Approximating the Outage Probability of the Pilot Channel for IS-95-Based Cellular CDMA Systems in the Soft Handover Region

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ABSTRACT—This letter presents an approximation of the outage probability of the pilot channel that can be used for CDMA cell planning. The approximation can determine system parameters for soft handover in IS-95-based cellular CDMA downlink design. Computer simulations show that our analytical results agree with empirical results.

Keywords—Pilot channel, outage probability, CDMA downlink design.

I. Introduction

Cellular CDMA systems based on the IS-95 standard are commercially available around the world. Korea continues to lead CDMA technology since the rollout of cdma2000. CDMA phones use rake receivers that allow reception of multiple base station signals simultaneously. Rake receivers enable CDMA phones to participate in soft handover between multiple base stations. There were three fingers in cdmaOne phones and four fingers in cdma2000 phones. When cellular CDMA providers design downlink coverage in the radio network, it is essential to examine the coverage of E_C / I_O, i.e., the ratio of the received pilot channel power to the total received signal power at the mobile station, since the CDMA soft handover mechanism is entirely based on E_C / I_O. There are several important parameters that have an effect on determining the value for E_C / I_O at the mobile station, such as the location of the mobile station, the number of mobile stations in the service cell and neighboring cells, and the pilot channel power for the wanted downlink. However, it is important for cellular CDMA providers to implement radio network planning in order to accelerate cellular CDMA service.

Several results have addressed the design and performance of the CDMA radio downlink by using the Monte-Carlo simulation [1]-[4]. In this letter, unlike in [1]-[4], we present an analytical expression to determine system parameters for the soft handover of the cellular CDMA systems based on the IS-95 standard.

II. Analytical Model

In general, the absolute threshold, for example T_ADD or T_DROP, are used in cdmaOne's or CDMA2000's soft handover mechanism. In this soft handover algorithm, the mobile station is connected to multiple base stations, corresponding to active sets, for a period of time. Thus, the outage probability of the pilot channel for cellular CDMA networks in the soft handover region is defined as

$$P_{out}(\delta) = \prod_{i=1}^{m} \Pr\left[\left(E_C / I_O\right)_i < \delta\right], \tag{1}$$

where m denotes the maximum number of active sets and is equal to the number of fingers in a mobile station. The m is 3 for cdmaOne and 4 for cdma2000. The δ represents the absolute threshold. The E_C / I_O for the i-th cell in the active set can be expressed as

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$$(E_C / I_O)_i = \frac{P_{pil} r_{i0}^{-\alpha} 10^{G_{i0}/10}}{h(P_{CO} + P_{tr}) r_{i0}^{-\alpha} 10^{G_{i0}/10} + \sum_{j=1}^{M} P_T r_{ij}^{-\alpha} 10^{G_{ij}/10} + \eta}, \tag{2}$$

where P_{pil} is the pilot channel power; P_{CO} denotes the common channel power excluded in the pilot channel; P_{tr} represents the average traffic channel power; P_T is the total transmit power summed of P_{pil}, P_{CO}, and P_{tr} in the downlink; h is the orthogonality factor in the home cell; G_{ij} is a Gaussian random variable with a zero mean and standard deviation σ_{ij}; r_{ij} is the distance between the base station in the *j*-th adjacent cell and the intended mobile station in the home cell described as the *i*-th serving cell, so that when *j*=0, the *j*-th adjacent cell is replaced by the home cell; α is the propagation path loss exponent; η represents the background noise power introduced by the thermal noise of the mobile station; and *M* denotes the number of adjacent cells.

However, power control in the downlink attempts to allocate the total transmitted power from the base station to its users according to their distances from the base station while maintaining a signal-to-noise ratio for all users in its cell above a minimal level. The transmitted power for the mobile located in a ring area at a distance *r* from its base station is controlled according to the following rule [5], [6]:

$$P(r) = \begin{cases} P_m \left(\frac{R_O}{R}\right)^2, & for\ r \le R_O \\ P_m \left(\frac{r}{R}\right)^2, & for\ R_O < r \le R, \end{cases} \tag{3}$$

where P_m is the maximum designed power to be delivered to mobiles at the cell boundary and *R* denotes the cell radius. The average traffic channel power transmitted from the base station is given by

$$P_{tr} = N \int_0^R P(r) f(r) dr, \tag{4}$$

where *N* is the total number of mobile users and $f(r)$ is the probability density function of the distance *r* between a mobile and the base station. The $(E_C / I_O)_i$ in (2) is dependent on the average traffic channel power P_{tr} determined by the mobile user spatial distribution. In this letter, we consider two user spatial distributions in [5] as follows:

- Uniform spatial traffic density

$$f(r) = \frac{2r}{R^2}, \quad for\ 0 < r < R. \tag{5}$$

- Truncated bell spatial traffic density

$$f(r) = \frac{2r}{R^2} erf\left(\sqrt{\pi}/2\right) \exp\left[-\frac{\pi}{4}(r/R)^4\right], for\ 0 < r < R. \tag{6}$$

By using (4), the average traffic channel power P_{tr} can be obtained respectively as follows:

- Uniform spatial traffic density

$$P_{tr} = \frac{1}{2} P_m N \left[1 + \left(\frac{R_O}{R}\right)^4\right]. \tag{7}$$

- Truncated bell spatial traffic density

$$\begin{aligned} P_{tr} = NP_m erf\left(\frac{\sqrt{\pi}}{2}\right) \Bigg\{ \left(\frac{R_O}{R}\right)^2 erf\left[\frac{\sqrt{\pi}}{2}\left(\frac{R_O}{R}\right)^2\right] \\ + \frac{2}{\pi}\left[\exp\left(-\frac{\pi}{4}\left(\frac{R_O}{R}\right)^4\right) - \exp\left(\frac{\pi}{4}\right)\right] \Bigg\}. \end{aligned} \tag{8}$$

Assuming $h = 1$, co-channel interference is dominant compared to the background noise and the $(E_C / I_O)_i$ can be rewritten as

$$(E_C / I_O)_i \approx \frac{\exp(X_i)}{\exp(Y_{i0}) + \sum_{j=1}^{M} \exp(Y_{ij})} \tag{9}$$

Because G_{i0} and G_{ij} are respectively zero mean Gaussian random variables with standard deviation σ_{i0} and σ_{ij}, the mean and variance of X_i, Y_{i0}, and Y_{ij} can be obtained as

$$\begin{aligned} &E(X_i) = \ln(P_{pil}) - \alpha \ln(r_{i0}),\ V(X_i) = \{[\ln(10)/10]\sigma_{i0}\}^2, \\ &E(Y_{i0}) = \ln(P_{CO} + P_{tr}) - \alpha \ln(r_{i0}),\ V(Y_{i0}) = \{[\ln(10)/10]\sigma_{i0}\}^2, \\ &E(Y_{ij}) = \ln(P_T) - \alpha \ln(r_{ij}),\ V(Y_{ij}) = \{[\ln(10)/10]\sigma_{ij}\}^2. \end{aligned} \tag{10}$$

The problem of computing the distribution of a sum of independent lognormal random variables has been studied extensively in the literature. However, in this letter, we use Schwartz-Yeh(SY) approximation because the SY approximation is valid in the case of different means and standard deviations. This implies that the distribution of a sum of independent lognormal random variables can be approximated as

$$\sum_{j=0}^{M} \exp(Y_{ij}) \approx \exp[Z_i(M)]. \tag{11}$$

By SY approximating, the mean $E[Z_i(M)]$ and variance $V[Z_i(M)]$ are recursively calculated by [7], [8]

$$\begin{aligned} E[Z_i(M)] &= E[Z_i(M-1)] + G_1\{E[W(M)], S[W(M)]\}, \\ V[Z_i(M)] &= V[Z_i(M-1)] - G_1^2\{E[W(M)], S[W(M)]\} \\ &\quad + G_2\{E[W(M)], S[W(M)]\} \\ &\quad - 2\frac{V[Z_i(M-1)]}{V[W(M)]} G_3\{E[W(M)], S[W(M)]\}, \end{aligned} \tag{12}$$

where $W(M)$ is assumed to be a Gaussian random variable with mean and standard deviation as follows:

$$\begin{aligned} E[W(M)] &= E(Y_{iM}) - E[Z(M-1)], \\ S[W(M)] &= \sqrt{V(Y_{iM}) + V[Z(M-1)]}. \end{aligned} \tag{13}$$

Note that $Z_i(0) = Y_{i0}(0)$, and G_1, G_2, and G_3 in (12) are given by

$$\begin{aligned} G_1\{E[W(M)], S[W(M)]\} &= E\{[\ln(1+\exp(W(M)))]\}, \\ G_2\{E[W(M)], S[W(M)]\} &= E\{[\ln^2(1+\exp(W(M)))]\}, \\ G_3\{E[W(M)], S[W(M)]\} &= E\{[W(M) - E(W(M))] \\ &\quad \cdot [\ln(1+\exp(W(M)))]\}. \end{aligned} \tag{14}$$

Therefore, the outage probability of the pilot channel at the mobile station with finger *m* in the soft handover region can be obtained as

$$P_{out}(\delta) = \prod_{i=1}^{m} \left\{ 1 - Q\left[\frac{\ln(\delta) - E(X_i) + E[Z_i(M)]}{\sqrt{V(X_i) + V[Z_i(M)]}} \right] \right\}. \tag{15}$$

III. Simulation

Let us consider the case that the cdma2000 mobile station is located in the soft handover region, as described in Fig. 1 [6]. Table 1 shows the distance of the wanted downlink when the *i*-th cell is in the active set. Recall that *m* is 3 for cdmaOne, 4 for cdma2000. The system parameters employed in this simulation are summarized in Table 2 [3], [4], [9].

Figure 2 illustrates the analytical expression for the outage probability of the pilot channel with respect to user spatial distribution and standard deviation. This figure reveals that the analytical curve given in (15) matches quite well with those obtained by the Monte-Carlo simulation. In addition, as we expected, the outage probability of the pilot channel increases as the value of the standard deviation σ_{ij} increases. The outage possibility is dependent on user spatial distribution because of the downlink power control. Equation (15) leads to an efficient method for assessing the outage probability of the pilot channel in the soft handover region and for investigating its sensitivity

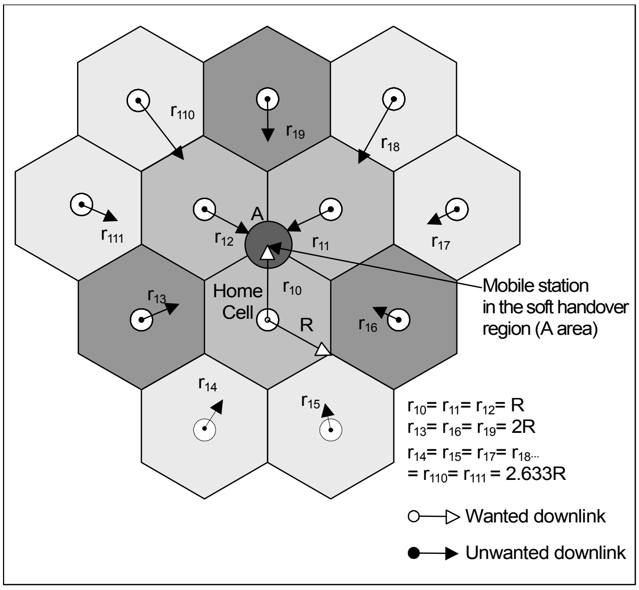

Fig. 1. Radio scenario for i=1.

Table 1. Distance of the wanted downlink.

i	Symbol in Fig. 1
1	r_{10}
2	r_{11}
3	r_{12}
4 (cdma2000)	r_{13}

Table 2. System parameters for the simulation.

Parameter	Value or type
N	25 (cdmaOne), 50 (cdma2000)
M	11
m	3 (cdmaOne), 4 (cdma2000)
P_{pil}	2.4 W
P_{CO}	1.14 W
σ_{ij}	5~17 dB
r_{ij}	See Fig. 1
α	3.76
R_m	1.2 W (cdmaOne), 0.7 W (cdma2000)
R_O	0.68 R
R	1000 m
d	–15 dB
Spatial distribution	Uniform or Bell type

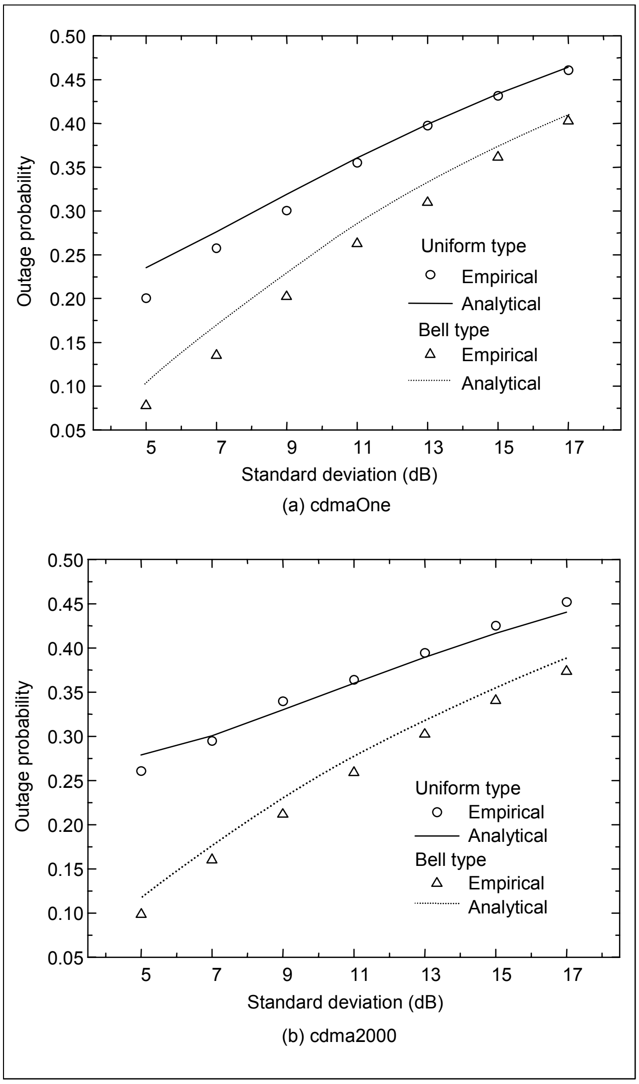

Fig. 2. Comparison of the analytical and empirical curves.

to propagation and system parameters. We can also use (15) to determine an optimum pilot channel power in CDMA downlink analysis.

IV. Conclusion

In this letter, we derived an analytical expression for the approximation of the outage probability of the pilot channel. Computer simulations show that our approximation agrees very well with the empirical curve. The proposed approximation can be employed in IS-95-based cellular CDMA downlink planning.

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