FORWARD LINK SMART ANTENNAS AND POWER CONTROL FOR IS-136

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Abstract--**In this paper we study the increase in range using smart antennas and transmit power allocation between beams on the forward link in IS-136. We consider the increase with fixed-beam antennas in low angular-spread environments, with transmit power allocation between beams with a total transmit power constraint. We compare the performance with a continuous downlink to that with a discontinuous downlink. With a total transmit power constraint, results show that the beamforming technique with a continuous downlink requires about 2 to 3 dB more peak transmit power than with a discontinuous downlink for the same coverage with four beams. Thus, most of the improvement of smart antennas and power control can be achieved even with the continuous downlink constraint by appropriate beamforming. Furthermore, with a handset performance loss with a discontinuous downlink of about 4 dB, the use of a discontinuous downlink with today's handsets will not result in an overall improvement in performance even with smart antennas.**

I. INTRODUCTION

Adaptive antenna arrays at the base stations have been shown to significantly increase the range and capacity of the uplink of the TDMA mobile radio system IS-136 [1,2,3]. However, for overall system improvement, we need to obtain range and capacity improvement on the forward link as well. Techniques that can be used by the base station to obtain these improvements include smart antennas, power control, and dynamic channel assignment [4,5].

However, in IS-136, use of these techniques is constrained by the requirement of a continuous downlink for all three time slots in each carrier. That is, the downlink beampattern and transmit power must remain the same for all users in each carrier. The carrier downlink beampattern and power can be optimized for the three users and adjusted at a rate perhaps as high as the Rayleigh fading rate (to adjust when users enter and leave the system), but cannot be changed between time slots without degrading the performance of the handsets (since most handsets use the information in the adjacent time slot to improve equalizer parameter tracking).

In this paper we study the increase in range using smart antennas and transmit power allocation between beams on the forward link in IS-136. We consider the increase with fixed-beam antennas in low angular-spread environments (in high angular spread environments, the range and capacity increases could be significantly lower [6], unless a significant portion of the signal power received from each user at the base station was within a small angle), with transmit power allocation with a total transmit power constraint. We compare the performance with a continuous downlink to that with a discontinuous downlink.

In Section II we discuss the range increase with downlink beamforming. A summary and conclusions are presented in Section III.

II. RANGE INCREASE

Here we consider and compare three techniques with downlink multibeam antennas for range increase: a discontinuous downlink, and a continuous downlink both with and without power allocation between beams, with a total transmit power constraint. We consider a fixed beam antenna with M non-overlapping beams over the coverage area, and assume the carriers are fully loaded, with random assignment of users to carriers. Both of these assumptions reduce the potential coverage area increase of the continuous downlink system relative to the discontinuous downlink system. With less than 100% loading, some carriers will have less than 3 users, resulting in greater coverage area for the continuous downlink system. However, most base stations use carrier packing, where the base station first attempts to assign new users to carriers with other users, which reduces the probability that carriers will have less than 3 users. Also, additional coverage area could be obtained with the continuous downlink system if new users were assigned to carriers with users in the same beam, or reassignments were used to group users in one beam in the same carrier. However, this would change the standard carrier assignment method and would require intracell handoffs.

The first technique we consider is a discontinuous downlink. For each user, one of M beams is chosen, resulting in an M-fold increase in received signal power. Thus, with a fourth-law power loss, an M-beam antenna provides a $\sqrt{M}$ increase in coverage area.

With the continuous downlink requirement, one technique is to turn on only those beams with users, with equal power in each beam. Thus, up to 3 beams can be turned on. With the total transmit power constraint, if all users are in one beam, the received signal power will be the same as that of the discontinuous case, but the power will be one-half and one-third of the discontinuous case if the users are in two and three beams, respectively. Since with random assignment of users to carriers, the probability of the three users being in N beams is given by

$$Pr(N) = \frac{1}{M^2}\begin{cases} 1 & N=1 \\ 3(M-1) & N=2(M>1) \\ (M-1)(M-2) & N=3(M>2) \end{cases} \quad ,(1)$$

the average coverage area increase (which is the square root of the average receive signal power increase) is given by

$$Coverage = M^{-3/2}\left[1 + \frac{(M-1)(M-2)}{\sqrt{3}} + \frac{3(M-1)}{\sqrt{2}}\right] \quad . \qquad (2)$$

The range with the continuous downlink requirement can be further increased by power allocation among the beams using a minimax criterion. Specifically, we adjust the power in each beam such that the minimum power received by any user in a carrier is maximized, with the total transmit power constraint. Thus, as shown in Figure 1, if two users were in one beam and one user was in another, and the greatest propagation loss was to a user in the first beam, then the transmit power in the first beam would be increased at the expense of the power in the second beam until the greater loss user in the first beam received the same signal power as the user in the second beam.

The average coverage area increase with this technique can be calculated as follows. With all users in the same beam, the received signal power is increased M-fold as before. With users in two beams, with received signal power P_1 and P_2 in one beam and P_3 in the second beam, the received signal power increase is given by

$$P_R = M\left[\frac{\max(P_a,P_3)}{P_a+P_3}\right] \quad , \qquad (3)$$

where

$$P_a = \min(P_1,P_2) \quad . \qquad (4)$$

With users in three beams, the received signal power increase is given by

$$P_R = \frac{M}{3}\left[1+\alpha_1+\alpha_2\right] \quad , \qquad (5)$$

where

$$\alpha_2 = \frac{P_2-P_3-\left[\dfrac{P_1-P_2}{P_1}\right]}{P_3+P_2+\dfrac{P_2P_3}{P_1}} \quad , \qquad (6)$$

and

$$\alpha_1 = 1 - \frac{P_2}{P_1}\left[\alpha_2-1\right] \quad . \qquad (7)$$

Note that the coverage area increase is just the square root of the above received signal power increase. Assuming uniformly distributed users with fourth-law propagation loss, we can show that

$$E\left[\left[\frac{\max(P_a,P_3)}{P_a+P_3}\right]^{1/2}\right] \approx 0.86 \quad , \qquad (8)$$

and

$$E\left[(1+\alpha_1+\alpha_2)^{1/2}\right] \approx 1.41 \quad . \qquad (9)$$

Thus, from (1), (3), (5), (8), and (9), the average coverage area increase is given by

$$Coverage \approx M^{-3/2}[1 + 0.814(M-1)(M-2) + 2.58(M-1)] \quad . \qquad (10)$$

The above results assume that the received signal power at the portable is accurately known at the base station. However, in IS-136, the portable sends received signal strength (RSSI) and BER measurements to the base station only once per second. Also, the RSSI is quantized in 2 dB steps, while the BER is quantized as in Table 1. For differential detection of DQPSK in a fading channel with additive white Gaussian noise, the BER is approximately given by

$$BER \approx \frac{1}{2(1+\rho/2)} \quad , \qquad (11)$$

where ρ is the received signal-to-noise ratio, and thus,

$$\rho \approx BER^{-1} - 2 \quad . \qquad (12)$$

Table 1 also shows the resulting quantized signal levels

TABLE 1

BER Quantization

Bit Pattern	BER Interval (%)	S/I (dB)
000	0.01 > BER	40
001	0.1 > BER ≥ 0.01	35
010	0.5 > BER ≥ 0.1	26
011	1.0 > BER ≥ 0.5	21
100	2.0 > BER ≥ 1.0	18
101	4.0 > BER ≥ 2.0	15
110	8.0 > BER ≥ 4.0	12
111	BER ≥ 8.0	10

using the BER information. Note that the BER data bits are a less accurate measure of the signal strength than the RSSI data bits. Therefore, for range extension, we will consider using the BER measurements to set the target RSSI level, and adjust the transmit power based on the RSSI measurement.

Thus, the accuracy of the received signal strength information at the base station is degraded both by the (up to) one second delay and quantization of the signal power information, with this degradation depending on the shadow fading statistics. These statistics in turn depend on the environment and portable velocity. To study this degradation, we used data collected during an IS-136 field trial [3]. This field trial was conducted in a suburban area with a vehicle speed ranging from 20 to 50 mph. Although the data was collected on the uplink, the downlink received signal power should be similar.

Figure 2 shows the measured received signal power for one data set from the field trial. Note that the received signal power varies significantly between measurements. Thus, filtering of the RSSI information will not improve the RSSI estimation, and therefore, we consider power allocation based only on the most recent measurement.

Figure 3 shows the probability distribution of the error in the RSSI estimate a) one second later, b) one second later using the quantized RSSI measurement, and c) one second later using the quantized BER measurement. For the RSSI and BER measurements, 1% of the time the measured value is in error by more than 4 and 7 dB, respectively.

To determine the effect of measurement error on the coverage area increase, we considered the following modification to the beamforming method. To compensate for a measurement accuracy of X dB, the difference in transmitted power between beams was reduced by X dB. Thus, with 2 beams, the received signal power increase (3) becomes

$$P_R = M\left[\frac{\max(P_b,P_c)}{P_b+P_c}\right] , \tag{13}$$

where

$$P_b = \begin{cases}\max(P_a-X,P_3) & \text{if } P_a>P_3 \\ P_a & \text{otherwise}\end{cases} , \tag{14}$$

and

$$P_c = \begin{cases}P_3 & \text{if } P_a>P_3 \\ \max(P_a,P_3-X) & \text{otherwise}\end{cases} . \tag{15}$$

With 3 beams, assuming without loss of generality that $P_1 \geq P_2 \geq P_3$, the received signal power increase (5) remains the same but with

$$\alpha_2 = \frac{P_2-P_e-\left[\frac{P_d-P_2}{P_d}\right]}{P_e+P_2+\frac{P_2P_e}{P_d}} , \tag{16}$$

and

$$\alpha_1 = 1 - \frac{P_2}{P_d}\left[\alpha_2-1\right] , \tag{17}$$

where

$$P_d = \max[P_1-X,P_2] , \tag{18}$$

and

$$P_e = \max[P_3+X,P_2] . \tag{19}$$

Now, by Monte Carlo simulation we can show that

$$E\left[\left[\frac{\max(P_b,P_c)}{P_b+P_c}\right]^{1/2}\right] \approx \begin{cases}0.86 & X=1 \\ 0.80 & X=4 \\ 0.77 & X=7\end{cases} , \tag{20}$$

and

$$E\left[(1+\alpha_1+\alpha_2)^{1/2}\right] \approx \begin{cases}1.36 & X=1 \\ 1.23 & X=4 \\ 1.15 & X=7\end{cases} , \tag{21}$$

and thus the coverage area increase is given by (10) with the appropriate modification of the coefficients.

Figure 4 shows the coverage area increase versus the number of beams with a discontinuous and with a continuous downlink. Results for the continuous downlink are shown without and with power allocation, where the power allocation is used with margins of 0, 4, and 7 dB. With a discontinuous downlink, the coverage area gain is $\sqrt{M}$. With a continuous downlink without power allocation, if the users were always in separate beams, the coverage area gain would be $\sqrt{M/3}$, but the curves show that, since sometimes users are in the same beam, the coverage gain is about $\sqrt{M/2.7}$. With a continuous downlink with ideal power allocation, the coverage area gain is about $\sqrt{M/1.5}$, making up most of the difference between the continuous without power allocation and discontinuous cases. However, margins of 4 and 7 dB significantly reduce this improvement.

III. CONCLUSIONS

In this paper we studied the increase in range using smart antennas and transmit power allocation on the forward link in IS-136. We considered the increase with fixed-beam antennas in low angular-spread environments, with transmit power allocation. With a total transmit power constraint, results showed that the beamforming technique with a continuous downlink requires about 2 to 3 dB more peak transmit power than with a discontinuous downlink for the same coverage with four beams. Thus, most of the improvement of smart antennas and power control can be achieved even with the continuous downlink constraint by appropriate beamforming. Furthermore, with a handset performance loss with a discontinuous downlink of about 4 dB, the use of a discontinuous downlink with today's handsets will not result in an overall improvement in performance even with smart antennas.

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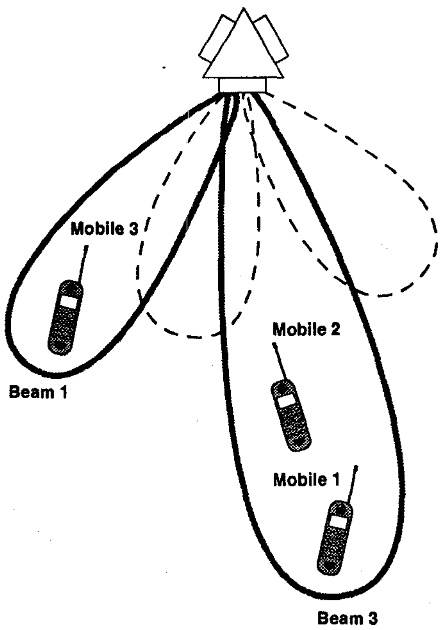

Fig. 1. Downlink with fixed beams and transmit power allocation.

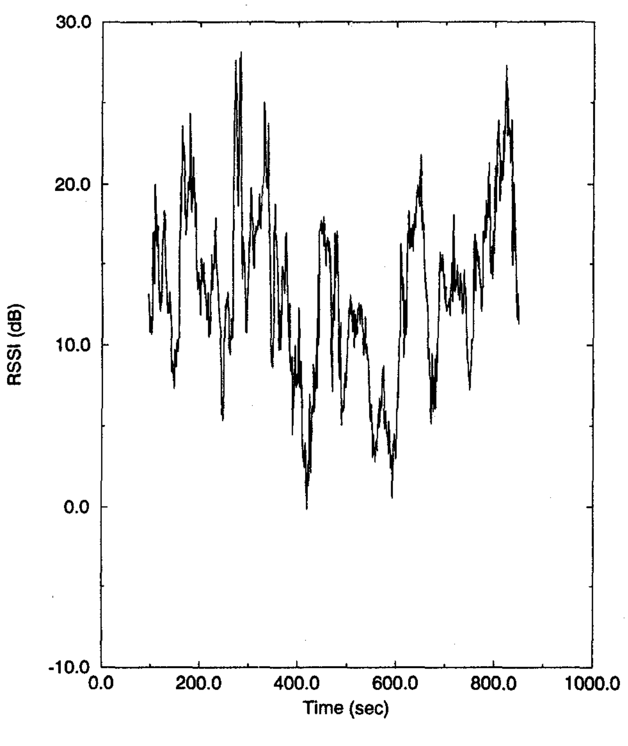

Fig. 2. The measured received signal power for one data set from the field trial.

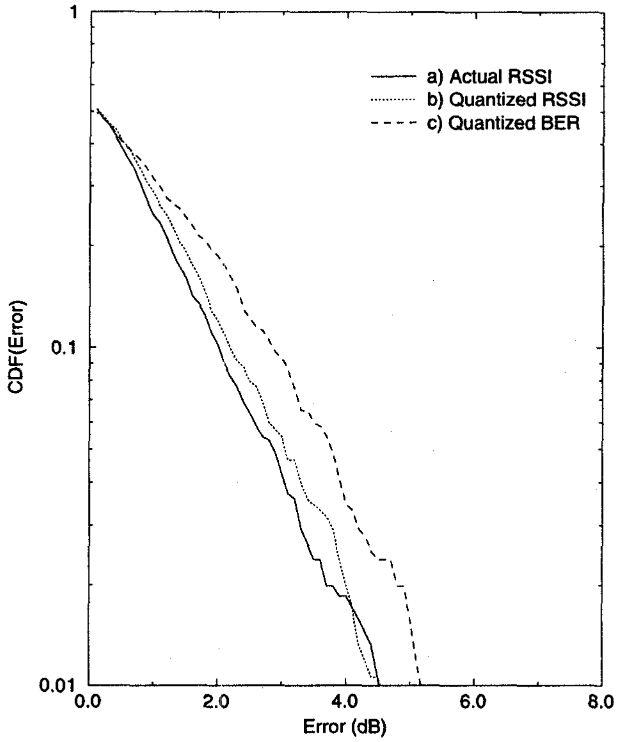

Fig. 3. The probability distribution of the error in the RSSI estimate a) one second later, b) one second later using the quantized RSSI measurement, and c) one second later using the quantized BER measurement.

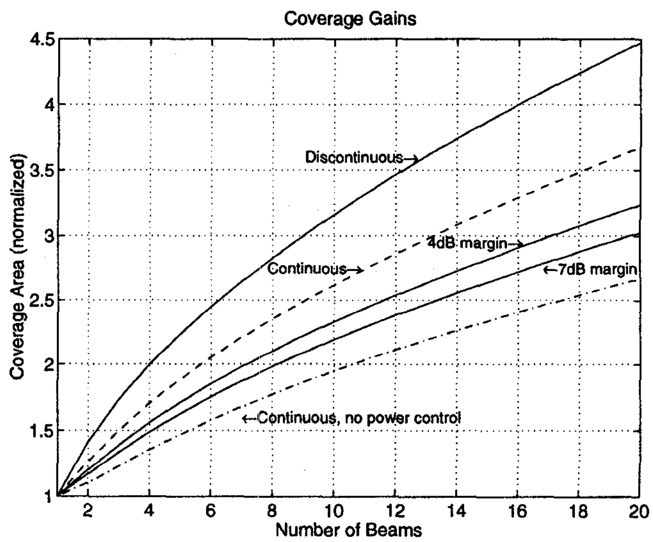

Fig. 4. The coverage area increase versus the number of beams with a discontinuous and with a continuous downlink.