Contention-free MAC protocol for Wireless ATM LAN

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Abstract: *This paper describes a contention-free reservation-based medium access control protocol for a wireless ATM local area network. The protocol is based on a sequence of control-data frames which can, in some ways, guarantee the quality-of-service in terms of allocated bandwidth by first reserving and then scheduling the required resources via a control channel. Preliminary simulations showed that the proposed protocol is a good candidate for wireless ATM networks.*

1. Introduction

With ATM being a key technology for supporting broadband multimedia services over wide area and local area networks, there is a high desire of it to go for "wireless" as seen from the recent wireless ATM activities in both industry and academy [1]. Several working groups on wireless ATM have been established including those in the ATM Forum in the U.S., the BRAN project of ETSI [5], and several ACTS projects in Europe (MagicWAND [4], MEDIAN [3], etc.). So far, many discussions have been devoted towards the definition of wireless ATM system requirements and among them, the medium access control (MAC) protocol is one of the most important issues.

Essentially, the MAC protocol specifies the method of access to the wireless channel among multiple users while satisfying the basic requirements of ATM. In order to fully utilise the bandwidth, a contention-free multiple-access method is desired. In this paper, we propose a contention-free reservation-based MAC protocol where a time-slot-based control-data frame (CDF) is defined which consists of a control phase and a data phase. During the control phase, various functions can be performed, including connection set-up, slot access, slot confirmation, and connection release.

When setting up a new connection, a nominal number of slots is reserved in every CDF so that the quality-of-service is guaranteed. However, owing to the traffic variation, there are chances where not all slots will be used, or more slots than nominal are requested in a given CDF. To be more efficient, a slot-access function is added in every CDF for non-CBR services. Essentially, each wireless terminal (WT) sends its slot request to the scheduler at the base station (or the central controller in the case of ad-hoc networks) for transmitting its data packets to other WTs in the next CDF. The scheduler in the base station then gathers the slot requests from all WTs and allocates the available slots according to a slot allocation policy based on a priority mechanism. After that, the base station broadcasts the allocation results to all WTs. We call it slot-confirmation. At this stage, each WT knows which slots in the next frame it can use to transmit and which slots in the next frame it need to receive its data packets. By reserving a nominal number of packets during connection set-up and assigning slots dynamically in each CDF, the wireless bandwidth can be fully utilised and the quality-of-service can be guaranteed.

The paper is organised as follows. Section 2 describes the basic concept of the protocol which includes the CDF structure and the functions associated with the control phase. Section 3 discusses the details of the contention-free multiple access scheme such as the MAC frame structure and a brief discussion of the slot allocation policy. Section 4 describes the simulation and its results by comparing the performance of the protocol with TDMA. Finally, Section 5 concludes our work.

2. Basic Concept

The basic idea behind the reservation-based MAC protocol is a sequence of control-data frames; each of which consists of a control phase followed by a data phase as shown in Figure 1. During the control phase, multiple wireless terminals specify a number of ATM slots required for their use. Once this request is successful, a certain number of ATM slots will be reserved for a particular wireless terminal and the wireless terminal can then transmit its designated packets in a specified sequence during the data phase.

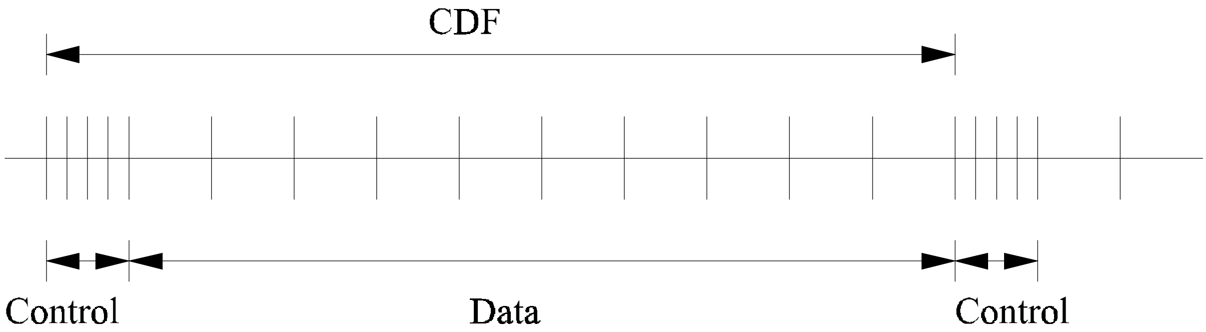

Figure 1: Control-Data Frame (CDF)

We allow the number of data slots in a CDF to be variable up to a maximum number. Similarly, the number of control slots are also variable up to a maximum number.

For operation in an ATM network, it is necessary to first set-up a connection by reserving a certain amount of bandwidth and then provide the reserved bandwidth over multiple CDFs. To accomplish this task, the control phase must provide the following four basic functions: connection set-up, slot access, slot confirmation, and connection release, as illustrated in Figure 2.

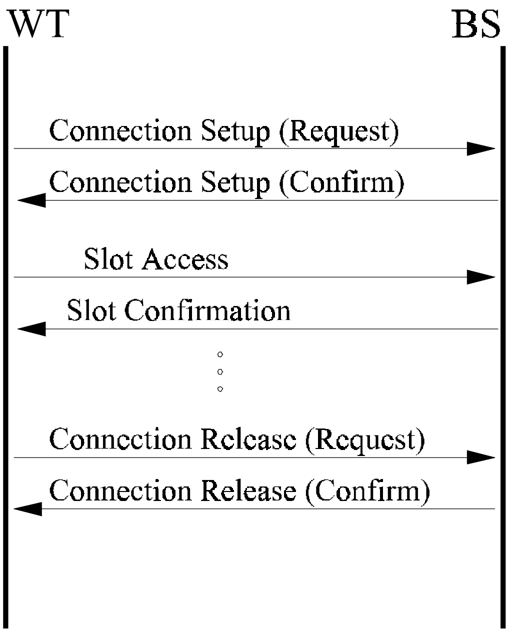

Figure 2: Basic control functions required throughout a connection

Before discussing these functions, we first define different modes of operation for a WT in a WATM network. It is assumed that network services will not be provided, unless a WT actually registers into the network. This is necessary to be able to provide security and authentication services to a WT. A wireless terminal that has registered into a network is termed a "Registered Wireless Terminal (RWT)", otherwise it is called "Non-registered Wireless Terminal (NRWT)". RWTs can be further classified into four categories as follows:

1. Non-networked Wireless Terminals (NNWT): RWTs who have registered into a network but have not had any service yet.
2. Networked Wireless Terminals (NWT): RWTs who have been allocated bandwidth for at least one service.
3. Active Networked Wireless Terminals (ANWT): NWTs who have been allocated bandwidth in the current CDF.
4. Inactive Networked Wireless Terminals (INWT): NWTs who have not been allocated any bandwidth in the current CDF.

Figure 3 shows the relationship among different modes of operation for WTs.

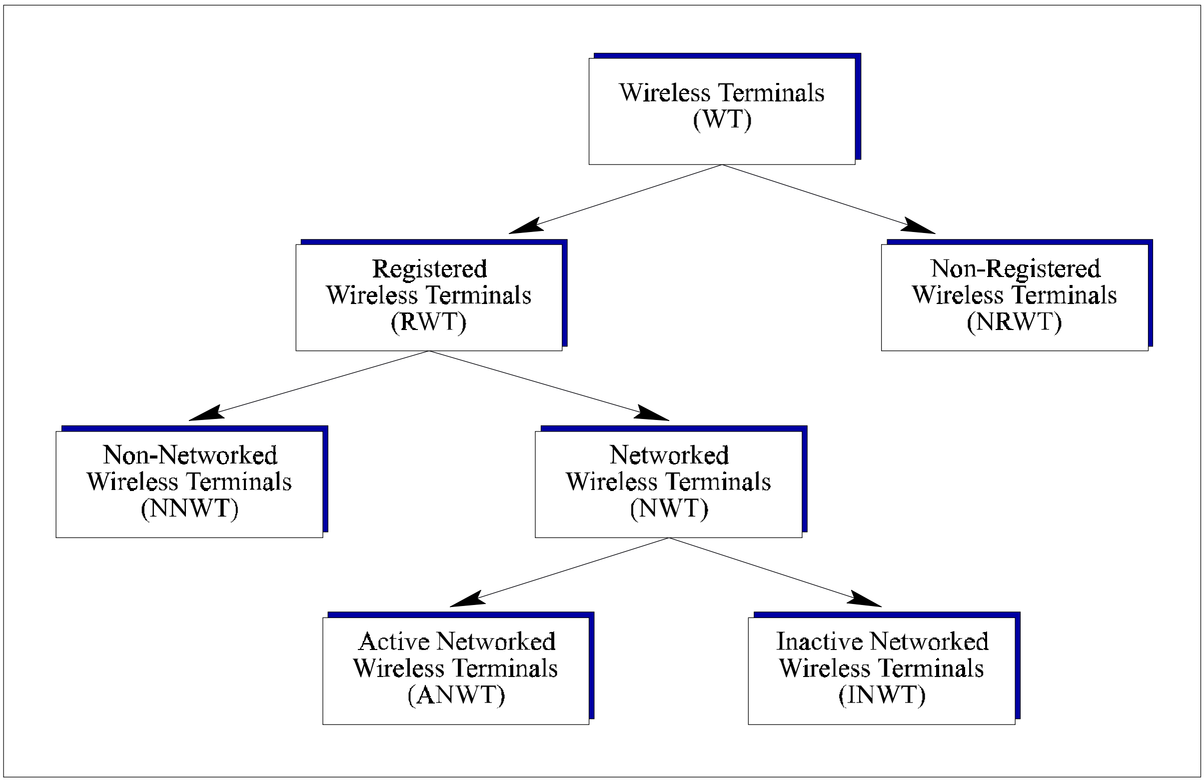

Figure 3: Modes of operations for WTs

Connection Functions:

The connection set-up function enables a wireless terminal to request a connection with a certain nominal number of ATM slots. Once the requested connection is granted, a nominal number of slots is then allocated to that wireless terminal. For CBR services these nominal slots can be kept unchanged for the whole connection lifetime. To ensure that a wireless terminal does not take over the entire bandwidth, an upper limit is specified on the total number of nominal slots that a wireless terminal can reserve. This upper limit should be less than the maximum number of data slots allowable in a CDF.

Clearly, even though a nominal number of slots are reserved for every NWT in a CDF, there is a high probability in ATM networks, especially with variable-rate sources, that not all slots in a given CDF will be used, or more slots than nominal are requested. Hence, after the connection set-up stage, all NWTs go into a slot access stage. Here, a deterministic method is used to poll each NWT for the total number of packets that it desires in the coming CDF. There is no necessity to use multiple-access techniques for the implementation of the slot access function.

In a slot access stage, there is a possibility that more resources may be requested than the maximum possible number of ATM slots in a CDF. Hence, there is a need to arbitrate between the actual allocated slots for the NWTs so that a consistent assignment can be maintained. This is provided by the slot confirmation function. When the service does not need the nominal slots, a connection release function is used to free the reserved bandwidth.

3. Proposed Contention-Free Multiple-Access Scheme

A primary principle used in the design of the MAC layer lies in the consideration of a contention-free multiple-access method. Multiple-access methods are used only during the control phase with no contention over the data slots. To ensure that a contention-free multiple-access method is also used in the control phase, it is assumed that all wireless terminals in the system must first register within the MAC layer before being allowed access to the MAC layer. In the following, a contention-free multiple-access method is described which includes *the superslot signalling scheme* for ANWT and the *E-burst signalling scheme* (both defined below) for INWT and NNWT.

To implement the control channel for ANWT, the piggybacking concept is used, i.e., signalling messages are sent along with the ATM packets. Two types of slots are used, namely, superslots and normal ATM slots. A superslot is composed of signalling messages attached to a normal ATM slot. Each ANWT at the start of its transmission during the data phase uses this superslot to transmit signalling information and an ATM cell. The succeeding slots for the same WT are normal ATM slots. Using the piggybacking concept, all wireless terminals which were allocated space in the previous CDF send signalling information within their allocated set of slots. This control information provides input to the slot-allocation policy of the base-station (BS) regarding static and dynamic parameters related to the ATM packets queued at the MAC layer of every WT.

To implement the control channel for INWT and NNWT, a polling strategy is used to determine the control information of the particular WT. For INWT and NNWT, a contention-free short energy burst, called E-burst, is used by a WT to announce that it has new data to send and is going to regain an up-link signalling channel. Then the BS uses a load-based estimation method to determine the number of slots to be assigned to the polled WTs, whose energy burst has been received by the BS. In the simplest case, the load-based estimation strategy may assign just one superslot for the WT, which is then used by the WT to communicate further information about its required number of data slots.

The above describes all up-link signalling information from the WT to the BS. To ensure that all WTs have a common understanding of the current allocated reservation, the BS must send some down-link signalling information. The content of this signalling information includes at least the following:

- Specification of the usage of slots in both down-link/up-link
- Specification of the polling of INWTs and NNWTs during the E_burst phase
- Operations and Maintenance messages

3.1 MAC Frame Structure

The above considerations lead to the following CDF structure.

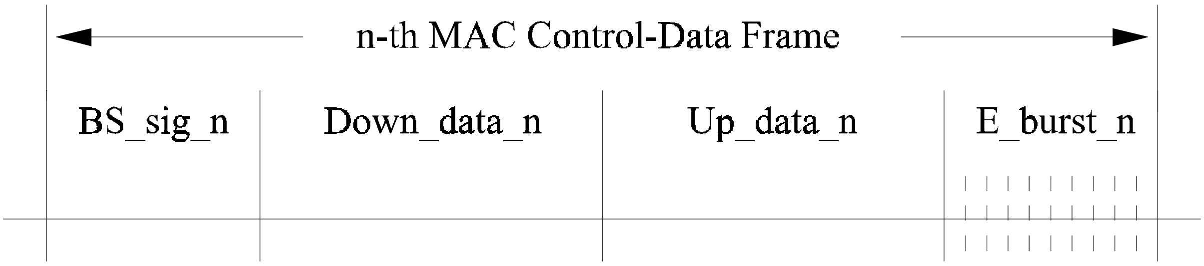

Figure 4: CDF for BS-Oriented Architecture

In each MAC control-data frame, there are four phases, namely, (1) BS_sig, (2) Down_data, (3) Up_data, and (4) E_burst. Synchronisation is achieved using periodically spaced transmission of beacons, similar to that described in IEEE 802.11 standard, and is not shown in Figure 4.

During the BS_sig phase, the BS transmits all of its signalling information to the WTs. Following its signalling phase, the BS sends the down-link data in the Down_data phase. This minimises the turn-around time of the BS. Next, the WTs transmit information in a pre-specified order in the Up_data phase, which includes piggybacked signalling information using the superslot technique as well as the ATM data. During the E_burst phase, all WTs who did not send any data in the previous CDF, and were assigned specific E-burst slots, transmit an energy signal at their specific E-burst slot. This energy signal indicates to the BS that a particular WT within that E-burst slot requires bandwidth to be allocated for transmission.

3.2 Slot Allocation policy

A slot allocation policy is a control mechanism which allocates a pre-defined number of slots among NWTs; each has multiple classes of traffic. Many allocation policies have been studied in literature [2]. All of them, in one way or another, rely on a priority mechanism in which multiple priority levels are provided and different priority levels are given to different classes of traffic. In general, the more global and accurate information the BS has, the better the performance of the allocation policy is. However, there exists a trade-off between the performance and the processing overhead.

4. Simulations and Results

In order to study the performance of our proposed MAC protocol, some simulations have been conducted. This includes a performance comparison between the protocol and TDMA in terms of cell loss ratio (CLR) and mean delay. In the following, we first discuss the simulation scenario, the parameters and the scheduling options, and then present the details of simulation results.

Simulation was performed on a Sun workstation (SPARC ULTRA-1) using a simulator written in BONeS [6]. It is a base-station oriented wireless ATM network consisting of one base station and five wireless terminals as shown in Figure 5.

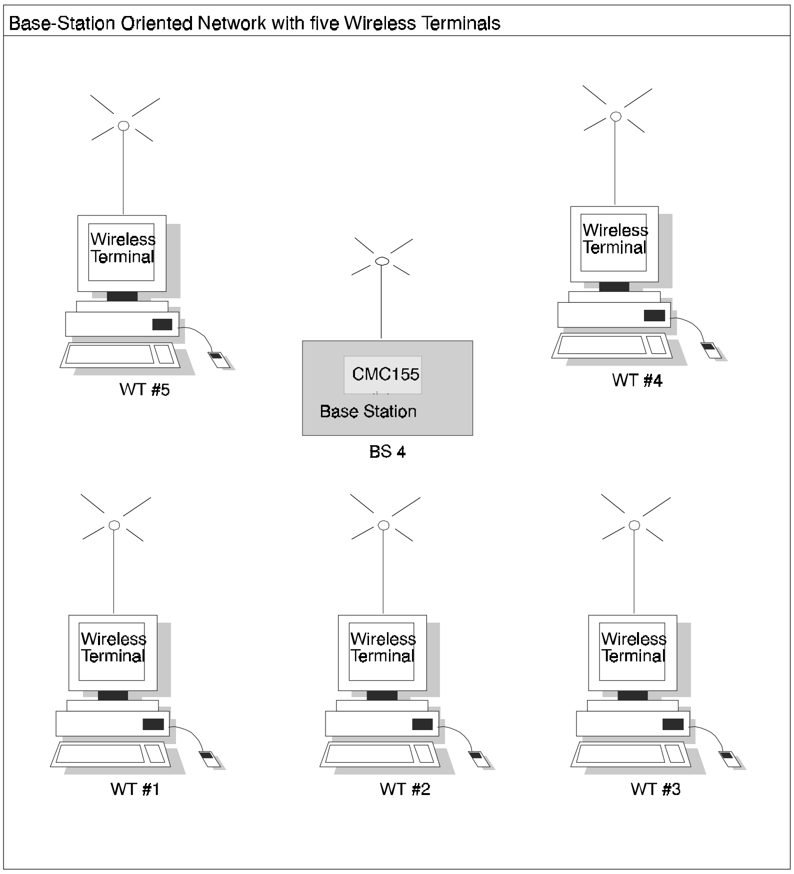

Figure 5: Simulation scenario: a base-station oriented network with five wireless terminals

Each WT has same load and same traffic composition. It is assumed that the system is conservative, i.e., there is no traffic flowing to/from the wired-ATM network connected to the BS, and a WT can only communicate with other WTs within the same “cell” served by the BS. The total nominal assigned bandwidth is assumed to constitute 80% of the maximum number of data slots per CDF. In its basic configuration, the system will use the following parameters: WT buffer size=50, Number of data slots per CDF=50, Traffic composition of CBR:VBR:ABR =0.2:0.7:0.1, Number of registered WTs=5, Number of networked WTs=5, and Simulation Time=1 sec.

The simulator can be programmed to operate in the following two scheduling modes:

1. TDMA Mode (TDMA):

The number of registered WTs equals to the number of networked WTs and every networked WT will be allocated a fixed number of slots (according to its nominal slot assignment) in each CDF irrespective of whether it has data to transmit or not.

2. E_burst+Extra_slot Mode (EbEx):

Three types of slots (with different slot lengths) are used, namely, the ATM slot, the superslot, and the E_burst slot. Normally, the length of E_burst slot is much shorter than the other two. In this mode, an E_burst slot is assigned to every INWT or NNWT and a superslot is assigned to any INWT or NNWT whose has sent an E_burst indication in the last CDF. For an ANWT, there are two allocation phases: Phase I is to allocate the smaller of (a) nominal number of slots and (b) the requested number of slots, and Phase II is to allocate the remaining slots in the current CDF to all terminals according to priorities in a round-robin fashion.

The effects of these two different scheduling strategies on the performance are studied and the results of cell loss ratio (CLR) versus load factor and mean delay versus load factor are shown in Figure 6 and Figure 7, respectively.

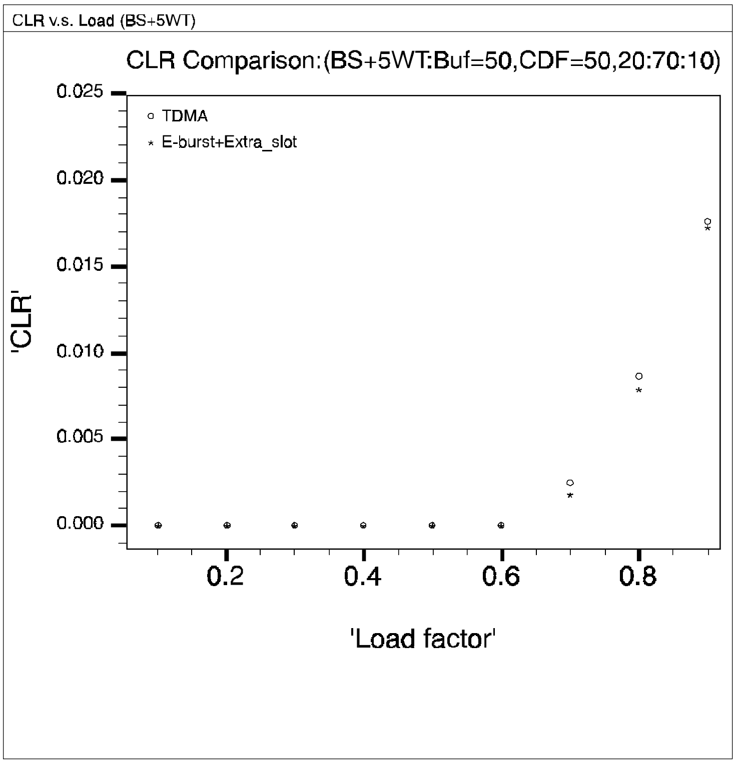

Figure 6: Cell loss ratio (CLR) comparison: TDMA vs. E-burst

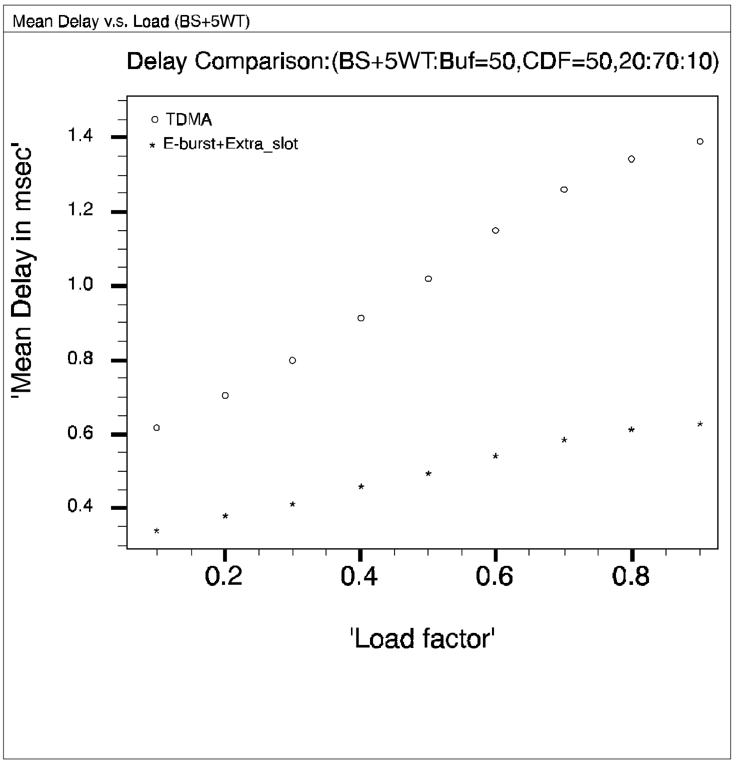

Figure 7: Mean delay comparison: TDMA vs. E-burst

Observe that: for CLR, the values obtained by the two scheduling strategies are almost the same (about 1% CLR at a load factor of 0.8). However, for mean delay, the TDMA gives a much larger delay than that in the E_burst+Extra_slot. For example, at a load factor of 0.8, the TDMA has a mean delay of about 1.3ms whereas the E_burst+Extra_slot has only 0.6ms.

Also, since more packets are being discarded at high load factors, mean delay becomes flatter when the load factor is above 0.7. In this case, a buffer of larger size may be required.

5. Conclusions

In this paper, we have proposed a contention-free reservation-based MAC protocol for wireless ATM local area networks. Such protocol can, in general, be applied to both base-station oriented and ad-hoc architectures. Essentially, it is based on a sequence of control-data frames which can, in some ways, guarantee the quality-of-service in terms of allocated bandwidth by first reserving and then scheduling the required resources via a control channel.

Preliminary performance study via simulation showed that the performance of our protocol gave much better results than that of TDMA. This together with its contention-free multiple access characteristics suggest that our proposed protocol can be a good candidate for the wireless ATM networks.

There is still a significant amount of work required, especially in defining the system control aspects, which will be subject to further studies within the wireless ATM groups.

Acknowledgement

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