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

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Abstract

We investigated the performances of the diversity combining and the adaptive combining schemes. Based on the results, we propose a hybrid combining for a dual smart antenna system at handsets for the 3GPP WCDMA system and present the performance of the hybrid combining scheme. The proposed hybrid combiner intends to exploit the advantages of the two combining schemes. We considered two different channel models for dual antenna signals and adopted the geometrically based single bounce (GBSB) elliptical and circular models to obtain the channel profile. The simulation results indicate that i) the adaptive combining scheme performs the best among the three combining schemes in an interference-dominant environment or for low mobile velocity, ii) the diversity combining scheme performs the best provided dual antenna signals are uncorrelated, the interference from an adjacent base station is weak, or the mobile velocity is high, and iii) the performance of the hybrid combining scheme always lies in between those of the two combining schemes.

Key words

Smart antenna, diversity combining, adaptive combining, 3GPP WCDMA system.

1. Introduction

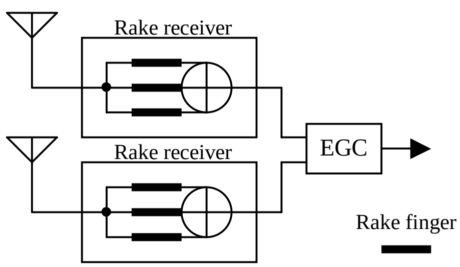
Smart antenna not only combats multipath fading, but also suppresses interference signals. When spatial signal processing achieved through smart antenna is combined with temporal signal processing, the space-time processing can repair signal impairments to result in a higher network capacity, coverage, 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.

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.

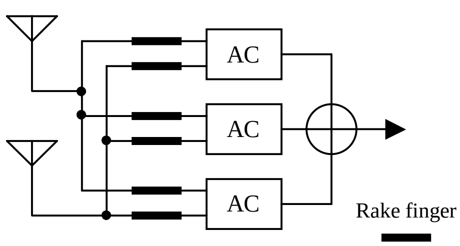
Smart antennas may employ two combining schemes, diversity combining and adaptive combining. The diversity combining scheme exploits the spatial diversity among multiple antenna signals. Thus, the diversity combining achieves higher performance when multiple antenna signals are less correlated. For instance, if each antenna signal undergoes independent fading, the diversity combining 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 more 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 achieve the highest performance. Due to the opposite nature of the two combining schemes, it may be possible to exploit the advantages of the both schemes, which is the motivation of the proposed research.

In [5]-[8], we showed that smart antennas at handsets with the two combining schemes are beneficial for the third generation wireless personal communication systems, cdma2000 and 3GPP WCDMA. The performance improvement (reduction of the frame error rate) with a dual smart antenna system for the cdma2000 system is in the range of 0.8 dB to 12.7 dB depending on the operating condition [5],[6]. The performance gain of a dual smart antenna system for the 3GPP WCDMA system is from 3.1 dB to 6.4 dB [7],[8]. In this paper, we compare the performances of the two combining schemes first. A diversity combiner (DC) combines two rake receiver outputs using the equal gain combining (EGC) scheme, while an adaptive combiner (AC) combines corresponding finger outputs from the two antennas with some antenna weights. Figure 1 shows the difference of the two combiners. Based on the results, we propose hybrid combining for a dual smart antenna system at handsets for the 3GPP WCDMA system and present the performance of the hybrid combining scheme. We consider two types of the channel model for the dual antenna signals. To obtain the channel profile, we adopted a statistical channel model known as the GBSB (geometrically based single bounce) elliptical and circular models [9],[10].

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 2. Our simulation environment and simulation results are provided in Section 3. Finally, Section 4 concludes the paper.



(a) Diversity Combiner



(b) Adaptive Combiner

Figure 1: Diversity Combiner versus Adaptive Combiner for a Dual Antenna System

2. 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 needs to 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).

In the LCFCM, each antenna signal is assumed to have independent Rayleigh fading. In the SCFCM, each antenna signal is subject to the same Rayleigh fading, but different in the phase due to a nonzero angle of arrival. The signal property under the LCFCM is beneficial for the diversity combining scheme, while the signal property under the SCFCM is beneficial for the adaptive combining scheme. The actual channel for any dual antenna signals is likely to lie in between these two channel models. This suggests that the hybrid of diversity and adaptive combining schemes may be advantageous.

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. The GBSB elliptical model is applicable for microcell environments found in urban areas. Meanwhile, the GBSB circular model is applicable for macrocell environments found in rural or suburban areas. It is assumed for the GBSB elliptical and circular models that multipath signals are created by single reflections of scatters, which are uniformly distributed in a predefined elliptical and 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 used in our simulation is available in [7].

The block diagram of a downlink transmitter considered in our simulation is shown in Figure 2.

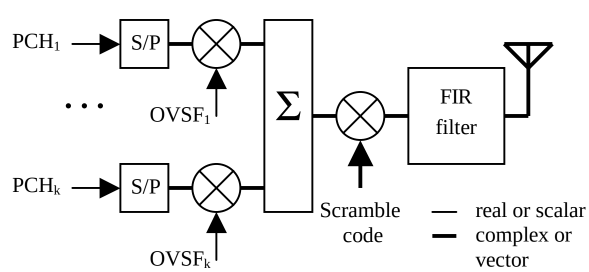


Figure 2: Block Diagram of a Downlink Transmitter

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.

3. Simulation environment and simulation results

The two types of the channel model, the SCFCM and the LCFCM, described in Section 2 are employed in the simulation. The GBSB elliptical and circular models are adopted to generate the channel profile of the multipath signal. 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. A diversity combiner (DC) combines two rake receiver outputs using the equal gain combining (EGC) scheme, which gives the best performance among three diversity combining schemes considered in [7]. An adaptive combiner (AC) combines corresponding finger outputs of the two antennas with appropriate antenna weights, which are recursively obtained based on the N-LMS (normalized least-mean-square) algorithm. The detailed description of the N-LMS algorithm to compute the antenna weights is available in [8].

The proposed hybrid combiner (HC) combines the diversity combiner and the adaptive combiner outputs after normalization. In our simulation, the output of each 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).

3.1 Simulation environment

The environment considered in our simulation is as follows. *To generate the channel profile, the following model parameters 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 is 2000 m and the maximum multipath delay is 35 chips in the GBSB circular model. 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 with 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. The two handset antennas also receive interference and background noise signals. Two multipath signals from an adjacent base station, which transmits the combined signal of eight users' signals and the common pilot signal, are considered. The background noise results in 25 dB of E_b/N_0 at the 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 to obtain the reference signal. The step size, $\mu = 0.3$, and the number of pilot symbols, Q = 3, are chosen and applied for the adaptive combining scheme.

3.2 Simulation results

We present the simulation results with three different combining schemes (AC, DC, and HC) and two types of the channel model (SCFCM and LCFCM) in the following. Simulation results with the channel profile obtained from the GBSB elliptical model are shown in Figure 3. In the figures, 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, the dash-dotted, and the dashed lines represent the BERs of a dual antenna system with DC, AC, and HC, respectively. Figure 3 (a) represents the performance of the dual antennal system under the SCFCM. As can be seen from the figure, the AC performs the best when the interference from an adjacent base station is significant. As the interference from the adjacent base station becomes weaker, the performance of the AC decreases, while the performance of the DC improves. The crossing point of the two graphs is 7.54 dB, which means that desired multipath signal is 5.7 times stronger than the interference signal. As expected, the performance of HC always lies between those of the DC and the AC.

Figure 3 (b) shows the performance of the combining schemes under the LCFCM. For the LCFCM, the DC performs the best for the wide range of x-axis. However, the trend is reversed when the interference from an adjacent base station is dominant. In such a case, the AC performs the best and the DC performs the worst. The opposite trend is exploited in the HC, whose performance lies in between the two combining schemes. It is interesting to note that as the interference from the adjacent base station becomes weaker, the AC performs worse than a single antenna system.

Figure 4 shows the performance of the combining schemes with the channel profile obtained from the GBSB circular model. Figure 4 (a) represents the performance under the SCFCM. The AC performs the

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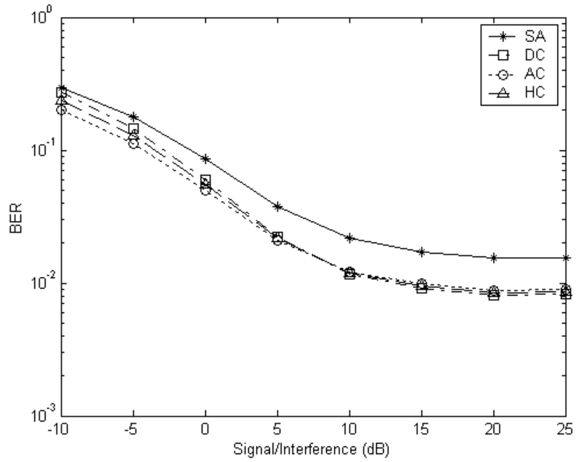
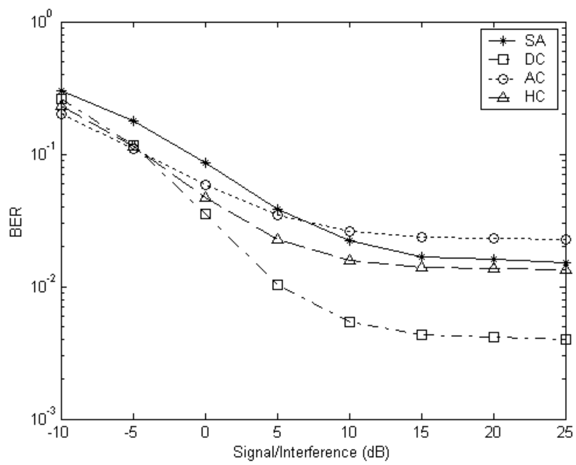
best for low signal to interference ratio, i.e., the interference from an adjacent base station is significant. All the three combining schemes show comparable performances for high signal to interference ratio, i.e., the interference from the adjacent base station becomes weaker. The trend is also true under the LCFCM as shown in Figure 4 (b).



(a) BER under the SCFCM

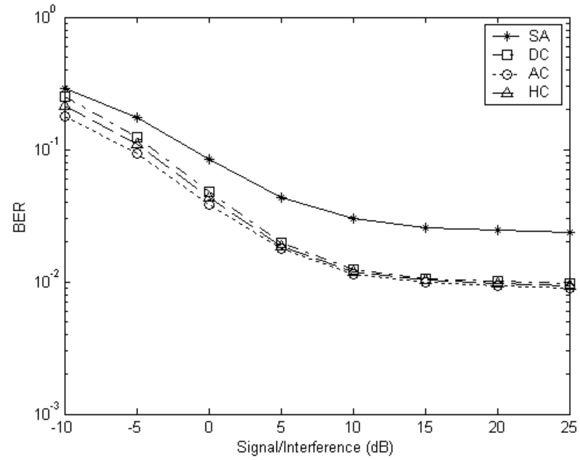


(b) BER under the LCFCM

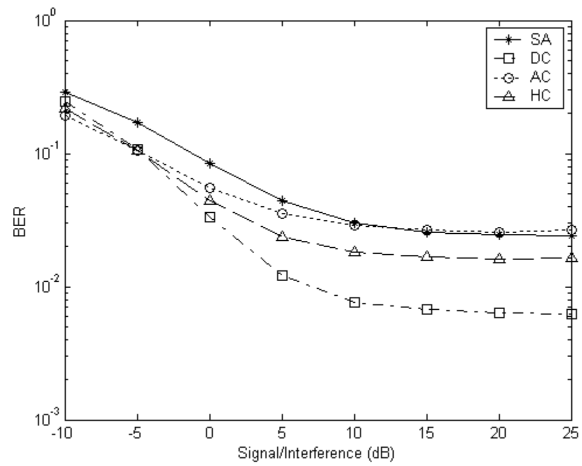
Figure 3: Bit Error Rate with the GBSB Elliptical Model

Our earlier works reported in [7],[8] suggest that the DC might perform better than the AC for high mobile velocity, but it might be reverse for low mobile velocity. We investigated it to confirm the trend and examined the benefit of the trend for the HC.

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) under the SCFCM with the GBSB circular model. The simulation results with the mobile velocity of 2 km/hr are shown in Figure 5 (a). As can be seen from the figure, the AC performs the best for the entire range of x-axis and the performance of the HC always lies in between those of the DC and the AC. When the mobile velocity was increased to 10 and 30 km/hr, we observed the same trend as that of 2 km/hr. The only difference is that the performance difference between the three combining schemes (AC, DC, and HC) becomes smaller as the mobile velocity increases from 2 km/hr to 30 km/hr.



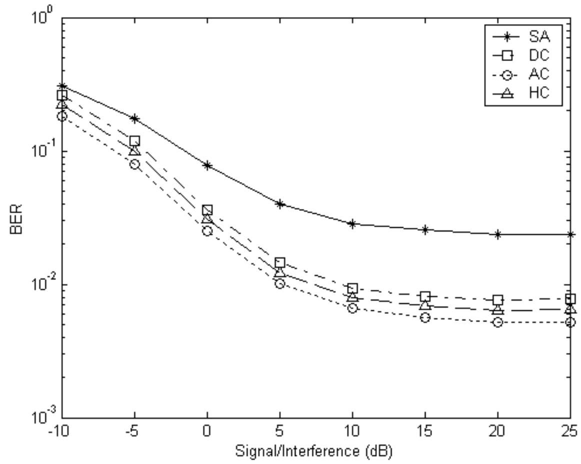
(a) BER under the SCFCM



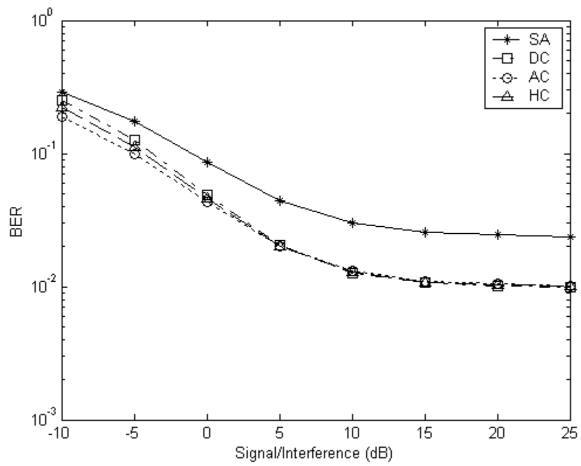
(b) BER under the LCFCM

Figure 4: Bit Error Rate with the GBSB Circular Model

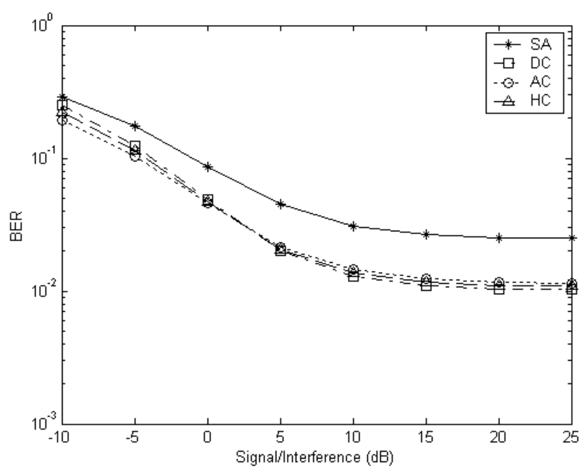
As the mobile velocity further increases, the performance of the three combining schemes further decreases, and the decreasing rate is higher for the AC in a high signal to interference ratio environment. It results in relatively poor performance for the AC in the region as shown in Figure 5 (b) for the mobile velocity of 90 km/hr. When the mobile velocity further increases to 120 km/hr, the AC performs better only for low signal to interference ratio environment, while the DC performs better for high signal to interference ratio environment as shown in Figure 5 (c). This demonstrates clearly the advantage of the HC, whose performance always lies in between the two schemes.



(a) BER with the Mobile Velocity of 2 km/hr



(b) BER with the Mobile Velocity of 90 km/hr



(c) BER with the Mobile Velocity of 120 km/hr

Figure 5: Bit Error Rate with the Various Mobile Velocities

4. Conclusion

In our early works, we investigated the performances of the two combining schemes (diversity combining and adaptive combining) [7],[8]. Based on the results, we propose a hybrid combining for a dual smart antenna system at handsets for the 3GPP WCDMA system and present the performance of the hybrid combining scheme. The proposed hybrid combiner simply combines the diversity combiner and the adaptive combiner outputs after normalization. We considered two types of the channel model for the dual antenna signals, the SCFCM and the LCFCM. To obtain the channel profile, we adopted the GBSB elliptical and circular models for the simulation. The simulation results indicate that

i) the adaptive combining scheme performs the best among the three combining schemes in an interference-dominant environment or for low mobile velocity,
ii) the diversity combining scheme performs the best provided dual antenna signals are less correlated (which is the LCFCM in our models), the interference from an adjacent base station is weak, or the mobile velocity is high, and
iii) the performance of the hybrid combining scheme always lies in between those of the adaptive combining and the diversity combining schemes.

In conclusion, a dual smart antenna system with the hybrid combining schemes at handsets always performs well for the 3GPP WCDMA system.

5. References

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