Optimal Power Allocation in CDMA Forward Link Using Dependency between Pilot and Traffic Channels

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Abstract **– This paper shows a new method for minimizing the transmit power on CDMA forward link channels. Different from previous works, the proposed method uses the dependency that exists between the respective signal qualities of the pilot channel and traffic channels. Since present CDMA forward link exploits coherent demodulation with continuously transmitting pilot signals, the stronger the pilot channel is, the less traffic power may be required while the same transmission quality is maintained. With laboratory tests, the dependency is graphed. And then an optimal pilot signal quality is found, which minimizes the total transmit power. Considering various mobile environments, -10 dB is an outstanding choice for the pilot signal quality. This solution can be directly applied to maximize the capacity of CDMA cellular and PCS systems or improve the service quality at cell edge.**

I. Introduction

CDMA systems are characterized as being interference limited. Reducing the interference or the transmitter power results in a direct increase in the system capacity [1]. One of the most efficient ways to reduce interference in forward link (base station to mobile station) is to use optimum power allocation [2]-[3] for different types of channel: one pilot channel, one sync channel, one or more paging channels, and one or more traffic channels. These channels are transmitted simultaneously by each base station [4]-[5].

Those studies in [2]-[3] on CDMA forward link power allocation have focused on computing the minimum power requirement for each forward link channel, since greater capacity is expected when less power is used. Each channel on the forward link requires a signal-to-interference ratio (SIR) in order to maintain a desired frame error rate (FER) and service coverage. FER is commonly regarded as a decreasing function of SIR. Such relationship has been analyzed for Rayleigh- or Rician-faded additive white Gaussian noise (AWGN) channel with respect to velocity of the mobile station [6]-[7].

Previous works on the forward power allocation [2]-[3], [8]-[9] assumed that the required SIR on each channel was given and fixed. Especially, the frame error performance of traffic channels was assumed to be independent to the SIR of the pilot channel. However, the pilot signal added and multiplexed with voice or data traffic in forward link provides coherent demodulation [4]-[5]. If the pilot signal has higher SIR than a required minimum level, the coherent demodulation process is better supported. In this case, the pilot channel needs additional power to be transmitted but decreases the power required for traffic channels through facilitating channel estimation. This is because stronger pilot signals reduce SIR required for delivering traffic signals while maintaining an adequate FER. If the increase in pilot power is less than the decrease in the power assigned to traffic channels, then the system performance can be improved by transmitting less power in using a higher pilot SIR as a design value. Thus, an optimal power allocation is possible only if the dependency between pilot and traffic channels is considered.

In this paper, we provide the reciprocal relationship between pilot channel's SIR (E_c/I_t) and traffic channel's SIR (E_b/N_o) required for providing 1% FER by laboratory test. And then we show the trade-off between the increase in pilot power and the decrease in the total traffic powers that still satisfy the required E_b/N_o. From the result, we will find an optimal power allocation that minimizes the level of total transmit power in forward link. The proposed solution can be used to simulate the CDMA system in a high level, optimize the base station's power level during system installation phase and improve the service quality of cell edge area.

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II. Experiment for Dependency between E_c/I_t and required E_b/N_o

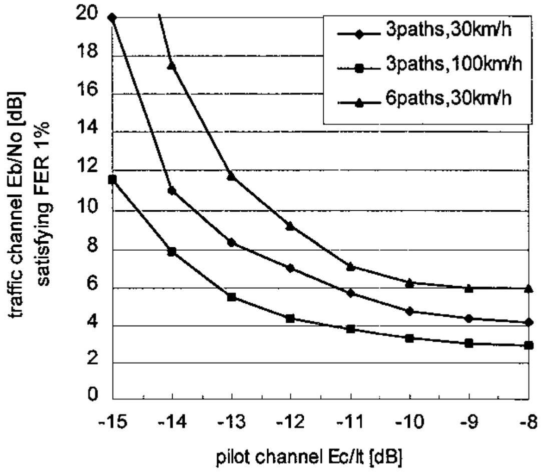

Fig.1. Relation between received pilot E_c/I_t and traffic E_b/N_o satisfying 1% FER in the forward link

The CDMA forward link adopts BPSK modulation with coding and interleaving process [4]-[5]. The demodulator in mobile station uses a coherent RAKE receiver followed by soft decision decoding. In order to characterize the dependency, laboratory tests have been performed for IS-95A forward link using a base station simulator, a class I mobile cellular phone [4]-[5] and a radio channel fading simulator to simulate various radio environments. In the test, we consider various mobile environments according to the number of multipaths at the receiver and mobile speed: 3 multipaths at mobile speed of 30 km/h, 3 multipaths at mobile speed of 100 km/h, 6 multipaths at mobile speed of 30 km/h, and 6 multipaths at mobile speed of 100 km/h.

Fig. 1 shows the reciprocal relationship, obtained from the test, between pilot E_c/I_t and traffic E_b/N_o required for 1% FER. For 6-multipath cases, a similar result is obtained though two different mobile speeds are applied and hence the result obtained for 30 km/h mobile speed is plotted in Fig. 1. The required E_b/N_o of the traffic channels varies with pilot E_c/I_t as well as mobile environments such as multipath fading, and mobile speed. It decreases rapidly between –15 dB and –12 dB of pilot E_c/I_t. We will use this result in optimizing the power allocation of the forward link.

III. Forward Link Power Allocation

Since radio capacity of CDMA systems is limited by interference, it is preferable to reduce transmit power while providing acceptable quality for each channel simultaneously. An efficient power allocation is to let all the channels enjoy the required quality at most. Each forward channel requires

$$\frac{E_i}{N_o} \ge \gamma_i, \qquad \text{for } i = c, s, g, \text{ and } t, \qquad (1)$$

where E_i denotes the received signal energy per bit or chip and γ_i denotes required SIR for each channel. In the following, subscripts for $i = c, s, g$, and t are consistently used to denote pilot, sync, paging, and total traffic channels, respectively. N_O is the total noise spectral density defined as

$$N_o = \alpha I_o + \xi I_o + \eta_o = \omega I_o + \eta_o, \qquad (2)$$

where α denotes the ratio of the same-cell interference density to the total received power density I_O from the home cell and ξ denotes the ratio of other-cell interference density to I_O.

$$I_o = \frac{R_c E_c + R_s E_s + R_g E_g + R_t \rho E_t}{W}, \qquad (3)$$

where W is the spreading bandwidth and R_i is the transmission rate for each channel and ρ denotes a forward link power control factor that represents the effectiveness of forward link power control for traffic channel. If all the mobile stations are located at the cell boundary, ρ approximates to 1.0.

Equating the inequality in (1) and considering equation (2) and (3), we can obtain the power allocation equations as in [8]. Let the minimum received powers E^*_i that is required for each channel located at cell boundary, then

$$E_i^* = \frac{\eta_o W}{D}\gamma_i, \qquad \text{for } i = c, s, g, \text{ and } t,, \qquad (4)$$

where

$$D \equiv W - \omega(\gamma_c R_c + \gamma_s R_s + \gamma_g R_g + \gamma_t R_t \rho) > 0 .(5)$$

Thus, using the equation (4), the transmit power P_i for each channel i is

TABLE 1

Typical parameters used in forward link based on IS-95A

Parameter	Typical Value
W	1.2288 MHz
ξ	1.9
α	0.5
ρ	1
η_o	-166 dBm/Hz
γ_s	7 dB
γ_g	5 dB
R_c	1.2288 Mcps
R_s	1200 bps
R_g	9600 bps
R_t	60.48 kbps (=15users*9600*0.42)
G	150 dB

$$P_i = \frac{\eta_o W}{GD}\gamma_i R_i, \quad \text{for } i = c, s, g, \text{ and } t, \qquad (6)$$

where G denotes path loss between the transmitter of a base station and the receiver of a mobile station including antenna gain.

Given the relation like in Fig. 1., we can see γ_t as a function of γ_c. If we assume that γ_s and γ_g are constant, we can compute the total transmit power P_{total} as

$$P_{total} = P_c + P_s + P_g + P_t. \qquad (7)$$

When γ_t and γ_c are given and fixed, the power allocation achieved by (6) is a unique optimal solution that minimizes (7) and satisfies the SIR requirements in (1). However, as shown in Fig. 1, the selection of γ_c has an effect on γ_t and, as a result, the power allocation. In the next section, we investigate an optimal selection of γ_c that minimizes the total transmit power.

IV. Numerical Examples for Optimal Power Allocation Using the Dependency

In the following numerical examples, unless noted otherwise we assume that each cell is equally loaded with 15 users located at cell boundary. And we also use the values of parameters in Table I, which are usually adopted in IS-95 based CDMA network design.

A. Minimum power allocation for each channel

Fig.1 shows that the required traffic E_b/N_o satisfying FER 1% subordinates to the received pilot E_c/I_t. Substituting the received pilot E_c/I_t in Fig.1 for γ_c in equation (6), we can obtain the transmit power P_i for each channel as a function of pilot E_c/I_t. Fig.2 and Fig.3 show that the pilot and the traffic transmit power as a function of the pilot E_c/I_t, respectively. In this work, we assume that γ_s and γ_g are constant values having nothing to do with γ_c and given as in Table 1. From equations (6) and (7), the total transmit power becomes unstable as the traffic load reaches a limit where D in equation (5) approximates to 0. Traffic load is assumed 60.48 kbps.

In Fig.2, the power allocated to the pilot channel decreases even though γ_c increases. The reason is that a certain decrease in γ_t obtained by increasing γ_c reduces the power assigned to traffic channels and turns to diminish the pilot power. Around –10 and –11 dB, the pilot power is minimized and 39.6, 37.3, and 42.4 dBm are allocated for the respective mobile environments.

Fig.3 shows that with an increase in γ_c the power allocated to traffic channels P_t decreases rapidly until γ_c reaches –10dB. Above –10dB, the traffic power P_t also increases with the increase in γ_c. The points omitted in the figure are due to the capacity limits where equation (6) does not satisfy the positive requirement.

In Fig.4, the total power has a minimum value at –10 and -11 dB for the respective mobile environments. When the mobile speed is 30 km/h, -10 dB is the best selection for γ_c. And –11 dB is the best if the mobile speed is 100 km/h. For the high-mobility case, other selections around –11 dB does not cause the transmit power to increase severely. Hence, -10 dB is a good candidate for γ_c.

B. Transmit power vs. traffic load

In this subsection, the total transmit power is examined as a function of traffic load for a variety of required pilot E_c/I_t from –14dB to –8dB. As the above subsection, three kinds of mobile environments are considered.

Fig.5 represents the result obtained from 3 multipaths and 30km/h mobile speed. The selection of –10 dB for γ_c outperforms other choices over almost the whole range of traffic loads. It also achieves the greatest capacity. –9 dB can be an alternative choice.

In Fig.6, the result is plotted for 3 multipaths and 100km/h mobile speed. For lower traffic load than 90 kbps, -11 dB is the best choice, while –10 dB is the best for higher traffic load. As expected from the fairly flat graph in Fig. 4, -9, -10, -11 and -12 dB selections are comparable in terms of the transmit power.

Fig.7 shows the result from 6 multipaths and 30km/h mobile speed. –10 dB for γ_C is the best choice over the whole range of traffic loads. Each of results described in Fig. 5 – Fig. 7 show a similar tendency for the power to increase when the traffic load in creases. Especially, all figures indicate that when the pilot E_c/I_t equals –10 dB, the total transmit power almost always achieves the minimum. Therefore, pilot E_c/I_t is able to set to –10 dB in order to minimize total transmit power of base station.

V. Concluding Remarks

CDMA systems realize a maximum capacity at a minimum level of transmit power. In this paper, we have examined a solution method to find a minimum transmit power on CDMA forward link. We have shown that a dependency exits between the pilot E_c/I_t and the traffic E_b/N_o while 1% FER is maintained. Since previous power allocation methods [2]-[3], [8]-[9] assumed that the pilot E_c/I_t and the traffic E_b/N_o are given and fixed, the dependency achieved in this paper enlarges the solution space considered in the previous works. We have shown that –10 dB is a best choice for the pilot E_c/I_t and achieves a highest radio capacity.

The dependence examined in this paper helps us to consider an important and practical question: which is better, for improving the service quality of the cell edge, to increase 1 dB of the pilot power or to increase 1 dB of traffic power? Our answer is that it is better to increase the pilot power if present E_c/I_t is below –10 dB. Though –11 dB sometimes can be a better choice for lower traffic load, -10 dB is still an outstanding choice that maximizes the radio capacity. Since the E_c/I_t changes depending on traffic load, adaptive control on the pilot power is also considered as in [10]-[11].

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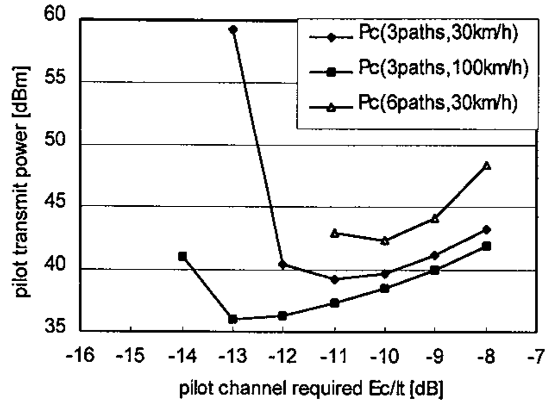

Fig. 2. Pilot transmit power as a function of required pilot E_c/I_t

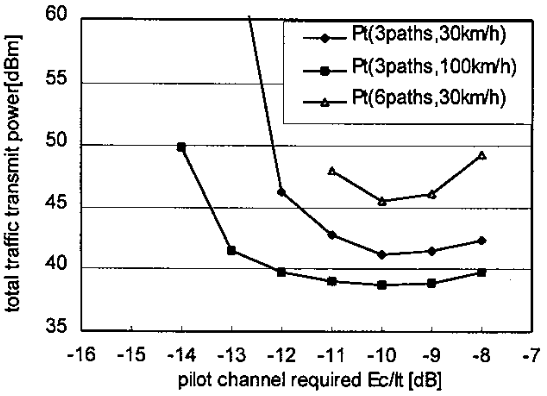

Fig. 3 Traffic channel total transmit power as a function of required pilot E_c/I_t

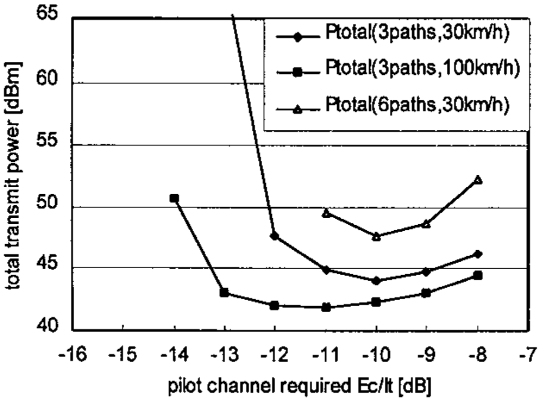

Fig.4. Total transmit power as a function of required pilot E_c/I_t

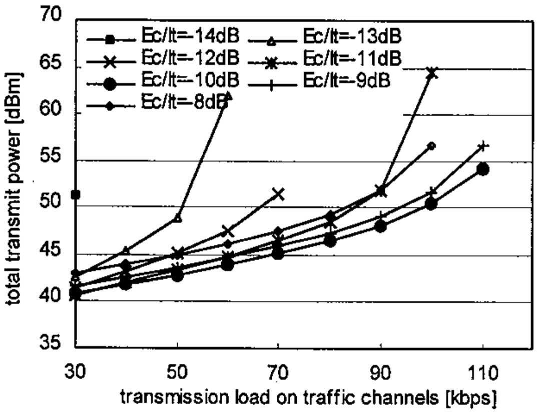

Fig.5. Total transmit power under 3 multipaths and 30 km/h mobile speed

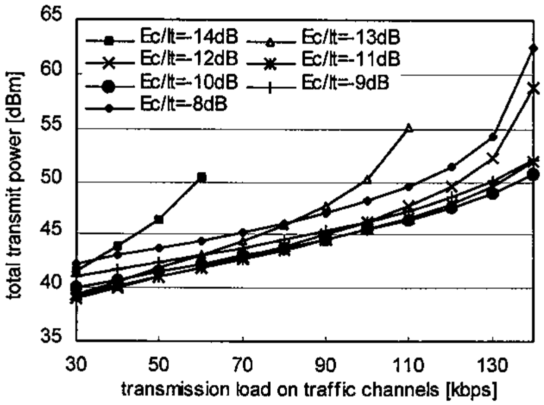

Fig.6. Total transmit power under 3 multipaths and 100 km/h mobile speed

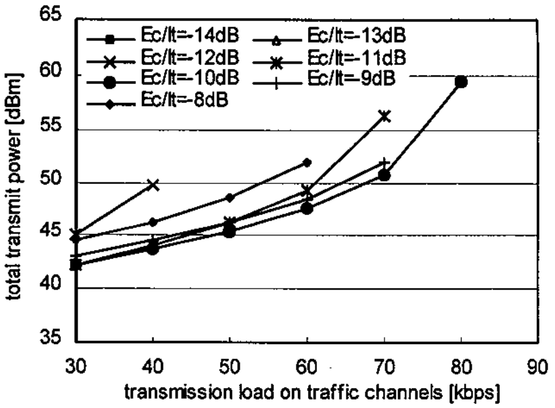

Fig.7. Total transmit power under 6 multipaths and 30 km/h mobile speed