IEEE Vehicular Technology Conference, pp. 2048-2052, October 2001, Atlantic City, New Jersey

Performance of Smart Antennas with Adaptive Combining at Handsets for the 3GPP WCDMA System

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***Abstract* - We present the performance gain of dual smart antennas with an adaptive combining at handsets for the 3GPP WCDMA system. The adaptive algorithm based on the normalized least-mean-square (N-LMS) algorithm is employed, in which antenna weights are recursively obtained. To obtain the channel profile, we adopted the GBSB (geometrically based single bounce) elliptical and circular models. The simulation results show that the dual smart antenna system with the adaptive combining performs better than a single antenna system and its performance gain is 3.3 dB for the GBSB elliptical model at BER = $5x10^{-2}$ and 5.5 dB for the GBSB circular model. The higher performance gain is achieved as the mobile velocity decreases.**

I. INTRODUCTION

Smart antenna not only combats multipath fading, but also suppresses interference signals. When spatial signal processing achieved through smart antenna is combined with temporal signal processing, the space-time processing can repair signal impairments to result in a higher network capacity, coverage, and quality [1]. When compared with the conventional single antenna system, a smart antenna system requires additional antennas and circuitry to process multiple antenna signals. The additional antennas and circuitry result in higher cost and more power consumption.

Smart antenna techniques have been considered mostly for base stations so far because of high system complexity and high power consumption. Recently, smart antenna techniques have been applied to mobile stations or handsets [2],[3]. Also, one of the third generation wireless personal communication systems, 3GPP (third generation partnership project) WCDMA (wideband CDMA) system [4], requires antenna diversity at base stations and optionally at mobile stations. Due to the compact size and stringent cost of handsets and the limited battery capacity, smart antennas at handsets should have low circuit complexity and low power dissipation. To justify employing smart antenna techniques at handsets, the performance gain should be large enough to offset the additional cost and power consumption.

The signal transmitted from the base station is the superposition of all active users' signals and control signals for the 3GPP WCDMA system. The desired user signal and multiple access interferences (MAIs) traverse the same paths, but they are inherently orthogonal to each other. So it does not pose a serious problem at handsets. A multipath signal is effectively an interference signal to another multipath signal. However, a rake receiver can manage multipath signals to its advantage to improve the performance. Another source of interference in the downlink is coming from adjacent cells (inter-cell interference), which can have a substantial impact on the performance. Note that the latter case is evident when the soft handover is occurred. Since the number of adjacent base stations and hence the number of interference signals from those base stations is small, a dual antenna system is a good candidate to combat such interference. It should be noted that a receiver with M antennas can suppress M-1 interferences.

In [5], we showed that smart antennas with a diversity combining scheme at handsets for the cdma2000 system improve the performance (reduction of the frame error rate) by from 1.7 dB to as high as 12.7 dB depending on the correlation of the dual antenna signals. We also showed that smart antennas with an adaptive combining scheme at handsets for the cdma2000 system improve the performance (reduction of the frame error rate) by from 0.8 dB to 2.2 dB depending on the mobile velocity [6].

In this paper, we investigated a dual smart antenna system incorporated into handsets for the 3GPP WCDMA system and present simulation results on the performance gain for an adaptive combining. The adaptive combining method based on the normalized least-mean-square (N-LMS) algorithm [7],[8] is applied, in which antenna weights are recursively obtained to minimize the mean square error. The major benefits of the N-LMS algorithm are its simplicity compared to other adaptive algorithms and fast convergence rate compared to the original LMS algorithm [7]. To reduce the simulation time while considering various operating conditions, we did not include the channel encoding and the channel decoding for the WCDMA system. In addition, to obtain the channel profile, we adopted statistical channel models known as GBSB (geometrically based single bounce) elliptical and circular models [9],[10] in the simulation.

The paper is organized as follows. The channel model employed for our simulation and the downlink of the 3GPP WCDMA system are briefly described in Section II. The adaptive algorithm to compute the antenna weights is presented in Section III. The system setup for simulation and the simulation results are provided in Section IV. Finally, Section V concludes the paper.

II. Channel Model and 3GPP WCDMA System

We assume that the dual antennas at a handset are identical, omnidirectional, and separated with a quarter wavelength of the carrier. For a wireless channel model, three components are considered for a typical variation in the received signal level [11]. The three components are mean path loss, lognormal fading (or slow fading), and Rayleigh fading (or fast fading). Since the change of a signal level due to the lognormal fading is insignificant for each simulation period, it is not included in our channel model. A channel model also should consider spreads such as delay spread due to multipath propagation, Doppler spread due to mobile motion, and angle spread due to scatter distribution. We consider the spatially correlated fading channel model (SCFCM) in this paper. In the SCFCM, each antenna signal is subject to the same Rayleigh fadings, but is different in phase due to a non-zero angle of arrival (AOA). Each multipath signal is assumed to have the same arrival time for the two antennas. The illustration of the SCFCM is available in [12].

To obtain the channel profile (such as delay, average power, and angle of arrival of each multipath signal), we adopted a geometrically based channel model known as GBSB (geometrically based single bounce) elliptical and circular models in our simulation [9],[10]. The GBSB elliptical model is applicable for microcell environments found in urban areas, while the GBSB circular model for macrocell environments found in rural or suburban areas. It is assumed in the GBSB models that multipath signals are created by single reflections of scatters which are uniformly distributed in a predefined elliptical or circular geometry. Delays, average power levels, and angles of arrival (AOAs) of each multipath signal are determined from the locations of scatters. The detailed description of the GBSB elliptical and circular models are available in [10] and the procedure to obtain a channel profile in our simulation is also available in [12].

The block diagram of a downlink transmitter considered in our simulation is shown in Fig. 1. Each bit of physical channels (PCH) is QPSK (quadrature phase shift keying) modulated. The modulated I (in-phase) and Q (quadrature) bits are channelized by multiplying OVSF (orthogonal variable spreading factor) codes at the chipping rate of 3.84 Mcps. All channelized signals are combined first and then scrambled by a complex long code, which is generated from the Gold code set. The scrambled signal is pulse-shaped by a root-raised cosine FIR filter with a roll-off factor of $\alpha = 0.22$. The shaped signal is transmitted through the wireless channel.

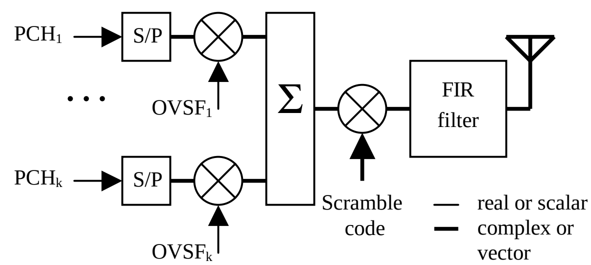


Fig. 1. Block Diagram of a Downlink Transmitter

III. Adaptive Algorithm

The most widely used adaptive algorithm is based on the least-mean-square (LMS) algorithm, in which antenna weights are recursively obtained to minimize the mean square error [7]. If the step size is chosen properly, the algorithm guarantees the convergence of the antenna weights. The major benefit of the LMS algorithm lies in its simplicity compared to other adaptive algorithms. The LMS algorithm, however, suffers from a gradient noise amplification problem for large input signals. To circumvent the problem, the normalized LMS (N-LMS) algorithm rather than the original LMS algorithm is usually used in practice. The N-LMS algorithm exhibits a faster rate of convergence than the original LMS algorithm for both uncorrelated and correlated input data [7].

Since each user sends its pilot signal to the base station periodically, a special channel estimation scheme (such as the weighted multi-slot averaging method [13]) is necessary for the base station to take care of non-continuous pilot signals. In contrast, each user receives the continuous common pilot (CPICH) signal from the base station. This pilot signal can be used for the adaptive combining as well as for a phase reference in the coherent combining. The pilot signal is used in the N-LMS algorithm for our smart antennas at handsets. Like any adaptive combining, the key aspect of the N-LMS algorithm is to compute the weights of antenna signals, and it is explained below for the case of two antennas. New antenna weights $\omega^{(j)}_m(n+1)$ are computed as follows.

$$\omega^{(j)}_m(n+1) = \omega^{(j)}_m(n) + \mu \left(y^{(j)}_{0,m}(n) \Big/ \sum_{j=1}^{2} | y^{(j)}_{0,m}(n)|^2 \right) e^{*}_{0,m}(n), \quad (1)$$

where $\omega^{(j)}_m$ is the antenna weight for the m_{th} multipath on the j_{th} antenna, $y^{(j)}_{0,m}(n)$ is the despread pilot signal (where spreading factor is 256) for the m_{th} multipath on the j_{th} antenna, μ is the step size in the range of $0 < \mu < 2$, and $e_{0,m}(n)$ is the error signal. To compute the error signal $e_{0,m}(n) = \check{z}_{0,m}(n) - z_{0,m}(n)$, the desired reference pilot signal $\check{z}_{0,m}(n)$ and the combined pilot signal $z_{0,m}(n)$ are required. The combined pilot signal $z_{0,m}(n)$ for the m_{th} multipath is obtained using the pilot signals $y^{(j)}_{0,m}(n)$ from each antenna and the previously obtained antenna weights $\omega^{(j)}_{m}(n)$ such that

$$z_{0,m}(n) = \sum_{j=1}^{2} y^{(j)}_{0,m}(n)\,\omega^{(j)}{}_{m}^{*}(n). \tag{2}$$

For the desired reference pilot signal, we assume that the pilot signals from each antenna are combined in a fully constructive manner. The desired reference pilot signal $\check{z}_{0,m}(n)$ is obtained by averaging the despread pilot signal such that

$$\check{z}_{0,m}(n) = (1+\mathrm{i})\,\frac{\sum_{l=0}^{Q-1}\left(\left|y^{(1)}_{0,m}(n-l)\right| + \left|y^{(2)}_{0,m}(n-l)\right|\right)}{Q}, \tag{3}$$

where Q is the number of pilot symbols to be averaged and (1+i) is the known transmitted pilot symbol (where i denotes the imaginary unit).

After the antenna weights are obtained, the despread k_{th} user signal for the m_{th} multipath from each antenna is weighted and combined as

$$z_{k,m}(n) = \sum_{j=1}^{2} y^{(j)}_{k,m}(n)\,\omega^{(j)}{}_{m}^{*}(n), \tag{4}$$

where $y^{(j)}_{k,m}(n)$ is the despread k_{th} user signal for the m_{th} multipath on the j_{th} antenna and $\omega^{(j)}_{m}$ is the obtained antenna weight. Then, the combined user signal from each multipath $z_{k,m}(n)$ is coherently combined to produce an output as shown below:

$$z_{k}(n) = \sum_{m=1}^{M} z_{k,m}(n)\, z_{0,m}^{*}(n). \tag{5}$$

It is noted that if the spreading factor of the user signal SF_k is smaller than that of the pilot signal SF_0, then the same antenna weights are applied to obtain the SF_0/SF_k successive user signals.

Finally, the antenna weight should adapt fast enough to track the fading of the desired and interfering signals, but it should be much slower than the data rate.

IV. Simulation Setup and Results

Each antenna receives not only the transmitted signal from the desired base station but also the transmitted signals from adjacent base stations. The received signal added with background noise is shaped back with the same FIR filter. Each rake finger despreads a multipath signal from each antenna. There are two rake finger outputs for each multipath signal – despread pilot signal and despread data signal. In a single antenna system, each despread data signal is coherently combined using the despread pilot signal. In a dual antenna system with the adaptive combining scheme, each despread data signal from each antenna is weighted with the antenna weight and combined. The antenna weights are adaptively obtained using the N-LMS algorithm described in Section III. Then the output of each adaptive combiner (AC) is coherently combined using the adaptively combined pilot signal. The considered dual antenna system with the adaptive combining scheme is shown in Fig. 2, in which the AC contains the adaptation logic to compute antenna weights and a combiner of each weighted rake finger output. In our simulation, the coherently combined output of an antenna system (both single and dual antenna systems) is hard decided to either 1 or 0, and compared with the original data bits to evaluate the system performance in terms of bit error rate (BER).

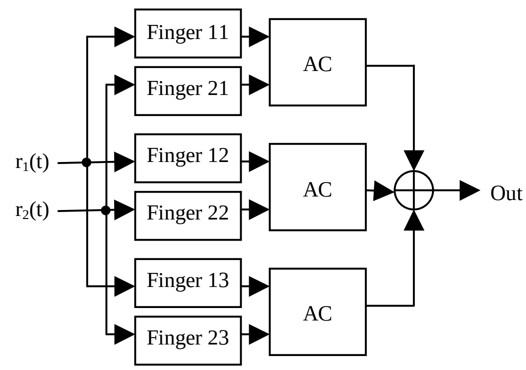
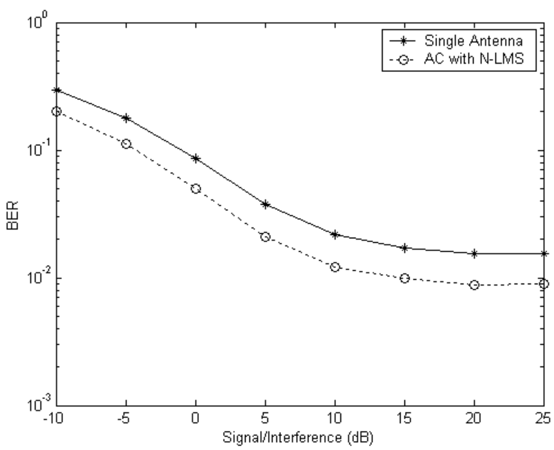


Fig. 2. Rake Receiver for Dual Antenna System with Adaptive Combining

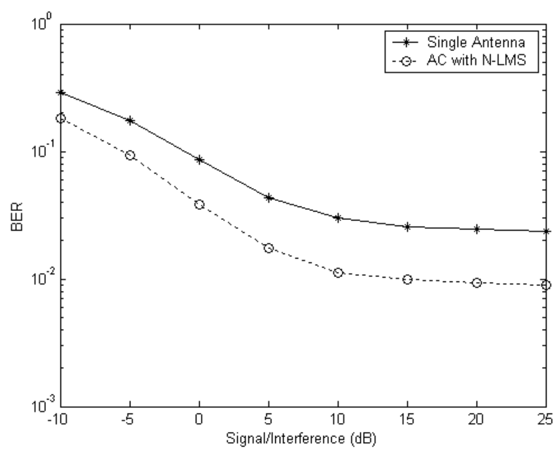
The environment considered in our simulation is as follows. The following model parameters, called *baseline parameters* in this paper, were assumed. The distance from the desired base station to the mobile station is 800 m, and the maximum multipath delay is 20 chips in the GBSB elliptical model. The distance from the desired base station to the mobile station is 2000 m, and the maximum multipath delay is 35 chips in the GBSB circular model. We also assumed that the mobile velocity is 60 km/hr, which results in 119 Hz of Doppler frequency under 2.14 GHz of the carrier frequency, and the distance between two antennas is $\lambda/4$ (= 3.5 cm). Eight users' signals of the spreading factor 32 and the common pilot (CPICH) signal are modulated, channelized, combined, scrambled, pulse-shaped, and transmitted through the channel. 20% of the total transmitted power is allocated to the CPICH, and the remaining 80% of the power is divided equally and allocated to each user signal. Four multipath signals with the channel profile obtained from the GBSB elliptical and circular models arrive at handset antennas. Two multipath signals from an adjacent base station (which is also assumed to transmit the combined signal of eight users' signals and the common pilot signal) and background noise (which results in 25 dB of E_b/N_0) are also added at handset antennas. A rake receiver with three rake fingers is considered at handsets.

The two factors that affect the performance of the N-LMS algorithm are the step size and the number of pilot symbols to be averaged. The step size, $\mu = 0.3$, and the number of pilot symbols, Q = 3, were chosen through trial and error. The three pilot symbol durations correspond to 0.2 ms in the real operation.

The simulation results for the adaptive combining with the GBSB elliptical and circular models are presented in Fig. 3. Fig. 3 (a) and (b) represent the performances of the dual antenna system with the channel profiles obtained from the GBSB elliptical and circular models, respectively. In the figure, the y-axis is the BER and the x-axis is the ratio of the average power of the first multipath signal of the desired base station to the average power of the first multipath signal of the adjacent base station. The solid line represents the BER of a single antenna system. The dotted line represents the BER of a dual antenna system with the adaptive combining. As can be seen from the figure, the dual antenna system with the adaptive combining performs better than a single antenna system for the GBSB elliptical and circular models. The performance gain of the dual antenna system with the adaptive combining over a single antenna system is 3.3 dB for the GBSB elliptical model at BER = $5x10^{-2}$ and 5.5 dB for the GBSB circular model.



(a) BER with the GBSB Elliptical Model



(b) BER with the GBSB Circular Model

Fig. 3. Bit Error Rate with the GBSB Elliptical and Circular Models

We investigated the impact of the mobile velocity on the performance of the dual antenna system with the adaptive combining. We varied the mobile velocity to 2, 10, 30, 60, 90, and 120 km/hr, which results in 4, 20, 59, 119, 178, and 238 Hz of Doppler frequency, respectively, with the GBSB circular model. Note that all the other parameters remain the same as the baseline parameters. The simulation results are given in Fig. 4. The top cluster of the six graphs represents the BERs of a single antenna system with the six mobile velocities. The bottom cluster of the six graphs represents the BERs of the dual antenna system. The simulation results reveal that the dual antenna system performs better than a single antenna system for all the six mobile velocities. It is notable that the impact of the mobile velocity is insignificant for a single antenna system. However, as the mobile velocity decreases, the BER of the dual smart antenna system with the adaptive combining also decreases. As expected, the adaptive combining based on the N-LMS algorithm adapts the antenna weights well as the mobile velocity decreases.

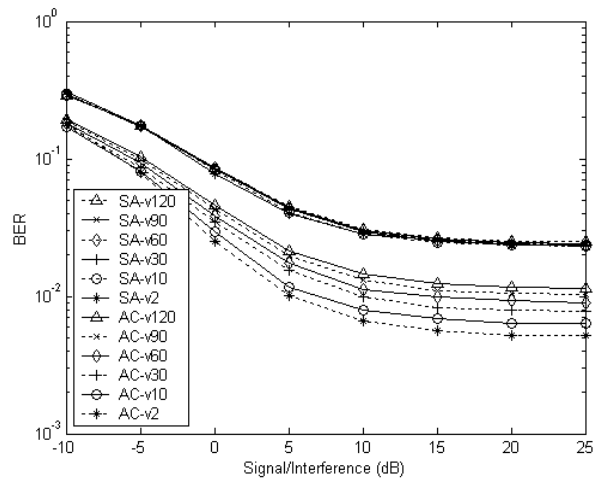


Fig. 4. Bit Error Rates with Various Mobile Velocities

V. CONCLUSION

In this paper, we propose a dual smart antenna system incorporated into handsets for the 3GPP WCDMA system and present simulation results on the performance gain for an adaptive combining. The adaptive combining method based on the normalized least-mean-square (N-LMS) algorithm is applied, in which antenna weights are recursively obtained to minimize the mean square error. To obtain the channel profile, we adopted the GBSB elliptical and circular models. The simulation results indicate that

i) the dual smart antenna system with the adaptive combining performs better than a single antenna system and its performance gain is 3.3 dB for the GBSB elliptical model at BER = $5x10^{-2}$ and 5.5 dB for the GBSB circular model.
ii) As expected, the higher performance gain is achieved as the mobile velocity decreases.

To investigate the impact of individual model parameters and the algorithm parameters on the performance of the smart antennas at handsets, further study in the area is necessary.

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