

Differentiated MAI Control for Hybrid ARQ-II in CDMA Networks

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Abstract- Multiple access interference (MAI) is a bottleneck to limit the capacity of CDMA system. Differential MAI control is proposed for hybrid ARQ-II of CDMA networks by noticing that successive trials of transmission have increasing error-correcting capability in hybrid ARQ-II. Data packets are classified and put into corresponding queues according to different trials of transmission. Scheduling algorithm is studied and applied to realize such control. Simulation shows that differential MAI control using Weighted Round Robin (WRR) or Deficit Weighted Round Robin (DWRR) scheduling has significant improvement by comparison to simple MAI control for hybrid ARQ-II in CDMA networks.

I. INTRODUCTION

CDMA enjoys advantageous features such as efficient spectrum utilization, soft handoff, but MAI is a threshold to improve its uplink capacity. Due to receiver complexity and limited number of PN codes with good correlation character, how to assign codes for different users is also a big problem.

PMCAP/CDMA is receiver-oriented protocol, which has considered both interference control and QoS guarantee [1, 2]. In order to control MAI, it is prescribed that simultaneous transmissions using PN codes cannot exceed a number called code threshold. This mechanism will be called simple MAI control in this paper. In our previous work, we have improved PMCAP/CDMA in many aspects to solve the problem of code assignment and interference limitation using hybrid ARQ-I and II respectively [2]. In hybrid type-I ARQ, if the erroneous data frame cannot be corrected, ARQ will be used to retransmit the packet. However, in hybrid ARQ-II, the receiver will decode by combing the signals of current retransmitted frames and previous failed frames. So hybrid ARQ-II is an adaptive error controlling mechanism with incremental redundancy. Some similar work such as [3] has shown that hybrid ARQ-II in DS-CDMA networks can improve performance, especially at high traffic load, but the problems of MAI control and code contention problems are rarely addressed.

[2] has applied hybrid ARQ-II to PMCAP/CDMA and studied the above two problems. It is shown that the simple MAI control strategy in hybrid ARQ-II with simple code combing outperforms

that of no MAI control strategy case and ARQ-I case. In [2], a single code threshold is used for a given channel condition. This threshold is determined by studying the error performance of the third or later trials. This simple MAI control mechanism was very effective to control MAI of these trials as shown in [2]. However, notice that two Mobile Terminals (MTs) may transmit packets in the same time slot while one is the second trial and the other is the third retransmission. As the second trial is less protected, most often it will fail since the code threshold is too loose for the second trial. In this paper, we try to solve this problem by classifying trials and assigning different timeslots and code threshold to these users.

We focus on the application of scheduling algorithm to hybrid type-II ARQ in CDMA networks. This paper is organized as follows: section II describes the elements of differentiated MAI control for hybrid ARQ-II in CDMA networks. In section III, how to apply hybrid ARQ-II with queuing and scheduling algorithm in CDMA networks are proposed. In section IV, performance of hybrid ARQ-II with differentiated MAI control is obtained by simulation. Conclusion is given in section V.

II. ELEMENTS OF DIFFERENTIATED MAI CONTROL FOR HYBRID ARQ-II

A. Differentiated MAI Control

MAI control is one of the most important issues in CDMA. In previous study, nearly all control methods concentrate on how to reduce MAI of the whole system. Most of them use the indistinctive criteria for all mobile users [2,3]. However, in CDMA system, different users may have different capability against MAI since the error-correcting capability may vary at different time slot in an MT. For example, later trials of transmission will have higher capability against channel errors by combining previous transmission if hybrid ARQ-II

is used among the MTs. But few papers target differentiated MAI control problem.

In the following part, Rate-Compatible Punctured Convolutional (RCPC) coded hybrid ARQ-II [4] in CDMA will be studied. The optimized RCPC codes with parent code rate 1/3 and memory length $K=9$ is used in this paper. The generator polynomials are (575, 623, 727) and puncturing patterns can be seen in [2]. Each frame consists of 512 bits (shown in Fig.1), which will enter the parent convolutional encoder [2].

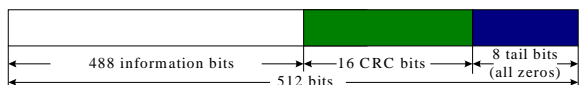


Fig.1 Frame structure of message part

Using the above RCPC code with the frame format shown in Fig.1, we obtain the Frame Error Rate (FER) for different trials of transmission of ARQ-II strategy by simulations. Fig. 2 presents the FERs of first, second and third trials of RCPC code in AWGN channel with MAI and different noise levels ($E_b/N_0=5\text{dB}$, 7dB). Gold code is used as PN code with processing gain of 31. From Fig.3, we find different trials have different ability against MAI. A maximum acceptable code threshold L is needed to reduce transmission failures for a certain trial. Let l be the simultaneous transmitted users, P_{ERR} the maximal tolerable FER, K_{total} the number of PN codes in code set of C , L can be obtained by

$$L = \max\{l \mid 0 \leq l \leq K_{total}, FER(l) \leq P_{ERR}\} \quad (1)$$

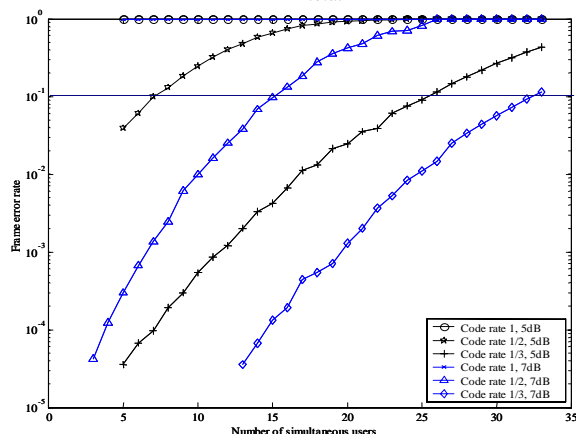


Fig.2. FER of the RCPC code with different code rate in AWGN

¹ Usually E_b/N_0 is defined as $\text{SNR} - 10\log_{10}(\text{code rate})$. However, in this paper, we define E_b/N_0 as $\text{SNR} - 10\log_{10}(1/3)$ for both rate 1/3 and 1/2 code.

Suppose the FER should be no more than 0.1, the code threshold of the first, second and third will be $\{0, 7, 25\}$ for $E_b/N_0=5\text{dB}$ and $\{0, 15, 32\}$ for $E_b/N_0=7\text{dB}$ cases. So the code threshold L will not be the same for different trials. Differential MAI control will be needed to adapt to this change.

B. RCPC coded hybrid ARQ-II

RCPC code has been widely used in hybrid ARQ-II. Rate 1 code is used in the first trial. If no ACK is received, rate 1/2 code is used by transmitting another 2 coded bits from each group. The receiver will decode by combining these two transmissions. If errors cannot be corrected, rate 1/3 code is used by sending the rest 2 coded bits. The decoder at the receiver will combine these three frames. If still no ACK is received, ARQ-II with simple code combining is studied. Namely, we keep the last two transmissions, which will be combined with the newly received frame to form decoding information. If a new packet is generated in the MT and it is the first one waiting in the buffer, it will contend PN code again.

C. Queuing method for hybrid ARQ-II

Based on previous discussion, we propose to define queues based on different trials. Each Queue has differentiated service classes owing to its MAI tolerance ability respectively. General queue model for hybrid ARQ-II in CDMA system can be seen in Fig.3a.

In Fig.3a, after the access requests are received, classifier will put them into the first trial access queue. If an access request is selected by scheduling algorithm, it will be cleared from its access queue and put into memory for request. And the data packet transmission permission will be sent to the mobile terminals. The base station will wait and receive message packets from mobile terminals. If message packet of a mobile terminal can be decoded correctly, the access request in the memory will be deleted. Otherwise, it will be re-classified and put into the tail of next trial queue.

Suppose there are l_i requests in the queue of i^{th} trial. For the i^{th} queue, it has its own code threshold L_i that is not defined to limit the length of i^{th} queue,

but to ensure the simultaneously transmitted mobile terminals in this queue cannot exceed L_i in the following message sub-timeslot. FIFO principle should be followed within each queue.

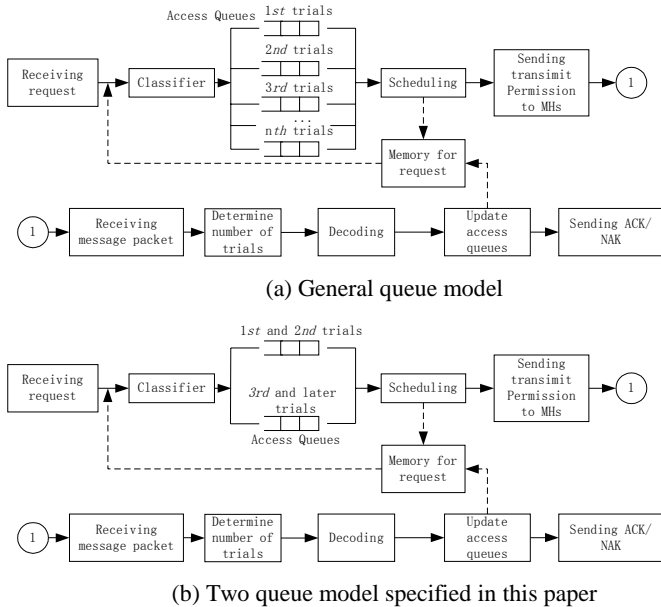


Fig.3. Architecture of queuing and scheduling for hybrid ARQ-II within a single service round in CDMA system

For special case in Fig.2, it is shown that nearly all transmissions are failed for the first trial, and the code threshold is 0 ($L_1=0$) for $E_b/N_0=5\text{dB}$ and 7dB . To deal with this problem, one solution is to combine the queue of the first trial with that of the second trial due to $L_1=0$. If the combined queue is selected by scheduling algorithm, the sum of transmit permission given to MTs should be no more than the maximum code threshold for the second trial (L_2). Another queue is maintained for the third and later trials. So totally two queues will be maintained if ARQ-II with simple code combining is adopted (see Fig.3b).

D. Scheduling algorithm for hybrid ARQ-II

After classification, scheduling algorithm will be responsible for selecting one suitable queue and determining the number of acknowledgement it can give. Traditional queue scheduling disciplines include [6]: First-in-first-out queuing (FIFO), Priority Queuing (PQ), Fair queuing (FQ), Round Robin (RR), Weighted Round Robin (WRR) and Deficit Weighted Round Robin (DWRR). These algorithms are originally designed for wired computer network, in which MAC protocols such as CSMA/CD are used to avoid packet collision. So traditional scheduling algorithm allows each

queue to send only a single packet each time that it is visited. And it visits higher-bandwidth queues multiple times in a single service round. However, it is possible for simultaneous multiple packet transmission in wireless network if the MTs share the channel using different PN codes. So, in contrast to traditional scheduling algorithm, scheduling algorithm in this paper only works at the end of each time slot. It processes access requests in the selected i^{th} queue without exceeding code threshold of L_i given differentiated MAI control is considered.

In this paper, WRR and DWRR scheduling algorithms will be studied. In WRR scheduling, packets are first classified into various service classes and then assigned to a queue that is specifically dedicated to that service class. Each of the queues is served in a round-robin order. Empty queues are skipped. WRR queuing allocates different amounts of bandwidth to different service class by allowing higher-bandwidth queues to send more than one packet each time it visited during a service round. This principle can ensure differentiated MAI control because mobile users belonging to different queues have no chance to transmit their packets in the same time slot. After the queue is selected, $\min\{l_i, L_i\}$ acknowledgements will be given to the mobile users that have requests in a queue.

DWRR scheduling was proposed by M.Shreedhar and G.Varghess[5,6]. In the classic DWRR algorithm, the scheduler visits each non-empty queue and determines the number of bytes in the packet at the head of the queue. The variable DeficitCounter is incremented by the value quantum. If the size of the packet at the head of the queue is greater than the variable DeficitCounter, the scheduler moves on to service the next queue. If the size is less than or equal to the variable DeficitCounter, the variable DeficitCounter is reduced by the number of bytes in the packet and the packet is transmitted on the output port. The scheduler continues to dequeue packets and decrement the variable DeficitCounter by the size of the transmitted packet until either the size of the packet at the head of the queue is greater than the variable DeficitCounter or the queue is empty. If the queue is empty, the value of DeficitCounter is set to zero and the scheduler moves on to service the next non-empty queue.

In this paper, all access requests have the same packet length. The scheduler visits each non-empty queue and determines the number of request l_i in this queue. Let Quantum[i] be the code threshold L_i for the i^{th} queue. The variable DeficitCounter[i] is defined as the number of request (l_i) in i^{th} queue decreased by the value of Quantum[i]. The case that the DeficitCounter is less than zero can be called deficit case. And the normal case happens when DeficitCounter is no less than zero. From Fig.2, we can see that FER increases rapidly when simultaneously transmitting users are more than code threshold L in CDMA system.

III. DIFFERENTIATED MAI CONTROL IN CDMA SYSTEMS

We focus on a single cell, in which a certain number of Mobile Terminals (MTs) communicate with Base Station (BS) using CDMA technique. Immediate feedback and error free feedback channel are assumed. In uplink, access request should be transmitted in preamble part upon new frame generated. In the downlink, three types of signaling message will be used, namely, access ACK/NAK, transmission INDICATION and transmission ACK/NAK.

A. Mobile Terminals

The MT can be in one of the three states: SL (Silence), AC (Acquirement) and TX (Transmission). When there is no data coming, a MT keeps in SL state, in which the MT occupies no PN code. As data packets are generated in a MT, the MT randomly selects one PN code from code pool (totally C codes) and sends its preamble part by this code to contend PN code for its message transmission, which is said to be AC state. If the access preamble is correctly received, the BS randomly assigns one of the available PN codes in code pool and sends access ACK to the corresponding MT immediately. The transmission of its message packets does not occur until the transmission INDICATION comes and its INDICATION flag equals to 1. If the message packet is correctly decoded, transmission ACK will be sent to the MT. Otherwise, transmission NAK will be sent, notifying that further punctured code should be used in retransmission. MT will perform retransmission after INDICATION is received, which indicates that the MT has the permission to retransmit its packets. Hybrid ARQ-II is applied

until the current message packet is decoded correctly. During this period, the MH is said to be in TX state.

B. Base Station

The base station receives access requests and determines if ACK should be given based on whether there are available PN codes. In contrast to [2][3], we do not restrict the number of accessed MTs to be smaller than L because we have more efficient classification and scheduling algorithm to deal with different trials of transmission and do code limitation thereafter. All successful access requests will be put into access queues if there are available PN codes in code set of C . Algorithm 1 shows the operation in base station after receiving access requests. Suppose the number of codes reserved by mobile terminals is r and number of access request received is l_a ,

```

IF  $l_a \leq C - r$ ,
    Select first  $l_a$  codes from available code set.
    Send access ACKs to  $l_a$  MTs;
    Mark these  $l_a$  codes "Reserved".
ELSE
    Send access ACKs to  $C - r$  MTs and reject the other
     $l_a - (C - r)$  MTs' request.
    Mark these  $C - r$  codes "Reserved".
ENDIF

```

Algorithm 1. Process access request in base station

In base station, the queuing and scheduling algorithm have been described in section II. The base station maintains queues based on different retrials of transmission in ARQ-II.

Suppose the length of i^{th} queue is l_i and the i^{th} queue is selected by scheduling algorithm. The base station gives permissions to the MTs in this queue based on WRR or DWRR scheduling algorithm. Due to two queues are maintained, the value of i can only be 1 or 2 (see Fig.3b).

In Algorithm 2, implementation of WRR scheduling is shown to realize differentiated MAI control in base station in a scheduling round for the i^{th} queue.

```

WHILE (TRUE) DO
    IF ( $pWRR = i$ ) && ( $l_i > 0$ ) //WRR pointer

```

```

IF  $l_i \leq L_i$ 
    Give permissions to all  $l_i$  MTs using reserved code
    respectively;
    Remove these  $l_i$  MTs from its queue.
ELSE
    Give permissions to first  $L_i$  MTs.
    Remove these  $L_i$  MTs from its queue.
ENDIF;
Break;
ENDIF;
ENDWHILE;
 $pWRR = (pWRR + 1) \bmod 2$ ; //Next round

```

Algorithm 2. WRR scheduling in differentiated MAI control

In Algorithm 3, implementation of DWRR scheduling is shown to realize differentiated MAI control in a scheduling round for the i^{th} queue.

```

WHILE (TRUE) DO
    IF ( $pDWRR = i$ ) && ( $l_i > 0$ ) //DWRR queue pointer
        DeficitCounter[i] =  $l_i - \text{Quantum}[i]$ ;
        IF DeficitCounter[i] < 0 //Deficit case
            IF switchQFlag == 1 //switched pDWRR in previous slot
                Give permissions to all  $l_i$  MTs using reserved code
                respectively;
                Remove these  $l_i$  MTs from its queue.
                SwitchQFlag = 0;
                Break;
            ELSE
                switchQFlag = 1; //mark the change of queue.
            ENDIF
        ELSE //normal case
            Give permissions to first  $\text{Quantum}[i]$  MTs.
            Remove these  $\text{Quantum}[i]$  MTs from its queue.
            Break;
        ENDIF;
    ENDIF;
ENDWHILE;


$pDWRR = (pDWRR + 1) \bmod 2$ ; //Next round


```

Algorithm 3. DWRR scheduling in differentiated MAI control

IV. SIMULATION RESULTS

Markov chain and equilibrium point analysis (EPA) are two dominated methods for protocol analysis. The former can provide exact system analysis, but it is too complicated in most cases. EPA is much

simpler since it does not calculate the system state transition probabilities. However, EPA is not an efficient analysis method for queuing systems. We use simulation to obtain the system performance.

In this paper, we simulated the performance of differentiated MAI control strategy in RCPC coded hybrid ARQ-II and compared it with simple MAI control strategy of [2] in AWGN channel. Simple code combining is adopted for ARQ-II. The signaling is assumed to be error free.

A. Simulation parameters

Suppose the number of MTs is finite (totally N), data packet generation rate of the MT (σ_d) and retransmission probability (If error happens) are equal. Then the traffic packets (m) that arrive the system will follow binomial distribution:

$$B(m, \sigma_d, N) = \binom{N}{m} \sigma_d^m (1 - \sigma_d)^{N-m} \quad (2)$$

Simulation parameters and their values are shown in Table 1. These values are the same as [2] to make a comparison of these two types of MAI control mechanism.

Parameter	Value
G (Processing gain)	31
K_{total} (Total codes in code pool)	33
R_b (Channel rate)	16 Kbps
F (Frame length)	512 bits
τ (Slot duration)	32 ms
σ_d (Data packet generation rate each slot)	0.2
p_d (Preamble transmit permission probability)	0.9
P_{ERR} (Maximal tolerable frame error rate)	0.1

B. Performance of Packet Delay

Let N be the number of MTs in the system, N_s the number of MTs in the SL state, θ be correctly decoded the data packet (message part) per slot with RCPC coded hybrid ARQ-II, the packet delay can be expressed as:

$$D = \frac{N - E(N_s)}{E(\theta)} \cdot \tau \quad (3)$$

Here $E(\bullet)$ means expected value.

For differentiated MAI control, the principle is to ensure that the different trials take place in different slots and use different code thresholds. To realize differentiated MAI control, two queues are used. From Equation (1), we obtain the code threshold of the first, second and third will be $\{0, 7, 25\}$ for $E_b/N_0=5\text{dB}$ in case of $P_{ERR}=0.1$.

Fig.4 is simulation result of differentiated MAI control and simple MAI control when $E_b/N_0=5\text{dB}$ and $P_{ERR}=0.1$. For differentiated MAI control, two queues are maintained (Fig.3b). Code threshold of each queue is 7 and 25 respectively. DWRR and WRR scheduling are studied to realize such MAI control. A general trend in Fig.4 is that packet delay will increase with the number of MTs increasing. The reason is that with increasing number of MTs, MAI will be higher. With FER rising, more packets need to be transmitted more times so as to be successful decoded. For differentiated MAI control, WRR scheduling is better than simple MAI control with code threshold ($L=25$) in most cases. DWRR scheduling has much better performance than WRR and simple MAI control when traffic is heavier.

In the case of less data traffic, data delay of DWRR is higher than that of WRR and simple MAI control. This can be explained as follows. When the system has less access requests, the queue length (l_i) will have more chances to be less than code threshold (L_i). So, in Algorithm 3, the queue pointer ($pDWR$) has to spend time switching from current queue to next queue. If the length of next queue is also smaller than code threshold number, such switching is a waste of time. However, for WRR strategy, if a queue is selected, all access requests in it will be processed directly unless the queue is empty. And for simple MAI control, all access requests (no more than L) will be acknowledged immediately.

When the number of MTs is larger than 19, delay performance of differentiated MAI control with DWRR scheduling is superior to that of other two strategies. The reason is that with DWRR scheduling adopted, the system has more chances to allow more MTs (totally L_i if the i^{th} queue is

selected) transmitting their data packet simultaneously.

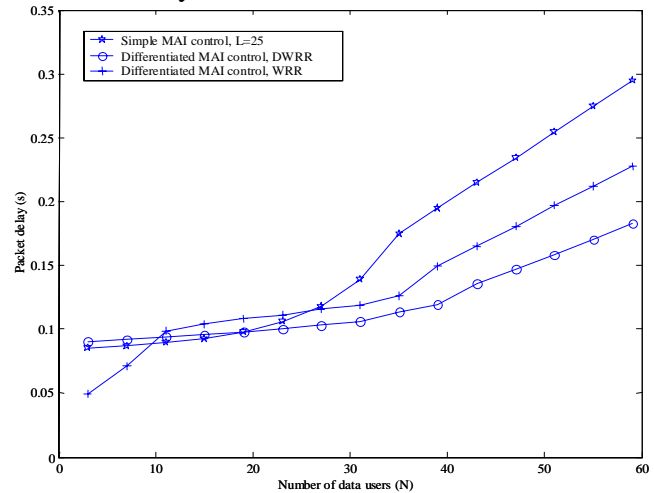


Fig.4. Packet delay of simple and differentiated MAI control

V. CONCLUSION

Differentiated MAI control is proposed in this paper for hybrid ARQ-II in CDMA networks. Queuing and scheduling algorithm are introduced to realize such MAI control. A two-queue module is proposed and WRR and DWRR scheduling are applied in this system. Simulation shows differentiated MAI control outperforms simple MAI control when the data traffic becomes heavier. This idea can also be applied to other hybrid ARQ-II system in CDMA networks.

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