Providing Variable-Rate Transmission for the Integrated Multimedia Services in the CDMA Network

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Abstract In this paper, we propose wireless medium access control protocol for CDMA network based on contention and reservation, which provides mobile terminals with connection-oriented/connectionless services and supports various bit rates required to support integrated multimedia services. Proposed mechanism improves utilization efficiency of spreading codes by allowing limited spreading codes to be shared among all mobile terminals. Mobile terminals can transmit user traffic using multiple spreading codes. Also, depending on the number of usable uplink slots within frame and the number of spreading codes usable within each slot, various bit rates can be provided for each mobile terminal. Proposed mechanism allows connection-oriented and connectionless services, and optimum bit rates are supported for each service. Also, we analyze the performance of proposed wireless MAC protocol in view of mean blocking rate of connection-oriented services and mean delay time of connectionless services.

I. Introduction

Mobile communication networks based on CDMA, which provides most efficient frequency reusability among neighboring cells, have been designed and developed mainly for voice services[1]. However, in recent, there are increasing numbers of users requiring various multimedia services including data, fax and video traffics. Especially, there are many researches on the wireless ATM, which extends ATM transmission mechanism to the area between access point and mobile terminal[5]-[7]. To provide multimedia services through wireless channels, it is important to satisfy required QoS of each service. It can be accomplished by employing many schemes, one of which is priority control and optimum resource allocation mechanism according to the traffics classes with different QoS requirements in view of maximum allowable delay, mean/peak transmission rate, error control and other factors[6]. Also, most efficient usage of wireless channel has to be accomplished because its capacity is very limited compared with wired networks.

To satisfy maximum allowable delay requirements of various traffics, mobile terminals must use connection-oriented service with dedicated channels, or connectionless service competing shared channels with different priorities among all terminals. To satisfy error control requirements of various traffics, we can apply different error control mechanisms according to traffic types. Meanwhile, to transmit multimedia traffics with various mean/peak bit rates according to applications, connection-oriented and connectionless mobile terminals have to be able to use variable capacity of uplink channels if necessary. Thus, wireless MAC protocol layer of each mobile terminal should provide proper mechanisms to request and use variable channel capacity, and should support connection-oriented and connectionless services to upper layers.

In the CDMA network with a given channel bandwidth or a maximum acceptable time delay for code tracking and synchronization, the number of spreading codes is limited[1]. Thus, how to fully exploit the limited code resource to provide integrated multimedia services is very important. In conventional CDMA networks, each mobile terminal is served with its own spreading code. However, for integrated services including various multimedia traffics as well as voice, various bit rates transmission should be supported over the common air interface(CAI)[6]. Therefore, channel utilization efficiency has to be improved by allowing limited spreading codes shared among mobile terminals. This enables CDMA network to provide many kinds of multimedia services requiring various bit rates, and to support higher capacity based on given channel bandwidth. In this paper, we propose new wireless MAC protocol sharing spreading code, and analyze its performance in view of mean blocking rate of connection-oriented services and mean delay time of connectionless services.

II. Spreading code sharing mechanism in CDMA network

A. PCRMA channel access mechanism

The proposed CDMA wireless MAC protocol is named as packet code reservation multiple access(PCRMA). Since downlink channels are used by AP to transmit forward traffics based on internal scheduling, there are no collisions and QoS can be guaranteed in maximum. Therefore, we investigate into only uplink channel access mechanism. PCRMA is designed to provide multimedia services with various bit rates, and supports both the connection-oriented and connectionless services. Here, resource allocation is controlled by central AP, satisfying QoS requirements of each traffic type.

PCRMA uplink channel structure is shown in Fig.1. AP broadcasts the information of spreading codes available in next uplink slot, through downlink control channel. Based
of Status information messages (AP → MH)

- 00: IDLE (available)
- 01: RES (reserved)
- 10: SRA (successfully received & available)
- 11: SRR (successfully received & reserved)

Usage of status information messages (AP → MH)

<table>
<thead>
<tr>
<th>Response</th>
<th>Connection-oriented contention</th>
<th>Collision: IDLE</th>
<th>Connectionless contention</th>
<th>Successful reception and reservation: SRA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadcast (&quot;idle&quot; or &quot;reserved&quot;)</td>
<td>Available code: IDLE</td>
<td>Reservation</td>
<td>Available code: RES</td>
<td>Reservation</td>
</tr>
<tr>
<td>Available code: IDLE</td>
<td>Available spreading code</td>
<td>IDLE</td>
<td>RES</td>
<td>Available spreading code</td>
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<Table I> Status information messages of uplink spreading code

In PCRMA, each uplink frame is divided into multiple slots. Mobile terminals can transmit packets by using multiple codes in each slot. PCRMA network provides connection-oriented service and connectionless packet transmission service according to traffic type. Mobile terminals using connection-oriented service are assigned with proper slots and spreading codes that can be used in each slot, according to required bit rate. However, in the case of connectionless service, mobile terminal transmits packets by using one available spreading code selected from a pool of all available codes in each slot. Therefore, if multiple terminals transmit channel request packet using the same available spreading code, there occurs collision. In this case, access point (AP) transmits no feedback message through downlink slot, and mobile terminals select one of available spreading codes randomly and retransmit channel request packet at next uplink slot.

Table 1 shows the broadcast messages related with uplink channel status information. These messages can be used as response to the channel request or packet data transmission from mobile terminals.

B. System modeling

The connection-oriented subsystem model of PCRMA is shown in Fig. 2, where $p_c$ and $q_c$ indicate the transition probabilities from state IDLE to CON, and from RES to IDLE, respectively. Mobile terminal which needs connection-oriented service transmits contention packet to the access point (AP), and transmits contention packet to the access point (AP) using available spreading codes which is randomly selected based on feedback message. Then, it waits until it receives feedback message from AP. Upon successful channel allocation, it goes to RES state, and remains in 'CON' state if contention fails. State 'RES'
indicates when mobile terminal is assigned with i-slots in frame, and j-spreading codes in each slot. When connection is released, mobile terminal goes to 'IDLE' state. Based on this model, we can represent PCRMA system state, and analyze the mean blocking probability and packet dropping probability based on equilibrium point analysis (EPA) method [2].

First, we can derive the transition probability from state 'CON' to 'RESi,j' of PCRMA by using the performance analysis method of [4]. Let $L$ denote the number of slots in frame, and let $N$ denote the number of spreading codes which can be used in each slot. Also, let $r_c$ and $r_d$ denote the permission probability of connection-oriented and connectionless terminals, respectively. Moreover, let $r$ denote the probability that certain spreading code is reserved, and let $1$ denote the number of available codes in a slot. In addition, let $c$ and $d$ denote the number of connection-oriented and connectionless mobile terminals in contention state, respectively. Then, a connection-oriented terminal in the 'CON state gets a reservation on $j$ spreading codes and enters into the 'RESi,j' state, as a result of the concurrence of the events $\{E_{c,1} \cup \ldots \cup E_{c,N} \}$. As described below:

1. $E_{c,0}$ terminal does not enter a 'IDLE' state at the end of the slot
2. $E_{c,1}$ $j$ codes happen to be randomly selected by connection-oriented terminal from a pool of all available codes
3. $E_{c,2}$ codes are unreserved
4. $E_{c,3}$ no other contending connection-oriented terminal selects these codes or gets permission to transmit a packet even if it selects these codes
5. $E_{c,4}$ no contending connectionless terminal(with backlogged data packets) selects these codes, or obtains permission($r_d$) even if it selects these codes

Also, the probability of each event is given by Eq. $1 - 6$.

$$\Pr\{E_{c,0}\} = (1 - r_c)$$ (1)

$$\Pr\{E_{c,1}\} = \sum_{i=1}^{N} \binom{N-j}{i} (1-r)^{N-j-i} \cdot \frac{1}{L}$$ (2)

$$\Pr\{E_{c,2}\} = (1-r)^j$$ (3)

Where $P_c = \frac{1}{L} \sum_{i=1}^{N} \binom{N-j}{i} (1-r)^{N-j-i} \cdot \frac{1}{L}$

$$c_{\gamma_c} + N r_c = \gamma_c \text{ ("idle")}$$ (10)

$$r_{\gamma_c} = c_{\gamma_c} \text{ ("res")}$$ (11)

$$b_0 \sigma_d = b_1 w(1-\sigma_d) \text{ ("BUF0")}$$ (12)

$$b_0 \sigma_d + b_2 w(1-\sigma_d) = b_1 w(1-\sigma_d) + b_0 \sigma_d (1-w) \text{ ("BUF1")}$$ (13)

$$b_j w(1-\sigma_d) + \sigma_d (1-w) = b_{j+1} w(1-\sigma_d) + b_{j+2} \sigma_d (1-w) \text{ ("BUF", } j \geq 2)$$ (14)

Then, the probability that mobile terminal gets reservation on $i$ slots in frame and $j$ spreading codes in each slot, $P_{i,j}$, can be obtained as Eq. $7$.

In Eq. $7$, if $L = 1 (i = 1)$ and $j = 1$, then it becomes the same system as RCMA, as described in Eq. $8$ of ref [4]. Namely, if mobile terminal uses continuous slots ($L = 1$, $i = 1$) and single code in slot ($j = 1$), then PCRMA becomes the same system as RCMA, where $J_{1,1}$ exists only. From these results, we can analyze the performance of PCRMA by using equilibrium point analysis (EPA) method [2]-[4].

Fig. 3 shows the connectionless subsystem model, where the state means the number of packets in the transmission buffer of terminal which is waiting to be transmitted to the AP. Here, $w_j$ indicates the probability that terminal transmits $j$ packets using $j$ spreading codes in a certain slot. Then, $w_j$ is calculated as

$$w_j = (1-r)^j \cdot P_{c} \cdot \left(1 - P_{c} \cdot P_{j} \right) \cdot \left(1 - P_{d} \cdot P_{j} \right)^{j-1}$$ (8)

III. Performance analysis and numerical results

A. Performance analysis

Equilibrium point analysis (EPA) method is proposed by Tasa[2] first, and used by Nanda[8] for the performance analysis of PRMA protocol. EPA method is simple and accurate in the sense that performance prediction of a stable system well agrees with the results using computer simulation, and is therefore adopted in our analysis. By definition, an equilibrium point is the point at which the expected increase in the number of users in each terminal state is zero. Let us denote system equilibrium state by $\omega$, and number of connection-oriented and connectionless terminals by $c$, $d$. Then, $\omega$ is represented as

$$\omega = (s, c, r_1, r_2, r_3, K, r_d, b_0, b_1, K, b_j, K)$$ (9)

Remember all the spreading codes are equally likely to be reserved. That is, $r_1 = r_2 = \ldots = r_N = r$.

Refer to the subsystem models shown in Fig.2 and Fig.3. By assuming that entering flow is the same as
leaving flow, Eq.10 - Eq.14 can be driven.

From these equations, if the total numbers of connection-oriented and connectionless terminals is given, the system equilibrium state is characterized by parameters $b$, $c$ and $r$. However, it is difficult to solve directly the above equations since equations are highly nonlinear. Therefore, we form equation of a single unknown symbol whose solution is relatively easy to obtain. Let us express above equations in terms of unknown $c$. Then, following equations can be obtained.

\[
\begin{align*}
    r &= \frac{1}{N} \left( \frac{\sigma_c - M_c - c}{\sigma_c + r} \right) \equiv \psi_r(c) \quad (15) \\
    w &= \frac{N \gamma_c \sigma_{ac} P_c (1 - r)}{P_c (1 - \gamma_c)} \left( 1 - r - P_d \right) \quad (16) \\
    b &= \frac{M_d \sigma_{ac} c (1 - \gamma_c) P_c (1 - r - P_d)}{N r \gamma_c P_d (1 - r - P_c)} \quad (17)
\end{align*}
\]

Eq.15 - Eq.17 can be solved from unknown $c$. Then, we can derive the packet dropping and mean blocking probability of connection-oriented service, and mean delay of connectionless service.

Finally, in the case that mobile terminal in 'CON' state needs $i$ slots and $j$ spreading codes, the blocking probability $v$ is described as Eq.18. Also, in the case of interactive multimedia traffic, average packet dropping probability $r_{drop}$ is calculated as Eq.19. In the case of connectionless service, mean packet delay is represented as Eq.20.

\[
\begin{align*}
    v &= 1 - \gamma_c - \sum_{i=1}^{N} \sum_{j=1}^{N} f_{i,j} \quad (18) \\
    P_{drop} &= \gamma_c \left[ \frac{v \gamma_c \left( 1 - \gamma_c \right)^j}{1 - v \left( 1 - \gamma_c \right)^j} \right] \left[ 1 - \frac{v \gamma_c \left( 2 + v \gamma_c - 2v \right)}{[1 - v \left( 1 - \gamma_c \right)^j]} \right] \quad (19) \\
    D_{av} &= \frac{1 - w}{w} \frac{1 - \rho_d \sigma_d}{1 - \rho_d} \quad (20)
\end{align*}
\]

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bit rate of mobile terminal in RCMA becomes 32Kbps\[4\]. Therefore, we assume the maximum traffic source rate is the same as that of RCMA for fair comparison, though higher bit rate can be supported in the proposed PCRMA. Considering interactive voice and video traffic, the maximum queuing delay time is set to 100ms. For traffic source, we consider multimedia traffic sources requiring various bit rates such as 4800bps, 9600bps, 16Kbps, and 32Kbps. Also, the number of mobile terminals requiring each bit rate is assumed to be the same.

Fig.4 and Fig.5 show the mean blocking probability and average packet dropping probability versus the number of connection-oriented mobile terminals in the system. For fair comparison with RCMA, it is assumed that \( r_c = r_d = 1 \) in PCRMA and slot width is 1ms, and \( N = 40 \) and \( N = 120 \) are considered. Also, considering interactive multimedia service, connection duration time of connection-oriented service is assumed to have exponential distribution with mean of 180sec. Here, there are little difference between simulation and numerical results. This phenomenon occurs because we limited the maximum threshold in the random number generation in this simulation.

As shown in figures, PCRMA provides better performance than RCMA, in terms of blocking probability and packet dropping probability. The reason is that non-continuous slots and multiple codes are assigned according to the required bit rate, and spreading code utilization efficiency is improved in PCRMA. However, in the case of RCMA, reserved single spreading code have to be used in continuous slots, and wireless channels are wasted in the case of traffic source with low bit rate. In addition, in PCRMA, mobile terminal can be provided with higher bit rate, unlike the RCMA. Thus, PCRMA network can provide integrated multimedia services with various bit rates, because of improvements of spreading code utilization efficiency.

The mean packet delay of connectionless service is shown in Fig.6, where the performance of PCRMA is better than that of RCMA. In PCRMA, the waiting time to transmit connectionless packet is reduced to slot length, and collision occurrence probability is lower than RCMA because mobile terminal randomly selects one of available spreading codes. In addition, since mobile terminal can transmit multiple packets using one or more available spreading codes in the same slot, PCRMA gives lower delay time compared with RCMA.

IV. Conclusions

In this paper, we proposed and analyzed the performance of PCRMA protocol as a wireless MAC protocol for the CDMA network supporting various multimedia services. PCRMA is designed to make limited spreading codes shared among mobile terminals in the indoor and micro-cell CDMA network, and provides connection-oriented and connectionless services. Also, not only voice but also various multimedia traffics can be supported, and various bit rates according to traffic type can be supported. From numerical results, it is shown that PCRMA provides better performance in view of blocking probability and packet dropping probability, compared with RCMA which is contention and reservation-based wireless MAC protocol for CDMA network. Also, PCRMA can support higher bit rate to mobile terminals, unlike conventional systems.
References