

Combined Beamforming and Channel Estimation in WCDMA Communication Systems

Nermin A. Mohamed and Mohamed F. Madkour

Abstract—We address the problem of joint beamforming 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). Most of the existing schemes rely on time multiplex a training sequence with the user data. In WCDMA, the channel parameters can also be estimated from a code multiplexed common pilot channel (CPICH) that could be corrupted by strong interference resulting in a bad estimate. In this paper, we present new methods to combine interference suppression together with channel estimation when using multiple receiving antennas by using adaptive signal processing techniques. Computer simulation is used to compare between the proposed methods and the existing conventional estimation techniques.

Keywords—Adaptive arrays, channel estimation, interference cancellation, wideband code division multiple access (WCDMA).

I. INTRODUCTION

DIRECT-SEQUENCE code division multiple access (DS-SS-CDMA) 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 [15]. The use of adaptive antenna arrays (beamforming) is also a

promising and attractive technique for improving the system coverage and spectral efficiency in high capacity mobile radio network. Beamforming 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 [14], 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], [16] 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 [16]. 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 beamformer 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 beamforming are described. Simulation results are provided

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in Section IV. Section V concludes the paper.

II. SYSTEM MODEL

A. Signal Model

Modeling the WCDMA data signal with pilot in uplink is different from that of downlink [16]. In uplink, data and pilot are separately modulated on I and Q channels, respectively. Pilot and data bits are spread using different Walsh codes to insure isolation. Therefore, if we neglect the mutual interference between the data and pilot (due to channel frequency selectivity), base station can easily separate them by two orthogonal carriers. In downlink, there are two types of pilots, as mentioned in Section I, the TDM and the CDM pilot. The CDM (CPICH) pilot is separated by a proper matched filter. There will be inter pilot interference. To clearly develop the receiver, let's consider that the isolation is perfect. Consider a CDMA system with K users with only the 1st one is desired and the rest are interferers. A block of S symbols need to be transmitted on time slots with total size of $N_s = N_p + N_d$. The spreading waveform of the k th user, $s_k(t)$, has N chips (processing gain $N = T_b/T_c$). The k th user signal is transmitted through a Rayleigh multipath fading (with L paths) channel to a receiver that consists of M antenna elements. The time varying channel impulse response to the m th antenna element is given by

$$h_k^m(t) = \sum_{l=1}^L g_{kl}^m(i) \delta(t - iT - \tau_{kl}) \quad (1)$$

where $g_{kl}^m(i) = a^m(\theta_{kl}) q_{kl}(i) e^{j\phi_{kl}}$. The parameters $q_{kl}(i)$, ϕ_{kl} , τ_{kl} , θ_{kl} are, respectively, the amplitude, phase shift, time delay and angle of arrival of the l th multipath component from the k th user. The column vector $\mathbf{a}_k(\theta_{kl})$ is the array response vector corresponding to the l th path of the k th user where $\mathbf{a}_k(\theta_{kl}) = [1 \ a^1(\theta_{kl}) \ \Lambda \ a^{M-1}(\theta_{kl})]^T$ where $a^m(\theta_{kl})$ is a complex number denoting the amplitude gain and phase shift of the signal at the $(m+1)$ th antenna relative to that at the first antenna. With perfect power control, the complex baseband expression of received signal vector $\mathbf{r}(t)$ is given by

$$\mathbf{r}(t) = \sum_{k=1}^K \sum_{l=1}^L \hat{\mathbf{a}}_k(\theta_{kl}) \sum_{i=0}^{S-1} b_k(i) s_k(t - iT_b - \tau_{kl}) + \mathbf{n}(t) \quad (2)$$

where $\hat{\mathbf{a}}_k(\theta_{kl}) = q_{kl}(i) e^{j\phi_{kl}} \mathbf{a}_k(\theta_{kl})$ is the channel vector and $\mathbf{n}(t)$ is the AWGN vector.

B. Receiver Model

The receiver will first separate the pilot of the desired user and then estimate the parameters of the channels that will be used in signal detection. We'll consider two detectors. The space-time (2-D) RAKE [12] and the conjugation matched beamformer followed by an iterative PIC [15]. Receiver block diagrams are shown in Fig. (1) and Fig. (2) below. Fig. (1) illustrates the Q channel uplink processing for channel parameter estimation. Fig. (2) shows the uplink space-time RAKE implementation.

III. METHODOLOGY ANALYSIS

A. Uplink Joint Channel Estimation and Beamforming

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

$$\mathbf{z}_1(\tau) = T_b b_1(i) \sum_{l=1}^L \hat{\mathbf{a}}_1(\theta_{1l}) \delta(\tau - \tau_{1l}) + \mathbf{s}_1(\tau) + \mathbf{m}_1(\tau) + \mathbf{n}_1(\tau) \quad (3)$$

where \mathbf{s}_1 is the self-interference signal vector due to own multipath, \mathbf{m}_1 is the MAI term and \mathbf{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 N_p 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 the desired user delay profile as

$$\bar{z}_1(\tau) = (1/MN_p) \sum_{m=1}^M \left| \sum_{n=1}^{N_p} z_{1,n}^m(\tau) \right|. \quad (4)$$

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

$$\text{SINR} = NM(\text{SNR}) / [(K-1)\text{SNR} + 1] \quad (5)$$

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

B. 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 N_p symbols, the u th slot instantaneous channel gain for the l th path of the k th user at the m th antenna is

$$\hat{A}_{kl}^m(u) = (1/N_p) \sum_{n=1}^{N_p} r_{kl}^m(uN_s + n) b_k(uN_s + n) \quad (6)$$

where $r_{kl}^m(i) = (1/T_b) \int_{iT+\tau}^{(i+1)T+\tau} r^m(t) s_k(t - iT_b - \tau_{kl})$. According to [5], [6], [13], the overall channel coefficients at the n th data bit from the m th antenna averaged over $2J$ time slots are

$$\hat{g}_{kl}^m(uN_s + N_p + n) = \sum_{j=-J+1}^J \text{sinc}(2f_d T_b (n - jN_s)) \hat{A}_{kl}^m(u + j) \quad (7)$$

where $n = N_p + 1, \dots, N_s$. If f_d is not known, set it to a 0.01 [13]

IV. SIMULATIONS

The simulated multiuser environment consists of up to 40 active users. The system chip rate is 3.84 Mcps in 5 MHz channel bandwidth. The carrier frequency is 1.965 and 2.155 GHz for up and down links, respectively. Data rates are fixed at 60 kbps using Gold codes of processing gain $N = 64$. The scrambling codes are Gold codes truncated to 38400 chips.

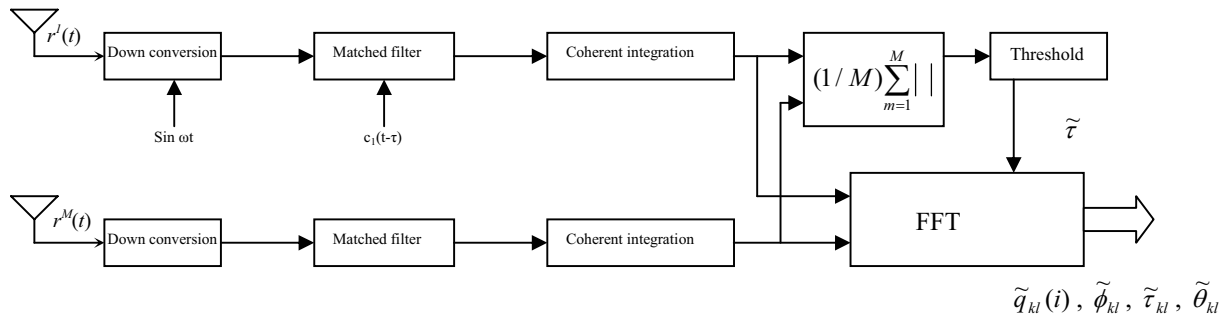


Fig. 1. Q-channel for channel parameters estimation

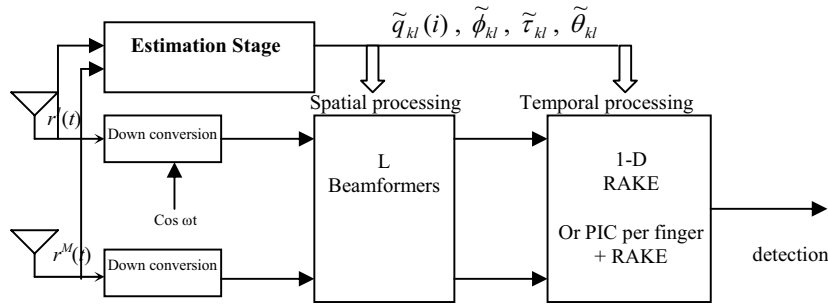


Fig. 2. 2D-RAKE receiver

The number of pilot symbols are 6 for uplink and 4 for downlink. Slots of 667 microseconds (40 bits) are used. Consider a uniform linear array of half wavelength spacing with an average SNR of 10 dB per antenna. The channel multipath profile of the desired user is chosen according to the 3GPP [16] and is shown in the table below.

Each interfering user also has 4 multipath. Their channel

TABLE I
 CHANNEL PARAMETERS OF THE DESIRED USER

Path	1	2	3	4
Angle (deg)	-40°	0	20°	40°
Delay	0	T_c	$2T_c$	$3T_c$
Power (dB)	0	-3	-6	-9

parameters $q_{kl}(i)$, ϕ_{kl} , τ_{kl} and θ_{kl} are Rayleigh, uniform over $[0, \pi/2]$, uniform over $[0, 3T_c]$ and the DOA is uniform over $[-60^\circ, 60^\circ]$.

The plot in Fig. (3) 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. 5) 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. Fig. (4) shows one beamformer response (the one matched to the third path) using 2 methods, the complex conjugation and the DOA method. In the DOA method, one would compute the pattern as soon as we know the DOA from the noncoherent combining by calculating the m th element weighting,

$$w_m = \sum_{p=1}^P e^{jk(m-1)d \cos \tilde{\theta}_p}$$

where P is the number of dominant paths. It is clear that the DOA one is better.

In Fig. (5), we combined the robust channel estimation method with the DOA beamforming technique. The system

uncoded BER is plotted as a function of the E_b/N_0 at $f_d = 500$ Hz when only 20 users are available in the cell with 4 elements in the array. In this simulation example, we simulate many receivers. First when we use robust interpolation with DOA beamforming and PIC in each of the RAKE finger. This yielded the best performance as we average out the MAI by a very good channel estimation technique which iterates with the PIC until the performance is satisfactory. Second when we drop the PIC, performance degrades but still good. Third when we drop the beamforming stage as well and use just the temporal RAKE with the robust estimation and 4th order diversity. Fourth when using the conventional WMSA estimation with diversity reception (no beamforming) and just a RAKE receiver.

I. CONCLUSION

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.

REFERENCES

- [1] T. Ojanpera and R. Prasad, *Wideband CDMA for Third Generation Mobile Communications*. Boston, London: Artech House, 1998.
- [2] G. L. Turin, "The effects of multipath and fading on the performance of direct sequence CDMA systems," *IEEE Trans. Veh. Technol.*, vol. VT-33, pp.213-219, Aug. 1984.
- [3] J. K. Cavers, "An analysis of pilot assisted modulation for Rayleigh fading channels," *IEEE Trans. Veh. Technol.*, vol. 40, pp. 689-693, Nov. 1991.

- [4] S. Buzzi and H. V. Poor, "Channel estimation and multiuser detection in long-code DS/CDMA systems," *IEEE Journal Selected Areas in Comm.*, vol. 19, pp. 1476 - 1487, August 2001.
- [5] Y. Li, L. Cimini, and N. Sollenberger, "Robust channel estimation for OFDM systems with rapid dispersive fading channels," *IEEE Trans. Commun.*, vol. 46, pp. 902-915, July 1998.
- [6] Y. Li, "Pilot-symbol-aided channel estimation for OFDM in wireless systems," *IEEE Trans. Veh. Technol.*, vol. 49, pp. 1207-1215, July 2000.
- [7] Anthony J. Weiss, Benjamin Friedlander, "Channel estimation for DS-CDMA downlink with aperiodic spreading codes," *IEEE Trans. Commun.*, vol. COM-47, pp. 1561 - 1569, October 1999.
- [8] M. Madkour, Nermin Mohamed, "A new channel estimation technique for any CDMA-based communications system," the 46th *IEEE Mid West Symposium on Circuits and Systems*, Cairo, Egypt, Dec. 28-30 2003.
- [9] Stephen E. Bensley, Behnaam Aazhang, "Subspace-based channel estimation for code division multiple access communication systems," *IEEE Trans. Commun.*, vol. COM-44, pp. 1009 - 1020, August 1996.
- [10] G. V. Tsoulos, et al "Low complexity smart antenna methods for third generation W-CDMA systems," *IEEE Trans. Veh. Technol.*, vol. 49, no. 6, pp. 2382-2396, 2000.
- [11] J. C. Liberti and T. S. Rappaport, *Smart Antenna for Wireless Communications IS-95 and 3rd Generation CDMA Applications*. Englewood Cliffs, NJ: Prentice-Hall, 1999.
- [12] H. Li, T. Liu, "Comparison of beamforming techniques for WCDMA communication systems," *IEEE Trans. Veh. Technol.*, vol. 52, pp. 752-760, July 2003.
- [13] G. Yue, X. Zhou, and X. Wang, "Performance comparisons of channel estimation techniques in multipath fading CDMA," *IEEE Trans. Wireless Commun.*, vol. 3, no. 3, pp. 716-724, May 2004.
- [14] S. Abeta, M. Sawahashi, and F. Adachi, "Performance comparison between time-multiplexed pilot channel and parallel pilot channel for coherent Rake combining in DS-CDMA mobile radio," *IEICE Trans. Commun.*, vol. E81-B, no. 7, pp. 1417-1425, July 1998.
- [15] G. Xue and J. Weng, "Adaptive multistage parallel interference cancellation for CDMA," *IEEE J. Select. Areas Commun.*, vol. 17, pp. 1815-1827, Oct. 1999.
- [16] "Spreading and modulation (FDD)," 3GPP, TS 25.213 V2.0.0, 1999-4, available at <http://www.3gpp.org/specs/specs.html>

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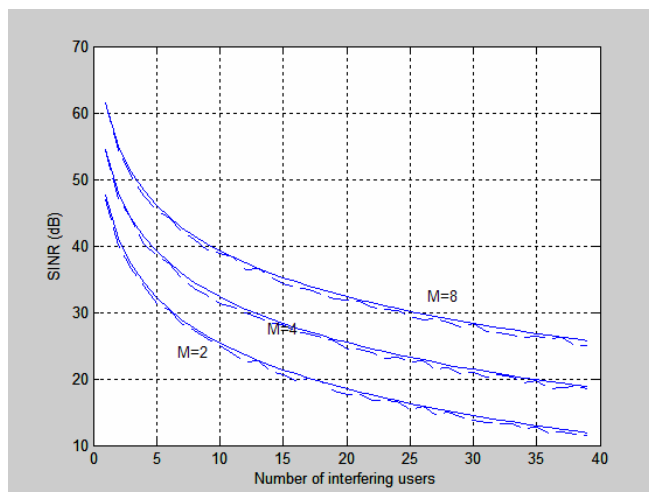


Fig. (3) Uplink mean SINR versus number of users and number of antennas

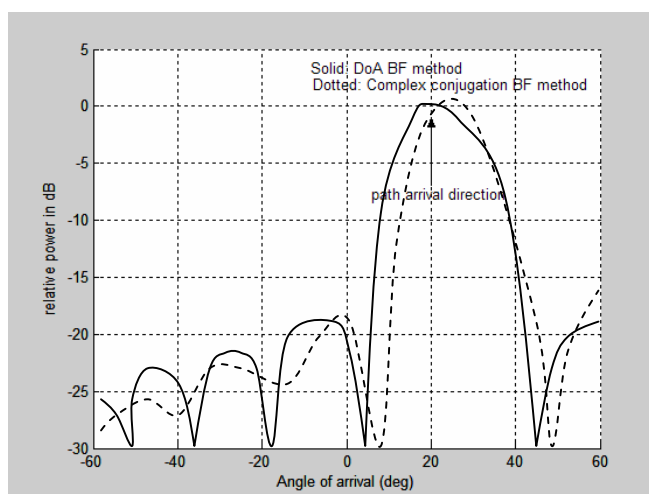


Fig. (4) Uplink antenna pattern using both DoA and conjugation method

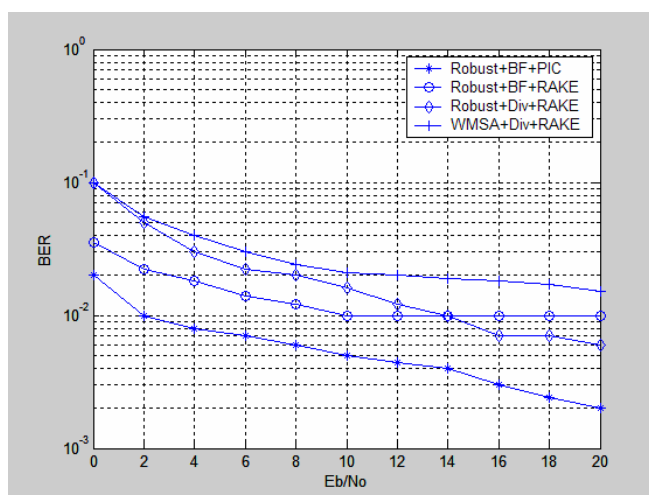


Fig. (5) BER versus Eb/No for different joint WCDMA receivers