IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 10, Issue 2, Ver. II (Mar - Apr.2015), PP 30-35
www.iosrjournals.org

Performance Improvement Technique for Multiuser Detection in DS-CDMA Systems Using Successive Interference Cancellation

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Abstract: *Multiple access interference (MAI) limits the capacity of Direct sequence Code Division Multiple Access (DS-CDMA) systems. In CDMA systems MAI is considered as additive noise and matched filter bank is employed. Traditionally, multiuser detectors— a code matched and a multiuser linear filter are used which increases the complexity of the system due to its nature of operation. Multiuser detection is an approach which uses both these filters for the optimization. However, the main drawback of the multiuser detection is one of the complexity so that suboptimal approaches are being sought. Much of the present research is aimed at finding an appropriate tradeoff between complexity and performance. These suboptimal techniques have linear and non-linear algorithms. In this work, we introduce Successive Interference Cancellation (SIC) which is a nonlinear suboptimal method of MUD and is based upon successively subtracting off the strongest remaining signal. Further analysis is to be carried out and simulations to be done for better understanding of SIC.*
Keywords: *Multiple Access Interference (MAI), Successive Interference Cancellation.*

I. Introduction

In CDMA every communicator will be allocated the entire spectrum all of the time. It uses codes to identify connection. A conventional DS/CDMA system treats each user separately as a signal, with the other users considered as a noise or MAI, multiple access interference. All users interfere with all other users and the interferences add to cause performance degradation. The near/far problem is serious and tight power control, with attendant complexity is needed to combat it. All users in a CDMA system interfere with each other. 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.

A simple modification of the decision feedback equalizer slicer is proposed to reduce the effect of error propagation. A comparison of the performance of the modified decision feedback equalizer is made for specific channels. This also offers some advantages in terms of the error probability conditioned on specific input sequences and in terms of the distribution of error burst lengths.

A solution to the shortcomings of the conventional CDMA system is Multiuser Detection in which all users are considered as signals for each other. Because all users are considered as signals for each other, therefore, instead of users interfering with each other, they are all being used for their mutual benefit by joint detection. The multiuser channel is just the superposition of many single user channels. Single user and multiuser spread spectrum systems have similar transmitter and receiver structures. Reduced interference leads to capacity increase of the system. It also solves the near/far problem. A cellular system has a number of mobiles which communicate with one base station (BS). The BS has to detect all the signals whereas each mobile is concerned with its own signal. This implies that the BS must know all the chip sequence. In multiuser detection, one of the main drawbacks is that of complexity. There is always a trade-off between complexity and performance of the system. Linear detection (LD) based on the minimum mean-square error (MMSE) or the zero-forcing (ZF) criteria is a low complexity scheme but the error performance is unacceptable due to the multiple access interference (MAI).

On the other hand, non-linear detection techniques such as the successive interference cancellation (SIC) used in the vertical Bell Labs layered space-time (V-BLAST) have a low-complexity, while achieving a reduced MAI than their linear counterparts. However, these decision-driven detection algorithms suffer from error propagation and performance degradation.

In this paper we introduce multiple feedback SIC algorithm with a shadow area constraints strategy for detection of multiple users which requires low computational complexity. Selection algorithm searches several constellation points rather than one constellation point in the conventional SIC algorithm by choosing the most appropriate point in the decision tree.

Subsequently, we select this appropriate constellation point as the feedback. By doing so, more points in the decision tree are considered and the error propagation is efficiently mitigated. The selection procedure is constrained to one selected symbol in each spatial layer, unlike sphere decoders which employ a search procedure for more layers that increases the computational load.

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.

II. System Data Model

A baseband model of a CDMA uplink is shown in the figure. The signal received at the BS is the signals from all users, multipath components for user's signal, and Additive White Gaussian Noise(AWGN). The figure also includes channel encoders for each transmitter. There are Nu users in the system and the data signals from these users are designated as d1(t),d2(t),….,dNu(t). The data symbols within the data signals are spread by multiplying with respective spreading sequences K1(t),K2(t),….KNu(t). The channel introduces delays τ1,τ2,...,τNu to signals from different users, and A1(t), A2(t),…ANu(t) are the fading coefficients for the single resolvable path each user. Spreading sequences K1(t),K2(t),…KNu(t) is given by

$$\tilde{K}_i(t) = \sum_{m=1}^{N} c_{im} p(t - (m-1)T_c)$$

Where,
Cim is the mth chip of the spreading sequence Ki(t).
N is the length of the spreading sequence.
p(t) is the chip pulse that is assumed to be rectangular.

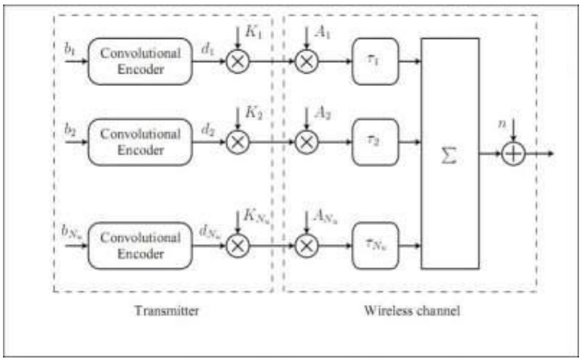

Fig.1.1 CDMA Uplink

Another BPSK model can be shown below:

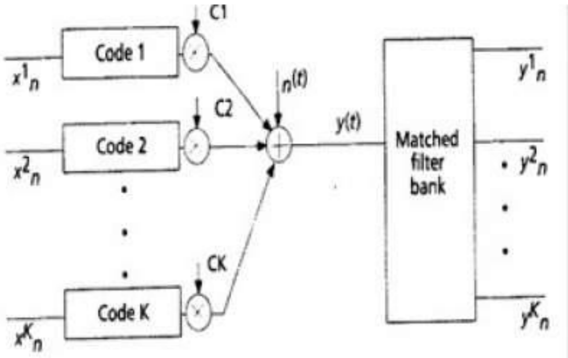

Fig 1.2 CDMA Channel Model

Baseband signal for the kth user is:

$$u_k(t) = \sum_{i=0}^{\infty} x_k(i) \cdot c_k(i) \cdot s_k(t - iT - \tau_k)$$

xk(i) is the ith input symbol of the kth user.
ck(i) is the real, positive channel gain.
sk(t) is the signature waveform containing the PN sequence.

τ_k is the transmission delay; for synchronous CDMA, τ_k=0 for all users.

Received signal at baseband is given by-

$$y(t) = \sum_{k=0}^{K} u_k(t) + z(t)$$

Where *K* number of users *z(t)* is the complex AWGN Sampled output of the matched filter.

III. Mud Algorithms And Description

A flow chart depicting the algorithm used for MUD is given below

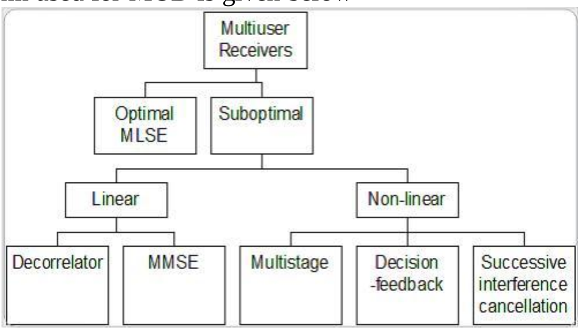

Fig. 1.3 Flowchart for MUD algorithm

Our emphasis is on finding a suboptimal method to find a combination having proper complexity and performance. In this work, we mainly deal with Successive Interference Cancellation which is a nonlinear suboptimal method of MUD.

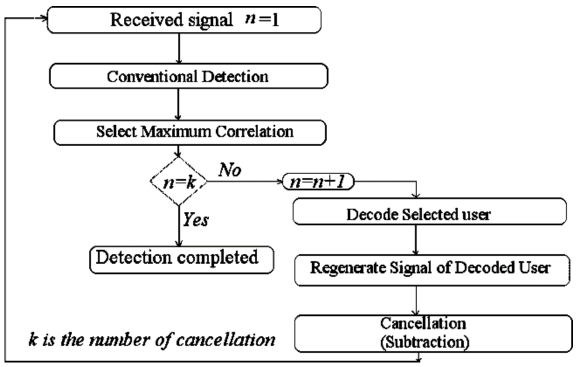

Fig. 1.4 SIC algorithm

GroupWise Successive Interference Cancellation Technique (GSIC) GroupWise multiuser detection has recently emerged as an 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 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 users increases to a certain level or some users signals becomes extremely strong, weak users with the conventional single user detector may lose communication because of the overwhelming MAI.

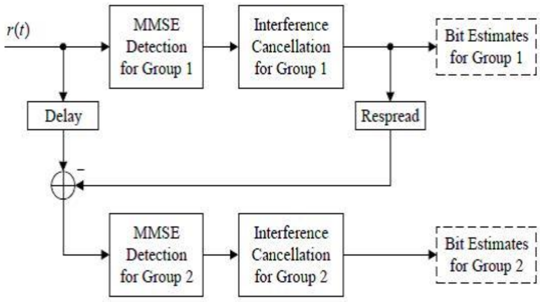

Fig 1.5 Block diagram of GSIC Receiver.

The best estimate of signal strength is from the strongest signal because te 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. 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 suboptimal multiuser detector, the GroupWise 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.

IV. Performance Evaluation

The GSIC has been implemented in MATLAB tool. By applying the GroupWise Successive Interference Cancellation (GSIC), 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 the 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 the receiving end the corrupted signals are multiplied with the PN-sequence. And at this instant channel noise and signal interference by multiple user 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.

V. Multi-Branch Sic Detection

In this section we describe about the MB-SIC detector for MIMO systems. WE present the overall principle and structures of the scheme. Based on different application requirements and system structures, better performance and lower complexity can be achieved by employing a proper selection and ordering scheme.

The proposed detection structure employs SICs on several parallel branches that are equipped with different ordering patterns. Namely, each branch produces a symbol estimate vector by exploiting a certain ordering pattern. Thus, there is a group of symbol estimate vectors at the end of the MB structure. We present MMSE-SIC for the design of the proposed MB MIMO receiver because the MMSE estimator usually has good performance, is mathematically tractable and has relatively simple adaptive implementation

VI. Simulation Results

The performance comparison of the optimum detector and linear MUD to the conventional matched filter is simulation output here. The average complexity was measured in terms of the average number of floating-point operations (flops) used. Simulations were performed in Matlab, in which the number of flops equals 2 for complex addition and 6 for multiplication. For real numbers, both addition and multiplication require 1 flop.

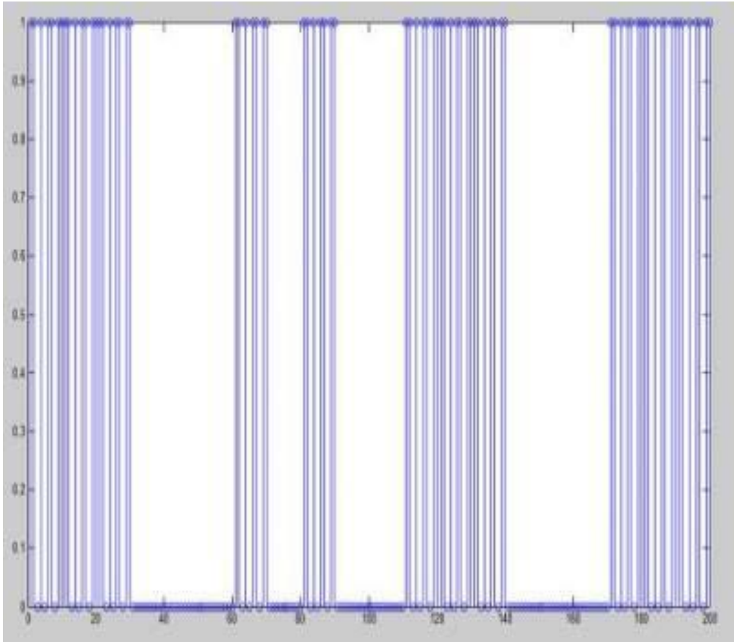

Fig 1.6 (WHEN ERROR=0) i.e. SNR=100

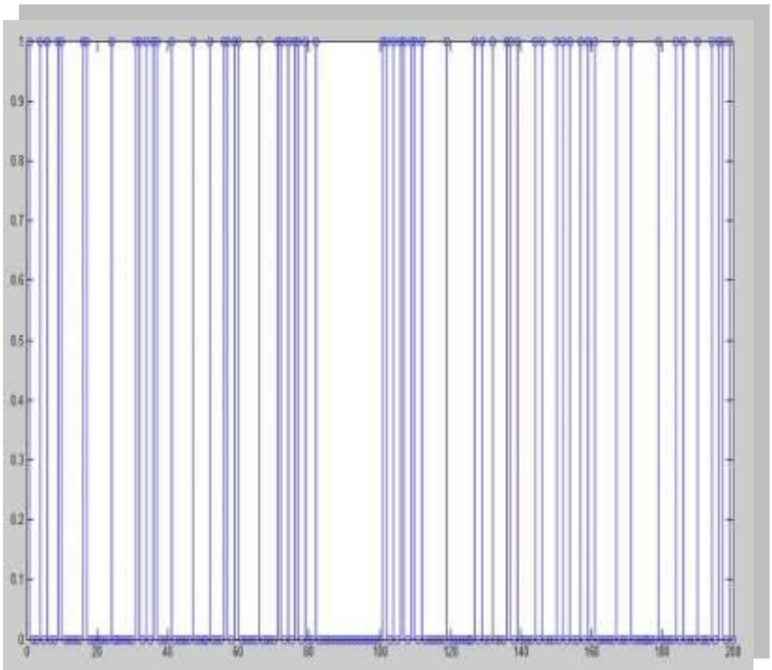

Fig 1.7 (WHEN ERROR=18) i.e. SNR=10

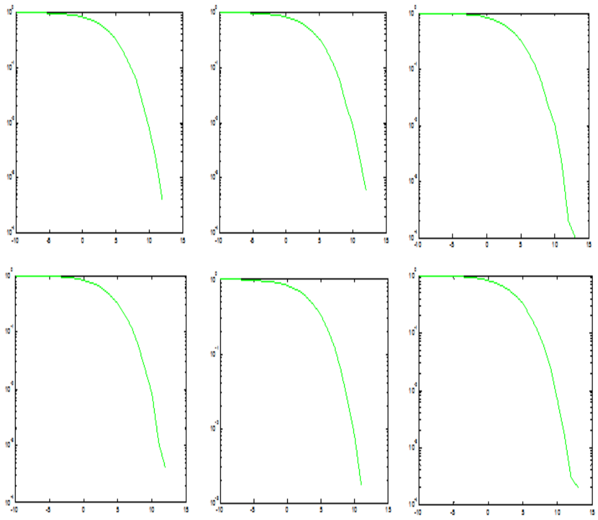

Fig. 1.8 Plot of SNR (x-axis) vs. BER (y-axis) for 6 different users.

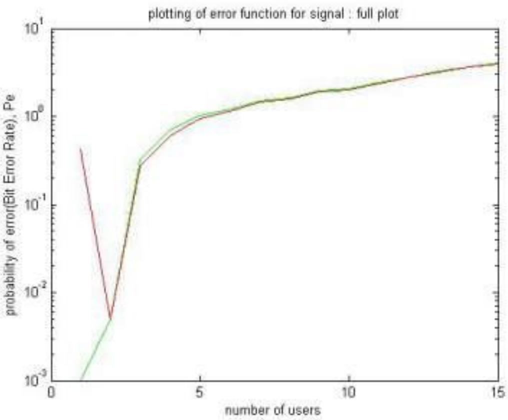

Fig. 1.9 Plot of BER vs. number of users.

The Shannon capacities as a function of the number of users divided by the spreading factor and the energy per bit divided by the noise spectral density respectively gives the simulation output.

VII. Conclusion

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

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