Highly Efficient BER Performance analysis for interference cancellation in non linear DS CDMA detectors using Dripple algorithm

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Abstract—The Interference Cancellation (IC) for code division multiple access (CDMA) is derived from the analysis of hybrid models termed ‘Dripple’ which provides an improved BER performance. The Multistage CDD yields highly efficient relaying network by increasing the frequency selectivity which provides the evaluation of end-to-end Bit Error Rate (BER). The context of Asynchronous transmissions and random spreading sequences for MC-DS-CDMA is derived based on accurate average Bit Error Rate (BER). The evaluation of the results are in terms of Bit Error Rate (BER) for different Signal-to-Noise Ratios (SNR)’s. This is done by allocating different subcarriers to the users at a lower data rate. With the increase of Eb/N0 the BER performance is simulated.

Keywords – DS-CDMA, Dripple algorithm, Minimum Mean Square Error (MMSE), Non-linear Receiver, Signal to Noise Ratio (SNR), Interference Cancellation, Multiple Access Interference (MAI).

I. INTRODUCTION

Conventional CDMA systems uses Matched Filter (MF) detector for each single-user and is detected individually while other signals are treated as Gaussian noise [1]. MAI stems from the asynchronous nature of the uplink channel where the orthogonality of different users is prohibited. By reducing MAI the spectral efficiency is considerably increased. The interference caused by time offsets and fading is jointly estimated by means of Multi User Detection (MUD) which provides better detection for individual users. Due to their extremely high complexity the optimum detection schemes are not used. This is shown by previous work [2]-[4]. Thus the focus of the ensuing research is based on the sub-optimal receiver structures [5]-[11]. The benefits inherent to both SIC and PIC schemes have been proposed in Hybrid-type MUD receivers [7],[8]. More accurate estimation is prioritized by ordering the Signal to Noise Ratio (SNR) in a decreasing order based on stronger signal strength. The subgroups for the K users are processed successively in stages.

Maximum Likelihood (ML) detection technique using Viterbi’s algorithm is proposed by Verdu for the optimal multiuser detector for CDMA systems in the mid of 1980’s in [2]. Unfortunately the complexity of the ML method increases exponentially with the increase in number of users and the length of the sequence. On the other hand, the complete cancellation of all MAI signals is done by Decorrelator detector at the output of the detector [3].

The Decorrelator detector structure is quiet complex than the Matched Filter detector where all the signature codes of all system users should be known to the detector. In this paper, we propose an improved “dripple” user configuration model modified from conventional hybrid MUD schemes [8], [9]. The basis for the proposed algorithm is provided by the two exponential designs. Through analysis, it is shown that better performance is achieved by employing user patterns with smaller initial group sizes. Accordingly, a count matrix is used to compute the non-linearly varying group sizes and to determine the number of users required for each group. A low-complexity version of the dripple algorithm is proposed whereby the user configuration is modified by limiting the maximum number of iterations for a given group size in order to reduce the overall processing delay. The proposed dripple algorithms are based on a scheme first introduced in [12]. It is shown that the proposed algorithms exhibit significant improvements in performance over previous hybrid, conventional SIC and PIC schemes, as well as slight improvement over models employing exponentially varying group sizes.

In Section II, the details of the signal model employed is provided. Section III includes both the detailed description of the dripple algorithm and its derivation. In Section IV, we compare the BER performance of the proposed dripple algorithm with both exponential schemes and previous standard hybrid designs, as well as provide timing analysis demonstrating gains in the overall processing delay. Section V provides conclusion for the paper.

II. SYSTEM MODEL AND MOTIVATION

A. Signal Model

Consider the uplink of an asynchronous CDMA communication system with K active users. Binary phase shift keying (BPSK) is employed over a multipath channel with L paths. For the signal representing the kth path of the ith user, the MAI component is given by [7]

\[ y_i(t) = \sum_{k=1}^{K} a_{i,k} \sum_{l=1}^{L} \alpha_{i,k,l} T_{i,k,l} (t - T_{i,k,l} - \tau_{i,k,l}) e^{j2\pi f_{i,k,l} t} (s - S_i) \]

..... (1)

where \( a_{i,k} \) represents the estimated path gains, \( T \) is the data bit period, \( P \) is the average signal power, \( b_k \) denotes the bit sequence of the \( k \)th user, \( c_k \) represents the corresponding Gold code sequence, \( \tau_{i,k,l} \) is the estimated asynchronous delay, and \( \phi_i \) is the estimated random phase of the \( i \)th user.
The potential negative effects of poor channel estimation are illustrated as $\alpha_{l,k}$, $\tau_{i,k}$, and $\phi_i$ in Equation (1). Thus MAI is emphasized by the channel estimation.

B. Motivation

In the conventional SIC systems, depending on the average signal strength users are ordered. Interference is cancelled in stages successively, each stage consisting of a certain number of users determined by the applied algorithm and the corresponding total number of users. At every stage regardless of the number of users, PIC is performed. The detrimental contribution by users with weaker signal strength is one of the major limiting factors of the joint estimation involved in PIC receivers. SIC can overcome this by processing the pre-ordered users individually, obtaining reliable channel estimates from the strongest user first, the next strongest user second, and so forth. Thus, despite their weaker signal subsequent users benefit from the reliable early estimates. However, as users contribute to channel estimation accuracy only once the advantages of joint estimation are lost.

III. DERIVATION OF THE DRIPPLE ALGORITHM

The proposed algorithm employs PIC at every stage, but contrary to standard PIC operation, all users are not included in every stage of the IC process. Joint estimation is utilized, albeit for various numbers of users per group. The initial stages include the strongest users exclusively in order to achieve improved joint estimation. In the following section two options for such a design are presented.

A. Exponentially Varying Group Sizes

Each interference cancellation stage produces an estimate of the signal that is carried over to the next group of users. Initial stages can be made to include fewer users, more specifically those exhibiting stronger signal power in order to take advantage of the more reliable early estimates. This results in varying group sizes amongst different interference cancellation stages. However, channel estimation does not improve linearly with every stage. Thus, to arrange users in linearly varying group sizes is counter-intuitive. Therefore, the number of users is increased in a non-linear manner. Two hybrid IC schemes are discussed. Both schemes employ exponentially varying group sizes. The first involves a greater number of users in the early stages, attempting to take advantage of joint estimation to establish reliable early estimates. Latter stages increase in size, but in inverse exponential fashion. The second model begins with a single user found to be strongest and therefore most reliable, and increases the number of users exponentially for each stage until the $K$ users are processed. For the hybrid schemes the number of additional users per stage is given by $U_i = \lceil K/(2s) \rceil$ and $U_e = 2s-2$, where $U_i$ and $U_e$ are the number of users to be added to a given stage for the inverse exponential and exponential schemes, respectively, and $s$ is the index of the given stage.

Fig. 1. Block diagram of inverse exponential group-wise scheme ($k=8$).

Equations for $U_i$ and $U_e$ are set as guidelines for the two models. They are arbitrary and are used merely as a means to compare two different strategies for early channel estimation. The first model is designed to benefit from the performance properties of the standard PIC scheme by first employing group-wise IC stages. The second model follows SIC principles during early IC stages, utilizing individual processing of users in order to obtain more accurate early estimates. As the number of total stages is maintained, both models demonstrate identical system latency. Sample configurations of both models for $K = 8$ users are shown in Fig 1.

B. The Dripple Algorithm

Motivated by similar factors as the exponential and inverse exponential group-wise schemes, the dripple algorithm employs non-linearly varying group sizes determined by the total number of users. A count matrix $Q$ of dimension $K \times 2K$ is created in order to compute the number of IC iterations required for all users. Each column represents one IC stage and each row corresponds to one user. According to their signal strength the users are ordered in a decreasing fashion such that the top rows of the matrix represent the stronger users and the bottom rows, the weaker ones. The system is first modeled as an upper-right triangular matrix thus replicating the appropriate processing pattern for $K$ number of users as in [8]. Secondly, from each of the first $u$ rows the last iterations are removed and the number of redistributions carried out by the dripple algorithm is redistributed amongst the first.

Thus, with the value of $u$ changing with every repetition of the process denoted by $i$, there are $u$ iterations to be redistributed among $v$ rows. For any given value of $k$, the index $u$ is created as such in order to ensure that the last column carries out detection for all users. It is also designed to limit the increase in the number of users to two for the latter columns of the matrix. Thus, joint estimation at a given stage involves no more than two additional users as
compared to the previous stage, guarding against degradation in channel estimation which can arise when several users with weak signal strength are being processed simultaneously for the first time. For example, if a given stage carries five more users than the previous, the resulting channel estimation is affected by five potentially unreliable users and the negative contributions are propagated throughout the IC process. The value of $v$ is set such that the users with the strongest signal power receive the greatest number of redistributed iterations. In other words, the rows located in the top half of the $Q$ matrix receive all redistributions and the corresponding users are consequently processed more often than those situated in the bottom half.

The redistribution process begins at row $v$ and continues through to row 1, each row acquiring $j$ supplementary iterations for $j = 1, 2, \ldots, v$, ensuring that the upper rows within the top half of the $Q$ matrix receive even more iterations than those closer to row $v$. More explicitly, row $v$ gains one iteration, row $v−1$ gains two, and so forth. Thus, the reliability of early channel estimation is further increased. For the final step, the remaining $v$ iterations left over from the original total $u$, given by $v = u − (v − 1)^2 + v − 1)/2$, are added to row 1. For certain values of $K$, however, this can lead to a row 1 having fewer iterations than row 2. Once all redistributions are carried out, an inversion of the two first rows is added if necessary to ensure that the strongest user is in fact relied on more heavily than all other users.

**Example 1:** In this example, we consider the execution of the dripping algorithm for $K = 7$ users. The corresponding computation of the $Q$ matrix is shown in detail in Fig. 3. The steps of the algorithm are

1) Create count matrix $Q$ of dimension $K \times 2K$: A matrix containing $7$ rows and $14$ columns is created.

2) Remove the first iterations from each of the first $u$ rows and redistribute amongst the first $v$ rows: $i = 0$, $u = (7−1)/2 \times 0 = 6$, and $v = (7/2) = 3$. In other words, the last iterations from rows 6 through 1 are eliminated and are inserted back into the matrix starting from row 3 through to the first row.

3) From row $v=3$ the redistribution of iteration starts. The algorithm adds $j$ supplementary iterations to each row, where $j = 1, 2, \ldots v$: $v = 6 − ((3 − 1)^2 + 3 − 1)/2 = 3$. Thus, rows 3 through 1 receive $j = 1, 2$, and 3 iterations, respectively.

4) The redistribution process is repeated $w$ times: $w = (7/2)/2 = 2$. For $K = 7$, redistribution is therefore executed only twice. The second and final execution is carried out with $i = 1$, $u = (7 − 1)/2 \times 1 = 4$, and $v = 4 − ((3 − 1)^2 + 3 − 1)/2 = 1$. The value of $v$ remains the same as it does not depend on $i$. In this final redistribution, $u = 4$ iterations are removed and rows $v = 3$ through 1 receive $j = 1, 2$, and 1 iterations, respectively.

5) Finally, if the number of total iterations is greater for user 2 than user 1, invert rows 1 and 2: this step is not as mentioned above, each row of the $Q$ matrix represents a single user while each column represents an individual PIC stage along with the number of users involved. Certain columns are repeated many times, resulting in greater latency while failing to improve the BER performance. This is due to the negligible gains achieved by executing PIC for more than three iterations. Typical convergence of PIC operation occurs after three successive stages and, as shown in [6], gains in the BER performance are greatly reduced following a third PIC run. By limiting each distinct grouping to a maximum of three repetitions in the $Q$ matrix, the BER performance is maintained and the overall processing delay is reduced.

The configuration of the reduced matrix remains dependent on $K$ and is therefore once again consistent for any given value of $K$. The improved algorithm does not increase the complexity as, similar to the original dripping scheme; matrix configurations can be constructed and stored prior to the detection process. Also, the larger the number of users, the greater the number of reduced stages. Thus, the gains in performance for the improved dripping algorithm become especially significant for systems with larger values of $K$.

**IV. RESULTS**

We consider the uplink channel of a CDMA system with $K = 20$ users. BPSK modulation is employed and the spreading factor is set to $N = 32$. The size of the frame is given by $38400/N = 1200$. The system incorporates $L = 3$ multipath with uniform power delay profile. Pilot data generated from a predetermined sequence known at the receiver, sent with the same SNR as the data generated. Short channel delay spread is assumed such that the $k^{th}$ user bit interferes only with its adjacent neighboring bits. Furthermore, the channel parameters are assumed to remain static during the detection window. Subsequently, it is used for initial channel estimation. This prevents the necessity for the re-ordering of users and ensures the validity of the pre-configured $Q$ matrix. For comparison purposes, identical channel conditions are applied to all simulation runs. The performance comparison of the two schemes involving exponentially varying group sizes discussed in Section III validated theoretical expectations as the exponential scheme achieved superior BER performance for higher values of SNR.

![Fig. 2. Sample Q matrix (K = 21).](image-url)
and small groups of users characterizing the initial stages of the exponential scheme, further validating the approach behind the construction of the "Q matrix. 

Fig. 3 compares the performance of the proposed dripple algorithm to that of the standard MF receiver, both SIC and 3-stage PIC schemes, the hybrid receiver based on [7] consisting of linearly varying group sizes, as well as the superior of the two exponential models discussed above. Despite the increase in processing delay, the dripple algorithm greatly outperforms both SIC and PIC schemes. The dripple model also shows improvement over previous hybrid models, albeit to a much lesser degree when compared to the exponential scheme presented in Section III. The proposed scheme offers better BER performance at the cost of increased latency due to the greater number of total IC stages. As can be seen, greater improvement is achieved at higher values of SNR.

![Figure 3. Bit error rate comparison between linear, exponential, MF, SIC, 3-stage PIC, and dripple algorithm.](image)

Furthermore, in order to provide a more accurate comparison to previously designed schemes, the system parameters are generated such that the near-far effect is accounted for. At BER = 10⁻³, the dripple MUD receiver exhibits an improvement of more than 1.5 dB over the linear model, and an improvement of 0.7 dB over the exponential scheme presented in Section III.

For instance, value of K = 7 is shown in Fig. 3, the number of processing events is 28. The number of stages is reduced only when the dripple configuration produces a repetition of more than three IC stages for a given group size. This happens for the first time at K = 11. The percent reduction in total number of IC stages increases with the number of users, reaching over 40% for the case where K = 30. It is once again important to note that the reduction achieved by the algorithm is identical for any realization of the algorithm as it depends on the number of users K. More specifically, the plot shown in Fig. 4 is universally true for all instances where the improved dripple algorithm is applied. The reduction in processing events illustrates the lack of degradation in the BER performance. By maintaining a sufficiently high number of processing events, the performance is also maintained.

![Figure 4. Percent reduction in number of IC stages and processing events for the improved dripple algorithm.](image)

V. CONCLUSIONS

In this paper, we proposed a novel interference cancellation receiver structure incorporating a user algorithm derived from previous hybrid IC schemes, termed “dripple”, in order to reduce the effects of MAI during the detection process. It is shown that the proposed improved dripple algorithm provides an improvement in BER performance over previously designed hybrid MUD receivers as well as significant improvement in overall system latency over the original dripple algorithm.

REFERENCES