Smart Buffering Technique for Lossless Hard Handover in Wireless ATM Networks

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Abstract - **The introduction of ATM technology in wireless environments, allowing mobile terminals to support multimedia traffic, is a subject of significant interest. Towards this objective, the mobility procedures need to be designed in an efficient way that will minimize the QoS deterioration, imposed by the movement of the users. This paper discusses the network architecture, its constituent functional entities, as well as the algorithms needed in support of mobility. In order to achieve minimum impact on the connection quality when a user crosses the boundaries of a cell, a so called "smart buffering technique" has been designed. Throughout the proposed design, special provision has been taken to minimize modifications or extensions, required on existing fixed ATM infrastructure. In this respect, existing versions of B-ISDN signaling protocols (Q.2931, ATMF UNI 3.1) are considered, which are enhanced by a supplementary mobility related protocol.**
Keywords: ATM, multimedia traffic, lossless handover, QoS, B-ISDN signaling

I. Introduction

In recent years, the research area of mobile computing is experiencing a rapid growth. At the same time the ATM technology seems to be leading as the network platform used for multimedia communications, since it can successfully support different classes of services, with QoS guarantees. Therefore, the next logical step is the combination of ATM and mobile computing. A common objective in several studies on this subject (e.g., [1] - [7]), is the efficient handling of the required mobility procedures, while minimizing the necessary modifications on the existing ATM infrastructure.

For the purposes of this paper we will adopt the network model shown in Figure 1. This model has been used in project Magic WAND (Wireless ATM Network Demonstrator)[1] for modeling wireless ATM Customer Premises Networks (CPN). [7].

In Figure 1, the mobile terminal (MT) is a full-fledged ATM end system that can support multimedia applications. The mobile terminal accesses the network via radio base stations, wherein after called Access Points (APs). The APs terminate the radio link and manage the resources in the radio part of the connection. Each AP is responsible for the transmission and reception of radio frames in one cell, has no switching capabilities, and merely acts as an advanced multiplexer. The APs are connected to an ATM switch, which also connects the wireless ATM system to the fixed ATM network.

One of the main difficulties in a wireless ATM system, is that the existing versions of the signaling standards ([8], [9]) provide only means to establish and release data connections. No provision exists for terminal mobility which may require the extension or the switching of data routes. This extension or switching of routes in a mobile environment takes place whenever a mobile terminal crosses the boundaries of two cells, while having active connections. This operation is called *handover* or *handoff*, and it can be of two types: hard or soft. The key difference between the two is that, in soft handover, the MT can communicate with both the old and the new Access Points simultaneously and for a certain time period, while in hard handover only one radio link between an MT and an AP exists at any time. Furthermore, we distinguish the kind of handover based upon its execution path, which can be via the old AP, in which case it is called backward handover, or via the new one, called forward. All types of handover are characterized as lossy or lossless, depending upon whether loss, re-ordering or duplication of ATM cells occurs during their execution.

This loss of data is most difficult to be handled in the downlink direction (from the switch to the MT), while the flow on the uplink can be dealt with an appropriate wireless data link control layer and the use of delimiters as presented in [3]. In this algorithm we deal only with the downlink traffic, since this is exactly the point where our algorithm presents a major difference from the other studies.

A major side-effect of cell loss is the deterioration of the QoS on the active connections of the mobile. These active connections can either be delay critical, or loss critical. In order to minimize this deterioration, a technique needs to be designed that will guarantee the correct transmission of cells, and will be fast enough to meet the delay constraints. This objective is difficult to be met in CPN, where micro-cells are used, and the fast fading effect leads to frequent and abrupt forward handovers.

[1] The Magic WAND project is funded by the EC in the context of the ACTS Programme.

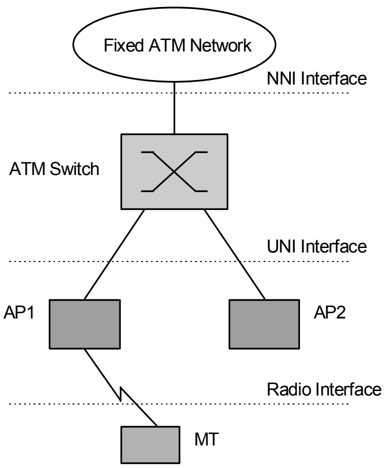

Figure 1 ATM Network Architecture

Existing proposals use the APs to deal with this problem, by forwarding cells from one AP to another, in order to achieve lossless HO. (e.g., [2],[3]) These solutions lead in complex APs, since they have to act not merely as concentrators of traffic, but they also have to perform routing functions among them. Since the APs are the most widely used components in the network these solutions may lead to an increase of the total system cost. Another drawback of such a solution is that the time needed to forward cells from the old AP to the new one my violate the delay constraints of delay critical connections. In other words, lossless handover cannot be claimed, for all classes of services.

The aim of this paper is to present an alternative solution that can be applied to CPN environments, where only hard handovers, either backward or forward can be performed. For our purposes, the wireless ATM infrastructure is considered to be an integral part of the fixed network. This means that, any required enhancements have been placed upon the standard switches in order to handle the mobility procedures in a fast and efficient way.

The key idea of our solution is that with smart buffering, an ARQ mechanism from the switch to the MT can be used to guarantee lossless handovers. Additionally, HO hints, as described in [1], and multicasting of delay critical connections, when a deterioration of the radio signal is measured, can be used to offer an acceptable overall solution.

In this paper, we describe a solution that does not affect heavily the switch, while keeping the cost and the complexity of the AP low. In section II, we describe the protocol stack at every network component. Section III presents the proposed algorithm focusing on the new elements that need to be added on the switch. Section IV, gives an example of a forward handover with hints, in a Message Sequence Chart (MSC) format. Finally, section V contains the conclusions.

II. Protocol stacks

Figure 2 gives the protocol stack of the three network elements (MT,AP, Switch) of the network model in Figure 1. The APs communicate with the switch whenever call admission control has to be performed (e.g., Call Setup, Handover). The APs are interconnected with the switch by permanent VCs (PVCs). The protocol used for this Switch-AP communication, is called Access Point Control Protocol(APCP) [3].

The Radio-Physical and MAC layers in the MT and AP are responsible for the transportation of the ATM cells over the radio link. The wireless data link control (WDLC) layer provides error control mechanisms to enhance the performance of the radio channel. [12]

The ATM switch is considered to support standard signaling protocols([8], [9]). Furthermore, it is enhanced with a mobility specific protocol, called Mobility Control Protocol (MCP)[10]. As a result the wireless ATM network is an integral part of the whole system. The mobility specific features are incorporated into mobility specific functional entities [11. These functional entities are responsible to handle any handover, registration or location update, that may occur in the system. All these mobility related functional entities are added in the switch in a modular way. Every switch is able to communicate with the fixed network by using an ATM NNI interface.

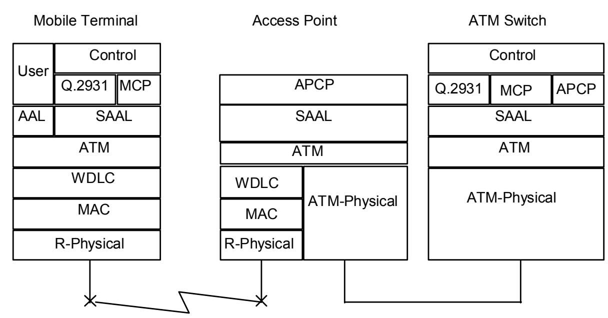

Figure 2 Protocol Stack

III Description of the proposed algorithm

The proposed algorithm can be thought of as a lossless handover algorithm for the loss critical connections that performs a good effort for the delay critical ATM traffic. Before describing the algorithm, two assumptions have been made that do not affect the algorithm but simplify its presentation: 1) there is a one-to-one relationship between APs and the switch ports and, 2) every mobile uses only one Virtual Path (VP) for all of its connections.

The key idea in our approach is to perform an appropriate buffering technique on every port of the switch, while using a protocol to acknowledge correctly transmitted cells over the radio interface as well techniques for multicasting and forwarding cells to new access points (APs). The modifications to a typical ATM switch, required for the implementation of the proposed buffering technique are described below.

The Proposed Modifications

A typical ATM switch consists of three basic modules: The Input Module (IM), which prepares the cells to be used by the rest of the switch, the Cell Switch Fabric (CSF), which performs the switching and, the output module (OM), which prepares the cells to be transmitted over SONET/SDH. To this typical switch architecture, for the proposed algorithm to work properly, we introduce a new module, called Multicast Arbitrator (MA). As shown in Figure 3, the MA module resides between the CSF and the OMs. Its main function is to direct the ATM cells from one OM to another during handover and its operation will be described later in this section.

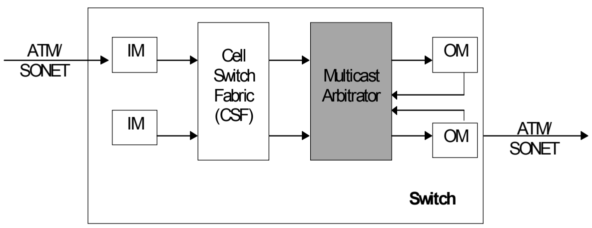

Figure 3 Switch Architecture

Another modification to the existing architecture concerning the output module is also needed. In a typical ATM switch the OM prepares the cells to be transmitted over the SONET/SDH. To perform such functions the OM consists of three basic modules, namely the Cell Processing, the Transmission Convergence, and the SONET functions. In the proposed algorithm, a new module has to be added in the input of the OM and before the existing modules. This new module, called x-ARQ, performs the following functions:

- Continuously executes the ARQ algorithm. Thus, the switch buffers the cells whose transmission over the radio interface has not been acknowledged yet.
- Initiates multicasting of the delay critical connections, whenever there are hints for an imminent handover.
- Initiates forwarding of the loss critical connections, when the handover procedure begins.

When an ATM cell is inserted into the OM, the x-ARQ module copies it inside an internal buffer, and forwards it to the Cell Processing Unit. The new architecture of the OM is shown in Figure 4.

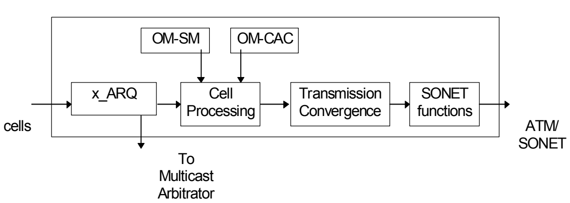

Figure 4 OM Architecture Model

Internally the structure of the x-ARQ module can be thought of as is shown in Figure 5.

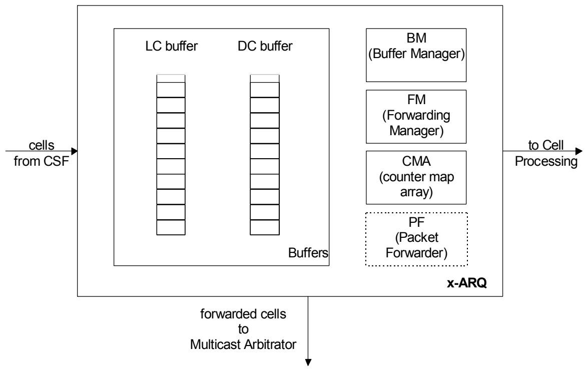

Figure 5 X-ARQ Module

Inside the x-ARQ module there are the following entities:

1. *LC and DC Buffers*: These buffers are used for the temporary storage of any unacknowledged cells. There is one buffer for each ATM traffic class, but for simplicity reasons, we can assume that only two buffers exist. One buffer is used for the loss critical connections (LC buffer) and one buffer is used for the delay critical connections (DC buffer). For each of these two buffers, there are two pointers showing the next available position in the buffer and the first not acknowledged cell residing in the buffer. These two pointers are managed by the buffer manager (BM). There are also pointers that are managed by the instances of the packet forwarder (PF) entity. Each pair of these pointers is related to a mobile that performs handover. Their functionality is to help the forwarding of cells residing in the buffers of the old AP to the buffers of the new AP.
2. *The buffer manager (BM) entity*: This entity is responsible for the maintenance of the buffers inside the x-ARQ module. As it was previously noted, there are two pointers in the BM entity, for each of the two buffers. One pointer points to the next available position in the buffer, while the other pointer points to the first unacknowledged cell. Except for these two pointers, there is a counter inside the BM. This counter is called *OMcounter*. Every time a new cell enters the x-ARQ module, the counter is incremented by one. The new value of this counter is stored in the internal flag of the cell, together with other information the switch keeps there. Another information that must be kept in the internal flag is the identity of the OM the cell is destined to, as well as whether the cell is a forwarded one or not. All that information is manipulated by an entity called Internal Flag Manipulator (IFM), that resides inside the BM.
3. *The Counter Map Array (CMA)*: This array is used when an OM is receiving cells from another OM during forwarding or multicasting. When a cell is inserted in the new OM it has a counter value that is related to the old OM. In order for the algorithm to perform correctly, the cell has to be related to a new counter value, taken by the OMcounter of the new OM. This correspondence

between old and new values of OMcounter is essential for the synchronization of the cells during forwarding or multicasting.

4. *The forwarding manager (FM) entity*: This entity manages the forwarding of the cells during handover. The FM entity initiates, destroys and manages the instances of the packet forwarder (PF).
5. *Instances of the packet forwarder (PF) entity*: There is one instance of the PF entity for each mobile terminal. Each instance is responsible for the multicasting and forwarding of cells. The PF instance contains information regarding the next/last cell to be forwarded, the identities of the old and the target AP, as well as the identity of the mobile terminal. The latter is needed because we assume that there is a one-to-one correspondence between mobile terminal and VP. In that way the distinction of cells related to a specific mobile terminal is trivial. Another responsibility of the PF, in cooperation with the MA, is to control the flow of forwarded cells destined to the same OM, via MA. Specifically, in the MA, there is an entity called packet arbitrator (PA) for each PF. This entity controls the traffic of a PF in order to avoid cell collisions.

The main responsibility of the MA is to control the flow of cells from multiple sources to a specific OM. Situations like these can take place whenever multiple MTs perform handover to a specific port (OM). In other words, the MA ensures that the forwarding procedure will work for multiple MTs that move into the same radio cell. The MA is also a key entity for the synchronization of the cell flows from the CSF and the old OM, when the switching of the data connections to the new OM has been completed. The way this scheme works is illustrated in Figure 6.

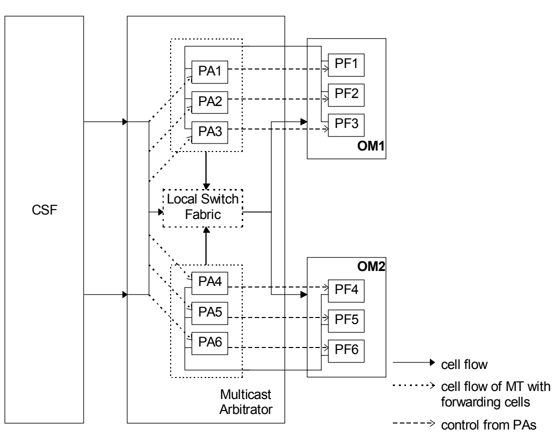

Figure 6 Operation of the Multicast Arbitrator

Some modifications are necessary to be made in the Access Point Control Protocol (APCP) too. In order for the algorithm to work correctly, two counters have to be added to the existing AP structure. The first counter is called APcounter. The operation of this counter is similar to that of the OMcounter in the switch. Its value is incremented by one each time a cell is successfully transmitted over the radio interface. The second counter is called SEGcounter. It is a circular counter with a maximum value. Its value is incremented by one each time a cell is successfully transmitted over the radio interface. When the value of the SEGcounter reaches zero, the value of the APcounter is transmitted to the switch. There is the possibility that such a transmission to the switch, takes place either upon the loss of the signal from the mobile terminal, or when a handover begins. Such an unscheduled transmission does not influence the regular transmission that takes place at regular intervals.

By using two counters, instead of one in the AP, the effect of a loss of an *ack* (transmission of the APcounter's value) is minimized on the operation of the algorithm. This is because the algorithm uses relative and not absolute values related to the cells.

Signaling Messages

There are some new signaling messages that the various components of the architecture described above exchange. Since the forwarding manager (FM) is the most important entity, it is natural to be the recipient of most of these messages. The new signaling messages are:

- **FORWARD_req:** Sent from the AP to the corresponding OM of the switch when the AP stops transmitting cells to the MT. When the FM receives the message, it forwards cells to the new AP, as soon as the CAC and the Wireless CAC are completed. This message has as a parameter the value of the APcounter. In that way the OM is not forwarding cells that have already been transmitted to the MT. At this point the FORWARD_req works like an unscheduled x-ack message, which does not change the content of the buffers, only the virtual buffers that a PF is managing.
- **HO_TARGET_AP:** It is sent from the MMC of the CS to the OM informing it about the identity of the AP that the MT is going to be handed over. This message is important because the hint for handover, if it exists, is not necessary to be for the same AP the MT will be eventually handed over. Beside this, the lack of such a message, makes impossible for the PF to know where the cells should be forwarded. More specifically, there two reasons for which this message is necessary:
    1. If a multicasting is in progress, then the algorithm must verify that the new AP is the same to the AP the hint was pointing to. If this is not happening, then the multicasting must be terminated and a forwarding should be initiated instead.
    2. If a multicast has not been initiated, then the old OM, although it has received a FORWARD_req, can't start the forwarding since it does not know the new AP. This situation arises when a forward handover without hints is taking place.
- **MULTICAST_req:** It is sent from the OM to the MMC. By using this message, the OM requires resources for the new AP, so as the multicast to begin. If the MT is going to be handed over to the AP indicated by this message, the CAC and the Wireless

CAC have already been performed and there is no need to be done again.

- **MULTICAST_cnf:** This message is a confirmation to the MULTICAST_req message.
- **SET_FORW_LIMIT:** It is sent from the MMC of the CS to the PF. Upon receiving this message, the PF knows that there are no cells coming to this PF for the specific MT. The PF sets the upper limit of the virtual buffer corresponding to the MT. In that way there will be no forwarded cells after this limit.
- **HO_HINT:** It is sent from the MT to the OM entity of the switch when there is an indication for a handover. It is similar to the HO_REQUEST message, but it does not start a handover. This message initiates the multicasting since the MT "understands" that a handover is imminent.

IV Forward Handover with Hint

In Figure 7 an example of a forward handover with hint is presented. In this figure, beside the Forwarding Manager (FM), the Mobility Management (MM) entity, the Radio Management, and the Signaling entities are illustrated. The MM entity is responsible for the handling of all MCP signals, that deal with the mobility procedures. The RM entity is the recipient of all APCP signals that deal with the management of the radio resources. Finally, the SIG entity is the one that deals with the standard signaling procedures as well as the interaction with the MM entity.

In this example, we assume that the radio link quality is fading fast, but there is enough time for the MT to send a notification to the switch that the probability for a handover is very high, with the signal *HO_HINT*. This signal contains a list of APs that are good candidates to support the connections of the mobile terminal. Upon reception of such a signal by the Forwarding Manager in the switch, a multicast is attempted for all delay critical connections*(signals MULTICAST_req and CAC_ind)*. This means that the characteristics of these connections need to be obtained by the SIG entity, and CAC needs to be performed for both the fixed *(done internally in SIG)* and the wireless resources *(signals CHECK_RR_req/cnf, RR_STATUS_ENQUIRY and RR_STATUS)*. For the result of the CAC as well as the new Access Point, FM is notified with signals *MULTICAST_cnf, and HO_TARGET_AP* respectively. If the CAC operation proves to be successful, then multicast for the delay critical connections can start.

At the other end of the network side, the mobile eventually looses its association with the AP *(link failure)*, and selects a new one through which it will perform the remaining steps of the handover *(New association)*. The old Access Point, through RM, is responsible to notify the Forwarding Manager to start forwarding to the new Access Point, all the cells of the data critical connections, that have not been received by the MT.

The next step is for the mobile terminal to communicate with the switch in order to obtain which connections are supported by the new Access Point and performs the necessary reconfigurations to resume its normal operation *(signals HO_REQUEST, HO_RESPONSE)*.

At the same time in the switch, the rerouting of all connections, both delay and loss critical, is triggered with signal *SWITCH_DATA_req*. This means that after this operation is completed, the cells will be directed only to the port where the new AP is attached to. During this phase the old AP is notified to release all resources dedicated for this MT *(signals CONN_DROP and CONN_RELEASE)*, and the new AP is notified that reconfiguration in the switch for the specified connections is completed *(signals CONN_SET and CONN_SWITCHED)*.

When the aforementioned task is completed the Forwarding Manager is notified to release any resources (e.g., buffer space, PF instances) used for the specific MT, after finishing with the forwarding of any remain cells.

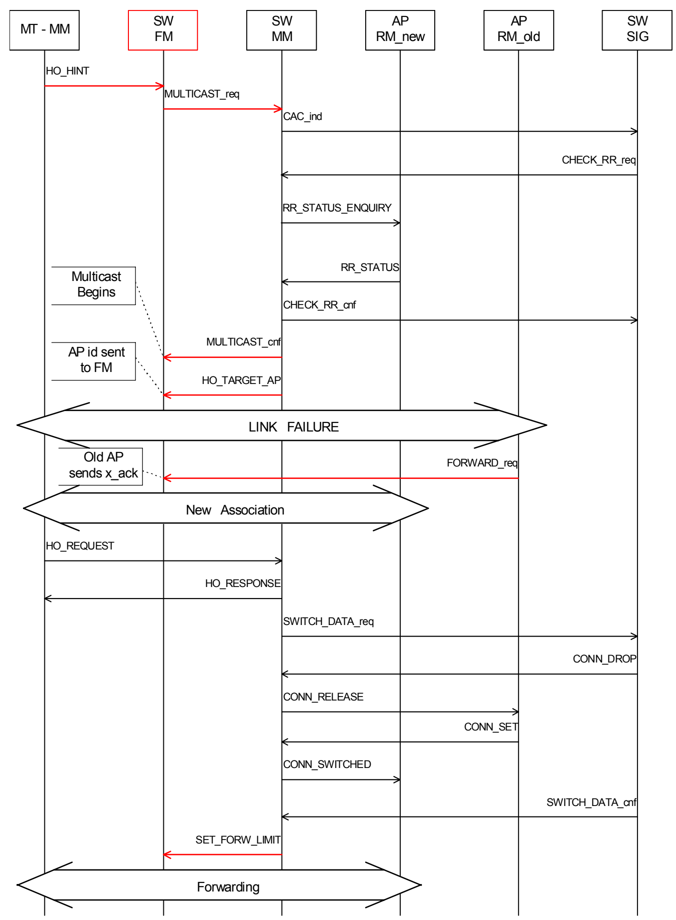

Figure 7 Forward Handover with hint

V Conclusions

In this paper, we have described a technique that attempts to handle hard handovers that can take place in a CPN environment, in a lossless way. This is achieved by a smart buffering technique implemented in the switch for all service classes.

Furthermore, hints for handover can be used in order to ameliorate the performance of the algorithm for the delay critical connections.

The main advantage that this solution offers, is that our goals can be achieved with minimum modifications in existing commercial switches. A potential problem in the proposed solution, is the requirements imposed upon the buffers in the switch ports. Although there exist switches that use a large buffer space, which can be dynamically partitioned among ports, analysis and simulations are needed before drawing any definite conclusions. Work is in progress for the quantitative evaluation of the proposed algorithm.

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