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PERFORMANCE ANALYSIS OF AN UPLINK MISO-CDMA SYSTEM USING MULTISTAGE MULTI-USER DETECTION SCHEME WITH V-BLAST SIGNAL DETECTION ALGORITHMS

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ABSTRACT

This paper investigates the Weighted Linear Parallel Interference Cancellation (WLPIC) Multiuser Detection (MUD) scheme with Vertical-Bell Laboratories Layered Space-Time (V-BLAST) signal detection algorithms in uplink Code Division Multiple Access based Multiple Input Single Output (MISO-CDMA) system. The Bit error rate performance of WLPIC scheme with V-BLAST signal detection and Conventional Linear Parallel Interference Cancellation (CLPIC) scheme with V-BLAST signal detection are compared in both correlated and uncorrelated Rayleigh fading channels. The simulation results show that the uplink MISO-CDMA system performs well with WLPIC MUD scheme and MMSE-SIC signal detection when compared with CLPIC MUD scheme and ZF-SIC signal detection in different channel conditions.

Keywords: *MISO, CDMA, ZF-SIC, MMSE-SIC, ML Detection, CLPIC, WLPIC*

1. INTRODUCTION

MIMO is a key technology in third generation (3G) cellular communication systems. The system using MIMO processing offers higher data rates, higher spectral efficiencies and longer link range without any increase in transmit power or bandwidth. Code Division Multiple Access (CDMA) technique has been regarded as the most important part of 3G wireless communication systems. The Wideband Code Division Multiple Access (WCDMA) systems employ direct sequence spread spectrum technology and were developed for 3G systems to achieve high quality voice services and other multirate multimedia services [1]. The combination of Multiple Input Multiple Output (MIMO) technique with Direct Sequence – Code Division Multiple Access (DS-CDMA) system can achieve high data throughput, capacity and reliability [2]. For example, Evolved High Speed Packet Access (HSPA+), High Speed Uplink Packet Access (HSUPA) and High Speed Downlink Packet Access (HSDPA) systems are based on MIMO-CDMA radio technology.

Nowadays, with increasing numbers of interactive high bandwidth services such as video sharing, video telephony, real-time IP, multicasting, multimedia and games appearing, there is a clear requirement for high data rates in both downlink and uplink [3]. The application of multiple antennas in the transmitter (i.e. user equipment) offers high data rates in the uplink and single antenna in the receiver (i.e. base station) reduces computation complexity. This concept is called uplink Multiple Input Single Output (MISO) system or transmit (Tx) diversity system [4]. It is assumed that the total transmitted power of all antennas in MISO transmission concept is limited.

This paper investigates the uplink performance of Multiuser MISO-CDMA cellular system in both correlated and uncorrelated Rayleigh fading

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channels. The major challenges in Multiuser MISO-CDMA system are Multiple Access Interference (MAI) and Inter Antenna Interference (IAI). In Multiuser CDMA systems, MAI is present due to nonzero cross-correlation between the spreading codes of different users [5]. The MAI limits the performance of Multiuser CDMA systems which is reduced either by allocating orthogonal spreading codes for different users or using optimal Multiuser detection technique in the receiver. Allocation of orthogonal spreading codes for different users is not considered to be an optimal solution since the orthogonality of the signature waveforms is lost due to multipath fading and delay [6]. Optimal Multiuser detection is required in uplink of MISO-CDMA systems to increase the capacity of the system. Although, the usage of multiple antennas in the transmitter (i.e. user equipment) increases the uplink data rate, it also introduces Inter Antenna Interference (IAI) in MISO systems when the data streams from different antennas are assigned same spreading code [7]. The IAI in MISO systems is effectively reduced by Vertical Bell Laboratories Layered Space Time (V-BLAST) signal detection algorithms [8].

In this paper, multistage Weighted Linear Parallel Interference Cancellation (WLPIC) [9] is used for MUD scheme in uplink MISO-CDMA system. PIC lends itself to a multistage implementation where the decision statistics of the users from the previous stage are used to estimate and cancel the MAI in the current stage, and a final decision statistic is obtained at the last stage [5]. The combination of WLPIC MUD scheme with V-BLAST signal detection algorithms reduces MAI and IAI introduced in uplink MISO-CDMA system. The Bit Error Rate (BER) performance of WLPIC, Conventional Linear Parallel Interference Cancellation (CLPIC) MUD schemes with Maximum Likelihood (ML), Zero Forcing Successive Interference Cancellation (ZF-SIC), Minimum Mean Square Error Successive Interference Cancellation (MMSE-SIC) signal detection algorithms are compared in uplink of MISO-CDMA systems.

This paper is organized as follows. Section 2 introduces the uplink MISO-CDMA system model. Section 3 outlines the Matched Filter (MF), Conventional LPIC and Weighted LPIC MAI cancellation schemes and Section 4 outlines Maximum Likelihood (ML), ZF-SIC and MMSE-SIC signal detection algorithms that can be employed in such system. Section 5 illustrates the block diagrams of the transmitter and the receiver. Section 6 demonstrates the simulation results of MUD schemes with V-BLAST signal detection algorithms. Finally, Section 7 draws the conclusion.

2. UPLINK MISO-CDMA SYSTEM MODEL

We consider an M-user uplink MISO-CDMA based cellular communication system using BPSK. The transmitters (user equipments) are equipped with N_t transmit antennas and the receiver (base station) is equipped with single antenna are shown in Figure 1. The received signal at the base station as shown in Figure 2 is given by

$$y(t) = \sum_{m=1}^{M} H_m x_m + n(t), \quad t \in [0,T], \qquad (1)$$

where $x_m = b_m w_m(t)$ and

$$b_m = [b_{m1}, b_{m2}, \dots, b_{mN_t}] \qquad b_m \in \{+1,-1\}$$

where b_m is the bit sequence transmitted by mth user, T is one bit duration; H_m is the uplink channel matrix of size $1 \times N_t$, $w_m(t)$ is the unit energy spreading waveform of mth user defined in the interval $[0,T]$ and $n(t)$ is the zero mean white Gaussian noise with variance σ^2. The mth user's data bit, transmitted by a transmit antenna in the interval $[0,T]$ is multiplied by spreading waveform $w_m(t)$. The fade coefficients in each user's uplink channel matrix are assumed to be independent and identically distributed complex Gaussian random variables with zero mean and unit variance. We assume that the perfect channel state information is known at the receiver. The following sections discuss about the stage by stage MAI and IAI cancellation using WLPIC MUD scheme and V-BLAST signal detection algorithms.

3. MULTIPLE ACCESS INTERFERENCE CANCELLATION

We consider a multistage Weighted Linear Parallel Interference Cancellation scheme at the receiver for MAI suppression. The following subsections discuss about the stage by stage parallel MAI cancellation for all active users.

3.1 Matched Filter

The conventional matched filter with a bank of M correlators is used in the first stage which is shown in Figure 2. Each correlator is matched to different users' spreading waveform. The m th

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user's received vector at the output of the matched filter stage is given by

$$y_m^{(1)} = H_m b_m + \sum_{j=1, j\neq m}^{M} \rho_{jm} H_j\, b_j + n_m \quad (2)$$

where the superscript (1) in $y_m^{(1)}$ denotes the first stage, ρ_{jm} is the cross correlation coefficient between the jth and mth user's spreading waveform, given by $\rho_{jm} = \int_0^T w_j(t) w_m(t) dt$, $|\rho_{jm}| \leq 1$, and n_m's are complex Gaussian with zero mean and variance $2\sigma^2$ when $j = m$. The output of the matched filter without hard decision is used for MAI estimation and cancellation in the second stage. Since this PIC scheme uses soft decision statistics of the current stage for MAI estimation and cancellation in the next stage, it is said to be as Linear Parallel Interference Cancellation (LPIC) [5]. The performance of both Conventional LPIC and Weighted LPIC in the second stage are analysed in this paper.

3.2 Conventional LPIC MUD

In a conventional LPIC MUD scheme, the soft decision statistics of the previous stage are used to generate MAI estimates for each user and these estimates are subtracted from the original observations to form new soft decision outputs for the current stage [10]. More specifically, the MAI estimate for the desired user m in stage, $k > 1$, is obtained by multiplying $y_j^{(k-1)}$ with ρ_{jm} for all $j \neq m$ and summing them up, i.e., $\sum_{j\neq m} \rho_{jm} y_j^{(k-1)}$ is the MAI estimate for the desired user m in stage k. That is, the kth stage output of the desired user m, $y_m^{(k)}$, is given by

$$y_m^{(k)} = y_m^{(1)} - \sum_{j=1, j\neq m}^{M} \rho_{jm} y_j^{(k-1)} \quad (3)$$

3.3 Weighted LPIC MUD

In a weighted LPIC MUD scheme, an estimate of the MAI for a desired user m in kth stage, $k > 1$, is weighted by a factor $p_m^{(k)}$ before MAI cancellation. In other words, $p_m^{(k)} \sum_{j\neq m} \rho_{jm} y_j^{(k-1)}$ is the weighted MAI estimate for the desired user m in stage k. That is, the kth stage output of the desired user m, $y_m^{(k)}$, is given by

$$y_m^{(k)} = y_m^{(1)} - p_m^{(k)} \sum_{j=1, j\neq m}^{M} \rho_{jm} y_j^{(k-1)} \quad (4)$$

Note that the Matched Filter and Conventional LPIC become special case of the Weighted LPIC for $p_m^{(k)} = 0, \forall k$ and $p_m^{(k)} = 1, \forall k$ respectively. The optimum weights $p_m^{(k)}$ for each stage are calculated using [9].

4. V-BLAST SIGNAL DETECTION

The signal detection algorithm in last stage of the receiver receives the MAI cancelled output from kth stage of WLPIC scheme for IAI suppression in each users' data stream. The following subsections briefs about the Maximum likelihood (ML) signal detection algorithm and V-BLAST signal detection algorithms.

4.1 Maximum Likelihood Signal Detection

The ML signal detection calculates the Euclidean distance between the received signal $y_m^{(k)}$ of user m from kth stage of WLPIC scheme and the product of all possible transmitted signal vectors with the known uplink channel matrix H_m, and finds the one with the minimum distance. Let C and N_t denote a set of signal constellation symbol points and a number of transmit antennas, respectively. Then, ML detection determines the estimate of the transmitted signal vector x as

$$\hat{x}_{ML} = \underset{x\in C^{N_t}}{argmin} \|y_m^k - H_m x\|^2 \quad (5)$$

where $\|y_m^k - H_m x\|^2$ corresponds to the ML metric. The ML method achieves the optimal performance as the maximum a posteriori (MAP) detection when all the transmitted vectors are equally likely. However, its complexity increases exponentially as modulation order and/or the number of transmit antennas increases. The required number of ML metric calculation is $|C|^{N_t}$, that is, the complexity of metric calculation exponentially increases with the number of antennas [11]. The following two sub-sections briefs about ZF-SIC and MMSE-SIC signal detection algorithms. The comparison between ML signal detection, ZF-SIC and MMSE-SIC are discussed in results section.

4.2 ZF-SIC Signal Detection

The zero-forcing (ZF) technique nullifies the IAI by the following weight matrix [11]:

$$W_{ZF} = (H^* H)^{-1} H^* \quad (6)$$

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The steps involved in decoding the data layers of user m in ZF-SIC signal detection algorithm is given below:

1. Find the diagonal entry of $(H_m{}^*H_m)^{-1}$ with minimum value. Let this be ith entry. Denote the ith row of $(H_m{}^*H_m)^{-1}H_m{}^*$ by W_i.

2. Compute $d_i = W_i y_m^{(k)}$ and decode it to the closest signal point a_l from the constellation $C = \{a_1, a_2, \ldots, a_{|C|}\}$, closest in the sense of Euclidean distance. This corresponds to i th entry among the layers to be decoded.

3. Update the received signal $y_m^{(k)}$ by subtracting out the contribution from the decoded data. That is, compute $y_m^{(k)} = y_m^{(k)} - h_i a_l$, where h_i denotes the ith column of H_m whose size is $1 \times (N_t - v + 1)$, where v is the iteration index.

4. Update H_m by deleting the column h_i.

5. Go to the first step and continue until all the data layers are decoded.

These steps are iterated N_t times to decode the data stream transmitted in the time interval $[0, T]$ of user m [8].

4.3 MMSE-SIC Signal Detection

The MMSE-SIC algorithm implements the same steps as in ZF-SIC to decode the data of user m with the following change in the first step. Find the diagonal entry of $(H_m{}^*H_m + \sigma^2 N_t I)^{-1}$ with minimum value, where I denotes an identity matrix. Let this be ith entry. Denote the ith row vector of $(H_m{}^*H_m + \sigma^2 N_t I)^{-1}H_m{}^*$ by W_i [8].

5. BLOCK DIAGRAMS OF THE TRANSMITTER AND THE RECEIVER

In this section, the block diagrams of the transmitter and the receiver for MISO-CDMA system are presented, including a mobile station system (see Figure 1) and a base station system (see Figure 2).

6. SIMULATION RESULTS

The BER performances of uplink MISO-CDMA system employing WLPIC with V-BLAST signal detection algorithm in correlated and uncorrelated fading channels are obtained by Monte Carlo simulation. The Channel state information is assumed to be perfect at the receiver. We generated and simulated the correlated and uncorrelated Rayleigh fading channels using [12]. The simulation parameters are shown in Table 1.

Figure 3-4 show that the WLPIC MUD scheme outperforms CLPIC scheme and Matched Filter detector in correlated and uncorrelated Rayleigh fading channels. The BER performance of WLPIC scheme at 2nd stage with 10 numbers of active users is almost equivalent with single user performance in this system. The performance of WLPIC can be further improved by considering 3rd stage MAI cancellation. The ML signal detection is considered for the performance comparison between Matched Filter, CLPIC and WLPIC MUD schemes. The BER performance of this uplink MISO-CDMA system in uncorrelated Rayleigh fading channels is better than in correlated Rayleigh fading channels. With the increase of E_b/N_0 the performance of this system with multistage WLPIC scheme and ML signal detection is nearly same in both correlated and uncorrelated Rayleigh fading channels. The results show that the system performs well in any channel condition at higher E_b/N_0 ratio.

Table 1: Simulation Parameters

No of Transmit Antennas	4
No of Receive Antennas	1
Processing Gain	64
Modulation	BPSK
Maximum Users	25
Active Users	10
Cross Correlation Coefficient For Correlated Rayleigh Fading Channels	0.95463
Cross Correlation Coefficient For Uncorrelated Rayleigh Fading Channels	0.32945

Figure 5-6 show the performance of V-Blast signal detection algorithms with WLPIC MUD scheme in correlated and uncorrelated Rayleigh fading channels. The simulation results show that the MMSE-SIC scheme outperforms ZF-SIC scheme under different channel conditions. The results show that the ML signal detection is better compared to ZF-SIC and MMSE-SIC schemes. At higher E_b/N_0 the BER performance of MMSE-SIC scheme equals the performance of ML signal detection. The computation complexity of WLPIC with ML is higher compared to WLPIC with ZF-

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SIC and MMSE-SIC with the increased number of transmit antennas in mobile system.

7. CONCLUSION

The performance of Matched Filter, Conventional LPIC, Weighted LPIC MUD schemes with the combination of Maximum Likelihood, ZF-SIC and MMSE-SIC signal detection schemes are compared for uplink MISO-CDMA system. The system performance is analysed in different channel conditions. The simulation results show that the uplink MISO-CDMA system performs well with WLPIC MUD scheme and MMSE-SIC signal detection when compared with CLPIC MUD scheme and ZF-SIC signal detection in both correlated and uncorrelated Rayleigh fading channels.

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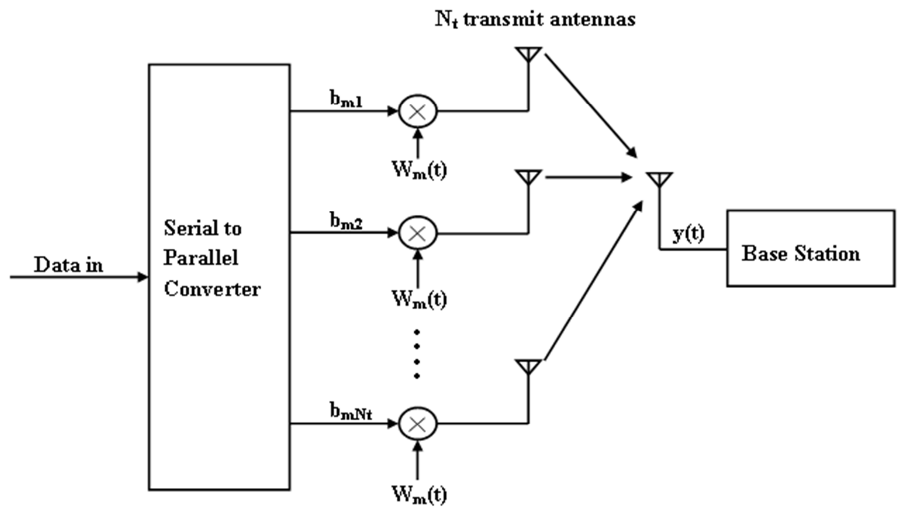

Figure 1: Block Diagram Of The Transmitter For Uplink MISO-CDMA System

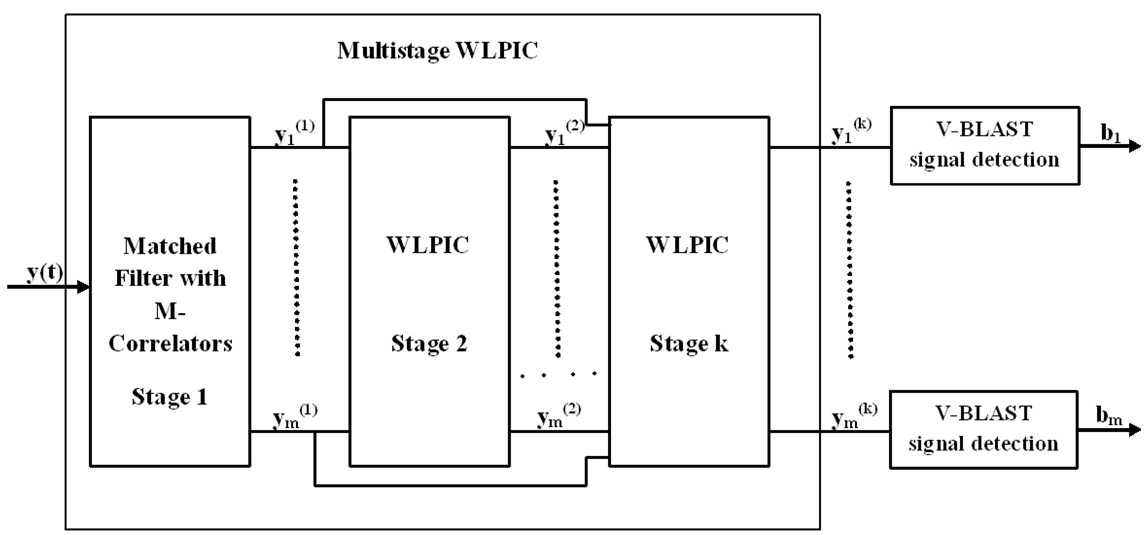

Figure 2: Block Diagram Of The Receiver For Uplink MISO-CDMA System

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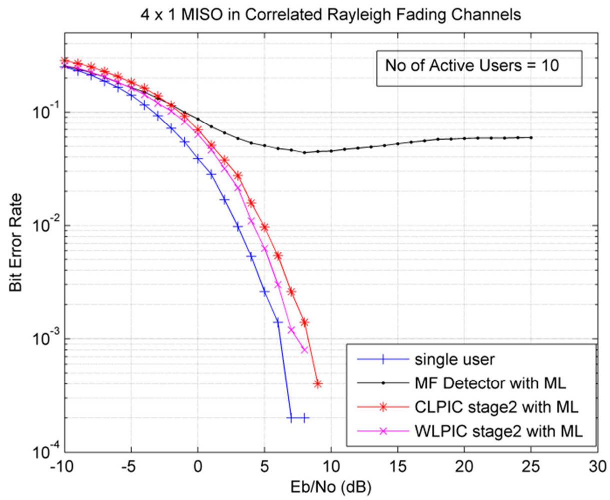

Figure 3: Comparison Of MF Detector, CLPIC, And WLPIC MUD Schemes With ML Signal Detection In Correlated Rayleigh Fading Channels

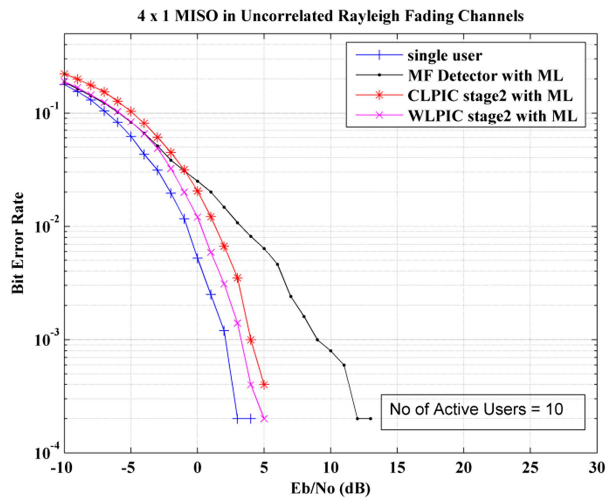

Figure 4: Comparison Of MF Detector, CLPIC And WLPIC MUD Schemes With ML Signal Detection In Uncorrelated Rayleigh Fading Channels

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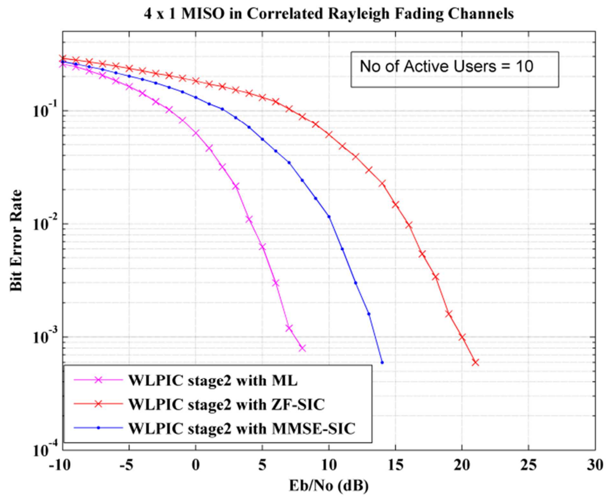

Figure 5: Comparison Of WLPIC MUD Scheme With ML, ZF-SIC And MMSE-SIC In Correlated Rayleigh Fading Channels

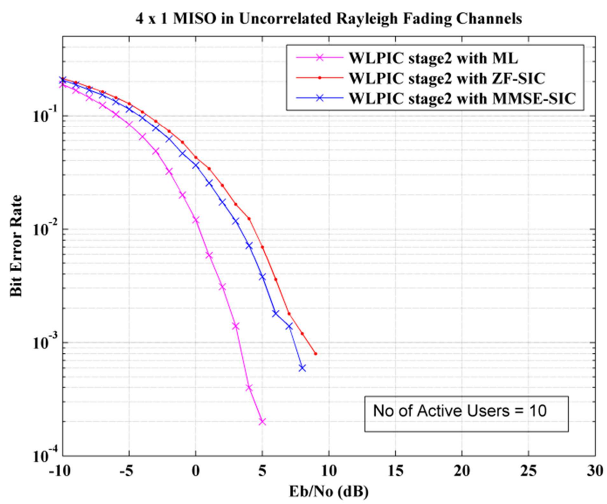

Figure 6: Comparison Of WLPIC MUD Scheme With ML, ZF-SIC And MMSE-SIC In Uncorrelated Rayleigh Fading Channels