A Distributed Media Access Control (DMAC) for Wireless ATM Networks

Ralf Holtkamp, Jean-Pierre Ebert, Adam Wolisz*, Louis Ramel#

Technical University Berlin
Telecommunication Network Group
{holtkamp, ebert, wolisz}@ee.tu-berlin.de

*also with GMD Fokus

# Thomson-CSF
Communication, Navigation, Identification Division
louis.ramel@cni.thomson.fr

Abstract
This article presents Wireless ATM MACs (WATM MAC) with an emphasis on DMAC, a new MAC protocol to be used in future W-ATM networks. DMAC is intended to serve as media access control protocol (MAC) for the ETSI radio network HIPERLAN/2/3 and 4. In contrast to most recent MAC protocols for wireless ATM systems DMAC works with a distributed control mechanism. The features of DMAC are discussed with respect to recently proposed WATM MACs.

I. Introduction
The ultimate vision of Personal Communication System steps closer and closer to the reality: small, inexpensive and persevering communicators with global access to voice, video and data. The current tendency of multimedia networking requires new wireless networks and protocols to satisfy the challenge of variable bandwidth, low latency and low jitter of multimedia networking. There are several proposals for wireless multimedia networks around which claim to offer the necessary features. Most of them rely on the paradigm of ATM, since ATM networks appears to be the future technology of wired multimedia networking. One important aspect of the wireless multimedia network protocol stack is the used MAC protocol. Therefore, the following outlines focus on how wireless ATM MAC protocols fit the requirements of multimedia communication. We overview the recent WATM MAC proposal (Section II) and introduce a new MAC protocol with a yet unique feature for WATM MACs - Distributed Access Control (DAC) (Section III). DAC allows a very flexible and spontaneous network configuration as it is required for ad hoc events like conferences or meetings. A DAC eliminates the need of any costly infrastructure like base station. In section IV we compare DMAC features with the reviewed WATM MAC protocols.

II. Overview on WATM MACs
The relevant recent literature offers several proposals of medium access control for wireless ATM systems. To give an overview on the work done in this field and for the sake of comparison to the later proposed DMAC, only the basic functionality of some of them is considered.

A. RATM’s MAC [Port94]²
Olivetti Research Limited proposed in 1994 an ATM-based protocol stack for a wireless LAN system. For that system they use a Slotted Aloha MAC mechanism with Binary Exponential Backoff (BEB) in a TDD/TDMA manner. Two physical separated channels for uplink (mobiles to base station) and downlink (base station to mobiles) communication are assumed. A base station (BS) is the central point of communication. By having a BS, synchronization of mobiles is simple. Each mobile resynchronizes with every reception of a downlink packet. The MAC layer packets consists according to ATM cells of an ATM payload of 48 Bytes, ATM control data, which is adapted to the radio system requirements, and additional control data needed for e.g. processing of immediate acknowledgments. The motivation for this approach is stated as follows:
- Slotted Aloha has a good delay performance at low utilization than fixed allocation schemes.
- It fits well with statistical multiplexing of ATM.
- Handover processing is possible without reconfiguration of resources on MAC level.
- Contention is receiver instead of transmitter based which can result in a higher utilization.

The RATM MAC doesn’t provide any means as reservation or priorities to guaranty the QoS. This is left open to higher protocol layers. Furthermore it can not ensure fairness between mobiles due to the capture effect.

1. We neither claim to be complete nor to give a detailed explanation of the presented MACs. For more details the reader is referred to the given articles (section VI).
2. There is already a more sophisticated MAC version for RATM [Port96]. However, the former MAC version is taken to illustrate the idea of simple MACs for application in WATM networks.
B. WATMnet’s MAC [RAYC95]

WATMnet was proposed by NEC Research Laboratories in Princeton. It is a wireless prototype system for Multimedia Personal Communication. The wireless part of the system consists of a BS and mobiles. The BS is the central point of communication and provides the synchronization information. The channel access is performed by a TDD/TDMA mechanism. The frame format for up- and downlink differs. The downlink frame consists of frame header, control and data. The uplink is built up on a contention access control subframe followed by allocated ABR, VBR and CBR data slots. Every frame has a fixed size but the boundaries between control, ABR, VBR and CBR and even uplink/downlink slots can vary.

Two wireless cell formats are defined: wireless link cells and control cells. The wireless link cell corresponds in general to an ATM cell and consists of 56 bytes. The control cells can be differentiated in meta signaling and acknowledgment cells each containing 8 bytes.

The MAC is split into two functional parts: the Core MAC (C-MAC), running in each mobile and the BS, and the Supervisory MAC (S-MAC), which is different for mobiles and BS. The C-MAC multiplexes/demultiplexes transmission and reception for corresponding VC’s based on the schedule table supplied by the S-MAC. The S-MAC contains the schedule table whereby each entry contains service and message types, duration of service etc. The BS S-MAC schedules data, for both uplink and downlink, based on requests received via control meta-signaling and required services. The scheduling policy for ABR services follows the burst-by-burst approach. Alternatively, a round robin policy may be used to prevent long burst. A consecutive allocation of ABR slots is used in order to reduce overhead caused by the burst preamble. CBR traffic is assigned to fixed periodic slots according to the required bit rate. VBR traffic is handled as a combination of static and dynamic assignment controlled by a statistical multiplexing method (e.g. usage parameter control-like). The mobiles S-MAC builds a scheduling table according to the received information from the BS. There is no error control mechanism provided but an specialized acknowledgment control packet. Error control is assumed to be performed by the data link control (DLC).

The WATMnet MAC protocol performs an approach that provides a sufficient degree of transparency for many ATM applications by integrating QoS handling into the MAC protocol. One main advantages of this approach is the limitation of contention only to control data, which only takes a small portion of bandwidth. Furthermore there is a flexible frame structure allowing a dynamic usage of available bandwidth to respective uplink/downlink and ABR/CBR/VBR service requirements.

C. DQRUMA [KARO95]

DQRUMA was developed by Bell Labs, Lucent Technologies to accommodate efficiently an integrated mix of multimedia traffic. It assumes a slotted uplink and a slotted downlink channel (TDMA). The downlink channel is a broadcast channel. The uplink channel is a multiple access channel with a limited contention phase. The system can be physically implemented as a TDD, FDD (with two or more frequency bands) or MC-CDMA system. Uplink and downlink channel are slotted. The time slot structure is shown in Figure 2. It is assumed that the payload phase is constituted by an ATM cell.

Associated with each mobile is a buffer. When a packet (ATM cell) arrives to mobile with an empty buffer, the mobile sends a Request Access via the Request Access Channel to the base station. There may be contention with other mobiles according to the used access protocol. DQRUMA proposes Slotted Aloha or Binary Stack Algorithm to access the Request Access channel. When the BS successfully receives the Request Access, it sets a corresponding entry in the Request Table. The BS also acknowledge the request via an Ack Request Access. Once a mobile receives an acknowledgment, it listen to the downlink for a Packet Transmit Permission, which is generated by the BS according to a specified scheduling algorithm. DQRUMA was evaluated with a weighted Round-robin (for the FDD version) and with a Bandwidth-on-Demand Fair-sharing Round-robin packet transmission policy (for the MC-CDMA version). After the reception of Packet Transmit Permission from the BS the mobile is allowed to transmit a packet during the next time slot. In case mobiles buffer contains already additional packets a Piggybacking Request is associated with the packet transmission. Note, the Piggybacking Request is contention free. The advantages of DQRUMA mainly constitutes from:

- Contention is limited to the Request Access transmission not to data
- Subsequent requests can be piggybacked, that means piggybacked request are contention free, so the bursty nature of ATM traffic is accommodated.
The slot by slot announcement (packet transmission permits) allow the base station to implement the “optimal” scheduling of packet transmission for mixes of traffic with multiple priority levels and service classes.

(Idle) data slots can be converted to multiple RA Channels to reduce contention probability in the RA channel, since many mobiles can be in the request phase.

At light traffic load DQRUMA behaves as Slotted Aloha resulting in excellent delay performance. At heavy traffic loads it behaves as weighted round robin ensuring each mobile to transmit according to its traffic load and service requirements. Thereby, an efficient channel utilization is maintained.

D. DSA++ [PETR95]
The DSA++ protocol was designed within the Mobile Broadband System (MBS) project. DSA++ extend the functionality of a statistical ATM multiplexer to the wireless environment, which is often difficult due to multiple access. DSA++ assumes a base station, buffered mobiles and two physical separated channels for uplink and downlink transmission. Uplink and Downlink channels are slotted (see Figure 3). Each slot contains either data consisting of about an ATM cell plus some signaling burst for downlink and request slots (RACH) for the uplink respectively. Signaling bursts contain Feedbacks, which are basically acknowledgments for request, covered in request slots, reservations (permissions) for uplink transmission of data and announcements for scheduled downlink transmission. The motivation for the latter fact is power saving. In case a mobile is not supposed to receive data, it can sleep until the next signaling burst, which is cyclically generated.

The base station schedules data transmission from mobiles according to QoS requirements of each mobile by sending requests (permissions). QoS requirements are expressed on a per packet base by residual life times of a certain number of critical ATM cells in buffer or number of ATM cells in buffer at mobiles. A mobile, that receives a permission, accesses the dictated slot. By doing so, it is able to send an ATM cell and requests with parameters mentioned above for further transmissions. Because this scheme may be too static with respect to the dynamic of applications running on mobiles, request access slots are introduced. These slots are dynamically scheduled by the BS and randomly accessed by mobiles. Request access slots are subdivided for the sake of collision reduction. Since plain random access protocols features instability, a splitting Priority Scheduling Algorithm is used for fast collision resolution.

DSA++ also provides a direct support of DLC. For every data slot transmission on uplink there is also a positive or negative feedback included in the signaling burst. For downlink data transmission feedback subslots are included on the uplink channel. These feedbacks can be directly used by the DLC to schedule retransmissions.

III. DMAC
The idea of the Distributed Multiple Access Control protocol is derived from RNET (Radio Network) as it has been proposed in [RAME95] to the HIPERLAN /2 standardization group (ETSI RES 10) by Thomson. As outlined in the following section the channel access contains elements of Frequency and Time Division Multiple Access (F/TDMA).
A. Channel structure

As shown in Figure 4 we consider a micro-cell with a certain number of independent buffered mobiles. The communication channel is subdivided into three subchannels which consume a certain amount of bandwidth. We assume, that the channels are physically separated (e.g. different frequency channels). Two subchannels, the Header and the Feedback Channel are designated for signaling purposes. Both are slotted (TDMA aspect). A slot consists of about an ATM cell and contains sender and receiver address, priority and other control information. There is no fixed format yet. The third, the Payload Channel, is used for data transmission. The payload channel is accessed by several ascending ramps. That is, packets are transmitted on a time ascending frequency ramp. The number of possible ramps at certain point in time is determined by the payload channel bandwidth, the ramp bandwidth and the ascend. It is assumed, that the payload channel bandwidth is relatively larger than the signaling together.

Framing

A frame is defined as a group of consecutive of header slots, feedback slots and payload ramps. The length of a frame is determined by the spanning width of a ramp. If a ramp spans over x (e.g. 3) slots then a frame consists of x+1 (e.g. 4) slots (see Figure 5). An header slot at time x, a feedback slot at time x+1 and a ramp, starting immediately after the header slot, are associated with each other and form a transmission block. There are guard times between the slots to encompass signal delays and clock variances.

Frame synchronization

A synchronization of all mobiles with respect to frame start and frame end is not required. This feature fits the paradigm of distributed control and simplifies the protocol (e.g. registration procedures). Rather than having a superframe to which all mobiles are synchronized, framing is locally. Every mobile maintains it’s own frame. Therefore there may be offsets between the start point of frames. A local frame starts as soon as a mobile is switched on and another mobile transmits in the header or feedback slots. Because of the spanning width of a frame every mobile can compute the frame length.

Time synchronization

Since DMAC use a TDMA a basic working condition is the time synchronization of all mobiles. There is no explicit synchronization signal defined. For synchronization purposes header and/or feedback signals are taken into account. Local timer are adjusted with every header or feedback transmission. To encompass signal trip times and variances of clocks an appropriate intergap time between two consecutive slots must be found. There are well known problems in distributed timing control related with time shift and erroneous timing of mobiles. Even the hidden terminal scenario’s may have influences on timing control. For some of these problems there are several distributed time control solutions proposed in the literature [e.g. Arvi94, Chua94]. A further evaluation of that topic is neccesary.

B. Access control

As mentioned before the MAC is based on a fully distributed mechanism. The DMAC consists of a access control mechanism and an associated buffer.
1. Generals
A mobile which wants to transmit a packet must have sensed the header and feedback channel for at least one frame duration. By doing this a mobile obtains information about the receive state of other mobiles and the availability of header slots in a frame. Sender and receiver of header and feedback slots are not ready to receive other data since they are either not able to receive while sending or they can not synchronize to a second ramp (see Figure 6).

Figure 6 - Single receiver station - the receiver can only synchronize to one ramp at a certain point in time

A header slot can be accessed if this slot was not used (reserved) in the last frame. The criteria of reservation can be determined only on header slot usage in the last frame, only on feedback information (remember that a feedback in time slot x is associated with a header in time slot x-1) or on both. This differentiation affects the channel efficiency in hidden terminal scenarios. After the transmission of the header the mobile starts the transmission of the ramp with the payload immediately.

If a station receives a header with its own address, it will respond with a feedback in the next slot. The feedback is not an acknowledgment for the correct transmission of the payload. It serves as a cut-off criteria for the sender if there is no feedback. If there is no feedback at the sender data transmission is stopped immediately.

2. Header channel access
Free (non-reserved) header slots are accessed in a Slotted Aloha principle. The success of transmission is determined by the feedback reception. The mobile will choose the first non-reserved header slot for access.

3. Temporal channel concept
After a successful header transmission determined by the reception of the feedback a mobile has reserved automatically this slot in the next frame. This extends the header channel access to an Reservation Aloha based scheme. Since a ramp starts immediately after the header transmission, a mobile is able to transmit constantly at certain data rate (see Figure 4). In other words, if a mobile has gained access for one slot, it has contention free access to the same slot in all consecutive frames as long as there is data to transmit. This reservation is lost if the mobile has nothing to send and the header slot remains empty.

As an design option, an extended reservation scheme is possible. For instance, only in every second (third ...) frame the same slot is reserved. This would fit very well for low bit rate CBR traffic.

The concept of temporal channels can provide a very good bandwidth utilization in high load cases. However, an increasing load per mobiles can result in a very unfair bandwidth sharing!

4. Channel Holding Time (CHT)
Since the temporal channel concept causes unfairness under high system load conditions, a Channel Holding Time is introduced. The Channel Holding Time defines the number of packets, which may be consecutively sent by a mobile. With respect to the header channel access, the CHT defines the maximum number of header slot reservations without disruption.

As an design option the channel holding time could be determined in a distributed dynamic fashion by every station. For instance CHT could be set with respect to QoS requirements of certain applications or due to the evaluation of network load condition. The latter could be done on the feedback channel information.

5. STOP Bit
A header slot plus the ramp in a frame can be used if no reservation exists. That is, the header slot has to be free (not used) at least in the last frame. This leads to waste of bandwidth. To eliminate this bandwidth waste, a stop or a follow bit in the header can be used to declare the next header as non-reserved. The stop/follow bit has to be switched on/off if the temporal channel holding time is over.

Simulation results on DMAC have shown the capability to work in an wireless ATM environment. For performance results, the reader is referred to [EBERT97]. Figure 7 summarizes the MAC mechanism.
In this section we are providing a high level comparison of DMAC with RATM MAC, WATMnet’s MAC, DQRUMA and DSA++ to illustrate some of the fundamentals differences. The comparison is by means not exhaustive.

A. Location of access control intelligence
For DMAC and RATM MAC the access control intelligence is equally distributed in all mobiles. All other MAC mechanism uses a centralized control, where the BS controls access of all mobiles to the communication channel. That is, the BS holds a great share of intelligence whereby the mobiles MAC is very simple. That has three implications. First, because mobiles MAC intelligence is very restricted, the mobiles need less powerful processors. That can lead to large power saving gains at mobiles. With DMAC, all mobiles have to hold all access control functions, that burdens the mobiles some more work load resulting in higher power consumption. Second, centralized control makes it easier to implement QoS control. With DMAC, QoS control is more complex, since it has to be performed in a distributed manner. However, with a proper design of QoS control the burden to the MAC functionality can be reduced. Third, because of centralized control, there has always to be a BS, which makes the introduced MAC protocols impractical for spontaneous applications like group meetings and conferences. In contrast, DMAC doesn’t need a BS. Therefore it allows working scenarios without the need of pre-installed (costly) infrastructure.

B. Communication paradigm
Besides location of access control intelligence, we can distinct between communication relations between the mobiles. Mobiles can communicate with each other directly or via a BS. The latter reduce the bandwidth efficiency by the factor two, since data from one to another mobile has to be transmitted to the BS and from the BS back. This principle is used in all presented MACs. However, DMAC employs a Point-to-Point communication, which leads to the most efficient use of available frequency spectrum. Further, DMAC can be employed in hidden terminal scenarios, where despite of contention at transmitting mobiles reception of data at hidden terminals is possible. As a result, frequency spectrum efficiency is improved.

C. Packet sizes / packet format
For transparency reasons a packet (frame) size, which can contain an ATM cell is desirable. This eliminates extra costs for splitting/reassembling or blocking/deblocking and some additional QoS mechanisms for these functions. All presented MACs, including DMAC, transmit ATM cell payloads without any conversion into smaller or larger entities. However, WATMnet’s MAC include the possibility to concatenate slots for ABR bursts, each containing an ATM cell. This minimizes burst preamble overheads for synchronization purposes. With DMAC, according to parameters chosen to constitute the ramp length, parts of an ATM cell, one or more ATM cells can be transmitted in one ramp. At least a ramp size of one ATM cell is preferable to avoid costly splitting/reassembling of ATM cells.

D. ATM QoS enforcement
ATM transparency is measured in terms of QoS support by MAC QoS support (CBR, VBR, UBR or ABR services). The RATM MAC doesn’t provide any means for QoS enforcement. This is left open to higher layers and can only be based on the statistical behavior of Slotted Aloha. With DSA++, ATM QoS parameters have to be translated in terms residual lifetimes of packets, which are put in the transmit
queues of mobiles. This could be a very complex and difficult work to do, since this can only be done for every mobile separately by considering its own queue and the statistical behavior of BS scheduling. Reservation is not enforced so QoS guarantees are statistical. WATMnet’s MAC as well as DQRUMA enforces call admission control (CAC) at the BS. The BS may schedule mobiles according to its QoS needs. Furthermore, WATMnet’s MAC uses usage parameter control (UPC) based statistical multiplexing algorithm for VBR traffic. DMAC also provides mechanism for QoS enforcement. First, reservation can be controlled by an dynamically adjustable channel holding time (CHT). Second, reservation can be made not only on a slot by slot base but by a certain rate, which result in usage of the same slot in every second, fourth etc. frame according to the required transmission rate.

E. Overall bandwidth usage
With overall bandwidth usage we refer to the maximum user data rate, which may be acquired by one or more mobiles\(^1\). For all presented MACs, except of RATM MAC, a nearly 100% usage of bandwidth is possible. With Slotted Aloha, as it is used in RATM MAC only about 36% (analytical limit) overal throughput is possible. DQRUMA as well DSA++ allow additional dynamic conversion of data slots to Request Access Slots for submissions of Request Access. By doing so, contention for Request Access can be reduced. That allows a very fast response to QoS requirement update requests.

F. Error Control support
Error control forms due to the error prone wireless link an important point in wireless communication. Considering ATM error control, time is critical for CBR and VBR schemes. Therefore a support on MAC level is desirable. Except of DQRUMA all presented MAC networks feature error control support. RATM MAC uses Slotted Aloha, where immediate acknowledgments are an implicit feature of the protocol. The acknowledgment may be used for MAC retransmission or by the data link control (DLC). WATMnet’s MAC provides acknowledgment control packets to be used by the DLC. Acknowledgment control packets are transmitted in the control subframes. Therefore these packets may be subject of collision and delays. DSA++ provides feedback for every data slot transmission. So the DLC is immediately informed of erroneous data reception. However, DSA++ provides no error handling (e.g. retransmission) on MAC level. DMAC features error handling on MAC level. We assume, that a feedback reception implies also a correct reception of data. This is based on the assumption, that the channel quality doesn’t change significantly in a sufficient short time gap (e.g. frame duration). In case feedback reception fails, data is subject for retransmission.

The following table summarizes the protocol features of all presented MACs.

<table>
<thead>
<tr>
<th>Access control</th>
<th>DMAC</th>
<th>RATM MAC</th>
<th>WATMnet ‘s MAC</th>
<th>DQRUMA</th>
<th>DSA++</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication Paradigm</td>
<td>distributed</td>
<td>distributed</td>
<td>centralized</td>
<td>centralized</td>
<td>centralized</td>
</tr>
<tr>
<td>Data Packet Size</td>
<td>Point-to-Point via BS</td>
<td>via BS</td>
<td>via BS</td>
<td>via BS</td>
<td></td>
</tr>
<tr>
<td>QoS guarantees</td>
<td>ATM cell or multiple</td>
<td>yes (CHT, reservation)</td>
<td>no</td>
<td>yes (use of CAC and UPC)</td>
<td>yes (use of CAC)</td>
</tr>
<tr>
<td>Bandwidth efficiency</td>
<td>high</td>
<td>low</td>
<td>high</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Error Control support</td>
<td>on MAC level</td>
<td>on MAC level</td>
<td>dedicated packets for DLC</td>
<td>no</td>
<td>feedbacks used by DLC</td>
</tr>
<tr>
<td>Implementation cost tendency</td>
<td>medium - high</td>
<td>low</td>
<td>low for mobile; high for BS</td>
<td>low for mobile; high for BS</td>
<td>low for mobile; high for BS</td>
</tr>
</tbody>
</table>

Table 1: MAC comparison

The comparison shown above doesn’t make any justification about the application capability in real world environments. For that purpose further criterias for comparison (e.g. access/queuing delays, protocol overheads, implementation costs ...) should be applied.

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\(^1\) Protocol overheads are not taken into account, which has to be weighted by the overall bandwidth.
V. Summary
We presented a new MAC protocol, that features in contrast to the known WATM MAC protocols a distributed access control. We have shown the potential of this MAC to work in wireless ATM environments. There is an flexibility-power save/cost trade-off between centralized and distributed control. Centralized control facilitate low complexity mobile resulting in low power and cost wireless transceiver. In contrast to that, decentralized control facilitate communication without any infrastructure. That results in a broader range of application scenarios. As the research in the battery field and electronically elements advance, the power supply/cost problem will be reduced. Furthermore, due to an intelligent design and implementation, the cost of decentralized access control may be substantially reduced. DMAC is compared to recently developed WATM MAC protocols by showing the capabilities.

VI. References


