Transmit Power Control Using Probabilistic Target for DS-CDMA Packet Mobile Radio

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Abstract

A new transmit power control (TPC) is proposed that changes TPC target randomly in order to obtain the capture effect for DS-CDMA packet mobile radio. The uplink capacity of a DS-CDMA packet mobile radio system with proposed random TPC in a frequency selective fading channel is evaluated by computer simulation. The simulation results show that random TPC provides larger link capacity than with slow TPC irrespective of the number of propagation paths.

Keywords: DS-CDMA, packet communication, capture effect, transmit power control, link capacity

1. Introduction

In a packet mobile communication system, the packet with larger power can survive when packets collide. This is known as the capture effect [1]. In DS-CDMA, transmit power control (TPC) and Rake combining are necessary to reduce the multiple access interference (MAI) [2]. There are two types of TPC: fast TPC and slow TPC [3]. Since fast TPC keeps the instantaneous received signal power constant, the capture effect cannot be expected. On the other hand, slow TPC keeps intact the instantaneous received signal power variation due to multipath fading, thereby yielding a larger capture effect. Therefore, slow TPC achieves a larger link capacity than fast TPC [4]. However, as the number of propagation paths increases, the received power variations become shallower due to the increased effect of Rake combining and thus, the capture effect obtainable by slow TPC decreases. In order to obtain a sufficiently large capture effect irrespective of the number of propagation paths, it may be effective to control the transmit power so as to intentionally fluctuate the received signal power.

In this paper, a new TPC called random TPC is proposed that changes TPC target randomly in order to obtain a large capture effect irrespective of the number of the paths. The uplink capacity of a DS-CDMA packet mobile radio system with proposed random TPC is evaluated by computer simulation. The remainder of this paper is organized as follows. Sect. 2 presents proposed random TPC. Sect. 3 introduces the throughput and outage probability and presents the throughput computation method for a multi-cell system under an interference-limited condition. Sect. 4 evaluates the link capacity by computer simulation. Sect.5 gives some conclusions.

2. Random TPC

A. Principle of operation

For simplicity, no fading is assumed. The received signal power P_R at the base station is give by

$$P_R = P_T \cdot r^{-\alpha} \cdot 10^{-\frac{\eta}{10}}, \qquad (1)$$

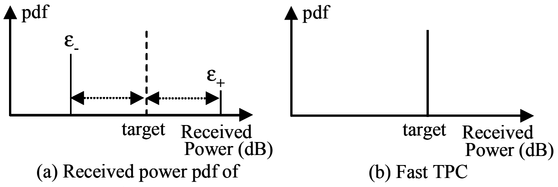
where P_T represents the mobile transmit power, r the distance between the base and mobile stations, α the path loss exponent, and η the shadow fading loss in dB. Denoting the TPC target by P_{target}, the base station received signal power P_R is kept at $P_R = P_{\text{target}}$. Therefore, the mobile transmit power with TPC become

$$P_T = P_{\text{target}} \cdot (r^{-\alpha} \cdot 10^{-\frac{\eta}{10}})^{-1}. \qquad (2)$$

If this TPC is applied to all users, all users' signals are received with the same power P_{target} at the base station. Hence, no capture effect is obtained. In this paper, we propose a random TPC that controls the transmit power so as to intentionally fluctuate the received signal power.

The mobile station intentionally fluctuates its transmit power by $\pm\Delta$ dB, with the probability of $\varepsilon_\pm$ ($\varepsilon_+ + \varepsilon_- = 1$), from its nominal power given by Eq.(2). By doing so, the base station received signal power from a certain user becomes $P_{\text{target}} \pm \Delta$ dB with a probability of $\varepsilon_\pm$. Fig.1 shows probability density function (pdf) of the received signal power with proposed random TPC. For comparison, the fast TPC case is also illustrated.

P_T can be determined using Eq.(1), but the sum of path loss and shadowing loss (propagation loss) must be known. The uplink and downlink propagation channel is symmetric except for the effect of multipath fading. Therefore, the propagation loss can be assumed the same for both links. If the mobile station is informed of the base station transmit power P_T, then $(r^{-\alpha} \cdot 10^{-\frac{\eta}{10}})$ can be computed using Eq.(1). However, this is only applicable when there is no fading. The most possible applicable system may be the time-division-duplex (TDD) system, in which the same carrier frequency is used for both uplink and downlink.



(a) Received power pdf of Random TPC

(b) Fast TPC

Fig. 1 Pdf of received signal power.

B. Application to TDD system

The above described random TPC can be easily implemented in a TDD system. Fig.2 illustrates the uplink (mobile to base)/downlink (base to mobile) timing structure. The mobile station can estimate the uplink propagation loss $(r^{-\alpha} \cdot 10^{-\frac{\eta}{10}})$ in Eq.(1), by measuring the received power of the signal transmitted from the base station since the same frequency channel is used for uplink and downlink. Thus, the mobile station can determine its transmit power by itself. The base station transmits pilot signals with the known power (P_{BTp}) periodically and the mobile station estimates the sum of path loss and shadowing using its measured received signal power P_{MRp} to determine its transmit power P_T frame by frame as follows.

$$P_T = P_{target} \pm \Delta + (P_{BTp} - P_{MRp}) \text{ in dB.} \qquad (3)$$

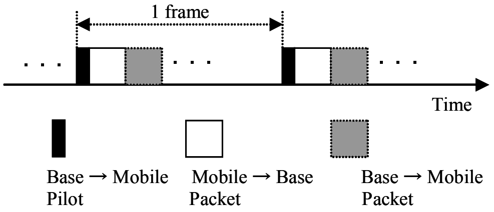


Fig.2 Timing structure.

3. Throughput Computation Method

The throughput computation method for the fast TPC case is presented in Ref.[4], which is used also in this paper.

3.1 Definition of throughput and link capacity

Outage occurs if the transmission quality drops below the required quality of services (QoS), i.e., packet throughput and delay. The link capacity is defined as the maximum number of active users that satisfies the allowable outage probability (Q_{allow}) and Q_{allow} is defined as the maximum outage probability that satisfies the system requirement. In a packet communication system, automatic repeat request (ARQ) is used. Assuming infinite number of retransmissions (infinite delay is allowed before successful transmission of a packet), the throughput S is given by

$$S = 1 - p(K,\lambda), \qquad (4)$$

where $p(K, \lambda)$ is the average packet error rate with K and λ being the number of active users and the packet occurrence rate, respectively. The outage occurs only if throughput is less than the required value. The outage probability Q is given by

$$Q = \text{Prob}[S < S_{\text{req}}], \qquad (5)$$

where S_{req} is the required throughput which is defined as the minimum throughput that satisfies the required QoS.

3.2 Obtaining $p(K,\lambda)$

For the throughput computation we need to obtain $p(K,\lambda)$. We assume that the occurrence rate of original packets is the same for all active users and is denoted by λ_0. The total packet occurrence rate λ is (1+(packet retransmission rate))× λ_0. When TPC is used, since packet errors occur equally likely for all active users, λ is given by

$$\lambda = \frac{\lambda_0}{1 - p(K,\lambda)}, \qquad (6)$$

There exist K-1 active interfering users. Assuming that the original and retransmitted packets are randomly produced, $p(K,\lambda)$ can be computed using

$$p(K,\lambda) = \sum_{k=0}^{K-1} p(k) \cdot \binom{K-1}{k} \lambda^k (1-\lambda)^{K-1-k}, \qquad (7)$$

where $p(k)$ is the conditional average packet error rate when k interfering packets are received and $\binom{K-1}{k} = \frac{(K-1)!}{k!(K-k-1)!}$ is the binomial coefficient.

Assuming a slotted packet transmission and a block fading (the fading stays almost constant over a packet), $p(k)$ can be computed using

$$p(k) = 1 - \left(1 - \overline{p_b(\gamma_k)}\right)^N, \qquad (8)$$

where $\overline{p_b(\gamma_k)}$ is the average bit error rate (BER) when k interfering packets are received and N is the number of bits in a packet. $p_b(\gamma_k)$ represents the instantaneous BER when the received SINR is γ_k. Mathematical expression for γ_k is presented in Sect. 3.3. Assuming coherent BPSK data modulation and that the sum of colliding packets is approximated as a Gaussian process, $p_b(\gamma_k)$ is given by [5]

$$p_b(\gamma_k) = \frac{1}{2} erfc\sqrt{\frac{\gamma_k}{2}}, \qquad (9)$$

where $erfc(x) = (2/\sqrt{\pi})\int_x^\infty e^{-t^2}dt$ is the complimentary error function.

3.3 Mathematical expression for SINR γ_k

We assume an interference-limited channel. A frequency selective block fading channel having L discrete paths is assumed. Below, we derive an expression for γ_k to compute the packet error rate $p(k)$ using Eqs. (8) and (9). The received signal $r_0(t)$ at the 0th base station is expressed, using equivalent baseband representation, as [6]

$$r_0(t) = \sum_{i=0}^{k-1} \sqrt{2P_{R,i\to0}} \left(\sum_{l=0}^{L-1} \xi_{i\to0}^{(l)} d_i(t - \tau_{i\to0}^{(l)}) c_i(t - \tau_{i\to0}^{(i)}) \right), \qquad (10)$$

where i denotes the user index, $P_{R,i\to0}$ is the average signal power of the ith user received at the 0th base station and $d_i(t)$ and $c_i(t)$ are the data-modulated waveform and the spreading chip waveform, respectively. $\xi_{i\to j}^{(l)}$ and $\tau_{i\to j}^{(l)}$ are the lth path complex gain and time delay, respectively, associated with ith user seen at the jth base station. It is assumed that $E[\sum_{l=0}^{L-1}\left|\xi_{i\to j}^{(l)}\right|^2] = 1$,where E[*] denotes ensemble average operation. Time dependency of the path gain is dropped for the sake of simplicity. $P_{R,i\to0}$ is given by-

$$P_{R,i\to0} = P_{Ti} r_{i\to0}^{-\alpha} 10^{-\frac{\eta_{i\to0}}{10}}, \qquad (11)$$

where P_{Ti}, $r_{i\to0}$, α, and $\eta_{i\to0}$ are the transmit power, the distance to the base station normalized by the cell radius, the path loss exponent, and the shadowing loss (dB), respectively, for the ith user. We assume an ideal Rake receiver with the number of fingers equal to L. The mobile station communicate with the base station that the received signal power is largest.

Each user finds the best base station having the minimum path loss. The best base station is indexed as $k(i)$. The ith users signal power $P_{Rake,i}$ after Rake combing at the

$k(i)$ th base station is given by

$$P_{Rake,i}=P_{Ti}r_{i\to k(i)}^{-\alpha}10^{-\frac{\eta_{i\to k(i)}}{10}}\sum_{l=0}^{L-1}\left|\xi_{i\to k(i)}^{(l)}\right|^2, \quad (12)$$

where

$$k(i)=\arg\max_k\left\{r_{i\to k}^{-\alpha}10^{-\frac{\eta_{i\to k}}{10}}\sum_{l=0}^{L-1}\left|\xi_{i\to k}^{(l)}\right|^2\right\}. \quad (13)$$

When random TPC is applied, the transmit power P_{Ti} becomes

$$P_{Ti}=\frac{P_{target}10^{\frac{\Delta}{10}\cdot\delta_i}}{r_{i\to k(i)}^{-\alpha}10^{-\frac{\eta_{i\to k(i)}}{10}}\sum_{l=0}^{L-1}\left|\xi_{i\to k(i)}^{(l)}\right|^2}, \quad (14)$$

where δ_i (1 or -1) represents the power state. δ_i=1 represents the target value of P_{target}+ΔdB and δ_i=-1 represents the target value of P_{target}-ΔdB with Prob(δ_i=±1)=$\varepsilon_\pm$, where $\varepsilon_+ + \varepsilon_- = 1$.

The received SINR γ_k after Rake combining is given by

$$\gamma_k=\frac{2SF\left(\sum_{l=0}^{L-1}\left|\xi_{0\to 0}^{(l)}\right|^2\right)^2 10^{\frac{\Delta}{10}\delta_0}}{\left(\begin{array}{l}\sum_{m=0}^{L-1}\sum_{\substack{l=0\\ l\neq m}}^{L-1}\left|\xi_{0\to 0}^{(l)}\xi_{0\to 0}^{*(m)}\right|^2 10^{\frac{\Delta}{10}\delta_0}\\ +\left(\sum_{l=0}^{L-1}\left|\xi_{0\to 0}^{(l)}\right|^2\right)\sum_{i=1}^{k-1}\frac{10^{\frac{\Delta}{10}\delta_i}\cdot r_{i\to 0}^{-\alpha}10^{-\frac{\eta_{i\to 0}}{10}}}{r_{i\to k(i)}^{-\alpha}10^{-\frac{\eta_{i\to k(i)}}{10}}}\frac{\sum_{m=0}^{L-1}\sum_{l=0}^{L-1}\left|\xi_{i\to 0}^{(l)}\xi_{0\to 0}^{*(m)}\right|^2}{\left(\sum_{m=0}^{L-1}\left|\xi_{i\to k(i)}^{(m)}\right|^2\right)^2}\end{array}\right)}. \quad (15)$$

For the single cell case, Eq.(15) reduces to

$$\gamma_k=\frac{2SF\left(\sum_{l=0}^{L-1}\left|\xi_{0\to 0}^{(l)}\right|^2\right)^2 10^{\frac{\Delta}{10}\delta_0}}{\left(\begin{array}{l}\sum_{m=0}^{L-1}\sum_{\substack{l=0\\ l\neq m}}^{L-1}\left|\xi_{0\to 0}^{(l)}\xi_{0\to 0}^{*(m)}\right|^2 10^{\frac{\Delta}{10}\delta_0}\\ +\left(\sum_{l=0}^{L-1}\left|\xi_{0\to 0}^{(l)}\right|^2\right)\sum_{i=1}^{k-1}10^{\frac{\Delta}{10}\delta_i}\frac{\sum_{m=0}^{L-1}\sum_{l=0}^{L-1}\left|\xi_{i\to 0}^{(l)}\xi_{0\to 0}^{*(m)}\right|^2}{\left(\sum_{m=0}^{L-1}\left|\xi_{i\to 0}^{(m)}\right|^2\right)^2}\end{array}\right)}. \quad (16)$$

It is found from Eq.(14) that γ_k is independent of the path loss and the shadowing loss, but is randomly fluctuated by random TPC.

4. Computer Simulation

Table 1 shows the simulation parameters. BPSK data modulation and ideal Rake combing based on maximum ratio combining (MRC) are assumed.

Table 1 Simulation parameters

User location		Uniform distribution
Propagation channel	Fading	Block Rayleigh
	Number of paths	L=1~16
Transmitter and receiver	Data mod. / and demod.	BPSK with coherent detection
	Spreading factor	SF=1~512
Packet	Length	N=128~4096 bits
	Data packet generation probability	λ_0=0.01~0.1
QoS	Required throughput	S_{req}=0.9
	Allowable outage probability	Q_{allow}=0.001~0.1

The uplink capacity is evaluated by the Monte-Carlo simulation using following procedure

Step1: set K=1.
Step2: increase the value of K by one.
Step3: obtain the throughput S as described in Sects.3 and 4.
Step4: obtain the outage probability (Q) that $S<S_{\text{req}}$.
Step5: repeat step 2 to step 4 until $Q\geq Q_{\text{allow}}$. The maximum number of K that satisfies $Q<Q_{\text{allow}}$ is the link capacity C.

The single cell case is considered first and then, the simulation is extended to the multiple cell case.

4.1. Single cell case

Fig. 3 plots the normalized link capacity C/SF as a function of Δ with ε_- as a parameter for L=2. For comparison, the cases with slow and fast TPC are also plotted. When Δ=0dB, the same link capacity as with the fast TPC is achieved. As Δ becomes larger, the link capacity increases due to increased capture effect. The link capacity approaches its maximum when Δ is 3dB. When Δ increases beyond 3dB, however, the link capacity starts to reduce since the increasing MAI offsets the capture effect. It can be seen that the proposed random TPC achieves a larger link capacity than slow TPC when $\Delta=3$ dB and $\varepsilon_-=0.8$. This is because the random TPC provides a larger capture effect due to controlled power fluctuations.

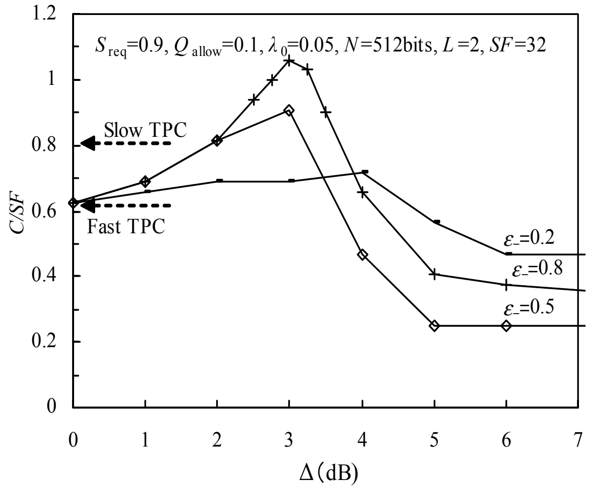


Fig.3 Normalized link capacity C/SF as a function of Δ.

Fig. 4 plots the normalized link capacity *C*/*SF* as a function of ε_- for Δ=3dB and *SF*=32. When $\varepsilon_-= 0$ or 1, since the received signal power is constant, the same normalized link capacity as with fast TPC is obtained. As ε_- increases, the link capacity becomes larger due to the increasing capture effect and it approaches its maximum when ε_-=0.8.

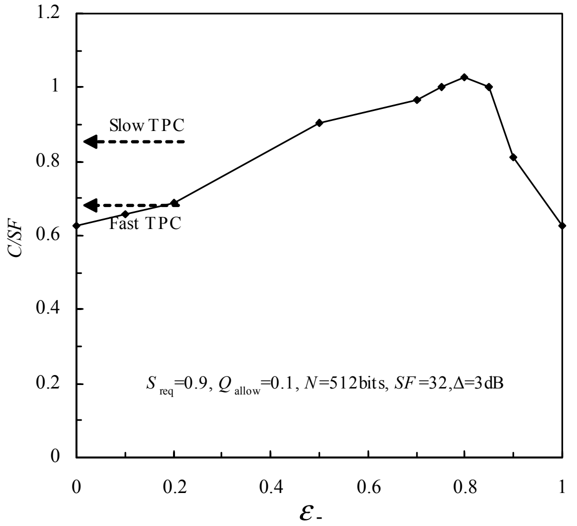


Fig. 4 Normalized link capacity *C*/*SF* as a function of ε_-.

Fig. 5 plots the normalized link capacity *C*/*SF* as a function of *L* for Δ=3dB, ε_-=0.8 and *SF*=32. For comparison, the cases with slow and fast TPC are also plotted. For the case of slow TPC, since the degrees of the received power fluctuations after Rake combining depends on *L*, the link capacity with slow TPC is sensitive to *L*. The link capacity with random TPC always obtains a larger link capacity than both slow and fast TPC irrespective of *L*. This is because the received power fluctuations are controlled by random TPC so that the capture effect can be maximized.

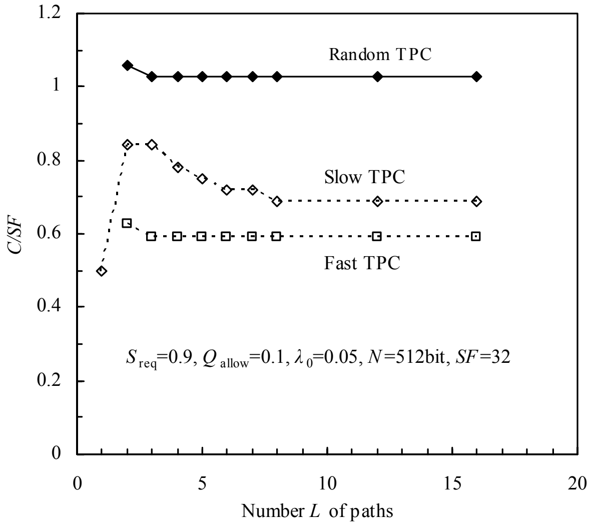


Fig.5 Normalized link capacity *C*/*SF* as a function of *L*.

Fig. 6 plots the normalized link capacity as a function of *SF*. When $SF \le 4$, the link capacity is almost zero because of large inter-path interference for all TPC schemes. When $SF > 8$, the proposed random TPC provides the largest link capacity. When *SF*>64, the normalized link capacity remains constant since the impact of inter-path interference can be neglected.

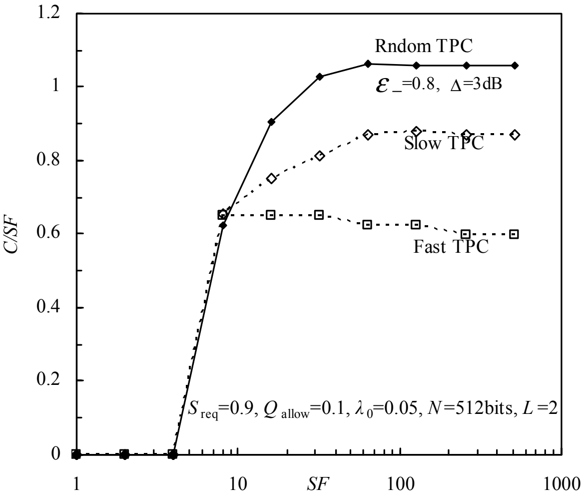


Fig. 6 Normalized link capacity *C*/*SF* as a function of *SF*.

Fig. 7 plots the normalized link capacity as a function of packet length *N*. As the *N* becomes larger, the normalized capacity decreases because the required SINR to achieve the required packet error rate increases. However, it is seen that the proposed random TPC always yields the largest capacity irrespective of the packet length *N*.

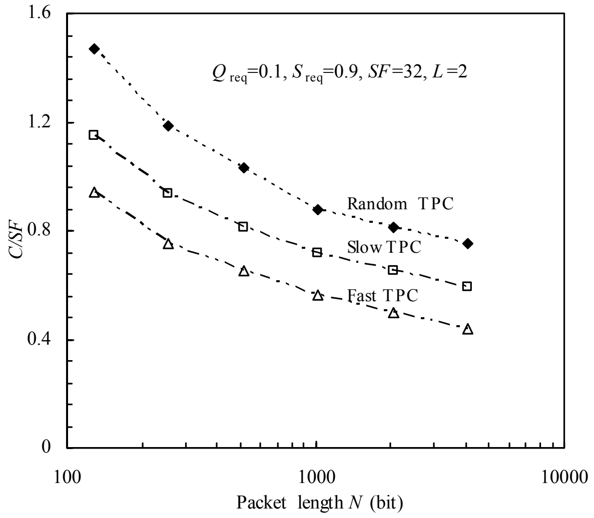


Fig.7 Normalized link capacity *C*/*SF* as a function of *N*.

4.2 Multi-cell

So far single cell case has been considered. In the case of multi-cell, the users communicating with other cells give interference to the cell of interest and this reduces the link capacity per cell compared to the single cell. In this paper, up to the second tiers of the surrounding cells are considered (i.e., 19 cells are considered in the simulation.) Fig. 8 plots the normalized link capacity per cell as a function of the number *L* of propagation paths for the multi-cell case. Similar to the single cell case, the link capacity with random TPC has identical value irrespective of *L*. Fig. 9 plots the normalized link capacity per cell as a function of the path loss exponent α. As α becomes larger, the link capacity increases. This is because the interference power from the other cell user decreases as α becomes larger. Fig. 10 plots the normalized link capacity per cell as a function of the standard deviation σ of the log-normally distributed shadowing loss. As σ becomes larger, the link capacity tends to decrease, but is not that sensitive to σ.

All the above results confirm that similar to the single cell case, the random TPC can achieve the largest capacity.

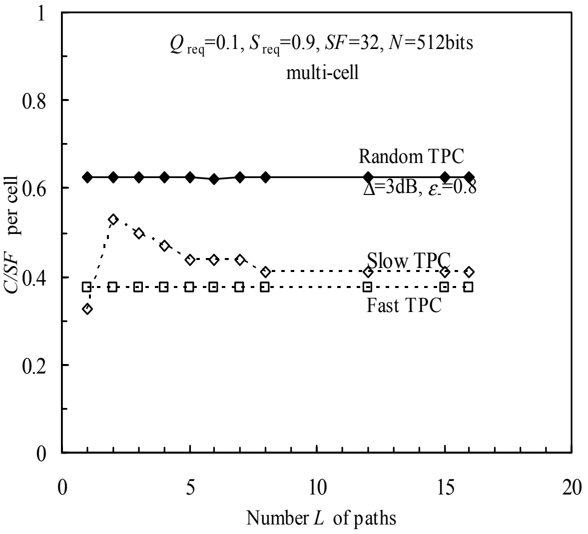


Fig.8 Normalized link capacity *C*/*SF* as a function of *L* in multi-cell environment.

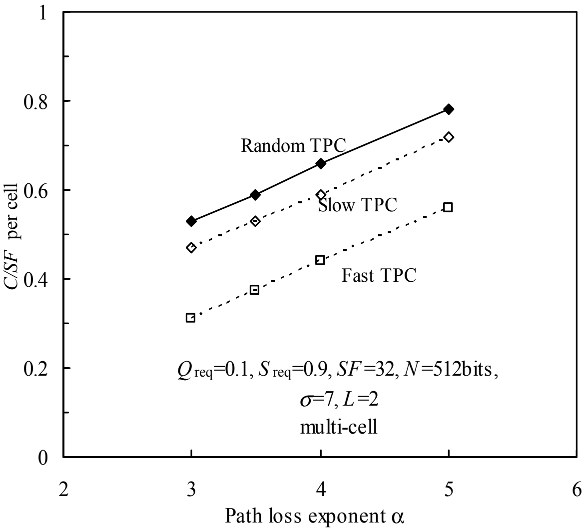


Fig.9 Normalized link capacity *C*/*SF* as a function of path loss exponent α in multi-cell environment.

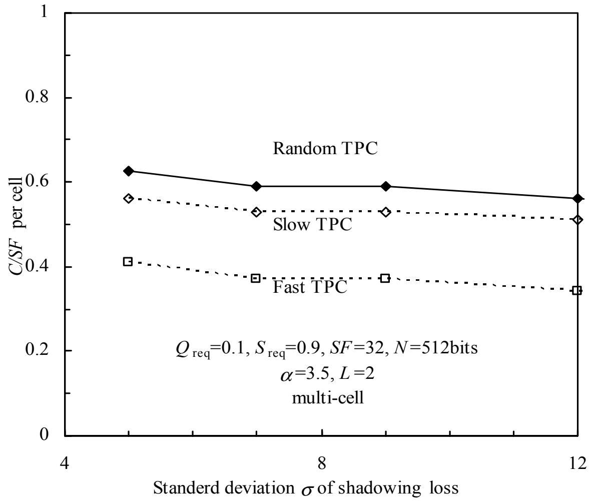


Fig.10 Normalized link capacity *C*/*SF* as a function of standard deviation σ of shadowing loss in multi-cell environment.

5. Conclusions

We proposed the random TPC whose received signal target power is randomly fluctuated in order to obtain the larger capture effect. The uplink capacity of DS-CDMA packet mobile radio was evaluated by computer simulation. The results obtained in this paper can be summarized as follows.

(a) The proposed random TPC achieves a larger maximum link capacity than slow TPC and fast TPC. This is because the random TPC gives adequate received signal power fluctuations which can obtain a larger capture effect.

(b) The maximum link capacity with random TPC is almost insensitive to the number *L* of the propagation paths. However, the capacity with slow TPC is sensitive to *L* since the statistics of received signal power fluctuation after Rake combining depends on *L*.

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