Signaling and Mobility Control
for Wireless Intelligent ATM CPNs

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ABSTRACT

A wireless intelligent ATM access system is explored in this paper from a signaling protocol viewpoint. The proposed architecture is consistent with the B-ISDN User-Network Interface (UNI) signaling structure as a wireless local area network to access the ATM core network infrastructure, and can be adapted to cater also for a wireless broadband access network for future mobile telecommunication systems. Emphasis is placed on taking advantage of well-developed protocol standards, where appropriate, to allow the easy introduction of the proposed architecture in the real world. The evaluation of the signaling performance of the system captures the effect of the proposed structure on the performance of call and mobility control and yields results, which fall within acceptable signaling performance measures.

I. INTRODUCTION

The introduction of the wireless ATM technology in Customer Premises Network (CPN) environments has recently gained particular research attention. Its main challenge is to harmonize the development of broadband wireless systems with fibber-optic-based infrastructure B-ISDN/ATM and ATM LANs, and offer similar advanced multimedia, multiservice features for the support of time sensitive voice communications, LAN data traffic, video and desktop multimedia applications to the wireless user.

This paper, following the design guidelines of [1], investigates the aspects related to the signaling protocols of a wireless ATM access system and the employment of Intelligent Network (IN) concepts to support mobility. The IN approach has been proved useful in several network design issues, especially in the areas of service deployment and mobility control in mobile networks, where the mobile-specific functions can potentially be implemented as IN-like services. The proposed design is consistent with the B-ISDN User-Network Interface (UNI) signaling structure as a wireless local area network to access the ATM core network infrastructure, but can be adapted to cater also for a wireless broadband access network of future Personal Communication Systems (PCS), such as the Universal Mobile Telecommunication System (UMTS), [2], which is currently being specified within European Telecommunication Standards Institute (ETSI) as the third-generation mobile system in Europe. The signaling protocol design carried out in this paper is quantitatively studied by simulation. The obtained results capture the effect of the proposed signaling structure on the performance of call and mobility control, and can be used for network design purposes in a CPN environment supporting many users.

The rest of this paper is organized as follows. Section II introduces the system's architecture, presents the IN-based functional configuration and gives the corresponding protocol stacks. Section III describes the signaling and control procedures encountered in the mobile system under study and gives the corresponding information flows. Section IV presents the simulation model used to evaluate the proposed architecture and the obtained numerical results. Finally, Section V contains our conclusions.

II. SYSTEM ARCHITECTURE

A. Network Architecture

The high-level view of the network configuration assumes a number of geographically distant local-area, CPN wireless (and fixed) ATM access systems, interconnected via a core B-ISDN/ATM network, as shown Fig. 1. In the wireless network part, the ATM Mobile Terminals (AMTs) comprise all the call, connection and mobility control functionality required from the user side. The AMTs are considered as the equipment of the mobile end-user, and contain the wireless ATM radio adapted cards interfacing the air interface. The ATM Wireless Access Points (WAPs) include the radio link management functions and serve the AMTs in their coverage area through a shared radio channel. WAPs act as gateways with no switching capability for communication between mobile terminals and the fixed ATM. WAPs act as simple interworking units that extract the encapsulated ATM cells from the Medium Access Control (MAC) frames and forward them to the fixed ATM network through proper ATM Virtual Connections (VCs).

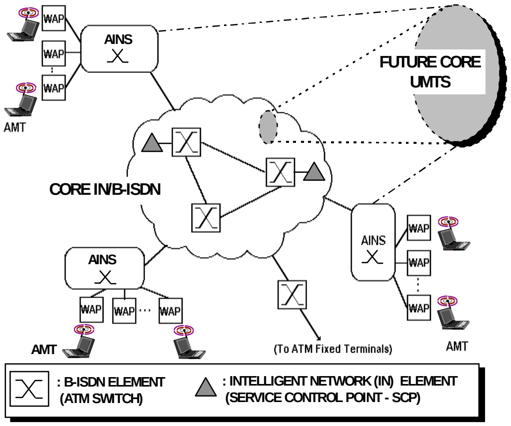

Figure 1 - High-Level Network Architecture

The ATM/IN Switch (AINS) is the focal network element providing the basic call and bearer control, the switching and the transmission functions, as well as the additional IN service and control logic required to support mobility. AINS realizes the interworking functions required between the wireless access network and the core intelligent broadband fixed network (B-ISDN/IN). The latter is anticipated to comprise the fixed, core network infrastructure upon which next-generation mobile systems will be based, [2].

B. Functional Architecture

The functional architecture considered in this paper is based on a generic IN functional model developed to support mobility in UMTS, thus offering the possibility for the modular introduction of the wireless ATM access architecture examined here into this system in the future. This can be easily realized, if we consider the proposed architecture as a specific domain (business/private environment) of a UMTS public domain (Fig. 1). In this sense, the business domain potentially can be associated with a core public domain to access services and data located externally to the business domain but provided by the public domain. This allows the same range of mobility services and features to be supported also in the private network environment as in the public domain. The IN concept has been proved useful in providing a common mobility management framework due to its convenience in introducing new service features independently regarding to the serving network. However, the study of the above integration scenario appears in [3] and it is beyond the scope of this paper.

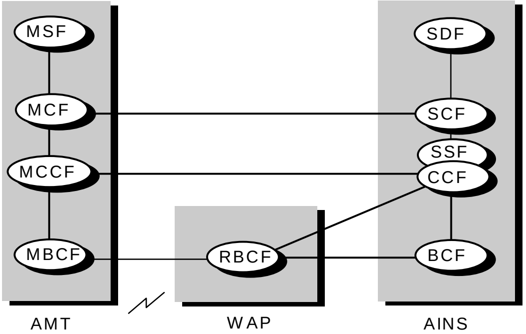

Figure 2 - Functional Architecture

Fig. 2 shows the employed IN functional model, and the mapping of its functional elements to the network architecture. The Service Control Function (SCF) stands for the support of IN user services and processing of mobility-related (non call-associated) services, such as user registration and location-related management. The SCF is supported by the Service Data Function (SDF), which actually comprises a database for storing IN mobility and service data. The peer entity to the SCF in the AMT is the Mobile Control Function (MCF), which is also supported by a small database, the Mobile Storage Function (MSF). The Mobile Call Control Function (MCCF) and the Call Control Function (CCF) are responsible for the set-up, monitoring and release of calls between the AMT and the AINS and the support of the handover function (call-related mobility), [5]. The Service Switching Function (SSF) in association with the CCF, provides the set of functions required for interaction between the CCF and the SCF. SSF extends the logic of CCF to include the recognition and correlation of service control triggers and to interact with the SCF. SSF processes event indications to/from the state model responsible for Call Control (CC). The Bearer Control Function (BCF), the Radio BCF (RBCF) and the Mobile BCF (MBCF) serve for the handling of fixed and radio bearers.

C. Protocol Stacks

The Control-plane protocol stacks are given in Fig. 3 (the storage functions - MSF and SDF - have been omitted for clarity). The CC signaling includes an extended B-ISDN CC signaling protocol, [4], (denoted as Q.2931*), for the set-up, modification and release of calls, over the Signaling ATM Adaptation Layer (S-AAL) and the ATM layer protocols. The major enhancements required in the current CC UNI signaling standards are related to the support of the handover function (e.g., inclusion of handover-specific messages), [5], as will be shown in Section III.

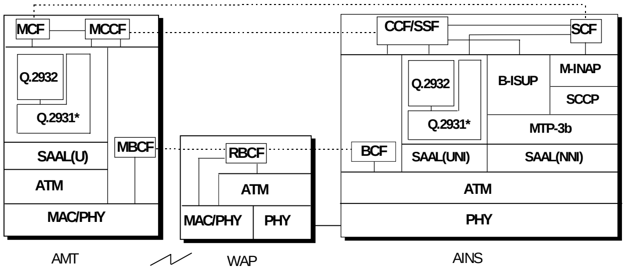

Figure 3 - Wireless Access Network Protocol Stacks

In the WAP-AINS interface, an extended VB_5 interface control protocol, [6], [13], serves for the handling of fixed bearer connections of the same call. The full set of the VB_5-based W**A**P-AIN**S** **C**ontrol **P**rotocol (ASCP) features and functions can be found in [5], [6], [13]. The broadband Network-to-Network Interface (NNI) is assumed in the core network with Broadband-ISDN User Part (B-ISUP) and Message Transfer Part 3 (MTP-3b) over the NNI S-AAL protocol. In addition, a Mobility-enhanced IN interface is considered based on the IN Application Part (M-INAP) operations, at the upper level and Signaling Connection Control Part (SCCP) at the lower level. The same protocol layering is also assumed for the interfaces between the IN physical entities in the core network.

In the access part, the mobility management (non-call associated) messages (e.g., registration) are handled by the MCF and the SCF. We consider that for each AMT both the call control and the mobility management messages are transported via the same signaling connection at the UNI. Signaling Virtual Paths/Channels (SVP/SVC) are allocated for each AMT in the AMT-AINS logical interface using the services of the Metasignaling protocol, [7]. More details relevant to this mechanism adapted to the wireless ATM architecture can be found in [5] and will not be covered here in detail. Note that the SVP/SVC pair is reserved for each AMT within the AINS coverage area (limited AMT population). However for large scale installations other techniques can be used, which serve for dynamic signaling channel allocation.

The SVP/SVC pair allocated for each AMT is notified to all WAPs during the signaling channel assignment using the ASCP. Upon initial establishment of the AMT-AINS signaling connection, an SAAL instance is created at each port of the AINS for that particular AMT. Each time an AMT associates with a new WAP, a binding procedure (which forms part of the wireless access network management plane) is performed to associate the AMT, the SVPI/SVCI pair and the corresponding AINS port. Such an approach removes the need for re-spawning the signaling connections each time the terminal associates with a new WAP, while provides for correctly addressing the AMT during the signaling interactions of the higher-layer entities.

Call-unrelated messages can be transported in a connectionless way at the transport layer according to the Q.2932 ConnectionLess Bearer Independent (CLBI) recommendation, [8], based on the use of FACILITY messages. Both 2931* signaling and FACILITY messages are conveyed transparently via the WAP (at the ATM layer) towards the AINS, where they are identified (by the message type value) and routed accordingly towards the CCF or the SCF.

III. SIGNALING AND CONTROL PROCEDURES

In the described framework, it is straightforward to identify the functional protocols of the signaling architecture presented above to support user registration, call set-up and handover.

A. User Registration

Registration (Fig. 5) is performed when an AMT is switched-on and caters for the AMT authentication, as well as to inform the network that the AMT user wants to be reachable for the services he/she is authorized to access.

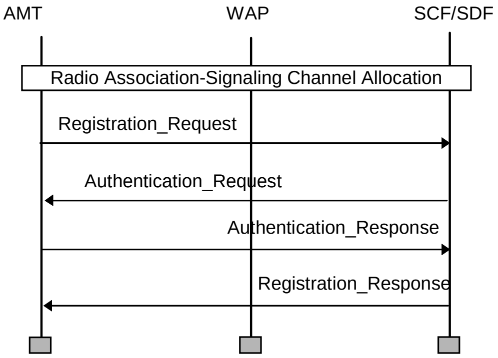

Figure 5 - AMT Registration

It is assumed that the AMT has already associated itself with the corresponding WAP and an SVP/SVC pair has been obtained using metasignaling. Upon request for registration, the AMT(MCF) reports its specific AMT address that uniquely identify the terminal within the AINS area. In case the current domain is the home domain of the AMT, the SCF checks the user subscription rights, obtains authentication information stored at the database, authenticates the terminal (exchange of security keys for ciphered data transfer - Auth_Req/Resp) and creates registration and location information in the database. During registration a Temporary ATM Address is assigned to the AMT that uniquely identifies the terminal within the AINS area, and it is used for efficiency reasons as well as to increase confidentiality.

In case the AMT registers in a domain different from its home domain, then registration involves the transfer of the registration/authentication data from the home domain to the new domain, the update of the routing data in the home domain and the deletion of the registration data from the old domain, [3]. The home domain coordinates these actions to ensure that user data is up-to-date in all the domains concerned. These actions are performed based on the M-INAP interface operations realized between the IN physical entities via the core broadband network.

B. Call Handling

The call control messages exchanged between the MCCF and CCF correspond to the Q.2931 UNI messages, [4]. When a mobile initiates a new call, it (MCCF) conveys a standard call SETUP message to the AINS(CCF) as shown in Fig. 6. Upon receipt of this request, the CCF triggers a service check procedure towards SCF via SSF. This procedure determines if the calling user has subscribed for the requested service and checks if the user is allowed to establish bearer(s) with the requested bandwidth. The specification of the service check procedures also considers extensions for the integration of supplementary services like, e.g., conditional call forwarding, or voice mailboxes.

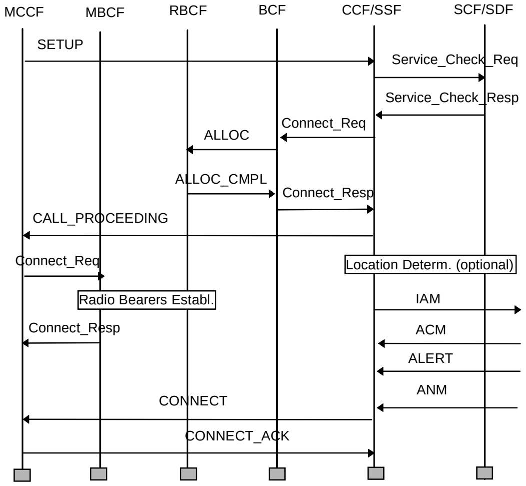

Figure 6 - Call Set-up (outgoing call)

After a successful service check, CCF draws an initial call acceptance decision based on the user service profile data and on the QoS requirements set by the AMT. Since the AINS(BCF) maintains the overall fixed connection information, it allocates the VPI/VCI values for the connections. In case the call set-up request is accepted at the AINS, the access network should be notified on the expected new traffic to decide about the admission on the radio part, to reserve radio resources accordingly, and to perform possible QoS negotiations. To this end, the traffic parameters of the new connection or at least a useful subset of them should be communicated to the WAP of the calling AMT. The task of the communication between the AINS and the WAP, as well as the bearer channel establishment in the fixed access network part is realized by the ASCP (ALLOC messages), [5], [6], [13]. WAP(RBCF) upon receipt of the ALLOC message performs radio resource allocation modifies the radio lower layers (MAC/PHY), before responding to the AINS(BCF) (ALLOC_CMPL message).

Following successful call/connection acceptance decision, the CCF then examines the dialed number of the called user to determine whether the destination is a fixed or mobile terminal.

In case the called user is an AMT in another domain, the CCF contacts SCF for the exact location of the called AMT. SCF obtains the node address of the AINS of the terminating domain from the home domain (SCF_{home}) of the called AMT based on M-INAP procedures. The CCF sets-up a route towards the called terminal (fixed or mobile) via the core network using standard NNI CC procedures (B-ISUP IAM/ACM/ANM messages). Service check, call set-up and bearer establishment procedures for the called AMTs are similar to the those described above and will not be presented.

C. Handover Signaling and Control

As AMTs are allowed to move freely among cells, the problem of handover inside one domain (intra-AINS) or that of roaming between different domains (inter-AINS) arises. Given the framework of a local-area (small scale) wireless network, this paper focuses only on intra-AINS handovers (between two WAPs of the same AINS). It is assumed that only the mobile terminal (MBCF) monitors the quality of the radio link for the current and the candidate WAPs, and decides whether to initiate a handover or not (mobile-initiated/controlled handover). From the signaling viewpoint, two types of handover are identified: backward and forward, [5]. Backward handover assumes that the handover is predicted ahead of time and the handover execution is initiated via the old WAP. In the forward handover, it is assumed that a new signaling connection is established with the new WAP because the AMT disappears abruptly from the old WAP's coverage area, and handover signaling procedures are initiated via the new WAP. The backward, intra-AINS handover scenario is depicted in Fig. 7.

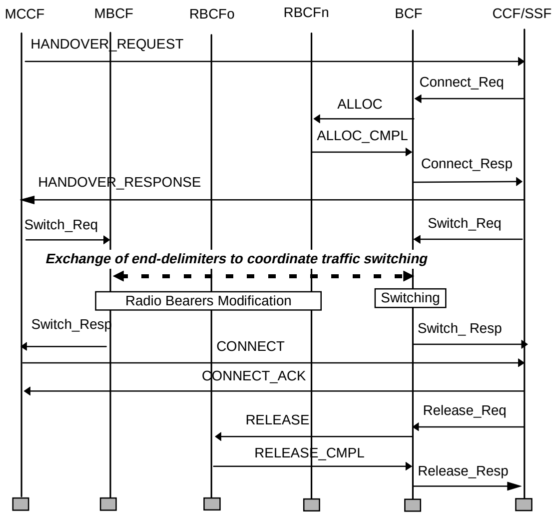

Figure 7 - Intra-AINS Handover

In case a handover needs to be performed, the MCCF sends a HANDOVER_REQUEST message towards the CCF of the AINS transparently via the old WAP. This message contains the AMT address, the call ID, and the target WAP(s) ID(s). The AMT may indicate the priorities of the different connections in case the new WAP cannot accommodate all the AMT connections in case of a multimedia call, [5]. The ASCP is also employed here for the establishment/release of the new/old bearers in the fixed network part and for performing possible QoS renegotiations during handover. Similar procedures to those described in Section III.B during call set-up are performed between the AINS(CCF, BCF) and the new WAP(RBCF). When the AINS(CCF) receives the response from the new WAP issues a HANDOVER_RESPONSE message to the AMT to inform it about the handover results, the new VPI/VCI values and possible QoS modifications and reconfigures the ATM connections towards the new WAP. The HANDOVER_RESPONSE message indicates to the AMT that it can proceed to perform handover. AMT(MBCF) releases its radio connection with the old WAP(RBCFo) and establishes a radio link with the new WAP(RBCFn), retrieving in this way its connectivity with the fixed network. Special ATM (and lower) layer inband signaling cell relay functions (use of end-delimiter cells) take place at AMT and AINS to coordinate the switching of traffic and to guarantee the transport of user data at an agreed QoS level in terms of cell loss, ordering and delay. Finally, the CCF triggers BCF to send a RELEASE message to the old WAP to notify it that the connection no longer exists and to deallocate the corresponding radio resources.

The forward handover scenario appears similar to the backward one. The main difference is that in this case the AMT communicates directly with the new WAP, so that all the signaling messages are sent to the AINS via the new WAP.

IV. PERFORMANCE MODEL - NUMERICAL RESULTS

A. Performance Model Description

The protocol design carried out in this paper is quantitatively studied by simulation for the evaluation of the signaling performance of the system. Here, we consider 4 geographically distant local-area, wireless ATM CPNs, interconnected via a core B-ISDN/ATM network, as shown Fig. 1. Each CPN configuration consists of 500 WAPs attached in one AINS.

In order to develop a convenient model for performance evaluation, we assume that each component of the signaling architecture is modeled as a multiclass processing queuing system, with different service times for each message type. The processing times for each signaling component and message were defined using as input the values of [9]-[14]. Propagation delays and cell switching times are considered of μsec/nsec order, and as such they have been ignored. The processing times of the signaling subsystems and protocol entities are shown in Tables I and II.

Signaling Subsystem	**Processing time (ms)**
CCF/SSF	20 (call set-up operation) 10 (call release operation) 5 (handover operation)
SCF	5 (service/profile check) 2,5 (all other operations)
SDF/DB	10 (queries) 20 (updates)
BCF	5 (bearer set-up operations) 2,5 (bearer release operations)
RBCF	5 (bearer set-up operations) 2,5 (bearer release operations) 5 (radio resource allocation)
Signaling operations at the AMTs	2,5 (all operations)

Table I. Processing Times of the Performance Model

Protocol Entity	Processing time (ms)
B-ISUP	4.5 (IAM) 1.5 (all other operations)
Q.2931* - Q.2932	0.5 (all operations)
M-INAP	9,5 (for outgoing messages) 6 (for incoming messages)
SAAL (UNI)	1.5 (all operations)
MTP-3b/SAAL (NNI)	2,5 (all operations)

Table II. Protocol Processing Times

Signaling links are assumed 1.5 Mb/s resulting in insignificant link emission and queuing times, [9]. The input parameters used in the evaluation are shown in Table III. We assume that the moving AMTs are uniformly spread within each wireless access system, so that the number of users within each WAP coverage area is the same. The system is tested by gradually increasing the number of AMTs per WAP and consequently the total number of AMTs under the same AINS area, assuming each time various call arrival rates for different mobility scenarios. The simulation tool used for this performance evaluation is the OPNET 2.5A.

Parameter	Value
Number of AMT users (N)	*variable*
% of roaming users (visiting remote CPNs)	10 %
Rate of call origination/delivery per AMT per hr, λ_c (Poisson)	*variable*
% of outgoing calls (to fixed or mobile terminals)	20 %
% of incoming calls	20 %
% of local calls in the same CPN	60 %
% of total busy calls	10 %
Call Duration (D) (exponentially distributed)	3 min
% of moving users within AINS area, P_{mov}	*variable*
Rate of AMT powering-up (down)	2 per day
Rate of WAP area crossings per moving AMT, R_c	3.5 per min

Table III. Input Parameters

B. Numerical Results

The performance evaluation focused on four parameters. First, the mean time from the start of a call SETUP message to the receipt of the CALL_PROCEEDING message at the calling AMT (for outgoing and local calls) or the AINS (for incoming calls) is measured. This time is referred to as T_{cp}. The CALL_PROCEEDING message acknowledges the SETUP message and indicates that the call is being processed and (according to the currently available standards) no more call establishment information will be accepted. The second performance measure is the mean local call establishment delay (T_{set-up}). The expiration interval of the corresponding timers for both parameters, defined by the existing standards, [4], serves as the upper limit for the evaluation of the call set-up processing procedures in the access network part. The third performance parameter is the mean time from the start of HANDOVER_REQUEST until the receipt of HANDOVER_RESPONSE at the AMT (T_{resp}), which the critical time interval for the system to decide on the handover acceptance and to establish the new bearers in the fixed radio part. The last performance parameter is the mean time for the AMT to complete the handover (T_{ho}), i.e., to retrieve its connectivity with the fixed network.

Figures 8-9 illustrate the mean processing times at call set-up (T_{cp}, T_{set-up}) for the two mobility scenarios at different call arrival rates per AMT. As expected, as the number of AMTs increases there is a straightforward increase at call set-up times. Note that a dramatic increase of the mean processing time for call set-up is observed in the high mobility scenario (P_{mov} = 80%). The difference between the maximum acceptable number of users between the two scenarios is quite obvious. This comes from the fact that in the high mobility scenario the signaling processing entities of the system are involved many times during an AMT call's lifetime due to the high rate of handover requests that arrive. Obviously, this effect is substantially limited when the percentage of mobile users is reduced to 50% (low mobility scenario).

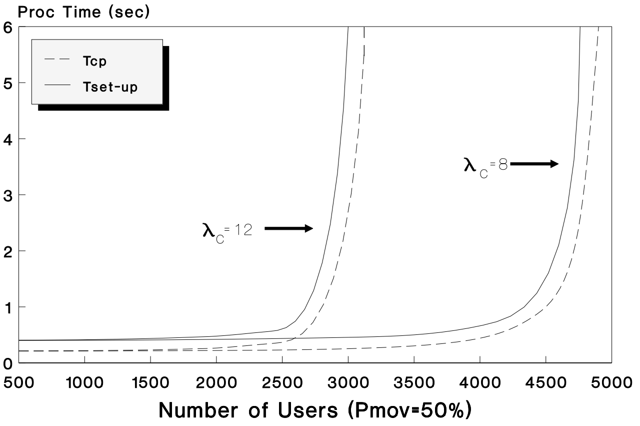

Figure 8- Mean Processing Times at Call Set-up (low mobility)

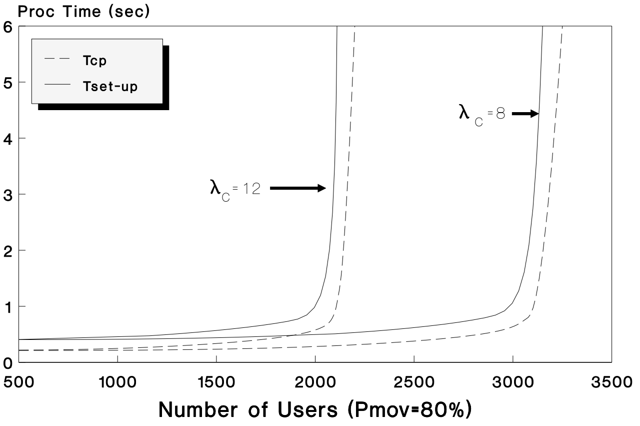

Figure 9- Mean Processing Times at Call Set-up (high mobility)

Figures 10-11 illustrate analogous results for the handover processing times (T_{resp}, T_{ho}). Note that these results indicate that the system can satisfy the handover processing time requirements set in [15] for wireless ATM systems. It has to be noticed that the presence of the MAC layer in a real wireless ATM access system will possibly increase the total signaling processing times. Concerning the signaling processing efficiency, it should be noted that the expectations of the capacity in such systems could be higher than the maximum values obtained in this paper.

However, based on (existing) implementations, on a one processor per signaling component basis (Section IV.A), it is expected that the range of operation reported here to be accurate, based on the results from [9]-[14]. In order for such systems to handle higher signaling activity rates or to accommodate a larger number of mobile users, each network node would need to be engineered with multiple processors for each signaling subsystem, [9].

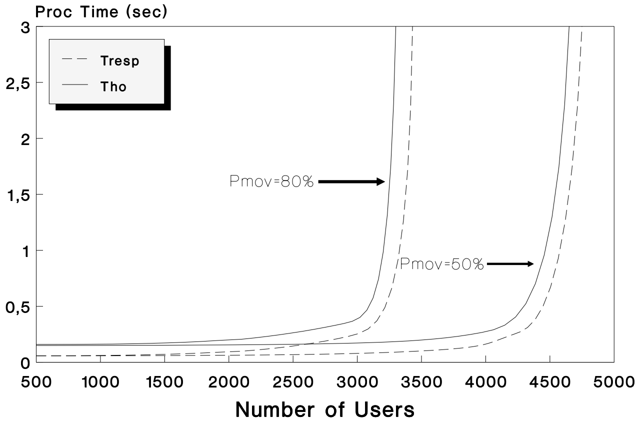

Figure 10- Mean Handover Processing Times (λ_c =8)

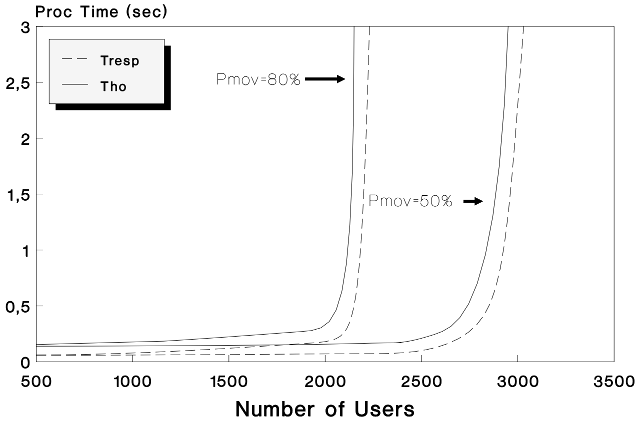

Figure 11- Mean Handover Processing Times (λ_c = 12)

V. CONCLUSIONS

In this paper, a broadband, wireless intelligent ATM access system was explored from a signaling architectural viewpoint. The protocol design is based on the basic control functions of a generic IN functional model to support mobility. The proposed design is consistent with both the inherent cellular/PCS architecture and the B-ISDN UNI signaling structure as a wireless ATM network to access the core B-ISDN. Emphasis is placed on taking advantage of existing protocol standards to illustrate the implementation feasibility of the proposed design. The evaluation of access signaling protocol structure introduced in this paper yields results, which fall within acceptable signaling performance measures and can be used for network design purposes.

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