Performance of Cellular CDMA with Truncated and Limited Power Control Schemes in Presence of Soft Handoff

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ABSTRACT

Effects of soft handoff on the performance of three power control schemes in cellular CDMA are investigated. Outage performance of truncated and limited power control schemes is studied incorporating soft handoff and compared with a conventional strength based power control. The effects of truncation/ limitation probabilities, power control error (pce), soft handoff parameters and shadowing correlation on the performance of these power control schemes have also been indicated. While truncation performs better for higher range of traffic intensity, power limitation is found to out perform both conventional and truncation schemes for lower traffic.

Key Words -- Power control, soft handoff, CDMA.

I. INTRODUCTION

Code division multiple access (CDMA) is a potential access technique for supporting multimedia services in wireless networks. One of the important features of CDMA is 'soft hand off' where the hand off (HO) mobile near a cell boundary transmits to and receives from two and more BS-s simultaneously [5]. Soft HO offers a smooth transfer of radio link than a traditional hard HO where the MS is only allowed to connect to one base station (BS) at a time. Soft HO provides a seamless connectivity in contrast to hard HO by allowing a 'make before break' connection. It also provides other advantages such as reduction of so called 'ping-pong' effect in hard HO, reduction in probability of lost call, ease of power control etc. [5]. Since a mobile (MS) is power controlled by the BS which requires the least power, soft HO extends the coverage area and increases the reverse link capacity [4] as the overall interference is reduced. Soft HO has been shown to improve outage performance in [3], which incorporates the shadowing correlation and interaction of power control in the analysis.

Power control on the other hand is one effective way to combat near-far problem and improve the cellular capacity [2]. Power control ensures that the received signal strength of all users at BS are almost equal. The power variation due to distance dependent path loss and shadowing can be overcome by using transmit power control. A large number of power control algorithms have been suggested in the literatures such as strength based, SIR based etc [2]. An interesting power control scheme called "truncated power control scheme" has been analyzed in [1]. In this scheme the power transmission from a mobile is suspended when the mobile is in deep fading and thereby the mobile goes into outage.

This saves the battery power but the mobile has to try for network access again. In a limited power control scheme, the transmitted power from the mobile is limited to a reduced level instead of completely suspending the transmission [6]. Though the service quality may be severely affected but the call may survive if the mobile goes in deep fading for a short duration only. In that case it will not have to try again for accessing the network since the communication link has been maintained.

In this paper we carryout simulation to study outage performance of cellular CDMA under different power control schemes (truncation/ limitation). We investigate the effects of soft handoff parameters such as degree of soft handoff, shadowing correlation, power control error. We simulate two power control schemes truncated power control and limited power control and compare their performance in presence of soft handoff. The power control is assumed to be imperfect. The effects of power control parameters are also investigated on the outage performance.

The paper is organized as follows. Section II and III describe the cellular scenario and our simulation model. Results and discussions are presented in section IV. Finally we conclude in section V.

II SYSTEM MODEL

A cluster of three sectored cells with uniformly distributed mobile users (MS) and an equal number of MS-s (N_d) per sector is considered. All users transmit at the same rate. The user transmits on a single code at a transmission rate R_b , the processing gain (pg) of all codes are equal, where $pg = W / R_b$; W is the spread bandwidth. The soft HO region is defined based on the distance from the base station (BS) as in Fig.1. An MS located outside the HO boundary R_h is considered to be under soft HO with three neighboring BS-s. Each sector is divided into two regions, soft HO regions (B, C, D) and non-HO region (A, E, F) of cell #0,1and 2 in Fig.1. BS_0, BS_1 and BS_2 are the BS-s of cell #0, 1 and 2 respectively. The propagation radio channel is modeled as in [3]. The link gain for a location (r,θ) is given

as $G_i(r,\theta) = d_i(r,\theta)^{-\alpha_p} 10^{\xi_S/10}$ (1)

where $d_i(r,\theta)$ is the distance between the MS and BS_i, α_p is the path loss exponent and $10^{\xi_s/10}$ is the log-normal component with ξ_s normally distributed with 0 mean and variance σ_S^2. The shadow fading at i-th BS is expressed as [3, 4]

$\xi_{s-i} = a\zeta + b\zeta_i$ with $a^2 + b^2 = 1$ (2)

ζ and ζ_i are independent gaussian random variables with zero mean and variance σ_s^2.

$$\frac{E[\zeta_{s-i}\zeta_{s-j}]}{\sigma_S^2} = a^2 \quad i \neq j \tag{3}$$

Interference from two adjacent sectors of neighboring cells i.e. region (E, C) of cell #1 and region (D,F) of cell #2 are considered. We focus our analysis on the reverse link. Two power control schemes namely, truncated scheme and limited power control scheme are studied and compared with a conventional strength based power control. Power control is assumed to be imperfect. In conventional strength based power control, the transmitted power from a mobile:

$S(G_i) = (S_R/G_i)e^{r_n}$ (4)

where S_R is the target power, G_i is the channel power gain as in eqn (1), r_n is the Gaussian random variable (r.v)with 0 mean and standard deviation σ. Expressing σ in dB we have $\sigma_e = \sigma/\lambda$ where $\lambda = \ln(10)/10$ and σ_e is pce in dB.

With truncated power control the 'k'th mobile estimates the propagation gain G_k and adjusts its transmission power as [1]

$$S(G_i) = (S_R/G_k)e^{r_n} \qquad G_k \geq \gamma_0$$
$$= 0 \qquad \text{otherwise} \qquad (5)$$

where γ_o is the cut-off fade depth. With power limiting scheme, the transmitted power is adjusted to compensate for shadowing and path loss above a certain cut-off fade depth γ_o, below which transmitted power is fixed at a level. Thus for 'k' th mobile transmitted power

$$S(G_k) = (S_R/G_k)e^{r_n} \qquad G_k \geq \gamma_d$$
$$= (S_R/K\gamma_d)e^{r_n} \qquad G_k < \gamma_d, \quad K = 1,2,3\ldots \qquad (6)$$

K is the power limiting factor which is an integer.

The desired user is assumed to be located anywhere in the reference sector. The interference due to other MS-s in reference sector and due to MS-s in E, C, D and F are generated for three power control schemes i.e. conventional strength based, truncated and limited.

III SIMULATION MODEL

Now we describe the simulation steps. The following parameters are considered: PR_h indicates the degree of soft handoff. The soft HO region boundary R_h given as $R_h = R_c\sqrt{1 - PR_h}$ where R_c is the radius of the cell, normalized to unity and hexagonal cell is approximated by a circular one with radius R_c. Users are assumed to be uniformly distributed.

1. The location of a desired user is generated and is checked whether the desired user is in soft HO region or non HO region. If it is in non HO region, it is power controlled by BS_0 else it is power controlled by any one of BS_0, BS_1 or BS_2.
2. Position (r,θ) of rest ($N_d - 1$) interfering users are generated in reference sector assuming users are distributed uniformly. Let K_d number of users is in soft HO region and $(N_d - K_d - 1)$ users are in non-HO region.
3. For each of those in soft HO region (K_d) and reference user if it is in soft HO, the link gains corresponding to each of three BS-s involved in soft HO are generated as

$$G_R(r,\theta) = r_0^{-\alpha_p} e^{\xi_R} \quad G_1(r,\theta) = r_1^{-\alpha_p} e^{\xi_1}$$
$$G_2(r,\theta) = r_2^{-\alpha_p} e^{\xi_2} \tag{7}$$

where ξ_R, ξ_1 and ξ_2 are Gaussian r.v-s with 0 mean and variance $b^2\sigma_s^2$. G_R, G_1, G_2 are the link gains of BS_0, BS_1 and BS_2 respectively. r_0, r_1 and r_2 are the distances from BS_0, BS_1 and BS_2 respectively. The user is power controlled by the BS for which the link gain is maximum i.e. it is power controlled by

(i) BS_0 if $G_R > G_1$ and $G_R > G_2$

(ii) BS_1 if $G_1 > G_R$ and $G_1 > G_2$

(iii) BS_2 if $G_2 > G_R$ and $G_2 > G_1$ (8)

After deciding the BS which power controls an MS, truncation and limitation algorithms are applied (if necessary) for these handoff mobiles on comparing their respective link gains with threshold (γ_o) for the respective cases of truncation /limitation.

(a) For conventional power control, interference received at reference BS (i.e. BS_0)

$$\text{I} = S_R \exp(r_n) \qquad \text{if connected to } BS_0$$
$$= S_R \exp(r_n)\left(\frac{G_R}{G_1}\right) \quad \text{if connected to } BS_1$$
$$= S_R \exp(r_n)\left(\frac{G_R}{G_2}\right) \quad \text{if connected to } BS_2 \qquad (9)$$

(b) For truncation case interference received:

$$I = \begin{cases} S_R \exp(r_n) & G_R \ge \gamma_0 \\ = 0 & G_R < \gamma_0 \end{cases} \quad \text{if connected to BS}_0$$

$$I = \begin{cases} (S_R/G_1) G_R \exp(r_n) & G_1 \ge \gamma_0 \\ = 0 & G_1 < 0 \end{cases} \quad \text{if connected to BS}_1$$

$$I = \begin{cases} (S_R/G_2) G_R \exp(r_n) & G_2 \ge \gamma_0 \\ = 0 & G_2 < 0 \end{cases} \quad \text{if connected to BS}_2 \qquad (10)$$

(c) For limitation case interference received:

$$I = \begin{cases} S_R \exp(r_n) & G_R \ge \gamma_0 \\ = (S_R/K\gamma_o) \exp(r_n) & G_R < \gamma_0 \end{cases} \quad \text{if connected to BS}_0$$

$$I = \begin{cases} (S_R / G_1) G_R \exp(r_n) & G_1 \ge \gamma_0 \\ = (S_R/K\gamma_o) G_R \exp(r_n) & G_1 < \gamma_0 \end{cases} \quad \text{if connected to BS}_1$$

$$I = \begin{cases} (S_R / G_2) G_R \exp(r_n) & G_2 \ge \gamma_0 \\ = S_R/K\gamma_o) G_2 \exp(r_n) & G_2 < \gamma_0 \end{cases} \quad \text{if connected to BS}_2 \qquad (11)$$

r_n is a normal distributed r.v. with 0 mean and standard deviation σ_e (dB). S_R is the required received power at the respective BS which is normalized to unity in the simulation. Since the outage probability will depend on SIR, assigning S_R=1 will not affect the simulation. The total interference power (I_1) for all 'K_d' interfering mobiles are found by summing the individual interference contribution.

4. Next MS-s in non HO region (A) of reference cell is considered. Each of ($N_d - K_d$) interfering user is power controlled by BS_0, hence the interference generated in conventional power control case

$$I_2 = S_R \sum_{i=1}^{N_d - K_d} e^{r_{n,i}} \qquad (12)$$

Link gains of each of ($N_d - K_d$) non HO Ms-s are compared w.r.t threshold (γ_0) for applying truncation and limitation to the MS-s in the respective power control schemes and received power is derived following eqn (9) to (11) for truncation/limitation scheme.

5. Now the interference contributed by MS-s in the adjacent sectors (i.e. region E, C, D and F) of cell #1 and #2 are found in similar manner For cell #1 and #2, the number of MS-s in region E and F considered for interference are ($N_d - K_d$). Let the interference from cell #1 and cell #2 are I_3 and I_4 respectively. Hence total interference at BS_0 $\quad I = I_1 + I_2 + I_3 + I_4 \qquad (13)$

6. Received power from the desired user is U. It is generated according to its location in soft HO or non HO region. After checking the link gains, truncation /limitation is applied to desired user depending on the situation under these two power control schemes.

7. SIR = U / I is generated and compared with the threshold $\gamma'_{th} = (\gamma_{th} / pg)$ to decide for outage. If $SIR < \gamma'_{th}$, a counter (indicating the number of outage) is incremented. If desired user is truncated, received power from desired user becomes zero (U = 0) and the counter indicating the outage is incremented.

8. Steps 1-8 are repeated for a large number of times ensuring at least 95% confidence interval in simulation of outage probability.

9. Also a counter is maintained to count the number of times a desired user goes into truncation or power limitation.

IV RESULTS AND DISCUSSION

Using the above simulation model we study the effects of soft handoff (PR_h), shadowing correlation (a^2), pce(σ_e) on the outage probability due to truncation/limitation power control for different truncation/limiting probabilities $p(\gamma_0)$ and compare the performance with strength based power control. Following parameters are assumed: $\alpha_p = 4$, σ_s = 8 dB, spread bandwidth W = 5 MHz, processing gain $pg = 128$, SIR threshold γ_{th} = 6 dB. Soft handoff parameter PR_h is chosen as 0, 0.3, and 1.0. Several values of pce σ_e = 0.5, 1.5 and 2 dB are chosen. Two values of shadowing correlation a^2 = 0, 0.6 are selected. Three values of truncation/limitation probabilities i.e. $[1 - p(\gamma_0)]$ = 10^{-1}, 10^{-2} and 10^{-3} for corresponding values of γ_0 as 1.116, 0.59 and 0.3955 are used [1]. Power-limiting factor K = 3 is assumed.

Fig.2 shows the relative outage performance of three power control schemes. With increase in traffic intensity, outage probability increases. For lower range of traffic (up to 7 MS s/ sector), power limitation yields lower outage as compared to truncation (curve Δ---Δ and o---o). The outage probability for truncation has two components: (i) outage due to truncation of the desired user when its G_k satisfies $G_k < \gamma_0$, the probability of which is $1 - p(\gamma_o)$. (ii) When the desired user is not truncated but its SIR falls below the threshold causing outage probability P'_{out}. Hence total outage probability

$$PR_{out} = (1 - p(\gamma_o)) + p(\gamma_o) P'_{out} \qquad (14)$$

In truncation scheme there is event of forceful outage of the desired user when its $G_k < \gamma_0$. For lower range of traffic this feature dominates yielding higher outage than limitation, where as in limitation scheme a user goes into outage only when the SIR is below the threshold. It may be noted that there is no forceful outage in power limiting case. For higher ranges of traffic, the second component of the truncation scheme [second term in equation (14)] dominates over the first and truncation is found to yield less outage.

Higher value of truncation / limitation probability i.e. [1- p(γ_0)], reduces the interference by putting more interfering users in truncation/ limitation mode and thereby achieves lower outage (curve o---o, .----. and curve *---* , Δ---Δ) for medium and high range of traffic (more than 7 Ms-s in limitation and 10 Ms-s in truncation). For higher range of traffic strength based power control gives higher outage as compared to the other two. However for lower traffic range the conventional scheme yields lower outage as compared to truncation because forceful outage of desired user is not present in strength based power control.

Fig.3 shows the effect of degree of soft handoff (PR_h) on limiting power control scheme. With increase in PR_h, more MSs are likely to go into soft handoff, which reduces the overall interference, and the outage probability is reduced while other parameters are same. Thus as PR_h increases from 0 to 0.3 and 1.0 the outage probability reduces. For example as the situation changes from hard HO (PR_h= 0) to a complete soft HO (PR_h= 1.0), the outage probability reduces from 0.3030 to 0.1912 for MS = 7 users/ sector.

Effect of power control error (pce) on outage is depicted in Fig.4. For higher valueas of pce, interference increases which increases the outage probability. Thus we observe an increase in outage probability as pce (σ_e) is increased from 0.5 dB to 2.0 dB for same number of users and identical values of other parameters. Outage due to conventional scheme for pce 1.5 dB is also plotted to compare it with the limiting case with pce = 1.5 dB.

In Fig.5 we show the effect of shadowing correlation on the outage performance. Increasing the shadowing correlation (a^2) has the same effect as reducing σ_s of non-HO mobiles for our assumed correlation model [3]. Hence for a given soft HO (PR_h = 0.3), interference contribution by non-handoff MS-s decreases. As a^2 is increased from 0 to 0.6, outage probability reduces significantly in both truncation and limiting power control schemes [curve *---*, o---o and Δ---Δ, ---.].

V CONCLUSIONS

We have simulated the outage performance of truncation, limitation and strength based power control schemes in presence of soft handoff in a three sectored CDMA cellular environment with imperfect power control. The outage performance is studied for various parameters of soft handoff like degrees of soft handoff, shadowing correlations and power control parameters like truncation/ limitation probabilities, power control error. Higher degree of soft handoff (PR_h) reduces outage probabilities for all three cases of power control. Increase in shadowing correlation reduces the outage probability. Power limiting algorithm yields a lower outage as compared to truncation and strength based power control for lower traffic range but truncation is found to outperform the other schemes for considerable increase in traffic intensity. Higher values of limitation/ truncation probability reduce the outage probability for medium and high traffic intensity. Further outage probability increases with higher power control error.

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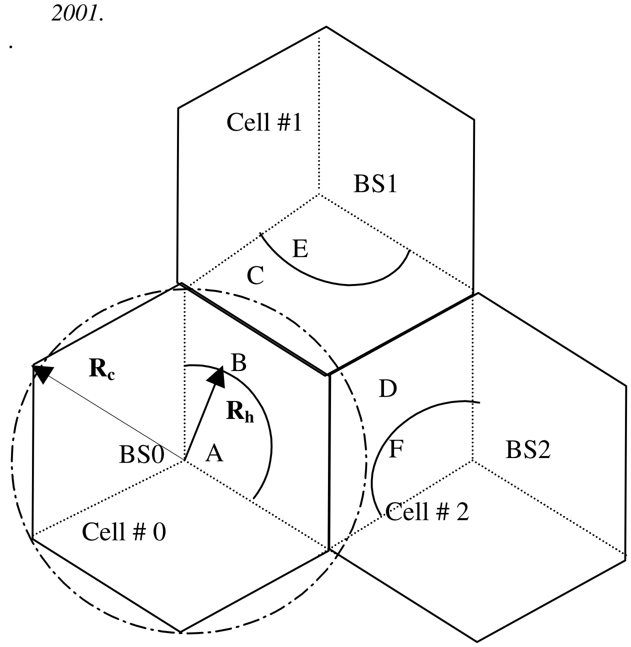

Fig.1 Cellular Layout for soft HO. A, E, F are non HO region. B, C, D are soft HO region. Cell # 0 is reference cell.

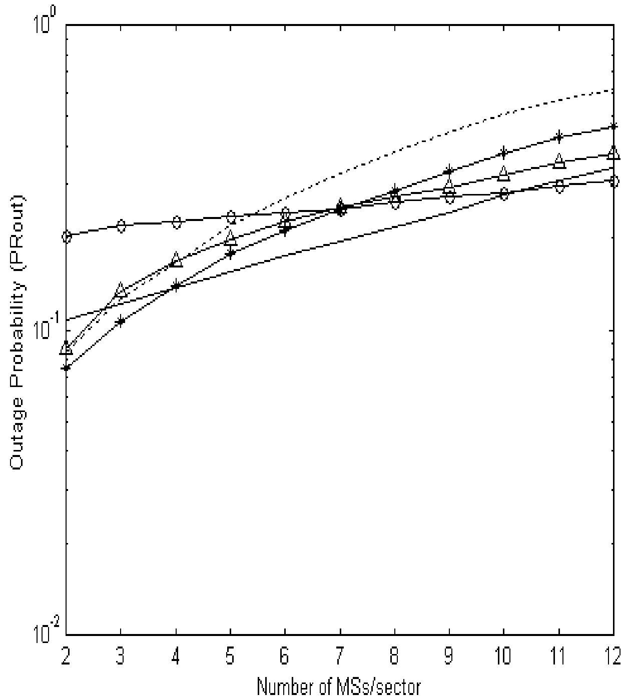

Fig. 2. Outage performance of three power control schemes
$PR_h = 0.3$, $K = 3$, $\sigma_s = 8$ dB, $\sigma_e = 2$ dB
.... Conventional power control
----- Limited power control for $[1- P(\gamma_0)] = 10^{-3}$
·------· Truncated Power control for $[1- P(\gamma_0)] = 10^{-3}$
Δ----Δ Limited power control for $[1- P(\gamma_0)] = 10^{-1}$
o-----o Truncated power control for $[1- P(\gamma_0)] = 10^{-1}$

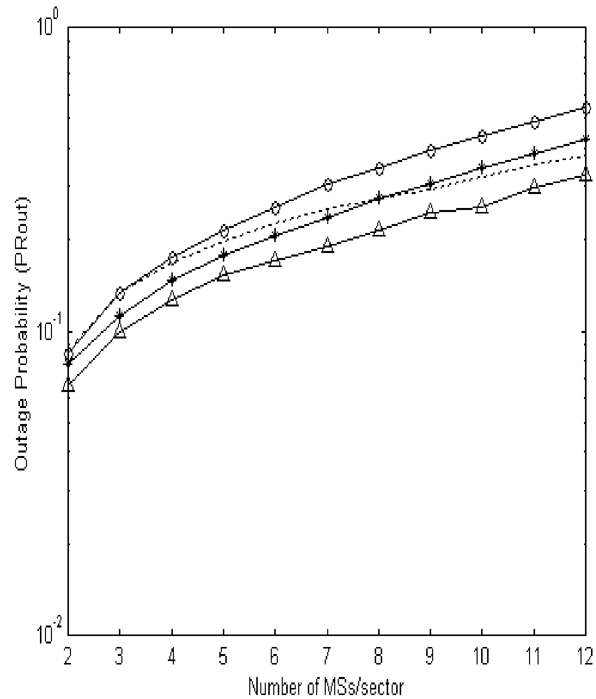

Fig. 3. Effect of soft handoff on outage performance
$\sigma_s = 8$ dB, $\sigma_e = 2$ dB, $K = 3$
o-----o Limited power control for $PR_h = 0.0$ and $[1-P(\gamma_0)] = 10^{-2}$
----- Limited power control for $PR_h = 0.3$ and $[1-P(\gamma_0)] = 10^{-2}$
Δ----Δ Limited power control for $PR_h = 1.0$ and $[1-P(\gamma_0)] = 10^{-2}$
.... Limited power control for $PR_h = 0.3$ and $[1-P(\gamma_0)] = 10^{-1}$

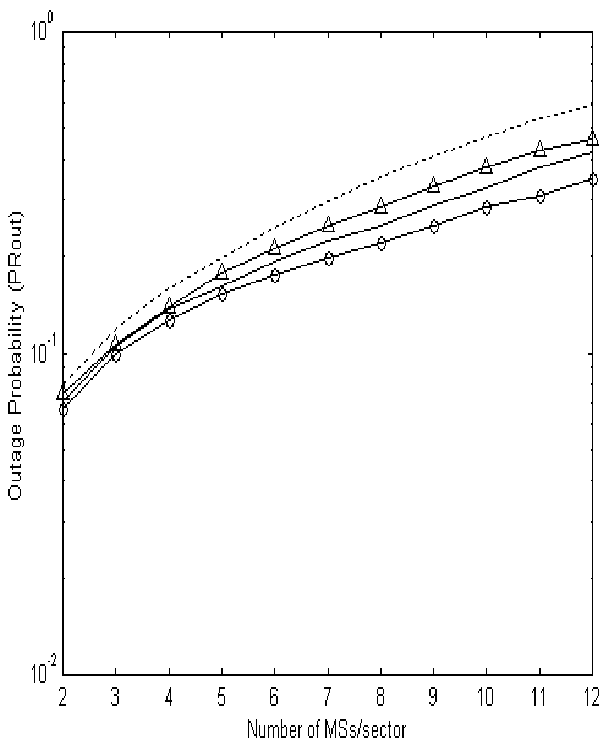

Fig. 4. Effect of power control error on outage performance
$P(\gamma_0) = 10^{-3}$, $PR_h = 0.3$, $\sigma_s = 8$ dB
o-----o Limited power control when $\sigma_e = 0.5$ dB and $K = 3$
·------· Limited power control when $\sigma_e = 1.5$ dB and $K = 3$
Δ----Δ Limited power control when $\sigma_e = 2.0$ dB and $K = 3$
.... Conventional power control when $\sigma_e = 1.5$ dB

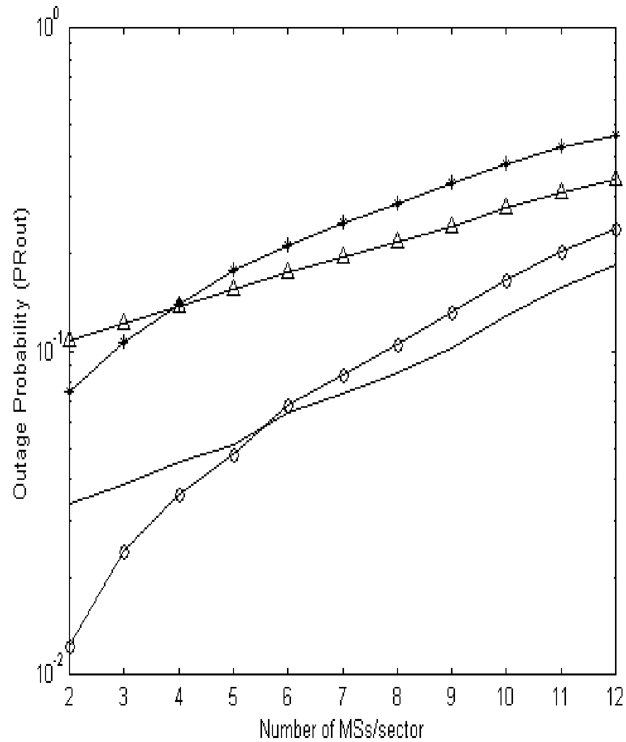

Fig. 5. Effect of shadowing correlation on outage performance
$PR_h = 0.3$, $\sigma_s = 8$ dB, $\sigma_e = 2$ dB
----- Limited power control for $[1-P(\gamma_0)] = 10^{-3}$, $a^2 = 0.0$, K=3
o-----o Limited power control for $[1-P(\gamma_0)] = 10^{-3}$, $a^2 = 0.6$, K=3
·------· Truncated power control for $[1-P(\gamma_0)] = 10^{-3}$, $a^2 = 0.6$, K=3
Δ----Δ Truncated power control for $[1-P(\gamma_0)] = 10^{-3}$, $a^2 = 0.0$, K=3