A NEW MEDIUM ACCESS CONTROL SCHEME FOR WIRELESS ATM NETWORKS

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Abstract

In this paper, we study medium access control (MAC) requirements for the wireless ATM and propose a new MAC scheme named the dynamic slot allocation multiple access (DSAMA) for wireless ATM networks. For a transparent and seamless transport of ATM traffic, the DSAMA supports a variety of service classes, bit rates, and QoS levels associated with ATM. The DSAMA provides a reliable, predictable aspects of medium access similar to those obtained in time division multiple access (TDMA) but extends for the support of multirate CBR traffic. The DSAMA is a collision-free MAC scheme, and it enables to limit the maximum slot access delay for multirate CBR traffic to the period of the traffic for guaranteed QoS.

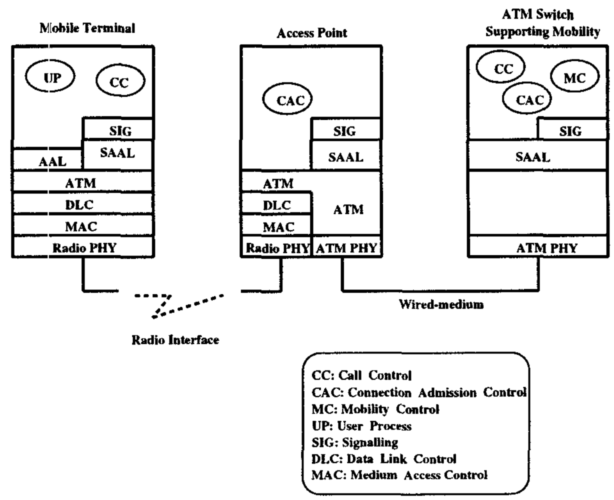

Figure 1: A system configuration and protocol stack for wireless ATM

1 Introduction

As multimedia applications with multirate characteristics migrate to portable devices, wireless extensions to broadband networks will be requested to support user requirements. With the growing acceptance of ATM as the standard for broadband networking, it is appropriate to consider the extention of ATM capabilities for wireless multimedia communications. We call the extended ATM network a wireless ATM network [1].

The wireless ATM is composed of two parts, radio ATM and mobile ATM. The radio ATM extends the ATM virtual connections over the radio interface to mobile terminals, and the mobile ATM provides mobility into ATM networks. A wireless ATM system is shown in Fig. 1. For the radio ATM, a MAC and a data-link layer are required for channel sharing and error control on the radio links. An access point (e.g., a base station in cellular mobile networks) makes it possible to construct the radio ATM subsystem for the creation of cellular coverage in distributed way.

In wireless ATM, an ATM cell serves as the basic unit for protocol processing and switching in both wired and wireless portions of the network. The overall transport architecture is based on the ATM protocol stack, with appropriate extensions to support new mobility functions and wireless channel specific requirements. For a transparent and seamless extension, the wireless ATM network should support a variety of service classes, bit rates, and QoS levels associated with ATM.

When designing a wireless ATM network, the MAC is a key design issue for reliable delivery of user data over a shared wireless channel. The overall MAC design goal is to provide sharing of radio link to multirate real-time traffic

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and best-effort data traffic, while maintaining a reasonable QoS on each service and high link utilization.

In this paper, we propose a new MAC scheme named the dynamic slot allocation multiple access (DSAMA) method for wireless ATM networks. The DSAMA provides a reliable, predictable aspects of medium access similar to those obtained in TDMA but extends for the support of multirate real-time traffic.

The remainder of this paper is as follows. In Section 5.2, we present a system model for a radio ATM subsystem, which has a star topology with an access point. In Section 5.3, we propose a new MAC scheme which is multimedia capable. For the purpose, the connection control procedure and the communication method for slot allocation, and the DSAMA algorithm are presented. In Section 5.4, we show that the delay for slot access for multirate CBR traffic is limited for guaranteed QoS without collisions. In Section 5.5, we conclude with discussions.

2 System Model

There are two general approaches to wireless networking topologies: ad-hoc and access point. In an ad-hoc topology network without a central control, it will be very difficult to give any QoS guarantees to connections because user will interact with one another in an uncontrolled and unpredictable manner [2]. A wireless ATM system with such an ad-hoc topology will necessarily introduce large overhead to support the real-time performance of the network. Designing the system with an access point approach has the advantages of providing a much higher bandwidth utilization, allowing the system to control the QoS of connections.

We are concerned with a radio ATM subsystem with an access point star topology. All terminals use a common channel to transmit packets to the access point. Upstream (terminal-to-access point) traffic generally needs a multiple access control protocol to handle the transmissions from all the active mobile terminals. The downstream (access point-to-terminal) communication is typically achieved by broadcasting.

The terminals under the control of the access point with the DSAMA share the channel in a manner closely resembling the TDMA which is typical to support voice traffic in narrow band cellular mobile radio systems. However, the DSAMA enables terminals with several different rate CBR traffic to share the same wireless access channel by allocating dynamically a larger or smaller number of time slots to individual terminal according to the traffic characteristic and the traffic contract. Also, it allocates fairly the remaining slots to best-effort data traffic terminals considering the status of each terminal.

The upstream channel is slotted in frames with M message slots, N status slots, and L signalling slots per frame, where M, N, and L are system parameters common to all terminals. In each message slot one ATM cell is transmitted. For guaranteed QoS of multirate CBR traffic, the access point controls the use of slots in a centralized manner. It allocates each slot in a frame to a specific terminal slot by slot using the DSAMA. The centralized MAC protocol can be considered as an extention of the statistical multiplexing sequence control scheme from ATM multiplexers to the multiple access situation which is not easy to co-ordinate terminals [3].

When all slots in a frame are allocated to terminals, the access point informs of it to all terminals through a downstream allocation slots before the terminals transmit upstream cells in the corresponding frame. Downstream traffic may be transmitted in a separated channel using a different frequency band or it can time share a single channel with the upstream traffic. In either case, the access point schedules the downstream traffic avoiding all contention. In this Chapter, we concentrate on the problem of dispersed terminals competing for access to the upstream channel.

3 Medium Access Control Scheme

3.1 Connection Control Procedure

When a terminal wants a new connection or a handoff, or receives a paging signal from access point, it requests a connection by using a signalling slot in upstream frame. There exist L signalling slots in an upstream frame for connection control. In order to get a signalling slot, the slotted ALOHA protocol is used [4]. The multiple access delay of a signalling slot will determine the performance of connection processing.

On receipt of a connection request, the access point determines whether it accepts the request or not by using a CAC function. When the access point accepts the connection request, it checks the characteristics of the connection. If the connection is for a CBR traffic, the access point updates status table by adding a new entry for the connection. A status table is maintained in the access point for CBR connections. If the connection is for a best-effort data traffic, it allocates a status slot for the connection. Therefore, for slot allocations for CBR traffic and best-effort data traffic, the status table information and status slot information are used, respectively. When a connection is completed or handoff occurs, the status table is updated by deleting the corresponding entry for CBR connection, and the corresponding status slot is deallocated for data connection.

3.2 Communication for Slot Allocation

In order to inform the access point about the current status, each on-connection mobile terminal for best-effort data service uses a status slot in upstream frame. The number of status slots determines the maximum number of connections for best-effort data service at a time. For CBR connection this status slot is not necessary because CBR connection requires message slots periodically while the CBR virtual channel is connected. The access point automatically allocates slots for a CBR traffic using the status table for CBR connections until the connection becomes disconnected or handoff occurs. The position of status slot for each data terminal is determined by access point in cooperation with the CAC function.

The upstream and downstream frame formats are shown in Fig. 2. A status slot is a semi slot indicating the terminal identifier and the counter value representing the number of message packets to send. If the number of on-connection terminals of best-effort data service is K, where K is not greater than N, the terminal identifier fields for the $N-K$ status slots are filled with null code.

Upon receipt of an upstream frame, the access point determines slot allocations for data terminals to available slots based on the status information. After the determination, the access point informs the slot allocations to all terminals by using allocation control slots in a downlink frame. In a downstream frame, there exist M allocation slots for message slot allocation of the next upstream frame. In a local wireless access system, the roundtrip propagation time between terminals and access point is on the order of a few tens of microseconds outdoors, and less than one microseconds indoors. The short propagation times allow to learn quickly the status and control information by the access point and terminals, respectively.

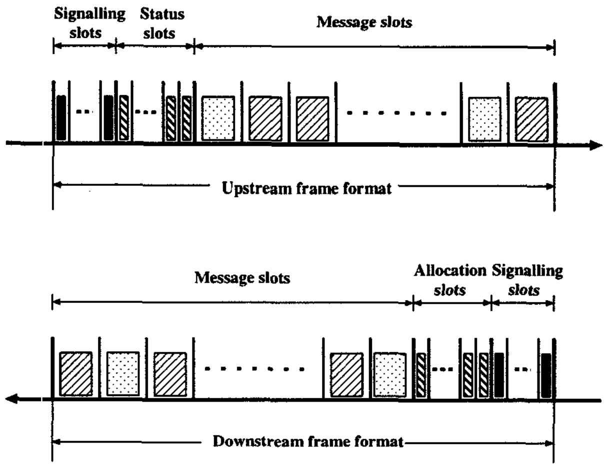

Figure 2: Frame format for upstream and downstream

3.3 Dynamic Slot Allocation Multiple Access

An access point controls the accessibility of physical channel by multiple mobile terminals. The physical channel offers a sequence of time slots. Each slot is for one ATM cell together with the necessary overhead for synchronization, physical layer overhead, and guard time. The allocation of capacity of the physical channel takes place slot by slot. It is controlled by the access point in a centralized manner by using the DSAMA algorithm. The DSAMA allows a combination of quasi-periodic allocation of slots over multiple TDMA frames for multirate CBR traffic, along with dynamic allocation of remaining capacity for best-effort data services such as ABR and/or UBR. For a CBR traffic, slots are allocated according to the PCR. CBR connection has higher priority in slot allocation than any other service classes because it is loss and delay sensitive.

For the determination of slot allocation for the CBR traffic, let C be the total bandwidth for message slots in an upstream radio link. Then the theoretical period of slot allocation for a CBR connection i, TP^i, with PCR value Ω^i should be $TP^i = \frac{C}{\Omega^i} \cdot \Delta$, where Δ is one message slot time and the value of $\frac{C}{\Omega^i}$ is not an integer. By the slotted nature of the radio channel, the practical k-th slot allocation period for connection i is as follows.

$$T_k^i = \begin{cases} ([\frac{C}{\Omega^i}] + 1) \cdot \Delta & \text{if } \frac{1}{k}(\sum_{j=1}^{k-1} T_j^i + [\frac{C}{\Omega^i}]) < TP^i \\ [\frac{C}{\Omega^i}] \cdot \Delta & \text{otherwise,} \end{cases} \quad (1)$$

where [x] represents the maximum integer value not greater than x. As a result, the CBR traffic becomes quasi-periodic, and as time approaches to infinity, the average value of T_k^i converges to TP^i.

In the case of multirate supporting, more than two CBR connections can be selected for a slot allocation. To solve the problem a slot allocation sequence control algorithm is needed. To solve this problem, we can define time-of-expiry (ToE) of a message packet as the time difference between the maximum limitation of service time and the elapse time of the packet. The elapse time of a packet is the time difference between current time and the target slot allocation time of the packet. The target slot allocation time of eack CBR packet is determined as discussed in (1). For the sequence control, we set the limitation of service time of the message packet to the theoretical period of the CBR traffic. The slot allocation sequence for a CBR traffic is determined based on the ToE. The packet with smaller ToE is served first. If more than two packets have the same ToE value, any one can be selected. Unselected packets at current slot time as well as the target allocation packets at the next slot time are the candidates for slot allocation of the next slot. The slot allocation sequence control continues until all slot allocations for CBR traffic are completed. After allocating slots for all CBR traffic, the DSAMA algorithm checks the received status slots for remaining slot allocation for best-effert data traffic. By checking the status slots, DSAMA allocates the slots to terminals with non-zero counter value by round-robin method for fairness.

4 Slot Access Delay of DSAMA

As CBR traffic is loss and delay sensitive, the avoidance of collision in slot allocation is desirable and the limitation of slot access delay is required for CBR connections. By using the DSAMA, the requirement can be satisfied. For the network stability, the following condition should be kept by a CAC function:

$$\sum_{i=1}^{K} \Omega^i \leq C, \quad (2)$$

where C is the total bandwidth for message slots in an upstream radio link and K is the number of CBR connections. Under the condition of (2), all requested slots for CBR traffic can be allocated by using the slot allocation sequence control in DSAMA without collision. When using the DSAMA, the slot access delay for CBR connection i to avoid collision is limited by TP^i for the CBR traffic. The proof of the limitation of slot access delay is as follows.

(Proof of the limitation of slot access delay)

Let C and C_c be the total bandwidth for message slots in an upstream radio link and the sum of bandwidths for total K CBR connections, respectively. And let Ω^i be the PCR for CBR connection i, where $1 \leq i \leq K$. Then, the following relation is satisfied by the CAC for the network stability:

$$\sum_{i=1}^{K} \Omega^i = C_c \leq C. \quad (3)$$

Assume that the connection i has the maximum slot access delay among K CBR connections. By using the DSAMA, the maximum slot access delay occurs at the connection i when a message slot is allocated to all K CBR connections at the same time, and the connection i has the maximum value of ToE. The maximum slot access delay is given by

$$Delay_{max} = [\frac{\Omega^1}{\Omega^i}] + \cdots + [\frac{\Omega^{i-1}}{\Omega^i}] + [\frac{\Omega^{i+1}}{\Omega^i}] + \cdots + [\frac{\Omega^n}{\Omega^i}] \quad (4)$$

where $[x]$ represents the maximum integer value not greater than x.

Therefore, the following relations are satisfied:

$$Delay_{max} \leq \frac{\Omega^1 + \cdots + \Omega^{i-1} + \Omega^{i+1} + \cdots + \Omega^n}{\Omega^i} < \frac{C_c}{\Omega^i} \leq \frac{C}{\Omega^i}. \quad (5)$$

Because the C/Ω^i is the same as TP^i, the maximum slot access delay for a CBR connection is limited by the theoretical period of the traffic.

q.e.d.

5 Conclusion

We have proposed a new MAC scheme named the DSAMA for wireless ATM networks. The DSAMA provides a reliable, predictable aspects of medium access similar to those obtained in TDMA but extends for the support of multirate CBR traffic.

The QoS parameter for multirate CBR traffic is slot access delay without collision, because transmitted message packets with large slot access delay are lost or become useless for the CBR traffic. The DSAMA enables to limit the maximum slot access delay for a multirate CBR traffic to the theoretical period of the traffic.

For best-effort data traffic, the DSAMA ensures no collision in slot access and provides high throughput with the collision-free property. Compared to PRMA techniques which have large over head for requesting and allocating time slots, communicating the amount of time reserved, and communicating the order in which the stations receive the time reservations, the overhead for upstream radio link in the DSAMA method is only due to the status slots in upstream frames. As the number of status slots is determined by the maximum number of on-connection data terminals at a time, the number can be relatively small in local wireless access environment. The throughput of a radio link increases as the ratio of the time portion for status slots to the time portion of messsage slots decreases.

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