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Performance Comparisons of Cooperative Multi-relay System with/without Opportunistic Transmission in Rayleigh Fading Channel

Rayleigh 페이딩 채널에서 기회전송 유무에 따른 협동 다중 릴레이 시스템의 성능비교

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요 약 레일레이 페이딩 채널에서 전력제한을 받는 기회전송 유무에 따른 협동 다중 릴레이 시스템의 성능을 연구하였다. 전체 네트워크의 전력이 제한되었을 때 3가지의 전력 할당방법을 검토하였고, 그 결과 기회전송 전력 할당방식이 다른 전력할당방식에 비해서 가장 좋은 성능을 나타내었다. 전체 네트워크의 전력이 증가할 경우 기회전송 릴레이가 증가하였고, 기회 협동 다이버시티의 차수를 증가시키게 되며, 결국 종단간 성능이 개선됨을 알 수 있었다.

Abstract The performance of power constrained cooperative multi-relay system with/without opportunistic transmission is considered in Rayleigh fading. The three power allocation methods are considered to maximize the system performance when the total network power is limited. It is analyzed that the opportunistic power allocation strategy has the best performance enhancement compared to the other power allocation strategies. The opportunistic relays increases with the total network power, which induce the higher diversity order of the opportunistic cooperative diversity, consequently improves the end-to-end outage probability.

Keywords: cooperative diversity, relay network, selection combining, opportunistic transmission

I. Introduction

Ad hoc network has attracted and focused to the key technology for the next generation wireless networking. However, the power consumption of wireless ad-hoc networks is critical to maintain the network lifetime and communication reliability [1].

Recently, relay transmission and cooperative diversity have been focused to mitigate the effects of fading and to reduce power consumption of a wireless ad-hoc network [2], [3], [4], [5]. The outage probability with a two-hop relayed transmission is derived for regenerative and non-regenerative systems in Rayleigh fading channel [2]. Extension to multi-relay cooperative diversity systems for the performance improvement of a network is investigated in [4], [6].

The opportunistic transmission which is firstly introduced to the scheduling of a multi-user diversity in a cellular system [7], can be applied to the relay communication. However the optimal power allocation and it's effect to the power reduction or performance improvements of an opportunistic cooperative diversity system has not studied as the author's knowledge.

With this motivation, the comparison study of power allocation of cooperative multi-relay diversity system with or without opportunistic transmission is

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performed. This study will be a guide line for a selection of a power allocation strategy in power constrained ad hoc networks. Therefore the main contribution of this paper is to address follows : Firstly, the performance comparison is made for the 3 different power allocation methods with the total network power is constrained; (1) equal transmit power system, (2) optimal power allocated system, (3) Opportunistic transmission system. Secondly, the effect of the total constrained power to the number of the opportunistic relays, which affects to the feedback traffic load for scheduling, is investigated. This paper is organized as follows. Section II provides background regarding the system model of cooperative multi-relay diversity system with or without opportunistic transmission. The optimal power allocation of cooperative multi-relay diversity system with/without opportunistic transmission system is discussed in Section III. Section IV considers some numerical examples and reviews the results. Finally, Section V summarizes the results of this paper.

II. System Model

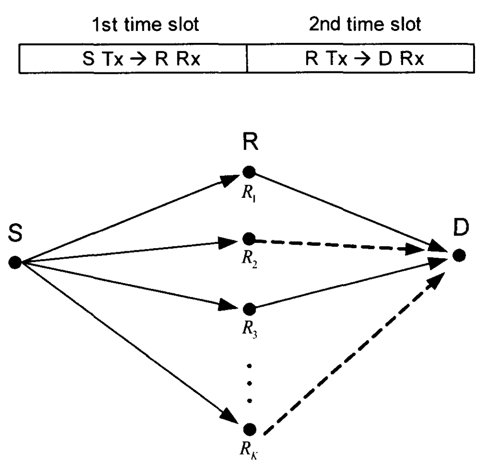

Fig. 1 System model

Fig.1 shows the system model of a cooperative multi-relay diversity, where S, R, and D denote a source node, relay node(R_k, $k=1, \dots, K$), and destination node, respectively. During the 1st time slot, the source node transmits and the relay nodes receive, while the 2nd time slot, the relay nodes transmit and the destination node receives. In the case of the cooperative relay diversity (CRD) system, every relay nodes are participated in the communication relay link [4], however the opportunistic cooperative relay diversity (OCRD) system, only the opportunistic relay nodes which satisfy the received signal-to-noise (SNR) of the relay node is greater than the predetermined threshold are participated [8].

In fig.1 the solid line represents the opportunistic relay communication link of OCRD, and both the solid and the dotted line denotes relay ink of CRD.

During the 1st time slot, the received signal y_{Sk} of the kth Relay node R_k ($k=1 \dots K$) from the source node can be written by

$$y_{Sk} = h_{Sk} x + n_k \tag{1}$$

where h_{Sk} denotes the channel gain between the source node and the kth relay node. We assume the Rayleigh fading channel in this paper. n_k represents the noise of the kth relay node, which has the Gaussian distributed with zero mean and variance of N_0 . In this paper, without loss of generality, we assume the noise power of each node is equal to N_0 . And x denotes transmit information which has the transmit power of P_S . The received SNR γ_{Sk} of the kth relay node can be given by

$$\gamma_{Sk} = |h_{Sk}|^2 \frac{P_S}{N_0} \tag{2}$$

According to the information theory, the total network capacity is given by

$$C = \frac{1}{2}\log_2(1+\gamma) \tag{3}$$

where γ denotes SNR of the channel.

During the two time-slot periods in Fig. 1 the same information is transmitted, therefore the scale factor 1/2 is introduced. The outage is declared if the capacity is less than the predetermined threshold capacity R [bps/Hz], then the outage probability can be written by

$$\begin{aligned} P_{out} &= \Pr(C < R) \\ &= \Pr\left(\frac{1}{2}\log_2(1+\gamma) < R\right) \end{aligned} \tag{4}$$

The outage probability in (4) can be modified to

$$P_{out} = \Pr(\gamma < \gamma_{th}) \tag{5}$$

where γ_{th} denotes the threshold SNR, which is

$$\gamma_{th} = 2^{2R} - 1 \tag{6}$$

2.1 Cooperative multi-Relay Diversity

It is well known that maximal ratio combining (MRC) receiver has the best performance improvements in wireless fading channel compared to the other special diversity technique, however, it requires the perfect knowledge of the channel state information (CSI) [9], [10]. Moreover the performance of the MRC receiver is very sensitive to imperfect CSI. The tracking of rapidly changing CSI in Rayleigh fading increases a receiver complexity, consequently this causes more power consumption. Since a wireless ad hoc sensor network is power limited, the increase of power consumption of each node is fatal to the network lifetime and network reliability [2], [11]. To avoid the complexity and the power consumption of MRC receiver, the selection combining (SC) is introduced. The SC diversity does not need to track the fading channel to obtain CSI which is necessary for MRC, consequently the receiver has simple structure and less power consumption [10], [12], [13]. Hence we assume the SC diversity at the destination node.

It is well known that there are two kinds of relaying, Amplify-and-forward (AF) relaying and Decode-and-forward (DF) relaying. For the simplicity we assume DF or regenerative relaying. We assume the each relay path is independent and identical distributed (i.i.d), then the end-to-end outage probability of CRD can be written by [10]

$$P_{out} = \prod_{k=1}^{K}\left[1 - e^{-\gamma_{th}(1/\bar{\gamma}_{Sk} + 1/\bar{\gamma}_{kD})}\right] \tag{7}$$

where $\bar{\gamma}_{Sk}$ and $\bar{\gamma}_{kD}$ denotes the average SNR of the Source- kth Relay, and the kth Relay-Destination, respectively and written by

$$\begin{aligned} \bar{\gamma}_{Sk} &= E[\gamma_{Sk}] = E\left[|h_{Sk}|^2\right]\frac{P_S}{N_0} = \Omega_{Sk}\frac{P_S}{N_0} \\ \bar{\gamma}_{kD} &= E[\gamma_{kD}] = E\left[|h_{kD}|^2\right]\frac{P_{Rk}}{N_0} = \Omega_{kD}\frac{P_{Rk}}{N_0} \end{aligned} \tag{8}$$

and where $E[\bullet]$ represents statistical expectation, γ_{kD} is the received SNR of the destination node from kth Relay node, h_{kD} represents the channel gain between the kth Relay node and the destination node, and P_{Rk} is the transmitting power of the kth Relay node. Also, $\Omega_{Sk} = E\left[|h_{Sk}|^2\right]$,and $\Omega_{kD} = E\left[|h_{kD}|^2\right]$ are defined.

When the total network power is constrained to P_T and each node transmits with an equal power, then the transmitting power of each node is

$$P_s = P_{Rk} = \frac{P_T}{K+1} \quad (9)$$

With this assumption, (8) can be written by

$$\bar{\gamma}_{Sk,eq} = \Omega_{Sk}\frac{P_T}{N_0(K+1)}$$
$$\bar{\gamma}_{kD,eq} = \Omega_{kD}\frac{P_T}{N_0(K+1)} \quad (10)$$

If we replace $\bar{\gamma}_{Sk}$ and $\bar{\gamma}_{kD}$ in (7) to $\bar{\gamma}_{Sk,eq}$ and $\bar{\gamma}_{kD,eq}$, the end-to-end outage probability when each node has same transmitting power can be obtained.

2.2 Opportunistic transmission

The relay node R_k ($k = 1...K$) of OCRD transmits the information when the received SNR is greater than the threshold. The probability that the received SNR of k Relays is greater than the threshold γ_{th} is given by

$$\Pr(k) = \binom{K}{k}[1 - P_\gamma(\gamma_{th})]^k P_\gamma(\gamma_{th})^{K-k} \quad (11)$$

where K denotes the total number of relays. The outage probability of $P_\gamma(\gamma_{th})$ is the cumulative distribution function of the received SNR γ in i.i.d Rayleigh fading and can be written by

$$P_\gamma(\gamma_{th}) = 1 - e^{-\gamma_{th}/\bar{\gamma}_{Sk}} \quad (12)$$

And the average number of relay nodes of which the received SNR is greater than the threshold γ_{th} can be obtained from (11),

$$M = \sum_{k=0}^{K} k\Pr(k)$$
$$= \sum_{k=0}^{K} k\binom{K}{k}[1 - P_\gamma(\gamma_{th})]^k P_\gamma(\gamma_{th})^{K-k} \quad (13)$$

The end-to-end outage probability of OCRD is written by

$$P_{out} = \sum_{k=0}^{K} P_{o.RD}\Pr(k) \quad (14)$$

where $P_{0,RD}$ denotes the outage probability at the destination node with SC diversity and given by [10]

$$P_{0.RD} = \left(1 - e^{-\gamma_{th}/\bar{\gamma}_{kD}}\right)^k \quad (15)$$

Therefore the end-to-end outage probability of OCRD can be obtained from (14),

$$P_{out} = \sum_{k=0}^{K}(1 - e^{-\gamma_{th}/\bar{\gamma}_{kD}})^k \binom{K}{k}(e^{-\gamma_{th}/\bar{\gamma}_{Sk}})^k\left(1 - e^{-\gamma_{th}/\bar{\gamma}_{Sk}}\right)^{K-k}$$
$$= \prod_{k=1}^{K}\left[1 - e^{-\gamma_{th}(1/\bar{\gamma}_{Sk} + 1/\bar{\gamma}_{kD})}\right] \quad (16)$$

where the 2nd equality is obtained from [14]. Consequently, the outage probability in (16) agrees exactly with that in (7) for CRD. The difference between (7) and (16), every relays are participated in the relaying process in (7) o r CRD, however, only the opportunistic relays are participated the process in (16) or OCRD. In other words, when the total network power is constrained, the aggregate relay power is distributed to every relays in CRD, however, the power is distributed only to the opportunistic relays in OCRD. Therefore we can reduce the interference caused by the non-opportunistic relays as well as improve the performance of a power constrained system.

III. Optimal Power allocation

In this chapter, the optimal power allocation is discussed to minimize the end-to-end outage probability under the total network power is constrained. The two power allocation strategies are considered: (a) strategy 2; the aggregated relay power is equally divided to the all relay nodes in CDR, (b) strategy 3; the aggregated relay power is equally divided to the opportunistic relay nodes in OCDR. In the case that each node has identical transmit power in (9), it defines power allocation strategy 1.

The total network power consists of the source power and the aggregate relay power,

$$P_T = P_S + P_R \tag{17}$$

where P_S and P_R denote the source power, and aggregate relay power, respectively. To minimize the end-to-end outage probability under the total network power is constrained, the problem is formulated as,

$$\text{Min} \quad P_{out} = \prod_{k=1}^{K}[1 - e^{-\gamma_{th}(1/\bar{\gamma}_{Sk} + 1/\bar{\gamma}_{kD})}] \tag{18}$$

$$\text{Subject to} \quad P_T = P_S + P_R .$$

$$P_S,\ P_R > 0$$

Minimizing the object function of P_{out} is equivalent to maximizing the term, $-\gamma_{th}(1/\bar{\gamma}_{Sk} + 1/\bar{\gamma}_{kD})$. The problem reduces to

$$\text{Max} \quad -\gamma_{th}(1/\bar{\gamma}_{Sk} + 1/\bar{\gamma}_{kD}) \tag{19}$$

$$\text{Subject to} \quad P_T = P_S + P_R$$

$$P_S,\ P_R > 0$$

Using Lagrenge maximization method, the modified objective function can be written by [15], [16],

$$J = -\gamma_{th}(\frac{1}{\bar{\gamma}_{Sk}} + \frac{1}{\bar{\gamma}_{kD}}) - \lambda(P_S + P_R - P_T) \tag{20}$$

The transmitting power of a relay node, $P_{Rk,eq}$,in strategy2 becomes

$$P_{Rk,eq} = P_R / K \tag{21}$$

Replacing (8) and (21) into (20), the objective function can be modified to

$$J = -\gamma_{th}(\frac{N_0}{\Omega_{Sk}P_S} + \frac{KN_0}{\Omega_{kD}P_R}) - \lambda(P_S + P_R - P_T) \tag{22}$$

which upon taking derivative to P_S, P_R and λ , and solving lead to the optimal power of source node P_S^* and optimal power of aggregate power of relay nodes P_R^* ,

$$\begin{aligned} P_S^* &= P_T / \left(1 + \sqrt{\frac{K\Omega_{Sk}}{\Omega_{kD}}}\right) \\ P_R^* &= P_T / \left(1 + \sqrt{\frac{\Omega_{kD}}{K\Omega_{Sk}}}\right) \\ &= P_T - P_S^* \end{aligned} \tag{23}$$

Consequently,

$$\begin{aligned} \bar{\gamma}_{Sk,opt} &= \Omega_{Sk}\frac{P_S^*}{N_0} \\ \bar{\gamma}_{kD,opt} &= \Omega_{kD}\frac{P_R^*}{KN_0} \end{aligned} \tag{24}$$

By replacing $\overline{\gamma}_{Sk,opt}$ and $\overline{\gamma}_{kD,opt}$ to $\overline{\gamma}_{Sk}$ and $\overline{\gamma}_{kD}$, respectively, in (8), the end-to-end outage probability of CDR with strategy 3 can be obtained form (18).

While the aggregate relay power is equally divided to the opportunistic relay nodes in OCDR, the optimal aggregate relay power becomes

$$P_R^* = \sum_{k=1}^{M} P_{kD} = MP_{kD} \tag{25}$$

and consequently,

$$\overline{\gamma}^*_{Sk,opp} = \Omega_{Sk}\frac{P_S^*}{N_0}$$
$$\overline{\gamma}^*_{kD,opp} = \Omega_{kD}\frac{P_R^*}{MN_0} \tag{26}$$

Therefore, by replacing $\overline{\gamma}_{Sk,opp}$ and $\overline{\gamma}_{kD,opp}$ to $\overline{\gamma}_{Sk}$ and $\overline{\gamma}_{kD}$, respectively, in (8), the end-to-end outage probability of OCDR with strategy 3 can be obtained form (18).

Ⅳ. Numerical examples

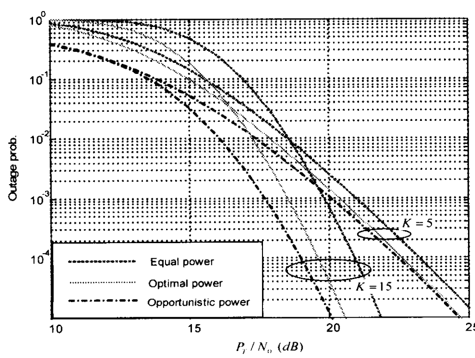

Fig. 2 Total power vs. outage probability ($R=1$ [bps/Hz], $\overline{\gamma}_{Sk}=\overline{\gamma}_{kD}=1$)

Fig.2 shows the end-to-end outage probability versus the total network power with the condition that the threshold capacity R is equal to 1 (bps/Hz), and the average SNR of Source- kth Relay path is identical to that of the kth Relay-Destination path ($R=1$ [bps/Hz], $\overline{\gamma}_{Sk}=\overline{\gamma}_{kD}=1$). It is noticed that the end-to-end performance improves with the increase of the number of the total relay nodes, K, from 5 to 15.

In this fig.2, "equal power" denotes each node has identical transmit power (power allocation strategy 1), "optimal power" represents each node's transmit power is decided from the power allocation strategy 2 of CDR. And "opportunistic power" denotes the power allocation of opportunistic nodes in OCDR obeys the power allocation strategy 3.

The required P_T/N_0 to satisfy the end-to-end outage probability of 1×10^{-3} is 20.9 dB, 20.4 dB, and 20 dB for the case of equal power, optimal power, and opportunistic power allocation strategy, respectively. From this fig.2 we noticed that the optimal power allocation strategy, strategy 2, has better performance than the equal power transmit case, strategy 1, when the total network power is constrained in CDT. Also the opportunistic power allocation strategy, strategy 2, in OCDR has the best performance among the other power allocation case: this performance improvement is caused by the fact that (1) the aggregate relay power is allocated to the opportunistic transmit relays only, not all relays in CDR, (2) the performance increasing rate with the space diversity order is slower than with the relay power. The power gain of OCDR increases with the increase of K to 15.

The number of the opportunistic relays increases as the total network power increases in fig. 3. It is interpreted that γ_{th} is determined from the given R irrespective of the total network power, this causes the probability that the received SNR exceeds the threshold increases with the increase of the total network power. The increase of the total network power induces the diversity order of OCDR, consequently the outage probability improves.

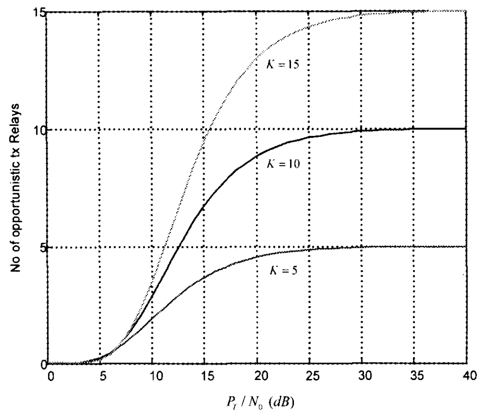

Fig. 3 Number of opportunistic relays ($R = 1\ [bps/Hz],\ \overline{\gamma}_{Sk} = \overline{\gamma}_{kD} = 1$)

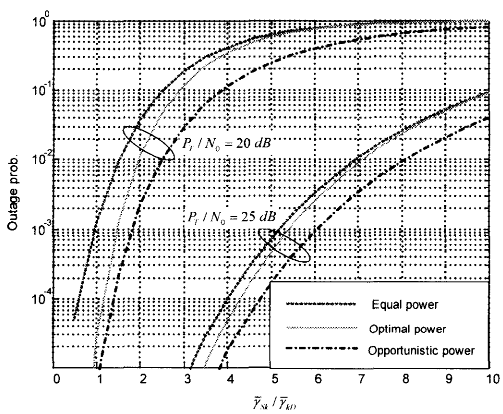

Fig. 4 Outage probability in asymmetric path ($R = 1\ [bps/Hz],\ K = 20$)

The asymmetrical path, the received average SNR of the Source-Relay path and that of the Relay-Destination path is not identical ($\overline{\gamma}_{Sk} \neq \overline{\gamma}_{kD}$),is shown in fig.4. From the fig.4, the performance degrades as the ratio of $\overline{\gamma}_{Sk} / \overline{\gamma}_{kD}$ increases. It is interpreted that the performance is a function of an average SNR, which decreases with the increase of distance. The increase of the ratio of $\overline{\gamma}_{Sk} / \overline{\gamma}_{kD}$ means the Relay-Destination path is longer than the Source-Relay path, hence, the decreased receiving SNR causes the performance degradation.

V. Conclusions

When the total network power is constrained, such as ad hoc networks, the power reduction is critical for the network lifetime and the communication reliability. Due to the fading, the performance of a wireless system is degraded. One easy way to improve the degraded performance is increasing the transmitting power. However, increasing the power causes not only the power consumption but also the interferences.

To mitigate the fading in wireless channel, recently introduced the cooperative relay communication which improves the system performance without the spectrum increase and the multiple antenna on a tiny nodes by utilizing the space diversity. Moreover, the opportunistic transmission decreases the interferences. In this study, the comparison of power allocation of cooperative multi-relay diversity system with/without opportunistic transmission is investigated.

From this study, we noticed that the opportunistic cooperation is desirable for the end-to-end performance improvements compared to the other power allocation strategies. Also the power gain is increasing as the number of the relay nodes increases. The opportunistic relays are increasing with the total network power, which increases the diversity order of OCDR, consequently the end-to-end outage probability improves.

The results of this study can be a basis for a selection of a power allocation strategy in power constrained ad hoc networks.

References

[1] M. Barbeau, and E. Kranakis, *Principlesofadhocnetworking*,JohnWiley&SonsLtd.,2007.

[2] M. Hasna, M. - S. Alouini, "Performance of two-hop relayed transmissions over Rayleigh fading channels," Proceedings of Vehicular Technology Conference 2002, vol. 4, pp. 1992-1996, Sept. 2002.

[3] J. N. Lanememan, G. W. Wornell, "Energy efficient antenna sharing and relaying for wireless networks," Proceedings of WCNC2000, vol. 1, pp.7-12, Sept. 2000.

[4] V. Emamian, P. Anghel, M. Mostafa Kaveh, "Multi-user spatial diversity in a shadow-fading environment," Proceedings of Vehicular Technology Conference 2002-Fall, vol.1, pp. 573-576, Sept. 2002.

[5] P. A. Anghel, M. Kaveh, "Exact symbol error probability of a cooperative network in Rayleigh-fading environment," IEEE Trans. on Wireless Communi., vol. 1, no. 5, pp. 1416-1421, Sept. 2004.

[6] A. Ribeiro, X. Cai, G. B. Giannakis ,"Symbol error probabilities for general cooperative links," IEEE Trans. on Wireless Communi., vol.4, no.3, pp. 1264-1273, May 2005.

[7] R. Knopp and P.Humblet," Information capacity and power control in single-cell multiuser communications," Proceedings of IEEE International Conference on Communications 1995, vol.1, pp. 331-335, June 1995.

[8] Davis Gesbet, Mohamed-S.Alouini, "How much feedback is multi-user diversity really worth?," ProceedingsonInternationalConferenceonCommunications,vol.1,pp.234-238,June2004.

[9] G. L. Stuber, *Principles of mobile communication*, Kluwer Academic Publishers, 2001.

[10] A. Goldsmith, *Wireless communications*, Cambridge University Press, 2005.

[11] Nam-Soo Kim, Beongku An, Do-Hyun Kim, "An architecture model for supporting power saving services for mobile wireless Ad-hoc networks," LNCS3560, pp. 415-416, Springer-Verlag, 2005.

[12] M. Yacuob, *Foundation of mobile radio engineering*, CRC Press 1993.

[13] M. K. Simon, M.-S. Alouini, *Digital communication over fading channels*, John Wiley & Sons, Inc, 2005.

[14] Aggelos Bletsas, Hyundong Shin, Moe Z. Win, "Cooperative communications with outage-optimal opportunistic relaying," IEEE Transactions on Wireless Communications, vol.6, no.9, pp. 3450-3460, Sep. 2007.

[15] Mazen O. Hasna, Mohamed-S. Alouini,"Optimal power allocation for relayed transmissions over Rayleigh-fading channels," IEEE Trans. on Wireless Communi., vol.3, no.6, pp.1999-2004, Nov. 2004.

[16] Alan P.T. Lau, Shuguang Cui, "Joint power minimization in wireless relay channels," IEEE Trans. on Wireless Communi., vol.6, no.8, pp. 2820-2824, Aug. 2007.

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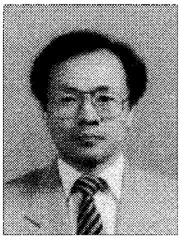

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