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PERFORMANCE GAIN OF SMART ANTENNAS WITH DIVERSITY COMBINING AT HANDSETS FOR THE 3GPP WCDMA SYSTEM

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ABSTRACT

In this paper, we propose a dual smart antenna system incorporated into handsets for the 3GPP WCDMA system, in which a diversity combiner combines the two rake receiver outputs using a diversity combining scheme. We considered three diversity combining schemes, selection diversity, square law combining, and equal gain combining (EGC), and two types of the channel model for the dual antenna signals, loosely correlated fading channel model (LCFCM) and spatially correlated fading channel model (SCFCM). To obtain the channel profile, we adopted a geometrically based channel model known as GBSB (geometrically based single bounce) elliptical model in the simulation. The simulation results indicate that i) the EGC scheme performs the best among the three diversity combining schemes and ii) as expected, the higher performance gain is achieved under the LCFCM than the SCFCM. The simulation results under the two channel models are likely to be the lower and the upper bounds for the performance gain of the dual smart antenna system. Our simulation results indicate that a dual smart antenna system with diversity combining at handsets is beneficial for the 3GPP WCDMA system.

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 [2],[3] because of high system complexity and high power consumption. In addition, two (or multiple) antennas at a handset are in proximity, which may reduce the effectiveness of the antenna system. One of the third generation wireless personal communication systems, 3GPP (third generation partnership project) WCDMA (wideband code division multiple access) system [4], requires antenna diversity at base stations and optionally at mobile stations [5]. The feasibility of implementing dual antennas at a mobile handset was investigated in [6]. 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.

Recently, the smart antenna technique has been applied to mobile stations [7]-[9]. For example, the HDR (high data rate) system of Qualcomm employed dual antennas at a mobile station [7]. Each antenna signal is applied to its own rake receiver followed by the maximal ratio diversity combining, which combines the two rake receiver signals. A dual antenna system for handsets was also investigated for the digital European cordless telephone (DECT) system for the indoor radio channel [8]. The dual antenna handset receiver selects one of two signals of the receivers based on the signal-to-interference plus noise ratio (SINR). Each receiver processes a signal that is an equal gain combining of the signal from one antenna and the phase-shifted signal from the other antenna. Wong and Cox proposed a dual antenna system which could be applied to handheld devices as well as base stations [9]. Summing the signals from two antennas with proper weights in complex numbers cancels the dominant interference and hence increases the signal-to-interference ratio (SIR). To compute the antenna weights, a technique to optimize the SIR was proposed. Unlike the above two methods, the signal weighting and summing was implemented at the radio frequency (RF) level instead of at the baseband signal level. Thus, it reduces the complexity of the receiver since it requires only one baseband processor.

Smart antennas may employ two different combining schemes, diversity combining and adaptive combining. The diversity combining scheme exploits the spatial diversity among multiple antenna signals. Thus, the diversity combining achieves higher performance when multiple antenna signals are less correlated. For instance, if each antenna signal undergoes independent fading, the diversity combing scheme would perform well. The adaptive combining scheme adjusts the antenna weights dynamically to enhance the desired signal while suppressing interference signals. Since the adaptive combining scheme aims to add multiple antenna signals constructively, the scheme performs better for correlated antenna signals. Thus, if multiple antenna signals are exactly the same except the phase difference due to a nonzero angle of arrival, the adaptive combining achieves the highest performance.

In [10], we showed that smart antennas with a diversity combining scheme at handsets for the cdma2000 system improve the performance (through 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 (through reduction of the frame error rate) by from 0.8 dB to 2.2 dB depending on the mobile velocity [11].

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 a diversity combining. A diversity combiner combines the two rake receiver outputs using a diversity combining scheme. We consider three diversity combining schemes, i) selection diversity (SD), ii) square law combining (SLC), and iii) equal gain combining (EGC). The SD scheme selects the signal with higher power. The SLC scheme weights each signal by its signal level and adds them according to the formula, $a\frac{|a|}{\sqrt{a^2+b^2}}+b\frac{|b|}{\sqrt{a^2+b^2}}$, where a and b are the two rake receiver outputs. The EGC scheme simply adds two signals with an equal weight of 0.5. We consider two types of the channel model for the dual antenna signals, i) loosely correlated fading channel model (LCFCM) and ii) spatially correlated fading channel model (SCFCM). In the LCFCM, each antenna signal is assumed to have independent Rayleigh fading. However, each antenna signal in the SCFCM is subject to the same Rayleigh fading, and the two signals are different only in phase due to a nonzero angle of arrival. A channel model with less correlated dual antenna signals, which is the LCFCM in our models, is expected to yield higher diversity gain [12]. We believe that the actual channel of dual antenna signals lies in between these two channel models. 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 model in our simulation [13][14]. The GBSB elliptical model is applicable for microcell environments found in urban areas.

The paper is organized as follows. The channel models employed for our simulation are presented in Section 2. The 3GPP WCDMA system is briefly described in Section 3. The system setup for simulation and the simulation results are presented in Section 4. Finally, Section 5 concludes the paper.

II. CHANNEL MODEL

Because the channel model influences the design of receivers and their performance, channel modeling is important when evaluating a smart antenna system. In the uplink of the 3GPP WCDMA system, each user signal is transmitted asynchronously and traverses different paths from a mobile station to the base station. Thus, the main source of interference is coming from other users' signals within the same cell (intra-cell interference). However, in the downlink of the 3GPP WCDMA system, the signal transmitted from the base station is the superposition of all active users' signals and common control signals. The desired user signal and multiple access interferences traverse the same paths, but they are inherently orthogonal to each other. So it dose 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 becomes manifest 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 [15]. As to be described in Section 4, we consider the interference from adjacent cells as additive white Gaussian noises (AWGNs). Thus, only the diversity (rather than adaptive) combining technique was considered to obtain the diversity gain at handsets in our simulation.

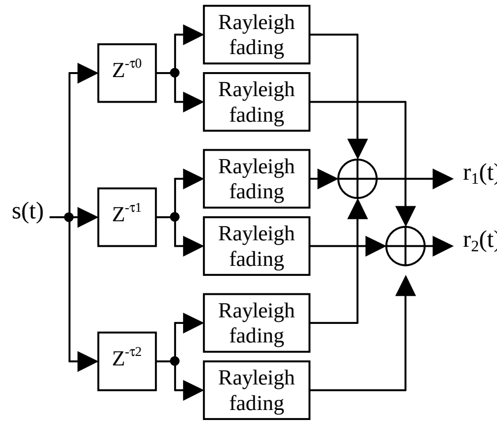
We assume that the dual antennas at a handset are identical, omnidirectional, and separated with a quarter wavelength of the carrier. For a wireless channel model, three components are considered for a typical variation in the received signal level [16]. The three components are mean path loss, lognormal fading (or slow fading), and Rayleigh fading (or fast fading). Since the change of 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, i) delay spread due to multipath propagation, ii) Doppler spread due to mobile motion, and iii) angle spread due to scatter distribution. In addition, we consider two types of the channel model specific to the dual antenna signals, i) loosely correlated fading channel model (LCFCM) and ii) spatially correlated fading channel model (SCFCM). The characteristics of each channel model are summarized in Table 1.

Table 1. Two Types of the Channel Model for a Dual Antenna System

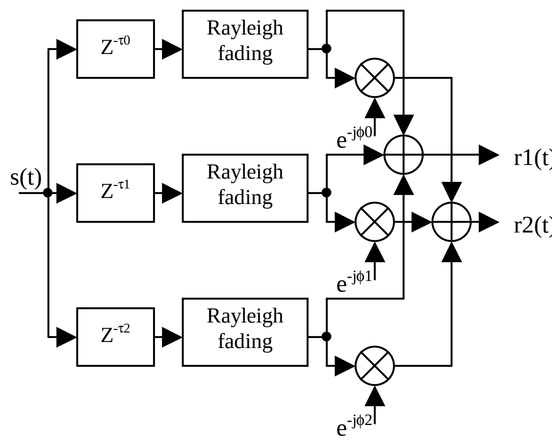
Channel model	Rayleigh fading	Phase difference
LCFCM	Independent	Independent
SCFCM	Same	Independent

Each antenna signal is assumed to have independent Rayleigh fading in the LCFCM. In the SCFCM, each antenna signal is subject to the same Rayleigh fading, but different in the phase due to a non-zero angle of arrival. A channel model with less correlated dual antenna signals, which is the LCFCM in our model, is expected to yield higher diversity gain [12]. We believe that the actual channel of dual antenna signals (for both the diversity combining and the adaptive combining) lies in between these two channel models.

It is assumed that a multipath signal has the same arrival time for the two antennas in the channel model. The two types of the channel model are illustrated in Figure 1. The signal s(t) represents the transmitted signal from the base station in the figure, and signals $r_1(t)$ and $r_2(t)$ represent the two received antenna signals at the mobile station.



(a) Loosely Correlated Fading Channel Model (LCFCM)



(b) Spatially Correlated Fading Channel Model (SCFCM)

Figure 1. Two Types of the Channel Model

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 model in our simulation [13][14]. The GBSB elliptical model is applicable for microcell environments found in urban areas. It is assumed in the GBSB elliptical model that multipath signals are created by single reflections of scatters which are uniformly distributed in a predefined elliptical geometry. Delays, average power levels, and angles of arrival (AOAs) of each multipath signal are determined from the locations of scatters.

In the GBSB elliptical model, a base station and a mobile station are assumed to locate at the foci of an ellipse as shown in Figure 2. The two major parameters of the model are D and τ_m. D is the distance between a base station and a mobile station, and τ_m is the maximum time of arrival (TOA), i.e. maximum delay. The maximum TOA τ_m is used to define the boundary (or a major axis and a minor axis) of the ellipse such that the major axis $a_m = c\tau_m/2$, where c is the speed of light. Related equations with detailed derivations including the joint TOA-AOA probability density function at the mobile station are available in [14]. Due to the symmetry of the geometry with respect to the base station and the mobile station, the joint TOA-AOA probability density function of the mobile station is the same as that of the base station.

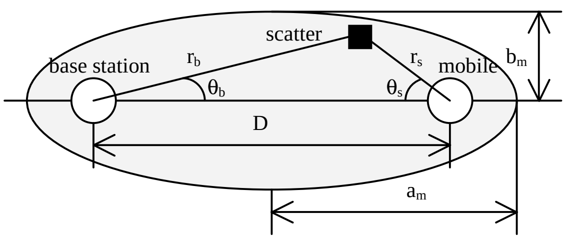
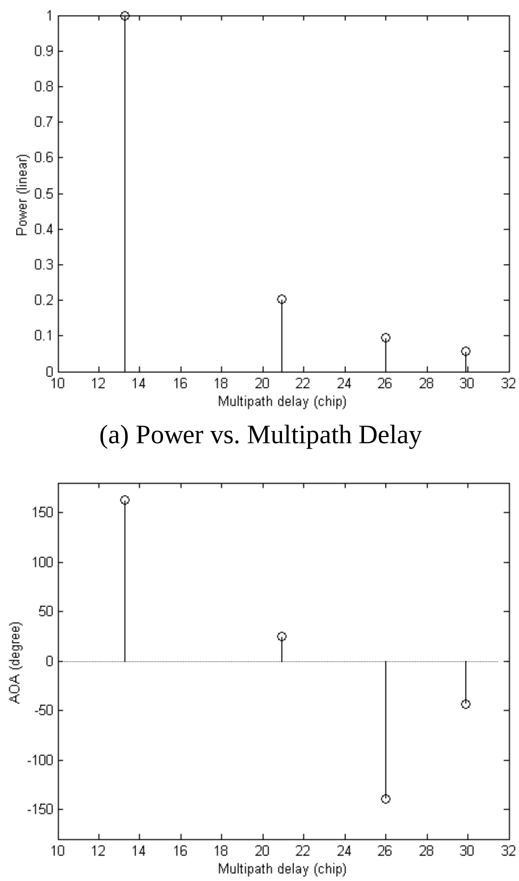


Figure 2. Geometry of the GBSB Elliptical Model

The following procedure is used to obtain a channel profile in our simulation. A scatter is placed randomly within a predefined ellipse. The distance r_b between the base station and the scatter and the distance r_s between the scatter and the mobile station are obtained from the location of the scatter. The propagation delay τ is calculated as $(r_b + r_s)/c$. Then a new scatter is placed randomly and the propagation delay calculated in the same manner. If the difference between the new propagation delay and any existing propagation delay is greater than one chip delay (which is about 260 ns for the 3GPP WCDMA system), then the scatter is selected. Otherwise, the scatter is deleted, as the multipath signal will not be processed by a rake finger. The process repeats until a predefined number of multipaths (or scatters) is achieved. The unit average power P_0 is assigned to the multipath signal with the smallest propagation delay τ_0. The average power of a multipath signal P_i, $i \neq 0$ is calculated using the mean pass loss model [16] such that $P_i = P_0 * (\tau_i/\tau_0)^{-n}$, where τ_i is the propagation delay of the multipath and n is the path loss exponent. We set n to 3.5 in our simulation. The AOA of each multipath signal is obtained from the location of the scatter and the mobile station.

Figure 3 illustrates a channel profile of four multipath signals obtained through the procedure described above. The distance D was set to 800 m and the maximum delay τ_m to 32 chips (equivalently 8.3 μs) in the process. It is observed from the figure that the relative power level of other multipath signals to the first multipath signal is much weaker.



(a) Power vs. Multipath Delay

(b) AOA vs. Multipath Delay

Figure 3. Channel Profiles for the GBSB Elliptical Model

III. 3GPP WCDMA SYSTEM

The code division multiple access (CDMA) technology proliferates as the next generation wireless personal communication systems. There are two proposed wideband CDMA systems as the third generation standard, which meet the ITU (International Telecommunication Union) IMT-2000 (International Mobile Telecommunications) requirements. The first one is the WCDMA (wideband CDMA) system often called Third Generation Partnership Project (3GPP) [4]. The second one is the cdma2000 system. There are two modes for the radio access technologies for the 3GPP WCDMA system, a TDD (time division duplex) mode and a FDD (frequency division duplex) mode. We consider the 3GPP WCDMA system with the FDD mode in this paper. Hereafter, we call the 3GPP WCDMA system with the FDD mode as the 3GPP WCDMA system for brevity.

The block diagram of a downlink transmitter considered in our simulation is shown in Figure 4. Each bit of physical channels (PCH) is QPSK (quadriphase-shift keying) modulated. The modulated I (in-phase) and Q (quadrature-phase) 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 and the unscrambled signal of the synchronization channel (SCH) are combined together. The combined 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.

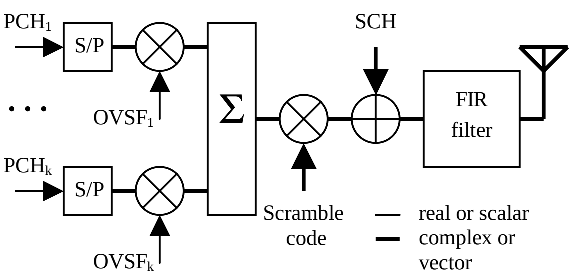


Figure 4. Block Diagram of a Downlink Transmitter

A receiver receives not only the signal transmitted from the desired base station but also the signals from adjacent base stations. The received signal is shaped back with the same root-raised cosine FIR filter. A rake receiver despreads received multipath signals and coherently combines them. The coherent combining of multipath signals necessitates each multipath signal be multiplied by the channel coefficient estimated from the despread common pilot signal. To reduce the simulation time, while considering various operating conditions, we did not include the channel coding and decoding for the 3GPP WCDMA system in our model.

IV. SIMULATION SETUP AND RESULTS

A signal from a base station propagates through the channel. The two types of the channel model described in Section 2 are employed in the simulation. The GBSB elliptical model is adopted to generate the channel profile of multipath signals. The signals received at the dual antennas of a handset are applied to their own rake receivers after pulse shaped by an FIR filter as shown Figure 5. A diversity combiner combines the two rake receiver outputs. Three diversity combining schemes, selection diversity (SD) scheme, square-law combining (SLC) scheme, and equal gain combining (EGC) scheme, were considered in our simulation. In our simulation, the output of a diversity combiner 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). For simplicity, we modeled the interference from adjacent cells as additive white Gaussian noises (AWGNs).

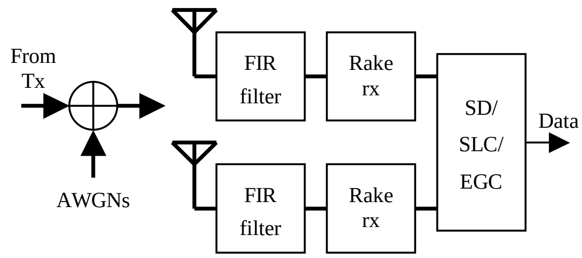


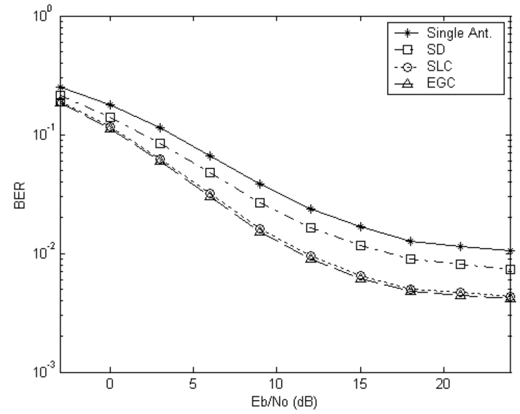
Figure 5. Dual Smart Antenna Receiver with Diversity Combiner

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 32 chips in the GBSB elliptical 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 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 model arrive at handset antennas. A rake receiver with three rake fingers is considered at handsets.

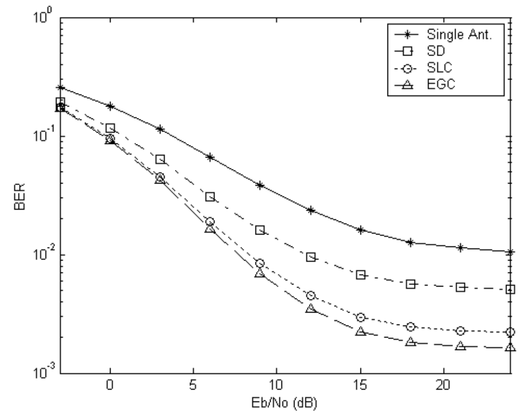
The simulation results with three diversity combining schemes and two types of the channel model are presented in Figure 6. Figure 6 (a) and (b) are the performance of the single and of the dual antenna systems under the SCFCM and the LCFCM, respectively. The y-axis of a plot is the BER, and the x-axis is the ratio of the symbol energy of the first multipath signal to the AWGN. The top graph in each plot is the BER of a single antenna system. The second, the third, and the bottom graphs are the BERs of the dual antenna system with SD, SLC, and EGC diversity combining schemes, respectively. As can be seen from the two figures, the dual smart antenna system always performs better than a single antenna system for both channel models. For the dual smart antennas, the EGC performs the best among the three diversity combining schemes. The performance of the dual smart antenna system with the EGC diversity combining scheme under the two channel models and that of a single antenna system is shown in Figure 6 (c). The performance gain of the dual antenna system with the EGC diversity combining over a single antenna system is 3.1 dB for the SCFCM at BER=10^{-1} and 4.1 dB for the LCFCM. The performance gain increases further with a lower BER. For example, the gain is 4.4 dB for the SCFCM at BER=$3x10^{-2}$ and 6.4 dB for the LCFCM. As expected, the higher performance gain is achieved under the LCFCM than the SCFCM.

It is worth noting that the BER is saturated beyond a certain level of Eb/No for both single and dual antenna systems, i.e., the increase of the transmitter power beyond a certain level fails to further decrease the BER. This is explained as the increased transmitter power increases the signal level of all multipath signals, i.e., the power level of the interference signals.

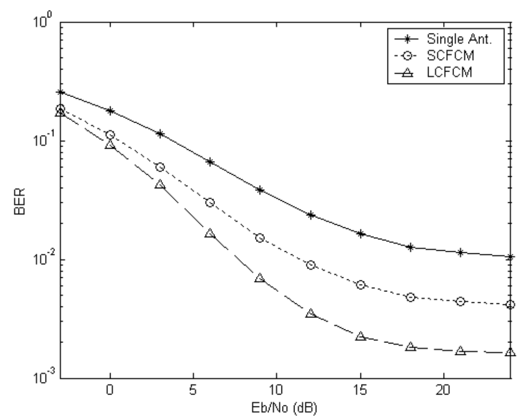
To investigate the impact of individual parameters, we also simulated variation of several individual parameters and present the results below. *Hereafter, we consider only the EGC diversity combining scheme for the dual smart antenna system*. Firstly, we investigated the impact of the number of users. The simulation results with the number of users of 8, 12, and 16 under the LCFCM are presented in Figure 7. Note that all the other parameters are the same as the baseline parameters in the simulation. The top cluster of the three graphs represents the BERs of a single antenna system where the number of users is 16, 12, and 8 from top to bottom. The bottom cluster of the three graphs represents the BERs of the dual antenna system where the number of users is 16, 12, and 8 from top to bottom. As the number of users increases, the signal power of the desired user decreases, which results in increase of the power level of the interference. Hence, the performance in BER decreases. Note that the deterioration of the performance is substantial for large Eb/No. For example, the BER of the dual antenna system for 8 users is 0.17 % at Eb/No = 21 dB, while the BER becomes 1.27 % for 16 users.



(a) BERs under the SCFCM



(b) BERs under the LCFCM



(c) BER Bound with the EGC

Figure 6. BERs with Three Diversity Combining Schemes and Two Channel Models

Secondly, we investigated the impact of the mobile velocity. We varied the mobile velocity to 30, 60, and 90 km/hr, which results in 59, 119, and 178 Hz of Doppler frequency, respectively, under the LCFCM, while all the other parameters are the same as the baseline parameters. The simulation results are given in Figure 8. The top cluster of the three graphs represents the BERs of a single antenna system with the three mobile velocities. The bottom cluster of the three graphs represents the BERs of the dual antenna system. The simulation results reveal that the dual smart antenna system performs better than a single antenna system for all the three mobile velocities. It is notable that the impact of the mobile velocity is negligible for the three mobile velocities for both single and dual antenna systems.

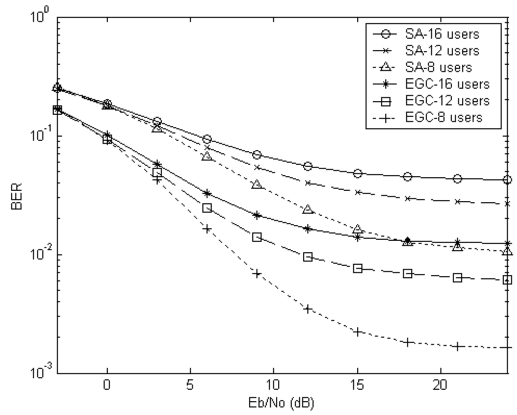


Figure 7. BERs with Various Numbers of Users

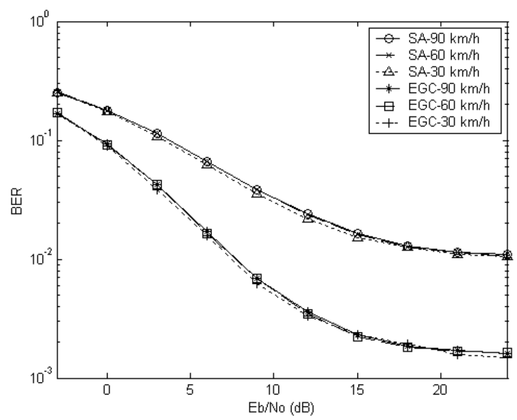


Figure 8. BERs with Various Mobile Velocities

Finally, we investigated the impact of the number of multipaths. We considered 4, 5, and 6 multipaths under the LCFCM, and the simulation results are presented in Figure 9. The top cluster of the three graphs represents the BERs of a single antenna system for the three different numbers of multipaths, and the bottom cluster represents the BERs of the dual antenna system. It should be noted that the number of rake fingers is fixed to three for all cases. As can be seen from the figure, the dual smart antenna system performs better than a single antenna system for all the three cases. If Eb/No is small, the figure indicates that the number of multipaths has little impact on the performance. This is due to the fact that AWGN is dominant for small Eb/No. Therefore, the interference due to the other multipaths is relatively insignificant. Obviously, the trend is reverse for large Eb/No as shown in the figure.

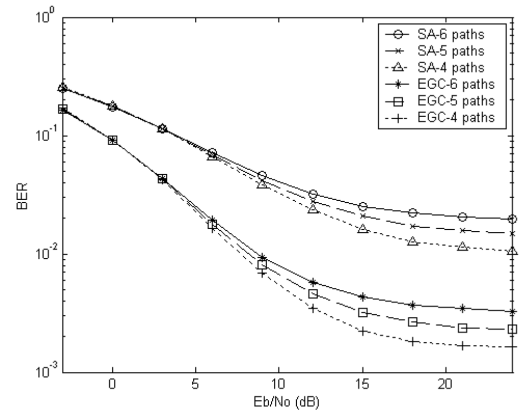


Figure 9. BERs with Various Numbers of Multipaths

We investigated the impact of three individual parameters. The simulation results indicate that a dual smart antenna system with diversity combining always performs better than a single antenna system.

V. CONCLUSION

In this paper, we propose a dual smart antenna system incorporated into handsets for the 3GPP WCDMA system, in which a diversity combiner combines the two rake receiver outputs using a diversity combining scheme. We considered three diversity combining schemes, selection diversity, square law combining, and equal gain combining (EGC). We also considered two types of the channel model for the dual antenna signals, loosely correlated fading channel model (LCFCM) and spatially correlated fading channel model (SCFCM). 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 model in the simulation. The simulation results indicate that

i) the EGC scheme performs the best among the three diversity combining schemes. This is beneficial as the EGC scheme is simple in implementation.
ii) As expected, the higher performance gain is achieved under the LCFCM than the SCFCM. It is believed that the actual performance of a dual smart antenna lies in between the performances obtained for the LCFCM and the SCFCM models.

In conclusion, a dual smart antenna system with diversity combining at handsets is beneficial for the 3GPP WCDMA system.

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