Reverse Link Capacity and Coverage Improvement Using Mobile Transmit Diversity

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1. Introduction

CDMA reverse link capacity is limited by interference caused by other users in the same bandwidth. The other-user interference is classified into two categories: same cell and other cell interference. Same cell interference is a function of power control accuracy and number of users within the cell. Other cell interference is a function of RF environment.

The ratio of other cell and same cell interference is generally represented by the factor f. In the past publications, only propagation loss and slow shadowing effect are taken into account to calculate the factor f. Under such assumptions, the same cell interference appears to be main part of total interference (f is about 0.6 in a typical RF environment). This approach was successful in illustrating the capacity improvement caused by soft handoff, but is not sufficient to demonstrate the benefit of handset transmit diversity.

In this report, we recalculate the factor f, following the same approach A. J. Viterbi described in his book, but adding fast Rayleigh fading into account. System capacity improvement is then evaluated based on new f factor and test results.

2. Propagation Model

In this discussion, system is limited to two-way soft handoff, but extension to three-way handoff is straightforward. Denote the base station of interest BTS_0, and other base stations $BTS_i \ (i = 1,2,..........)$. Let the total path loss from jth user to ith BTS be

$$L_{total}(i,j) = r^m(i,j) \bullet 10^{\zeta(i,j)/10} \bullet \lambda(i,j) \quad .... (1)$$

where the first two terms represent path loss due to propagation and slow shadowing, respectively. Experimental data suggest the choice of m = 4 for power law and $\sigma = 8$ for standard deviation of ζ, the log-normal shadowing.

$$L_{slow}(i,j) = r^m(i,j) \bullet 10^{\zeta(i,j)/10} \quad ....(2)$$

The shadowing is considered to have to contributors: near field effect of the mobile that is independent of propagation path, and the one only associated with propagation path.

$$\zeta(i,j) = a\xi + b\xi(i,j)$$

$$a^2 + b^2 = 1$$

$$E(\xi) = E(\xi(i,j)) = 0$$

$$Var(\xi) = \mathrm{var}(\xi(i,j)) = \sigma^2$$

$$E(\xi \cdot \xi(i,j)) = 0$$

$$E(\xi(i',j') \cdot \xi(i,j)) = 0, \quad \text{for all distinct pair}$$

The third term of (1) is contributed by fast fading. For the reason of simplicity, we assume single path between each antenna pair. For a user with single transmit antenna, fading loss can be written as

$$\lambda(i,j) = \frac{1}{\rho^2(i,j)} \quad \text{..............................} \ (3)$$

For a user with dual transmission antenna, if total power is equally split into each antenna and only phase is adjusted so that signals from two antennas are coherently added when they arrive base station antenna, then it can be shown the equivalent fading loss is

$$\lambda(i,j) = \frac{2}{(\rho_1 \ (i,j) + \rho_2 \ (i,j))^2} \quad \text{...........................} \ (4)$$

If the user also adjusts its power distribution between two antennas to achieve the optimum reception at base station, then

$$\lambda(i,j) = \frac{1}{\rho_1^{\,2}(i,j) + \rho_2^{\,2}(i,j)} \quad \text{..............................} \ (5)$$

In the above equations (3) to (5), $\rho(i,j)$ is random variable following Recian distribution.

3. Formulation of Interference from Other Cells

To simplify the calculation of the interference from other cell, we first divided users into two categories according to their geometrical locations. When a user is in S_o as shown in Figure 1, it can be in soft handoff with BTS_0. When a mobile is in its complementary region $\overline{So}$, BTS_0 will not be involved in handoff with that user.

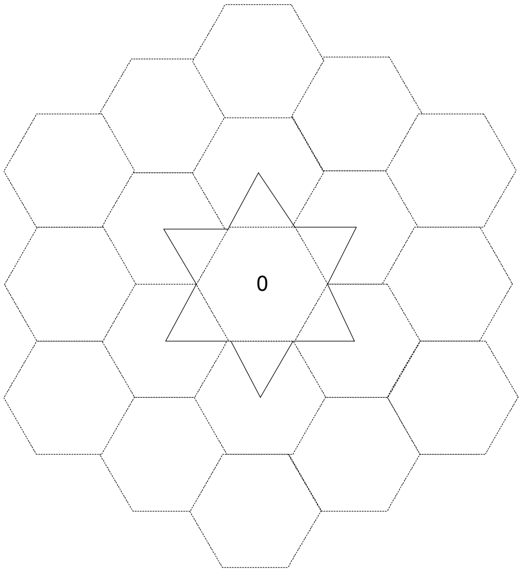


Figure 1. S_o region for a two way handoff network

The total other cell interference can be written as:

$$I_o = I_{So} + I_{\overline{So}}$$

where I_{So} and $I_{\overline{So}}$ is the interference from users within geometrical region S_o and its complementary part $\overline{So}$. Within S_o, any mobile that is communicating with one of the six nearest neighbors will introduce interference to BTS_0, but this only happens when path loss to that neighbor is less than to BTS_0, In which case the mobile is power controlled by that neighbor. Since soft handoff (SO) is a relatively slow procedure, we assume here SO status is only determined by power law propagation low and slow log-normal shadowing. After normalizing cell radius, we also assume the mobile transmission power is upper-bounded by $P_{m\arg in}$.

Letting the nearest neighbor BTS_1, it is easy to show:

$$I_{So} = \iint_{So} E\left[\frac{\min\left(L_{total}(1,j), P_{m\arg in}\right)}{L_{total}(0,j)}; L_{slow}(1,j) < L_{slow}(0,j)\right]\kappa \bullet dA(x,y) \quad \text{.... (6)}$$

and outage rate

$$p_{out0} = \underset{So}{\Pr oc}\left(L_{total}(1,j) > P_{m\arg in}; L_{slow}(1,j) < L_{slow}(0,j)\right) \quad \text{....................(7)}$$

When mobile is in $\overline{So}$, BTS_0 will not be in soft handoff. Letting the two nearest neighbors BTS_1 and BTS_2, we can further divide interference into

$$I_{\overline{So}} = I_1 + I_2$$

where

$$I_1 = \iint_{So} E\left[\frac{\min\left(L_{total}(1,j), P_{m\arg in}\right)}{L_{total}(0,j)}; L_{slow}(1,j) < L_{slow}(2,j)\right]\kappa \bullet dA(x,y) \quad \text{......... (8)}$$

and

$$I_2 = \iint_{So} E\left[\frac{\min\left(L_{total}(2,j), P_{m\arg in}\right)}{L_{total}(0,j)}; L_{slow}(2,j) < L_{slow}(1,j)\right]\kappa \bullet dA(x,y) \quad \text{....... (9)}$$

The outage rate when user in region $\overline{So}$ is

$$p_{out1} = \frac{1}{2}(P_1 + P_2) \quad \text{..(10)}$$

where

$$P_1 = \Pr_{\overline{So}} oc\left(L_{total}(1,j) > P_{m\arg in}; L_{slow}(1,j) < L_{slow}(2,j)\right) \quad \text{...........................(11)}$$

and

$$P_2 = \Pr_{\overline{So}} oc\left(L_{total}(2,j) > P_{m\arg in}; L_{slow}(2,j) < L_{slow}(1,j)\right) \quad \text{.........................(12)}$$

In the equations above, κ is the user density (number of users per unity area), defined as

$$\kappa = \frac{2K_u}{3\sqrt{3}}$$

where K_u is the average number of users per cell. Finally we have other-cell user interference

$$f = \frac{I_o}{K_u} = \frac{2}{3\sqrt{3}} \bullet \left(I_{So} + I_{\overline{So}}\right)$$

and outage rate

$$P_{out} = \text{avg}(P_{out0}, P_{out1})$$

where function $\text{avg}(\ )$ is weighted average.

4. System Capacity Improvement

The reverse link capacity of a CDMA system is approximated as

$$K_u \approx \frac{C}{1+f}$$

where C is an constant, determined by factors such as bandwidth, spreading gain, voice activity and base station antenna gain etc..

As will be shown below, mobile transmit diversity dramatically reducing f factor, therefore, increases the capacity.

$$\eta = \frac{1+f_{no}}{1+f_{di}} \tag{13}$$

where f_{no} and f_{di} are other cell interference factor of a user without and with diversity.

5. Numerical Results

In all the numerical results calculation, we assume mobile only adjusts its phase. Table 1 and 2 is the numerical results for Rayleigh fading based on Equation (6), (8) and (9), for a conventional and diversity phone, respectively. Fast fading effect is included. Table 3 and 4 include outrage rate for a normal and diversity phone.

Table 1: f factor of a convention phone, $P_{m\arg in} = 14dB$

o^2	0	2	4	6	8	10	12
m=3	3.99	4.05	4.40	5.24	7.04	11.16	19.26
m=4	2.38	2.36	2.34	2.82	3.46	4.98	9.08
m=5	1.68	1.56	1.66	1.77	2.19	3.12	4.68

Table 2: f factor of a diversity phone, $P_{m\arg in} = 14dB$

o^2	0	2	4	6	8	10	12
m=3	1.26	1.27	1.31	1.55	2.04	3.32	6.06
m=4	0.80	0.76	0.78	0.87	1.09	1.54	3.10
m=5	0.62	0.55	0.59	0.61	0.69	0.95	1.63

Table 3: Outage rate (%) of a normal phone, $P_{margin} = 14dB$, K=0

σ^2	0	2	4	6	8	10	12
m=3	0.76	0.77	0.80	0.87	0.96	1.13	1.34
m=4	0.60	0.60	0.61	0.67	0.75	0.90	1.10
m=5	0.46	0.46	0.49	0.54	0.61	0.72	0.88

Table 4: Outage rate (%) of a diversity phone, $P_{margin} = 14dB$, K=0

σ^2	0	2	4	6	8	10	12
m=3	0.006	0.006	0.008	0.011	0.022	0.0046	0.10
m=4	0.004	0.004	0.005	0.008	0.016	0.034	0.075
m=5	0.003	0.004	0.004	0.006	0.012	0.026	0.055

It can be seen from the tables that transmit diversity reduces both interference from other cell and reverse link outage rate. The outage rate can be adjusted by changing power margin P_{margin}. To maintain the same outage rate, a diversity phone requires less power margin, therefore, increases coverage. Figure 2 shows the other cell interference as a function of outage rate in a typical RF environment of m=4, $\sigma = 8$. It can be seen, for 2% outage rate, f factor of a normal phone is about 2.8 and 2.3 for Rayleigh fading and Recian fading with K=1, respectively. For a diversity phone, it is 0.9 and 0.6. Plugging these numbers into equation (13), we will have capacity improvement of about 100%. Figure 2 is generated by adjusting power margin from 2 to 14 dB with 2 dB step size. From the figure, it can also be seen, at 2% outage rate, mobile diversity reduces power margin by about 6 dB, which means, double the coverage.

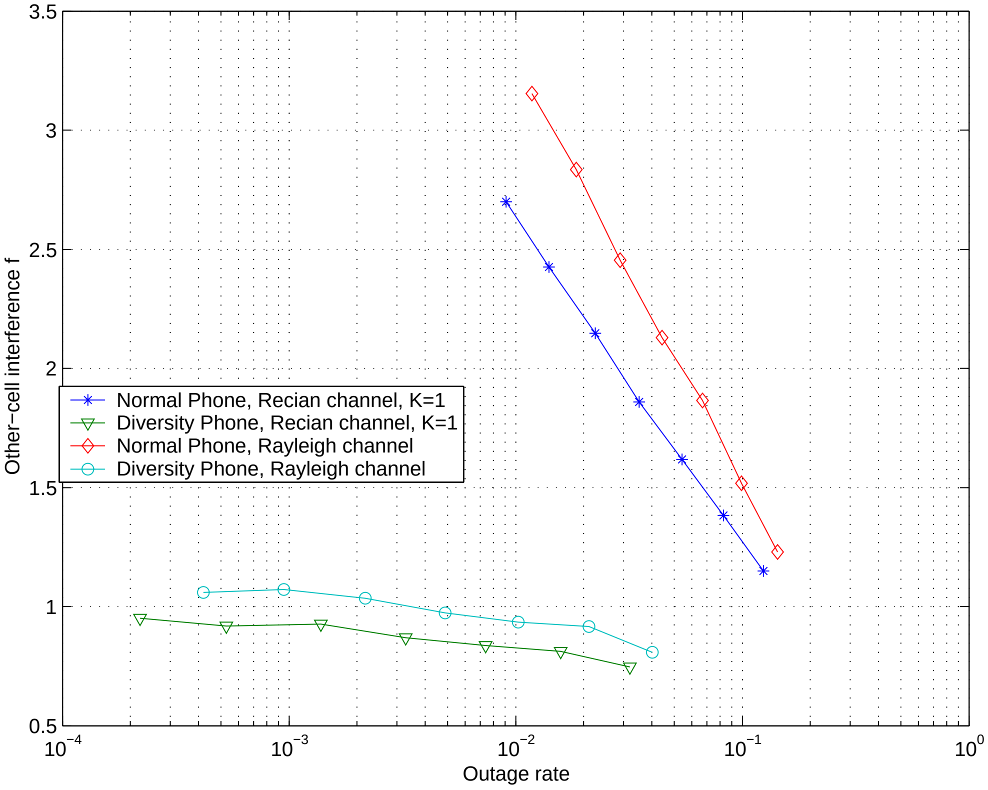
Numerical results for a Recian channel are also shown in table 5 and 6.

Table 5: f factor of a normal phone, $P_{margin} = 14dB$, K=1

σ^2	0	2	4	6	8	10	12
m=3	3.26	3.35	3.62	4.32	5.87	9.02	16.43
m=4	1.92	1.90	2.06	2.34	2.91	4.29	7.98
m=5	1.41	1.37	1.39	1.53	1.84	2.54	3.97

Table 6: f factor of a diversity phone, $P_{margin} = 14dB$, K=1

σ^2	0	2	4	6	8	10	12
m=3	1.09	1.07	1.14	1.35	1.74	3.06	5.26
m=4	0.70	0.67	0.69	0.77	0.94	1.51	2.39
m=5	0.51	0.49	0.50	0.53	0.59	0.85	1.43



6. Conclusions

In a realistic wireless environment with fast fading in presence, interference from the users of other cells is significant compared to the same cell interference. Mobile transmit diversity dramatically reduces other cell interference factor f and average mobile transmission power. As a result, system capacity improves to about 200% in a typical wireless environment. Also, mobile transmit diversity reduces the power margin that maintains certain outage rate, therefore, improves site coverage.

This is only the first attempt to address capacity and coverage improvement by utilizing mobile transmit diversity. Further work will include the issues such as the impact of multipath and base station receive diversity.

7. References

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