www.ijecs.in
International Journal Of Engineering And Computer Science ISSN:2319-7242
Volume 3 Issue 1, January 2014 Page No. 3617-3623

Performance Improvement Technique for Multiple User Detection in DS-CDMA System using Groupwise Successive Interference Cancellation (GSIC)

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Abstract: Code Division Multiple Access (CDMA) system is being most popular communication technique due to its robustness & spread spectrum techniques. The CDMA include the pseudo sequences (PN-sequences) which provide the secure communication over a wide band. But the Multiple Access Interference (MAI) limits the capacity of Direct Sequence Code Division Multiple Access (DS-CDMA) based systems. For DS-CDMA systems, MAI is behaves as additive noise and a matched filter bank is employed and due to superposition of MAI with noise the capacity of the system reduced. Traditionally, multiuser detectors a code-matched and a multiuser linear filter are employed which increases the complexity of the system due to its operation methodology.

The Multiuser Detection (MUD) is an approach which uses both these filters for the optimization. However, the limitation at implementation-end of the optimal multiuser detection is its processing complexity and processing delay. Recent research in communication system with MUD is concentrate to find an appropriate trade off between complexity and performance. These suboptimal techniques are further sub-divided into linear and non-linear algorithms.

In this dissertation, we implement Groupwise Successive Interference Cancellation (GSIC) and Successive Interference Cancellation (SIC). Both Interference Cancellation techniques are nonlinear suboptimal methods of MUD and are based upon successively removing a fraction which results in optimal Interference. Further analysis and rigorous study is to be carried out and extensive simulations are done for better understanding of GSIC and SIC techniques.

There are several schemes for the performance evaluation of a CDMA scheme which omits the Interference Cancellation, the main analysis is to be done is SIC & improvement in SIC using Multi User Group Wise Detection & Interference Cancellation (GSIC). The rigorous simulation work is being carried out to resolve the Multi User Detection for CDMA system; a novel approach can be derived for Interference Cancellation using Successive subtractions & GroupWise estimation for better results.

Key Word: DS-CDMA, GSIC, Interference Cancellation, SIC, MUD, Performance Improvement of CDMA System

1. Introduction

Code Division Multiplexing (CDMA) is a digital cellular communication technology which uses spread-spectrum technique i.e. it works by digitizing multiple conversations. Initially, it was developed and verified by Qualcomm, Inc. Likewise, after its versatility it was universally adopted by community and standardized by the Telecommunications Industry Association (TIA) as an Interim Standard (IS-95). In this technology, several users share the same physical medium i.e. same frequency band at same time.

Code Division Multiple Access (CDMA) is used as a multiple access technique in telecommunications radio system that can transport multimedia traffic at high data rates. The basic requirements for the evolution in wireless systems are,

i. Need for highly reliable and secure telecom network.
ii. Implementation of inexpensive communication network.
iii. Introduction of new data services like video conferencing, telephony, various types of internet services etc.
iv. Low cost and reliable mobile devices with large processing rate and good reception capabilities.

1.1. Theoretical Background

In general three multiple access techniques are used in the recent communication systems. These multiple access techniques are; Time Domain Multiple Technique (TDMA), Frequency Multiple Access Technique (FDMA) and Code Division Multiple Access (CDMA) The idea of CDMA was originally developed for military communication devices and developed by Allies in World War II.

In CDMA technology every mobile station or user will be allocated the entire spectrum all of the time [1]. It uses codes to identify each user connection. In conventional DS/CDMA system it treats each user separately as a signal and other users are considered as noise or multiple access interference (MAI). All mobile station or users interfere with all other users. These interferences added to primary (main) message signal and therefore degradation in system performance. The near/far issue is serious and tight power control, with attendant complexity is necessary to combat it. Potentially significant capacity increases and near/far resistance can theoretically be achieved if the negative effect that each user has on others can be cancelled. To overcome these problems (of the conventional CDMA system) Multiuser Detection (MUD) is used. In this technique all users are considered as signals for each other.

After 3rd generation cellular mobile communication system multi-carrier code division multiple access (MC-CDMA) networks are proposed for fourth generation (4G) system. These networks are defined by the ability to integrate heterogeneous networks, particularly radio mobile networks and wireless networks, which offers anytime anywhere access of all kind of services. The rapid growth of internet services in portable computing devices creates a strong demand for high speed wireless data services. Key issues to fully meet these evolution perspectives are based upon the multi-carrier systems which have become popular for their spectral efficiency and robustness against frequency-selective fading and inexpensive implementation. Multi-carrier code division multiple access (MC-CDMA) is a technique that combines the advantage of multi-carrier modulation with that of code division multiple access to offer reliable high data rate downlink cellular communication services. It is used, as it has proven to be better than conventional CDMA, FDMA and TDMA networks.

1.2. Related Works

1. Jeffrey G. Andrews and Teresa H. Y. Meng, “Performance of Multicarrier CDMA with Successive Interference Cancellation in a Multipath Fading Channel”

A high capacity, low complexity and robust system design for a successive interference cancellation (SIC) system were proposed and analyzed. Multicarrier Code-Division Multiple Access (MC-CDMA) was used to suppress multipath and to overcome or minimize the multipath channel estimation problem in single-carrier SIC systems. Furthermore, an optimal power control algorithm for MC-CDMA with SIC was derived, allowing analytical bit-error rate expressions to be found for an un-coded system. Low-rate forward error-correcting codes are then added to the system to achieve robustness. It was observed that the capacity of the coded system approaches the additive white Gaussian noise capacity for SIC, even in a multipath channel fading with channel estimation error. This indicates that MC-CDMA technique is very attractive for systems employing SIC.

A low-complexity MC-SIC system was proposed to increase CDMA capacity in a multipath fading channel, and its analytical BER performance was derived. In addition, the optimum PC distribution for such a system was derived in the presence of channel estimation error. Using this distribution, it was shown that coded MC-CDMA is capable of mitigating the multipath fading channel for a SIC system, and able to nearly achieve the performance of SIC in a flat-fading channel, even with a substantial amount of channel estimation error. The derived PC distribution also allows the capacity falloff with cancellation error to be gradual relative to other IC systems, if the IC accuracy is conservatively estimated.

2. Tao Li and Nicholas D. Sidiropoulos, “Blind Digital Signal Separation Using Successive Interference Cancellation Iterative Least Squares”

Blind separation of instantaneous linear mixtures of various digital signals is a basic problem in communication processes..When less or nothing can be presumed about the digital signal mixing matrix then separation of signal may be achieved by exploiting structural properties of the transmitted signals, e.g., finite alphabet or coding constraints.

The authors proposed a monotonically convergent and computationally efficient iterative least squares (ILS) blind separation algorithm based on an optimal scaling lemma. The signal estimation step of the proposed algorithm was reminiscent of successive interference cancellation (SIC) ideas. For well-conditioned data and moderate SNR, the proposed SIC-ILS algorithm provides a better Performance/Complexity trade-off than competing ILS algorithms. Coupled with blind algebraic digital signal separation methods, SIC-ILS offers a computationally inexpensive true least squares refinement option. They also point out that a widely used ILS finite alphabet blind separation algorithm can exhibit limit cycle behaviour.

They proposed an algorithm for blind separation of linear mixtures of digital communication signals. The algorithm features moderate complexity, monotone convergence, and performance close to ILSE in all cases considered with the exception of the high SNR fully blind regime. A bonus feature is that the optimal scaling lemma allows easy incorporation of coding constraints. Although high-frequency limit cycles can potentially be detected and ILSP can be randomly reinitialized when this happens, re-initializations are likely to be avoided in practice due to complexity considerations; hence, oscillatory behaviour can be problematic. In addition, lower frequency limit cycles are possible.

3. S.R. Sheikh Raihan1 and B.C.Ng, “DS-CDMA System with Linear Multiuser Detection in AWGN Channel”

Direct sequence code division multiple access (DS-CDMA) technology is a popular wireless technology. In this paper a comparative study between linear multiuser detectors, optimal multiuser detector, and conventional single user matched filter in DS-CDMA system. Analysis and simulations was conducted in synchronous AWGN channel, and Gold code sequences are used as the spreading codes. Their study shows that optimal multiuser detector performs better than the conventional matched filter and linear multiuser detector in terms of BER performance. However, optimal multiuser detector suffers from complex computation and costly implementation. MMSE detector provides better error performance than the decorrelating detector, but it utilizes the estimation of the received powers.The optimal multiuser detector performs better than the conventional matched filter and also the linear multiuser detectors. However, this detector is more complex for implementation in practical DS-CDMA system. MMSE detector generally performs better than the decorrelating because it considers the background noise. As number of user increases, the performance of all detectors will degrades. This is because the density of MAI becomes higher with increasing the number of interfering users.

4. Jeffrey G. Andrews and Teresa H. Meng, "Optimum Power Control for Successive Interference Cancellation with Imperfect Channel Estimation"

Successive interference cancellation (SIC), in conjunction with orthogonal convolution codes, has been shown to approach the Shannon capacity for an Additive White Gaussian Noise channel. However, this technique requires highly precise estimates for the amplitude and phase of each user's signal. In this paper, author derives an optimal power control strategy specifically designed to maximize the overall capacity under the constraint of a high degree of estimation error. Power control strategy used by authors presents a general formula of which other power control algorithms are special cases. Even with estimation error as high as 50%, capacity can be approximately doubled relative to not using interference cancellation. In addition, when properly applied to multi-cell mobile networks, this power control method can reduce the power transmission from mobile handset and therefore other-cell interference is also reduces by more than an order of magnitude.

In order for SIC to work properly, a power control algorithm which takes inevitable channel estimation error into account is required. It was authors contention that fast and appropriately designed power control was a key element in allowing a SIC system to achieve high performance in practice. While this introduces complexity into the system, the potential rewards for doing so are considerable. A general formula for the optimum power control distribution for SIC and conventional CDMA was derived in this paper. Using this distribution, it was shown that channel estimation error up to 50% can be tolerated, while still at least doubling the capacity of a system without SIC. On the other hand, by using suboptimal power control results in greatly reduced capacity. In addition to this large gain in capacity, OCI can be simultaneously reduced by around an order of magnitude if users are assigned power levels based on their distance from the base station.

5. Seung Hee Han and Jae Hong Lee, "Group-wise Successive Interference Cancellation (GSIC) Receiver with Adaptive MMSE Detection for Dual-rate DS-CDMA System**"**

In this paper, group-wise successive interference cancellation (GSIC) receiver with adaptive minimum mean squared error (MMSE) detection and extended GSIC (EGSIC) receiver with adaptive MMSE detection are proposed for dual-rate DS-CDMA system. For this, Users are broadly divided into two groups for their data rates: high-rate (HR) users and low-rate (LR) users. Initial bit estimates for the HR users are obtained by adaptive MMSE detection. Multiple access interference (MAI) between the HR users is cancelled by parallel interference cancellation (PIC) and updated bit estimates for the HR users are obtained. Then, the estimation for the received signals of the HR users is regenerated using the updated bit estimation and summed up to be subtracted from the received signal. The initial bit estimates for the LR users which are obtained by adaptive MMSE detection using the received signal with MAI from the HR users being subtracted. MAI between the LR users is cancelled by PIC and updated bit estimates for the LR users are obtained. In the extended GSIC (EGSIC) receiver with adaptive MMSE detection there is an extra stage is used to take the interference from the LR users to the HR users into account. It is observed that the receiver based on EGSIC with adaptive MMSE detection is achieved significant performance improvement over the MF receiver in Rayleigh fading channel.

In this paper, the GSIC receiver with adaptive MMSE detection and EGSIC receiver with adaptive MMSE detection are proposed for dual-rate DS-CDMA system with the MPG scheme. Users with the same data rate are grouped and the bits for the group 1 users are detected using adaptive MMSE detection. The effect of the MAI between intra-group users is mitigated by PIC. Then interference from the group 1 users is regenerated. Initial bit estimates for the group 2 users are obtained from the received signal with MAI from the group 1 users being cancelled. Updated bit estimates for the group 2 users are obtained by PIC. In the EGSIC receiver with adaptive MMSE detection, the MAI from the group 2 users are regenerated and cancelled from the received signal using the updated bit estimates for the group 2 users. Next, the updated bit estimates for the group 1 users are obtained using adaptive MMSE detector. Final bit estimates for the group 1 users are obtained by PIC stage for the group 1 users.

The adaptive MMSE detection employed in the proposed receiver is implemented by simple LMS algorithm so that it improves the performance of the receiver with little added computational complexity over the MF. It is shown from the simulation results that the EGSIC/MMSE/PIC receiver achieves significant performance improvement over the MF receiver, EGSIC receiver, EGSIC/MMSE receiver, EGSIC/PIC receiver for all user groups in a Rayleigh fading channel.

6. Sudhir Babu and Dr. K.V Sambasiva Rao, "Evaluation of BER for AWGN, Rayleigh and Rician Fading Channels under Various Modulation Schemes"

Several transmission modes are defined in IEEE 802.11 a/b/g WLAN standards. A very few transmission modes are considering for IEEE 802.11 a/b/g in physical layer parameters and wireless channel characteristics. This paper evaluated the performance of available transmission modes in IEEE 802.11b [1]. However, the performance analysis can be done straight forward using the evaluation of IEEE 802.11b. The performance of transmission modes are evaluated by calculating the probability of Bit Error Rate (BER) versus the Signal Noise Ratio (SNR) under the frequently used three wireless channel models (AWGN, Rayleigh and Rician). They consider the data modulation and data rate to analyze the performance that is BER vs. SNR. Authors also consider multipath received signals and therir simulation results had shown the performance of transmission modes under different channel models and the number of antennas. Based on simulation results, it was observed that some transmission modes are not efficient in IEEE 802.11b. The evaluation of performance confirms the increase in the coverage area of the physical layer in the 802.11b WLAN devices.

From the simulation results, The Bit Error Ratio of a digital communication system is an important figure of merit used to quantify the integrity of data transmitted through the system. By implementing the different modulation techniques, the criterion is comparison of the variation of BER for different SNR. It is observed that the BER is minimum for AWGN and maximum for RAYLEIGH and RICIAN. For RICIAN it is found that the BER is less than AWGN and RAYLEIGH except in case of 16-DPSK. And it is observed that 16-QAM is performing better than 64-QAM. For higher values of Eb / N0, the BER is decreasing in all the fading channels for different modulation schemes.

1.2.1 Conclusion of Literature Review

Since thesis work cannot be complete without the literature review because literature review helps us to find out the problem statement for further research and thus also able to know progress or new invention in the relevant field. In wireless communication the main requirement is signal reception with minimum noise or interference or we can say with higher SNR value. This requirement is the key source for new research or invention of new techniques because there are various types of noise and interference and many factors in the environment which affects the performance of CDMA wireless systems.

Some of techniques are used by various research scholars in different mode or different methods to improve the band width efficiency, performance, capacity and SNR of the CDMA wireless system for different types of channels and noise environment.

As summary of literature review, I found that research scholars did work on Interference cancellation and performance improvement using Successive Interference cancellation (SIC) these techniques used in different noise medium like AWGN and Rayleigh environment and modulation technique BPSK, MSK, QPSK etc. By applying various types of interference cancellation techniques the performance, SNR, BER and capacity of CDMA wireless system can be improve.

1.2.2 Problem Formulation

In the CDMA wireless system the SNR is affected due to interference and noise in the channel or environment of medium due to interference the signal received with low SNR or higher BER at the receiver end and generate some delay due to successive process of signals hence performance also decrease as well, so here I am using a technique to reduce delay and improve SNR value which is known as Groupwise Successive Interference Cancellation Technique (GSIC) with the help of MATLAB Tool.

1.2.3 Methodology

By using this technology Bit Error Rate (BER) can be reduce by processing the signals in group of certain signals simultaneously. For this work MATLAB tool is used here and investigate the received signal with different values of SNR, different length of message and PN Sequence and observe the BER and compare it with SIC for BER improvement.

2. Proposed Algorithm

Multi-User Detection (MUD) Concepts and Techniques

Figure 3.1 shows the baseband model of a CDMA uplink. The signals received at the base station (BS) are the superposition of signals. These additive signals are, from all mobile devices, the multipath components of signals from corresponding users, and Additive White Gaussian Noise (AWGN). The channel encoders for each transmitter are show in figure 2.1

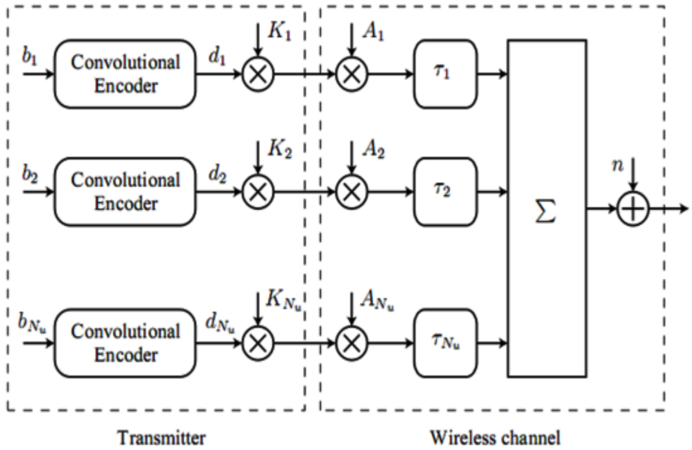

Fig 2.1 CDMA Uplink

Let, there are N_u users in the system and the corresponding data signals from these users are designated as $d_1(t), d_2(t), \ldots, dN_u(t)$. The data symbols within the data signals are spread by multiplying with respective spreading sequences K_1 (t), $K_2(t), \ldots$, $K_{Nu}(t)$. The AWGN channel introduces delays τ_1, $\tau 2, \ldots$, τNu to signals transmitted from different users and fading coefficients are $A_1(t)$, $A_2(t), \ldots, A_{Nu}(t)$ for the single resolvable path of each user introduces by the multipath propagation of the signal. Spreading sequences $K_1(t)$, K_2 $(t), \ldots$, $K_{Nu}(t)$ is given as, $\tilde{k}_i(t) = \sum_{m=1}^{N} c_{im} p(t-(m-1)T_c)$ Where,

C_{im} is the m^{th} sequence chip of the spreading sequence $K_{i(t)}$ .N is the length of spreading sequence

p(t) is the chip pulse shape. In this case, it is rectangular pulse

MUD Algorithms

Figure2.2 Shows the hierarchical categorization of different techniques adopted for the multiuser detection. The efficient algorithm for the implementation of MUD is suboptimal methods. The recent development in these techniques further categorized in two methods, i.e. linear and non-linear. Due to simple in implementation and easy to processing nonlinear techniques are more powerful and developed algorithm [4]. Further, the successive interference cancellation technique (SIC) and group wise successive interference cancellation technique (GSIC). Our emphasis is on finding a suboptimal method to find a combination having proper complexity and performance. In this dissertation, we study and compare the both MUD implementation techniques i.e. Successive Interference Cancellation Technique and Group-wise Successive

InterferenceCancellationTechnique

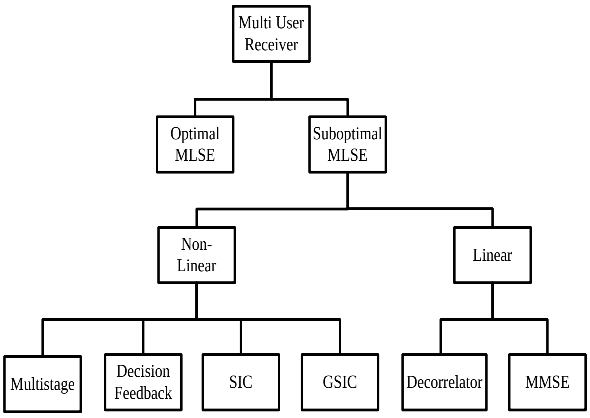

Fig 2.2. Flowcharts for MUD Algorithms

Groupwise Successive Interference Cancellation Technique (GSIC) Groupwise multiuser detection has recently emerged as a effective solution for multirate multiuser detection, since GSIC provides interference cancellation in groups instead of individual user signal, and the groups can be straightforwardly formed by considering users that have equal transmission rates. Within a group, any type of detectors can be implemented, although the simplest, most common choice is to use matched filter receivers. Groupwise successive interference cancellation (GSIC) performance analyses and iterative power control schemes have been presented in [13] for a simplified case that considers perfect interference cancellation among groups and matched filter receivers within groups.

The performance of a DS-CDMA system is limited by multiple access interference (MAI) and near-far effect. Such problem arises from the use of the conventional single-user detector, which ignores the existence of other available users. As a consequence, whenever the number of active user's increases to a certain level or some user's signals becomes extremely strong, weak users with the conventional single-user detector may lose communication because of the overwhelming MAI.

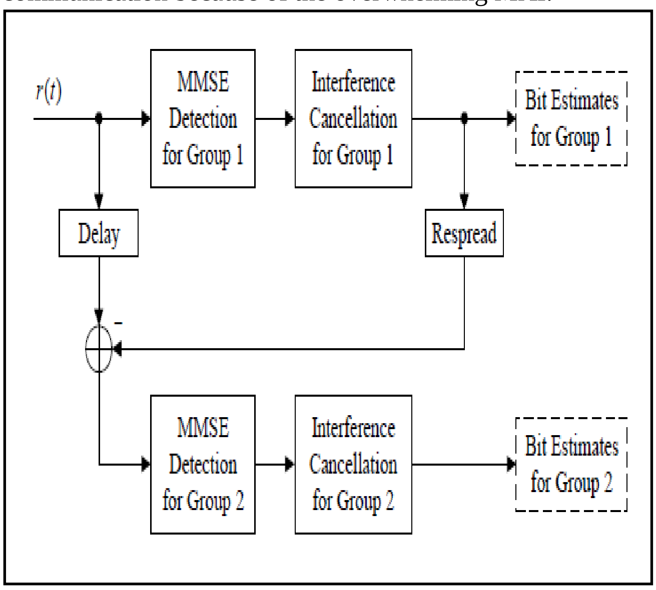

Fig 2.3 Block Diagram of GSIC Receiver

Figure 2.3 shows the system block diagram of GSIC based DS-CDMA system for the multi-user detection. Sampled output of the matched filter for the k^{th} user

$$y_k = \int_0^T y(t)s_k(t)dt = c_k x_k + \sum_{j\neq k}^{k} x_j c_j \int_0^T s_k(t)\, s_j(t)\ dt + \int_0^T s_k(t)\ z(t)dt$$

the factor $x_j c_j$ are introduces to cancel the **Multiple Access Interference** (MAI). Two approaches are used for the determination of x_j and c_j. In first method, the x_j and c_j are estimated separately. In second method, the product of $x_j c_j$ is estimated using the correlator output. The strongest incoming signal has to be cancelled out before the detection of other signals because it is most negative. [5] The best estimate of signal strength is from the strongest signal because the best bit decision is made from that signal; further the strongest signal has least MAI, since the strongest signal is excluded from its own MAI.

The optimal maximum likelihood (ML) detector that jointly detects all active users' signals eliminates the MAI and provides substantial increase in system capacity. However, the complexity of the optimal ML detector is exponentially proportional to the number of users, so it is impractical for implementation, and was discussed in prior sections. Therefore, new version of SIC is proposed. This extension of SIC try to approach the performance of the optimal ML detector with reduced computational complexity.

As a sub-optimal multi-user detector, the group-wise successive interference cancellation (GSIC) receiver was considered for CDMA system. In the GSIC receiver for the CDMA system, user signals are divided into groups according to data rates and interference from each group is estimated and subtracted successively from the received signal in an order of decreasing data rate. The GSIC receiver use the MF to obtain initial bit estimates that are used to cancel the MAI between groups [15].

3. Performance Evaluation

As discussed in previous section, the effective multiuser detection technique is adopted. The GSIC has been implemented in MATLAB (ver 7.10.0.499) tool. By Applying the Groupwise Successive Interference Cancellation (SIC), the comparison is made between SIC BER vs. Number of Users and GSIC BER vs. Number of Users. Following steps are used for the implementation of GSIC at receiver end,

i. Initially, a random binary signal is generated. This binary signal is act as message signal
ii. This message signal is multiply with PN-sequence. This multiplied signal is transmitted over medium
iii. In the communication medium, the AWGN noise is superimposed to transmitted signal and corrupt the signal
iv. Likewise, signals from multiple users are added in the communication channel.
v. At receiving end the corrupted signals are multiplied with the PN-sequence. And at this instant channel noise and signal interference by multiple users is taken into account. The symbol threshold is taken place to get the corresponding sender message signal
vi. To compute the error, firstly the transmitted message signal is multiplied with the same PN-sequence. Secondly, this signal is subtracted from received signal.
vii. This error is used for the up-gradation of the weights. This includes the previous estimation of output and the previous weight of the estimator.

viii. These weights are multiplied with the next received signal to get the next estimated output. Finally, the estimated output is multiplied with PN-sequence and after applying threshold value; the desired output signal is obtained.

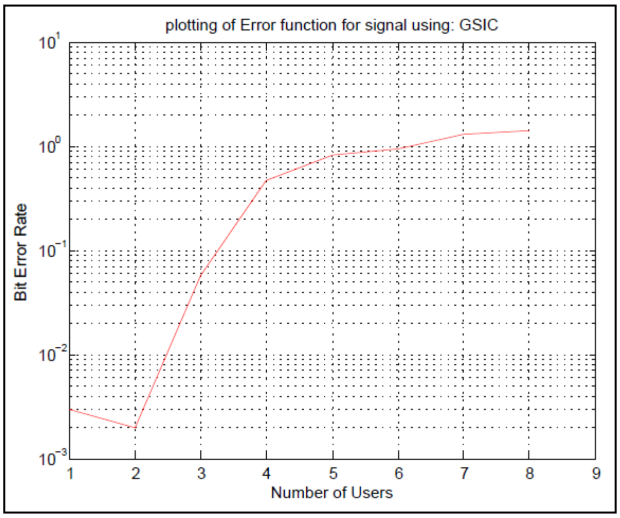

Fig 3.1 Graph of BER using GSIC Receiver

Comparison Table of Improvement in BER between GSIC & SIC having some fix parameters PN Sequence=16 bit, SNRr=20, msg=1000, user=15.

user	BER_GSIC	BER_SIC	% BER Improve
1	0.0010	0.0010	0.00%
2	0.0020	0.0020	0.00%
3	0.0030	0.0030	0.00%
4	0.0050	0.1270	96.06%
5	0.0620	0.0880	29.55%
6	0.1040	0.2420	57.02%
7	0.2880	0.4090	29.58%
8	0.4310	0.4340	0.69%
9	0.4580	0.5480	16.42%
10	0.6510	0.8590	24.21%
11	0.8920	1.0440	14.56%
12	1.2150	1.2250	0.82%
13	1.3280	1.4010	5.21%
14	1.4190	1.6210	12.46%
15	1.7550	1.9070	7.97%

Table3.1**.** Comparison Table of Improvement in BER between GSIC & SIC

Analysis chart of Improvement in BER between GSIC &SIC SNR=20dB and PN-16 bit For User =15 in one Group

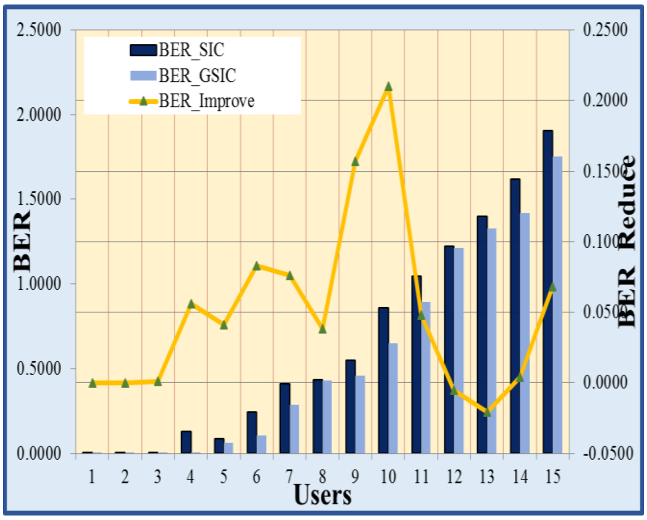

FIG3.2 Analysis Chart of Improvement in BER between GSIC & SIC

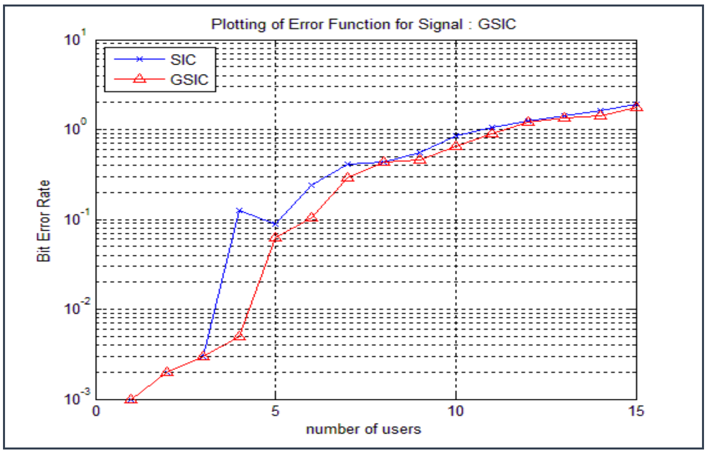

FIG3.3 Stimulated Graph of Improvement in BER between GSIC & SIC.

5. Conclusions & Future Work

The inclusion of GSIC in a CDMA receiver can significantly improve its performance relative to that of conventional CDMA receiver where no interference cancellation is attempted. GSIC appears to be more resistant to fading than SIC, and achieves better result with regards to BER and ability performance, it is due to extremely from a high processing delay.

While doing practical execution, problem occurred due to sensitivity, robustness and processing delay. In determining overall capacity, Capacity improvements only on the uplink would only be partly used anyway. Doing multiuser detection Cost must be as low as possible so that there is a performance/cost trade off advantage. Using better channel estimation technique the performance of the GSIC can be improved further.

For delay, one of the way is to limit the number of cancellation also Group wise SIC (GSIC) has proposed to deal with delay it may degrade the routine. Study of GSIC and comparison it to PIC and EGSIC could be left for some future work.

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