Up/Downlink Hybrid Inter-Cell Coordination Patterns of the TDD/MC-CDMA System, TDD/MC-CDMA

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ABSTRACT

Inter-cell coordination has been an emerging issue for mitigating inter-cell interference in broadband wireless access networks such as IEEE802.16 and 3GPP LTE (Long Term Evolution). This paper proposes uplink/downlink hybrid inter-cell coordination patterns for a TDD (Time Division Duplex)/MC-CDMA (Multi-Carrier Code Division Multiple Access) system. For the performance analysis, closed forms of inter-cell interferences are derived when uplink and downlink transmissions coexist over a multi-cell environment. In the analysis, we find an optimal ratio of downlink transmit powers of BSs (Base Stations) based on the target outage probability and the performance according to ratios of uplink/downlink transmit powers of MSs (Mobile Stations)/BSs is explored. Our numerical results show that interference mitigation utilizing the characteristics of the uplink and downlink power ratio is very effective in improving system performance in terms of QoS.

Key Words : TDD/MC-CDMA, Forward Link Capacity, Reverse Link Capacity, Inter-cell Coordination, Multi-cell Environments

Ⅰ. INTRODUCTION

As a dynamic resource management mechanism, the inter-cell coordination techniques have been presented in literature for maintaining QoS dynamically dependent on the volume of traffic through interference-avoidance and load balancing. Interference avoidance aims at forcing a few surrounding BSs to be idle to limit the impact of interference on edge users. In [1], an FFFR (Flexible Fractional Frequency Reuse) scheme is proposed by employing power allocation and frequency reuse over the FDD (Frequency Division Duplex) system. In [2], an inter-cell scheduling mechanism in the TDMA (Time Division Multiple Access) network is presented, in which a typical symmetric sectorized hexagonal pattern is used and a potential capacity gain is demonstrated. In [3], general optimality conditions for static policy is formulated in a three-cell system with an inhomogeneous traffic distribution.

However, the main drawbacks of the traditional algorithms are follows. A lack of numerical analysis exists as to how to guarantee QoS when the number of users exceeds a threshold. In addition, most of them have focused on mitigating downlink interference at the cell boundary rather than on utilizing the effect of interference compensation when the up/down-link cells coexist over the cellular network.

This paper explores a numerical approach to uplink and downlink coordination for mitigating inter-cell interferences. The main goal aims at investigating feasible coordination patterns for a given QoS constraint by limiting the number of admissible users or by controlling the transmission power. In order to

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utilize the characteristics of the uplink and downlink transmission power, a TDD/MC-CDMA (Time Division Duplex/Multi-Carrier Code Division Multiple Access) system is dealt with as the target system, where the transmission power ratio is controlled to mitigate interference and achieve a better throughput. Since these coordination patterns become more meaningful as the user density is increased, a region-based partition (i.e., inner and outer regions for downlink and angular symmetric regions for uplink) is accomplished. For the QoS measurement, the outage probability is derived as a closed form and utilized as a tool for the performance measurement.

Ⅱ. Inter-cell Coordination

2.1 Interference Scenario in the TDD/MC-CDMA System

Fig. 1 depicts possible interferences when downlink and uplink transmissions occur simultaneously over a multi-cell environment[4].

When MS_x is communicated with the home BS, the interferences numbered 1 and 3 contribute to the quality degradation of the desired signals at the uplink and downlink transmissions, respectively. Similarly, the arrows numbered 2 and 4 indicate the interferences affected by neighboring MS_y to the home BS and to MS_x against the uplink and downlink transmissions of the desired signals, respectively. MS (Mobile Station)-to-BS and BS-to-MS interferences can occur in TDD and FDD systems. On the other hand, MS-to-MS and BS-to-BS interferences occur only in the TDD system.

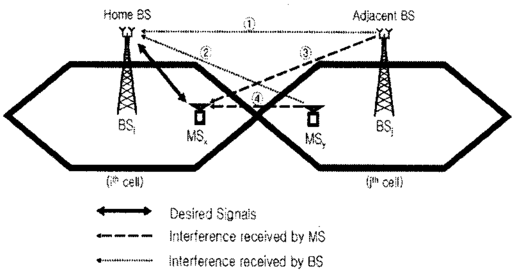

Fig. 1. Possible Interferences at the TDD/MC-CDMA

2.2 Primitive Coordination Patterns

Here, it is assumed that a general TDD mechanism is used without the use of cell-coordination when the user density is low. To distribute a large volume of users into the space and time domains, a region division partitioning is accomplished relying on the downlink and uplink transmission of each cell.

Fig. 2 depicts two pairs of primitive region patterns for each downlink or uplink cell where R_A and R_I indicate the active and inactive regions. For a given time slot, only users in the active region are served to transmit data. Note that the downlink cell is divided into inner and outer regions in Fig. 2 (a).

This paper focuses on an analysis of inter-cell coordination patterns consisting of such primitive patterns, and on the coordination gain afforded by using the designed patterns in terms of throughput and QoS. which results in maintaining a QoS constraint at the cell boundary. On the other hand, a low power is allocated to MSs located in the inner region for the Type-B cell in Fig. 2 (b), resulting in a reduction in ICI from the reduced power to neighboring cells while maintaining the QoS constraint.

2.3 Inter-cell Coordination Patterns

Fig. 3 (a) shows a cellular coordination with two tiers. In pattern 1-1, cell 0 is assumed to be the home cell being surrounded by 18 neighboring cells. A cell filled with grey over the outer region of a hexagon represents that the BS transmits signals with a full power. On the contrary, a cell which has a grey hexagon inside of the cell represents that the BS transmits signals with a reduced power and the associated ratio of the reduced power over the full power is η_1. For the inter-cell coordination, alternative power patterns can be used by using pattern 1-1 to pattern 1-3. It can be seen that the home cell provides full power to the downlink

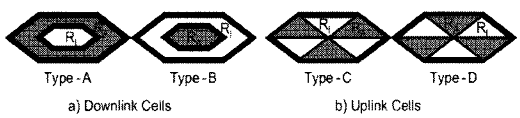

Fig. 2. Examples of primitive coordination patterns according to the downlink and uplink cells

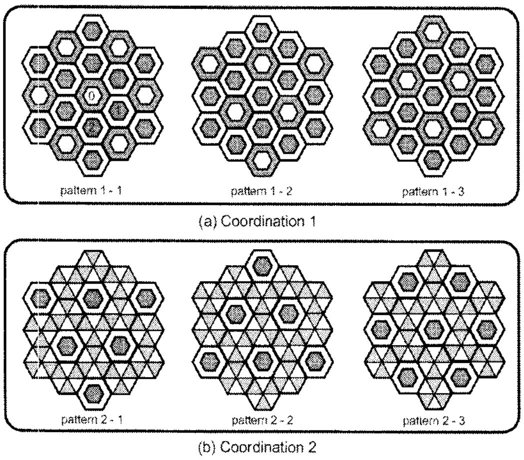

Fig. 3. Inter-cell Coordination Patterns

transmission at pattern 1-1 for providing services to MSs at the cell boundary. At patterns 1-2 and 1-3, the home cell provides a reduced power for providing services to MSs at the inner region.

Fig. 3 (b) shows a hybrid coordination combining the primitive uplink and downlink patterns depicted in Fig. 2. In pattern 2-1, cell 0 is an uplink cell where three of the neighboring cells are uplink cells and the other three are downlink cells. In pattern 2-2, cell 0 is still an uplink cell, but the alternative region is selected. The uplink cells in pattern 2-1 are converted to downlink cells in pattern 2-2 and vice versa. In pattern 2-3, cell 0 becomes a downlink cell and its 6 neighboring cells are uplink cells.

η_1 is the ratio of the reduced power to the full power in the downlink transmission, η_2 is the ratio of the target power at the BS in the uplink transmission to the full power of BS in the downlink transmission.

In order to obtain an optimal η_1, it is necessary to investigate how much the inter-cell interference needs to be reduced either by pruning interference sources or by controlling their transmitting power. If primitive patterns in Fig. 2 (a) are used in the coordination patterns of 1-1, 1-2, 1-3, in Fig. 3(a), the optimal η_1 can be obtained by

$$\eta_1^* = \arg\max_{\eta_1}[n(R_A)]$$

$$subject\ to \quad \max \Pr[(\frac{E_b}{N_0})_{i,x} < \gamma] \le \overline{P}^{out}$$

where x is the x^{th} position, i is the index of the cell (i=0 is the index of the home cell), $\overline{P}^{out}$ is the target outage probability, $n(R_A)$ is the number of accommodated users in the active region R_A, γ is a target threshold of (E_b/N_0). $\arg\max$ stands for the argument of the maximum.

Ⅲ. Capacity Analysis

3.1 Interference Analysis

Fig. 4 depicts a general MC-CDMA transmitter and we employs the terms in [5][6].

Let an MS be located in an ''x'' position of the i^{th} BS (i.e., the home BS). Then, the path loss between the MS of the i^{th} BS and an adjacent BS (here, the j^{th} BS) is given by

$$L_{(i,x;j)} = r^{-l}_{(i,x;j)} 10^{\xi_{(i,x;j)}/10} = r^{-l}_{(i,x;j)} \chi_{(i,x;j)}$$

where l is a path-loss exponent (typically three to four), $r_{(i,x;j)}$ is the distance between x in the i^{th} BS and the j^{th} BS, $\xi_{(i,x;j)}$ is a Gaussian distributed random variable with a zero mean and a standard deviation representing shadowing and $\chi_{(i,x;j)}$ is a lognormally distributed random variable. Typically, the standard deviation of ξ is in the range of 6-10 dB for signals from adjacent BSs and 2-2.5 dB for signals from the home BS. Here, it is assumed that l=4.

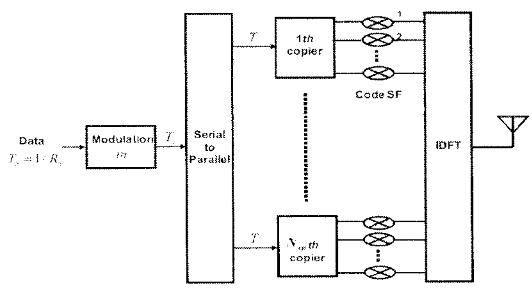

Fig. 4. An MC-CDMA transmitter

3.2 inter-cell interference

Fig. 5 depicts possible inter-cell interferences when downlink and uplink coexist in a multi cell environment. Since the interference is a function of the transmitted signal power, the associated path loss and its shadowing, the interferences can be described in terms of some pertinent details; distance, shadowing, and path loss. Note that we will simplify the E_b/N_0 formula following this section using the tranditional path loss notations.

3.3 intra-cell interference

Suppose that a cell is in downlink and an MS receives a signal from the home BS. Other signals which are not destined to reach the MS, become intra-cell interference. In MC-CDMA system, there is no intra-cell interference when each subcarrier uses a unique code which is orthogonal to the others. Let $\alpha_{i,k,f}$ be the normalized power portion assigned to the f^{th} sub-carrier of the k^{th} user in the i^{th} BS. Then,

$$\alpha_{i,k} = \sum_{f=1}^{N_{sc}} \alpha_{i,k,f} \text{and} \sum_{f=1}^{N_{sc}} \sum_{k=1}^{N} \alpha_{i,k,f} = 1$$

where N is the total number of users in the i^{th} cell. In this paper, the worst case analysis is employed. We assume that there is intra-cell interference for mobile stations which use the same code and we consider the mobile stations are in multi-cell environments. Therefore, the intra-cell interference in the downlink cell is given by $I_{sc}^{down} = (1-\alpha_{i,k}) \cdot S_{BS} \cdot L_{(i,x;i)}$. On the other hand, in the case of uplink, assume that all MSs are power-controlled. In such a case, the home

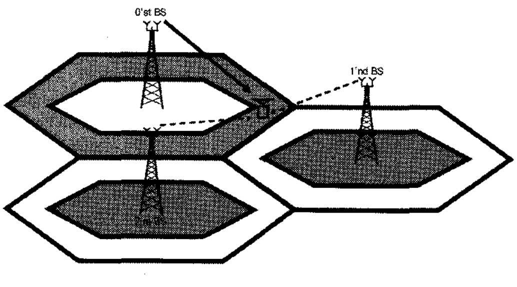

Fig. 5. The inter-cell interference when only downlink cells are coordinated

BS receives signals from MSs at the target level of power. All signals, except the desired signal, then become intra-cell interference which is given by $I_{sc}^{up} = (N-1)S_{MS}$ where S_{MS} is the transmit signal power at the base station in the uplink transmission. Note that N is a constant which means the total number of users in a cell.

3.4 E_b/N_0 formula

Without loss of generality, the SINR (Signal to Interference plus Noise Ratio) when an MS places at position x in the i^{th} cell is given by $[SINR = \frac{S \cdot L_{(i,x;i)}}{I_{oc} + I_{sc} + N_0 BW_T}]$ where S is the signal power of a transmitter, $L_{(i,x;i)}$ is a path loss between the MS and the i^{th} BS, I_{oc} is the inter-cell interference, I_{sc} is the intra cell interference, N_0 is the power spectral density of AWGN(Additive White Gaussian Noise). Therefore, for $I_{oc} + I_{sc} \gg N_0 BW_T$, $N_{cp} \cdot SF \gg 1$, $BW_T/R_b = SF/2m$, E_b/N_0 at the x position in the i^{th} cell is then simplified by

$$\frac{E_b}{N_0} = SINR \cdot \frac{BW_T}{R_b} = \frac{L_{(i,x:i)} \cdot S \cdot \frac{SF}{2m}}{I_{oc} + I_{sc}}.$$

In the following sections, E_b/N_0 formulas are derived according to the type of each link. To analyze the inter-cell coordination patterns in Fig. \ref{fig:policy}, three classes can be selected: downlink only, uplink with downlink, and downlink with uplink.

Ⅳ. SIMULATION RESULTS

The outage probability is used as a tool for measuring the performance of the proposed algorithm and for designing the system parameters based on a target SNR. In order to obtain an optimal power ratio for the downlink transmission , a hexagonal cell is divided into two regions. W.r.t. a normalized cell radius of 1, region partitioning is accomplished using a normalized distance of 0.7. Thus, the inner (outer) region is in the range of 0 to 0.7 (0.7 to 1) and the area ratio becomes 0.49 to

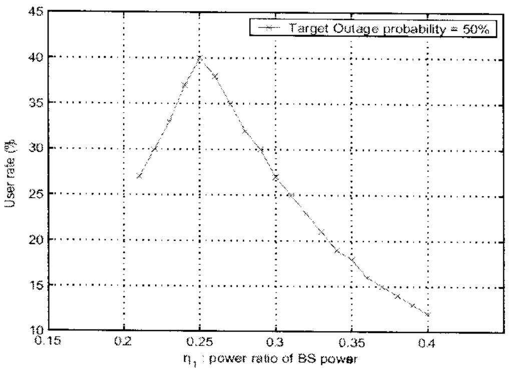

Fig. 6. The power ratio measurement for obtaining the maximum user rate accommodated in the system

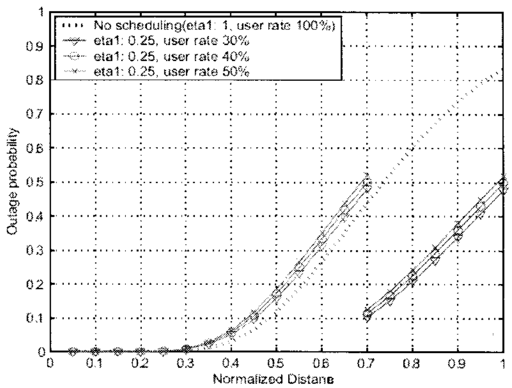

Fig. 7. The outage probability according to the user rate.

0.51. Under the assumption of a uniform distribution, the number of users in the two regions is almost equal. For the simulation environment, the target SNR is set to 4 dB using a QPSK modulation. In the downlink, the outage probability is measured over the location from the central point to the boundary of the home cell. The user rate, especially, user rate 100% is the maximum number of users which a cell can accommodate in the MC-CDMA downlink system when the system does not adopt a TDD scheduling scheme. In addition, the user rate 200% means that a cell can accommodate the twice number of users with the proposed scheme than the conventional cellular system cell can. Through a Monte Carlo simulation, we can measure the user rate accommodated by the system for a given target outage probability of 0.5 shown in Fig. 6.

It can be seen that the system can maximally accommodate 40 % user rate with $\eta_1^* = 0.25$ at the inner and outer regions, respectively.

In Fig. 7, we measure the outage probability with $\eta_1 = 0.25$ according to the user rate. From the simulation result, it can be seen that the maximum user rate is 40 % in both regions for a given target outage probability of 0.5. For the benchmark, a conventional cellular system with an FRF of 1 is employed, where each BS sends data using full power, no region partitioning is performed and only uplink or downlink transmission over the entire cell coverage is performed at each time slot. In the conventional system, 100 % user rate is assumed to be uniformly distributed over each cell.

It can be observed that the outage probability of the proposed mechanism in the inner region is slightly greater than that of the conventional system due to its lower power allocation. On the contrary, the probability can be effectively reduced in the outer region. Since the outage probability is a function of the user rate, the user rate that is suitable can be determined for a given target QoS.

Fig. 8 show the system capacity per user. The system capacity per user is the capacity allocated to a user and is calculated by the spectral efficiency obtained by the corresponding user rate. Due to the reduced user rate for region-based QoS control, it is appropriate that an increase in channel capacity per user is attainable, compared to the conventional scheme.

For the fairness of the performance comparison,

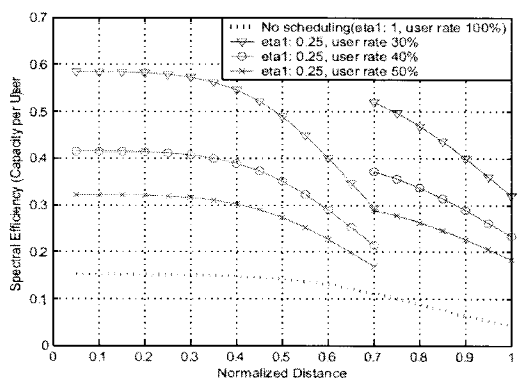

Fig. 8. The channel capacity per user according to the user rate.

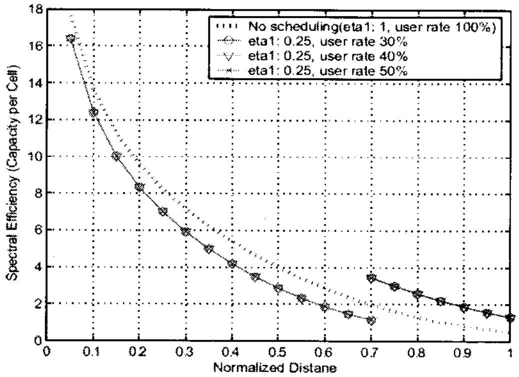

Fig. 9. The channel capacity per cell according to the of user rate.

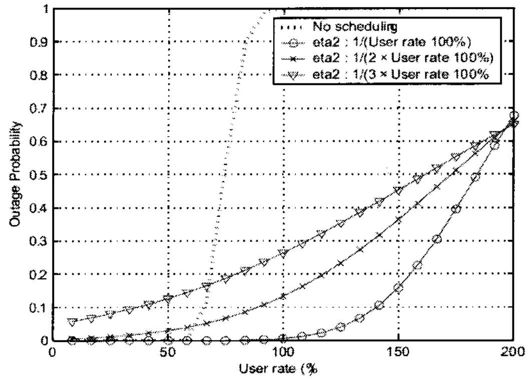

Fig. 10. The outage probability according to the user rate as a function of η_2

the channel capacity per cell is measured according to the user rate in Fig. 9. From the channel capacity per cell stand point of view, the inner region of a cell in the proposed scheme has lower signal power due to η_1 when the region is activated, for example, in the patterns of 1-2, 1-3. Therefore the proposed scheme has lower system capacity than the conventional system since the interference from neighbor cells is relatively higher. Meanwhile, since the number of users in inner region is smaller than that of users in entire cell, the system capacity per user increases as the user rate decreases. In addition, since the inner region-activated cells have less signal power, there is less interference in the outer region-activated cell in the proposed scheme than that of in the entire-activated cell in the conventional system. This is the reason that the outer region has higher system capacity per cell. Based on these calculations, the throughput in the outer region can be improved considerably by utilizing inter-cell coordination compared to the conventional system. However, it is lower than that of the conventional system in the inner region.

For a performance evaluation of patterns 2-1 and 2-2, the outage probability and the spectral efficiency are measured according to η_2, the user rate and the normalized distance. η_2 is the signal power of a mobile station divided by the signal power of a base station. For the fairness of power portion between a mobile station and a base station, we basically set the η_2 be one over the user rate 100 % which means the signal power of a base station is the signal power of a mobile station multiplied by the number of users in a cell.

Fig. 10 shows the outage probability in the uplink according to the user rate. At a lower density of users, the outage probability of the conventional system is lower than that of the proposed pattern due to the high ratio of the downlink power. However, by a combination of uplink and downlink transmissions, the volume of the interference can be effectively reduced. Thus, the outage probability is decreased remarkably compared to a conventional uplink transmission.

It should be noted that the magnitude of η_2 has a direct influence on the behavior of the outage curve. As the magnitude is decreased, the outage probability is increased at a low user density. In such a case, the outage probability is less sensitive to user density so that it is increased more slowly. If η_2 is increased, i.e., the power ratio of the uplink relative to that of the downlink becomes larger, a lower outage probability can be obtained at a lower user density. On the contrary, a larger η_2 results in a lower outage due to its higher SNR at a lower user density and vice versa. Utilizing the inter-cell coordination, the half of uplink users can be pruned off. Moreover, the effect of the BS-to-BS interference on uplink transmission is also insignificant due to the relatively large BS-to-BS

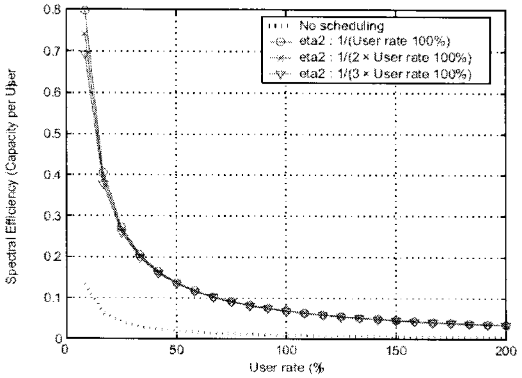

Fig. 11. The channel capacity per user according to the user rate as a function of η_2

distance. Thus, it turns out that the coordination pattern makes an effective contribution to reducing the outage, in particular, at a lower user density.

Fig. 11 shows the channel capacity per user according to the user rate as a function of η_2. It can be seen that the channel capacity is highly increased compared to the conventional uplink transmission at the lower user rate.

V. Conclusion

In the proposed system, each downlink cell is divided into two regions (i.e., inner and outer regions). To obtain a QoS gain, a small power is allocated for the inner region while full power is allocated to the outer region. In addition, an uplink cell is divided into 6 triangular regions and three of the six regions are alternatively active for maintaining the uplink QoS requirement. Using region partitioning, the volume of intra-and inter-cell interferences can be effectively reduced.

REFERENCES

〔1〕 Samsung Electronics, "R1-051341, Flexible Fractional Frequency Reuse Approach," 3GPP LTE, Nov. 2005.

〔2〕 T. Bonald, S. Borst, and A. Proutiere, "Inter-cell scheduling in wireless data networks," in European Wireless conference, 2005.

〔3〕 S. Liu and J. Virtamo, "Inter-cell coordination with inhomogeneous trac distribution," in Proceedings of the Second EuroNGI Conference on Next Generation Internet Design and Engineering, NGI 2006, (Valencia, Spain), pp. 64 - 71, 2006.

〔4〕 X. Wu, L.-L. Yang, and L. Hanzo, "Uplink Capacity Investigations of TDD/CDMA," in VTC Spring 2002, vol. 2, pp. 997 - 1001, May 2002.

〔5〕 S. Lee and S. Lee, "Reverse-Link Capacity Analysis over Multi-Cell Environments," IEICE Trans. Commun., accepted to be published. 2006.

〔6〕 H. Son and S. Lee, "Forward-Link Capacity Analysis for MCCDMA," IEICE Trans. Commun., vol. E88-B, No. 10, pp. 4094- 4096, Oct 2005.

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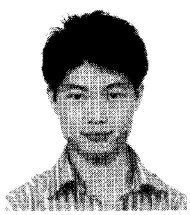

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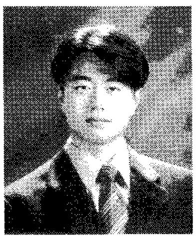

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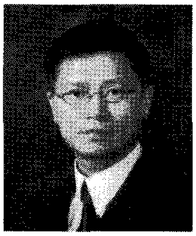

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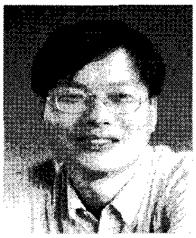

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