MEDIUM ACCESS CONTROL PROTOCOLS FOR WIRELESS ATM

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Abstract

The most crucial issues in the conception of an efficient wireless ATM network are the design of the physical layer, data link layer, Medium Access Control (MAC) protocol and mobility management functions. In this article we focus on MAC protocols, namely on requirements for MAC protocols and on basic concepts of TDMA and CDMA based one. For illustration we consider with Time Division Duplex (TDD) as well as Frequency Division Duplex (FDD).

Keywords

Wireless ATM, Medium Access Control (MAC), TDMA, CDMA.

1. Introduction

Asynchronous Transfer Mode (ATM) is the transfer protocol for B-ISDN (Broadband Integrated Services Digital Network), standardised by ITU-T. ATM is a cell switching connection-oriented technique, designed to support all service types. Typical services carried by ATM include telecommunication services such as telephony and video conferencing, and bearer services for local, metropolitan and wide area networks. The initial development of ATM assumed that fixed (optical) networks with high bandwidth and low error rates would be used. The promising performance characteristics, as well as the tremendous popularity of ATM, have encouraged investigations of possible wireless implementations. Initially it is not expected that it is technically possible to combine the full-featured mobility found in GSM (Global System for Mobile communications) with the very high bandwidth requirements (several Mbit/s) for broadband services. Still, with isolated access islands (e.g. airports, hotels) it will be possible to achieve speeds in excess of tens of Mbit/s per cell and radio channel. Consequently, there is a need for new standards for radio access in ATM that can play the same role in broadband wireless environments as DECT (Digital Enhanced Cordless Telecommunications) does in narrowband wireless environments, as well as standards that can handle mobility management within ATM. Even so, the first versions of the technology should allow a seamless evolution to a full-featured mobile broadband network.

2. Wireless ATM Architecture

The overall architecture consists of a fixed ATM network part and a access radio ports called Base Station (BS). In the fixed ATM network, the switches, which communicate directly with radio ports are mobility enhanced ATM switches, and switches which provides interconnection this switches are mobility enhanced too. The mobility supported part of ATM network to be able provide access non wireless users is interconnected via NNI to standard ATM network without mobility support. The switches and fixed terminals are interconnected via wireline links. The radio ports provides connectivity to mobile terminals via shared radio link, as shown in Fig. 1.

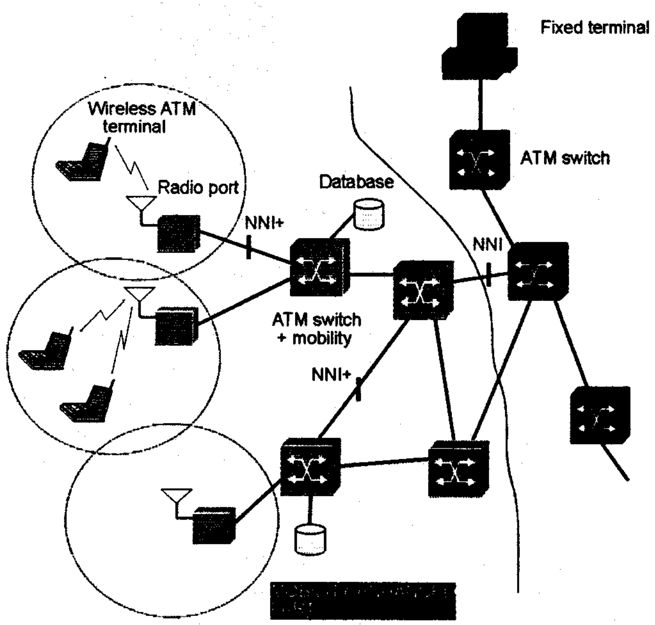

Fig. 1: Wireless ATM Architecture

Architecture is referred as "wireless ATM architecture" [1]. The radio ports are responsible for maintaining physical connectivity to the wireless users, transmitting information from the wireline ATM network to the wireless users and in reverse direction. To avoid channel interference, each radio port operates at a different radio frequency in relation to neighbouring radio ports. Each radio port provides a cell switching function between one or more of its wireless and wired interface and offers UNI+ (User Network Interface with mobility support) to wireless terminals and NNI+ (Network Node Interface with mobility support) to the other switches. The architecture is assumed to consists of enhanced ATM switches, that include mobility specific functions to support terminal mobility in the system. The enhanced ATM switches are responsible for performing routing of user connections between the radio ports and fixed ATM network, controling the radio ports, provisioning of signaling between the wireless users and the fixed ATM network, rerouting the existing users connections to the new radio port during handoff event. The support of mobility in the wireless ATM (WATM) network will be detaily discussed latter.

3. Wireless ATM Protocol Stack

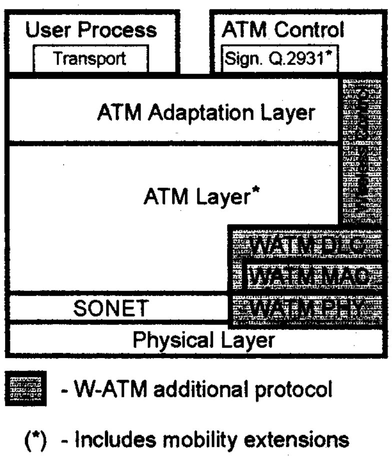

Fig. 2: Wireless ATM Protocol Stack

The unreliable behavior of the radio link as well as the access to the shared radio resources lead to requirements of new additional functions at the ATM wireless interface which have to cope with the unreliability and accessibility of the radio channel. The functions are executed by the extended ATM protocol stack, referred as "Wireless ATM Protocol Stack", which is shown in Fig. 2.

It contains a wireless physical sublayer (WATM PHY) to ensure transmission of a sequence of bits at a high bit-rate on the radio link, a medium access control sublayer (MAC) to establish how every contending mobile user can transmit data to the radio port, a data link control sublayer (DLC) to ensure the reliability of the radio link and a wireless control.

4. Medium Access Control Sublayer

The demands for transparent transmission of ATM cells over the air interface between several mobile terminals and radio port leads to a MAC scheme which is characterized by the competition of mobile terminals. MAC sublayer has to provide support for standard ATM services, including ABR (Available Bit Rate), VBR (Variable Bit Rate), CBR (Constant Bit Rate) and UBR (Unspecified Bite Rate) classes with associated QoS (Quality of Services). Several proposals for MAC protocol can be found in the literature [1], [2], [3]. It can be seen that most of these protocols are using the same concepts and are only varying in small details. The medium access protocol needs to make maximum use of shared radio resource and needs to achieve full utilization of the radio frequencies in a variety of environments.

4.1 Proposed Requirements

The IEEE study group 802.11 was formed to find and recommend a standard for wireless LANs. They formulated 20 requirements [9] on a general wireless MAC layer. The list of requirements is presented next, in a rough priority order, with the most important requirements listed first.

1. Throughput
2. Delay
3. Ability to serve data, voice and video
4. Preservation of packet order
5. Ability to support handoff/roaming between service areas
6. Robustness in collocated networks
7. Establish peer-to-peer connectivity without a priori knowledge
8. Support priority traffic
9. Ability to support non-reciprocal traffic
10. Ability to work in a wide range of systems
11. Battery power consumption
12. Fairness of access
13. Maximum number of nodes
14. Transparent to different physical layers
15. Unauthorized network access impact on throughput
16. Ability to support broadcast (multicast)
17. Critical delays limit large area coverage
18. Insensitivity to capture effects
19. Limit the complexity of the physical layer
20. Ability to market and complexity

4.2 Basic Concepts of Wireless Network Access Techniques

According to the way bandwidth is allocated, MAC protocols can generally be grouped into the following categories [10]:

- fixed assignment techniques (TDMA[1], FDMA[2], CDMA[3]);
- random access (ALOHA[4], CSMA[5] or variations of the same);
- demand assignment, which can be:
    - centrally controlled;
    - distributed control.

Fixed assignment techniques reserve a constant-capacity subchannel for the duration of each connection. They operate very well with CBR connections, in terms of both QoS and channel efficiency. However, their performance drops drastically when they have to support several users using the channel with infrequent VBR connections.

Random access, protocols work better in such cases. They make the whole capacity of the channel available to the user and allow him to transmit when he needs to. The drawback being that in the event of collision the messages involved have to be re-transmitted. However, although these protocols are simple to implement, they require minimal scheduling and are highly suitable for the statistical multiplexing philosophy of ATM networks, it is a well-known fact that their performance is only good when there is not much traffic, i.e. when delays are short and throughput high because the number of collisions is limited. If, on the other hand, there is a large amount of traffic or different services have to be supported guaranteeing the QoS, their performance is inadequate. They therefore use collision-solving algorithms to increase the channel utilisation factor (throughput) and keep the system stable [4].

Demand assignment protocols reserve a portion of bandwidth for each connection that can be modified if necessary. Unlike random access techniques, they have two phases: reservation and transmission. In the first phase the user, in contention with others, reserves a portion of bandwidth for his transmissions and, if the reservation is successful, he transmits in the second phase with no risk of collision. Demand assignment protocols are generally complex but they work well in a vast range of conditions, although the reservation phase wastes time and bandwidth. On the other hand, they are stable in the event of traffic variations, they provide a high throughput level and, importantly for WATM networks, they guarantee a predictable QoS. Control of the reservation and transmission phases can be **centralised** or **distributed**: in the former the BS is responsible, in the latter the MTs themselves decide to transmit on the basis of broadcast information.

As the first two methods are only suitable for one type of traffic, and as the task of WATM networks is to support multimedia traffic, demand assignment is the most suitable technique.

The protocols for radio interface in WATM networks belong to the three families mentioned above, i.e. TDMA, FDMA, CDMA. The limited number of frequencies available for radio communications and dynamic bandwidth allocation requests make use of the FDMA technique inefficient. The CDMA technique limits the peak bit rate of a connection to relatively low values, which is a problem in broadband applications (i.e. with a bit rate over 2 Mbit/s). Many protocols therefore use an adaptive TDMA scheme due to its capacity to meet the various bit-rate requirements by assigning a varying number of slots according to the traffic conditions.

Although the FDMA technique seems to have been completely abandoned, virtually all TDMA and CDMA schemes have a frequency division component, even though it is not explicitly mentioned. This component is introduced because complete occupation of the whole range of frequencies the system is allocated (usually a few tens of MHz) would require broadband components that are not easy to implement in the presence of user mobility.

An important concept, which differs according to the technique used, is that of re-use, in which the frequency, or time slot, or CDMA code a user in a certain cell is assigned is also assigned to users located in other cells, according to a certain re-use pattern. This gives rise to co-channel interference, both intracell and intercell. The problem of intracell interference is implicitly eliminated in FDMA and TDMA techniques, but not in CDMA.

In this article our attention focuses mainly on TDMA protocols, which we consider to be the most suitable for the requirements of multimedia networks like WATM. It is, however, useful to give a brief outline of the two techniques (TDMA, CDMA) so as to justify better our choices. The FDMA technique was excluded a priori for the reasons mentioned above.

4.3 General Remarks on the TDMA and CDMA Protocols

TDMA protocols. MAC protocols based on an adaptive TDMA scheme differ in the way in which adaptation is achieved. There are three main techniques used, alone or in combination:

- contention;
- reservation;
- polling.

The first two offer the advantages and disadvantages discussed in the previous section, especially in terms of QoS. Those based on adaptive polling assign each connection a time slot, periodically and without the need for a previous request, on the basis of the expected traffic conditions. They are simpler than reservation-based protocols as they eliminate the reservation phase, but their performance is greatly affected by the algorithm which establishes the polling period for each connection. If it is

[1] TDMA - Time Division Multiple Access
[2] FDMA - Frequency Division Multiple Access
[3] CDMA - Code Division Multiple Access
[4] ALOHA - random access protocol
[5] CSMA - Carier Sense Multiple Access

shorter than necessary, channel utilisation may be poor, as many slots will remain empty; if it is too long, there is a risk of increasing delay and the QoS will be poor. Establishing the optimal polling period is a difficult problem to solve in the presence of bursty variable bit-rate connections [4].

All in all, there is no scheme that outperforms the others in all conditions. A good solution may be to try to create a protocol based on reservation which grants high-priority traffic random access, trying not to make it excessively complex, in order to reduce the costs for remote terminals and increase the life of their batteries.

According to the number of carrier senses used for communications between BSs and mobile terminals, TDMA protocols can be divided into **FDD** (Frequency Division Duplex) and **TDD** (Time Division Duplex). Those using the FDD technique have two separate channels, a UL (Uplink, from MT to BS) one and a DL (from BS to MT) one, whereas those based on the TDD technique have a single channel which they switch according to whether the communication is UL or DL [5].

CDMA protocols. In direct competition with access techniques belonging to the TDMA family we have CDMA techniques. The original numerical signal is distributed over a much wider range of frequencies than that strictly necessary for it to be transmitted, as it is multiplied by a sequence of pseudo-noise, i.e. a code. Various codes are used, but the most common one comprises functions that mathematically form an orthogonal set; so, as only the scalar product between a function and itself is other than zero, two transmitters using different functions should not cause reciprocal interference in the demodulation phase.

In the protocols used for transmission based on the CDMA technique, all the information is usually transmitted in packets of a fixed length. Access to the channel is completely free, so MTs and BSs usually work in a completely asynchronous fashion. An exception is a number of cases involving mobility management.

For VBR services, after a code negotiation phase, the user starts to transmit when he considers it to be appropriate and he can then resume transmission when he needs to. Each packet sent is associated with receipt of an ACK, and if a packet is not delivered the transmission has to be repeated. In CBR services, on the other hand, the flow of traffic is sent as a sequence of packets which follow each other at regular intervals with a duty cycle chosen on the basis of the source's time constraints. For this kind of service the re-transmission of incorrect packets is not allowed.

TDMA or CDMA? This question has already been answered, as we believe that the performance of TDMA protocols is on the whole better and more suitable for a W-ATM network.

CDMA is certainly more robust than its competitor TDM, as it tolerates a large number of interfering signals. This makes it possible to simplify channel assignment, to limit interference between adjacent cells and to avoid filtering operations, which TDMA requires. However, CDMA involves certain technical problems. A crucial point is power control. Users close to the BS, in fact, may cause considerable interference for those further away. To avoid this, control algorithms have to be implemented so that all users can transmit at a power level low enough not to cause interference but high enough to keep the signal quality acceptable. In addition, in a CDMA system the amount of interference increases as the number of users simultaneously trying to transmit grows. CDMA does not allow for dynamic bandwidth allocation either. Each user has the entire bandwidth at his disposal when he wants to transmit, but this does not mean, as is erroneously believed, that channel access is immediate: users have to contend for the code words needed to transmit. An example of this can be found in [6], where the Spread-Slotted Random-Access (SSRA) protocol is described. Another problem caused by the CDMA technique is the considerable delay during transmission at high bit rates. This is due to the fact that the packet to be transmitted has been multiplied by a codeword whose length is proportional to the number of users being allowed to transmit in the same cell. So, bearing in mind that the transmission delay for a packet L bits in lengths is L/C when the channel capacity is C, it follows that if L increases the time required to transmit the packet also increases. CDMA is therefore only advantageous for short messages (~1 Kbit) and not for longer ones (~8 Kbit) typical of certain multimedia applications.

	CDMA	TDMA
Frequency Re-Use Coefficient	Not definable	1 / number of channels
Power Control	Necessary	Not necessary
Level of interference	Depends on the number of users trying to transmit	Depends on geometry, the number of users, etc....
Statistical Multiplexing	No	Yes
Channel Access Delay	Non-null	Non-null
Robustness	Yes	No
Limited Transmission Speed	Yes	No

Table 1: CDMA vs TDMA

Another important concept to bear in mind when comparing the two access techniques is frequency re-use: whereas in TDMA systems the re-use coefficient is 1/N, if N is the number of channels, in CDMA it cannot be defined a priori as it depends on various parameters such as the propagation loss constant or the modulation techniques [7]. Additionally, CDMA techniques do not ensure that delay jitter requirements are met for all classes of traffic [8].

4.4 Demand assignment protocols for TDMA and CDMA

TDMA/TDD.

In the demand assignment protocols the channel bandwidth is time-slotted and represented as a single or several frames, which is depended on the channel rate, type and rate of applications. Each frame is divided into UL and DL periods, as shown in Fig. 3.

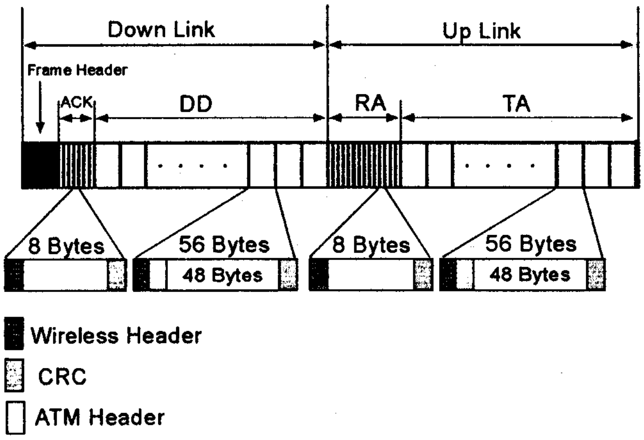

Fig. 3: MAC TDMA/TDD Frame Structure

The periods (channels) are further divided into two subperiods. For transmitting of the downlink traffic can be used different frequency band or the channel can be time-shared by using TDD. The approach using the time sharing of a single frame between downlink and uplink provides better flexibility in controlling the available bandwidth by dynamically allocating the length of each period. The uplink period is subdivided into request access (RA) and data transmission access (TA) subperiods. The users transmit their RA packets in which requires bandwidth to radio port in the RA subperiod. After that, the radio port will identify the successful users and assign them required bandwidth in the TA subperiod. It is expected in case that radio port have resources for allocation. The downlink period is subdivided into acknowledgment (ACK) and data downstream (DD) subperiods. In the acknowledgment subperiod the radio port notifies the RA terminals about their request status. Finally, in the DD subperiod, the radio port transmits downstream data to the destined terminals. The length of each subperiod can be dynamic or fixed. Downlink transmissions are controled by the radio port and supported by a contention-free-time-division multi-plexing (TDM) broadcast mode. It is expected that not all the terminals under radio port coverage are active simultaneously, therefore the MAC scheme used in the RA subperiod is random such as ALOHA.

CDMA/FDD.

In the MC-CDMA (Multi-Code CDMA) system, data are transmitted over the radio channel only at the basic rate R_b. When a mobile needs to transmit at rate m times the basic rate, it converts its serial data into m parallel basic-rate data streams. Each one is then spread with a different code and they are superposed for radio transmission. The parallel spreading codes used by mobile are generated by a sub-concatenation scheme that avoids self-interference. Thus, higher transmission rate sources will experience less interference than low-rate users. The transmitted power from high rate mobiles can therefore be lowered in order to increase the channel capacity.

Figure 4 shows the structure of a MC-CDMA time slot for multi-rate packet transmission protocol. For illustration the UL and DL channels are assumed to be on different frequencies. In the DL frame, the Request-Access Acknowledgment mini slot acknowledges UL request-access that occurred in the same time slot while packet transmit permissions are for the next time slot. There is a time shift between the UL and DL frame due to transmission and processing delay.

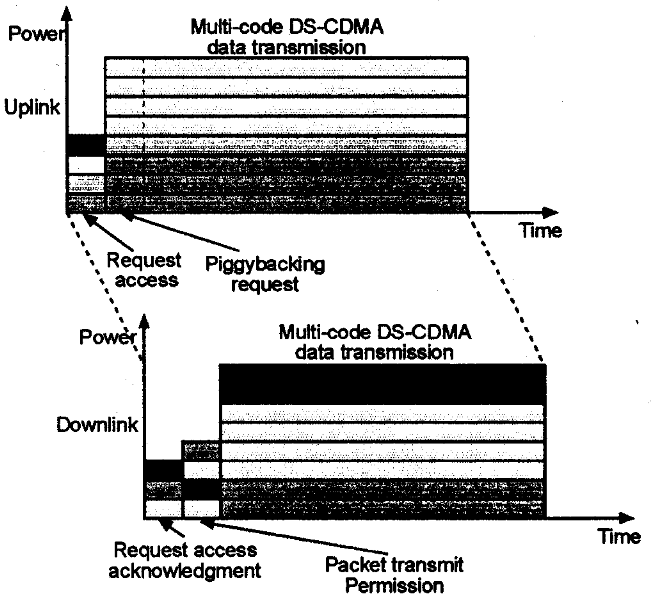

Fig.4: MC-CDMA with DQRUMA[6] for multi-rate packet transmission protocol

When packets arrive to a mobile with empty buffer, the mobil sends a Request Access packet in the UL Request Access mini slot. The packet includes the mobile Access ID (assigned by the base station at the admission of the mobile in the system) and the number of packets for witch the mobile is requesting to transmit. To transmit a Request Access packet, a mobile randomly chooses one of the dedicated control PN codes. The number of dedicated PN codes can be chosen smaller than the number of mobiles admitted in the system which implies a form of random access in the Request Access mini slot.

When the base station successfully receives a Request Access packet from a mobile, it sets the corresponding entry in the request table to indicate that the mobile has packets to transmit and acknowledges the reception on the DL Request Access Acknowledgment mini slot using the mobile's spreading code. Once a mobile receives a positive acknowledgment that its Request Access was received by

[6] DQRUMA – Distributed Queuing Request Update Multiple Access

the base station, it will listen with its despreading code at the DL Packet Transmit Permission mini slots. A Transmit Permission directed to a mobile includes a field indicating the number of codes with which the mobile is given permission to transmit, a field assigning the primary PN code for the mobile's packet transmission in the next time slot and a field allocating the mobile's power level (for channel efficiency). Becouse the Transmit Permission are annonced on slot-by-slot basis, primary codes can be assigned on a slot-by-slot basis to those mobiles given the Transmit Permission. Transmit Permission are allocated according to the desired packet transmission policy.

When a mobile receives a Transmission Permission in a time slot, it configures its MC-CDMA transmitter according to the received parameters in the Transmit Permission packet. In the next UL time slot, the mobile transmits packets to the base station with the new transmitter configuration. The mobile can also send a contention-free Request Access to the base station via the Piggybacking Request field in the data transmission packet.

5. Conclusion

In general TDMA, FDMA, CDMA or a hybrid combination of these approach seems to be possible. Because of the statistical multiplexing (similarity with time division multiple access) in ATM network, and because of the high bandwidth required on the physical channel, a TDMA with TDD (Time Division Duplex) or FDD (Frequency Division Duplex) duplexing schemes seems to be the candidate for a wireless ATM systems. The dominant services in the broadband environment are VBR services, therefore MAC protocol must be based on the demand assignment to fulfil requirements of a wireless network.

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