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MMSE Rake Receiver and Channel Estimation in WCDMA Communication Systems

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Abstract:
We address the problem of joint beam-forming and multipath channel parameters estimation in Wideband Code Division Multiple Access (WCDMA) communication systems that employ Multiple-Access Interference (MAI) suppression techniques in the uplink (from mobile to base station). Several types of Rake Receivers like A-Rake, S-Rake, P-Rake, Adaptive frequency Rake, Time frequency Rake, Conventional MMSE Rake and Adaptive MMSE rake are used for WCDMA. In this paper we observed that the BER performance of the Adaptive MMSE Rake receiver gives better result in WCDMA. The comparative analysis proved that the Adaptive MMSE Rake Receiver is much better than Conventional Rake Receiver. Both Genetic Algorithm (GA) and as well as Conventional algorithm are derived for WCDMA environment. Computer simulation is used to compare between the proposed methods and the existing conventional estimation techniques.

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I. Introduction

We provide a complete optimization theoretical framework for the finger selection problem for MMSE SRake receivers. First, we formulate the optimal MMSE SRake as a nonconvex, integer-constrained optimization, in which the aim is to choose the finger locations of the receiver so as to maximize the overall Signal-Plus- Interference-Noise-Ratio (SINR). While computing the optimal finger selection is NP- hard, we present several relaxation methods to turn the (approximate) problem into convex optimization problems that can be very efficiently solved by interior-point methods, which are polynomial time in the worst case, and are very fast in practice. These optimal finger selection relaxations produce significantly higher average SINR than the conventional one that ignores the correlations, and represent a numerically efficient way to strike a balance between SINR optimality and computational tractability. Moreover, we propose a genetic algorithm (GA) based scheme, which performs finger selection by iteratively evaluating the overall SINR expression. Using this technique, near-optimal solutions can be obtained in many cases with a degree of complexity that is much lower than that of optimal search.

Direct-sequence code division multiple access (DSCDMA)has been adopted as the air interface technology in the third-generation wireless systems [1]. The high and different user data rates and the large number of users together with multipath dispersive fading channels cause a severe multi-user interference in both up and down links which limits the link capacity and/or coverage of the base station [2]. The multipath fading channel, on the other hand, is one of the

major impediment to reliable communication in CDMA systems. There are two major techniques in order to enhance the performance of CDMA systems, multiuser detection (MUD) or interference cancellation schemes and the use of adaptive antenna arrays (beamforming). It is well known that the complexity of the optimal MUD is too excessive. As a result, many suboptimal MUD receivers have been proposed in the last two decades [1], [4], [9]. In particular, the minimum mean-squared error (MMSE) receiver; parallel interference cancellation (PIC); and successive interference cancellation (SIC) have gained much attention because of their high spectrum efficiency, simplicity and adaptive structure. promising and attractive technique for improving the system coverage and spectral efficiency in high capacity mobile radio network.

Beam forming is a technique that can be used to focus the antenna beam to the desired user so that the signal to-(interference plus noise) ratio (SINR) can be increased [10], [11]. Both of the above techniques need a good and reliable multipath channel parameters estimate to effectively do their job. The channel estimation process is conventionally done by pilot-symbol-aided method per finger [3], [14]. By comparing the exact and the decoded pilot symbols of the desired user, one can estimate the channel random amplitude and phase. Most pilot-symbol-aided channel estimation methods are based on interpolation of channel values corresponding to pilot symbols. In the weighted multislot average (WMSA) method is proposed for channel estimation in CDMA systems. In [13], a new linear robust interpolation channel estimation technique were proposed which is based on a similar technique developed for orthogonal frequency division multiplexing (OFDM) systems [5], [6]. The robust interpolation method outperforms the WMSA method. In WCDMA, the channel parameters can also be estimated from the common pilot channel (CPICH) [8]as the desired user pilot symbols may be weak (for voice application) resulting in a bad channel estimate. This common pilot channel could also be corrupted by strong interference resulting in a bad estimate. Most of the research that combined MUD and channel estimation converted the multiuser parameter estimation problem into a set of single user optimization problems and then determine the channel parameters for every user using some kind of iterative algorithm [4], [9]. In [8], we benefited from the strong interferer as well in the channel estimation process instead of suppressing it. We also coupled interference cancellation with pilot-symbol-aided method using single antenna in [8]. The contribution of this paper is proposing a new iterative joint channel estimation and interference cancellation scheme to improve the WCDMA uplink and downlink performance when using a receiver adaptive antenna array. The proposed system is analyzed and tested in a channel profile specified by the 3GPP. We'll use both robust interpolation for pilot symbols and the CPICH after iteratively cleaning them from the MAI by using both PIC and RAKE receiver when employing matching beam former that estimates the desired signal direction of arrival DOA [12].

The rest of the paper is organized as follows. Section II presents the signal model as well as the system description. In Section III, both channel estimation algorithm and the process of beam forming are described. Simulation results are provided

II. System Model

A. MMSE Rake Receiver with Conventional Algorithm:

Instead of the solving the problem in [14], the "conventional" finger selection algorithm chooses the M paths with largest individual SINRs, where the SINR for the lth path can be expressed as

$$SINR_1 = \frac{E_1(\alpha_1^{[1]})^2}{(S_1^{[MAI]})^T A^2 S_1^{(MAI)} + \sigma_n^2} \qquad (1)$$

for l = 1, . . . , L.

This algorithm is not optimal because it ignores the correlation of the noise components of different paths. Therefore, it does not always maximize the overall SINR of the system given in [15]. For example, the contribution of two highly correlated strong paths to the overall SINR might be worse than the contribution of one strong and one relatively weaker, but uncorrelated, paths. The correlation between the multipath components is the result of the MAI from the interfering users in the system.

B. MMSE Rake Receiver with Genetic Algorithm

The GA is an iterative technique for searching for the global optimum of a cost function [16]. The name comes from the fact that the algorithm models the natural selection and survival of the fittest [17]. We propose a GA (Genetic Algorithm) based approach to solve the finger selection problem, which directly uses the exact SINR expression and does not employ any relaxation technique in MMSE receiver. The GA is an iterative technique for searching for the global optimum of a cost function. The name comes from the fact that the algorithm models the natural selection and survival of the fittest. The GA has been applied to a variety of problems in different areas.

Also, it has recently been employed in the multi-user detection problem. The main characteristics of the GA algorithm are that it can get close to the optimal solution with low complexity, if the steps of the algorithm are designed appropriately. In order to be able to employ the GA for the finger selection problem we need to consider how to represent the chromosomes, and how to implement the steps of the iterative optimization scheme in MMSE. By choosing the fitness function, the fittest chromosomes of the population correspond to the assignment vectors with the largest SINR values. Now, we can summarize our GA-based finger selection scheme as follows: Generate Nipop different assignments randomly and select Npop of them with the largest SINR values.

1. Pairing: Pair Ngood of the finger assignments according to the weighted random scheme.
2. Mating: Generate two new assignments from each pair.
3. Mutation: Change the finger locations of some assignments randomly except for the best assignment.

The GA has been applied to a variety of problems in different areas [16] [18]. Also, it has recently been employed in the multi-user detection problem [19][20]. The main characteristics of the GA algorithm are that it can get close to the optimal solution with low complexity, if the steps of the algorithm are designed appropriately

C. Uplink Joint Channel Estimation and Beamforming

After down conversion, the baseband signal is passed to a matched filter. Its output can be written as

$$Z_1(\tau) = T_b b_1(i) \sum_{1=1}^{L} \hat{a}_1(\theta_{1l})\delta(\tau - \tau_{1l}) + S_1(\tau) + m_1(\tau) + n_1(\tau) \quad (2)$$

where **s**1 is the self-interference signal vector due to own multipath, **m**1 is the MAI term and **n**1 is the AWGN [12]. Under the assumption that the MAI of each pilot bit can be modeled as independent Gaussian noise, we can coherently integrate and average over the *Np* to obtain the mean delay profile at the *m*th antenna. We can further reduce the MAI by averaging the delay profile over the M antenna elements to get he desired user delay profile as

$$\bar{Z}_1(\tau) = (1/MN_p)\sum_{m=1}^{M}\left|\sum_{n=1}^{N_p} Z_{1,n}^m(\tau)\right| \quad (3)$$

We can then put a threshold and choose the desired time bin from Eq. (3). We can further calculate the DOA by finding the Fourier Transform of Eq. (3) w.r.t. the selected time bins. Now we are ready to detect by the 2-D RAKE shown in Fig. (1) which gives an approximate output SINR of
$SINR = NM(SNR)/[(K-1)SNR + 1]$ (4)

where SNR is the uplink signal-to-noise ratio per each antenna.

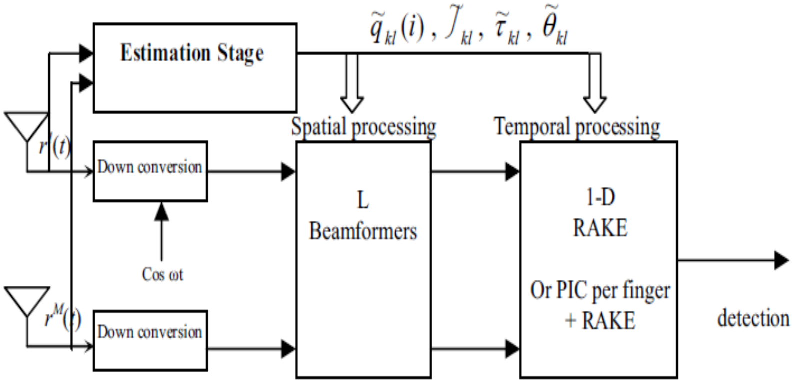

Fig.(1) 2D-RAKE receiver

$\hat{A}_{kl}^m(u) = (1/N_p)\sum_{n=1}^{N_p} r_{kl}^m(uN_s + n)b_k(uN_s + n)$ (5)
Where $r_{kl}^m(i) = (1/T_b)\int^{(i+1)T+\tau} r^m(t)S_k(t - iT_b - \tau_{kl})$

D. Channel Estimation by Robust Interpolation

Using the WMSA method [14], the channel is estimated by linear interpolation. Since the fading is the same for all pilot duration of *Np* symbols, the *u*th slot instantanious channel gain for the *l*th path of the *k*th user at the *m*th antenna is the overall channel coefficients at the *n*th data bit from the *m*th antenna averaged over 2*J* time slots are

$$\hat{g}_{kl}^m(uN_s + N_p + n) = \sum_{j=-J+1}^{J} \sin c\left(2f_d T_b(n - jN_s)\right)\hat{A}_{kl}^m(u + j) \quad (6)$$

Where $n = N_p + 1, \dots\dots, N_s. If\ f_d$ is not known, set it to a 0.001[13]

III. Simulation Results

Simulations were carried out to evaluate and compare the bit error probability performance of the proposed adaptive MMSE Rake receiver in multipath channels with AWGN. The system for simulations considered in this paper is, synchronous WCDMA UWB with the following specifications. All users have equal power with Gold sequence of spreading gain 31 as spreading code. Binary phase shift keying with sampling frequency of 50 GHz, chip time of 0.5 nsec and second derivative of Gaussian pulse of width 0.5 nsec used. Random binary data is generated for each user, the data is spread with the respective spreading code followed by modulation with second derivative of the Gaussian pulse. Each user undergoes a different UWB channel. Channel models CM1,CM2 and CM3 from IEEE P802.15 [14] are used. Channel model parameters are listed in table (1). The number of multipaths is selected in such a way that 90 percent of the transmitted energy is captured. Proposed adaptive MMSE Rake receiver and conventional adaptive MMSE Rake (C-Rake) receiver use training signals of 500 bits followed by decision directed operation. Proposed MMSE Rake receiver does not require spreading code of any user, where as, it is assumed that C –Rake receiver knows spreading code of the user of interest. Figures shows simulation results for bit error probability vs. number of users with E*b* /N*o* = 20 *d*B for CM1, CM2 and CM3 respectively. It is observed that the proposed detector performs much better than C-RAKE even for large number of users.

parameters	CM1	CM2	CM3
Cluster arrival rate, (1/ns)	0.0233	0.4	0.0667
Ray arrival rate, (1/ns)	2.5	0.5	2.1
Cluster decay factor	7.1	5.5	1.4
Ray decay factor	4.3	6.7	7.9
Std. dev. of cluster, (dB)	3.3941	3.3941	3.3941
Std. dev. of ray,(dB)	3.3941	3.3941	3.3941
Std. dev. of total MP, (dB)	3	3	3

Table 1: IEEE UWB channel parameters

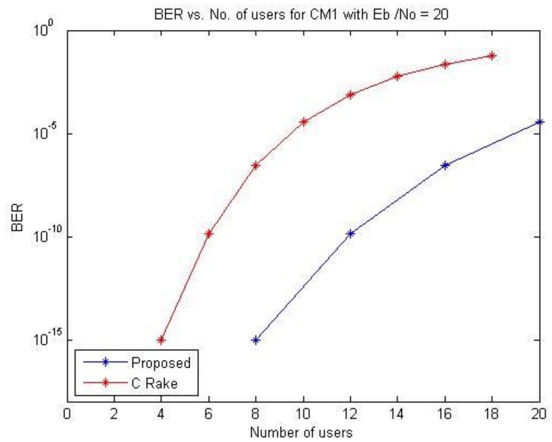

Fig 2: BER vs. No. of users for

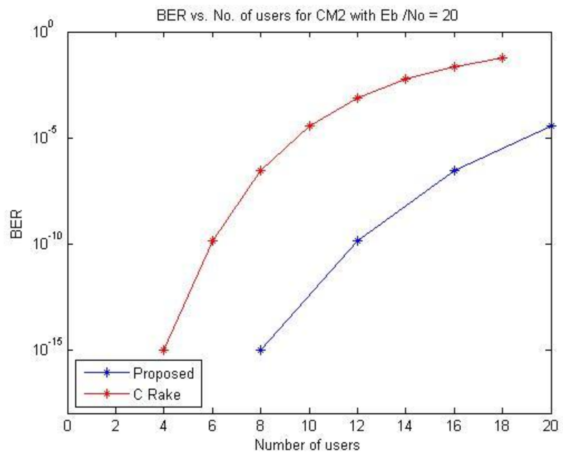

Fig 3: BER vs. No. of users for CM2

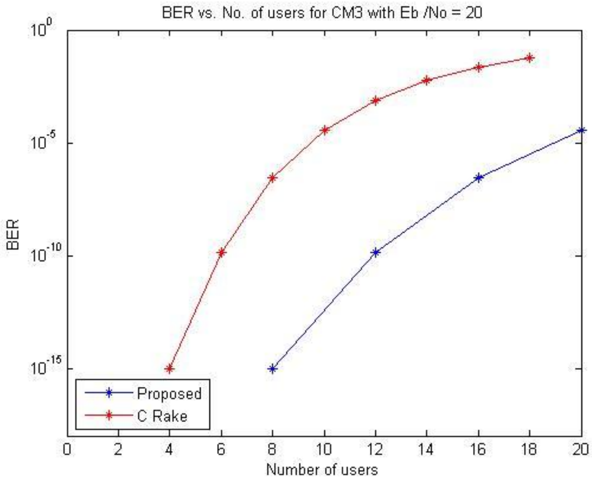

Fig 4: BER vs. No. of users for CM3

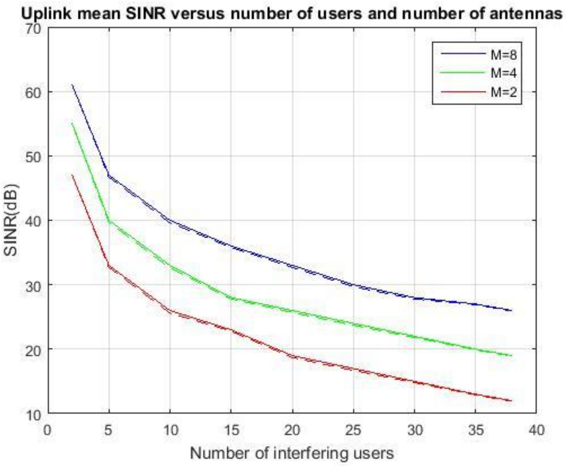

Fig. (5) Uplink mean SINR versus number of users and number of antennas

The plot in Fig. (5) is the SINR as a function of the number of interfering users and the number of antenna elements in the array. The solid lines are those from theory (Eq. 4) the dotted lines are from Mont Carlo simulations when estimating the channel parameters in the uplink from the Q channel using the complex conjugation beamformer.

IV. Conclusion

We have derived that the Adaptive MMSE Rake receiver for WCDMA UWB multipath channels and studied its BER performance in multiuser environment with AWGN**.** It is observed that the BER performance of the Adoptive MMSE Rake receiver is much better in comparison with conventional MMSE Rake receiver. We developed a WCDMA receiver that utilizes adaptive antenna arrays and interference cancellation RAKE receiver which self estimate the multipath channel parameters as well as the desired user direction of arrival. In estimating the channel, we used a robust interpolation method as well as iterative joint detection and estimation. Performance curves in the 3GPP recommended channel shows very good performance compared to the existing receivers.

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