Contention-based Reservation MAC Protocol for Burst Traffic in Wireless Packet Networks

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Abstract—In this paper, centralized access control and slot allocation algorithm is proposed for wireless networks. The proposed algorithm is characterized by the contention-based reservation. In order to reduce the collision probability of reservation request, the base station calculates and broadcasts the transmission probability of reservation requests, and the wireless terminal transmits its reservation request with the received transmission probability. The scheduler allocates the uplink data slots based on the successful reservation requests. Simulation results show that the proposed algorithms can provide high channel utilization, and furthermore, maintains constant delay performance in the heavy traffic environment.

Index Terms—Access control, MAC protocol, TDMA, Transmission probability.

I. INTRODUCTION

A major issue related to the realization of wireless packet networks is the design of a medium access control (MAC) protocol. The MAC protocol should efficiently and equitably allocate the scarce radio resources among the competing wireless terminals. It also has to be designed to maximize the multiplexing gain over the radio interface.

The MAC protocols that have been proposed in the literature [3]-[7] are usually classified according to the scheme used to assign uplink data slots: contention, reservation, and polling. However, almost all of the adapted method for burst traffic is based on a hybrid contention-reservation method [4]. Since the wireless terminals change their state from active to idle and vise versa, the scheduler must exactly know the state of each terminal to avoid assigning vain uplink slots to idle terminal. Moreover, since burst traffic requires its varying bandwidth demands, it is important to transmit instantaneous queue length in a timely and accurate manner. As for how to notify the dynamic parameter from the wireless terminal to the base station, there exist mainly two different types of access method: contention-based and contention-free method [7].

The contention-based method is to transmit the dynamic parameter over the pre-designated contention slots with a random access protocol, e.g., slotted ALOHA. The contention slots are usually given in minislots to reduce the wastage of bandwidth in case of collision. If two or more wireless terminals transmit their reservation request in the same contention slot, collision occurs. This collision incurs transmission delay. On the other hand, the contention-free method is based on either a piggyback mechanism or a polling mechanism. In the piggyback mechanism, the wireless terminal transmits its dynamic parameters with the uplink data packet. In the polling mechanism, the scheduler assigns an uplink slot (typically given in minislot) to an individual wireless terminal for transmitting the dynamic parameters. The contention-based method cannot guarantee the required QoS for the real-time services because of the random access delay. The contention-free piggyback mechanism can be useful only when there exists an uplink data burst to transmit.

In this paper, we propose a hybrid contention-based reservation MAC protocol for non-real-time burst traffic services in wireless packet networks. The proposed protocol is characterized by the contention-based reservation request and reservation-based transmission of burst traffic. The design objective of the proposed protocol is to reduce contention delay during the contention phase. In order to reduce collision of reservation request, the base station scheduler calculates the transmission probability based on the estimated load of reservation requests and the number of random access minislots, and broadcasts it over the frame header of downlink channel. Wireless terminal, which has traffic burst, selects a random access minislot and transmits its reservation request with a received transmission probability. Based on the successfully received reservation request, the scheduler allocates the uplink data slots to wireless terminal.

This paper is organized as follows. Section II describes the proposed protocol including a frame structure. Section III presents simulation results for the proposed protocol. Finally, Section IV concludes this paper.

II. PROTOCOL DESCRIPTION

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A. Frame Structure

The radio channel is time slotted, and slots are grouped into a frame of fixed duration. These are used for the uplink and downlink transmissions according to the TDMA/TDD scheme and are dynamically assigned frame by frame. Fig. 1 illustrates the format of the frame. The boundary between an uplink and a downlink channel is dynamically adjusted as a function of the traffic load. The uplink and downlink channels are further divided into control and data transmission periods.

Downlink channel has three different periods, namely, modem preamble (MP), frame header (FH) and downlink data slots. MP is used for frame synchronization between the wireless terminal and the base station. The frame header contains a variable number of information elements, each dedicated to specify the slots assigned in the current frame. It also contains the result of reservation requests and the transmission probability of subsequent frame. Uplink channel consists of two different periods, namely, random access slots (RAS) and uplink data slots. RAS contains an integer number of minislots long enough to contain a control packet. RAS is for transmission of the reservation request when the wireless terminal generates a new burst.

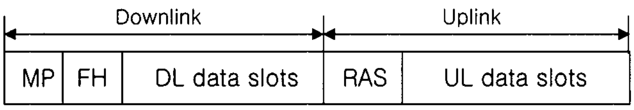

Fig. 1 Frame structure.

B. Access Control Algorithm

Wireless terminal, which generates a new burst, selects a minislot in RAS, and transmits the reservation request with the number of required uplink data slots for this burst. If the base station receives reservation requests without collision, it assigns the data slots to wireless terminals according to slot allocation algorithm described in the next subsection. If the base station has successfully received a reservation request of wireless terminal but cannot temporarily assign uplink data slots, it broadcasts a wait signal over the frame header to force wireless terminal to wait until any uplink data slots become available. Wireless terminal, which has obtained contention-free uplink data slots, sends data packets over the allocated uplink data slots.

A burst traffic source can be described with an ON-OFF model. In ON-OFF model [8], the burst traffic source alternates between the ON state where the source generates traffic burst and the OFF state where no traffic bursts are generated. Data packets, which are generated during the ON state but cannot be transmitted in the next frame due to collision of reservation request or lack of uplink data slots, should be buffered in the transmission buffer of wireless terminal. The access control algorithm is summarized as follows:

Step 1: Wireless terminal waits a new burst during the OFF state. If a new burst arrives during the OFF state, it changes its state to the contention phase of the ON state.

Step 2: At the beginning of the contention phase, wireless terminal transmits its reservation request over a randomly selected RAS minislot with the received transmission probability. If it is not allowed to transmit the reservation request, wireless terminal repeats this step in the next frame.

Step 3: Wireless terminal remains in the contention phase and repeats *Step 2* if it fails to transmit its reservation request.

Step 4: In the case of successful reception of reservation request packets, the base station allocates uplink data slots if uplink data slots are available. Otherwise, it broadcasts a wait signal though it successfully receives reservation request packet. Wireless terminal, which is assigned uplink data slots by the base station, changes its state from the contention phase to the reservation phase.

Step 5: During the reservation phase, wireless terminal transmits data packets over uplink data slots. If the base station scheduler signals a wait signal, wireless terminal waits until any uplink data slots are allocated.

If the number of reservation request is more than the number of RAS minislots, collision will occur. Therefore, the number of simultaneous reservation request needs to be limited with the control of transmission probability. In the conventional transmission control algorithm such as harmonic backoff algorithm [9], wireless terminal that fails to transmit reservation request retransmits it with the decreased probability. By continuously decreasing the transmission probability, the transmission probability of a specific reservation request becomes excessively decreased. As a result, the delay of traffic burst may be significantly increased. In order to reduce collision probability and improve the fairness between reservation requests, this paper also proposes a transmission probability control scheme used in *Step 2*.

In the proposed scheme, the base station controls the transmission probabilities based on the number of reservation requests and RAS minislots in current frame. Wireless terminal that fails to transmit its reservation request at frame t will retransmit with a retransmission probability $P_r(t+1)$ at subsequent frame, while wireless terminal that have a new burst at frame t will sent with a new transmission probability $P_n(t+1)$ in subsequent frame. The base station calculates $P_n(t+1)$ and $P_r(t+1)$ based on the number of reservation requests and RAS minislots. The $P_n(t+1)$ and $P_r(t+1)$ are given as follows:

$$P_n(t+1) = \begin{cases} 1, & \text{if } N_r(t+1) \le K \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

$$P_r(t+1) = \begin{cases} 1, & \text{if } N_r(t+1) \le K \\ \dfrac{K}{N_r(t+1)}, & \text{otherwise} \end{cases} \tag{2}$$

where K is the number of RAS minislots and $N_r(t+1)$ is the number of reservation requests retransmitted at frame $(t+1)$. The $N_r(t+1)$ can be calculated with the number of reservation requests retransmitted at frame t, the number of successful reservation request at frame t, and the number of new reservation requests at frame t. This can be expressed by

$$N_r(t+1) = N_n(t) + N_r(t) - N_s(t) \quad (3)$$

Where

$$0 \le N_r(t) \le N_d,$$
$$N_n(t) = \{N_d - N_r(t)\} \cdot \lambda,$$
$$\begin{cases} 0 \le N_s(t) \le Min\{K, N_n(t) + N_r(t)\}, & \text{if } P_n(t) = 1 \\ 0 \le N_s(t) \le Min\{K, N_r(t)\}, & \text{if } P_n(t) = 0 \end{cases}$$

In the above equation, N_d is the number of wireless terminals, $N_s(t)$ is the number of successful reservation requests at frame t, and $N_n(t)$ is the number of new reservation requests at frame t. λ is the probability that each wireless terminal generates a new traffic burst per frame.

In the proposed scheme, if the number of reservation requests retransmitted is less than the number of RAS minislots, all wireless terminals with reservation request are allowed to transmit their reservation request. If collision of reservation requests occurs more frequently, the number of reservation requests retransmitted should increase. Therefore, if the number of retransmitted reservation requests becomes more than the number of RAS minislots, the base station sets the new transmission probability as 0 to suppress the transmission of new reservation requests. Also, in this case, the base station scheduler sets the retransmission probability as the values at which the total number of retransmitted reservation requests becomes the number of RAS minislots in order to minimize the contention delay of burst traffic.

C. Slot Allocation Algorithm

In order to allocate uplink data slots, the base station scheduler maintains burst information, e.g., burst length and remaining number of packets in the transmission buffer of wireless terminal. The base station maintains an active virtual connection list (AVCL) as shown in Fig. 2. The base station scheduler constructs an AVCL node whenever it receives a reservation request. An AVCL node represents transmission buffer state, which is related to a traffic burst. Each entry in AVCL specifies virtual connection identifier (VCid), total number of data packets of burst (Ntp), remaining number of data packets in the buffer (Nrp), and a pointer to the next entry. The base station updates AVCL after it receives reservation requests and allocates uplink data slots.

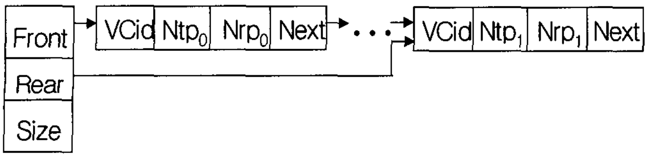

Fig. 2 Data structure of AVCL.

In this paper, it is assumed that wireless terminal does not transmit reservation requests until all the packets of a burst already in the reservation phase are completely transmitted. Therefore, VCid in AVCL is uniquely identifying wireless terminal. A node of AVCL, which represents a traffic burst, is inserted at the rear of AVCL, and consequently, AVCL is sorted in an arrival time of reservation request.

The base station scheduler allocates uplink data slots based on Ntp in each node of AVCL. All the available uplink data slots are fairly assigned to wireless terminal, in proportion to the burst size. The required parameters for slot allocation algorithm are listed in Table 1, and the slot allocation algorithm, named as APTP (Allocation Proportional to Total Packet) algorithm, is summarized as follows:

Step 1: Allocate Nrp_i slots to each burst if the total number of remaining slots in AVCL is less than the number of uplink data slots.

```
if (RP ≤ N_I) then
{       for i = 1 to L
             A_i = Nrp_i;
        goto Step 4; }
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Step 2: Otherwise, allocate uplink data slots in proportion to the total number of packets of each burst, and update the number of remaining slots in a frame.

for $i = 1$ to L

$$A_i = \left\lfloor \frac{Ntp_i}{TP} \times N_I \right\rfloor;$$

$$R = N_I - \sum_{i=1}^{L} A_i;$$

Step 3: If there are remaining slots left over after Step 2, the remaining slots are allocated one by one in the order from the front to the rear in AVCL.

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for i = 1 to L
        A_i = A_i + 1;
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Step 4: Update AVCL.

In the proposed APTP algorithm, uplink data slots are allocated to each wireless terminal in proportion to the number of data slots, which is equal to the burst length. If the burst length is larger than any other bursts, the base station scheduler gives high priority to the associated terminal, and allocates more uplink data slots to it.

Table 1 Algorithm parameters.

Parameter	Descriptions
N_I	Number of uplink data slots
L	Number of AVCL nodes

A_i	Number of allocated slots to burst i
RP	Total number of remaining slots in AVCL $\left(=\sum_{i=1}^{L} Nrp_i\right)$
TP	Total number of requested slots in AVCL $\left(=\sum_{i=1}^{L} Ntp_i\right)$
R	Number of remaining slots in a frame. Initially set to N_I

III. SIMULATION RESULTS

This section presents the simulation results for the proposed protocol. In order to evaluate performance, an ON-OFF model was chosen as burst traffic source model, where a traffic source alternates between ON and OFF state. It is assumed that the inter-arrival time of traffic bursts is exponentially distributed with mean 50ms and the number of data packets in each burst is exponentially distributed with mean 5 cells. The system parameters used in the simulation are listed in Table 2.

Table 2 System parameters for simulation.

Simulation Parameters	Value
Channel bit rate	25Mbps
Frame duration	2msec
Data slot size	54 bytes
Minislot size	9 bytes
Number of uplink data slots (N_I)	50
Number of downlink data slots	50
Number of RAS minislots (K)	30
Mean inter-arrival time between bursts	50msec
Mean burst length	5 cells

The performance measures are: the slot utilization, defined as the ratio between the total number of uplink data slots and the number of allocated uplink data slots; the delay, defined as the average time from the arrival of a packet at the terminal to its reception at the base station.

Since the downlink channel is a broadcasting channel from the base station, only the uplink channel is considered in the simulations. To focus on the performance of the access control and slot allocation algorithms, the wireless channel is assumed to be ideal such that there is neither noise nor other interference during transmission.

Fig. 3 and Fig. 4 show the slot utilization and delay of the proposed scheme according to the number of connections compared with the conventional harmonic backoff scheme, respectively. In the harmonic backoff scheme, wireless terminal that fails in reservation request decreases its transmission probability independently with the traffic load of reservation requests. On the other hand, in the proposed scheme, the base station scheduler controls the transmission probability based on the number of reservation requests and RAS minislots.

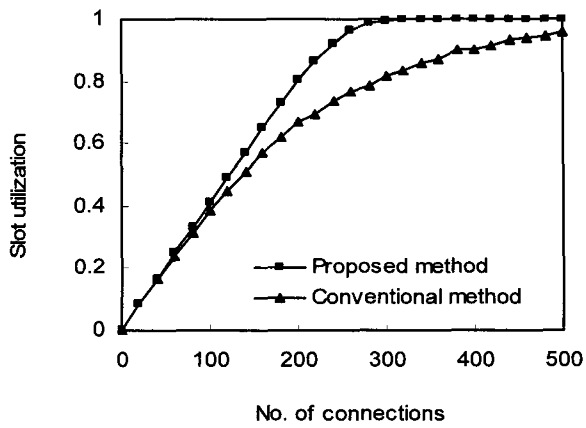

Fig. 3 Slot utilization vs. number of connections.

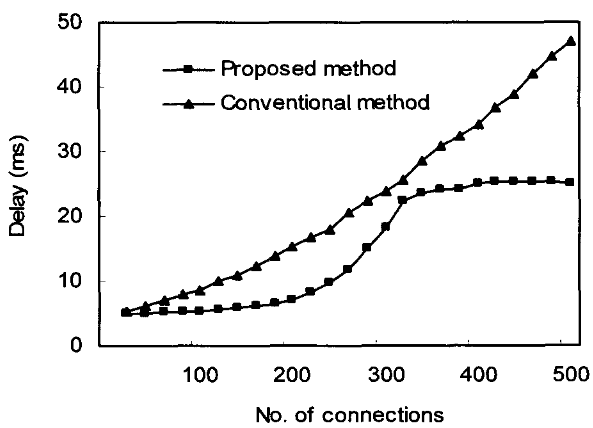

Fig. 4 Delay vs. number of connections.

As shown in Fig. 3, there is no significant difference in the slot utilization between both schemes in a light traffic load. However, in a heavy traffic load, the slot utilization of the proposed scheme can be enhanced compared with the harmonic backoff scheme. Furthermore, as depicted in Fig. 4, the proposed scheme maintains constant delay in a heavy traffic. The reasons are as follows: i) the proposed scheme can control the number of simultaneously transmitting reservation requests more precisely than the harmonic backoff scheme; ii) the base station does not permit new reservation requests in a heavy traffic. Therefore, in contrast to the conventional scheme, the proposed scheme can guarantee fair transmission of reservation requests among all wireless terminals.

IV. CONCLUSIONS

The design of MAC protocol for wireless packet network is an important issue, whose performance is crucial for an efficient use of the wireless channel. In this paper, we have presented a MAC protocol that efficiently supports burst traffic. The proposed protocol is based on TDMA/TDD scheme with fixed frame duration. So as to avoid all aspects of disadvantages associated with the random access based approaches, it works with totally contention-free transmission of data packets for a traffic burst. The proposed protocol is characterized by the contention-based transmission of the reservation request and contention-free transmission of burst traffic. The design objective of the proposed protocol is to reduce contention delay during the contention phase. In order to reduce the collision probability of reservation requests, the base station calculates and broadcasts the transmission probability based on the estimated load of reservation requests and the number of random access minislots. Based on the successfully received reservation, the scheduler allocates the uplink data slots to wireless terminal. Simulation results show that the proposed protocol can provide higher channel utilization, and furthermore, maintains constant delay performance in a heavy traffic environment.

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