Radio Resource Management and Power Control for W-CDMA Uplink with High Data Rate Packet Transmission

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***Abstract*— In W-CDMA uplink, immediate accommodation of high data rate packet causes power control error and makes active users' signal quality deteriorate in the beginning of a frame. To avoid the deterioration, we propose a new radio resource management(RRM) which accommodates high data rate traffic gradually in several frames. The proposed RRM reduces signal quality deterioration in the beginning of a frame. We also propose an effective power control scheme, where a power increase command is sent to all users before a new high data rate packet is transmitted. Simulation results show that joint utilization of the proposed two methods is effective to keep signal quality good for all users.**

I. INTRODUCTION

W-CDMA systems are expected to provide flexible data rate services such as voice, data, and internet access in wireless communications. The specifications have been developed in Third Generation Partnership Project(3GPP) and, recently, the specifications for high data rate packet transmission has become a key issue for enhanced CDMA [5].

In W-CDMA Release99, that is the first standardized specification, the system was optimized for voice telephony. The base station (BS) manages each terminal ' s maximum data rate and a terminal can change his data rates autonomously in each frame based on his maximum rate constraint. Since there are many voice users, the variance of total interference power is reduced by statistical averaging effect.

Apart from voice telephony, in high data rate packet transmission, a few users transmit packets with much larger power. Since statistical averaging effect is not used sufficiently, it is difficult to apply the same management with voice telephony. In such a situation, it is more desirable to manage the users' data packets frame by frame to reduce the interference variance. In addition, the frame-by-frame management has the advantage of using scheduling and adaptive modulation and coding(AMC), based on delay insensitive characteristics of data traffic. In practical W-CDMA systems, the high data rate packet services will be mixed with voice services. Therefore, the radio resource management(RRM) for high data rate packet is required to harmonize with voice telephony.

One of the problems in an integrated voice and data system is that immediate accommodation of high data rate packet impairs active users' signal quality in the beginning of a frame. Normally, on W-CDMA uplink, closed-loop power control is used so that the received signal-to-interference ratio (SIR) corresponds to the target SIR. However, immediate increase of much larger power by data packet prevents active users from maintaining their target SIRs. Then, active voice users' signal quality will deteriorate instantaneously and it takes a certain duration to recover the signal quality. To avoid the deterioration of the signal quality, it is important to consider a feasible method to accommodate voice and data. Although there are many papers on CDMA radio resource management, the previous papers have not dealt with this problem because most of them assume a perfect power control.

In this paper, we propose a new RRM and a transmit power control (TPC) scheme for W-CDMA uplink, to avoid the deterioration of active users' signal quality. In our RRM, high data rate traffic is accommodated gradually in several frames. Active users do not experience drastic increase of interference power and can keep their signal quality good. In addition, our TPC scheme sends a power increase command to all users before a new high data rate packet is transmitted. Our TPC is expected to compensate the interference increase by increasing the power of desired signal. Using these two methods, we will show that all users can maintain good signal quality under high data rate packet transmission.

II. RADIO RESOURCE MANAGEMENT AND TRANSMIT POWER CONTROL FOR W-CDMA UPLINK

In this section, we describe conventional RRM, new RRM, and new TPC for W-CDMA uplink.

A. Conventional Radio Resource Management

In W-CDMA uplink, RRM schemes based on interference power have been widely investigated[1–3]. In these schemes, the BS manages traffic to satisfy the constraint of

$$\frac{KE_b}{SF} + N_0 + I_{other} \leq I_{0,max}, \tag{1}$$

where K is the number of active users, $I_{0,max}$ is the maximum allowable total interference, I_{other} is the interference from other cells, E_b is the bit energy, N_0 is the noise power density, and SF is the spreading factor. Normally, the allowable interference-to-noise-ratio (INR) $\eta_{max} = I_{0,max}/N_0$ is set to 6 to 10[dB][1].

In case of multimedia traffic with various transmission rates, the BS is required to manage traffic to satisfy[1]

$$\sum_{i=1}^{K} \frac{E_{b,i}}{SF_i} + N_0 + I_{other} \leq I_{0,max} \tag{2}$$

where $E_{b,k}$ and SF_k are the bit energy and the spreading factor for the k-th user, respectively.

To achieve the constraint of (1), the literature [2] uses a threshold T_{block}, where a new call is blocked if the observed interference level is above T_{block}. This access control strategy will be useful for voice services, whereas the strategy has some problems to apply for multimedia communications [6]–[9].

One problem is that many packets with different transmission rates cannot be managed by the same threshold T_{block}, because interference level after accommodating the packet is different. Therefore, a feasible management scheme applicable to packets with different rates is required. Another problem is how to accommodate a high data rate packet without causing power control errors for active users. Immediate accommodation of a high data rate packet causes drastic increase of interference and makes the signal quality of active users deteriorate due to the power control errors. Therefore, a feasible method to avoid the power control errors is required.

Figure 1 (a) shows an example of traffic load in conventional RRM scheme. The active users' signal quality deteriorates in the beginning of a frame. In multimedia communications, the constraint of (1) or (2) is not enough to keep all active users' signal quality good. To solve these problems, we propose new RRM and TPC schemes.

B. New Radio Resource Management

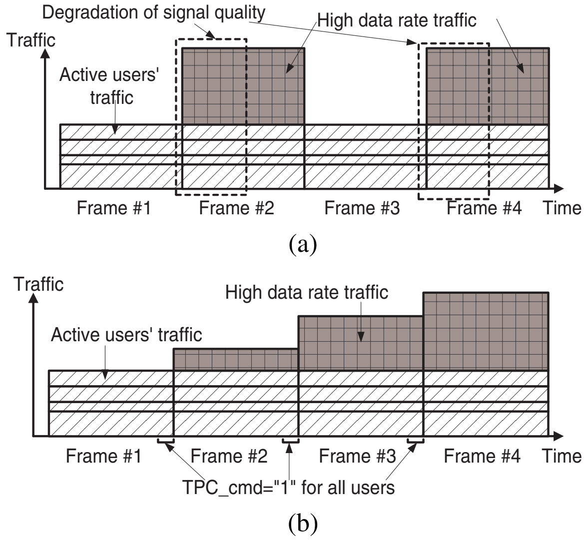
We propose a new RRM scheme which restricts the interference variation between frames within D[dB]. Figure 2 shows the flowchart of our RRM, which manages traffic as follows:

[RRM-1] The BS measures total interference power I_c before despreading process in current frame.

[RRM-2] The BS determines power threshold T=min$\{I_c \cdot 10^{D/10}, I_{0,max}\}$, where $I_{0,max}$ is the BS's maximum allowable interference level.

[RRM-3] The BS assigns new traffic on the constraint that the total interference power after TPC convergence is less than T in next frame.

The details of **[RRM-3]** is addressed in **III**. The conventional RRM corresponds to the case with $D \to \infty$. Under our RRM, all users experience a smaller increase of interference and less degradation of signal quality. Figure 1 (b) shows an example of traffic load in our RRM scheme. Although our RRM admits smaller transmission rate to a new user, a high data rate transmission can be admitted gradually using several frames. For example, in case of $D = 2$[dB], the received power can be increased by 10[dB] using 5 frames, which corresponds to the maximum allowable interference level under $\eta_{max} = 10$[dB]. Then, the maximum delay for a new user can be kept within 5 frames.



(a)

(b)

Fig. 1. Traffic load in CDMA frames (a)Conventional method (b)Proposed method.

C. New Transmit Power Control

There remains a small interference variation in the beginning of a frame, even under our RRM. To compensate the interference variation, we propose a new transmit power control scheme. The proposed TPC scheme controls active users' transmit power based on traffic knowledge assigned for the next frame. Fig. 3 shows the flowchart of our TPC, which controls transmit power as follows:

[TPC-1] The BS completes a RRM for the next frame.

[TPC-2] If traffic increases in the next frame, the BS sends a power increase command to all active users in the last slot of the current frame; otherwise the BS uses a normal TPC mode.

In the proposed TPC, all users have one step higher transmit power and compensate increase of interference in the beginning of the next frame. Therefore, each terminal can keep his signal quality when a new high data rate user is accommodated.

For further study, we also consider a frame-by-frame power step $\Delta_{TPC}^{(2)}$[dB] different from a slot-by-slot power step $\Delta_{TPC}^{(1)}$[dB], which can be achieved by broadcasting $\Delta_{TPC}^{(2)}$ to the all active users in downlink. [1] Using a frame-by-frame power step $\Delta_{TPC}^{(2)}$[dB], we can change transmit power more dynamically between frames. If $\Delta_{TPC}^{(2)}$[dB] is larger than D[dB], the interference variation can be perfectly compensated by our TPC and the deterioration of signal quality will not occur in the beginning of a frame.

III. TRAFFIC MANAGEMENT STRATEGY

In this section, we explain details of **[RRM-3]**, or a method to manage traffic on the constraint of total received power.

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[1] The current W-CDMA systems correspond to the case with $\Delta_{TPC}^{(2)} = \Delta_{TPC}^{(1)}$. Some modifications of specifications will be required to use $\Delta_{TPC}^{(1)} \neq \Delta_{TPC}^{(2)}$.

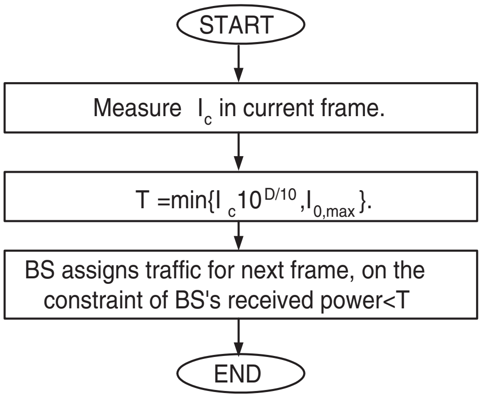

Fig. 2. Flowchart of proposed radio resource management.

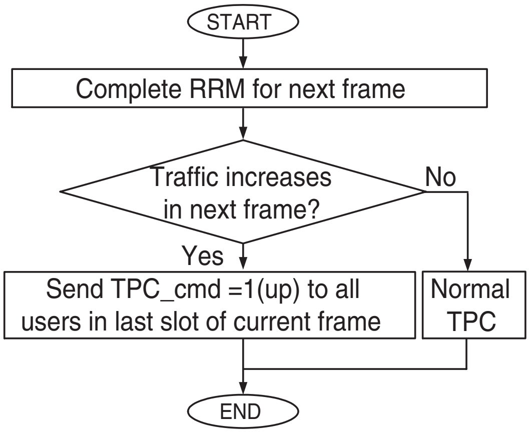

Fig. 3. Flowchart of proposed power control method.

For simple description, we assume a perfect power control and no multipath environment in our analysis. The effects of a practical power control and multipath environments are evaluated by simulations.

A. Total Received Power in Base Station

Suppose K active users in the current frame. Under a perfect power control, we have

$$\frac{SF_kP_k}{\sum_{i=1,i\neq k}^{K} P_i + P_{IN}} = \gamma_k, \qquad k=1,...,K \tag{3}$$

where γ_k is the target SINR for the k-th user, P_k is the received power for the k-th user, and P_{IN} is the sum of the outer-cell interference and noise power. Using (3), the received power for the k-th user can be expressed as[6]

$$P_k = \frac{P_{IN}}{SF_k/\gamma_k + 1}\left\{1 - \psi(K)\right\}^{-1} \tag{4}$$

$$\psi(K) = \sum_{i=1}^{K} \frac{1}{SF_k/\gamma_k + 1} \tag{5}$$

where $\psi(K) < 1$ from $P_k > 0$. Therefore, the total received power in the BS is given by

$$\sum_{k=1}^{K} P_k + P_{IN} = P_{IN}\frac{\psi(K)}{1-\psi(K)} + P_{IN} = \frac{P_{IN}}{1-\psi(K)} \tag{6}$$

The total received power increases rapidly as $\psi(K)$ approaches to 1.

B. RRM Strategy

Suppose K active users in the current frame and $K+\Delta K$ active users in the next frame. To keep the interference variation between frames within $D^{'} = 10\log_{10}(T/I_c)$[dB], it is required to satisfy

$$\frac{1}{1-\psi(K+\Delta K)} \leq \frac{10^{D^{'}/10}}{1-\psi(K)}. \tag{7}$$

Using (5), (7) is rewritten as

$$\sum_{k=1}^{K} \frac{1}{SF_k/\gamma_k + 1} + \frac{1}{1-10^{-D^{'}/10}} \sum_{k=K+1}^{K+\Delta K} \frac{1}{SF_k/\gamma_k + 1} < 1. \tag{8}$$

Considering users which finish sending packets in the current frame, the constraint is given by

$$\sum_{k=1}^{K+K_1} \frac{1}{SF_k/\gamma_k + 1} + \frac{1}{1-10^{-D^{'}/10}} \cdot \left\{ \sum_{k=K+K_1+1}^{K+K_1+K_2} \frac{1}{SF_k/\gamma_k + 1} - \sum_{k=K+1}^{K+K_1} \frac{1}{SF_k/\gamma_k + 1} \right\} < 1, \tag{9}$$

where $k = 1, ..., K$ is the continuous active users, $k = K + 1, ..., K + K_1$ is the terminated active users in the current frame, and $k = K+K_1+1, ..., K+K_1+K_2$ is the new users in the next frame.

Eqn. (9) includes both low and high rate users. Since low rate voice users have statistical averaging effect, all voice users are considered as the continuous active users, the number of whom is reduced by voice activity factor. High rate users are classified into the continuous active users, the terminated active users, and the new users. The transmission rates of the high rate users are managed by a frame-by-frame RRM.

Eqn. (8) has a similar expression to (9) in [6], which represents the condition for admission in conventional method. Only the difference between (8) and (9) in [6] is the existence of $(1 - 10^{-D^{'}/10})^{-1}$ in (8). It is found that the constraint of interference variation can be expressed by using $(1 - 10^{-D^{'}/10})^{-1}$ in (8). As a special case of $D^{'} \to \infty$, (8) is identical to (9) in [6].

In practice, there are many types of radio resource management algorithms to meet (9). Therefore, our RRM scheme can be combined with many other algorithms. For example, scheduler [7][8] considering propagation condition and quality of service(QoS) can be jointly used on the constraint of (9).

IV. NUMERICAL RESULTS

Let us evaluate the performance of the proposed RRM and TPC schemes by simulations.

A. Simulation Setup and Parameters

Table I lists the simulation parameters. Assume that each user transmits a signal using a 10ms frame with 15 slots in asynchronous W-CDMA uplink. The k-th user has a spreading factor SF_k and a transmit power $W_k^{(n)}$ in the n-th slot. Considering characteristics of long codes, an output SINR of the BS's RAKE receiver for the k-th user is given by

$$\Gamma_k^{(n)} = \frac{SF_k \cdot W_k^{(n)} \cdot \beta_k}{\sum_{i=1}^{K} W_i^{(n)} \alpha_{i,k} + P_{IN} \sum_{l=1}^{L} |g_{k,l}|^2 - W_k^{(n)} \cdot \beta_k} \tag{10}$$

$$\alpha_{i,k} = \sum_{-L+1 \le \Delta l \le L-1} \left| \sum_{l=max\{1,1-\Delta l\}}^{min\{L,L-\Delta l\}} g_{k,l}^{*} h_{i,l+\Delta l} \right|^2 \tag{11}$$

$$\beta_k = \left| \sum_{l=1}^{L} g_{k,l}^{*} h_{1,l} \right|^2 , \tag{12}$$

where $g_{k,l}$ and $h_{k,l}$ are the RAKE combining weight and the propagation coefficient for the k-th user and the l-th path, respectively. We assume 4-path Rayleigh channel with the same average power for each path and ideal RAKE combining weight $g_{k,l}$ $(= h_{k,l})$. In (10), an output SINR $\Gamma_k^{(n)}$ includes the signal power averaged over I and Q channels. In actual CDMA uplink, I and Q channels have different signal power, where the power ratio of I and Q channels is $\beta_d^2 : \beta_c^2$ in W-CDMA specifications [4].

In a transmit power control scheme, the BS estimates an output SINR $\tilde{\Gamma}_k^{(n)}$ for the k-th user. Comparing the estimated SINR $\tilde{\Gamma}_k$ with the target SINR γ_k, the BS reports a TPC command TPC_cmd to the k-th user in downlink. Therefore, TPC_cmd is given by

$$\text{TPC\_cmd} = \begin{cases} 0 & \tilde{\Gamma}_k^{(n)} > \gamma_k \\ 1 & \tilde{\Gamma}_k^{(n)} \le \gamma_k \end{cases} \tag{13}$$

An active user increases or decreases his transmit power iteratively in each slot by $\Delta_{TPC}^{(1)}$[dB] in case of TPC_cmd=0 or 1, respectively. TPC command in the 15-th slot is reflected on the first slot in the next frame, using a power step $\Delta_{TPC}^{(2)}$[dB]. In the simulation, the estimated SINR $\tilde{\Gamma}_k^{(n)}$ is given by

$$\tilde{\Gamma}_k^{(n)} = \epsilon \Gamma_k^{(n)}, \tag{14}$$

where ϵ is the estimation error of Gaussian variable with standard deviation $\sigma = 1$[dB].

TableII lists the types of users in the simulation. Traffic type #1 is the low rate voice user with 12.2kbps, $SF_k = 64$, and $\gamma_k = 1$ [dB]. Traffic type #2 is the high rate data user, whose transmission rate is adaptively changed within the maximum rate of 768kbps. A single spreading code is used for 384kbps with $SF_k = 4$ and $\gamma_k = -2$[dB], whereas two spreading codes are multiplexed for 768 kbps with $SF_k = 4$ and $\gamma_k = 1$ [dB].

In the simulation, 20 active voice users and a high rate user only transmitting a control channel are initially accommodated. This situation is made by updating a transmit power 60 times iteratively. Then, a high rate user (traffic #2) requests a new transmission of 768kbps and the BS determines his transmission rate in the next frame based on our RRM scheme. According to the informed transmission rate from the BS, the high rate user starts to send a packet in the next frame, increasing the transmit power by $256\gamma_k/(SF_k\gamma_0)$, where γ_0 is the target SINR for a control channel. In the following, we evaluate the performance of our RRM and TPC schemes.

TABLE I

SIMULATION PARAMETERS

Chip rate	3.84Mchip/s
Channel	4-path Rayleigh channel
Modulation (Data)	BPSK
Modulation (Spreading)	QPSK
SINR estimation error	$\sigma = 1$[dB]
TPC step	$\Delta_{TPC}^{(1)} = 1$ dB (slot by slot) $\Delta_{TPC}^{(2)} = 1, 2, 3, 4$ dB (frame by frame)
Amplitude ratio of I:Q	β_d:β_c
Number of BS antennas	Single antenna
Maximum allowable INR	$\eta_{max} = 10$[dB]
Number of users	Traffic#1:20 users Traffic#2:1 user
TTI	1frame(10ms)

TABLE II

TRAFFIC TYPES

Traffic Type	Data rate	SF	γ_k	$\beta_c : \beta_d$
# 1	12.2kbps	64	1.0dB	11:15
# 2-0(control ch. only)	2.4kbps	256	3.0dB	15:0
# 2-1	144kbps	8	-1.0dB	5:15
# 2-2	384kbps	4	-1.0dB	5:15
# 2-3(2 codes)	768kbps	4	2.0dB	5:15

TABLE III

PACKET TRANSMISSION RATE ADMITTED BY RRM WITH D[DB]

(Request Rate: 768kbps)	1st frame	2nd frame	3rd frame
RRM with $D = 1$[dB]	144bps	384kbps	528kbps
RRM with $D = 2$[dB]	384kbps	768kbps	768kbps
Conventional($D = \infty$)	768kbps	768kbps	768kbps

B. Transmission Rate Admitted by RRM

Table III lists transmission rates of traffic #2 admitted by our RRM. The admitted transmission rate depends on D and becomes higher as the number of frames increases. Under a small D, it takes many frames to accommodate a full data rate. On the contrary, under a large D, the immediate accommodation of high rate packets makes active users' signal quality deteriorate. Therefore, an appropriate solution of D is important to achieve a reasonable data rate accommodation and a small increase of interference. From table III, it is seen that $D = 2$ [dB] is an appropriate solution.

C. Characteristics of Received Signals

Fig. 4 shows the average SINR of active voice users when a packet with 384kbps or a packet with 2×384 kbps is newly

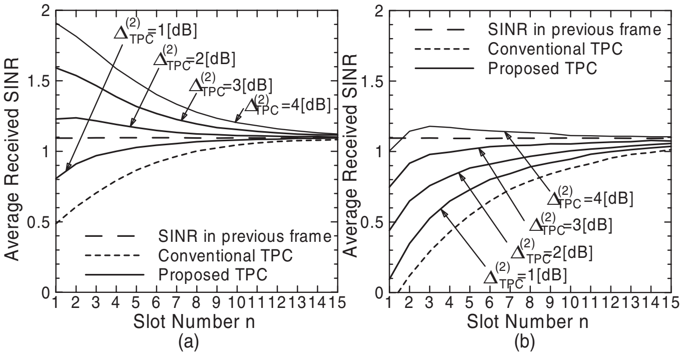

Fig. 4. Average SINR of active voice users (a) 384 kbps packet admitted (b) 2× 384 kbps packet admitted.

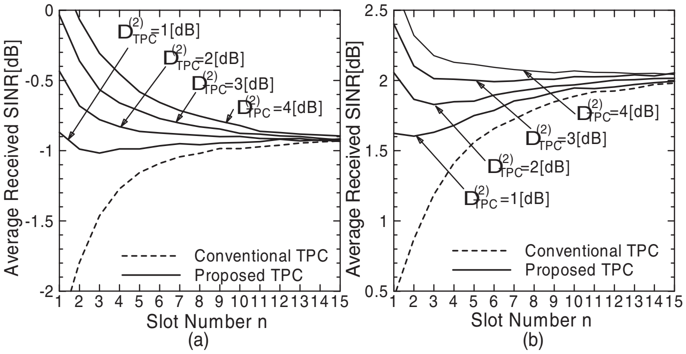

Fig. 5. Average SINR of active data users (a) 384 kbps packet admitted (b) 2× 384 kbps packet admitted.

accommodated in the first frame. Average output SINR $\overline{\Gamma}^{(n)}$ is calculated by averaging output SINR over simulation trials and multiple active users. In the figure, the signal quality deteriorates under a normal TPC scheme, whereas our TPC scheme lessens the deterioration of the signal quality. As $\Delta^{(2)}_{TPC}$ increases, the signal quality becomes better. When $\Delta^{(2)}_{TPC}$ is larger than D, the deterioration of the signal quality can be perfectly dissolved in the beginning of the frame. Figure 5 shows the average SINR of newly assigned high rate data user. The performance of the high rate user is almost the same with active voice users. Using a large $\Delta^{(2)}_{TPC}$ of 4[dB], we can keep all users' signal quality good, even when a high data rate packet with 2×384 kbps is accommodated. As $\Delta^{(2)}_{TPC}$ becomes smaller, the joint utilization of our TPC and RRM schemes become more important to keep the signal quality good.

D. Received Power in Base Station

Figure 6 shows the transient of average interference to noise power ratio (INR) $E[\eta](\eta = I_c/N_0)$ for the case of accommodating a packet with 384kbps or a packet with 768kbps. In the figure, the interference variation can be kept within 2 [dB], when accommodating a packet with 384 kbps. This results agree with the theoretical consideration, where a transmission rate up to 384kbps can be accommodated within the interference variation of $D = 2$[dB]. In the simulation, SINR estimation errors, quantized power steps for TPC, and multipath environments are considered. The similar results between theory and simulation shows that theoretical description in (9) becomes a good approximation in an actual W-CDMA uplink. It is also found that the interference variation is very large when accommodating a packet with 768kbps.

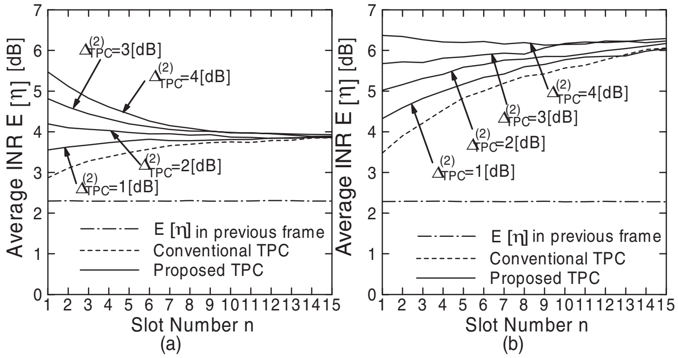

Fig. 6. Total interference to noise power ratio (a) 384 kbps packet admitted (b) 2× 384 kbps packet admitted.

V. CONCLUSION

This paper presented new RRM and TPC schemes to avoid the deterioration of active users' signal quality caused by a newly admitted high rate packet. Numerical results show that the joint utilization of our RRM and TPC is effective in maintaining good signal quality for all users.

There are many types of algorithms to satisfy the condition of our RRM scheme. Our method can be jointly used with other algorithms, such as scheduler considering the propagation characteristics in W-CDMA uplink. Considering easy implementation and low cost, our RRM and TPC schemes will be practical in W-CDMA systems with high data rate packet transmission.

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