FIELD TEST RESULTS OF DOWNLINK SMART ANTENNAS AND POWER CONTROL FOR IS-136

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Abstract – In this paper we present field test results obtained from our IS-136 Smart Antenna Test Bed showing the improvement in performance obtained using downlink smart antennas and power control for IS-136. We describe the test bed which consists of an adaptive uplink system with dual polarization antennas and a downlink multibeam antenna with power control. Tests were conducted at 1900 MHz on drive routes in a typical cellular base station site located in a suburban environment. We implemented and tested the performance of downlink power control algorithms which slowly adjust the transmit power based on the downlink or uplink RSSI while adaptively adjusting the RSSI threshold based on the BER. The field test results show that our beamforming technique with a fixed multibeam antenna with power control provides additional gain and can closely track channel variations thereby requiring less margin and less average transmit power while maintaining the C/I level needed for good signal quality. We show that power control improves the C/I by 2 to 3 dB for a 1% BER for both vehicular and pedestrian fade rates when the uplink RSSI is used to estimate the downlink received power. The field test demonstrates the feasibility of using smart antennas on the uplink and downlink to increase both the range and capacity of the IS-136 system.

I. INTRODUCTION

Smart antennas have the potential to significantly increase the range and capacity of base stations in the IS-136 North American Digital Cellular System. We have previously presented field test results showing that a 70% increase in coverage can be obtained and capacity can be more than doubled with adaptive antennas on the uplink [1, 2]. However, for overall system improvement, additional gain and capacity improvement are needed on the downlink as well. We have proposed an approach for the downlink using a fixed multibeam antenna array with transmit power control to obtain these improvements which does not require changes to the IS-136 standard or to existing mobiles. With this technique only the beams with users are turned on during transmission and the power is adjusted slowly in each beam to keep the carrier-to-interference ratio (C/I) at the mobile above a given threshold with the minimum required transmit power. Simulation results show that with the continuous downlink constraint of IS-136 our downlink beamforming technique with four beams and power control can provide more than a 50% increase in coverage and a 75% increase in capacity [3, 4].

To demonstrate feasibility, verify the simulation results, and show the improvement in performance obtained using downlink smart antennas and power control for IS-136, we conducted field tests with our IS-136 Smart Antenna Test Bed. The test bed consists of an adaptive antenna array on the uplink with a fixed multibeam antenna on the downlink. Tests were conducted at 1900 MHz on drive routes within a test sector in a typical cellular base station site located in a suburban environment with IS-136 mobiles for both vehicular and pedestrian fade rates. To assess performance we evaluated the distributions of the mobile reported Received Signal Strength Indicator (RSSI), the bit error rate (BER), and the downlink transmit power for different test cases.

For this study we implemented and tested the performance of downlink power control algorithms that adjust the transmit power about once a second based on the downlink or uplink RSSI as compared to an RSSI threshold while adaptively adjusting the RSSI threshold based on the mobile BER. With a relatively slow power control update rate, slowly-changing shadow fading can be tracked and mitigated thereby reducing both the fading margin in the link budget and the average transmit power and

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interference to other users. We consider the use of the downlink RSSI for control, but also consider using the uplink RSSI averaged over the uplink diversity branches to better average the multipath fading and obtain a more accurate measure of the shadow fading, especially for pedestrian traffic. The BER measurements from the mobile are used to adjust the RSSI threshold to maintain a good C/I and to correct for stationary effects.

The field test results show that our beamforming technique with a fixed multibeam antenna with power control provides additional gain and can closely track channel variations thereby requiring less margin and less average transmit power while maintaining the C/I level needed for good signal quality. We show that power control improves the C/I by 2 to 3 dB for a 1% BER for both vehicular and pedestrian fade rates when the uplink RSSI is used to estimate the downlink received power. The field test demonstrates the feasibility of using smart antennas on the uplink and downlink to increase both the range and capacity of the IS-136 system.

In Section II we describe the IS-136 Smart Antenna Test Bed and test environment. The field test results are presented in Section III. Finally, Section IV briefly summarizes the key results.

II. SMART ANTENNA TEST BED

The IS-136 Smart Antenna Test Bed consists of an adaptive antenna array uplink system with a fixed multibeam antenna downlink with power control operating at 1900 MHz. Figure 1 shows the Smart Antenna Test Bed configuration used for the downlink tests. The antennas are mounted on the roof of a four story office building in a suburban office park. The uplink uses two 65° beamwidth slant 45° dual-polarized antennas which are spaced about 10 ft apart (20 wavelengths at 1900 MHz), and these signals are fed directly to three receivers of the adaptive antenna array system. The output from the uplink system is input to a standards-compliant TDMA test set which can support a single user IS-136 channel performing base station operations, such as call origination and call processing.

The downlink system uses a vertically-polarized fixed multibeam antenna with four orthogonal beams separated by 30° each with a 3 dB beamwidth of about 30° in azimuth. The signals from the four beams are fed directly to duplexers where the received signal is scanned at the appropriate time by the downlink control processor, a laptop PC, using the beam scanning receiver to select the best beam choice for the desired mobile. Timing signals from the TDMA test set are used to control the scanning process.

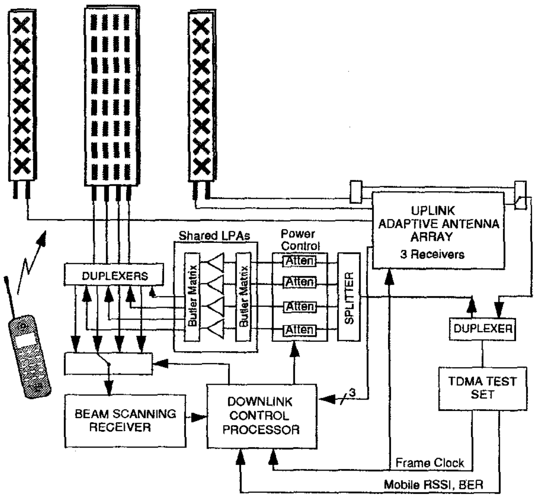

Figure 1: IS-136 Smart Antenna Test Bed.

The downlink signal transmitted from the TDMA test set is split four ways, for each of the beams. The downlink control processor determines the appropriate transmit power on the selected beam using the RSSI from the uplink diversity branches and the mobile reported RSSI and BER. Programmable attenuators are used to control the transmit power, and the beam inputs are then fed through shared linear power amplifiers (LPAs) and routed to the appropriate antenna beam through the duplexers. The shared LPAs are a key component of a downlink smart antenna system enabling the sharing of amplifiers by all the beams which increases trunking efficiency and allows the handling of a high concentration of calls in any particular beam. Additional benefits include a reduction in amplifier linearity requirements, reduced power backoff, and soft failure performance.

The downlink control processor selects the best beam, runs the power control algorithm to determines the transmit power settings, and collects uplink RSSI data, mobile BER and mobile RSSI data. To assess performance the following data is recorded by the processor every second: (1) the power control settings; (2) the average uplink RSSI on each beam; (3) the selected beam; (4) the average uplink RSSI on each diversity branch; and (5) the mobile-reported BER and RSSI.

Field tests were conducted for both vehicular and pedestrian traffic to cover slow and moderate fade rates. The drive tests were conducted with a standard dual-band IS-136 handset with a roof mounted omnidirectional antenna traveling along a drive route in a 60° test sector within the coverage of the uplink antennas and the two center beams of the downlink multibeam antenna. The test environment can be characterized as suburban with gently rolling terrain. The drive route passes by a dense residential area with two story houses and tall trees and an open area with office parks. The entire drive route covers a distance of 8.5 miles with a downrange distance of 2.5 miles. Typical drive tests are 20 minutes in duration with an average speed of 30 mph. The pedestrian tests were conducted using the handset antenna at several locations along the drive route.

The data collected along the same drive route on separate drive tests was processed to compare downlink performance with and without power control and to test different power control algorithms. The average uplink and downlink RSSI measurements, which should track the shadow fading, collected over the same drive route were very repeatable over the course of a day. Thus, to assess performance we evaluate and compare the distributions of the mobile reported RSSI and BER, and the downlink transmit power for different cases along the same drive route.

III. FIELD TEST RESULTS

Initial tests were done with a power control algorithm that adjusts the transmit power about once a second based on the mobile RSSI measurements using a fixed RSSI threshold of -101 dBm based on a target BER of 1%. For all test cases, we adjust the transmit power in 2 dB steps with a maximum dynamic range of 30 dB. Figure 2 shows the mobile reported RSSI with and without power control versus time over the drive route. These results show a 9.6 dB reduction in the reported RSSI and a 2 dB improvement in the RSSI with power control. In Figure 3 we show that with power control we can maintain the mobile BER in the desired range achieving less than a 1% mean BER with the BER exceeding 2% less than 5% of the time. In this case, the power control tracked and mitigated the shadow fading, resulting in an 8.8 dB reduction in the average transmit power and interference to other users.

Next, we consider using the uplink RSSI measurements to estimate the downlink RSSI averaged over the multipath fading. This technique further improves performance by eliminating the one to two second reporting delay and the 2 dB quantization of the mobile measurements [3]. Also, we can use the uplink diversity antennas to average the multipath fading to obtain a more accurate measure of the shadow fading. This is a significant factor at slow fade rates, such as with pedestrian traffic and at stop lights, where the mobile RSSI and BER measurements may not provide a good average over the multipath fading.

Figure 4 compares the downlink RSSI reported by the mobile with the uplink RSSI averaged over three

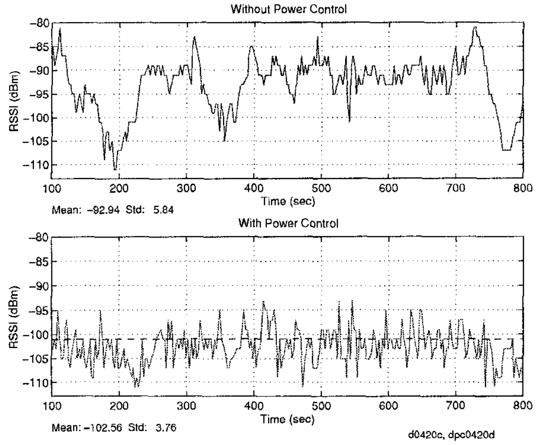

Figure 2: Mobile RSSI with and without power control.

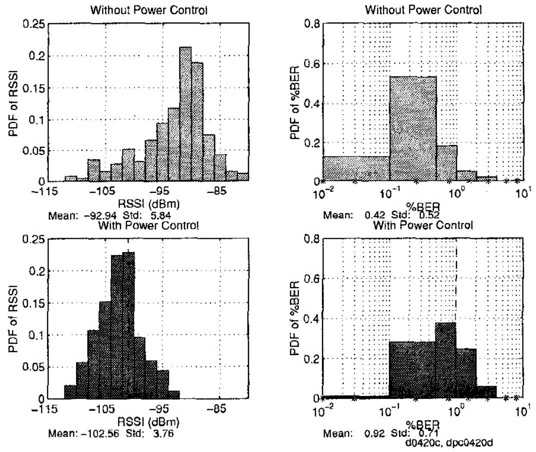

Figure 3: Distributions of mobile RSSI and BER with and without power control.

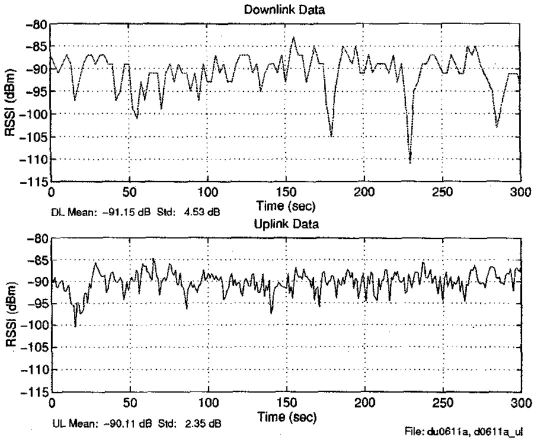

Figure 4: Mobile RSSI downlink and uplink RSSI with diversity at pedestrian fade rates.

diversity branches, with both RSSI's averaged over a one second interval in a pedestrian test case. As seen, the standard deviation in the signal strength measurements from multipath fading has been reduced by 2.2 dB by using diversity on the uplink. To accurately assess performance for pedestrian test cases and avoid the inaccuracies in the mobile measurements, we compare the transmit power distribution obtained using the uplink RSSI measurements for power control with those using the mobile RSSI and BER measurements. We measured a 1 to 2 dB improvement in the transmit power distribution using the uplink RSSI for power control, showing that this technique can provide tighter power control while maintaining the desired signal quality.

At vehicular fade rates, the field test results show that power control using the uplink RSSI measurements improves both the RSSI and BER distributions. This is most likely due to the elimination of the reporting delay since at these fade rates the mobile measurements should adequately average over the multipath fading, and these gains were also seen in computer simulation results when the reporting delay was decreased. The field test results show better tracking of the shadow fading using the more frequent uplink measurements, with an additional 1 dB improvement in the RSSI.

Since the uplink measurements do not measure the downlink interference, power control based on the uplink RSSI alone cannot provide desirable performance when downlink interference is present. Thus, to maintain a good C/I we adaptively adjust the RSSI threshold based on the mobile reported BER.

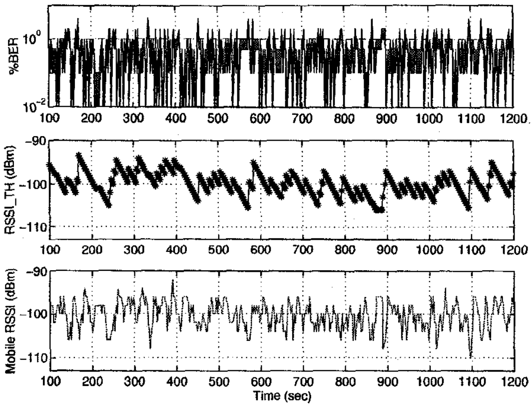

Figure 5: Effect of power control with adaptive threshold.

The mobile BER can also be used to correct for antenna pattern variations between the uplink and downlink antennas and for stationary or slowly-varying effects. With this power control technique, the transmit power is adjusted based on the uplink RSSI comparison to the RSSI threshold and the RSSI threshold is adjusted based on the mobile BER comparison to the BER threshold. When the mobile BER is above the BER threshold the RSSI threshold is adjusted upward, and when the mobile BER is below the threshold there is a downward adjustment.

Figure 5 illustrates the performance of this power control technique under noise-limited conditions. The top plot shows the mobile reported BER versus time along the drive route with a 1% BER threshold. The middle plot shows the adaptive RSSI threshold and the bottom plot shows the mobile reported RSSI with power control. In this example, the RSSI threshold is increased by 3 and 6 dB if the BER exceeds 1% and 2%, respectively, and is lowered by 1 dB if the BER falls below 1%. This can be clearly seen from the top two plots. When the BER increases above 1%, due to a burst error, we see that the RSSI threshold increases by 3 dB and then decays slowly as the BER decreases. At several times we see the threshold increase by more than 9 dB because the BER goes over 1% for several consecutive measurements and the signal level is raised accordingly. The field test results without interference show similar performance in the RSSI and BER distributions with and without BER adjustment of the RSSI threshold with less than a 1 dB increase in the average transmit power. This increase may be due to the reporting delay and quantization of the mobile BER. Laboratory testing with a static inter-

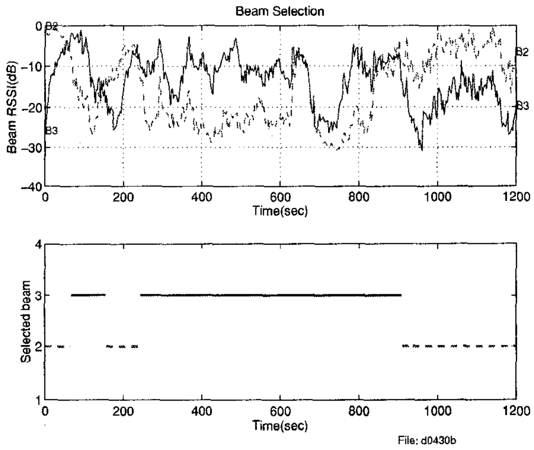

Figure 6: Beam selection performance.

ferer showed that with this power control technique the RSSI threshold and transmit power are raised rapidly by the BER comparison loop when the interference increases to maintain a stable C/I.

With the downlink multibeam antenna, the base station selects the best beam for transmission by locating and tracking the mobile based on the RSSI received on each of the beams. Experimental results have been previously presented to characterize the tradeoff between hysteresis level, switching time, and gain for a multibeam base station antenna [5]. Increasing the hysteresis level and switching decision time reduces ping-ponging between the beams, reduces the required scan rate of the beam selection processor, and reduces problems associated with beam handoffs and deployment issues for multibeam antennas. However, increasing the dwell time on a particular beam reduces the effective gain of the multibeam antenna.

For the field tests, we evaluated the performance of a simple beam selection algorithm for switching times of 1 to 2.5 seconds and hysteresis levels of 1 to 3 dB. Figure 6 shows the received RSSI on the two center beams, 2 and 3, along with the beam selected by the scanning receiver, using a 2 dB hysteresis level and 2.5 second switching decision time. These parameters provided robust and repeatable performance without beam selection errors or ping-ponging. However, we did not see a significant difference in performance over the range of parameters tested. Note that as shown in [5], beam selection performance may vary for different propagation environments.

IV. CONCLUSIONS

In this paper we presented field test results obtained from our IS-136 Smart Antenna Test Bed showing the improvement in performance obtained using downlink smart antennas and power control for IS-136. The field test results show that our beamforming technique with a fixed multibeam beam antenna with power control provides additional gain and can closely track channel variations thereby requiring less margin and less average transmit power, while maintaining the C/I level needed for good signal quality. We showed that power control improves the C/I by 2 to 3 dB for a 1% BER for both vehicular and pedestrian fade rates when the uplink RSSI is used to estimate the downlink received power. The field test demonstrates the feasibility of using smart antennas on the uplink and downlink to increase both the range and capacity of the IS-136 system.

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