Combined Effect of Inter-Path Interference Cancellation And Random Transmit Power Control on DS-CDMA Packet Mobile Communications

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Abstract— **In mobile communication systems, high speed packet data services are demanded. In the high speed data transmission, throughput degrades severely due to severe inter-path interference (IPI). Recently, we proposed a random transmit power control (TPC) to increase the up link throughput of DS-CDMA packet mobile communications. In this paper, we apply IPI cancellation in addition to the random TPC. We derive the numerical expression of the received signal-to-interference plus noise power ratio (SINR) and introduce IPI cancellation factor. Then we evaluate, by Monte-Carlo numerical computation method, the combined effect of random TPC and IPI cancellation on the uplink throughput of DS-CDMA packet mobile communications.**

Keywords-component; IPI cancellation, random TPC, capture effect, packet, throughput

I. INTRODUCTION

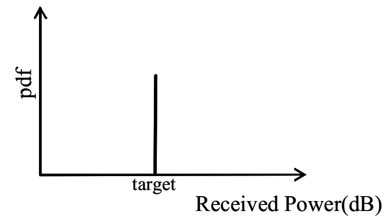
Since users transmit their packets randomly in wireless packet communication, packet collision occurs, thereby decreasing the system throughput. When the received signal power difference among colliding packets is small, all packet transmissions fail. Otherwise, a packet with larger received signal power can survive and thus the throughput increases [1]. This is known as the capture effect. In [2], we applied the random transmit power control (TPC) [3]~[6] to obtain the controlled capture effect for the DS-CDMA packet mobile communications.

There have been strong demands for high speed packet data services [7]. As the transmission rate increases, the inter-path interference (IPI) caused by the delayed paths gets stronger and the throughput performance severely degrades. If the IPI can be suppressed by an interference canceller [8] or an equalizer [9], the throughput increases. However, to the best of our knowledge, the combined effect of IPI canceller and random TPC has not been fully discussed yet in DS-CDMA packet mobile communications. In this paper, we derive the numerical expression of the received signal-to-interference plus noise power ratio (SINR) and introduce IPI cancellation factor. Then we evaluate the combined effect of IPI canceller and random TPC in the slotted Aloha DS-CDMA.

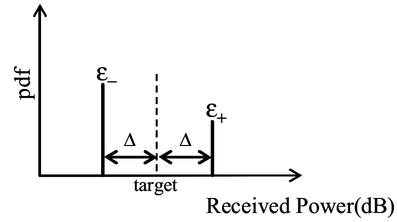
The remainder of this paper is organized as follows. Sect. II introduces random TPC and derives the system throughput. Sect. III derives the numerical expression of the received signal-to-interference plus noise power ratio (SINR) and introduces IPI cancellation factor. Sect. IV evaluates the throughput performance. Sect. V gives some conclusions.

II. RANDOM TPC AND SYSTEM THROUGHPUT

Fig.1 shows the probability density function (pdf) of the received signal power for the random TPC and the fast TPC. With the random TPC, the transmit power is controlled so that the signal power received at the base station becomes $P_{\mathrm{target}} \pm \Delta$ dB with a probability of $\varepsilon_{\pm}$ ($\varepsilon_{+}+\varepsilon_{-}=1$).



(a) Fast TPC



(b) Random TPC

Fig.1 Pdf of received signal power.

Assuming the constant chip rate and packet bit length, the slot duration is proportional to *SF*. The traffic *G* normalized by the slot duration when spreading factor *SF*=1 is given by

$$G = \frac{\lambda Q}{SF}\ , \qquad (1)$$

where Q is the number of active users and λ is the packet occurrence rate per slot. In a packet communication system, automatic repeat request (ARQ) is necessary. Assuming an infinite number of retransmissions (infinite delay is allowed before successful transmission of a packet), the system throughput S is given by

$$S = G\{1 - p(Q,\lambda)\} , \tag{2}$$

where $p(Q, \lambda)$ is the average packet error rate.

For the throughput computation, it is necessary to find $p(Q,\lambda)$. We assume that the occurrence rate λ_{SF} of the original packets excluding the retransmitted packets is the same for all active users. λ_{SF} is given by

$$\lambda_{SF} = SF \cdot \lambda_0 , \tag{3}$$

where λ_0 is the original packet occurrence rate per slot when SF=1. When TPC is used, packet errors occur equally likely for all active users and thus, λ is given by

$$\lambda = \frac{\lambda_{SF}}{1 - p(Q,\lambda)} . \tag{4}$$

Assuming that the original and retransmitted packets are randomly produced, $p(Q,\lambda)$ for the given λ can be computed as

$$p(Q,\lambda) = \sum_{q=0}^{Q-1} p(q) \binom{Q-1}{q} \lambda^q (1-\lambda)^{Q-1-q} , \tag{5}$$

where $p(q)$ is the conditional packet error rate when q interfering packets collide and $\binom{Q-1}{q} = \frac{(Q-1)!}{q!(K-q-1)!}$ is the binomial coefficient. Since $p(Q,\lambda)$ and λ are mutually related, theoretical evaluating λ for the given λ_{SF} is quite difficult if not impossible. If the conditional packet error rate $p(q)$ is known, $p(Q,\lambda)$ for the given λ can be evaluated using Eq.(5). We search for λ which satisfies Eq.(4) by the iterative computation method [6]. This gives $p(Q,\lambda)$ for the given λ_{SF}. Once $p(Q,\lambda)$ is obtained, the system throughput S is computed using Eq.(2).

First, we derive $p(q)$. We approximate the instantaneous packet error rate $p(\gamma_q)$ for the given SINR γ_q as

$$p(\gamma_q) = \begin{cases} 0 & \text{if } \gamma_q \ge \gamma_{th} \\ 1 & \text{otherwise} \end{cases} , \tag{6}$$

where γ_{th} is the threshold SINR. Since γ_q is a random variable, the average packet error rate $p(q)$ is given by

$$p(q) = E[p(\gamma_q)] . \tag{7}$$

III. NUMERICAL EXPRESSION OF RECEIVED SINR

We assume a single cell system with an interference-limited channel and ideal TPC. Below, an expression of γ_q to compute the packet error rate $p(q)$ is derived for fast TPC and random TPC.

The transmit signal $s_i(t)$ of the ith user can be expressed, using equivalent baseband representation, as

$$s_i(t) = \sqrt{2P_i}\, d_i c_i(t) c_{scr}(t) , \tag{8}$$

where P_i is the transmit power, d_i is the data symbol, $c_{scr}(t)$ is the scramble code and $c_i(t)$ is the orthogonal spreading code satisfying $(1/SF)\sum_{t=0}^{SF-1} c_j(t) c_i(t) = \delta_{i,j}$ (where $\delta_{i,j}$ is the Cronecker's delta function). A frequency-selective block fading channel having L discrete paths is assumed. The received signal $r(t)$ at the base station is given by

$$r(t) = \sum_{i=0}^{q} \sum_{l=0}^{L-1} \sqrt{A_i}\, h_i^{(l)} s_i(t-l) + n(t) , \tag{9}$$

where A_i is given as

$$A_i = r_i^{-\alpha} 10^{-\frac{\eta_i}{10}} \tag{10}$$

with r_i, α, η_i, $h_i^{(l)}$, q, and $n(t)$ denoting respectively the distance between the i-th mobile and the base station, the path loss exponent, the shadowing loss in dB, the complex l-th path gain, the number of interfering users, and the complex Gaussian noise with the single sided power spectrum density N_0. Without loss of generality, the i=0th user is considered as the desired user. The received signal r_R after Rake combining is given by

$$\begin{aligned} r_R &= \sqrt{2P_0A_0} \sum_{l=0}^{L-1} \left| h_0^{(l)} \right|^2 \\ &+ \frac{\sqrt{2P_0A_0}}{SF} \sum_{l=0}^{L-1} \left\{ \sum_{\substack{j=0 \\ j \ne l}}^{L-1} \left(h_0^{(j)} h_0^{(l)*} \sum_{t=0}^{SF-1} \left(\begin{array}{l} d_0 c_0(t-j) c_0^*(t-l) \\ \times c_{scr}(t-j) c_{scr}^*(t-l) \end{array} \right) \right) \right\} \\ &+ \frac{1}{SF} \sum_{l=0}^{L-1} \left\{ \sum_{i=1}^{q} \sqrt{2P_iA_i} \left(\begin{array}{l} \sum_{j=0}^{L-1} h_i^{(j)} h_0^{(l)*} \\ \times \sum_{t=0}^{SF-1} \left(\begin{array}{l} d_i c_i(t-j) c_0^*(t-l) \\ \times c_{scr}(t-j) c_{scr}^*(t-l) \end{array} \right) \end{array} \right) \right\} , \\ &+ \frac{1}{SF} \sum_{l=0}^{L-1} h_0^{(l)*} \sum_{t=0}^{SF-1} n(k) c_0^*(t-l) c_{scr}^*(t-l) \end{aligned} \tag{11}$$

where the first, second, third, and forth terms represent the desired signal, IPI, multi-access interference (MAI) and noise, respectively. The desired signal power P_s, IPI power P_{IPI}, MAI power P_{MAI}, and noise power P_N are respectively given by

$$\begin{cases} P_s = 2P_0A_0\left(\sum_{l=0}^{L-1}\left|h_0^{(l)}\right|^2\right)^2 \\ P_{IPI} = \frac{1}{SF}P_0A_0\left\{\left(\sum_{l=0}^{L-1}\left|h_0^{(l)}\right|^2\right)^2 - \sum_{l=0}^{L-1}\left|h_0^{(l)}\right|^4\right\} \\ P_{MAI} = \frac{1}{SF}\sum_{i=1}^{q}P_iA_i\left(\sum_{l=0}^{L-1}\left|h_0^{(l)}\right|^2\right)\left(\sum_{l=0}^{L-1}\left|h_i^{(l)}\right|^2\right) \\ P_N = \frac{N_0}{T_b}\left(\sum_{l=0}^{L-1}\left|h_0^{(l)}\right|^2\right) \end{cases}, \quad (12)$$

where T_b is the bit duration. The received SINR γ_q is given by

$$\gamma_q = \frac{P_s}{P_{IPI}+P_{MAI}+P_N} = \frac{2P_0A_0\left(\sum_{l=0}^{L-1}\left|h_0^{(l)}\right|^2\right)^2}{\left[\begin{array}{l} \frac{1}{SF}P_0A_0\left\{\left(\sum_{l=0}^{L-1}\left|h_0^{(l)}\right|^2\right)^2 - \sum_{l=0}^{L-1}\left|h_0^{(l)}\right|^4\right\} \\ +\frac{1}{SF}\sum_{i=1}^{q}P_iA_i\left(\sum_{l=0}^{L-1}\left|h_0^{(l)}\right|^2\right)\left(\sum_{l=0}^{L-1}\left|h_i^{(l)}\right|^2\right) \\ +\frac{N_0}{T_b}\left(\sum_{l=0}^{L-1}\left|h_0^{(l)}\right|^2\right) \end{array}\right]}. \quad (13)$$

The transmit power P_i of the i-th user is given by

$$P_i = \begin{cases} \dfrac{P_{target}}{r_i^{-\alpha}10^{-\frac{\eta_i}{10}}\sum_{l=0}^{L-1}\left|h_i^{(l)}\right|^2} & \text{for fast TPC} \\ \dfrac{P_{target}10^{\frac{\Delta}{10}\cdot\delta_i}}{r_i^{-\alpha}10^{-\frac{\eta_i}{10}}\left(\sum_{l=1}^{L}\left|h_i^{(l)}\right|^2\right)} & \text{for random TPC} \end{cases}, \quad (14)$$

where P_{target} is the target received signal power and δ_i (=1 or -1) is the power state. δ_i takes ±1 with the probability of $\varepsilon_\pm$, where $\varepsilon_+ + \varepsilon_- = 1$. Assuming the interference-limited channel and substituting Eq.(14) into Eq.(13), γ_q is obtained as

$$\gamma_q = \begin{cases} \dfrac{2}{\frac{1}{SF}\left\{1-\dfrac{\sum_{l=0}^{L-1}\left|h_0^{(l)}\right|^4}{\left(\sum_{l=0}^{L-1}\left|h_0^{(l)}\right|^2\right)^2}\right\}+\frac{q}{SF}} & \text{for fast TPC} \\ \dfrac{2}{\left[\begin{array}{l} \frac{1}{SF}\left\{1-\dfrac{\sum_{l=0}^{L-1}\left|h_0^{(l)}\right|^4}{\left(\sum_{l=0}^{L-1}\left|h_0^{(l)}\right|^2\right)^2}\right\} \\ +\frac{1}{SF}\sum_{i=1}^{q}10^{\frac{\Delta}{10}(\delta_i-\delta_0)} \end{array}\right]} & \text{for random TPC} \end{cases}. \quad (15)$$

The first and second terms of the denominator in Eq. (15) represent the IPI and the MAI, respectively. It is understood from Eq.(15) that the random TPC can mitigate the MAI by the capture effect when the desired user's received signal power is larger than the sum of colliding user's packets. However, IPI is the same for fast TPC and random TPC and cannot be suppressed by random TPC. If the IPI can be suppressed by an interference canceller or an equalizer, the throughput can be improved. We introduce the IPI cancellation factor β to which extent the IPI is suppressed. Neglecting MAI, γ_q is given by

$$\gamma_q \approx \frac{2SF}{1-\beta}. \quad (16)$$

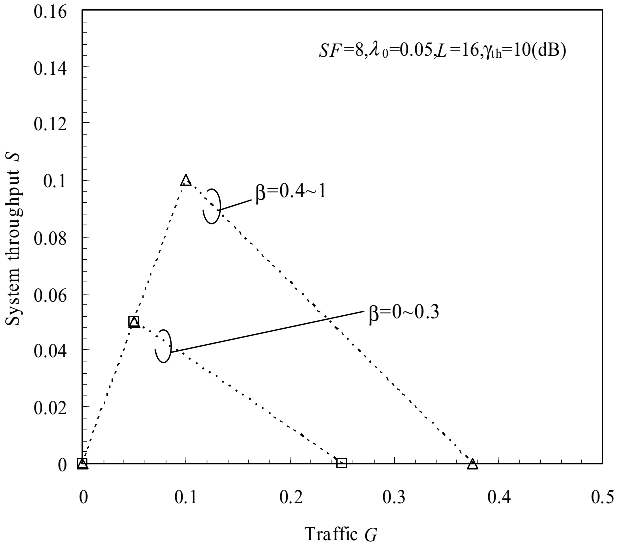
IV. COMPUTER SIMULATION

The system throughput is evaluated by Monte Carllo numerical computation method. Table 1 shows the simulation conditions.

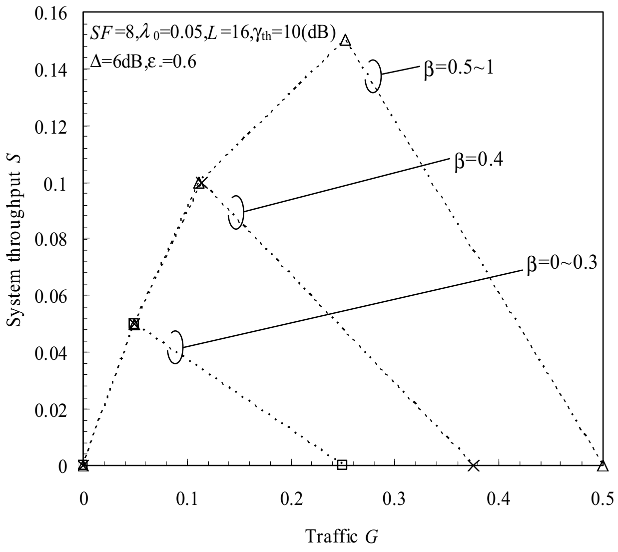
Table 1 Simulation conditions

No. of cells		1
Packet	Length	N=512
	Required SINR	γ_{th}=10(dB)
	Normalized original packet generation rate	λ_0=0.05
Transmitter	Data modulation	BPSK
	Spreading factor	SF=1~8
	Transmit power control	Ideal Fast TPC Ideal Random TPC (Δ=6(dB),ε_-=0.6)
Propagation channel	Fading	Block Rayleigh
	Power delay profile	L=16-path uniform
Receiver	Channel estimation	Ideal

The effect of IPI canceller on the system throughput is shown in Figs. 2 and 3 for *SF*=8 and 1, respectively. As β increases, the system throughput increases for both fast TPC and random TPC. It is also seen that when β approaches 1, random TPC can achieve larger system throughput, due to the capture effect, than fast TPC. Fig.4 plots the maximum system throughput S_max as a function of β. From this figure, it is seen that the system throughput drops when β<0.6 (0.8) for *SF*=2 (1). When $\gamma_q<\gamma_{th}$, the packet transmission fails. Substituting $\gamma_q<\gamma_{th}$ into Eq.(16), we have β<0.6 and 0.8 for *SF*=2 and 1, respectively. This agrees well with the result shown in Fig.4. Random TPC achieves larger S_max than fast TPC. It is also seen from Fig. 4 that as β increases, the optimum spreading factor *SF* that maximizes the maximum system throughput decreases. A possible reason for this can be given below. As *SF* decreases, the transmission data rate increases and the IPI gets stronger. Increasing transmission data rate increases the system throughput, but the IPI gets stronger and this degrades the system throughput; therefore, there exists the optimal *SF* which maximizes the system throughput. As β increases, the IPI is more suppressed and therefore, the optimum *SF* decreases. Since β depends on the capability of an equalizer and an IPI canceller, we should select *SF* according to β (β must be known for this) in order to maximize system throughput.

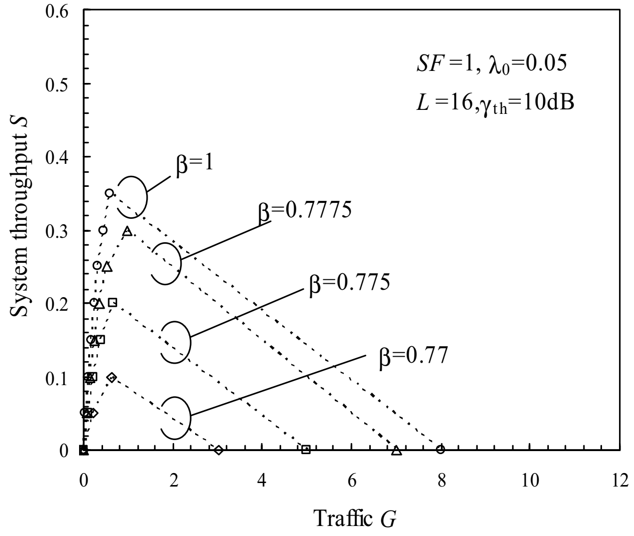


(a) Fast TPC

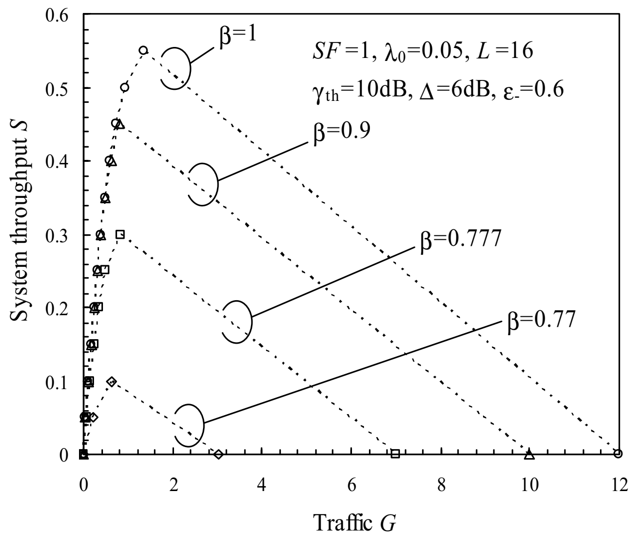


(b) Random TPC

Fig.2 System throughput (*SF*=8)



(a) Fast TPC



(b)Random TPC
Fig.3 System throughput (SF=1)

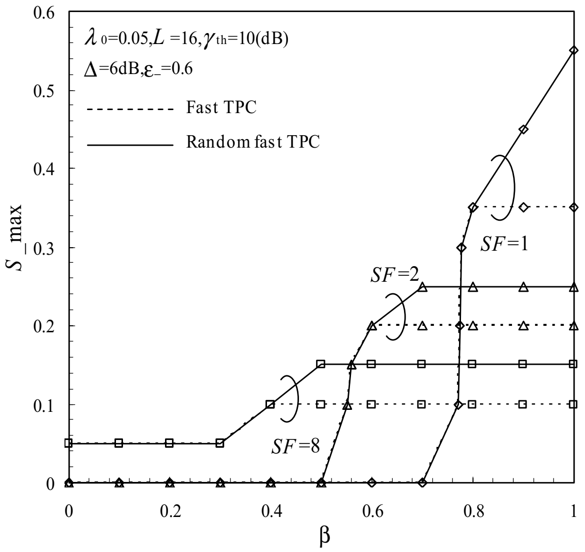


Fig.4 Maximum system throughput as a function of β

V. CONCLUSION

In this paper, we evaluated the combined effect of IPI cancellation and random TPC on the uplink system throughput of slotted Aloha DS-CDMA packet mobile communications by Monte-Carlo numerical computation method. If the IPI can be cancelled, the system throughput increases significantly. It was shown that as the IPI cancellation factor β increases (IPI is more suppressed), the optimum spreading factor SF that maximizes the system throughput decreases. This suggests that the introduction of IPI canceller and random TPC is very effective to improve the system throughput.

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