Data and Voice Integration in DR-TDMA for Wireless ATM Networks

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ABSTRACT
This paper proposes data and voice scheduling algorithms for the Dynamic Reservation Time Division Multiple Access (DR-TDMA) MAC protocol for wireless ATM networks. Featuring a novel framed pseudo-Bayesian priority Aloha algorithm that provides access priority to voice control packets, DR-TDMA improves the Quality-of-Service offered to voice connections and increases the maximum throughput for integrated voice and data traffic. The DR-TDMA protocol can also be extended to integrate Constant Bit Rate (CBR) and Variable Bit Rate (VBR) traffic in general. Simulation results show that the DR-TDMA protocol can achieve throughput in the range of 96% while maintaining reasonable quality of service for data traffic and a voice loss rate lower than 1%.

1. INTRODUCTION
To meet the anticipated demand for wireless access to the broadband asynchronous transfer mode (ATM) network, the concept of wireless ATM has been proposed in 1994 [1]. For compatibility with the wired ATM network, the wireless ATM (WATM) hop must support the standard ATM service classes: Constant Bit Rate (CBR), Variable Bit Rate (VBR) and Available Bit Rate (ABR) traffic. One of the crucial issues in the design of an efficient wireless ATM system is therefore the selection of a Medium Access Control (MAC) protocol able to satisfactorily handle these different services while efficiently using the wireless channel. In the past couple of years, several projects have developed MAC protocols to implement wireless ATM [2]. In this paper, we introduce the Dynamic Reservation TDM A (DR-TDMA) wireless ATM MAC protocol that can efficiently support CBR, ABR and VBR traffic while maintaining their required Quality-of-Service (QoS). This protocol offers high flexibility and a performance superior to what has previously been reported in the literature. In the near future, voice and data are still expected to be the most common types of traffic. Therefore, in this paper we will describe and evaluate the bandwidth allocation algorithms for voice and data traffic for the DR-TDMA protocol.

Many system have been proposed to integrate voice and data on a single radio channel [3, 4]. Most of these protocols use an Aloha protocol to transmit control packets. However, this protocol is known to be unstable and it will introduce a performance degradation in high speed channels. To solve this problem, a long fixed control period must be used [5], which reduces the maximum throughput. Furthermore, no efficient mechanism is provided to reduce the contention delay of time sensitive voice control packets which is the most determinant factor for the QoS of voice connections.

In the DR-TDMA wireless ATM MAC protocol, we propose to use the novel framed pseudo-Bayesian priority (FPBP) Aloha algorithm [6] to manage the control mini-slots access such that contention can be minimized and priority service is provided to voice request packets in order to reduce their access delay. Moreover, the FPBP protocol is used to dynamically adjust the number of uplink control slots as a function of the traffic load to optimize the channel utilization. Voice connections are served using a Time-to-Expiry approach while data connections scheduling is done with a fair bandwidth allocation algorithm. The DR-TDMA protocol improves the QoS offered to voice connections, and therefore, the maximum sustainable throughput with DR-TDMA for integrated voice and data traffic is higher than that of previously reported MAC protocols.

In the next section, we describe the DR-TDMA MAC protocol. In Section 3, the voice and data source models are presented. The scheduling algorithms are described in Section 4. Finally, simulation results are presented in Section 5.

2. DYNAMIC RESERVATION TDMA PROTOCOL
A dynamic reservation TDM A/TDD MAC protocol approach is adopted to multiplex multimedia connections into a single radio channel. A complete description of the DR-TDMA MAC protocol can be found in [7]. In this paper we just give a brief overview of the protocol. Fig. 1 illustrates the frame structure of the DR-TDMA MAC protocol for supporting ATM multiservice traffic. The fixed length DR-TDMA MAC frame is time-duplexed into an uplink and downlink channel and the boundary between these two parts is dynamically adjusted as a function of the traffic load. Downlink and uplink channels
A voice source generates a signal that follows a pattern of talkspurt and silent gaps. A speech activity detector can be used to detect this pattern. Data are thus transmitted only during periods of activity to reduce the traffic and increase the statistical multiplexing. Therefore, a voice source can be described by an ON/OFF model: the source alternates between the ON state where the source generates packets at rate \( R_v \) and the OFF state where no packets are generated. ON and OFF state durations are modeled by exponential distribution with mean \( t_b \) and \( t_i \), respectively. This model is similar to the “slow” speech activity detector model described in [9] and we have therefore selected the same parameters value for \( t_b \) and \( t_i \).

A voice source is also characterized by the encoder bit rate \( R_e \) and the packetization delay to assemble a packet payload \( T_v \). In our case the payload is 48 bytes; therefore \( T_v = 384/R_e \). If a voice packet is not delivered to its destination within its Maximum Transfer Delay (MTD), it would be dropped. In our voice source model, the MTD is set equal to the packetization delay \( T_v \) (i.e., one voice packet is buffered). Finally, voice control packets are assigned a high priority for the FPBP protocol. The values of the voice source parameters are: \( t_b = 1.00 \) seconds, \( t_i = 1.35 \) seconds, and \( T_v = 16 \) msec.

Data sources are represented by a model in which groups of packets arrive in the buffer at a certain rate. This model is in accordance with the AAL5 layer that will be used for data (ABR and UBR) traffic in ATM. When AAL5 receives a packet from an upper layer, it segments the packet into ATM cells of 48 bytes. It is reasonable to assume that these cells arrive in the data buffer at approximately the same time.

The interarrival time between groups of packets is exponentially distributed with mean \( t_d \). The number of packets in a batch arrival is given by \( n = \lceil x \rceil \), where \( x \) is gamma distributed with parameter \( \beta \) and \( \theta \). Using a random number generator, we find that \( n \) has a mean \( \mu_b \) approximately given by \( 1/\theta + 0.5 \) and a mode value of \( \lceil 1/\beta \rceil + 0.5 \). We have selected this model instead of the usual geometric model because the latter one has a mode value of one which is not realistic for ATM data traffic. In this paper, we used the following data parameter values: \( t_d = 0.1 \) seconds, \( \beta = 3 \) and \( \mu_b = 5 \) packets.

Even if data are non-real time traffic, we also assigned a maximum transfer delay of 60 seconds to the data packets. When the load is heavy, old packets are discarded which is similar to having a finite buffer length. Finally, data control packets are assigned a low priority for the FPBP protocol.

### 4. Allocation Algorithm

The main objective of a wireless ATM bandwidth allocation algorithm is to efficiently exploit statistical multiplexing while maintaining the negotiated quality of service of each admitted connection in the network. In this work, we only considered the allocation for uplink connections since downlink allocation can be done like in a usual wired ATM switch which is not the case for uplink scheduling [7]. For our DR-TDMA MAC protocol architecture, the scheduler decides, based on its current knowledge of the network state and connection traffic parameters, how to assign slots to each connection and for control traffic. In the following subsections we describe the uplink allocation algorithms for voice, data and control traffic. Then the integration of these algorithms is described.

#### 4.1. Allocation for Voice Traffic

The slot allocation algorithm for voice traffic uses a Time-To-Expire (TTE) approach in which the connection for which the voice packet will be discarded first receive the next slot allocation. When a new voice call is established, the mobile sends a high priority request packet in the contention period using the FPBP protocol until success. This control packet contains the voice connection encoder bit rate from which the cell interarrival time can be computed in the base station. At the beginning

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### TABLE 1: DR-TDMA MAC FRAME PARAMETERS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel bit rate</td>
<td>8.528 Mbps</td>
</tr>
<tr>
<td>Frame duration</td>
<td>2 ms</td>
</tr>
<tr>
<td>Uplink data slot size</td>
<td>60 bytes</td>
</tr>
<tr>
<td>Uplink control slot size</td>
<td>20 bytes</td>
</tr>
<tr>
<td>Preamble size</td>
<td>16 bytes</td>
</tr>
<tr>
<td>Frame header</td>
<td>16 bytes</td>
</tr>
<tr>
<td>Number of slots per frame</td>
<td>35</td>
</tr>
<tr>
<td>Number of control mini-slots per slot</td>
<td>3</td>
</tr>
</tbody>
</table>
of a new talkspurt, the mobile also sends a high priority control packet until success or the talkspurt ends. The control packet contains the time of arrival of the last voice packet. A connection is considered as active when the base station receives the control packet indicating the beginning of the talkspurt.

For each active voice connection, the base station records the time of the last packet arrival if it has not yet been sent or, the time of the next packet arrival otherwise. The scheduler is thus able to find the waiting time experienced by a packet and when it will be lost. It can also predict the arrival time of the next voice packet. When the voice activity detector detects the end of a talkspurt it will set a bit in the last voice packet to indicate to the scheduler the beginning of a silent gap. The scheduler then removes the connection from the active set after receiving the last voice packet of the talkspurt.

Active voice connections are sorted in increasing order of TTE where TTE = MTD − (Time − Arrival Time). The scheduler allocates the S available slots to the voice connections that have waiting packets in order of increasing TTE [7].

4.2. ALLOCATION FOR DATA TRAFFIC

For the data traffic slot allocation algorithm, the base station keeps the buffer length status of each active connection (defined as a connection with a non-zero buffer occupancy) and allocates slots to the connections using a fair bandwidth allocation algorithm. When a batch of packets arrive at a mobile during frame t, the mobile sends a piggybacked request or a control packet depending on the mobile’s queue state at the beginning of frame t + 1. If the queue is empty, the mobile sends a low priority control request packet in the following contention periods using the FPBP protocol until success. Otherwise, the request will be piggybacked to the next information packet transmitted to the base station. The request contains the number of packets in the new batch arrival. This allows the base station to keep track of the exact buffer length of each active connection.

Based on the current buffer length status of all active connections, the base station scheduler allocates the S available slots to the connections according to the fair bandwidth allocation algorithm [7]. When a mobile receives its slots allocation, it transmits packets that are queued in its buffer using a FIFO strategy. Finally, at the beginning of each frame, the base station scheduler updates the buffer length and the status of each connection for which it has received a request in the last frame.

4.3. ALGORITHM FOR CONTENTION TRAFFIC

The uplink control mini-slots access as well as the number of uplink control slots is controlled by the FPBP protocol introduced in [6] that implements a random access protocol with mixed priorities. We will now briefly describe the FPBP algorithm in the context of the DR-TDMA WATM MAC protocol.

Suppose that K′ control mini-slots are available in frame t and there are p different priority classes with arrival processes of intensities λ1, . . . , λp. λi is the average number of control packet arrivals of class i per frame in all mobiles and is computed using a moving time-average of the number of successful uplink control packet transmissions from class i per frame (for our simulations, we have used a window length of 100 frames to compute the moving time-average). A lower index corresponds to a higher priority packet class. Let γi be the priority parameter of each traffic class i. In order to maintain the priority order we must have γ1 ≥ γ2 ≥ · · · ≥ γp−1 ≥ γp and the parameters satisfy the relation ∑p i=1 γi = 1.

The algorithm operates by maintaining for each priority class i an estimate ˆni of the total number of backlogged control packets at the beginning of each frame t and an effective priority parameter ˆγi. A control packet arriving during frame t is immediately regarded as backlogged and the mobile attempts transmission in each subsequent frame after its arrival until success.

At the beginning of frame t, for each priority class i, ˆni is updated from ˆni−1, ˆγi−1, K−1 and the feedback for frame t − 1 (let n NC be the number of idle or success slots and nC the number of collision slots in frame t − 1) according to the rule [6]:

\[
\hat{n}_i = \lambda_i + n_{NC} \max \left(0, \frac{\hat{n}_i^{t-1} - \hat{\gamma}_i^{t-1}}{K^{t-1}} \right) + n_c \left(\frac{\hat{n}_i^{t-1} - \hat{\gamma}_i^{t-1}}{K^{t-1} + \frac{1}{e-2}}\right) \tag{1}
\]

After having computed ˆni, a certain number of slots are requested for uplink control purpose during frame t. Let CR be the number of control mini-slots per slot and CMAX the maximum number of slots that can be requested for control purpose. Then, the number of requested uplink control slots is determined as follows:

\[
\text{Total} = \sum_{i=1}^{p} \hat{n}_i \\
\text{if} \quad \text{(Total} \geq 1) \\
\text{Request} = \min \left(\frac{\text{Total}}{CR}, \text{CMax} \right) \\
\text{else} \quad \text{Request} = 0
\]

This ensures that when the algorithm estimates that there is at least one control packet waiting for transmission, uplink control slots will be assigned in the following frame. Furthermore, before allocating slots for best-effort traffic, if the time since the last allocated control slot exceeds a parameter Tmx, then a slot is allocated for the next contention period. This process ensures that a contention period will be regularly available to allow potentially time sensitive control packets to be transmitted. The parameter Tmx is therefore set such that delayed control packets do not result in losses of time sensitive packets. In our case, Tmx is set to a value smaller than the MTD of voice packets. After slot allocations for voice and data have been done, all unused slots are allocated to the contention period.

When the values of ˆni and K′ are known, the effective priority parameter of each class are computed using the following algorithm [6]:
different priorities and QoS of each ATM service. The current NAS is the number of available slots $S$ used at the beginning of the Time-to-Expiry and fair bandwidth allocation algorithms. When the integration algorithm is finished, the slot allocation is announced in downlink control slots. Contention parameters (number of control mini-slots and transmission probabilities) are also transmitted.

5. RESULTS

A C++ simulator has been written to evaluate the performance of the proposed wireless ATM DR-TDMA MAC protocol for voice and data traffic. Because we strictly focus on the MAC and the resource allocation algorithm performance, we have assumed a perfect radio channel without errors and fading. The simulations have been run for a minimum time of 5000 seconds in order to assure accurate results. For comparison purposes, we have simulated the “Non-Priority” system where voice and data control packets are assigned the same contention priority and the “Priority” system where voice and data control packets respectively have a high and low contention priority. Therefore, we can evaluate the impact of the proposed FPBP protocol on the DR-TDMA WATM MAC protocol. For the contention allocation algorithm, CSmax is set to 2, Tmax to 12 msec, $\gamma_1 = 1$ and $\gamma_2 = 0$. We have assumed an infinite buffer model where cell losses are only due to exceeding their MTD.

We have only evaluated the efficiency of the protocol for uplink transmissions; therefore we have assumed that downlink control slots take no transmission bandwidth. The throughput is defined as the ratio of the average number of slots used for data packet transmissions per frame to the total number of slots available per frame (i.e., 35 slots). The offered load thus includes cell headers but does not include control packets. Therefore, control traffic is considered as a bandwidth loss in the throughput calculation.

The presented cell loss results (Fig. 3) show that whereas in the non-parity case the cell loss rate would become high enough to degrade the voice performance as data load increases, the FPBP protocol keeps it to an acceptable level where the cell loss rate is not a limiting factor of the DR-TDMA MAC protocol. Therefore, if the number of voice con-
In our results, we have considered that downlink control slots take no transmission bandwidth, but, if we allocate 8% of the bandwidth to downlink control slots (the achievable throughput is therefore limited to 92%), the DR-TDMA throughput is reduced from 96.5% to 88.8%. On the other hand, for the NEC protocol, the achievable throughput is 75%. While the performance of the allocation algorithms for voice and data traffic are similar (i.e. achievable throughput versus maximum throughput), the dynamic nature of the DR-TDMA uplink control period as well as the FPBP algorithm allows the DR-TDMA protocol to require less uplink control slots and achieve a much higher throughput than the NEC protocol.

6. CONCLUSION

In this paper, we have presented a scheme to efficiently integrate voice and data traffic in the DR-TDMA wireless ATM MAC protocol. Simulation results show that the FPBP protocol can maintain the voice cell loss rate under 1% for data traffic loads where the voice loss rate would become unacceptable without the priority contention scheme. Furthermore, results show that DR-TDMA offers a maximum throughput in the range of 96% while maintaining a data waiting time of less than 250 ms. The utilization of the FPBP protocol to reduce the voice control packet access delay and to dynamically adjust the number of uplink control slots allows the DR-TDMA protocol to improve the voice QoS and increase the maximum throughput compared to previously reported MAC protocols. Finally, the proposed scheduling algorithms in this paper can be integrated with CBR and VBR allocation algorithms to give an efficient DR-TDMA wireless ATM MAC protocol.

REFERENCES