CHAPTER 4

A NOVEL TECHNIQUE FOR MAI REDUCTION IN DS-CDMA COMMUNICATION SYSTEMS

4.1 INTRODUCTION

Wireless communication has developed into an integral part of the modern time communication systems. Many new innovative scopes are added every day by the researcher to the models of wireless communication systems to develop robustness and performance in order to provide better quality of service to its users. Yet another significant characteristic of modern time communication systems is digitization. This provides better immunity against noise in channel apart from many more advantages. The CDMA communication system has all the characteristics and capabilities to take on challenges of high quality demanding and ever increasing modern time wireless communications needs.

CDMA, a widely used communication method, is based on principles of spread spectrum technique. This technique spreads the bandwidth of the data to be transmitted by using pseudo-random codes. The spread sequence is obtained by performing different type of logical operations between actual data input and pseudo-random codes in a predetermined procedure. Logical operation may be as simple as bitwise XOR. CDMA allows many transmitters to transmit simultaneously over the same channel. In other words, several users simultaneously share the same bandwidth by
way of multiplexing. In CDMA system, however, the modulated spread sequence has much higher data bandwidth than the actual data has.

Each of the CDMA users is assigned a unique code to modulate the signal to be transmitted. The fundamental rule of unique codes is that all unique codes must differ among themselves by a difference as wide as possible. This is the main concept used at the receiver to distinguish between desired signal and other user’s signals. If the received code is matching with desired user’s code, the correlation function will have high value whereas in the non-matching condition, the correlation function will have low value. If the received signal is matched only after time shifting then it is assumed to have autocorrelation and is a case of multi path interference. The CDMA systems can be classified into two types, synchronous and asynchronous. In synchronous type, the data vectors have orthogonal property which mathematically implies that scalar product of any two data vectors is always zero. Orthogonal codes have cross-correlation equal to zero and thus there is no interference between codes. In asynchronous type of CDMA, Pseudo Noise (PN) sequence is used for spreading. PN sequence is a binary random bit sequence that is essentially random in nature but it can be reproduced by using certain polynomial based sequential circuits consisting of shift registers and delay elements. Also, PN sequences are not correlated but large numbers of sequences cause MAI which can be estimated by using Gaussian noise model. Asynchronous CDMA system receivers decode signal of interest by reproducing same PN sequence and then performing logical operations. The signals meant for other users will appear as noise for the current user and cause interference. The interference due to signals of other users is proportional to the total number of user’s presence and thus it is important to control the signal strength. Since asynchronous CDMA is not using orthogonal property, rejection of unwanted signals is big challenge and needs to be addressed with different approach. One approach is to match signal
power level which is normally used in CDMA cellular communications. Asynchronous CDMA is better choice as it is flexible in resources utilization and allocations to users. The numbers of users in asynchronous CDMA systems are limited by the amount of tolerable bit error rate. Signal to Interference Ratio (SIR) varies inversely to the number of users. Bit error rate is allowed to fluctuate randomly to allow flexibility.

4.2 MAI IN CDMA COMMUNICATION

The primary ideas of MAI suppression consists of the fact that in CDMA Communication System several user utility by same frequency and bandwidth separated at receiver only using various spreading codes in Hassan Moradi et al (2006). This development involve that in CDMA, transmitters are permitted to transmit concurrently in the same channel. Finally, the sharing of bandwidth is through several users. This is named as multiple accesses. CDMA Communication System functions just good condition under different ideal of orthogonal and synchronized codes of users. It may be however, inconvenient in real time non-ideal conditions below which is presence for the period of mainly practical implementation and then at the same time as the system being in operation. Appropriate to non-ideal orthogonality and complexity in sustaining synchronization at receiver, every user of the system acquires interference from a lot of supplementary users challenging multiple accesses. Channel delays and frequency offset in addition to include the interference quantity. The quantity of interference may differ from an insignificant altitude at times to extremely concentrated levels affecting the quality of the received communications harmfully in Ojanpera & Prasad (1998). Due to multiple accesses the interference is called as MAI. In this problem, detrimental effects may be impossible disgustingly in asynchronous communications, which are well known, succeed in downlink. The mobile node positioned secure to the base station be capable of source set
of interference to the mobile nodes situated at a distance ensuing in path loss. In this type of secure station position causes blockage of the power level to nearby mobile node which is not managed in proper manner by large number of users. This problem is called as near-far effect. A well organized designing and testing is required for controlling of power flow in different strategy is needed to utility of the power received in many different mobile nodes in Hassan Moradi et al (2006). The CDMA communication system capacity only depends upon the quantity of MAI appear in the system in Guo et al (2004). The CDMA system is of higher capacity in comparison to the other system, under the investigation of reuses the frequency and has different rate of transmission. In practical and life time an implementation of capacity achieved is not much greater than the maximum rate of theoretically achieve ability in Andrews & Meng (2004). Communication industry is quite struggling for well-organized multiuser detection receivers to enhance the capacity. Multiuser detection receivers are having high complexity and lack of robustness. To overcome these problems, a well organized and good quality research has been investigated for interference cancellation and use of the adaptive filtering based techniques for different applications of DS-CDMA wireless communications. The research literature considered under the first model system is based on the use of smart antenna system. This literature analysis is done for Uplink / Downlink / Dual smart patch antenna system which is supplemented by digital signal processing. Fundamentally, several artificial intelligence based algorithmic techniques are implemented and experimentally tested for smart antenna systems, namely array antenna system, beam forming antenna, smart patch antenna etc. The smart antenna systems are designed under different parameters such as control of radiation and direct power. The system has minimized the undesirable interference and given a controlled radiation power for only desired users. The proposed algorithm has scope of enhanced successive interference cancellation for improving the overall performance of CDMA communication system.
Basically interference cancellation techniques can be classified into two types’ viz., serial techniques and parallel techniques which are widely used in quite often for reducing interference quantity in CDMA. The serial module reduces the interference in the form of successive steps which is well-organized and is a better technique for reducing the interference during its compatibility test with real time industrial systems. It has excellent capability of error correcting with use of codes and it better suits for asynchronous communication types. The successive interference cancellation (SIC) technique is very simple and highly powerful to reduce interference to such a level that spectral efficiency of a channel can be equal to Shannon capacity under ideal conditions in Viterbi (1990). The SIC system may have a few drawbacks which are reported here.

- Signal Strength Estimation
- Accuracy of Estimation
- Decoding Problem
- More Processing
- Complex Power Management

Our Proposed system overcome above problems using improved techniques implemented with MAI which employed Gaussian Mixture model and maximum likelihood algorithm based receiver at an optimum computational cost in Erseghe & Tomasin (2009). Gaussian mixture system has mathematical and analytical capability to analyze accurately and also free from complexities in Mitra & Lampe (2008). Gaussian mixture model is widely used for ultra wide band interference reduction. The model may be implied for wide applications including frequency offset estimation and time-hopping ultra wide band communications with MAI in Tomaso Erseghe &
Antonio Maria Cipriano (2011). In the received signals, successively subtracting the interference is used by Successive Cancellation Scheme techniques for cancelling interference. The highest power $P$ of the signal may be detected and then it is eliminated from the received signal $s(t)$. This further more accurately detects the next weaker signal in Mosa Ali Abu-Rghelff (2007).

The received signals are sequenced in particular order depending upon their strength such as Equation (4.1) in descending order of their magnitudes.

$$\sqrt{P_1} > \sqrt{P_2} > \sqrt{P_3} \ldots \ldots > \sqrt{P_k} \quad (4.1)$$

where $P_k$ is the power level of $k^{th}$ user. Here the user-1 is assumed with highest power. The detection of user-1 signal $S_1(t)$ is normally estimated by using matched filters and may be given by (4.2)

$$S_1(t) = \sqrt{P_1} x_1(t) C_1(t) \quad (4.2)$$

Where $x_1(t)$ is symbol detected by user-1 and $C_1(t)$ is spreading wave for user-1. Subtracting signal strength of user-1 from received signal $s(t)$, the input for the next stage is estimated by (4.3)

$$S_2(t) = s(t) - S_1(t) \quad (4.3)$$

The procedure is repeated for the next strongest signal continuously until all users are detected and resolved in the same order. The input to the final stage is given by (4.4)

$$S_k(t) = s(t) - \sum_{i=1}^{k-1} S_i(t) \quad (4.4)$$
The successive interference cancellation procedure is linear function and is illustrated in Figure 4.1 as shown below.

Figure 4.1 Successive interference cancellation techniques for CDMA systems
The SIC can be easily implemented using hardware circuits and thus it is very robust in nature. It, however, as mentioned earlier, has drawbacks and thus needs to be improved upon. The main limitations is regarding any detection inaccuracy happening at a particular stage which may be carried forward in a feedback loop and cumulatively cause further deterioration in the quality of the signal. It will, thus increase the interference subsequently beyond tolerable limit quickly. The recent research shows use of intelligent techniques for countering cumulative deterioration of the signals due to multiple interferences. The neural networks based techniques can handle the problem far better way in Maity & Sumanta Hati (2011). Despite many hardware solutions, the problem still exist and need to be tackled by using combination of hardware and algorithm based reduction in interference. One such technique of optical time gating is examined and found quite worthy. It, however, needs clock recovery and timing coordination. This finally leads to a very complicated and non-cost-effective receiver design in Changjian Guo et al (2009). The key lies in the determining that precisely how many active users are required to be cancelled in order to achieve a predetermined level of bit error rate (BER). A trade off may be worked out between the number of cancellation of active users and the tolerable delay that will happen in SIC technique. The cancellation of active user will lead to the degradation of the system in terms of BER. The adaptive learning property of neural networks offers good scope for improving BER performance. The commonly used parameters to estimate reduction in SIC have been throughput and receiver complexity. There are not many references which have examined the effects of variations in the channel parameters, such as multipath, latency and estimation of errors in Maity & Sumanta Hati (2011). This research work reports the simulated results of adaptive type neural network based algorithm
to reduce BER in order to improve overall performance of the CDMA communication systems.

**Figure 4.2 General architecture of ADALINE for reducing BER in CDMA**

4.3 PROPOSED ALGORITHM FOR MAI CANCELLATION

A very particular type of neural network called adaptive linear neuron (ADALINE) model is chosen for improving BER. The ADALINE is a very flexible technique commonly used in error cancellation, signal processing, and control systems. The ADALINE is similar to perceptron except that its transfer function is linear and not based on the rigid logic. This indicated that the output of ADALINE can have any continuous value and not merely discrete 0 and 1 as is normally found in other cases. The least mean square (LMS) learning technique is chosen for ADALINE to make it more powerful. LMS also moves the decision boundaries beyond current knowledge acquired through training and thus it is adaptive to the present conditions. An adaptive linear system, as shown in Figure 4.2, has been
designed and validated for the simulation tests using MATLAB. It has shown good response to the variations in the incoming signals from many users simultaneously. The weights of target vectors are updated at each step on the time scale in such a way that overall total mean square error is reduced to a minimum level.

An ADALINE is a particular artificial neural network based algorithm designed to be intelligent enough to self learn from its ambience conditions and adapts itself to a given model. A simple and representative architecture of ADALINE is illustrated in Figure 4.2. The network output of the equation (4.5) is generated by a linear combination of inputs and constant terms.

\[
\text{Output} = \sum_{i=1}^{n} w_i x_i + w_0
\]  

where \(x_i\) are inputs detected from users and \(w_i\) are weights of the input matrix. The output of the network is finally detected signal from \(k^{th}\) user after subtracting all other user signals as computed by the algorithm. For the \(k^{th}\) user, the error of an ADALINE network can be computed in (4.6) as

\[
e_k = \left[L_k S_k(t)\right]^2
\]
where \( t_k \) is target output for \( k^{th} \) user and \( e \) is an error. Differentiating Equation (4.6) with respect to the weights \( w_i \), and using Equation (4.5), gives an Equation (4.7)

\[
\frac{\partial e_k}{\partial w_i} = -2 [t_k - S_k(t)] x_i
\]  

(4.7)

To decrease \( e_k \), the weights matrix is to be updated in (4.8) such a way that updated weight is computed using -

\[
w^{\text{updated}}_i = w_i - \eta [t_k - S_k(t)] x_i
\]  

(4.8)

where \( \eta \) is learning rate and an arbitrary value can be assigned to it. This is very important property of self learning capability of ADALINE networks. It is linear, has distributed learning property or learning is local for each user signal and has online learning capability which means weights are updated automatically after new inputs are available to the system. The proposed system block diagram is shown in Figure 4.3.

The design of ADALINE module has two inputs, \( e_1 \) and \( e_2 \) as shown in Figure 4.3, where \( e_2 \) is delayed signal of \( e_1 \). The delayed signal \( e_2 \) is deliberately chosen and incorporated in the proposed system since ADALINE is not known to have memory and in CDMA the final output depends upon previous interference cancellation levels as well. This additional feature works similar to the conditions where current output depends upon past states.

**4.4 RESULTS AND DISCUSSIONS**

The simulation tests are carried out using MATLAB communication tool box. The first analysis is done for BER as number of users increases and thus interference also goes up. The graphical visuals are presented in Figure 4.4.
The standard simulation tests are carried out at 40% of users interference cancellation level and 6 dB of signal to noise ratio is maintained. A predefined and uniform size of bits per user is used for estimating BER at receiver end. The type of channels considered are additive white Gaussian noise (AWGN) and Rayleigh fading models. Figure 4.4 shows BER analysis considering AWGN model. The simulations tests are carried out in MATLAB using ADALINE neural network based controller as shown its architecture in Figure 4.3 and C programming. The model assumed 90 users in the network simultaneously accessing the CDMA channel. As shown in Figure 4.4, it is clear that BER increases as the number of users increases. This is quite predictable as MAI is also expected to become more and more prominent as the number of users goes up. The simulated result analysis computation shows that if the number of users is increased from about 5 to 90, as can be seen in Figure 4.4, the BER is increased about 100% or in other words the BER
almost doubles for the increased number of users. This computation is based on 40% interfering users cancelled out in the descending order of their signal strength.

The simulation tests are also carried out without cancelling interfering users and then a comparison is analyzed. The results are illustrated in Figure 4.5 as shown below.

Figure 4.5 BER analysis without cancellation of any interfering users

It can be easily figured out that BER increases at a quite higher rate as the number of user increases under the condition of no interfering user cancellation. This was main finding of the simulation tests. The quantitative analysis shows that the BER is higher under no cancellation of interfering user by a factor of 3.5 times at the lowest to 13 times at the highest level as the number of users increased from about 5 to 90. The computation shows that an average rate of BER is higher by about 7.8 times of the BER at 40%
cancellation of number of interfering users. The both analyses are shown in Figure 4.4 and Figure 4.5 for 40% cancellation of interfering users and no cancellation of the interfering users respectively. Simulations are also done to verify the common principle that the BER decreases with increasing SNR value. This is usually expected result and is within the normal range which has shown the same trend as most of the research literature has been reporting. At a very high SNR value, for example, 20 dB and above, the BER is almost insignificant and has very low value.

The next analysis is carried out for the effect on BER due to different combination of the interfering user cancellation. This implies two separate analytical conclusions. The first, simulations are carried out by starting at no cancellation of interfering user to a 40% of cancellation of interfering users. The observations are that as cancellation of more and more interfering users is done, the average BER decreases. The decrease is quite significant at initial stage but after some level of cancellation of interfering users, reduction in BER is slowed down. Furthermore cancellation of interfering users causes very minimal decrease in BER. The final conclusion is that cancellation of interfering user serves the purpose to some extent only. Beyond that, it becomes insignificant on the performance improvement. It, rather, slows down the communication process and increases complexity due to increased use of algorithm. This analysis is carried out for a set of 90 users and for a fixed amount of bits per user. The trade-off needs to be reworked if any of the above mentioned parameters, such as number users and bit size per user etc. changes. The analysis of BER Vs % cancellation is depicted in Figure 4.6 as shown below.
Results show that at about 25% cancellation of the total interfering users, the BER is reduced significantly. Furthermore, cancellation doesn’t help much. This is the threshold value at which the proposed algorithm stops cancellation process and an acceptable level of BER is reached. This optimizes the trade-off between cancellation of interfering users and acceptable BER value. This also leads to the definite conclusion that the proposed algorithm is intelligent enough to reduce delay by reaching on decision point that BER is not much going to improve further and thus stops further cancellation. In other words, it converges on reaching a predefined acceptable BER value.

The second type of analysis consists of finding out that what type of interferers would dominant in very immediate future time due to mobility of the users. Current user location may have been used to find out the signal strengths of each users attempting simultaneous access. But, users may
change location immediately and probably before the transmission is completed. This needs an additional capability of the algorithm to address the issue of updating the signal strength of different users by sampling. At every sampling event the order of the users in descending order of the signal strength changes as the current strengths of the signals gets updated. A few simulation tests are carried out for this analysis and results shows small improvement in BER performance. The analysis in this regard is further verified with more simulations tests to conclude quantitatively validations. The adaptive model filters out an interference component by identifying measurable interference component of other users.

4.5 SUMMARY

In this chapter, the concept of spread spectrum systems is considered and provided the main features of the direct sequence spread spectrum system using ADALINE neural network for reducing BER as well as successive interference cancellation. A key component of BER / SIC is the calculation of 40% cancellation and better system preference without interference. The ADALINE algorithm for SIC is presented for error-free communications. It has proven that it is possible to design practical CDMA systems for energy-per-bit to noise for actual value of $E_b/N_0$ at about 6 - 7dB.