Design and Performance Evaluation of Combined Adaptive Beamformer and Rake Receiver for WCDMA Uplink

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Abstract—**This paper presents a low-complexity adaptive baseband receiver for the uplink WCDMA system based on 3GPP Radio Access Network FDD mode. The proposed receiver includes an adaptive beamformer that utilizes the spatial signature of the multipath signals to form beam pattern so that the desired signal is constructively enhanced. The adaptive beamformer weights are derived using a novel adaptive algorithm. The proposed adaptive algorithm uses the simple LMS algorithm with Direct Matrix Inversion (DMI) algorithm initialization to ensure fast convergence. Time diversity reception is achieved by the Rake combiner, whose weights are derived from the multipath information obtained by the channel estimator. The bit error rate (BER) performance of the proposed combined adaptive receiver for WCDMA uplink under Rayleigh fading channels is demonstrated with purpose-made simulation model developed in Matlab and Simulink. The adaptive receiver has satisfactory BER performance. Simulation results showed uncoded BER performance by the proposed receiver of the order of 10^{-2} at $E_b/N_0 \leq 10dB$ under Rayleigh fading channels.**

Index Terms— **Adaptive beamformer, Rake receiver, Diversity reception, Wideband-CDMA, Maximal ratio combining.**

I. Introduction

The Third Generation Partnership Project (3GPP) WCDMA specification for the third generation mobile communication systems is intended to achieve two major goals simultaneously:

(1) Provision of wide-area mobility, such as urban and suburban areas, hilly and mountainous areas and indoor environments;

(2) Support for a wide range of bearer services with different data rates, e.g., 144Kbps in vehicular, 384Kbps in outdoor pedestrian, and 2Mbps in the fixed indoor environment [1].

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To achieve the aforementioned goals, the 3GPP WCDMA proposal includes an uplink pilot channel to serve as reference for channel parameters estimation. Information of channel parameters such as the number of multipath components, their location (in the time domain), and their (complex-valued) attenuation facilitates implementation of several advanced receiving techniques that help increase the signal to interference plus noise ratio (SINR) of the received signal. Among these techniques, Rake combining for diversity receiving in multipath fading channels is adopted to maximize the amount of received signal energy. Adaptive antenna array technique is another technique that uses pilot channel of each user for multiple access interference elimination.

While adaptive antennas improve the performance of WCDMA communications in space domain, a Rake receiver attempts the same goal through temporal operations. Recently there has been an increasing interest in the use of space-time processing to simultaneously exploit space and time diversities by combining adaptive antennas with Rake receivers. This research area is largely concerned with developing practical low cost and low complexity algorithms suitable for implementation in 3G and future mobile communication systems.

Morrison and Sharif in [2] described complex adaptive receivers called two-dimensional (2-D) Rake receivers. The 2-D Rake receiver exploits both the multipath diversity of Rake receiver and the spatial diversity of adaptive beamformer to improve the bit error rate (BER) performance of CDMA-based mobile communication systems. In the 2-D Rake receiver architecture, one beamformer is used for each of the estimated incoming signal in a multipath channel. In these configurations, sophisticated algorithms are needed for computing the weights of the beamformers. These algorithms often involve computationally intensive beamforming algorithms. Thus the 2-D Rake receiver architecture is seldom implemented in real-time hardware.

A baseband receiver for WCDMA uplink communication is proposed in [3]. The proposed uplink baseband receiver is composed of a channel estimator, a Rake combiner, and a carrier synchronization circuit. In this receiver architecture, a correlator-based beam searcher computes the beamformer weights using simple arithmetic operations. The proposed beamformer architecture in [3] works best in the nondiffused case where there is a single dominant path. However, this is not always valid.

In [4] the author proposed an adaptive space-time scheme, which is a combination of adaptive beamforming and adaptive equalization. The proposed adaptive receiver structure uses minimum mean square error (MMSE)-based

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adaptive beamforming algorithm to compute the optimized weights, while linear adaptive equalization using least mean square (LMS) adaptive algorithm is used to reduce inter-symbol interference (ISI) effects due to multipath fading in the propagation channel. Simulation results show that in multipath fading environment, the BER performance of a communication system using the proposed combination of adaptive beamforming and adaptive equalization is remarkably improved. However, the slow convergence of the LMS algorithm makes the scheme not suitable for high data rate communication in multipath environment.

In this paper a simple adaptive beamforming receiver is developed for WCDMA uplink communication. Our receiver differs from the reviewed 2D-Rake receiver structures as it propose a cascade of low-complexity reference signal based adaptive beamformer and maximal ratio combining Rake receiver for WCDMA uplink communication. By combining the adaptive beamforming antenna with the Rake receiver we exploit the spatial as well as time distribution characteristics of the radio signal in multipath environment to enhance the link-level performance of a WCDMA mobile communication system. Link level simulation of the combined adaptive array antenna and Rake receiver at the base station of a WCDMA communication system is implemented according to the physical layer specifications of the IMT-2000 WCDMA. In the simulation only the uplink communication is considered. Binary Phase Shift Keying (BPSK) modulation, Walsh codes spreading and Gold code scrambling with processing gain are assumed. The channel between the mobile station and the base station is modeled as time varying vector of impulse response. All necessary channel parameters such as path attenuation, path delay, and number of multipath components are estimated from deterministic ray tracing simulations. The bit error rate (BER) performance of the proposed combined adaptive receiver in WCDMA uplink communication is investigated using a purpose-made simulation model. The simulation program is developed and tested in Matlab 7.0.1 and Simulink Toolbox. The combined adaptive antenna receiver showed satisfactory BER performance. For example, at bit energy to noise spectral density, $E_b/N_0 = 20dB$ the BER for only the Rake combiner is of the order of $10^{-1.0}$, but the BER performance of the combined adaptive receiver is on the order of $10^{-2.0}$ at $E_b/N_0 \leq 10dB$.

II. ANALYTIC MODEL OF WCDMA (FDD) AND PROPOSED ADAPTIVE BEAMFORMER-RAKE RECEIVER MODEL

A. Transmitter Model

The block diagram of mobile stations transmitters for WCDMA frequency division duplex (FDD) mode mobile cellular system is shown in Fig.1.

The mobile station transmitter consists of the information source, a spreader, pulse shaping filter, a digital-to-analog converter (DAC) and an IF-RF converter. For simplicity, an uncoded system is considered, i.e., the channel encoder is ignored. This approach is widely used as it allows the bit error rate (BER) performance analysis of direct sequence CDMA communication systems employing multiple antennas. In practice, however, channel coding is an essential component of DS-CDMA wireless communication system.

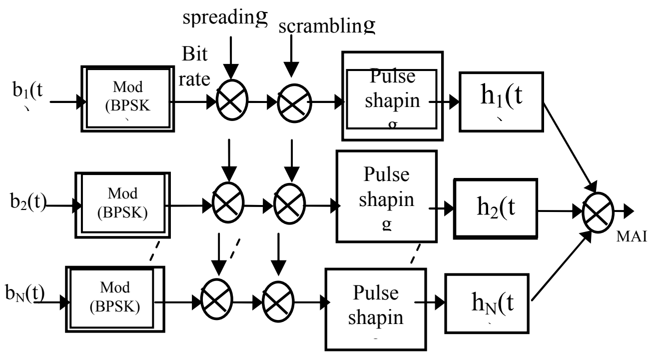

Fig.1: Block diagram of mobile stations transmitters of WCDMA in uplink

In the uplink the data modulation of both the DPDCH and the DPCCH is Binary Phase Shift Keying (BPSK), Walsh-Hadamard codes are used to spread data, and Gold codes are used to scramble data following the reverse link specifications of the WCDMA FDD [5]. The spreading, scrambling and modulation operations of WCDMA for an uplink user are shown in Fig. 2.

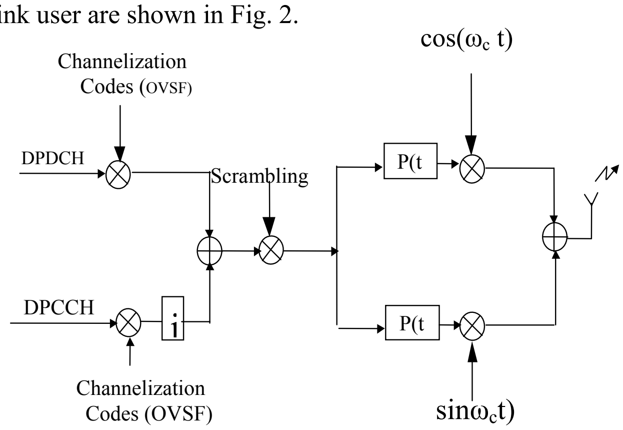

Fig. 2: Uplink Spreading and Modulation

The data sequence b_n generated by user *n* is spread with the channelization codes to chip rate of *3.84Mcps*. The channelization codes in WCDMA uplink are orthogonal variable spreading factor (OVSF) codes which are derived from Walsh-Hadamard codes.

To maintain separation among different mobile stations, the users' information is scrambled with Gold codes. The scrambled sequence is then passed through a square root raised cosine pulse shaping filter with a roll-off of 0.22. The digital signal is converted then to analog and modulated onto an analog carrier for transmission. Assuming that there are *N* active users transmitting signals in the uplink of WCDMA system. The transmitted signal $s_n(t)$ of the *nth* user can be written as [6]:

$$s_n(t)=\sqrt{2p_n}b_n(t)a_n(t)\cos(\omega_c t+\phi_n) \qquad (1)$$

where $b_n(t)$ is the *nth* user's binary data sequence, $a_n(t)$ is a Walsh-Hadamard sequence, p_n is the power of the transmitted signal, ω_c is the carrier angular frequency and ϕ_n is the phase angle of the *nth* carrier. The *nth* user's data signal is a sequence of unit amplitude rectangular pulses of duration T_b, taking values from $\{-1, \quad +1\}$ with equal probability. The *nth* data sequence can be expressed as

$$b_n(t)=\sum_{j=-\infty}^{\infty} b_j^n pT_b(t-jT_b) \qquad (2)$$

where $pT_b = 1$, for $0 \le t \le T_b$,

$pT_b = 0$, elsewhere.

The spreading signal can be expressed as

$$a_n(t)=\sum_{t=-\infty}^{\infty} a_i^n \varphi(t-iT_c) \qquad (3)$$

where $\varphi(t)$ is a chip waveform that is time-limited to $[0, \quad T_c]$ and T_c is the chip period. The *ith* chip of the *nth* user denoted as a_i^n assumes values from $\{-1, \quad +1\}$.

B. Channel Model

The propagation channel $h_n(t)$ between the *nth* user and the base station is assumed to be a Raleigh fading multipath channel. The channel is also assumed to be frequency selective in which the chip rate $1/T_c$ is greater than the channel coherence bandwidth. Thus the delay difference between any two different paths is greater than the chip duration, T_c. Using the vector channel impulse response model, the received signal at the *mth* antenna element can be written as

$$x_n(t)=\sum_{n=1}^{N}\sum_{l=1}^{L} h_n(t)s_n(t-\tau_{n,l})+n(t) \qquad (4)$$

where $h_n(t)$ is the channel impulse response between user *n* and antenna element *m*, $s_n(t)$ is the *nth* user's transmitted signal and $n(t)$ is the Additive White Gaussian noise at the antenna element.

C. Receiver Model

The major goal of this research work is to develop and investigate a simple wideband-CDMA receiver that combines adaptive beamforming with Rake receiver in a multipath fading propagation channel. Fig. 3 shows the conventional way to combine a Rake receiver with adaptive antenna [7].

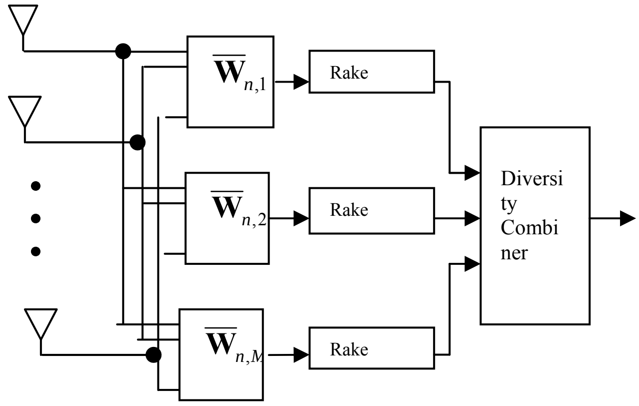

Fig. 3: Conventional Adaptive Antenna system and Rake Receiver

A major drawback of this arrangement is the high computational complexity and the hardware complexity of the system.

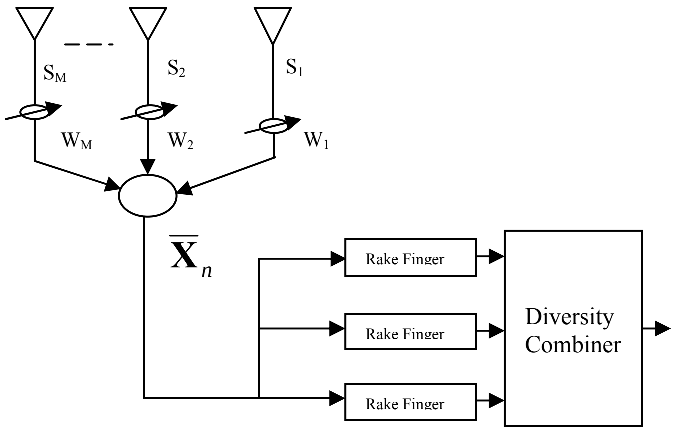

Fig. 4: Adaptive Antenna system and Rake Receiver

Our proposed adaptive beamformer-Rake receiver consists of a beamformer followed by an *L-finger* Rake combiner so that the different Rake fingers receive signals from a common beamformer. The aim is to use one weight vector for all the multipath components instead of using a different weight vector for each Rake finger. A conceptual model of the proposed adaptive receiver is shown in Fig. 4. The proposed adaptive receiver consists of an adaptive beamformer and a Rake combiner. The adaptive beamformer utilizes the spatial signature of the received multipath signal to form optimum weights so that the desired signal can be constructively enhanced. The optimum weights can be computed using any of the reference signal-based adaptive beamforming algorithms. After applying the optimum weights on the antenna array outputs, the resulting baseband signal is used by the Rake receiver in time diversity. After aligning, despreading and combining of multipaths by the Rake receiver, symbol estimation is done to get the final output signal from the receiver.

The functional block diagram of the proposed adaptive beamformer-Rake receiver is shown in Fig. 5. The proposed receiver consists of a beamformer and adaptive beamforming algorithm, a channel estimator, a *4-finger* Rake combiner and a carrier synchronization circuit.

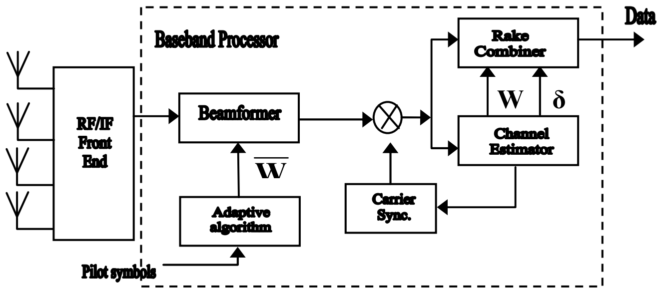

Fig. 5: Block diagram model of proposed adaptive

The beamformer uses an *M-element* uniform linear array (ULA) antenna $m = 3,\ 4,\ 5,\ 8$ to gather signals from the mobile stations. After receiving the signal at the antenna elements, a beamforming algorithm is applied which enhances the desired signal with respect to interfering signals. The channel estimator is used to generate per symbol period, delays and phases that correspond to four most significant transmission paths in the multipath channel from the mobile station to the base station. The Rake combiner takes in the delays and weights estimated by the channel estimator and use the maximal ratio combining method to generate the receiver outputs.

To reconstruct the signal of user *n*, the total received signal is multiplied by a weight vector $\overline{\mathbf{W}}_n$:

$$Y(k) = \overline{\mathbf{W}}_n^H \overline{\mathbf{X}}(k) \qquad (5)$$

The weight vector $\overline{\mathbf{W}}$ can be determined by maximum signal-to-interference plus noise ratio (SINR) optimization algorithm or using an adaptive beamforming algorithm [8].The maximum SINR beamforming antenna array is usually referred to as the conventional or fixed weight beamformer [9].

Using the maximum SINR optimization algorithm, the optimum weight vector $\overline{\mathbf{W}}_{opt}$ for uniform linear array (ULA) beamformer was computed in [10] as:

$$\overline{\mathbf{R}}_{\mathbf{d}} = \frac{\overline{\mathbf{W}}^{\mathbf{H}}.\overline{\mathbf{R}}_{\mathbf{d}}.\overline{\mathbf{W}}}{\overline{\mathbf{W}}^{\mathbf{H}}.\overline{\mathbf{R}}_{\mathbf{u}}.\overline{\mathbf{W}}}.\overline{\mathbf{R}}_{\mathbf{u}}.\overline{\mathbf{W}} = SINR.\overline{\mathbf{R}}_u.\overline{\mathbf{W}}_{opt} \qquad (6)$$

Where $\overline{\mathbf{R}}_d$ and $\overline{\mathbf{R}}_u$ are the correlation matrices for the desired signal and the undesired signal respectively.

The conventional beamforming approach is assumed to apply to fixed arrival angle emitters. In mobile communication where there are many users sharing the same frequency channel such as in WCDMA systems and where the signal environment is highly time varying and the desired arrival angles change with time, it is necessary to devise an optimization scheme that adaptively calculates the optimum array weights. The adaptive beamforming algorithm must allow for continuous adaptation to an ever-changing electromagnetic environment. Several adaptive beamforming algorithms have been proposed in literature for DS-CDMA based systems [11]. Most of the adaptive beamforming algorithms can be categorized under two classes according to whether training signal is used or not: non-blind and blind adaptive beamforming algorithms. Direct Matrix Inversion (DMI), Least Mean Square (LMS), Normalized Least Mean Square (NLMS) and Recursive Least Square (RLS) algorithms are categorized as non blind algorithms [9]. Blind algorithms do not require any training sequence to update its complex vector. Constant Modulus Algorithm (CMA) and Spectral Self-Coherence Restoral (SCORE) algorithms are examples of blind beamforming algorithms. These algorithms use some of the known properties of the desired signal.

A systematic comparison of the performance of different Adaptive Algorithms for beamforming for adaptive array antenna is extensively studied in [9]. Two training sequence-based adaptive algorithms; Least Mean Square and Direct Matrix Inversion are considered in this paper. The main advantage of the training signal algorithm is the faster convergence rate. They can be applied to WCDMA communication system because a pilot signal is presented in the structure of the uplink WCDMA frame of UMTS/IMT 2000 physical channel [12]

The Least Mean Square (LMS) algorithm is the simplest and most widely used adaptive algorithm that is well suited for continuous transmission system. The LMS algorithm is based on the steepest decent method that adapts the weights sample by sample towards the optimum weight vector. The fundamental equations of the basic LMS algorithm are as follows:

output: $$Y(k) = \overline{\mathbf{W}}^H(k)\overline{\mathbf{X}}(k) \qquad (7)$$

error: $$\varepsilon(k) = d(k) - Y(k) \qquad (8)$$

weight: $$\overline{\mathbf{W}}(k+1) = \overline{\mathbf{W}}(k) + \mu\overline{\mathbf{X}}(k)\varepsilon^*(k) \qquad (9)$$

where

$\overline{\mathbf{W}}(k)$: $M \times 1$ complex array weight vector

$\overline{\mathbf{W}}(k+1)$: $M \times 1$ weight vector computed at iteration *k+1*

M: number of antenna elements in the adaptive antenna array

k: time index (sampling instants $(1,\ .\ .,\ K)$

K: maximum number of iterations

$\varepsilon(k)$: complex error

$d(k)$: sequence of reference signal or training symbols

The constant μ is the LMS adaptive step size which is related to the rate of convergence; in other words, how fast the LMS algorithm reaches steady state. The smaller the step size the longer it takes the LMS algorithm to converge. Stability and convergence of the LMS algorithm is insured provided that the following condition is met [9]:

$$0 \le \mu \le \frac{1}{2\lambda_{\max}} \qquad (10)$$

Where $\lambda_{\max}$ is the maximum eigenvalue of the input signal covariance matrix $\overline{\mathbf{R}}_X$. Since $\overline{\mathbf{R}}_X$ is an autocorrelation matrix with all positive eigenvalues, the condition in equation (6) can be approximated as:

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$$0 \le \mu \le \frac{1}{2Trace\left(\overline{\mathbf{R}}_X\right)} \tag{11}$$

The direct matrix inversion (DMI) algorithm alternatively known as sample matrix inversion is a block adaptive approach in which the received signal is divided into short segments. If a prior information about the desired and interfering signals are known, then the optimum weight vector corresponding to each *K-samples* can be computed directly using the optimum Wiener solution given by:

$$\overline{\mathbf{W}}_{\mathbf{opt}} = \overline{\mathbf{R}}_{\mathbf{X}}^{-1}\overline{\mathbf{P}} \tag{12}$$

where $\overline{\mathbf{R}}_X = E\left\{\overline{\mathbf{X}\mathbf{X}^H}\right\}$ and $\overline{\mathbf{P}} = E\left\{d^*.\overline{\mathbf{X}}\right\}$ are the covariance matrix and the cross-correlation matrix respectively.

However, in practice signals are not known and the signal environment keeps changing. Therefore optimum weights can be computed from the estimates of the covariance matrix $\overline{\mathbf{R}}_X$ and the cross-correlation matrix $\overline{\mathbf{P}}$, by calculating the time average from a block of input data [13]. The estimates of the matrices over a block of *K-samples* are given by:

$$\hat{\mathbf{R}}_X = \frac{1}{K}\sum_{k=1}^{K} \overline{\mathbf{X}}(k)\overline{\mathbf{X}}^H(k) \tag{13}$$

$$\hat{\mathbf{P}} = \frac{1}{K}\sum_{k=1}^{K} d^*(k)\overline{\mathbf{X}}^H(k) \tag{14}$$

where K is the observation interval (block length).

The weight vector can now be estimated by the following equation:

$$\overline{\mathbf{W}} = \hat{\mathbf{R}}_{\mathbf{X}}^{-1}\hat{\mathbf{P}} \tag{15}$$

The direct matrix inversion has fast convergence behaviour. However, because its speedy convergence is achieved through the use of matrix inversion, the direct matrix inversion algorithm is computationally intensive and a very challenging task even with today's powerful digital signal processors. Moreover, the direct matrix inversion algorithm uses block adaptation approach for which it is required that the signal environment does not change significantly during the course of block acquisition.

The Least Mean Square algorithm is the simplest adaptive algorithm that is well suited for continuous transmission system. However, the convergence of the algorithm depends on the eigenvalue spread of the covariance matrix. When the covariance matrix has large eigenvalue spread, the algorithm converges very slowly. For rapidly changing signal characteristics such as the WCDMA signal, the LMS algorithm may not allow satisfactory tracking of the desired signal. In this paper, we proposed a technique to accelerate the convergence of the LMS algorithm through the use of DMI algorithm in the weight vector initialization.

In the basic least mean square algorithm, the array weight vector $\overline{\mathbf{W}}(k)$ is initialized arbitrarily, and updated in the next step using equation (9). The initial weights vector to be used in the LMS update equation (9) can be found using the direct matrix inversion algorithm and taking only the first few samples of the incoming data signal.

Using the direct matrix inversion algorithm, the initial weight vector $\overline{\mathbf{W}}(0)$ to be used in the LMS update equation is computed as:

$$\overline{\mathbf{W}}(0) = \hat{\mathbf{R}}_X^{-1}(0)\hat{\mathbf{P}}(0) \tag{16}$$

The estimates of the covariance matrix and cross-correlation vector are given by:

$$\hat{\mathbf{R}}_X(0) = \sum_{k=1}^{b} \mathbf{X}[k]\mathbf{X}^H[k] \tag{17}$$

$$\hat{\mathbf{p}}(0) = \sum_{k=1}^{b} \mathbf{X}[k]d^*[k] \tag{18}$$

where b represents the first few samples or small block of the incoming data.

The final weight vector is updated using the LMS update equation. The optimum weight computation using this modified least mean square algorithm can be implemented as follows:

compute initial vector: $\overline{\mathbf{W}}(0) = \hat{\mathbf{R}}_X(0)\hat{\mathbf{P}}(0)$

output: $Y(k) = \overline{\mathbf{W}}^H(k)\overline{\mathbf{X}}(k)$

error: $\varepsilon(k) = d(k) - Y(k)$

weight vector at time instant *k+1*: $\overline{\mathbf{W}}(k+1) = \overline{\mathbf{W}}(k) + \mu\overline{\mathbf{X}}(k)\varepsilon^*(k)$

The weight initialization as given in equation (16) is not any arbitrary value but an estimate of the optimum value computed by the direct matrix inversion algorithm. After an estimate of the initial weights is made using the direct matrix inversion algorithm, the modified – LMS algorithm uses a continuous approach to adapt itself to the changing signal environment by updating the weights for every incoming sample, hence it is well suited for continuous transmission systems such as WCDMA mobile communication systems.

III. MATLAB/SIMULINK IMPLEMENTATION OF COMBINED ADAPTIVE BEAMFORMER-RAKE RECEIVER

Simulation model of the combined adaptive beamformer-Rake receiver for WCDMA uplink was implemented as Simulink blocks. Simulink was chosen primarily for its collection of several application-specific blocks that support different design disciplines, and specific to this work, a real world WCDMA model in the form of a complete UMTS WCDMA system operating over a multipath fading channel. However, our major design effort in this work among others is the creation of new blocks that implement the different modules of a combined adaptive beamforming and Rake receiver system.

The different components of the system are obtained from different Simulink libraries including models defined using Matlab Embedded functions. All Matlab Embedded functions used in this model are created from Matlab m-files which have been developed to implement the maximum SINR beamforming, standard LMS adaptive beamforming and modified-LMS adaptive beamforming algorithms.

The Simulink model can be divided into four main modules: transmitter, channel, receiver and control/display.

A. *Transmitter Module*

At the transmitter of each user, random data were generated using BPSK modulation. The information was then spread and sent over the channel. To simulate multiple users on the system, an interfering user module was created. The combined use of the Simulink "Enable" and "Constant" blocks defines and regulates the number of simulated users accessing the system. Twenty users were modeled by defining a vector E(1) representing the number of users transmitting simultaneously, Fig. 6.

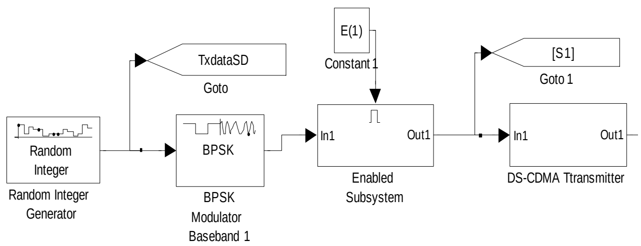

Fig. 6: WCDMA Transmitter in Simulink

B. *Channel Module*

The channel module is based on the Simulink Rayleigh fading and the additive white Gaussian noise (AWGN) blocks, see Fig. 7. The Simulink Rayleigh fading channel block parameter field enables the manipulation of the "Maximum Doppler shift", "Sample time", "Delay vector", "channel Gain", and the "Initial seed" parameters. Radio Propagation Simulator (RPS) – a ray tracing program developed by Radioplan GmbH of Germany is used to obtain the channel data used in this simulation. The simulation area is the area around the Awka-005 base station of Visafone. This base station is located in a suburban environment.

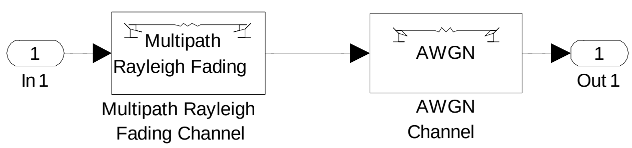

Fig. 7: Simulink Rayleigh fading and AWGN channel

C. *Receiver Module*

The receiver module was implemented by creating two subsystems, an adaptive beamformer subsystem and a Rake combiner subsystem. The adaptive beamformer subsystem is created using Matlab Embedded functions for the maximum SINR beamforming, basic LMS adaptive beamforming and modified-LMS adaptive beamforming algorithms.

The Rake combiner subsystem is obtained from a Simulink demo available in commspreading_randbpsk2ump of Matlab 7.4.0.

D. *Display and Control Module*

The performance criterion used to quantify the performance of the proposed combined adaptive receiver is the Bit-Error-Rate (BER). The performance of the proposed adaptive beamformer-Rake receiver is evaluated for multipath Rayleigh fading wireless channels.

The Control/Display Module consists of the "Set Model Parameters" and the "BER Results Display". The simulation parameter values are summarized in Table 1.

Table 1: Link-level simulations input parameters

Power control	Perfect
RF frequency	1.9GHz
Chip period	$T_c = 1 / 3.84 \times 10^6$ sec
Modulation	BPSK
Spreading codes	OVSF
Scrambling codes	Gold
Channel	Rayleigh fading
	Delay vector: $[0 \quad T_c \quad 2T_c \quad 5T_c]$
	Gain vector (dB): $[0 \quad -5 \quad -10 \quad -20]$
	Doppler shift: 100Hz
	Noise: AWGN

IV. SIMULATION AND PERFORMANCE EVALUATION

The performance of the proposed adaptive beamformer-Rake receiver is evaluated for multipath Rayleigh fading wireless channels. The performance criterion used to quantify the performance of the proposed adaptive receiver in WCDMA base station is the Bit-Error-Rate (BER) for set values of Energy per bit to noise power spectral density ratio $\left(E_b / N_o\right)$. BER is a performance measurement that specifies the number of bit corrupted or destroyed as they are transmitted from its source to its destination in a digital communication system.

To ensure statistically valid performance results in reasonable simulation time a simulation run is defined as the transmission and reception of 100 symbols. The bit error rate values from a set value of the ratio of bit energy to noise spectral density $\left(E_b / N_o\right)$ is collected for 10 simulation runs, then the average BER is calculated. This procedure ensures that the bit error rate performance of the system represents an average measure of the system performance and is not conditioned on a particular state of the system.

In addition to the bit error rate performance of the system for the different adaptive beamforming algorithms, we investigated the bit error rate performance of the system for different number of antenna elements.

A. BER Performance for Rake-only Receiver

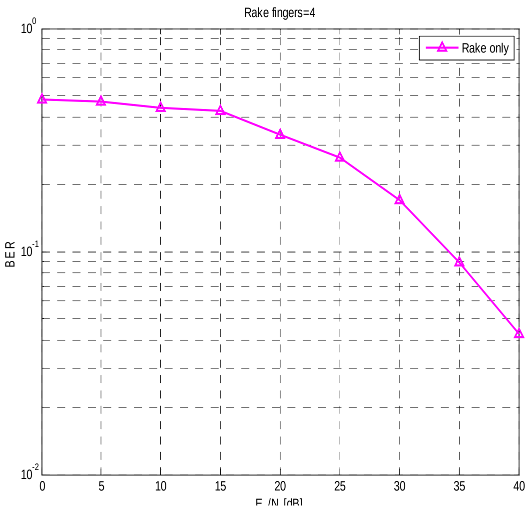

Fig. 8: BER performance for Rake only

Fig. 8 shows a plot of mean bit error rate (BER) versus E_b/N_o for *4-finger* Rake- only receiver. In this simulation, 20 users are assumed and a user sends a total of 100 symbols. The symbols are modulated by BPSK, and then the data are spread by Walsh code and scrambled by Gold code with processing gain of 8. The maximum Doppler frequency considered is $f_d = 100Hz$, corresponding to a fast vehicular channel. In the Rake-only receiver, no spatial processing is adopted only one omnidirectional antenna is used. Maximal ratio combining is used in the Rake.

B. BER Performance: Conventional Beamformer plus Rake Receiver

Fig. 9 shows the performance improvement with conventional beamforming algorithm. In this simulation, an active user sends a total of 100 symbols. Then the data are spread by Walsh code and scrambled by Gold code with processing gain of 8. Maximum Doppler frequency considered is $f_d = 100Hz$, corresponding to a fast vehicular channel. In the receiver, a uniform linear antenna array, with four antenna elements $M = 4$ and inter-element spacing $d = 0.5\lambda$ is employed. Conventional beamforming is employed for spatial processing. Maximal ratio combining *4-finger* Rake is used.

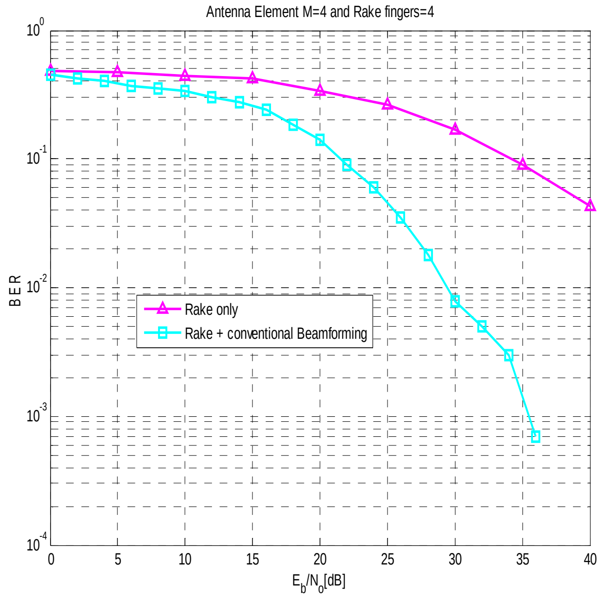

Fig. 9: BER performance Conventional Beamforming plus Rake Receiver

Spatial processing with the conventional beamforming algorithm has remarkable improvement on the receiver BER performance. In Fig. 9, at $E_b/N_o \le 30dB$, the average BER of Conventional Beamforming algorithm and Rake is of the order of $10^{-2.0}$.

C. BER Performance: LMS-based Adaptive Beamformer plus Rake Receiver

Fig. 10 shows the comparison of the receiver average BER performance for conventional beamforming algorithm and LMS adaptive algorithm, and shown in Fig. 11 is the comparison of the receiver BER performance for conventional beamforming algorithm, LMS adaptive algorithm, and modified-LMS algorithms.

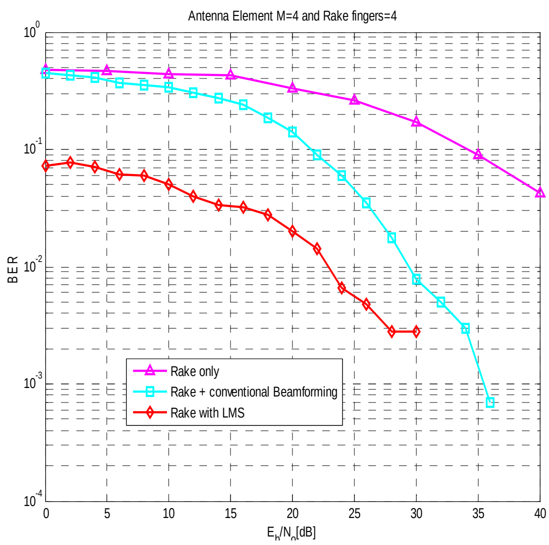

Fig. 10: Receiver BER performance: LMS Based –Adaptive Beamformer plus Rake Receiver

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While the average receiver BER is improved with the LMS adaptive beamforming compared to the conventional beamforming algorithm, there is remarkable improvement in the BER performance of modified-LMS compared to the LMS adaptive algorithm. The BER rate of the modified-LMS at $E_b/N_o \leq 10dB$ is of the order of 10^{-2}. The improvement in the BER performance of the modified-LMS is due to the faster convergence by the modified-LMS even in rapidly varying channels.

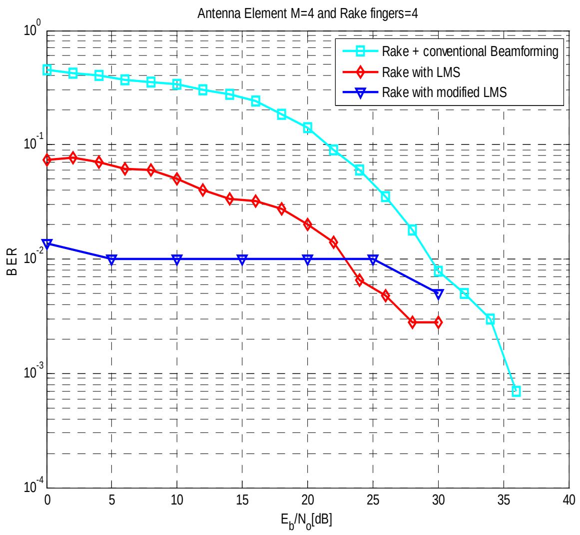

Fig. 11: Receiver BER performance: Modified LMS Based –Adaptive Beamformer plus Rake Receiver

V. Conclusion

In this paper, the BER performance of WCDMA baseband receiver with different beamforming algorithms for spatial filtering, Rake receiver for multipath fading mitigation and for different number of antenna elements are investigated using purpose-made Simulink model. The results show the importance of the space-time processing techniques to WCDMA system.

According to the standard base station testing specification [14], the required BER performance for convolution-coded information bits is 10^{-3}. Since simulation results show uncoded BER performance of the order of 10^{-2} at $E_b/N_o \leq 10dB$, the proposed adaptive receiver can provide satisfactory BER performance under Rayleigh fading channels.

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