A Simulation Testbed for Performance Evaluation of Open Loop Power Control Algorithms for Cellular CDMA

Joydeep Acharya* Sumit Kundu#, Umesh Jalan#, Saswat Chakrabarti*

* G.S.Sanyal School of Telecommunications
# Department of Electronics and Electrical Communications Engg.
Indian Institute of Technology, Kharagpur
Kharagpur-721302, India
Email: {joydeep@gssst.iitkgp.ernet.in, (sumit,saswat)@ece.iitkgp.ernet.in,jalan@ieee.org}

ABSTRACT

Power control algorithms are very important for increasing the average traffic and quality of service in CDMA systems. Recently some interesting open loop power control schemes, namely 'Power Truncation' and 'Power Limitation' algorithms have been proposed. The present work describes a simulation testbed developed for carrying out performance studies on the two algorithms. It also verifies some of the analytical results

1. Introduction

Power control ([1],[2]) can substantially impact the cellular capacity and quality of service in cellular CDMA system. Several power control algorithms have been suggested in literature

Conventionally each mobile estimates the channel power gain G(t) at time t and adjusts the transmit power such that a target received power S_R is received at the base station(BS). In this method a mobile may be required to transmit a large average power to compensate for deep fading. Thereby the interference caused to other cell by the boundary mobiles increases.

Recently one interesting power control algorithm called 'Truncated power control' has been suggested in [3] to overcome the above-mentioned problem. According to this algorithm a user adjusts its transmit power to compensate for the channel power gain above a certain cut off fade depth γ_o only. Below this cut off fade depth, transmission is suspended.

However even if a mobile goes into deep fading momentarily it would be truncated as per this scheme. Another power control scheme called 'power limitation algorithm' has been proposed [4], where transmission of a mobile is limited to a fixed level (instead of suspending the transmission) when the mobile is in deep fading. This allows the call to survive when the mobile comes out of deep fading after a momentary dwell.

In the present work we have:

- Developed a simulation testbed for testing open loop power control algorithms.
- Using this testbed we have studied the performance of the power truncation and power limitation algorithms and have compared their results.

The channel model is described in Section 2 , the system description for the two power control algorithms is described in Section 3, the simulation testbed and the parameters chosen for simulation are described in Section 4 and the simulation results are discussed in Section 5. Finally we conclude in Section 6.

2. Channel Model

In a mobile radio environment the channel power gain consists of fast Rayleigh short term fading and the propagation gain

Part of this work has been supported by National Semiconductors Corporation, U.S.A., under a sponsored project with approval no., IIT/SRIC/GSSST/2000-2001/76/RC/1

associated with slow lognormal fading and path loss.

The propagation gain L, can be thus modeled as [3]

$$L = Ar^{-m}10^{x/10} \quad (1)$$

where

A: constant that depends on the antenna gains, the signal wavelengths etc. and has been normalized to unity in this paper.

m: path loss component

x: zero mean Gaussian random variable with variance σ^2

r: normalized distance between the base station and mobile

3. System Description for both the algorithms

In the power truncation algorithm, if $L_k$is the channel power gain at time t, then the transmitted power from a mobile is [3]

$$S(L_k) = S_R/L_k, \quad L_k \geq \gamma_o$$
$$= 0 \quad , \quad L_k < \gamma_o \quad (2)$$

The fraction of time for which the mobile transmits, $p(\gamma_o)$, is given by[3]

$$p(\gamma_o) = \int_0^1 Q(\frac{10\log(\gamma_0 r^m)}{\sigma})2rdr \quad (3)$$

For the power limitation algorithm if the time limit for which a call is limited is chosen as unity (measured in terms of simulation iterations) then equation (2) is modified as

$$S(L_k) = S_R/L_k \quad L_k \geq \gamma_o, t = t_j$$
$$(4)$$
$$= S_R/\gamma, \quad L_k < \gamma_o, \ t = t_j; \ L_k \geq \gamma_o, \ t = t_{j-1}$$
$$= 0, \quad L_k < \gamma_o, \ t = t_j; \ L_k < \gamma_o, \ t = t_{j-1}$$

Where $t = t_i$, $i = 1,2,\ldots j-1,j,\ldots$are the instants of time when the base station estimates the propagation gain for the mobile unit and accordingly decides on its transmission power.

In the case of power truncation algorithm the average transmit power is given by [3]

$$S_T = E[S(L_k)]$$
$$= S_R E_{\gamma_0}[1/L_k] \quad (5)$$

where $S(L_k)$ is transmit power associated with propagation gain L_k

S_T has been assumed to be a constant irrespective of γ_0[3]. So we can show that the target received power S_R is actually a function of γ_0 given by

$$S_R(\gamma_0) = S_T \Big/ E_{\gamma_0}[1/L_k] \quad (6)$$

In the case of perfect power control ($\gamma_0 = 0$) S_R has been assumed to be 1 in this present work. Thus an expression of $S_R(\gamma_0)$ normalized wrt the perfect power control case can be achieved by evaluating the above integral. The result is

$$S_R(\gamma_0) = \frac{1}{(\frac{m+2}{2})\int_0^1 r^{m+!}Q(\frac{10\log(\gamma_0 r^m)}{\sigma} + \sigma b)} \quad (7)$$

where b = ln(10)/10

Another parameter of interest is the power gain Gp of the power control schemes over perfect power control. If the received energy per bit is called E_b then G_p for the power truncation scheme is [3]

$$G_p = \frac{E_b\gamma_0)}{E_b(\gamma_0 = 0)} \quad (8)$$

$$= \frac{2\int_0^1 rQ(\frac{10\log(\gamma_0 r^m)}{\sigma})dr}{(m+2)\int_0^1 r^{m+1}Q(\frac{10\log(\gamma_0 r^m)}{\sigma} + \sigma b)dr} \quad (9)$$

4. Simulation Testbed

The following assumptions have been made during our study.

- A single cell CDMA environment for the simulation purposes. The extension to the multi cell case can be easily incorporated in the testbed developed.
- L(t) is estimated perfectly and transmit power is adjusted to fully compensate for this component of channel gain.[3] The effect due to Rayleigh fading, R(t) has been taken care of by the RAKE receiver at the receiver end.

- Call arrival is Poisson distributed with mean (λ) = 3 Initial traffic at the start of simulation has been assumed to be 10.
- The mobile's location is uniformly distributed within a cell. This leads to a probability density function (pdf) of 'r' given by

$$P_r(r) = \begin{cases} 2r, & 0 \le r \le 1 \\ 0, & r > 1 \end{cases} \quad (10)$$

The simulation procedure and the parameters defined are:

- We run 1000 simulation cycles and the duration of each cycle has been assumed to be 1 sec.
- A parameter called 'monitoring period' is introduced which denotes the maximum amount of time (measured in terms of simulation cycles for which a particular call can be limited) after which it is dropped.
- The position of each user is modified in each iteration. From its position in the previous iteration it moves an incremental distance in a direction θ (uniformly distributed between $[0,2\pi]$). The value of this incremental radius, normalized wrt the cell radius has been chosen to be 0.1. This means that a vehicle will take at least 20 sec to cross a cell.
- The γ_0 threshold is chosen in such a way that $p(\gamma_0)$ or the percentage of time the mobile is active has a value of around 0.5-0.9. For σ = 8 dB, m = 4 and γ_0 = 0.1, $p(\gamma_0)$ = 0.98.
- The average call duration has been assumed to be 100 sec.
- Some parameters like monitor count (m_C), ratios η_L, η_S, have been defined to interpret the results in a more clear way. These are explained in Sec 5.

5. Results and Discussions

Fig 1 shows the variation with time, the number of active calls when power truncation and power limitation algorithms have been applied. Parameters chosen are m = 4, σ = 8 dB and γ_0 = 5. We have assumed 100 sec as average call duration. So prior to 100 sec calls arrive every second and the graph is increasing. After 100 sec, the calls start expiring and so the graph fluctuates about a mean value. Fluctuations in Fig 1 are also due to calls dropped after being limited for the entire monitoring period during which they did not return above threshold. Values obtained from simulation are $\overline{N_{trunc}}$ = 32 and $\overline{N_{\lim it}}$ = 95 where the two quantities denote average number of users when truncation algorithm and limitation algorithm is applied respectively.

Fig 2 traces the same situation as Fig 1 but with γ_0 = 0.5. We see that the number of users increases. This is because lowering the threshold decreases the probability of a call going below it. Corresponding values obtained are $\overline{N_{trunc}}$ = 95, $\overline{N_{\lim it}}$ = 211.

Fig 3 shows the history of a typical call from the moment of its inception till its dropping. The simulation parameters are same as in the case of Fig 1. One of our defined parameters called monitor count (m_C) which is a function of a particular call and the time instant. m_C indicates how many times the call has been limited. Monitoring period has been chosen to be 3 sec. We see that the call had lasted for 49 iterations (49 sec). In the 30th sec it had been limited once. As per power truncation algorithm the call would have been truncated but in limitation algorithm it has been limited. As we see that the channel gain for the call falls below threshold in, the next instant and the call survives. Similarly in 34th and 35th time instants the call had been limited but returned below threshold the next time instant. However even after limitation in 47th and 48th sec when it failed go above threshold the call was dropped.

For better understanding of the effects of power limitation and its advantages over power truncation, we have defined a parameter η_L that gives the ratio of the total number of limited users to the total number of users at any time instant. The variation of η_L has been plotted with time in Fig 4. The parameters are same as that of Fig 1. We see that a good amount of the calls are limited (η_L varies from 0.11 to 0.35 with mean of

0.22) which would have been truncated in the truncation algorithm.

Let us examine Fig 3 once again. The total duration of the call was 49 sec. The call was first limited at the 30^{th} observation instant and then in the next instant it returned to the normal state ie above threshold. In case of power truncation this call would have been dropped. So we can say that the call has survived once. In the same way the call survives on 4 more occasions as seen. We have defined another parameter called survival ratio (η_S) of a call, which is the total number of such survivals divided by the call duration. In case of the call in Fig 3 ,η_S = 5/49 = 0.102. We note that the value of η_S in case of power truncation is 0 so a higher value of η_S indicates an improvement of power limitation algorithm over truncation algorithm. The average value of η_S, ($\overline{\eta_S}$) averaged over all calls has been plotted wrt $p(\gamma_0)$ in Fig 5. We see that for low values of $p(\gamma_0)$,$\overline{\eta_S}$ is low. This is because a low value of $p(\gamma_0)$ means that the mobile does not transmit for most of the time. So the cut-off threshold (γ_0) is very high and the call has a lower probability to return to normal state once it has been limited. A high value of $p(\gamma_0)$ also leads to fall in ,$\overline{\eta_S}$ as the threshold value is very low and a call is hardly going below threshold. However the received signal quality may not be acceptable in practice if the threshold is too low.

Fig 6 traces the variation of $\overline{\eta_S}$, with increase in the time of the monitoring period. As expected the values of $\overline{\eta_S}$ obtained for higher values of monitoring period are higher. However the duration of time for which the mobile may momentarily be in deep fading is small, so increasing the value of monitoring period above a certain duration yields no extra benefits. For a lower value of γ_0, $p(\gamma_0)$ is higher and hence ,$\overline{\eta_S}$ is lower for reasons stated in the explanation of Fig 5.

Finally Fig 7 plots the variation of gain G_P with truncation probability calculated analytically. Fig 8 plots the same variation as per our simulation results. They are found to match very closely and thus the analytical results are verified. For a typical case of $(1 - p(\gamma_0))$= 10^{-4} and σ = 6 dB $(G_P)_{analytical}$ = 0.0128 dB and $(G_P)_{simulation}$ = 0.0130 dB (error = 1.56%) ,for σ = 8 dB $(G_P)_{analytical}$ = 0.091 dB and $(G_P)_{simulation}$ = 0.0915 dB (error = 5.49%), for σ = 10 dB $(G_P)_{analytical}$ = 0.491dB and $(G_P)_{simulation}$ = 0.4916dB (error = 1.22%)

6. Conclusion

We have thus simulated the performance of power truncation and power limitation algorithms in single cell CDMA systems with lognormal fading and path loss. We showed that power limitation leads to more number of active users in the system and thus leads to an increase in average traffic. This increase depends on the threshold value of γ_0 and also the duration of the monitoring period. We also verified that power truncation scheme exhibits a power gain of 1.3-1.4 dB relative to conventional power control for truncation probabilities between 10^{-2} to 10^{-1}.

REFERENCES

[1] William C. Y. Lee, " Overview of cellular CDMA ", IEEE trans on Vehicular Technology, Vol. 40,No 2, May 1991

[2] A.J. Viterbi, A.M. Viterbi and E. Zehavi, "Performance of power controlled wideband terrestrial digital communications" IEEE Transactions on Communications, Vol 41, pp. 559-569, April 1993.

[3] S.W.Kim, A.J.Goldsmith, "Truncated power control in code division multiple-access communications", IEEE trans on Vehicular Technology, Vol. 49,No. 3, May 2000

[4]S Kundu, S. Chakrabarti, "Performance of a limited power control scheme in cellular CDMA", 5th International Conference on Systemics, Cybernatics and Informatics (SCI-2001), Orlando, Florida, July 2001

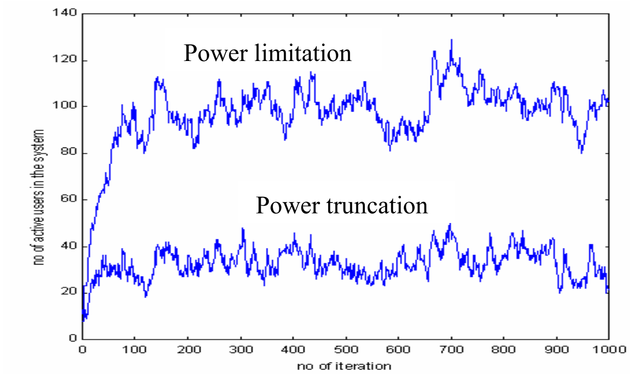

Fig 1. Number of users vs period of observation (measured in terms of no of iterations) for both the algorithms, $\gamma_0 = 5$

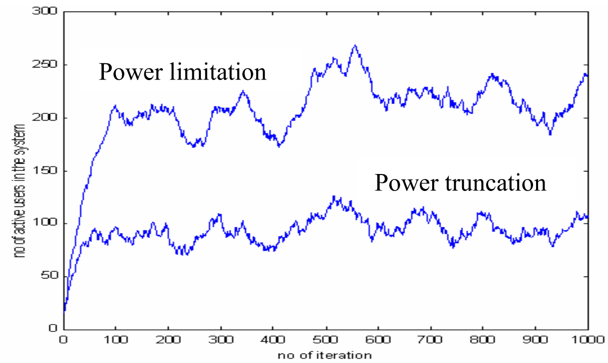

Fig 2. Number of users vs period of observation (measured in terms of no of iterations) for both the algorithms, $\gamma_0 = 0.5$

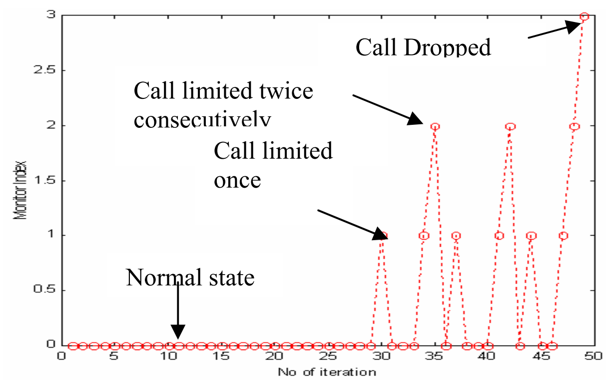

Fig 3. History of a particular call when power limiting algorithm is used

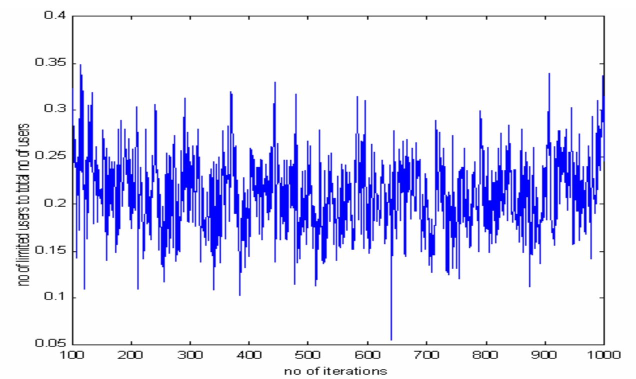

Fig 4. Ratio of the total no of limited calls to total no of calls vs period of observation (measured in terms of no of iterations)

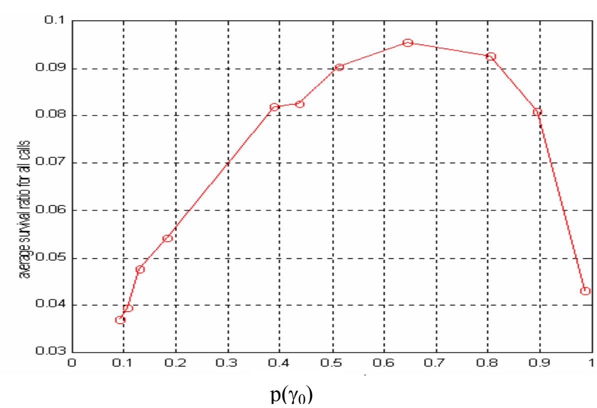

Fig 5. Average survival ratio for all calls vs $p(\gamma_0)$

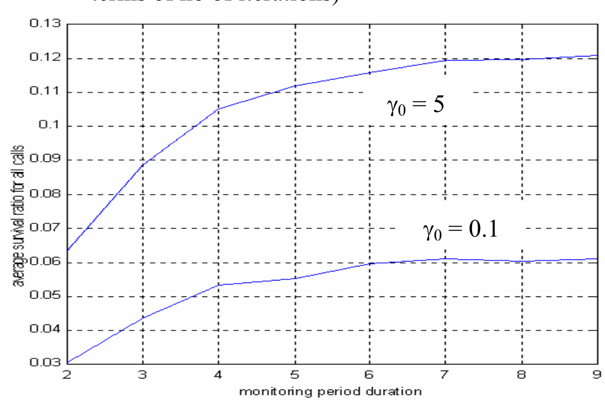

Fig 6. Average survival ratio vs duration of monitoring period (measured in terms of iterations)

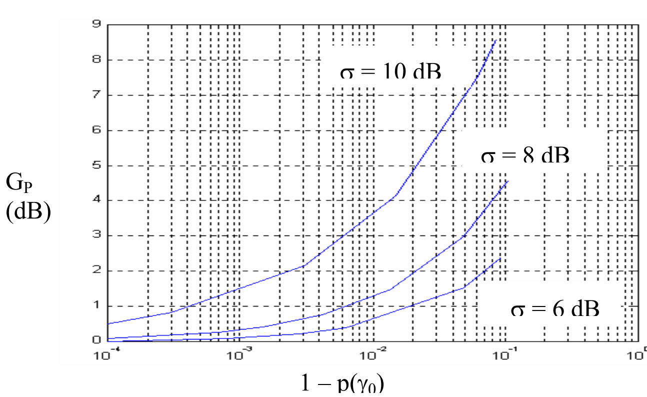

Fig 7: Analytical values of power gain Gp vs truncation probability $1 - p(\gamma_0)$ for several values of σ, for $m = 4$

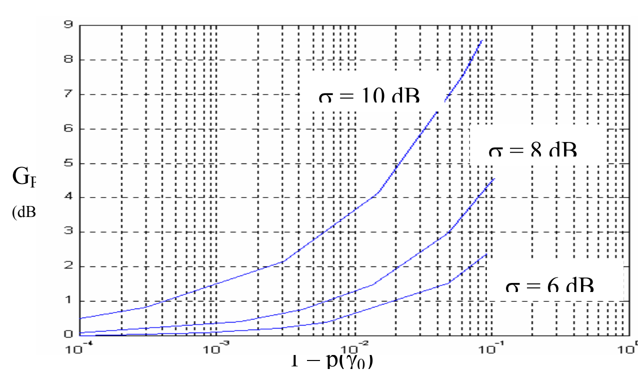

Fig 8: Simulation values of power gain Gp vs truncation probability $1 - p(\gamma_0)$ for values of σ, for $m = 4$