A Medium Access Control Protocol for rt-VBR Traffic in Wireless ATM Networks

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Abstract—This paper proposes a MAC protocol for real-time VBR (rt-VBR) services in wireless ATM networks. The proposed protocol is characterized by a contention-based mechanism of the reservation request, a contention-free polling scheme for transferring the dynamic parameters, and a priority scheme of the slot allocation. The design objective of the proposed protocol is to guarantee the real-time constraint of rt-VBR traffic. The scheduling algorithm uses a priority scheme based on the maximum cell transfer delay parameter. The wireless terminal establishes an rt-VBR connection to the base station with a contention-based scheme. The base station scheduler allocates a dynamic parameter minislot to the wireless terminal for transferring the residual lifetime and the number of requesting slots as the dynamic parameters. Based on the received dynamic parameters, the scheduler allocates the uplink slots to the wireless terminal with the most stringent delay requirement. The simulation results show that the proposed protocol can guarantee the delay constraint of rt-VBR services along with its cell loss rate significantly reduced.

Index Terms—MAC protocol, Slot allocation algorithm, TDMA, Wireless ATM.

I. INTRODUCTION

With the growing acceptance of ATM as the standard for broadband networking, the concept of wireless ATM was introduced to extend the capabilities of ATM over the wireless channel. Essentially, wireless ATM has been envisioned as a potential framework for next generation wireless networks, which are capable of supporting integrated multimedia services with a wide range of bandwidth and QoS requirements [1][2].

A major issue related to the realization of wireless ATM 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 while guaranteeing the QoS requirements of each admitted connection. For compatibility with the wired ATM network, it must support the standard ATM service classes: constant bit rate (CBR), variable bit rate (VBR), and available bit rate (ABR) traffic. The MAC protocol also has to be designed to maximize the multiplexing gain over the radio interface while guaranteeing the various QoS requirements for all ATM traffic classes, especially for the stringent real-time constraint of CBR and rt-VBR services. Numerous researches for this kind of MAC protocol have been done during recent years.

The MAC protocols that have been proposed in the literature [3]-[7] is usually classified according to the scheme used to assign the uplink data slots: contention, reservation, and polling. However, almost all of the adapted method for ABR services is based on a hybrid contention-reservation method. Since, during the data phase, ATM connections can dynamically change their state from active to idle and vise versa, the scheduler must exactly know the state of each connection to avoid assigning vain uplink slots to idle terminal. Moreover, since ATM connections require their varying bandwidth demands, it is important to transmit the dynamic parameters such as instantaneous queue length, residual lifetime, or cell arrival rate, in a timely and accurate manner. This is crucial for variable bit rate traffic. As for how to transfer the dynamic parameter information from the wireless terminal to the base station, there exist mainly two different types of access method: contention-based and contention-free method [8].

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 with the dynamic parameters in the same contention slot, collision occurs. This collision incurs unnecessary power consumption and 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 on the uplink data burst. In the polling mechanism, the scheduler assigns an uplink slot (typically given in minislot) to an individual wireless terminal for transferring the dynamic parameters. The contention-based method cannot guarantee the required QoS for the real-time services because of the random access delay for transferring the dynamic parameters. The contention-free piggyback mechanism can be useful only when there exists an

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uplink data burst to transmit. In a system to support the real-time services with the on-off characteristics of cell generation, therefore, it is required to employ the contention-free polling mechanism during a data burst.

In this paper, we propose a MAC protocol for rt-VBR services to guarantee the real-time constraint of rt-VBR traffic. The proposed protocol is characterized by a contention-based mechanism of the reservation request at the beginning of a data burst, a contention-free polling mechanism for transferring the dynamic parameters during a data burst, and a priority scheme of the slot allocation. When the wireless terminal generates a data burst, it transmits reservation request with the dynamic parameters such as queue length and residual lifetime by the contention-based random access mechanism. The base station scheduler allocates an uplink minislot to the contention-succeeding wireless terminal for transferring the dynamic parameters. Based on the received dynamic parameters, the scheduler allocates the uplink data slots to the wireless terminal with the most stringent delay requirement.

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

A. Frame Structure

The radio channel is time slotted with slots long enough to contain an ATM cell payload plus the overhead for the MAC and physical layers. 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) period, frame header (FH) period, and downlink data slots period. MP period 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 to each uplink and downlink connection. It also contains the result of reservation requests in RAS period from wireless terminal. Uplink channel consists of three different periods, namely, dynamic parameter slots (DPS) period, random access slots (RAS) period, and uplink data slots period. A slot in DPS and RAS period can contain an integer number of minislots, each one long enough to contain a control packet. DPS is used for rt-VBR connections to transfer the dynamic parameters, e.g., residual lifetime, the number of required slots, and the queue length, to the base station with contention-free access during the data transmission phase. RAS is for transmission of the reservation request in contention with other reservation requests in a burst-by-burst basis to the base station when rt-VBR connections generate a new burst.

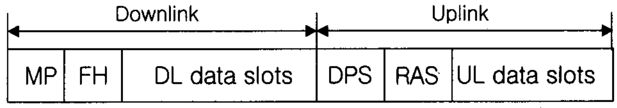


Fig. 1 Frame structure.

B. Access Control Algorithm

In the uplink channel, RAS provides a communication mechanism for a wireless terminal to send a reservation request during the contention phase of the connection. On the other hand, during the data transmission phase, DPS period and uplink data slots period supply it with contention-free transmission of the dynamic parameters and the data packets, respectively. In the proposed protocol, before obtaining contention-free access to DPS period and uplink data slots, a wireless terminal must wait for its reservation request to be successfully transmitted to the base station in contention with reservation requests from other connections. Therefore, the contention phase that a connection goes through before obtaining contention-free transmissions of the dynamic parameters and data packets may have a major effect on the delay QoS of MAC protocol. As the QoS of rt-VBR traffic is more sensitive to the contention delay than others, it is important to design a contention access scheme that provides a lower contention delay to time sensitive reservation requests of rt-VBR traffic.

Wireless terminal, which generates a new burst, selects a minislot in RAS period, and transmits the reservation request with its current buffer status information, e.g., residual lifetime and the queue length, in contention with reservation requests from other terminals. If the base station receives reservation requests without collision, it assigns the number of allocated uplink data slots to wireless terminals according to slot allocation algorithm described in the next subsection. It also broadcasts the allocated DPS minislot number over the frame header period of the next frame. In the case where the base station has successfully received a reservation request of wireless terminal but cannot temporarily assign uplink data slots, it allocates only DPS minislot until any uplink data slots become available. Wireless terminal, which has obtained contention-free DPS minislot and uplink data slots, sends the dynamic parameters and data packets over the allocated minislot and uplink data slots, respectively.

An rt-VBR traffic source can be described as an ON-OFF model. In ON-OFF model [9], the traffic source alternates between the ON state where the source generates data packets and the OFF state where no packets are generated. Data packets, which are generated during the ON state but cannot be transmitted until the maximum cell transfer delay (max_CTD), should be dropped. The access control algorithm is summarized as follows:

Step 1: Wireless terminal, which requires a new rt-VBR connection, sends the traffic parameters to the base station for connection admission control (CAC).

Step 2: An admitted 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 3: At the beginning of the contention phase, wireless terminal selects a minislot in RAS period and transmits the reservation request in contention with other reservation requests according to the transmission probability. If it is not allowed to transmit the reservation request, wireless terminal repeats this step in the next frame.

Step 4: Wireless terminal remains in the contention phase and repeats *Step 3* if fails to transmit its reservation request. If terminal in the contention phase cannot reserve uplink data slots until the max_CTD, it drops data packets that the cell transfer delay exceeds the max_CTD.

Step 5: Wireless terminal, which is assigned a DPS minislot and uplink data slots by the base station, changes its state from the contention phase to the reservation phase. The base station allocates a DPS minislot to wireless terminal, and assigns uplink data slots if uplink data slots become available.

Step 6: During the reservation phase, wireless terminal transfers the dynamic parameters over the allocated DPS minislot at every frame. It also transmits data packets over uplink data slots if possible.

Step 7: At the end of a traffic burst, terminal changes its state to the OFF state and repeats from *Step 2* until the connection terminates.

If the number of reservation requests that transmit simultaneously increases above the number of RAS minislots, collision will occur. Therefore, the number of simultaneously transmitting reservation requests needs to be limited through the use of transmission probabilities. In conventional transmission control algorithm such as harmonic backoff algorithm [10], wireless terminal that fails to transmit reservation request retransmits it with a decreased transmission probability. However, by continuously decreasing the transmission probability of reservation requests that have failed to transmit, the transmission probability of a specific reservation request becomes excessively decreased. As a result, the delay QoS of rt-VBR traffic cannot be guaranteed.

The contention delays of time sensitive reservation requests have to be reduced to guarantee the delay QoS of rt-VBR traffic. Wireless terminals that reservation requests have experienced a collision will repeat the contention process in subsequent frames until they are successful. In order to reduce collision of reservation requests and improve the fairness between transmitting reservation requests, this paper proposes a transmission probability control scheme used in *Step 3* of the access control algorithm.

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 next 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 $P_n(t+1)$ and $P_r(t+1)$ are calculated and broadcasted over the frame header by the base station using 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

$$N_r(t+1) = N_n(t) + N_r(t) - N_s(t) \tag{3}$$

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 rt-VBR 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 will be allowed to transmit each reservation request. If collision of reservation requests occurs more frequently, the number of reservation requests retransmitted should increase. Therefore, if the number of reservation requests retransmitted 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 sets the retransmission probability as the values at which the total number of reservation requests retransmitted becomes the number of RAS minislots, in order to minimize the contention delay of rt-VBR traffic.

C. Slot Allocation Algorithm

The base station allocates a DPS minislot and uplink data slots to wireless terminals if the base station receives reservation requests without collision. In order to allocate uplink data slots, the base station scheduler must have burst information for each rt-VBR connection. For this purpose, the base station maintains an active virtual channel list (AVCL) as shown in Fig. 2. The base station scheduler constructs an AVCL node whenever receives reservation request. An AVCL node represents dynamic parameters, which are related to a traffic burst of rt-VBR connection. Each entry in AVCL specifies virtual channel identifier (VCid), remaining number of slots of burst (Nrp), residual lifetime (RLT), and a pointer to the next entry. The base station updates AVCL at each frame after receives dynamic parameters and allocates uplink data slots.

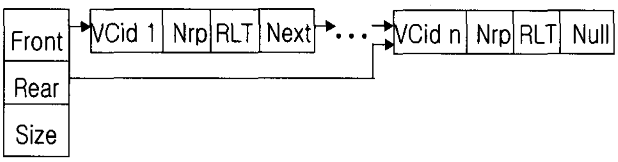


Fig. 2 Data structure of AVCL.

In the proposed slot allocation algorithm, the base station scheduler allocates uplink data slots based on Nrp and RLT in each node of AVCL. The proposed slot allocation algorithm first serves rt-VBR traffic burst of which the relative residual lifetime is smallest. At the start of a frame, AVCL is sorted in an ascending order of RLT, and consequently rt-VBR traffic burst with the least residual lifetime is stored in the head of AVCL. Then, all the available uplink data slots are fairly assigned to bursts with the minimum RLT. If there are remaining uplink data slots after allocating to bursts of the minimum RLT, the base station scheduler continues with the next RLT. The required parameters for slot allocation algorithm are listed in Table 1, and the slot allocation algorithm is summarized as follows:

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

```
if (TP ≤ N_I) then
        for i = 1 to L
                A_i = Nrp_i;
        goto Step 4;
```

Step 2: Find the minimum RLT value in L_{RLT}.

$$R_{\min} = \underset{R_i \in L_{RLT}}{Min} \{R_i\}$$

$$L_{RLT} = L_{RLT} - \{R_{\min}\}$$

Step 3: If the total number of requested slots that RLT is $R_{\min}$ is less than the remaining slots, allocate *Nrp* slots to wireless terminals that have traffic bursts with $R_{\min}$ RLT, and repeat Step 2. Otherwise, allocate remaining slots in proportion to the number of requested slots.

```
if (RP(R_min) < R) then
        for i = 1 to NR_i
                A_i = Nrp_i;
                R = R - A_i;
        goto Step 2;
else
        for i = 1 to NR_i
                A_i = floor( Nrp_i / RP(R_min) × R );
```

Step 4: Update AVCL. After allocating uplink data slots to wireless terminal according to the above-mentioned algorithm, the base station scheduler also assigns a DPS minislot to the same terminal for transferring the dynamic parameters until transmission of a traffic burst finishes.

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*
L_{RLT}	Set of RLT $\{R_1, R_2, \ldots, R_k\}$, $R_1 < R_2 < \ldots < R_k$, $k \leq$(max_CTD-1)
NR_i	Number of AVCL nodes that RLT is R_i
$RP(R_i)$	Number of requested slots that RLT is R_i, $\left(= \sum_{\forall R_i = RLT} Nrp_i\right)$
TP	Total number of requested slots in AVCL $\left(= \sum_{i=1}^{L} Nrp_i\right)$
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 rt-VBR traffic source model, where a traffic source alternates between the ON state and the OFF state. The selected performance parameters are: the cell loss rate (CLR), defined as the ratio between the number of lost cells and the total number of cells offered to each connection; the cell transfer delay (CTD), defined as the average time between the arrival of a cell in the transmission buffer and its reception at the base station. It is assumed that the transmission buffer in wireless terminal is large enough to contain all the cells that are not dropped. Therefore, cells are dropped only if the max_CTD constraint is not satisfied.

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 only, the wireless channel is assumed to be ideal such that there is no noise, or other interference for cell transmission. The system parameters used in the simulation are listed in Table 2. The simulation is run for 1,200 sec, which turns out to be long enough to ensure the accurate simulation results.

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_l)	50
Number of downlink data slots	50
Number of DPS minislots	60
Number of RAS minislots (K)	30
Mean duration of ON state	40msec
Mean duration of OFF state	136msec
max_CTD for rt-VBR traffic	20msec

Fig. 3 and Fig. 4 show the cell loss rate and cell transfer delay of rt-VBR traffic versus the number of connections offered for rt-VBR traffic, respectively. To verify that the cell loss rate and cell transfer delay are sensitive to the offered traffic load, simulations are performed with two different peak cell rate (PCR) of rt-VBR traffic. The cell transfer delay depends on the contention delay of contention phase and the slot allocation delay of reservation phase. The cell loss occurs only if total delay exceeds the max_CTD.

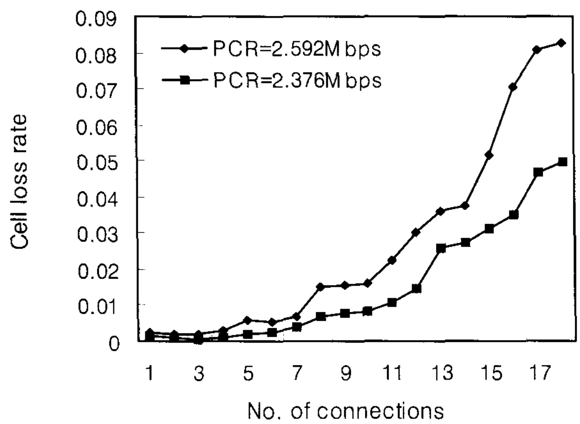


Fig. 3 Cell loss rate vs. number of connections.

Therefore, as depicted in Fig. 3, the cell loss rate increases as the traffic load increases. In the proposed protocol, wireless terminal transmits the exact dynamic parameters of rt-VBR traffic over a DPS minislot allocated in parallel with uplink data slots. Therefore, the base station scheduler has more accurate information of the current status of each wireless terminal, and allocates uplink data slots to wireless terminal of which the residual lifetime is relatively small. As can be seen from Fig. 4, the proposed protocol maintains the cell transfer delay of an rt-VBR connection within the maximum cell transfer delay bound (=20msec), regardless of the number of connections and offered traffic load.

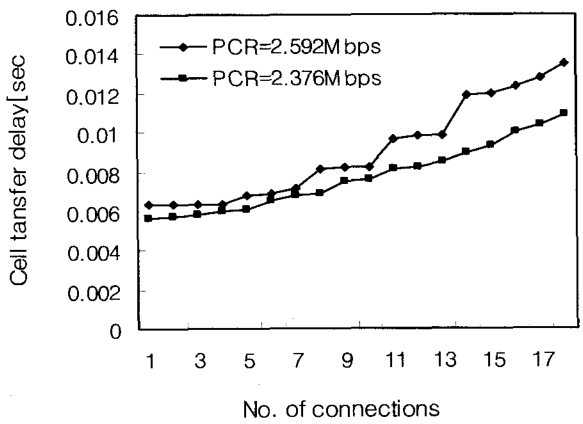


Fig. 4 Cell transfer delay vs. number of connections.

IV. CONCLUSIONS

The design of MAC protocol for radio interface of a wireless ATM network is an important issue, whose performance is crucial for an efficient use of the wireless channel and for the QoS guarantee to the accepted ATM connections. In this paper, we have presented a MAC protocol that efficiently supports rt-VBR traffic class over a wireless ATM link. 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 bandwidth request for rt-VBR traffic. The proposed protocol is characterized by a contention-based mechanism of the reservation request for a data burst, a contention-free polling mechanism for transferring the dynamic parameters during a traffic burst, and a priority scheme of the slot allocation. Based on the received dynamic parameters over an assigned DPS minislot, the scheduler allocates the uplink data slots to the wireless terminal with the most stringent delay requirement. The simulation results show that the proposed protocol can guarantee the delay constraint of rt-VBR services along with its cell loss rate significantly reduced.

REFERENCES

[1] A. Acampora, “Wireless ATM: A Perspective on Issues and Prospects,” *IEEE Personal Commun. Mag.*, vol.3, no.4, pp.8-17, Aug. 1990.

[2] D. Raychaudhuri, and N. D. Wilson, "ATM-based Transport Architecture for Multi- Services Wireless Personal Communication Networks," *IEEE J. Select. Areas Commun.*, vol.12, pp.1401-1414, Oct. 1994.

[3] M. Umeuchi, A.Ohta, and M. Umehira, "Dynamic Time-Slot Assignment Schemes for TDMA-Based Wireless ATM," *IEICE Trans. Commun.*, vol.E80 - B, no.8, pp.1182-1191, Aug. 1997.

[4] T. V. J. Ganesh Babu,. "Performance of a Priority-Based Dynamic Capacity Allocation Scheme Wireless ATM Systems," *IEEE J. Select. Areas Commun.*, vol.19, pp.355-369, Feb. 2001.

[5] J. Sanchez, R. Martinez, and M.W.Marcellin, "A Survey of MAC Protocols Proposed for Wireless ATM," *IEEE Network Mag.*, vol.11, no.6, pp.52-62, Nov./Dec. 1997.

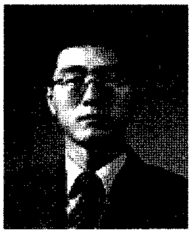
[6] J. Frigon, V. C. M. Leung, and H. C. B. Chan, "Dynamic Reservation TDMA Protocol for Wireless ATM Networks," *IEEE J. Select. Areas Commun.*, vol.19, no.2, pp.370-383, Feb. 2001.

[7] L. Musumeci, P. Giacomazzi, and L. Fratta, "Polling- and Contention-based Schemes for TDMA -TDD Access to Wireless ATM Networks," *IEEE J. Select. Areas Commun.*, vol.18, no.9, pp.1597-1607, Sept. 2000.

[8] S. K. Biswas, D. Reininger, and D. Raychaudhuri, "UPC Based Bandwidth Allocation for VBR Video in Wireless ATM Links," *Proc. ICC'97*, pp.1073-1079, 1997.

[9] R. O. Onvural, *Asynchronous Transfer Mode Networks: Performance Issues*, Artech House Inc., pp. 43-65, 1994.

[10] S. Choi, and Kang G. Shin, "A Unified Architecture of Wireless Networks for Real-Time and Non-Real-Time Communication Services," *IEEE/ ACM Trans. Networking*, vol.8, no.1, pp.44-59, Feb. 2000.



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