A New MAC Protocol with RCPC Coded Hybrid ARQ-II for CDMA Networks

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***Abstract*- In this paper, we propose and investigate a new type of multiple access protocol that combines the characteristics of PRMA, CDMA, and the hybrid ARQ error controlling and retransmission scheme to reduce the retransmissions and keep the frame error rate low when channel experiences heavy traffic. It is an adaptive optimization of the balance between the CDMA processing gain and FEC coding gain to obtain a better throughput. We use both TUA and EPA method to analyze performance of the protocol. Simulation shows that using hybrid ARQ-II with code combing in PMCAP/CDMA can significantly improve delay performance in AWGN. Code limitation strategies can decrease the MAI level and frame error rate, which in turn improve the system performance when the background noise is very high.**

I. INTRODUCTION

CDMA has become an attractive technique for medium access control in cellular network and personal communication systems. CDMA enjoys advantageous features such as efficient spectrum utilization, soft handoff, simple frequency planning, but Multiple Access Interference (MAI) is a threshold to improve its capacity. Also due to code number limitation and receiver complexity, how to assign codes for different uses is also a big problem.

Preamble Minislot Channel Access Protocol (PMCAP/CDMA) is receiver-oriented protocol, which has considered both interference control and QoS guarantee[1]. Instead of using a common signaling channel that brings too much interference to traffic channel, this protocol sends preamble before the message part and requires the acknowledgement of its preamble received at the end of the preamble. Only upon receiving a preamble acknowledgement, will a mobile host (MH) continue its packet transmission using the same code as its successful received preamble. Fig.1 shows PMCAP/CDMA work procedure. It has a limitation of maximum simultaneous transmissions to control MAI. In our previous work[2], we have improved PMCAP/CDMA in many aspects to solve the problem of code assignment and interference limitation. In [2], if the erroneous data frame can not be corrected by BCH code, ARQ will be used to retransmit the packet. According [3], that strategy is called hybrid type-I ARQ. As an extension of that work, we apply hybrid type-II ARQ to PMCAP/CDMA in this paper. For hybrid type-II ARQ, *type-II ARQ with code combing* and *conventional type-II ARQ* (no code combing) are studied and compared. Rate-compatible punctured convolutional (RCPC) code is used for providing adaptive channel coding applied in the hybrid ARQ-II schemes.

Hybrid type-II ARQ schemes in DS-CDMA packet networks have been studied in some paper[4], but few of them have considered MAI control and code contention problems. In this paper, based on previous work, we focus on the application of hybrid type-II ARQ to PMCAP/CDMA protocols. This paper is organized as follows: section II describes the improved PMCAP/CDMA using hybrid type-II ARQ. In section Ⅲ, performance analysis is conducted. In section Ⅳ, simulation results and comparisons with type-I ARQ, conventional type-II ARQ, and ARQ-II with code combing in PMCAP/CDMA are shown. Conclusion is given in section Ⅴ.

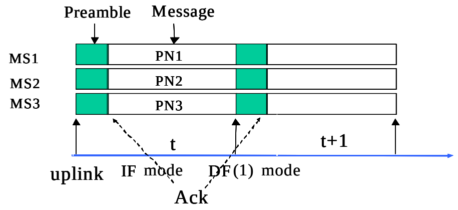


Fig. 1 PMCAP/CDMA protocol

II. IMPROVED PMCAP/CDMA USING HYBRID TYPE-II ARQ

A. System description

Future wireless personal communication networks will be composed of a large number of small cells. In our study, we focus on a single cell, in which a certain number of MHs communicate with Base Station (BS) using CDMA technique. We assume that the number of codes devoted to data communications within a cell by a BS is fixed.

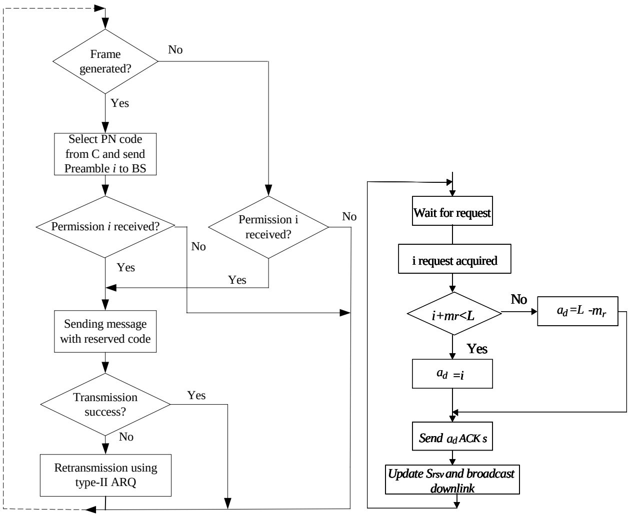
The MH can be in one of the three states: SL (Silence), AC (Acquirement) and TX (Transmission). When there is no data coming, a MH keeps in SL state, in which the MH occupies no PN code. As data packets are generated in a MH, the MH randomly selects one PN code from code pool (totally *C* codes, see Ref.[1] to determine *C*) and sends its preamble part by this code to contend PN code for its Message packet transmission, which is said to be AC state. If the preamble is correctly received, the BS randomly assigns one of the available PN codes in code pool and sends ACK to the corresponding MH. The system is based on IF model if ACK is received by MH immediately after preamble, and on DF(1) model if ACK is received after one slot. The MH will transmit its message packets with PN code obtained from ACK until the current Message data packet is received correctly. At that time, the MH is in TX state. Immediate feedback and error free feedback channel are assumed. Some parameters are shown in table 1.

Table 1. Some parameters of the systems

p_0	Probability that a MH is in SL state
p_r	Probability that a MH is in TX state
p_d	Preamble transmit permission probability
σ_d	Data packet generation rate each slot
p_{c_succ}	Contention success probability
p_{t_succ}	Transmission success probability
L	Limitation of Maximum simultaneous uses

C	Total codes in code pool
M	Total MHs in the system

The MH and base station flowchart is shown is Fig.2.



(a) Mobile host (b) Base station

Fig.2. Mobile host and base station flowchart

B. RCPC code and its application in hybrid type-II ARQ

In [2], BCH code is used to protect data packets, and the failed data packet will be retransmitted again using the same code as the last failed transmission. In this paper, rate-compatible punctured convolutional (RCPC) codes are used to adaptively correct channel errors.

RCPC codes are introduced by Hagenauer[5]. RCPC codes are a family of codes constructed from a single rate 1/N convolutional code called parent code. The higher rate codes are obtained by puncturing successively greater number of coded bits. The puncturing rules require that all the coded bits in a higher rate code be contained in the lower rate code. If higher rate codes cannot correct channel errors, lower rate codes will be used in the manner that only additional coded bits previously punctured will be transmitted. The practical advantage of RCPC codes is that they only require a single convolutional encoder and Viterbi decoder. The optimized RCPC codes with parent code rate 1/3 and memory length K=9 in [6] is used in this paper. The generator polynomials are (575, 623, 727) and puncturing patterns are as follow.

$$P_1 = \begin{bmatrix} 0 & 0 \\ 1 & 0 \\ 0 & 1 \end{bmatrix} \qquad P_{1/2} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 1 \end{bmatrix}$$

The output of the rate 1/3 parent encoder is divided into groups, with each group consisting of 6 coded bits, corresponding to 2 information bits in the input of the encoder. First, rate 1 code is used, that is, 2 coded bits are selected from each group according to P_1 and then transmitted. If no ACK is received, rate 1/2 code is used by transmitting another 2 coded bits from each group according to the difference between $P_{1/2}$ and P_1. The receiver will decode by combining these two transmissions. If no ACK is received, rate 1/3 code is used by sending the rest 2 coded bits in each group. The decoder at the receiver will combine these three frames. If still no ACK is received, two schemes are studied, that is, *conventional ARQ-II* and *ARQ-II with simple code combing*. In the first scheme, the previous three transmissions are dropped and another turn of ARQ-II transmission is started. In the second scheme, we keep the last two transmissions, which will be combined with the newly received frame to form decoding information. Complete code combining is not adopted here because decoding is too complicated and receiver buffer is finite.

For the failed transmission, the MH will retransmit it using the same PN code until the ACK is received. If next packet is generated and is the first one waiting in the buffer, it will contend the PN code as previous packet. The block diagram of the system is shown in Fig.3.

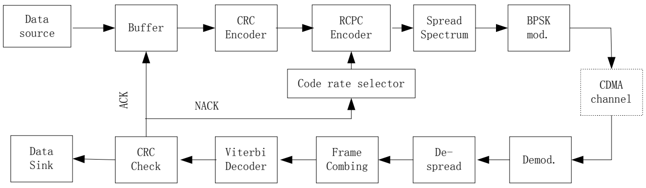


Fig.3: Diagram of ARQ-II schemes in CDMA

C. Frame structure

The MH sends message part after preamble part. For message part, frame format used in this paper is the same as 3GPP[7]. Each frame has 488 information bits. First, 16 CRC parity check bits are calculated and added. Then, 8 zeros are appended to enforce the RCPC encoder end in zero state. Now each frame consists of 512 bits (shown in Figure 4), which will enter the parent convolutional encoder.

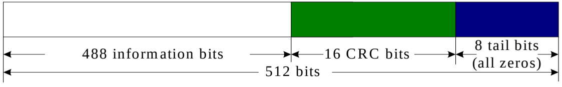


Fig.4 Frame structure of message part

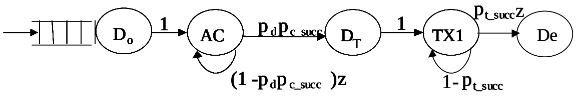
III. PERFORMANCE ANALYSIS

Markov chain analysis and equilibrium point analysis (EPA) are two dominated methods for MAC 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 queueing systems. Tagged user approach (TUA) is proposed in [8]. It is rather simple and efficient. This paper combines TUA and EPA to analyze this protocol.

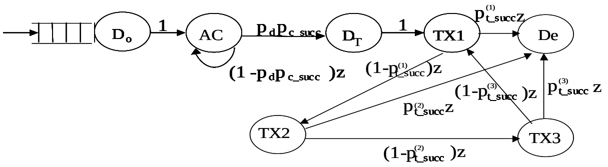
A. Tagged user analysis

Suppose there are M MHs, the number of MHs in {SL, AC, TX} state is $\{m_s, m_c, m_r\}$. Packets arrive in the buffer of data user following Bernoulli process with a probability σ_d. The queue in each data user is FCFS. A new packet ready for service will start transmit its preamble to contend PN code with probability p_d. The retransmission packet is treated in a manner similar to the new packet. With the assumption that the channel is symmetric and the statistical behaviors of all users are identical, we focus on the behavior of an arbitrarily chosen user among all users and the influence of other users on it through the shared channel. The behavior of the tagged user is then used to find the system performance.

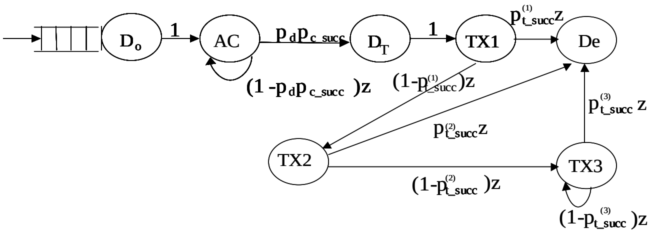
According to section II, state flow graph of the tagged data user for three hybrid ARQ schemes can be obtained in Fig.5. In Fig.5, TX$_i$ means the *i*th transmission in TX state. In Fig.5(b) and Fig.5(c), $p_{t\_succ}^{(i)}$ means the frame success probability of the *i*th transmission. We suppose in steady state, this probability is fixed. In hybrid type-II ARQ with simple code combing, FER of the *i*th (i>3) retransmission would be the same as the third transmission in steady state. Simulation will validate our assumption.



(a) Hybrid type-I ARQ



(b) Conventional Hybrid type-II ARQ



(c) Hybrid type-II ARQ with simple code combing

Fig.5. State flow graph of tagged user in hybrid ARQ schemes

In this paper, we only analyze hybrid type-I ARQ with PMCAP/CDMA. Using similar method, we can obtain stead probability of each state for hybrid type-II ARQ.

The state flow graph of the tagged data user for ARQ-I with PMCAP/CDMA is shown in Fig.5(a). When data packet comes, the MH transmits its preamble with probability of p_d. After successful obtaining an available PN code with probability of p_{c_succ}, it transmits its data packet until packet has been successfully received. p_{t_succ} is transmission successful probability.

From Fig.5, the PGF of *C(z)* of the duration of the MH at AC is given by

$$C(z)=\frac{D_T}{D_o}=\frac{p_d\cdot p_{c\_succ}}{1-(1-p_d\cdot p_{c\_succ})z} \qquad (1)$$

And the PGF of *R(z)* of the duration of the MH at TX is given by:

$$R(z)=\frac{p_{t\_succ}z}{1-(1-p_{t\_succ})z} \qquad (2)$$

Let T_1 and T_2 be the average time that a MH spends in SL, AC and TX respectively during each message service time, then

$$\begin{cases} T_1 = C'(1) = (1-p_d p_{c\_succ})\big/(p_d p_{c\_succ}) \\ T_2 = R'(1) = 1\big/p_{t\_succ} \end{cases} \qquad (3)$$

The activity of the tagged user consists of cycles of alternating idles and busy periods. The message arrivals follow a Bernoulli process with rate σ_d, therefore the mean length of SL period is

$$T_{SL} = 1/\sigma_d \qquad (4)$$

If each departing message leave the buffer empty with probability π_0, the number of messages served in each busy period is geometrically distributed with the mean $1/\pi_0$.

Hence similar to [9], in each cycle, the mean times of a busy user spending at AC and TX state are given by:

$$\begin{cases} T_{AC} = \dfrac{1-p_d p_{c\_succ}}{p_d p_{c\_succ}}\cdot\dfrac{1}{\pi_0} \\ T_{TX} = \dfrac{1}{p_{t\_succ}}\cdot\dfrac{1}{\pi_0} \end{cases} \qquad (5)$$

Next we try to obtain π_0. The probability flowchart of the queue for a tagged user is shown in Fig. 6.

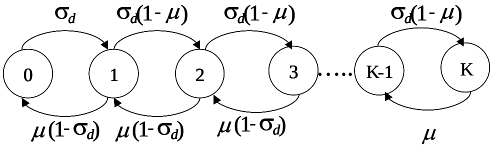


Fig.6 The probability flowchart of the queue for a tagged user

Here μ is message serve rate which can be estimated by $p_d p_{c\_succ} p_{d\_succ}$ according to Fig.5(a). Based on classic queue analysis (M/M/1/K model), if *K* is large enough, π_0 is

$$\pi_0 = \frac{\mu-\sigma_d}{\mu} \qquad (6)$$

Then p_r and p_0 can be expressed by p_{c_succ} and p_{t_succ}:

$$p_r = f_1(p_{c\_succ}, p_{t\_succ}) = \frac{T_{TX}}{T_{SL}+T_{AC}+T_{TX}} \qquad (7)$$

$$p_0 = f_2(p_{c\_succ}, p_{t\_succ}) = \frac{T_{SL}}{T_{SL}+T_{AC}+T_{TX}} \qquad (8)$$

Transmission success probability of p_{t_succ} is determined by the influence of other users on the tagged user. Due to the channel symmetry, the busy probability of the tagged user would be the same as the other users, that is p_r. When the tagged user transmits a packet in a slot, each of other M-1 users would transmit a packet in the same slot with probability p_r. Hence p_{t_succ} is given by

$$p_{t\_succ} = \sum_{i=0}^{M-1} \binom{M-1}{i} (p_r)^i (1-p_r)^{M-1-i} Q_e(i+1) \quad (9)$$

where *Qe(k)* is the frame successful probability given *k* simultaneous transmission. Because there is still no close form for *Qe(k)* of convolutional code, we obtain RCPC coded hybrid ARQ-I and hybrid ARQ-II by simulation.

Figure 7 presents the frame error rates of the parent convolutional code in AWGN channel with MAI and different noise levels (Eb/N0=3db, 5db and 7db). From Fig.7, we can see that with channel noise increasing, Frame Error Rate (FER) of the parent convolutional code in AWGN also rises. For example, when background noise is 3db, suppose there are 33 users transmitting their packet simultaneously, nearly all the transmitted packets can't be correctly received. In this case, there should be a maximum acceptable code number threshold *L* to limit correctly received access request.

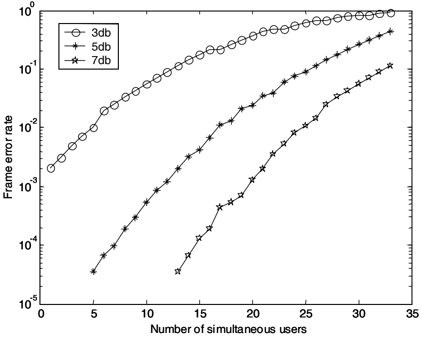


Fig.7. FER of the parent convolutional code in AWGN channel with MAI

When the steady state comes, the probability of the tagged MH into or out each state would be the same. Also, in this paper, we assume that new packet is generated no matter the MH is in SL, AC or TX state. Because the probability that a MH goes into AC state is equal to the probability that the MH leaves this state, the following equations must hold according to EPA analysis:

$$\sigma_d = (1 - p_0 - p_r) p_d p_{c\_succ} \quad (10)$$

From equation (7-10) above, we obtain the system with four equations in four unknown terms, namely p_0, p_r, p_{c_succ}, p_{t_succ}. So these equations can be solved. By the way, if our simulation results well fit these four equations, the correctness of simulations will be proved. Throughout this paper, equations (7-10) are used to validate all our simulation results.

The data throughput is:

$$\theta = M p_r p_{t\_succ} \quad (11)$$

Let τ denotes slot duration, data delay (second) can be expressed as:

$$D = \frac{M - m_r}{\theta} \cdot \tau \quad (12)$$

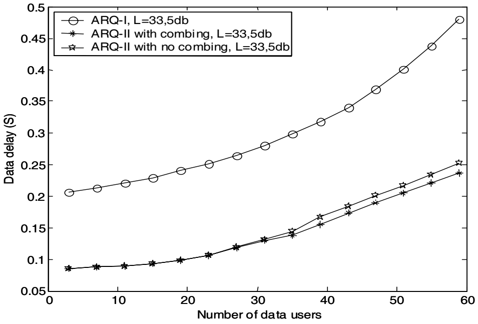
IV. COMPARISONS AND SIMULATION RESULTS

We simulated three ARQ strategies in PMCAP/CDMA, namely ARQ-I, *conventional* ARQ-II and *simple code combing* ARQ-II in AWGN channel with fixed parameters shown in Table 2. Due to the slot duration of ARQ-I and ARQ-II is different, the packet generate rate each slot of these two strategies is also different accordingly to ensure the same average traffic each second. RCPC codes are used to correct errors in data packets. We assume preamble is highly protected and transmission of preamble is error free. All our simulation results are verified by equation (7-10).

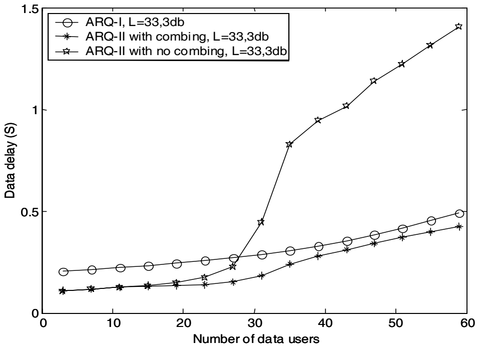
Table 2. Some fixed parameters in simulation

Variable	ARQ-I	ARQ-II
Processing gain (G)	31	31
Total codes in code pool (C)	33	33
Channel rate (R)	16 Kbps	16 Kbps
Frame length (F)	1536 bits	512 bits
Slot duration (τ)	96 ms	32 ms
Packet generate rate each slot (σ_d)	0.6	0.2
Preamble transmission permission probability (p_d)	0.9	0.9

Fig.8 is simulation result of three strategies when no code limitation exists (*L*=*C*=33). From Fig.8(a), when E_b/N_o equals to 5db, data delay of ARQ-II is much lower than that of ARQ-I. The reason is that in ARQ-II, most traffic can be successfully received in the first or second transmission when the channel condition is good. With increasing number of MHs, multiple access interference (MAI) would be higher. Some of the packet needs to be transmitted more than 3 times. In this case, frame error rate of ARQ-II with code combing outperforms that of conventional ARQ-II. So the performance of ARQ-II with code combing is slightly better than conventional ARQ-II. From Fig.8(b), the channel noise is very high when E_b/N_o equals to 3db. With the number of MHs in the system increasing, the performance of ARQ-II with code combing is very similar but still superior to ARQ-I. The performance of conventional ARQ-II drops rapidly when number of MHs exceeds 27. In that case, there are too many retransmissions, which add too much MAI in the system. Besides, contention success probability will be very low because many PN codes are always reserved by some MHs whose packets can't be correctly received.



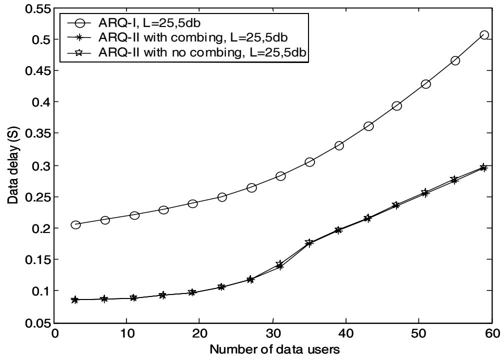
(a) E_b/N_o =5db



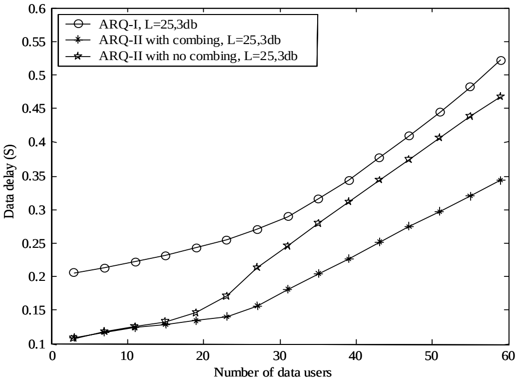
(b) E_b/N_o =3db

Fig.8. Comparison of three ARQ strategies with L=33

Fig.9 is the simulation result of three ARQ strategies with code limitation (L=25). With this limitation, there are maximum 25 simultaneous users permitted to transmit their data packet. So the contention success probability (p_{c_succ}) would drop and the transmission success probability (p_{t_succ}) would increase. From Fig.9(a), when the channel noise is not very high, to apply code limitation strategies would decrease performance compared to Fig.8 (a). But in bad channel condition of Fig.9 (b), code limitation strategies improve performance of conventional ARQ-II greatly. This conclusion can also be drawn from Fig.7, in which the FER (L=25) is improved greatly in contrast to L=33. For ARQ-II with code combing, the delay is also dropped.



(a) E_b/N_o =5db



(b) E_b/N_o =3db

Fig.9 Comparison of three ARQ strategies with L=25

Fig.8 and Fig.9 shows in good channel conditions, delay performance of hybrid ARQ-II (no matter with or without code combining) in PMCAP/CDMA outperforms that of ARQ-I greatly. And in bad channel condition, delay performance of hybrid ARQ-II with code combing is superior to the other two candidates, but code limitation strategy are needed to reduce MAI and especially further improve performance of conventional hybrid ARQ-II (without code combining).

V. CONCLUSION

In this paper, two ARQ-II strategies are used in PMCAP/CDMA. We use both TUA and EPA method to analyze the performance of the protocol. Simulation shows that using hybrid ARQ-II with code combing in PMCAP/CDMA can significantly improve the delay performance in AWGN. Code limitation strategy can decrease the MAI level and frame error rate, which in turn improve the system performance when the background noise is very high.

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