:- Flow Chart of Particle Swarm Optimization

2.5.3.2 Application of Particle Swarm Optimization for optimal MC-CDMA detector:

The particle swarm optimization is used to find the optimal point of given non-linear problem. The system model is described in chapter 2. The model consist of multi carrier code division multiple access (MC-CDMA). The system also has Rayleigh fading channel, with multi path. The number of multi path is used is three. Their gains are generated by using complex Gaussian number and normalized to the unity. The number of user are 8 and the signal to noise ratio is 20 db. The subcarrier used here are the size of length 32.

In the above system, new relationship was derived for the weights of the MC-CDMA system. So the error will also be modified.

The new modified error for this system is

$$e_{M,1}(i) = w_{1,1}^{H}(i)r(2i-1) + w_{2,1}^{T}r^{*}(2i) - a_1(2i-1) \quad (8)$$

$$e_{M,2}(i) = w_{2,1}^{H}(i)r(2i-1) - w_{1,1}^{T}r^{*}(2i) - a_1(2i) \quad (9)$$

The $r_{(2i-1)}$ and $r_{(2i)}$ are the symbols which arrive at the receiver side at the first symbol interval. The difference between the sent symbol and arrived symbol is error. This error can be due to Additive White Gaussian Noise (AWGN) or any other factor. The optimal solution is to find the minimum value of the error. The conventional scheme like least mean square error (LMS) and recursive least square (RLS) often stuck in the local minima. The non-convention scheme like particle swarm optimization (PSO) does not stuck in the local minima. Rather these schemes move toward the global minima. Which is the optimal solution of the problem.

The convergence of the conventional scheme is slow and has higher complexity factor. By the mean of convergence rate, it is defined as, how much iteration dose a scheme require to achieve the optimal value of the error. The conventional scheme requires a large number of the iteration to achieve a steady error. By the complexity factor, it is meant, how much mathematical operation is required for the algorithm to perform a specific task?

2.5.3.3 Terminology of PSO

1. Particles

Every bird or fish of the flock is known as the particle. This particle updates its velocity or its intelligence and tries to be near, as possible as, to the other particle of the flock.

2. Velocity

Initially all the particles are at rest. The particle start movement on their historical aspects of their position and best location. All the particle try to match their velocities to the neighborhood particles.

3. Personal Best or Local Best

All the particles find their best positions, which generate the individual intelligence. If every particle find its best location, the flock can easily reached at optimal point. To enhance the overall intelligence, every particle is to be trained to enhance its own intelligence.

4. Global best

Among all the local best intelligence, one is global best. The global best is the movement of the flock in the search of the food. When each particle is trained to enhance its own intelligence, this will give rise to enhancement of collective intelligence.

Usually, in the velocity update equation, the local intelligence gets more value than the global intelligence initially. As the time passes, the global intelligence got more value than the local intelligence. By interchanging of this local best to global best, the flock fined its optimal point or food. Global best is our optimal solution.

5. Velocity update Equation

The basic velocity update equation is as fallow.

$$x_i(t+1) = x_i + v_i(t+1) \quad (10)$$

The velocity update equation consists of local intelligence and global intelligence can be written as

$$V\_im\ (n)=V\_im\ (n-1)+a\_1*local\ intelligence+a\_2*global\ intelligence \qquad (11)$$

Where

$a_1 = a_2$ random numbers. They can be used to weigh the local intelligence and global intelligence.

And

$$\text{local intelligence} = P_{i,m} - \text{local best}\,(n-1) \qquad (12)$$

$$\text{global intelligence} = P_{i,m} - \text{global best}(n-1) \qquad (13)$$

And finally the position update for each particle is given by

$$P_{i,m} = P_{i,m}(n-1) + V_{i,m}(n) \qquad (14)$$

2.6 Multiuser Detection

The adaptive [72] [73] implementation of batch processing receiver is better approach in order to overcome the computation complexity problem. Matthijs [62] purposed boot strap blind adaptive signed separator for multi user detection for down link MC-CDMA. The Minimum Mean Square Error (MMSE) based adaptive receivers for asynchronous MC-DS-CDMA is proposed in [74] [75]. They consider two design structures: separate detection and joint detection. The adaptive receiver was implemented via Recursive Least Square (RLS), Normalized Least Mean Square (NLMS), and Affirm Projection Algorithms (APA). The proposed Affirm algorithm gives better results as compared to NLMS and RLS. Similarly multi user detection of MC-DS-CDMA was done by Jamoos [63] by using blind LMS and blind kalman filter. They showed that blind LMS based multi user detection gives better BER as compared to blind kalman filter. The channel estimation of single carrier multi user detection system is computed via RLS, such that this scheme improves the channel estimation as compared to conventional schemes. The Least Mean Square (LMS) and Fast Least Mean Square (Fast-LMS) adaptive receivers are proposed for MC-CDMA systems in [76]. This mechanism belongs to classical optimization problem. Classical optimization

(CO) uses deterministic rules to move from one point in search space to next point. In [76] Bangwon used Least Mean Square (LMS) algorithm in order to optimize multi carrier code division multiple access (MC-CDMA) receiver. Such methods have slow convergence rate and not so attractive BER [77]. Modern Computational Intelligence (CI) approaches may improve the BER and convergence rate of conventional multi carrier system. The brief evolution of CI is given below:

Multiple input multiple output (MIMO) are better than single input single output (SISO) for coding complexity of the system. In MIMO system multiple antenna are used at transmitter side as well as at receiver side, different combination of such arrangement can be used for the required purpose. However, using of multiple system causes more chances of user interference, like twisted pair digital subscriber line, when treated as whole [78]. So in this case, it is preferred to transmit the signal by using the principal of orthogonally. Which cancel out each other when got combine with each other. Coding in multiple antenna is done by transmitting signal at the same time. The scheme is known as space time block coding (STBC).

With increase in the demand of high data rate in wireless communication system MIMO system were proposed. These MIMO system can be implemented using space time block coding (STBC) by Alamouti's Scheme. These MIMO are implement on the multi carrier code division multiple access (MC-CDMA). Forward- backward [42] averaging techniques and Eigen space techniques are used to enhance the system performance. The direct sequence code using multiple antenna with space time block coding is one of the best techniques to achieve this.

Blind adaptive MIMO linear receiver for DS-CDMA system using multiple transmitter antenna and space time block coding in multiple channel. The parameters of [79] linear receiver were estimated by receiving least square algorithm. The proposed recursive least square (RLS) algorithm are proved better in performance in several situation against existing method.

The problem of blind detection is addressed in MIMO code division multiple access (CDMA) channel. Each user is assigned a code which is used on all transmitting antenna. On receiver side two stages are [80] used to receiving date. One is performing linear interface blocking transformation. The second stage is using a normal differential Space Time Block Coding (STBC) decoder situation for frequency- selective channel.

Least mean square algorithm is used to enhance the convergence conditions like convergence rate, excess mean-square error. The proposed [76] algorithm is better in converging rate than the formal algorithms like steepest decent algorithm (SDA). The proposed system employing two antenna at transmitter side [2] and one at receiver side.

A letter was produced by Bangwon Seo , Woo-Geun Ahn and Cheol Jeong in August 2010 , in which a new relation is derived for the calculating the weights of the adaptive receiver. The proposed relation calculate [81] the half of the weights and other half weights are calculated by taking negative and transpose of the weights. This reduces half computational [82] complexity of the system and the system converge faster. At the receiver it employees a simple LMS techniques to update weights equation. Which ultimately updates the cost function of the system. The mathematical model of that system is given below.

$$y(i)=\sum_{k=1}^{K}\{g_{k,1}d_k(2i-1)+g_{k,2}d_k(2i)\}+v(i) \quad (15)$$

Where K is the number of user and

$$g_{k,1}=\left[c^T{}_{k,1}c^H{}_{k,2}\right]^T \quad (16)$$

$$g_{k,2}=\left[c^T{}_{k,2}-c^H{}_{k,1}\right]^T \quad (17)$$

and

$$c_{k,m}=H_{k,m}s_{k,m} \quad (18)$$

Where $$H_{k,m}=diag(H_{k,m,0}.......H_{k,m,N-1}) \quad (19)$$

The cost function of the system is

$$J(w_1,w_2)=E[|w^H{}_1y(i)-d_1(2i-1)|^2]+E[|w^H{}_2y(i)-d_1(2i)|^2] \quad (20)$$

$$J(w_1,w_2)=J_1(w_1)+J_2(w_2) \quad (21)$$

The MMSE receiver for STBC MC-CDMA system is obtained by solving the following minimization problem

$$[w_{1,opt}, w_{2,opt}] = \arg\min_{w1,w2} J(w1, w2) \tag{22}$$

$$w_{1,opt} = R_y^{-1} g_{1,1} \tag{23}$$

$$w_{2,opt} = R_y^{-1} g_{1,2} \tag{24}$$

Fast convergent LMS adaptive receiver

$$R_y = \sum_{k=1}^{K} \{g_{k,1} g^H_{k,1} + g_{k,2} g^H_{k,2}\} + \sigma^2 v I_{2N} \tag{25}$$

$$R_y = \sum_{k=1}^{K} \begin{pmatrix} c_{k,1} c^H_{k,1} + c_{k,2} c^H_{k,2} & c_{k,1} c^T_{k,2} - c_{k,2} c^T_{k,1} \\ c^*_{k,1} c^H_{k,1} - c^*_{k,1} c^H_{k,2} & c^*_{k,1} c^T_{k,1} + c^*_{k,2} c_{k,2} \end{pmatrix} \tag{26}$$

Therefore, the following property for Ry is obtained

$$R_{2,2} = R^*_{1,1} \quad , R_{2,1} = -R^*_{1,2} \tag{27}$$

$$w_{1,opt} = \begin{bmatrix} w_{1,1,opt} \\ w_{1,2,opt} \end{bmatrix} \quad , \qquad w_{2,opt} = \begin{bmatrix} w_{2,1,opt} \\ w_{2,2,opt} \end{bmatrix} \tag{28}$$

The subsector satisfy the following relationship:

$$w_{1,2,opt} = w^*_{2,1,opt}, \; w_{2,2,opt} = -w^*_{1,1,opt}, \tag{29}$$

2.7 Different Approaches for Adaptive Receivers

In adaptive receiver, the calculation of the weights is challenging an area. These weights can be calculated by using various algorithms like LMS, RLS, GA or PSO and many more. All of them have different advantages. All of these algorithms have various parameters. By tuning these parameters, we can find the optimal values of the weights coefficient of the adaptive receiver.

LMS and RLS are conventional algorithms. These algorithms can find the optimal point of the cost function but there is chance of sticking in the local minima. The working of these algorithms depend upon the step size. By using suitable step size, the algorithm can pass more close to the optimal point.

Whereas the GA and PSO are nature based evolved algorithms. These algorithms can find the optimal point of a cost function without sticking in the local minima. The convergence rate of these algorithms is better than the conventional algorithms. These algorithms use less number of iteration to reach the optimal value. These algorithms reach more quickly to the global minima.

3. Chapter 3:- System Model

3.1 System Model

The system model consist of two transmit antenna and receiving antenna. This is multi input multi output (MIMO) system, which is implemented using the space time block codes (STBC). The extension of such system requires a little modification.

In the first symbol interval, two consecutive symbols $a_{k(2i-1)}$ and $a_{k2(i)}$ are transmitted by the transmitted antenna 1 and 2 respectively. On the next symbol interval $-a^{*}_{k2(i)}$ and $a^{*}_{k(2i-1)}$ are transmitted [83] [84].

The spreading code of size N X 1 is used for each antenna of the form ($S_{K,1}$, $S_{K,2}$). Since the cyclic prefix length is larger than the maximum delay spread. So the output signal after fast Fourier transform (FFT) can be written as...

$$z(i) = [z_1(i) \ldots\ldots\ldots\ldots\ldots\ldots\ldots . z_n(i)]^T \quad (30)$$

Where z(i) can be written as

$$z(i) = \sum_{k=1}^{K} \{q_{k,1} a_{k(2i-1)} + q_{k,2} a_{k(2i)}\} + n(i) \quad (31)$$

$$\textit{Here} \quad q_{k,1} = [b_{k,1}^T \ , \ b_{k,2}^H] \quad \textit{and}\, q_{k,2} = [b_{k,2}^T \ , \ -b_{k,1}^H] \quad (32)$$

$$\textit{Where} \qquad b_{k,m} = C_{k,m} S_{k,m} \quad (33)$$

The $C_{k,m}$ is the frequency domain channel response from the mth transmitter antenna.

$$C_{k,m} = \mathrm{diag}(C_{k,m,0}\, , C_{k,m,1}, \ldots\ldots\ldots, C_{K,m,N-1}) \quad (34)$$

And n(i) is Additive White Gaussian Noise (AWGN) with zero mean and covariance of $\delta^2 I_{2K}$ where I_{2N} is identity matrix of size 2N X 2N.

The filter weight vector for the detecting a_{2i-1} and $a_{2(i)}$ by w_1 and w_2 of size 2N X 1 respectively.

$$J(w_1\, , w_2) = E\left[\left|w_1^H z(i) - a_1(2(i-1))\right|^2\right] + E[\left|w_2^H z(i) - a(2i)\right|^2] \quad (35)$$

$$J(w_1, w_2) = J_1(w_1) + J_2(w_2) \quad (36)$$

The MMSE receiver for MC-CDMA system is obtained by minimizing the problem stated in equation (37) and (38).

$$[w_{1,opt}, w_{2,opt}] = \underset{min}{\arg} J(w_1, w_2) \quad (37)$$

$$[w_{1,opt}, w_{2,opt} = \arg\{ \underset{w_1}{min} J(w_2) + \underset{w_2}{min} J(w_2)\} \quad (38)$$

By setting derivative by W_1 and W_2 equal to zero, the MMSE filter output is given by the

$$w_{1,opt} = R_y^{-1} q_{1,1} \ , \ w_{2,opt} = R_y^{-1} q_{1,2} \quad (39)$$

Where *R* is autocorrelation matrix and given by

$$R = E[z(i) z^H(i)] \quad (40)$$

In case of minimum of MMSE filter

$$J_{min=(w_{1,opt}, w_{2,opt})} \quad (41)$$

$$J_{min} = (1 - q_{1,1} R_y^{-1} q_{1,1}) + (1 - q_{1,2}^H R_y^{-1} q_{1,2}) \quad (42)$$

3.2 Fast Convergent Adaptive Receiver

3.2.1 Relationship of MMSE filter and weight vector

The relationship between $W_{1,\ opt}$ and $W_{2,\ opt}$ is derived in this section. By defining the autocorrelation matrix R of size N X N.

$$R_y = \begin{bmatrix} R_{1,1} & R_{1,2} \\ R_{2,1} & R_{2,2} \end{bmatrix} \quad (43)$$

R(y) can also written as

$$R_y = \sum_{k=1}^{K} \{q_{k,1}q_{k,1}^H + q_{k,2}q_{k,2}^H\} + \delta n^2 I_{2N} \quad (44)$$

$$R_y = \begin{bmatrix} b_{k,1}b_{k,1}^H + b_{k,2}b_{k,2}^H & b_{k,1}b_{k,2}^T - b_{k,2}b_{k,1}^T \\ b_{k,2}^* b_{k,1}^H - b_{k,1}^* b_{k,2}^H & b_{k,1}^T b_{k,1} + b_{k,2}^* b_{k,2}^T \end{bmatrix} \quad (45)$$

The property of R(y) can be seen easily that

$$R_{2,2} = R_{1,1}^* \qquad R_{2,1} = -R_{1,2}^* \quad (46)$$

3.2.2 Theorem

Defining the weight vector in the sub vector form

$$w_{1,opt} = \begin{bmatrix} w_{1,1,opt} \\ w_{1,2,opt} \end{bmatrix} \qquad w_{2,opt} = \begin{bmatrix} w_{2,1,opt} \\ w_{2,2,opt} \end{bmatrix} \quad (47)$$

The sub vector also satisfy the following condition

$$w_{1,2,opt} = w_{2,1,opt}^* \quad \text{and} \quad w_{2,2,opt} = -w_{1,1,opt}^* \quad (48)$$

This relation reduced the complexity to half for all the system. By calculating the $W_{1,2,opt}$ and $W_{2,2,opt}$, the remaining weights will be computed by the complex conjugation of the early computed weights [2].

3.3 Adaptive LMS Receiver

Least mean square (LMS) algorithm can be used to find the weights of the adaptive receiver.

LMS is easy to apply at any cost function. For the above said system, the LMS can be applied as fallow.

$$e_{m,1}(i) = w_{1,1}^H(i)r(2i-1) + w_{2,1}^T r*(2i) - d_1(2i-1) \quad (49)$$
$$e_{m,2}(i) = w_{2,1}^H r(2i-1) - w_{1,1}^T r*(2i) - d_1(2i) \quad (50)$$

The weight update equation is as fallow

$$w_{1,1}(i+1) = w_{1,1}(i) - \mu\{e_{m,1}(i)r(2i-1) - e_{m,2}(i)r(2i)\} \quad (51)$$

$$w_{2,1}(i+1) = w_{2,1}(i) - \mu\{e_{m,1}(i)r(2i) + e *_{m,2}(i)r(2i-1) \quad (52)$$

Where μ is the step size. The $w_{1,2}(i+1)$ and $w_{2,2}(i+1)$ can be easily obtained by above theorem.

$$w_{1,2}(i+1) = w_{2,1}^{*}(i+1) \qquad w_{2,2}(i+1) = -w_{1,1}^{*}(i+1) \quad (53)$$

3.4 Adaptive RLS Receiver

Recursive least square (RLS) algorithm can also apply to the above stated problem. RLS also require tuning of some parameters for its better working. In RLS, the optimal value to forgetting factor (Λ) is responsible for its better working. The working to RLS algorithms is given below.

Initialize the algorithm by setting

$$w(0) = 0 \quad (54)$$

$$P(0) = \delta^{-}I \quad (55)$$

$$\delta = \begin{Bmatrix} small\ positive\ constant\ for\ high\ SNR \\ large\ positive\ constant\ for\ low\ SNR \end{Bmatrix}$$

For each instance n=1, 2 ... compute

$$k(n) = \frac{\Lambda^{-1}P(n-1)u(n)}{1 + \Lambda^{-1}u^{H}P(n-1)u(n)} \quad (56)$$

$$\varepsilon(n) = d(n) - w^{H}(n-1)u(n) \quad (57)$$

$$w(n) = w(n-1) + k(n)\varepsilon * (n) \quad (58)$$

$$P(n) = \Lambda^{-1}P(n-1) - \Lambda^{-1}k(n)u^{H}(n)P(n-1) \quad (59)$$

3.5 PSO based Adaptive Receiver

Particle swarm optimization (PSO) can also apply to this receiver to find the optimal value of the adaptive receiver. The PSO require a fitness function. By that fitness function, the fitness of the particle is measure. The PSO algorithm uses the concept of food searching of swarm particle. As the all the particles are at rest initially then they move to certain points in the search of food. Working of the PSO algorithms is as fallow [84]. The general flow of this algorithm is given as below and detail discussion of the terminology related to the PSO algorithm is given in chapter No. 4.

The modified error can be given as

$$e_{M,1}(i) = w_{1,1}^{H}(i)r(2i-1) + w_{2,1}^{T}r^{*}(2i) - a_1(2i-1) \tag{60}$$

$$e_{M,2}(i) = w_{2,1}^{H}(i)r(2i-1) - w_{1,1}^{T}r^{*}(2i) - a_1(2i) \tag{61}$$

$$x_i(t+1) = x_i + v_i(t+1) \tag{62}$$

$$V_{i,m}(n) = V_{i,m}(n-1) + a_1 * \text{local intelligence} + a_2 * \text{global intelligence} \tag{63}$$

Where a1 and a2 are the randomly generated numbers and

Local intelligence = Pi, m – local best (n-1)

Global intelligence = Pi, m-global best (n-1)

The update in the position

$$P_{i,m} = P_{i,m}(n-1) + V_{i,m}(n) \tag{64}$$

3.6 GA based Adaptive Receiver

Genetic algorithm is also nature based evolved algorithm. The main concept of GA is from the genetic behavior. GA also require a fitness function to evaluate its gene fitness. However GA is different from the PSO. PSO use the concept of velocity of swarm particle, whereas the GA use various operator like cross over, mutation and selection function to find the optimal point.

The fitness function for GA is given below.

$$e(n) = u(u) * w(n) - d(n) \tag{65}$$

GA is used to find out the optimal values of w(n), for which the e(n) have minimum value. The brief discussion of the GA is given in chapter no 5 and its related terminology.

4. Chapter 4:-Simulation and Result

4.1 PSO Simulation and Result

In this research work the uplink is designed using Alamouti's STBC for MC-CDMA. The subcarriers used is 32 that is equal to the length of the spreading sequence. The spreading sequence used is complex for every user. The Rayleigh fading channel is used with the multiple three path. The tap gains of the fading channel are generated by complex Gaussian distribution. Which is normalized to unity. The signal to noise ratio (SNR) of 25 dB is used. The number of user is 20. The tool used in this research work is MATLAB 2012b.

4.1.1 The Convergence of PSO VS LMS

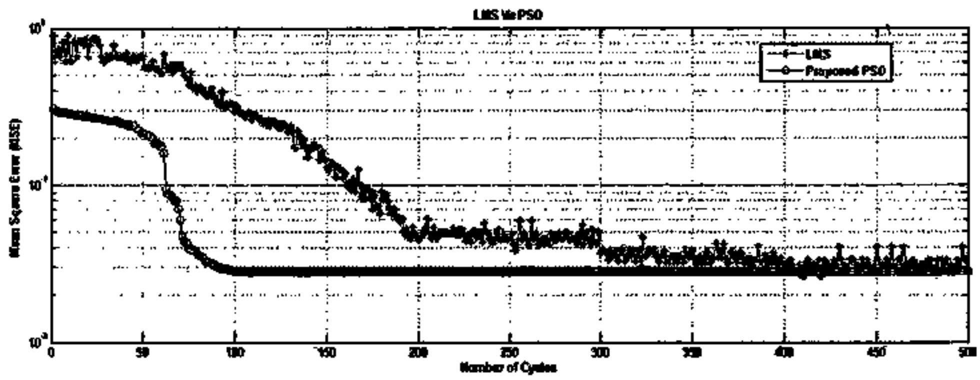

Figure 12: Convergence of PSO compared with the LMS

In communication system the requirement of engineers is to design such system that could achieve its steady state error in less time. It can also be stated as, the algorithms should be such that, which has less transient state. The presented algorithms should acquire its optimal minimum value in less number of cycles and less time. So the system easily and quickly processes the upcoming signals. Which makes system more efficient. These systems are more suitable for the large data transmission and receiving, while keep the same number of transmit antenna and the receiving antenna. The classical optimization technique use deterministic methods to find the optimal point in the given space of the problem. However the non-conventional optimization techniques use nature based techniques. These techniques do not have a mathematical model, but they are more efficient in finding the optimal point of the given problem.

From figure (12), it is very obvious that the rate of convergence of LMS is very slow. LMS is achieving its desired bit error rate (BER) after long number of cycles or iteration. Whereas PSO algorithm is achieving the same bit error rate (BER) in less number of cycles or iterations.

If a point is selected in the above graph, or the point of convergence (achieving a steady error), for LMS, the point of convergence is at 400 number of cycles. It is taking a large number of iteration, which causes the computational complexity and also the time consuming problem.

Whereas PSO is taking only 100 number of cycles to achieve its convergence point, which makes the system faster and quicker in achieving the steady state of error. This makes this system to less computational complex and also time saving algorithms.

4.1.2 The Complexity Of PSO and LMS

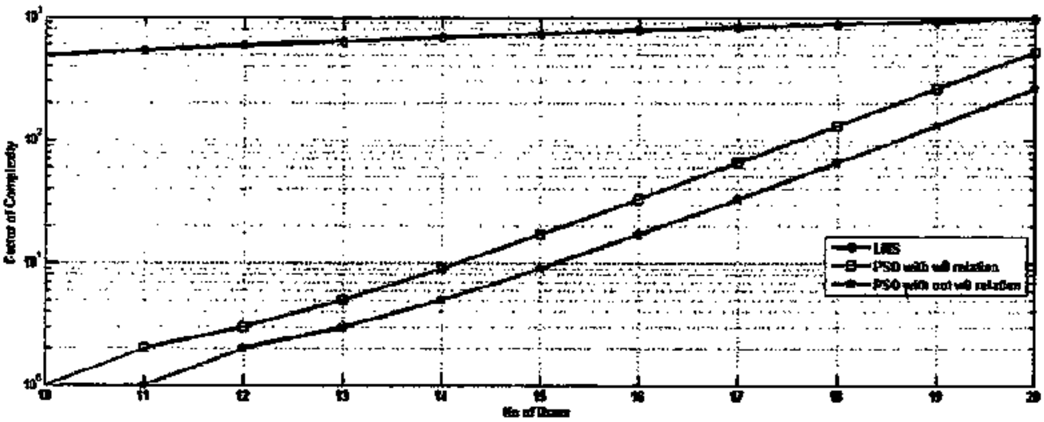

Figure 13: Complexity graph of PSO compared with LMS

Figure (13) is showing computational complexity of the LMS and PSO. The graph for LMS is showing that, the less number of user, LMS require a lot of calculations to find the optimal solutions. PSO algorithms requires less number of mathematical operation to find its optimal point. This graph is linked between the number of user and number of mathematical operation to solve that problem. The factor of complexity is referred as the number of required mathematical operation for a fixed number of user. In this problem of multicarrier code division multiple access (MC-CDMA), the transmitted signal is often in the form of bipolar signals like [1, -1]. With the increase in the number the combination of the signal increase with the function of 2^K .The system goes on complex with the increase in the number of user. For example the combination of signals that arrive at the receiving station for two user will be 4 and for 10 user their combination will be 1024. As the number combination increases, the computational complexity of the system also increases.

Factor of complexity of the PSO can be calculated as

$$Factor\ of\ Complexity = K * P * it \quad (1)$$

Here

K= Number of User

P= Number of Particle

It= Number of Iteration

Complexity factor of LMS is given by:

$$Factor\ Complexity(LMS) = k * (N - 1)^2 \quad (2)$$

Where

K= number of user

N= number of iterations

In the above graph if the number of users are fixed, then the factor of complexity can be found for that number of user. For example for 15 users, the factor of complexity of PSO (without the proposed relation) is 10^1. While the same complexity factor for the PSO (with the proposed relation) is more than 10^1 and less than 10^2. Whereas for LMS, the factor of complexity is higher than 10^2 and less (but close to the) 10^3.

4.1.3 SNR Vs. BER

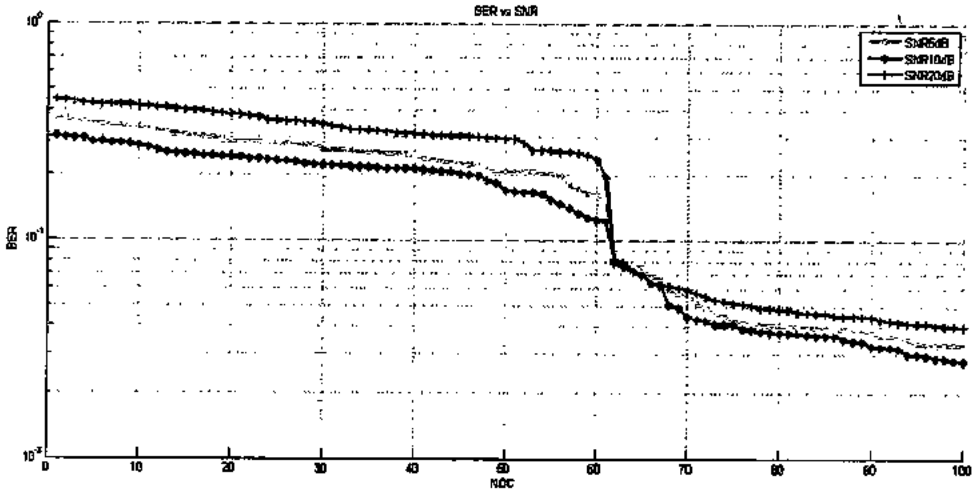

Figure 14: SNR VS BER

The performance of MC-CDMA system undergoes in variation due to noise. This noise cannot be completely removed from the system. However, the approaches are adapted to minimize it. The noise can be of different levels and can disturb the signal to its ability. During the research or designing a particular system, it always try to design such a system, which can perform its specific task over a particular range to obstacles. Form obstacles, it is meant how much the noise (dB) is disturbing our system.

The given graph shows a multiple signal to noise ratio (SNR). The larger SNR results in the large opposition to optimal error of the system. Smaller the SNR, easy to find the optimal error of the system. The simulation consists of SNR of 5dB, 10dB and 20dB. Their respective graph of convergence are shown in figure 14. For future concern, these simulation can be easily performed for the higher SNR to estimate the working of the system.

4.2 Genetic Algorithm Simulation Results

The optimization of genetic algorithm is dependent on the type of cross over used in generating the new generation and the mutation. Finding the fitness of the new generation is our key point. But, how they are being populated or generated is the key issue of genetic algorithms. The simulation is performed using different types of the cross over technique and the results of simulation are given below. The mutation part of genetic algorithm also help us to find the optimization point quickly. Some simulation of different types of mutation are also listed below.

4.2.1 Variation of Cross Over Operator

Cross over operator is responsible for the generation of new children or offspring's from the parents. This idea is evolved from the production system of genes. In this section, the variation of cross operator is under observation. By change in the type of cross over operator the performance of the genetic algorithm is changed. Cross over operator has many different types. Some of them are simulated for the MC-CDMA adaptive receiver. The simulations are showing the results of convergence of the algorithms. The graphs are plotted between the bit error rate (BER) and the number of iterations. Single point cross over , two point cross over , intermediate cross over , heuristic cross over and arithmetic cross over are the example of the cross over operator. The graphs are showing the best and mean values of the genes. The simulation results has shown that, the heuristic cross over is better than the other cross over operator for above said model. At the end of this section table is given, which is showing the comparison of the all cross over operator.

4.2.1.1 Single Point Cross Over

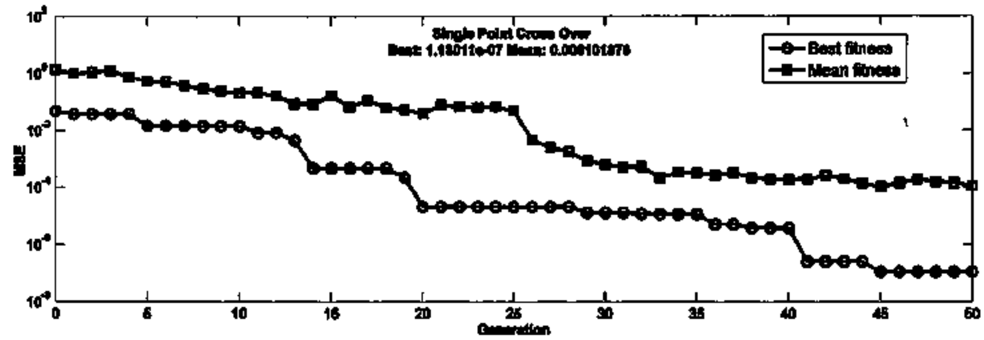

Figure 15: Single Point Cross Over

Figure 15 is showing the simulation result of single point cross over. The number of generation used is 50 to achieve optimal value. The line with square marker is showing the average value of the optimal weights and the graph line with the circle is showing the convergence rate with best fitness. The best value 1.13011e-07 and mean 0.000101878 is achieved by single cross over operator.

4.2.1.2 Two Points Cross Over

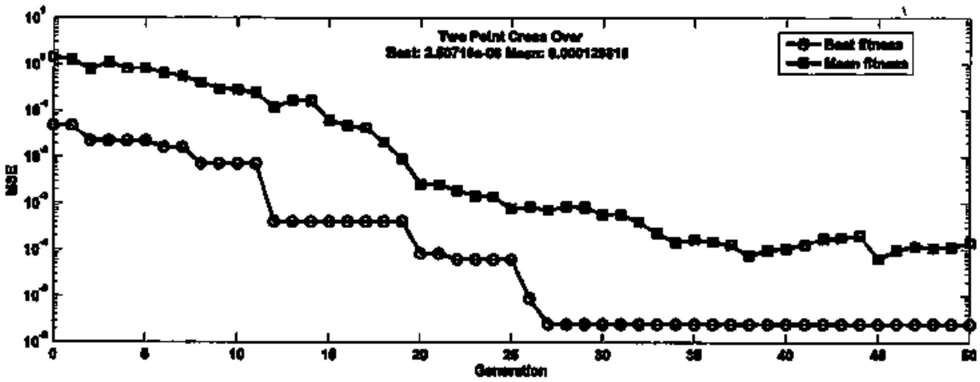

Figure 16: Two Point Cross Over

Figure 16 is showing the result of two point cross over. The line with the square marker is showing the mean fitness and line with the circle is showing the result of the best fitness. The best value achieved is 2.50719e-06 and mean value is 0.000129819.

4.2.1.3 Intermediate Cross Over

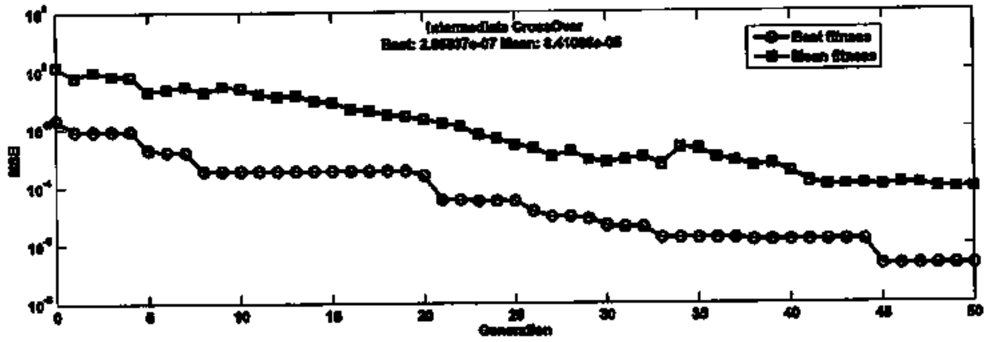

Figure 17: Intermediate Cross Over

Figure 17 is showing the simulation result of intermediate cross over. The number of iteration or generation taken for this result is 50. The graph line with the square marker is showing the result of the mean fitness and graph line with the circle is showing best fitness result. The best value 2.05837e-07 and mean value 8.41058e-05 is achieved by this cross over operator.

4.2.1.4 Heuristic Cross Over

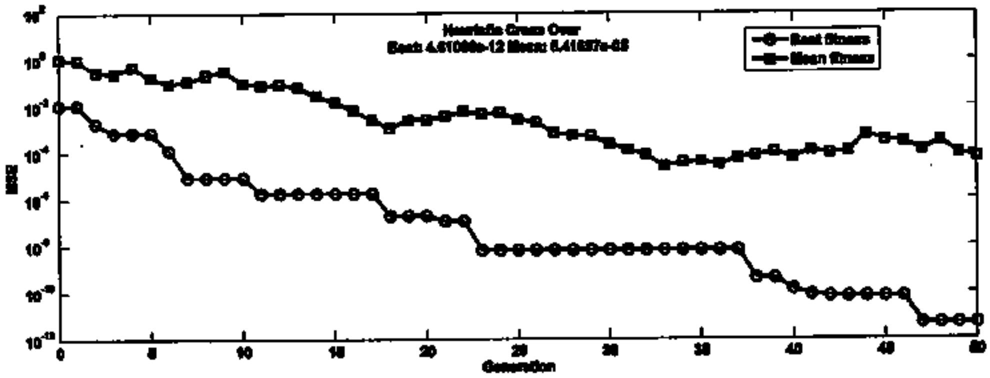

Figure 18: Heuristic Cross Over

Figure 18 is showing the simulation result of heuristic cross over. The graph line with the square marker is showing the mean fitness and line with the circle marker is showing the best fitness. The best value 4.61086e-12 and mean value 0.00611835 is achieved by this cross over operator.

4.2.1.5 Arithmetic Cross Over

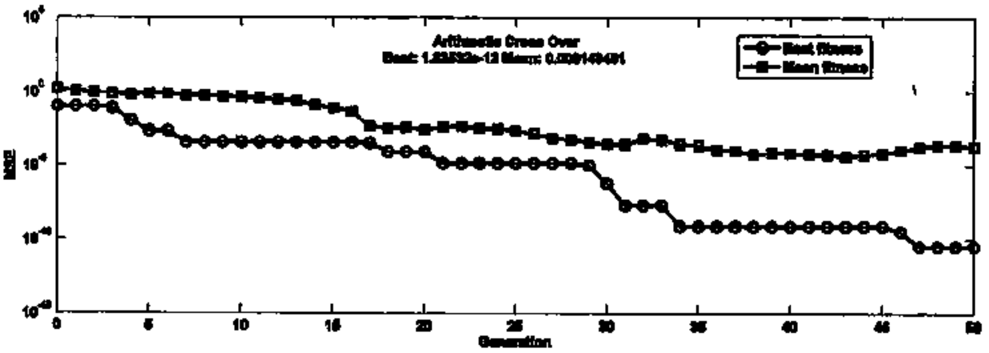

Figure 69: Arithmetic Cross Over

Figure 19 is showing the simulation results of the arithmetic cross over. The graph line with the square marker is showing the mean fitness and with the circle marker is showing best fitness value. The number of iteration used is 50 to achieve optimal point. The best value 1.83532e-12 and mean 0.000149481is achieved by this cross over operator.

4.2.1.6 Comparison of Cross Over Operator

S.NO	Cross Over Operator	Mean Value	Best Value(MSE)	Iteration
1	Single Point Cross Over	0.000101878	1.13011e-07	50
2	Two Point Cross Over	0.000129819	2.50719e-06	50
3	Intermediate Cross Over	8.41058e-05	2.05837e-07	50
4	Heuristic Cross Over	5.41697e-05	4.61086e-12	50
5	Arithmetic Cross Over	0.000149481	1.83532e-12	50

Table 1: Cross over Operator

From the table 1, it is obvious that arithmetic cross over is achieving best fitness 1.83532e-12 and in the case of mean value heuristic cross over is achieving 5.41697e-05. All the cross over operators are using same number of generation to achieve optimal point. However arithmetic cross over operator is more suitable due to its better optimal value.

4.2.2 Variation of Mutation Operator

Mutation is another operator of the GA. This operator also plays an important role in the convergence of the algorithms. This operator also has different types like Gaussian mutation, uniform mutation and adaptive feasible mutation. The above said model is test for these types of the mutation. The simulation result has shown that adaptive feasible mutation work better than the other mutation operators.

4.2.2.1 Gaussian Mutation

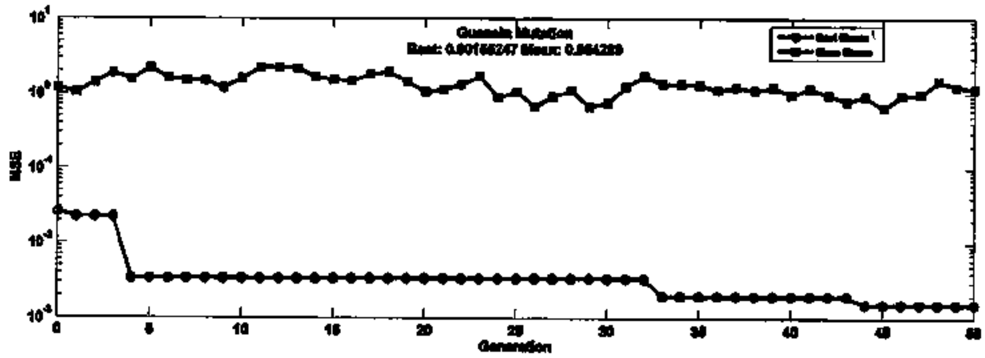

Figure20: Gaussian Mutation

Figure 20 is showing the simulation result of the Gaussian mutation operator. The graph with the square marker is showing the mean fitness and line with the circle is showing the best fitness. The best fitness 0.00155247 and mean fitness 0.954289 is achieved by this operator.

4.2.2.2 Uniform Mutation

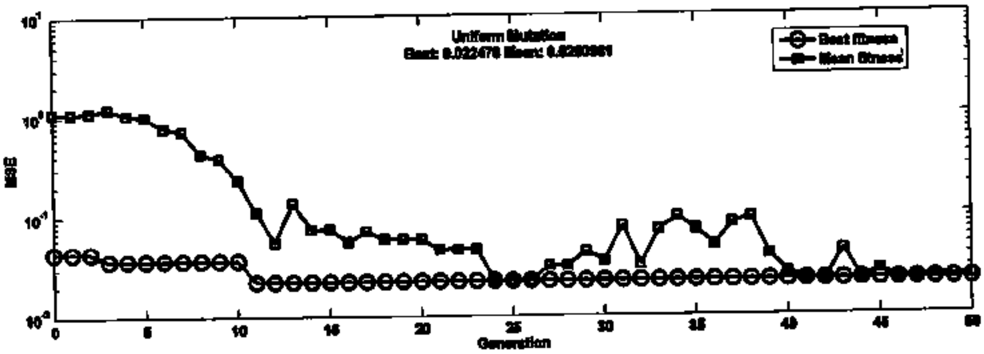

Figure 27: Uniform Mutation

Figure 21 is showing the simulation result of uniform mutation. The graph line with square marker is showing the mean fitness and the line with circle marker is showing the best fitness value. The best fitness 0.022478 and mean fitness 0.0260961is achieved by this operator.

4.2.2.3 Adaptive Feasible Mutation

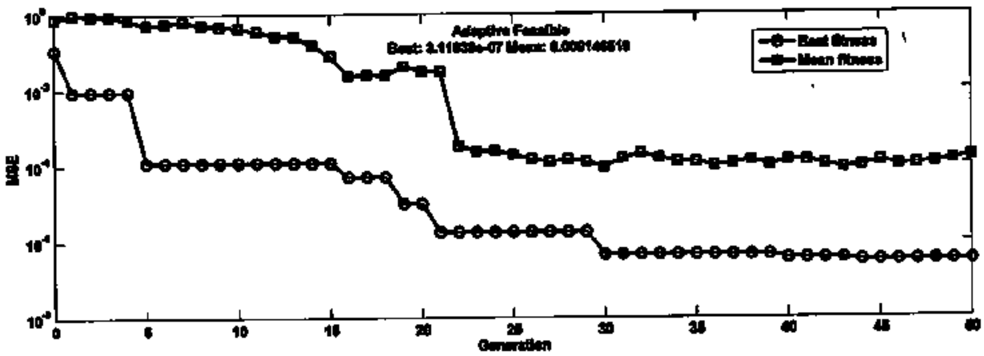

Figure 22: Adaptive Feasible

Figure 22 is showing the simulation results of adaptive feasible mutation. The graph line with the square marker is showing mean fitness and line with the circle marker is showing the best fitness value. The best value 3.11939e-07 and mean value 0.000146519 is achieved by this operator.

4.2.2.4 Comparison of Mutation Operator

S.NO	Mutation Operator	Mean Value(MSE)	Best Value(MSE)	Iteration
1	Gaussian Mutation	0.954289	0.00155247	50
2	Uniform Mutation	0.0260961	0.022478	50
3	Adaptive Feasible Mutation	0.000146519	3.11939e-07	50

Table 2: Mutation Operator

It is clear from the table (2) that, the working of the adaptive feasible mutation is achieving the optimal minimum value of bit error rate (BER). Adaptive feasible mutation is achieving better optimal value for best fitness and mean fitness. All the mutation operator is using the same number of iteration for their convergence, however the other mutation operators are not attractive in terms of bit error rate (BER).

4.2.3 Variation of Selection Function

Selection function plays an important role in the performance of the algorithms. The selection function is responsible for the selection of genes of newly generated offsprings. This operator selects the gene based on their fitness and the some other methods also. This operator also has various types like stochastic uniform, uniform, roulette and tournament. By change of the selection function the performance of algorithms also vary.

Simulation results have shown that tournament selection function is achieving optimal BER as compared to the other selection functions.

4.2.3.1 Stochastic Uniform

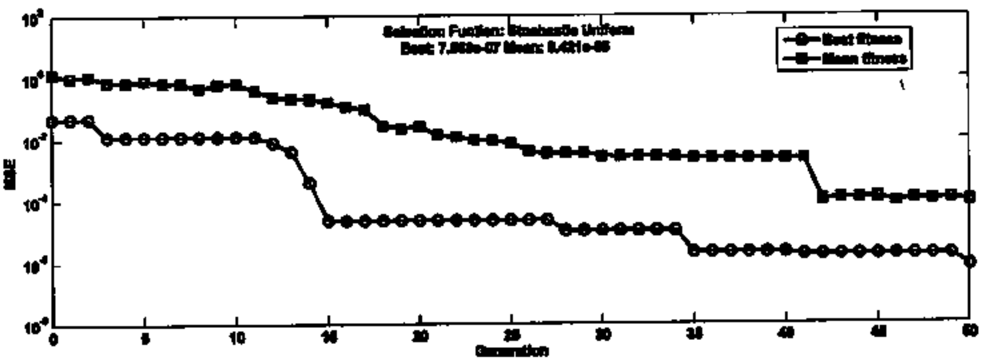

Figure 23: Selection Function: - Stochastic Uniform

Figure 23 is showing the simulation result of stochastic uniform selection function. The graph line with the square marker is showing the mean fitness and line with the circle marker is showing the best fitness. The best value 7.569e-07 and mean value 8.421e-05 is achieved by this operator.

4.2.3.2 :- Uniform

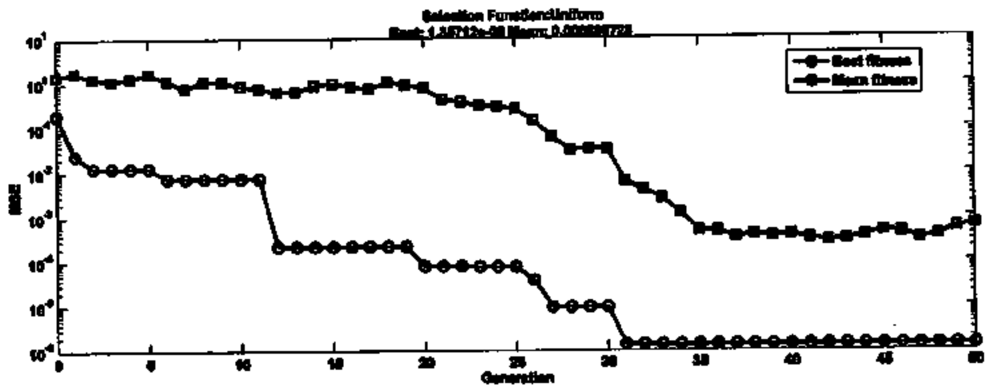

Figure 284: Selection Function: - Uniform

Figure 24 is showing simulation result of uniform selection function. The graph with square marker is showing the mean fitness and line with circle marker is showing best fitness value. The best value 1.35712e-06 and mean value 0.000696725 is achieved by this operator.

4.2.3.3 Selection Function: - Roulette

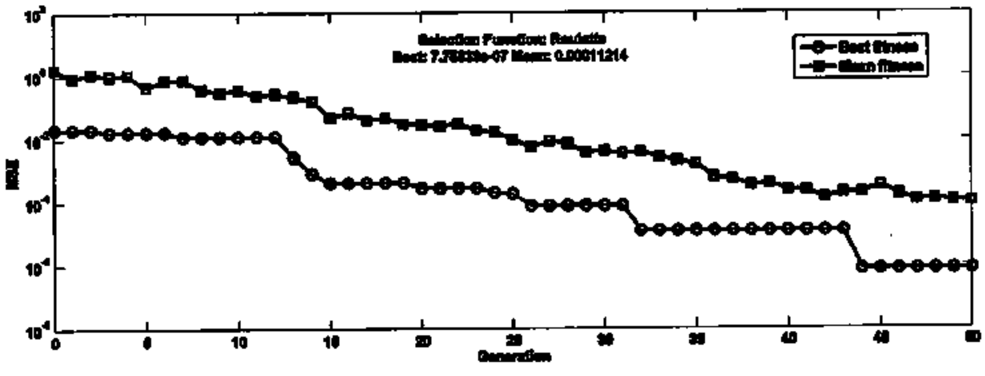

Figure 25: Selection Function: - Roulette

Figure 25 is showing the simulation result of roulette selection function. The graph line with the square marker is showing mean fitness and line with circle marker is showing the best fitness. The number of generation taken is 50. The best value 7.75839e-07 and mean value 0.00011214 is achieved by this operator.

4.2.3.4 Selection Function: - Tournament

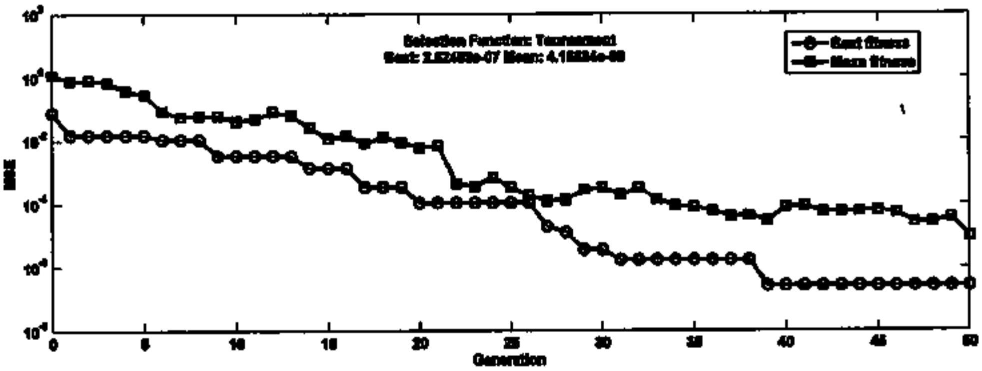

Figure 9: Selection Function: - Tournament

Figure 26 is showing the simulation result of tournament selection function. The graph line with square maker is showing mean fitness and line with circle marker is showing best fitness. The best value 2.62489e-07 and mean 4.18664e-05 is achieved by this operator.

4.2.3.5 Comparison of the Selection Function

S.NO	Selection Function Operator	Mean Value(MSE)	Best Value(MSE)	Iteration
1	Stochastic Uniform	8.421e-05	7.569e-07	50
2	Uniform	0.000696725	1.35712e-06	50
3	Roulette	0.00011214	7.75839e-07	50
4	Tournament	4.18664e-05	2.62489e-07	50

Table 3: Selection Function operator

The tournament selection operator is achieving mean value of bit error rate is 4.18664e-05and the best value achieved is 2.62489e-07. All the selection function operators are using the same number of iteration, however in the terms of BER, tournament selection is better than the others.

4.2.4 Comparison of performance of LMS, PSO and GA

S.NO	Algorithm		MMSE (BER)	Iterations
1	LMS		10^{-2}	300
2	PSO		10^{-2}	100
3	GA	Cross Over(Arithmetic Cross Over)	1.83532e-12	50
		Mutation Operator(Adaptive Feasible Mutation)	3.11939e-07	50
		Selection Function(Tournament)	2.62489e-07	50

Table 4: Comparison of Performance of LMS, PSO and GA

The table (4) provides over view of all the algorithms that are used to estimate the optimal value of the weights of adaptive receiver. Table shows that the best MMSE is achieved by using arithmetic cross over. Genetic algorithms and particle swarm optimization is using less number of iterations as compared to the LMS, which make its more suitable candidate for given problem. But in terms of bit error rate (BER) genetic algorithm with the arithmetic cross over is more suitable.

5. Chapter 5:- Conclusion

5.1 Conclusion:-

The goal of this research work was to find optimum weights for MC-CDMA adaptive receiver. The parameter, which are taken in consideration for this research work is bit error rate (BER) and the number of iteration taken by the algorithm. These parameter are responsible for computational complexity of the system. The main goal of the research is to find the optimal values of these parameter.

In the optimization problem, the acquiring or reaching the optimal point is hot research areas for the engineers and the scientists. The main task of this research area is to undergo all the search space of the problem. This is due to un-deterministic behavior of the problem. That's why, the deterministic solution do not applicable to such problem. The deterministic solution does not possess the ability to search all the available space for the optimal point. Instead of searching all the possible search space, the deterministic solution makes the system fixed way problem. If the deterministic solutions are applicable to, then it makes the system too heavy regarding the computational complexity factor. It is desired to find such algorithms and such mechanisms, which can find the optimal point of the given solution and also search for all available space. The process of searching all the available space is made by creating the randomness in every step of the algorithms.

These algorithms, which can search for all the search space and have a wide variety of the search space were developed in past. These algorithms are based on the nature based techniques. These algorithms are evaluated from the behavior of the nature. Since the nature rules are most stable than man made, so the implementation of such algorithms also provide us with the best results. These results can be made better, by creating the randomness in every step of such algorithms. Which make these algorithms to have more ability to undergo all the search space.

Many natural behavior like genetic behavior, fish schooling, ant social life, honey bee colony formation to give the basis for the genetic algorithm, particle swarm optimization, ant colony optimization, honey bee optimization etc. These algorithms helps us to find the optimal point of any problem. All the algorithms have different mechanism for the finding the optimal point. However, it is not declarable, that which one is better or worse. The performance of such system is problem dependent. It is not evident that, an algorithm is giving the best result, should also give best result to another problem.

The classical algorithms like least mean square (LMS), recursive least square (RLS) are deterministic algorithms. These algorithms also have problem, that they can't find the global minima exactly. Mostly these algorithms stuck in the local minima. Handling of step size is another sensitive issue for these algorithms in finding the optimal point. The step size means a vibrating distance. Sometime the classical algorithms (CA) do not exactly reach the optimal point. During its course, it takes more step size, or less step size but does not touch the optimal point. By reducing the step size, it takes too much computation, which makes system too balky from the point of complexity factor.

The simulation has shown that the non-conventional algorithms (NCA) are better in the result than that of conventional algorithms (CA). These algorithms can be implemented to the real time problem, like mobile communication system, satellite communication system to analyze the channel behavior and estimating the received signal. The NCA take less number of iteration, reduce the probability of error and reduce the complexity factor of the system.

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