

INTERFERENCE CANCELLERS FOR SPREAD SPECTRUM MODULATION BASED MULTIPLE ACCESS SYSTEMS

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Abstract

Systems based on spread spectrum technique are inherently interference resistant. However, asynchronous transmission and multipath propagation causes manifestation of multiuser interference. Multiuser interference in a multiple access system limits the capacity of the system. Hence, it becomes imperative to mitigate the interference. This work presents the design and mathematical analysis of Hybrid Interference Cancellation (HIC) detector for direct-sequence code division multiple access (DS-CDMA). The detector is analysed for single path as well as multipath propagation over a Rayleigh fading channel. Simulation results are compared with the results of Successive Interference Canceller (SIC). Furthermore, the SIC and HIC detectors are tested for convergence. An HIC detector is proposed for MC-CDMA system. The interference canceller discussed in this paper dispenses with the RAKE receiver for diversity combining and data estimation, which averts the likelihood of errors because of incorrect data estimates.

Keywords:

DS-CDMA, MC-CDMA, HIC, Multipath Propagation, Convergence

1. INTRODUCTION

In wireless multiple access systems, it is not uncommon for the signals of multiple users, accessing the channel simultaneously, to interfere with each other. Various measures are taken by system designers to avoid the interference such as use of different frequencies per user, allotment of time slots for each user etc. In some systems, distinct codes are allotted to the users for unique identification. In systems which use codes for user identification, orthogonal codes are used. The orthogonality of the codes ensures that the user signals do not interfere and individual users' signals can be detected without interference from other active users. In these systems the data symbols are spread using these codes, distributing the energy over wide bandwidth, hence called spread spectrum modulation.

Wireless Local Area Networks (WLANs), Direct Sequence Code Division Multiple Access (DS-CDMA) system, Wideband CDMA (WCDMA) system, and Multi Carrier CDMA (MC-CDMA) system are the widely used communication systems employing spread spectrum. In CDMA all users transmit their signals simultaneously on the same frequency. Every user signal is spread and distinguished by one of the orthogonal codes assigned to it. As long as these signals are orthogonal, the users can be detected correctly.

In case of MC-CDMA system, a user data is broken into N blocks, spread by N orthogonal codes of length N , and is transmitted over N orthogonal frequencies. However, in CDMA as well as MC-CDMA, in asynchronous transmission and/or in case of multipath propagation, the orthogonality of signals from users is not guaranteed, which results in the signals from the multiple active users interfering with each other. Such

interference is called Multiple Access Interference (MAI). The probability of error increases at the receiver due to MAI, thus limiting the capacity of the conventional detector.

MAI is further aggravated by near-far problem. Although MC-CDMA can tackle the near-far problem better than CDMA due to its intrinsic properties, MAI mitigation requires advanced interference cancellation techniques in order to improve the performance of the system and in turn, enhance the capacity.

Interference cancellation can be implemented using Serial Interference Cancellation (SIC) and Parallel Interference Cancellation (PIC) algorithms. Both algorithms use subtractive method for cancellation of interference. SIC shows better performance than PIC but has a limitation of being slow. Conversely, in PIC, the interference is cancelled in parallel, making it faster. However, PIC is computationally complex as compared to SIC. The Hybrid Interference Cancellation (HIC) algorithm combines SIC and PIC to take advantage of their merits and achieve improvement in performance.

Remaining paper is arranged in the following sequence: Literature survey is discussed in section 2. Mathematical representation of the received signal for CDMA and MC-CDMA is elaborated in section 3. The receiver structure is described in section 4. The mathematical analysis of the HIC detector for single path as well as multipath propagation is presented in section 5. The simulation results for the SIC, conventional HIC and the proposed HIC detector are discussed for both types of propagation and the convergence of the detectors is proved in section 6. Lastly, in section 7, conclusions of the work are outlined.

2. LITERATURE SURVEY

Of the spread spectrum-based technologies, DS-CDMA and MD-CDMA are the most widely used techniques. Various ways of cancelling MAI for both systems have been reported previously. Conventional receiver is simple but it not optimum in terms of error probability and the complexity of the optimum receiver increase exponentially with the number of users [1]. The successive interference cancellation (SIC) multistage detector has the computational complexity which is a linear with the number of users [2]. However, the algorithm requires exact knowledge of energies. For the SIC proposed in [3] the users are ranked based on the correlation of the spreading sequences and the received signal rather than on the signal energies. SIC is found to be resistant to multipath fading also. Performance of the SIC further improved when used along with adaptive Minimum Mean Square Error (MMSE) detector [4]. In [5] the authors analyzed the SIC based on matrix algebra and represented the SIC as a one-shot linear matrix filter. A multistage SIC using RAKE receiver for multipath combining is analyzed in [6] with and without knowledge of the channel parameters. The same SIC is further

investigated for multirate, mixed modulation as well as multicode systems in [7].

The PIC detector for CDMA system is analyzed in [8] and compared with SIC. In multistage PIC, a wrong decision at one stage will cause further incorrect decisions in the subsequent stages. An improved PIC is presented in [9] where a weighted MAI cancellation is recommended. Partially cancelled PIC along with joint decoding is studied in [10]. In [11] the authors analyzed the PIC based on matrix algebra and represented it as a linear matrix filter. PIC suffers from computational complexity. The complexity is reduced in [12] by hybridizing subtracting type and partial PIC.

A hybrid interference cancellation (HIC) detector in which soft decisions are made using clipped mapping function is investigated, considering both power control and power control errors in [13]. A matrix algebraic approach employed for HIC design shows that the detector can be represented by a one-shot linear matrix filter and the expression for the Bit Error rate (BER) can be obtained using a Q-function [14]. The rate of convergence of the detector is also explored. It is found that a suitable value of the weighting factor along with slight variation in the detector can assist in achieving the convergence of the detector. An HIC scheme for multipath propagation, based on K - P - S configuration, is tested and its performance is compared with that of SIC and PIC in [15]. In this scheme P users are cancelled using PIC and remaining $S=K-P$ users are cancelled using SIC. In [16] Authors have suggested an HIC in which grouping of users is improved by the use of K -means clustering algorithm since the groups contain users having similar powers. Linear HIC is presented as a weighted combination of linear SIC and linear PIC in [17]. HIC scheme based on [15] is presented in [18] [19]. A novel technique of HIC is presented in [20] for multipath propagation, where the groups contain the signals of multipaths of a user. The technique avoids the use of RAKE receiver needed for diversity combining. HIC for an overloaded CDMA is proposed in [21] in which the number of users exceed the processing gain. A hybrid of SIC and PIC is proposed in [22] where instead of cancelling single user at a time, the users are cancelled in groups in SIC, followed by PIC. This technique significantly reduced the processing delay involved.

PIC, designed for DS-CDMA, is applied for asynchronous MC-CDMA in [23]. Application of serial concatenated convolutional codes combined with SIC improves the performance of the MC-CDMA receiver significantly [24]. The codes work well even for a fully loaded system. In order to improve the reliability, an equalized PIC (EPIC) is implemented in [25] for MC-CDMA system. EPIC is based on the equalization of data estimates found in two preceding stages and addition of these estimates with the latest ones, keeping the complexity same as the complexity of conventional PIC. Frequency domain interference cancellation, block decision feedback equalizer and chip level interleaving when combined can reduce BER and complexity of implementation significantly [26]. The authors have also used an altered transmission format. A hybrid cancellation technique in which SIC follows the PIC is presented in [27]. PIC is analyzed at each stage of cancellation in [28]. The MC-CDMA receiver with PIC and maximum ratio combining (MRC) shows improvement in BER performance compared with conventional MC-CDMA receiver with matched filters and MRC.

Users having decision statistics above a threshold are cancelled parallelly and remaining users are cancelled serially in conventional manner. It is seen that it is likely for the RAKE receiver to make incorrect estimates of data, as a result of some cross correlation existing among the spreading codes. Using equalizer as an initial data estimator improves the performance compared to RAKE receiver as initial data estimator [29]. The equalizer followed by multiple stages of PIC shows improvement in the BER performance. MC-CDMA system with multiple receiving antennas employs optimum combining after Orthogonal Frequency Division Multiplexing (OFDM) demodulation [30]. The combined signals are then cancelled using SIC. MC-CDMA system using Carrier Interferometry (CI) codes, spread by Walsh-Hadamard codes is discussed in [31]. The proposed scheme offers lower peak to average power ratio as compared to conventional MC-CDMA in multipath environment. HIC scheme based on [15] is implemented iteratively taking two iterations of PIC and one iteration of SIC [32]. The performance the HIC is optimum, though not at par with the SIC. ASIC implementation of PIC for MC-CDMA system is presented in [33].

Performance of Hybrid interference canceller and its mathematical analysis for CDMA system for single path propagation is presented in this paper. Two types of HIC detectors for multipath propagation are also proposed and tested for BER performance. The performances of the HIC detectors are compared with the performance of SIC. Furthermore, the convergence of the detectors is proved. Additionally, the HIC detector for MC-CDMA is also proposed.

3. RECEIVED SIGNAL MODELS

In this section, mathematical representation of the received signal for a multiuser DS-CDMA system and MC-CDMA system are explained. The DS-CDMA system is symbol synchronous and a channel considered is Rayleigh fading. Before transmission, the spread DS-CDMA signal is Binary Phase Shift Keying (BPSK) modulated. The received signal, $s(t)$, is expressed as,

$$s(t) = \sum_{k=1}^U \{ a_k(t - \Delta t_k) c_k(t - \Delta t_k) \cos \omega_c t + n_k \} \quad (1)$$

where

U : number of active users,

a_k : user data,

c_k : spreading code of the user of length N ,

Δt_k : transmission delay for the user, and

n_k : Rayleigh noise added by the channel to the user signal, a Gaussian random variable having zero-mean and variance $\sigma^2=0.25\eta N$, η being the noise power.

The data sequence waveform is expressed as

$$a_k(t) = \sum_{n=-\infty}^{\infty} b_n^k W_{T_b}(t - nT_b) \quad (2)$$

where,

$$W_{T_b}(t) = \begin{cases} 1 & \text{if } 0 \leq t \leq T_b \\ 0 & \text{elsewhere} \end{cases}$$

T_b is the time span of the data bit, and $b_n^k \in \{+1, -1\}$ indicates the n^{th} data bit of user k . Thus, the user data sequence, having bit rate $R_b = 1/T_b$, is represented by a rectangular waveform, $a_k(t)$. The bits of $a_k(t)$ are equiprobable assuming the data sources to be uniform.

The mathematical expression for the spreading sequence waveform, $c_k(t)$ is,

$$c_k(t) = \sum_{j=-\infty}^{\infty} C_j^k W_{T_c}(t - jT_c) \quad (3)$$

where,

$$W_{T_c}(t) = \begin{cases} 1 & \text{if } 0 \leq t \leq T_c \\ 0 & \text{elsewhere} \end{cases}$$

T_c is the chip duration, $T_b = NT_c$, and $C_j^k \in \{+1, -1\}$ is the j^{th} chip of the spreading code. Δt_k is the transmission delay of each user including the propagation delay. $\{\Delta t_k\}_{k=1}^U$ are random variables (RVs), ranging from 0 to T seconds. Since $\{\Delta t_k\}$ and $\{b_n^k\}$ are generated by different physical sources, they are mutually independent RVs.

The received signal for MC-CDMA system is

$$s(t) = \sum_{k=1}^U \left\{ a_k(t - \Delta t_k) c_k(t - \Delta t_k) \sum_{r=1}^R \cos(\omega_r t + \theta_r) + n_k \right\} \quad (4)$$

where R is the number of subcarriers, θ_r includes the phase of the carrier and the phase shift added by the channel, and $T_b = NRT_c$.

After demodulation, the received signal is low pass filtered. The filter output, $r(t)$, is the integrated base-band signal of U users, including the MAI.

4. RECEIVER STRUCTURE

The Fig.1 illustrates the receiver structure for DS-CDMA. Based on the correlation obtained from the Matched Filters (MF), the users are sequenced in decreasing order of their strength. The matched filtering of each user is performed assuming that the transmission delays, Δt_k , are perfectly known.

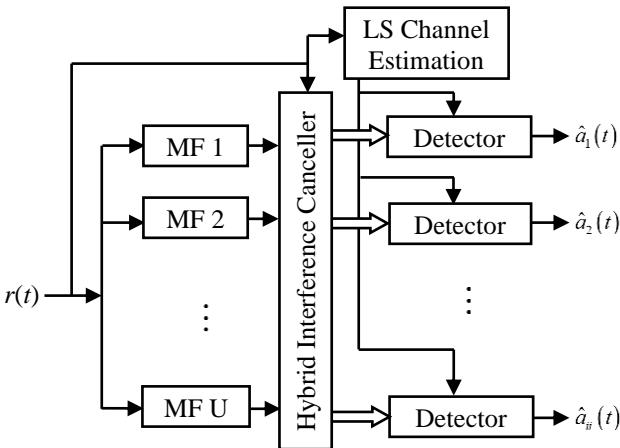


Fig.1. Receiver block diagram

The U signals are broken up into K groups with signals of the U users equally distributed among all groups. The base-band signal from the low pass filter, $r(t)$ is an input to the interference

Cancellation Unit (ICU) of the first group. In the ICU, the estimates of the users in a group are evaluated in parallel (PIC), the MAI due to this group is cancelled from the input signal. Using the remaining signal, estimates for the users in the next group are evaluated and MAI cancellation is done in the same manner. Thus, MAI of the groups is cancelled serially (SIC). In this way, the PIC and the SIC proceeds until the MAI due to the K^{th} group at the present stage is cancelled.

The remaining signal obtained after the cancellation of the K^{th} group is input to ICU of the first group at the next stage. The interference cancellation continues in the same way for a desired number of stages.

The channel estimates obtained using Least Square (LS) method [34], along with the user estimates found at the last stage of the HIC, determine the user symbols.

5. MATHEMATICAL ANALYSIS OF HIC DETECTOR

The expressions for various output signals from the ICU of the HIC detector for DS-CDMA system, such as, the MAI, the remaining signal and the decision variables are derived at every stage of interference cancellation. The U -users, S -stages, K -groups HIC detector is illustrated in Fig.2.

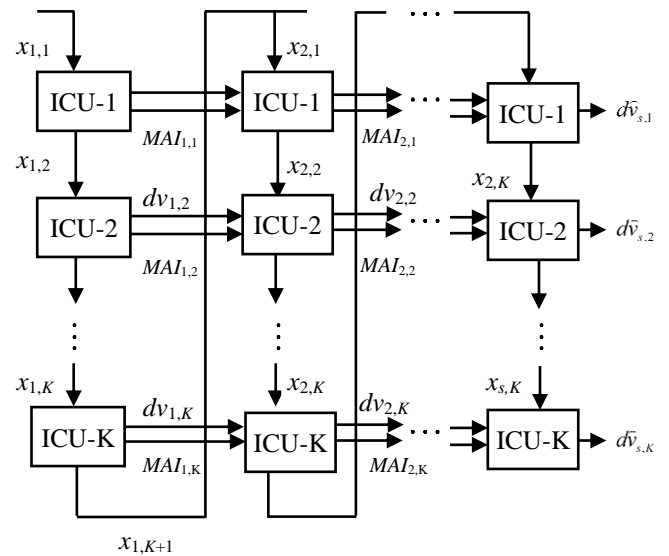


Fig.2. HIC detector having K -groups, and S -stages

5.1 STATISTICS AT FIRST STAGE

At the first stage, the input signal to the ICU of first group is given by

$$x_{1,1} = r \quad (5a)$$

The decision variables are evaluated for users in group 1 by performing matched filtering on the input signal vector, r , in parallel. These decision variables are

$$dv_{1,1} = \Lambda_1^T r \quad (5b)$$

where, r is a single column input signal vector with N rows, and Λ_1 is a matrix containing spreading codes of users in group 1 of size $m \times N$ wherein, m is number of users in each group. $dv_{1,1}$ is a

vector of size $m \times 1$ which contains the decision variables for the users in group 1. $x_{s,g}$ is the input signal vector to the m^{th} group of size $N \times 1$ at the s^{th} stage.

The MAI contribution of this group is

$$MAI_{1,1} = \Lambda_1 dv_{1,1} \quad (5c)$$

After cancellation of MAI the remaining signal applied as input to the ICU of group 2 is

$$x_{1,2} = x_{1,1} - \Lambda_1 dv_{1,1} = (I - \Lambda_1 \Lambda_1^T) r \quad (6a)$$

The decision variables for group 2 are

$$dv_{1,2} = \Lambda_2^T x_{1,2} = \Lambda_2^T (I - \Lambda_1 \Lambda_1^T) \Lambda_1 \Lambda_1^T r \quad (6b)$$

The MAI incurred due to this group is

$$MAI_{1,2} = \Lambda_2 dv_{1,2} = \Lambda_1 \Lambda_1^T (I - \Lambda_1 \Lambda_1^T) r \quad (6c)$$

Continuing similarly till the last group,

$$x_{1,K} = \prod_{j=K-1}^1 (I - \Lambda_j \Lambda_j^T) r = \xi_{K-1} r \quad (7a)$$

$$dv_{1,K} = \Lambda_K^T x_{1,K} = \Lambda_K^T \prod_{j=K-1}^1 (I - \Lambda_j \Lambda_j^T) r = \Lambda_K^T \xi_{K-1} r \quad (7b)$$

$$MAI_{1,K} = \Lambda_K^T dv_{1,K} = \Lambda_K \Lambda_K^T \xi_{K-1} r \quad (7c)$$

where $\xi_K = \prod_{j=m}^1 (I - \Lambda_j \Lambda_j^T)$ and $m=1,2,\dots,K$, $\xi_0 = I$ and I is an identity matrix of dimensions $N \times N$.

5.2 STATISTICS AT SECOND STAGE

The input signal to the first group of second stage is calculated as

$$x_{2,1} = x_{1,K+1} = x_{1,K} - MAI_{1,K} + MAI_{1,1} = (\xi_r + \Lambda_1 \Lambda_1^T) r \quad (8a)$$

The decision variables are obtained as:

$$MAI_{2,1} = \Lambda_1 (dv_{2,1} + dv_{1,1}) = \Lambda_1 \Lambda_1^T (\xi_r + I + \Lambda_1 \Lambda_1^T) r \quad (8b)$$

and the MAI is obtained as

$$MAI_{2,1} = \Lambda_1 (dv_{2,1} + dv_{1,1}) = \Lambda_1 \Lambda_1^T (\xi_r + \Lambda_1 \Lambda_1^T) r \quad (8c)$$

As in Eq.(8a), the baseband estimates of the m^{th} group from the previous stage (MAI) are reinserted at the current stage so as to improve the estimates of that group. However, for improved performance, MAI is reinserted partially instead of entire MAI. Similarly, the estimates of the m^{th} group from the preceding stage are also added to the estimates of that group at the current stage, as in Eq.(8b) for the same purpose.

Likewise, for the second group at the second stage,

$$x_{2,2} = x_{2,1} - MAI_{2,1} + MAI_{1,2} = (\xi_r + \Lambda_1 \Lambda_1^T + \Lambda_2 \Lambda_2^T) \xi_1 r \quad (9a)$$

$$dv_{2,2} = \Lambda_2^T x_{2,2} + dv_{1,2} = \Lambda_2^T (\xi_r + \Lambda_1 \Lambda_1^T + \Lambda_2 \Lambda_2^T) \xi_1 r \quad (9b)$$

$$MAI_{2,2} = \Lambda_1 (dv_{2,2} + dv_{1,2}) = \Lambda_2 \Lambda_2^T (\xi_r + \Lambda_1 \Lambda_1^T + \Lambda_2 \Lambda_2^T) \xi_1 r \quad (9c)$$

Pursuing the same way, the above equations for the K^{th} group are expressed as

$$\begin{aligned} x_{2,K} &= (\xi_r + \Lambda_1 \Lambda_1^T + \Lambda_2 \Lambda_2^T + \dots + \Lambda_K \Lambda_K^T) \xi_{K-1} r \\ &= (\xi_r + \chi_K) \xi_{K-1} r \end{aligned} \quad (10a)$$

$$\begin{aligned} dv_{2,K} &= \Lambda_2^T x_{2,K} + dv_{1,K} \\ &= \Lambda_2^T (I + \xi_r + \Lambda_1 \Lambda_1^T + \Lambda_2 \Lambda_2^T + \dots + \Lambda_K \Lambda_K^T) \xi_{K-1} r \\ &= \Lambda_2^T (I + \xi_r + \chi_K) \xi_{K-1} r \end{aligned} \quad (10b)$$

and

$$\begin{aligned} MAI_{2,K} &= \Lambda_K (dv_{2,K} + dv_{1,K}) \\ &= \Lambda_K \Lambda_K^T (I + \xi_r + \Lambda_1 \Lambda_1^T + \Lambda_2 \Lambda_2^T + \dots + \Lambda_K \Lambda_K^T) \xi_{K-1} r \\ &= \Lambda_K \Lambda_K^T (I + \xi_r + \chi_K) \xi_{K-1} r \end{aligned} \quad (10c)$$

where, $\chi_m = \sum_{j=1}^m (\Lambda_j \Lambda_j^T)$, $m = 1, 2, \dots, K$ and $\chi_0 = 0$.

5.3 STATISTICS AT THIRD STAGE

At the third stage, these signals are derived for the first group as

$$\begin{aligned} x_{3,1} &= x_{2,K} - MAI_{2,K} + MAI_{2,1} \\ &= (\xi_r + 2\Lambda_1 \Lambda_1^T + \Lambda_2 \Lambda_2^T + \dots + \Lambda_K \Lambda_K^T) \xi_{K-1} r + (\Lambda_1 \Lambda_1^T)^2 r \end{aligned} \quad (11a)$$

$$\begin{aligned} dv_{3,1} &= \Lambda_1^T x_{3,1} + dv_{2,1} \\ &= \Lambda_1^T (I + \xi_r + 2\Lambda_1 \Lambda_1^T + \Lambda_2 \Lambda_2^T + \dots + \Lambda_K \Lambda_K^T) \xi_{K-1} r \\ &\quad + \Lambda_1^T (\Lambda_1 \Lambda_1^T)^2 r + \Lambda_1^T \xi_1 r \end{aligned} \quad (11b)$$

and

$$\begin{aligned} MAI_{3,1} &= \Lambda_1 \Lambda_1^T (\xi_r + 2\Lambda_1 \Lambda_1^T + \Lambda_2 \Lambda_2^T + \dots + \Lambda_K \Lambda_K^T) \xi_{K-1} r \\ &\quad + \Lambda_1 \Lambda_1^T (\Lambda_1 \Lambda_1^T)^2 r \end{aligned} \quad (11c)$$

Correspondingly, the respective signals for the second group are obtained as

$$\begin{aligned} x_{3,2} &= x_{3,1} - MAI_{3,1} + MAI_{2,2} \\ &= (\xi_r + 2\Lambda_1 \Lambda_1^T + 2\Lambda_2 \Lambda_2^T + \dots + \Lambda_K \Lambda_K^T) \xi_1 \xi_r r \\ &\quad + (\Lambda_1 \Lambda_1^T)^2 \xi_1 r + (\Lambda_2 \Lambda_2^T)^2 \xi_1 r + \Lambda_2 \Lambda_2^T \Lambda_1 \Lambda_1^T \xi_1 r \end{aligned} \quad (12a)$$

$$\begin{aligned} dv_{3,2} &= \Lambda_2^T x_{3,2} + dv_{2,2} \\ &= \Lambda_2^T (I + \xi_r + 2\Lambda_1 \Lambda_1^T + 2\Lambda_2 \Lambda_2^T + \dots + \Lambda_K \Lambda_K^T) \xi_1 \xi_r r \\ &\quad + \Lambda_2^T (\Lambda_1 \Lambda_1^T)^2 \xi_1 r + \Lambda_2^T (\Lambda_1 \Lambda_1^T)^2 \xi_1 r + \Lambda_2^T \Lambda_2 \Lambda_2^T \Lambda_1 \Lambda_1^T \xi_1 r \\ &\quad + \Lambda_2^T (I + \Lambda_1 \Lambda_1^T + \Lambda_2 \Lambda_2^T)^2 \xi_1 r \end{aligned} \quad (12b)$$

$$\begin{aligned} MAI_{3,2} &= \Lambda_2 \Lambda_2^T (\xi_r + 2\Lambda_1 \Lambda_1^T + 2\Lambda_2 \Lambda_2^T + \dots + \Lambda_K \Lambda_K^T) \xi_1 \xi_r r \\ &\quad + \Lambda_2 \Lambda_2^T (\Lambda_1 \Lambda_1^T)^2 \xi_1 r + \Lambda_2 \Lambda_2^T (\Lambda_2 \Lambda_2^T)^2 \xi_1 r \\ &\quad + \Lambda_1 \Lambda_1^T (\Lambda_2 \Lambda_2^T)^2 \xi_1 r \end{aligned} \quad (12c)$$

For the last group, these equations are derived as

$$x_{3,K} = ((\xi_r + 2\chi_K)) \xi_{K-1} \xi_K r + \Gamma_K \xi_{K-1} r + \Omega_K \xi_{K-1} r \quad (13a)$$

$$dv_{3,k} = \Lambda_k^T (I + \xi_k + 2\chi_k) \xi_{k-1} \xi_k r + \Lambda_k^T \Gamma_k \xi_{k-1} r + \Lambda_k^T \Omega_k \xi_{k-1} r + \Lambda_k^T (I + \chi_k) \xi_{k-1} r \quad (13b)$$

$$dv_{3,k} = \Lambda_k \Lambda_k^T (\xi_k + 2\chi_k) \xi_{k-1} \xi_k r + \Lambda_k \Lambda_k^T \Gamma_k \xi_{k-1} r + \Lambda_k \Lambda_k^T \Omega_k \xi_{k-1} r \quad (13c)$$

where, $\Gamma_g = \sum_{j=1}^g (\Lambda_j \Lambda_j^T)^2$ and $\Omega_g = \sum_{j=2}^g (\Lambda_j \Lambda_j^T \chi_{j-1})^2$.

The interference cancellation process can continue for the desired number of stages and the expressions for the respective signals can be obtained in the same way.

5.4 CONVENTIONAL HIC FOR MULTIPATH PROPAGATION

The scheme presented in Fig.2 is implemented for multipath propagation assuming L multipaths for each user. Matched filtering gives the estimates of the UL signals. The UL signals are then arranged in decreasing order of their strength, and further split into U groups, each group containing L signals. The HIC (conv HIC) is implemented in the conventional manner. After the last stage of interference cancellation, estimates of the multipaths of a user and channel estimates are combined to make decision on the transmitted symbols.

5.5 MHIC FOR MULTIPATH PROPAGATION

In another type of HIC (mHIC) L signals corresponding to the multipaths of an i^{th} user form a group, resulting in U groups, each of size L . Once grouping is done, the interference is cancelled and transmitted symbols are estimated in the same manner as discussed before [35].

Extending the mathematical analysis of single path propagation for multipath propagation, the generalized equations for signal at the input of the ICUs of the users, the estimates of the users, and the interference caused by the users at various stages are obtained as follows:

At stage I:

$$x_{1,i} = \xi_{i-1} r \quad (14a)$$

$$dv_{1,i} = \Lambda_i^T \xi_{i-1} r \quad (14b)$$

$$MAI_{1,i} = \Lambda_i \Lambda_i^T \xi_{i-1} r \quad (14c)$$

At stage II:

$$x_{2,i} = (\xi_U + \chi_i) \xi_{i-1} r \quad (15a)$$

$$dv_{2,i} = \Lambda_i^T (I + \xi_U + \chi_i) \xi_{i-1} r \quad (15b)$$

$$MAI_{2,i} = \Lambda_i \Lambda_i^T (\xi_U + \chi_i) \xi_{i-1} r \quad (15c)$$

At stage III:

$$x_{3,i} = (\xi_U + \chi_U + \chi_i) \xi_{i-1} \xi_U r + \Gamma_i \xi_{i-1} r + \Omega_i \xi_{i-1} r \quad (16a)$$

$$dv_{3,i} = \Lambda_i^T (I + \xi_U + \chi_i + \chi_U) \xi_{i-1} \xi_U r + \Lambda_i^T \Gamma_i \xi_{i-1} r + \Lambda_i^T \Omega_i \xi_{i-1} r + \Lambda_i^T (I + \chi_i) \xi_{i-1} r \quad (16b)$$

$$MAI_{3,i} = \Lambda_i \Lambda_i^T (\xi_U + \chi_U + \chi_i) \xi_{i-1} \xi_U r + \Lambda_i^T \Gamma_i \xi_{i-1} r + \Lambda_i \Lambda_i^T \Gamma_i \xi_{i-1} r + \Lambda_i \Lambda_i^T \Omega_i \xi_{i-1} r \quad (16c)$$

Expression for the probability of error is derived using Simplified Improved Gaussian Approximation (SIGA) method as

$$P_e = \frac{2}{3} P(\mu') + \frac{1}{6} P(\mu' + \sqrt{3}\sigma') + \frac{1}{6} P(\mu' - \sqrt{3}\sigma') \approx \frac{2}{3} \left[1 - \frac{N}{\sqrt{\mu + \frac{N\eta}{4} + N^2}} \right] + \frac{1}{6} \left[1 - \frac{N}{\sqrt{\mu + \sqrt{3}\sigma' \frac{N\eta}{4} + N^2}} \right] \quad (17)$$

where σ'^2 and μ' are the variance and the mean of MAI, respectively $\mu' \approx \frac{(U-1)N}{3}$ and $\sigma'^2 \approx \frac{23(U-1)U^2}{360}$.

5.6 HIC FOR MC-CDMA

Despite being capable of handling interference due to its inherent properties, performance of MC-CDMA systems degrades due to MAI. HIC proposed for DS-CDMA for multipath propagation can be employed for interference cancellation in MC-CDMA with the following changes: the baseband signals of a user received on R number of carriers will form a group. The interference of these signals will be cancelled parallelly. The interference among the U groups thus formed will be cancelled serially. The estimates obtained after desired number of stages can be Maximum Ratio Combined, followed by a detector which makes hard decisions on the transmitted bits.

6. SIMULATION AND RESULTS

The SIC detector, conventional HIC and mHIC detector are simulated for single path as well as multipath propagation to test their BER performance in the Rayleigh-faded channel. Due to asynchronous transmission, there is a relative delay between the user signals. This delay includes propagation delay as well as transmission delay.

For single path propagation, the spreading factor, $N=128$ with $U=50$ users is used. The interference is cancelled using SIC as well as HIC algorithm. As seen in Fig.3, the performance of HIC is close to the performance of SIC.

For multipath propagation, 3 paths are considered. Fig.4 and 5 illustrate the BER characteristics of the CDMA system with SIC detector, conventional HIC detector and the mHIC detector for $N=128$ and $U=50$ and 75, respectively. The SIC detector provides very good system performance, though with longer processing delay. For lower E_b/N_0 , the performance of conventional HIC and the mHIC matches with the performance of SIC. For higher values of E_b/N_0 , these detectors exhibit satisfactory performance. However, they have the advantage of being faster than SIC.

The effect of increasing traffic is evident from the BER curve in Fig.6. The conventional HIC provides better performance than the mHIC. The interference cancellers discussed in the literature survey have been tested for number of users up to 30. The performance of the detectors presented in this paper is tested for number of users up to 100, corroborating the capability of the detectors to handle heavy traffic.

Condition for convergence of the detector is that user estimates should remain constant for consecutive stages of cancellation. Mathematically expressed as,

$$dv_{s+1,i}=dv_{s,i} \quad (18)$$

For testing the convergence of the HIC detector, the interference cancellation process is simulated for 8 stages. The simulation is performed for multipath propagation over Rayleigh channel. The Fig.7 demonstrates the simulation results for $E_b/N_0=10\text{dB}$. It is observed that the BER remains roughly constant, which signifies the assured convergence of the detectors.

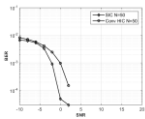


Fig.3. BER performance of SIC and HIC detector for single-path propagation over Rayleigh fading channel for $U=50, N=128$.

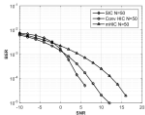


Fig.4. BER performance of SIC and HIC detector for multi-path propagation over Rayleigh fading channel for $U=50, N=128$

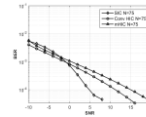


Fig.5. BER performance of SIC and HIC detector for multi-path propagation over Rayleigh fading channel for $U=75, N=128$

It is likely for the RAKE receiver to make incorrect estimates of data, as a result of some cross correlation existing among the spreading codes. The interference cancellation scheme proposed in this paper does not need RAKE receiver for diversity combining and data estimation. Thus, the possibility of incorrect data estimation and the consequent degradation in BER is eliminated.

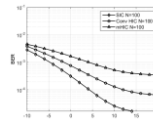


Fig.6. BER performance of SIC and HIC detector for multi-path propagation over Rayleigh fading channel for $U=100, N=128$

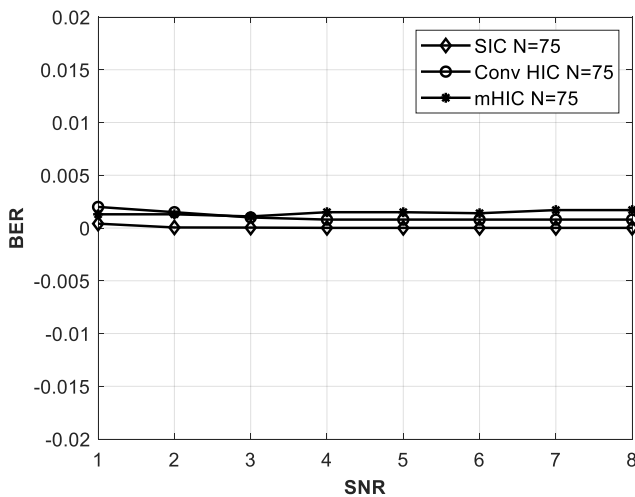


Fig.7. BER performance demonstrating the convergence of the detector using $N=75$, $L=128$

7. CONCLUSION

In this work, an HIC detector is put forward and analysed for single path propagation. Based on the expressions obtained for single path, the closed form expressions for the same signals for multipath propagation are presented along with the expression for the probability of error. The BER performance of the conventional HIC detector is nearly at par with the SIC detector performance.

Considering the BER performance of the conventional HIC detector, mHIC and SIC detector, it is evident that the performance of SIC detector surpasses the performance of the two HIC detectors for multipath propagation. However, since SIC takes longer processing time, HIC detectors, requiring shorter processing time, are preferred.

The detectors are further tested for convergence. The results of simulations signify the assured convergence of the detector. It is proposed that the mHIC detector will be suitable for MC-CDMA system also.

For the HIC detector discussed in this paper, deployment of RAKE receiver for diversity combining is not necessary for CDMA systems; hence, the probable errors due to the limitations of the RAKE receivers are avoided.

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