PERFORMANCE GAIN OF SMART DUAL ANTENNAS AT HANDSETS IN 3G CDMA SYSTEM

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ABSTRACT

In this paper, we present simulation results for the performance gain of smart dual antennas at handsets for the forward link in the cdma2000 system. The system was modeled with the SPW of Cadence. Three types of the channel model, two levels of diversity combining, and three diversity combining schemes were investigated. Our simulation results show that the average performance gain (reduction of the frame error rate) of a smart dual antenna system lies in the range of 1.7 dB to 12.7 dB depending on the correlation of the dual antenna signals.

I. INTRODUCTION

Signal impairments in wireless personal communications are mainly due to intersymbol interference (ISI) and co-channel interference (CCI). The signal delays through the multipath channel cause the ISI, while the multiple accesses cause the CCI. Temporal and/or spatial signal processing is applied to repair the signal impairments. Temporal signal processing reduces the ISI using an equalizer or a rake receiver. Meanwhile, spatial signal processing reduces the CCI using a smart antenna. When spatial signal processing is combined with temporal signal processing, the space-time processing can further improve the impairments to result in a higher network capacity, coverage, and quality [1][2][3]. A smart antenna not only suppresses interferences, but also combats multipath fading by combining the multiple antenna signals.

The smart antenna technique has been considered mostly for base stations [4] because of its high system complexity and large power consumption. In addition, two (or multiple) antennas at a handset are in proximity, which may reduce the effectiveness of the antenna system. The feasibility of implementing dual antennas at a mobile handset was investigated in [5]. The 3GPP (third generation partnership project) system requires antenna diversity at base stations and optionally at mobile stations [6]. Recently, the smart antenna technique has been applied to mobile stations. For example, the HDR (high data rate) system of Qualcomm employs dual antennas at a mobile station [7]. Each antenna signal is applied to its own rake receiver that combines signals from different multipaths. Then, maximal ratio diversity combining is used to combine the two rake receiver signals. A dual antenna system for handsets is also applied to the digital European cordless telephone (DECT) system for 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 combination of the signal from one antenna and the phase-shifted signal from the other antenna.

The additional antenna and the circuitry to process multiple antenna signals increase the cost and power consumption of the system. To justify employing multiple antennas at handsets, the performance gain should be large enough to offset the additional cost and power consumption. In this paper we present simulation results on the performance gain (in terms of frame error rate (FER)) of smart dual antennas at handsets for the cdma2000 system, which is one of the third generation (3G) code division multiple access (CDMA) systems proposed by TIA (Telecommunications Industry Association) [9]. Three types of the channel model, two levels of diversity combining, and three diversity combining schemes are considered. For the simulation, we used the SPW (signal processing worksystem) tool of Cadence to model the cdma2000 system and to evaluate the performance.

The paper is organized as follows. The channel models employed for our simulation are presented in Section 2. The cdma2000 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 system employing an antenna array. In the reverse link of the cdma2000 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 (inter-cell interference), in which other user signal (interference) may be stronger than the desired user signal. However, in the forward link of the cdma2000 system, the signal transmitted from the base station is the superposition of all active users' signals and control signals (pilot, sync, and paging signals). The desired user signal and multiple access interferences (MAIs) traverse the same paths, and they are inherently orthogonal of each other. Meanwhile, the main source of interference is coming from adjacent cells (intra-cell interference). Thus, unlike in the case of the reverse link, the interference is not a severe problem; the mobile station can select the strongest signal from different base stations and the number of adjacent base stations is small. Since a receiver with M antennas can suppress M-1 interferences [10], the dual antenna is a good candidate for the handsets. In this paper, we consider the interferences from adjacent cells as additive white Gaussian noises (AWGNs). Thus, only a simple diversity combining technique to process dual antenna signals is applied to obtain the diversity gain at handsets.

We assume that the dual antennas at a handset are identical, omnidirectional, and separated within a wavelength of the carrier. For a wireless channel model, three components are considered for a typical variation in the received signal level. The three components are mean path loss, lognormal fading (or slow fading), and Rayleigh fading (or fast fading). A channel model also considers spreads: i) delay spread due to multipath propagation and ii) Doppler spread due to mobile motion. We consider three types of the channel model for the dual antenna signals: i) uncorrelated fading channel model (Type I), ii) loosely correlated fading channel model (Type II), and iii) spatially correlated fading channel model (Type III). The characteristics of each channel model are summarized in Table 1.

Table 1. Three Types of the Channel Model for Dual Antenna Signals

Channel model	Lognormal fading	Rayleigh fading	Phase difference
Type I	Independent	Independent	Independent
Type II	Same	Independent	Independent
Type III	Same	Same	Independent

Each antenna signal is assumed to have independent lognormal and Rayleigh fadings in the uncorrelated fading channel model of Type I. In the loosely correlated fading channel model of Type II, each antenna signal is assumed to have independent Rayleigh fading but is subject to the same lognormal fading. Each antenna signal is assumed to have the same lognormal and Rayleigh fadings in the spatially correlated fading channel model of Type III. Thus the two signals are different only in phase due to a non-zero angle of arrival (AOA). A channel model with less correlated dual antenna signals is expected to give higher diversity gain [11]. Hence, Type I is for the best case and Type III the worst case. We believe that the actual channel may be close to Type II.

Six multipath signals are considered in the channel model, and a multipath signal is assumed to have the same arrival time for the two antennas. The loosely correlated fading channel model is illustrated in Figure 1. For simplicity, only three multipath signals are presented in the figure. 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.

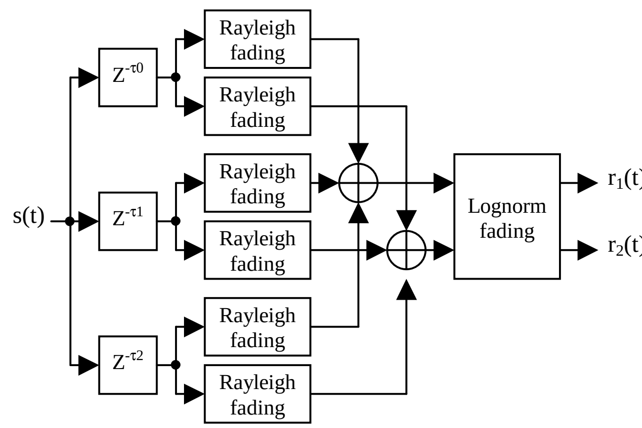


Figure 1. Loosely Correlated Fading Channel Model

III. THE cdma2000 SYSTEM

The cdma2000 is a synchronous CDMA system that was proposed by TIA as a third generation standard to meet the ITU (International Telecommunication Union) IMT-2000 (International Mobile Telecommunications) requirements. A detailed description of the cdma2000 system is available in [9]. Figure 2 shows a block diagram of a typical forward link of the cdma2000 system that was considered for our simulation. One frame of user data bits is randomly generated with a variable traffic data rate of 9600 bps, 4800 bps, 2700 bps, or 1500 bps. The generated data bits are appended with CRC (cyclic redundancy check) and tail bits. The data bits are convolutional coded with the rate of ¼ and the constraint length of 9 and block interleaved. Then, data bits are parallelized for QPSK data modulation, and each parallel data bit is spread by Walsh code with the spreading factor of 64 and the chipping rate of 1.2288 Mcps. The resultant data signal is added with the pilot signal, the paging signal, the sync signal, and all the other users' signals. The added signal is quadrature modulated by two short-PN sequences and up-sampled by 8, and then is applied to shaping filters. The shaped signal is transmitted through the channel.

The received signal is shaped back and down-sampled by 8. A four-finger rake receiver despreads each multipath signal and combines the despread multipath signals. The despread and combined signal is applied to the channel decoder consisting of a block deinterleaver, a Viterbi decoder, and a CRC decoder. In our simulation the decoded data bits are compared with the original data bits to evaluate the system performance in terms of data rate decision error rate (DER), frame error rate (FER), and bit error rate (BER).

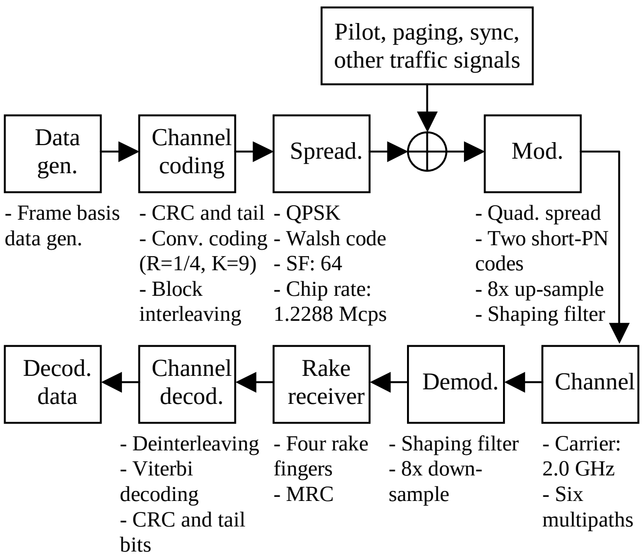
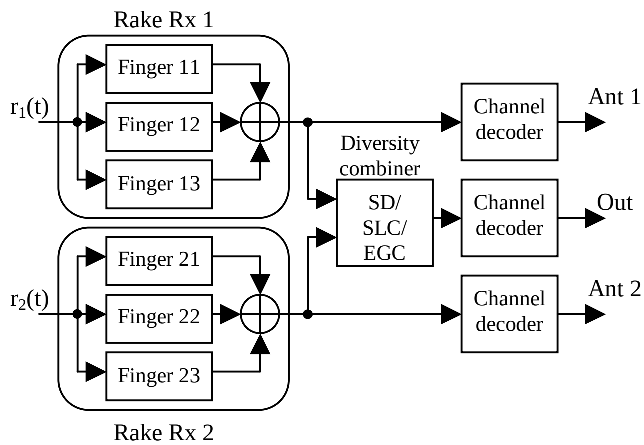


Figure 2. Forward Link of the cdma2000 System

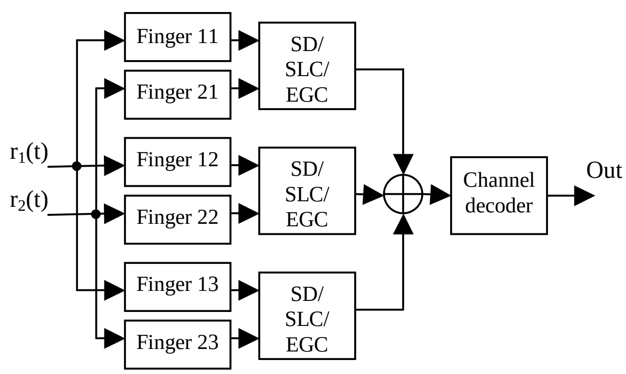
IV. SIMULATION SETUP AND RESULTS

A signal from the base station propagates through the channel. The three types of the channel model described in Section 2 are employed for the simulation. The signal received at a handset antenna is applied to its own demodulator and then to a four-finger rake receiver. To process the dual antenna signals, two levels of diversity combining schemes are considered in this paper. The first one is the rake level diversity combining in which a diversity combiner combines rake receiver outputs. The second one is the finger level diversity combining in which a diversity combiner combines finger outputs. The two schemes are shown in Figure 3. The rake receiver considered in our model has four fingers, but only three fingers are shown in the figure. It should be noted that all finger signals are pre-weighted (according to the magnitude and phase information of the pilot signal) before a diversity combiner combines finger outputs.

Three diversity combining schemes are considered for each level (the rake level and the finger level). The first one is the selection diversity (SD) scheme that is based on the signal power. The signal with higher power is selected. The comparison of signal powers is performed at the outputs of rake receivers or fingers at the symbol rate (which is the chipping rate divided by the spreading factor). The second diversity combining scheme is the square-law combining (SLC) scheme, which is expressed as $\sqrt{a^2+b^2}$ for two signals *a* and *b*. The third one is the equal gain combining (EGC) scheme, which simply adds the two signal values with an equal weight of 0.5.



(a) Rake Level Diversity Combining



(b) Finger Level Diversity Combining

Figure 3. Diversity Combing

We assumed that the distance from the base station to the mobile station is 1000 m. We also assumed that the mobile velocity is 100 km/hr, which results in 185 Hz of Doppler frequency under 2.0 GHz of carrier frequency. In simulating the system with the SPW of Cadence, we used the link budget and system parameters (such as multipath delays and powers) shown in Table 2 and Table 3. From

Table 2, only 2.5% (or 0.74 W) of the total transmitted power of 30 W is allocated to the desired user traffic channel. The relative path delays and signal power levels of other multipath signals to the first multipath signal are shown in Table 3. A proper level of AWGNs is added to the channel to achieve 9.75 dB of the signal-to-noise ratio (Eb/N_0) on the desired user traffic channel for the six multipath signals.

Table 2. Link Budget

Channel	Power (W)
Pilot	5.99
Paging	1.89
Sync	0.75
User traffic	0.74
Power control	0.13
Other users	20.50
Total	30.00

Table 3. Multipath Delays and Powers

Path	Delay (nsec)	Power (dB)
Path 1	0	0.0
Path 2	310	-1.0
Path 3	710	-9.0
Path 4	1090	-10.0
Path 5	1730	-15.0
Path 6	2510	-20.0

The simulation was performed for 3999 frames in which the period of each frame is 20 ms. Hence, it covers 80 seconds of the real operation. To evaluate the system performance, three system performance metrics were calculated as described next. After receiving a frame of data, the transmitted data rate is determined based on the CRC bits and the error metric from the Viterbi decoder. If the determined data rate is incorrect, a data rate decision error (DRDE) occurred for the frame. In such a case, a large number of bits are usually erroneous. We assume that 40% of bits of a frame are in error if a DRDE occurred in the frame. The data rate decision error rate (DER) is the ratio of the number of DRDE frames to the total number of transmitted frames (which is 3999). A frame is erroneous if a DRDE occurred and/or at least one bit in the frame is erroneous. The frame error rate (FER) is the number of erroneous frames to the total number of frames. A bit error occurs if the received bit does not match the transmitted data bit. The bit error rate (BER) is the ratio of the number of bit errors to the total number of transmitted data bits.

We performed simulation on a Sun UltraSPARC10 workstation with 1 GB of main memory. The CPU time was not measured, but the elapsed time for the simulation is about six days for each simulation run. We performed the simulation three times for each type of the channel model. Then the three simulation results are averaged. The simulation results with three types of the channel model, two levels of diversity combining, and three diversity combining schemes are summarized in Table 4. The first two rows represent the performance of a single antenna. The remaining five rows represent the performance of the dual antennas with different diversity combining schemes and different level of diversity combining. The top element of each entry is the average number of frames out of 3999 frames simulated, and the bottom element is the percentile. The EGC scheme for the rake level and the finger level is the same, since the operation is the same except for its order.

Table 4. Performance of Smart Dual Antennas

Scheme	Level	Channel Type I			Channel Type II			Channel Type III		
		DER	FER	BER	DER	FER	BER	DER	FER	BER
Antenna 1		354.3 8.86%	355.3 8.89%	3.55%	315.7 7.89%	316.0 7.90%	3.16%	343.0 8.58%	344.3 8.61%	3.44%
Antenna 2		335.3 8.39%	336.3 8.41%	3.36%	321.0 8.03%	322.0 8.05%	3.22%	336.0 8.40%	336.7 8.42%	3.36%
SD	Rake	21.7 0.54%	22.0 0.55%	0.22%	200.0 5.00%	200.3 5.01%	2.00%	240.0 6.00%	240.3 6.01%	2.40%
	Finger	18.3 0.46%	18.7 0.47%	0.19%	193.3 4.83%	193.7 4.84%	1.93%	233.7 5.85%	235.7 5.89%	2.35%
SLC	Rake	17.3 0.43%	17.3 0.43%	0.17%	186.0 4.65%	187.3 4.68%	1.88%	226.0 5.65%	226.7 5.67%	2.27%
	Finger	16.3 0.41%	16.3 0.41%	0.16%	183.3 4.58%	184.0 4.60%	1.84%	224.0 5.60%	225.7 5.64%	2.26%
EGC	Rake Finger	17.0 0.43%	17.0 0.43%	0.17%	179.7 4.49%	180.0 4.50%	1.80%	220.0 5.50%	221.0 5.53%	2.21%

When a single antenna is employed, the DERs and the FERs are about the same and are around 8%. Since a DRDE always causes a frame error, it can be concluded that most frame errors are due to DRDEs. When dual antennas are employed, the FERs are reduced to below 1% for all diversity combining schemes under channel type I. However, as the correlation of dual antenna signals increases from Type I to Type III, the FERs increase up to 6%. The results also indicate that i) diversity combining scheme at the finger level performs slightly better than the rake level diversity combining scheme, and ii) EGC scheme performs the best among the three diversity combining schemes. When EGC scheme is employed for the diversity combining, the average reduction ratio of the FER for the dual antenna system over the single antenna system is 13.0 dB (8.65% to 0.43%) for Type I, 2.49 dB (7.98% to 4.50%) for Type II, and 1.87 dB (8.51% to 5.53%) for Type III. In conclusion, a smart antenna at handsets significantly improves the performance for Type I channel model, but the improvement is moderate for the other two channel models.

V. CONCLUSION

In this paper, we presented simulation results for the performance gain of smart dual antennas at handsets for the forward link in the cdma2000 system. The SPW of Cadence was used to model the system and to evaluate the performance. We considered three types of the channel model, two levels of diversity combining, and three diversity combining schemes. Our simulation results indicate that

i) a dual antenna system reduces the FER by in the range of 1.7 dB to 12.7 dB over a single antenna system depending on the correlation of the dual antenna signals,

ii) diversity combining scheme at the finger level performs slightly better than the rake level diversity combining scheme, and

iii) EGC (equal gain combining) scheme performs the best among the three diversity combining schemes.

In conclusion, smart dual antennas at handsets are beneficial for the cdma2000 system. The channel model is sensitive to the performance of smart antennas at handsets, and further study in the area is necessary.

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