

# The implementation and performance evaluation of hand-off in a CORBA-based WATM signalling system\*

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## Abstract

In this paper, the design, prototyping and performance evaluation of a CORBA-based handoff signalling system is discussed. The wireless terminal communicates with the base stations using UNI 4.0 signalling augmented by handoff control messages. The base stations then call on the services provided by a Handoff Manager CORBA entity that performs the handoffs using an incremental re-establishment scheme with the crossover switch being dynamically selected using Dijkstra's shortest path algorithm. The Handoff Manager makes use of a generic control of the switches using SNMP whereby WATM mobility management can be realized with commercially available ATM switches. The signaling system provides a flexible platform to evaluate different handoff algorithms. The experimental results show that effective ATM handoffs can be achieved with a latency of  $\approx 92$  ms, transition delay of  $\approx 18.5$  ms, and a low cell loss depending on the traffic characteristics. It was found that fewer packets were lost when using AAL 5 as compared to AAL 3/4.

**Keywords:** Handoff, wireless ATM, UNI signalling, open signalling.

## 1. Introduction

Asynchronous transfer mode (ATM) is advocated as a key technology for the provision of scalable, high-performance networks for telecommunications, local area network and even the home.<sup>1</sup> Portable computers, including notepads and palmtops are becoming increasingly pervasive. As the computing power and functionality of these devices approach that of their desktop counterparts, there is an even greater requirement for wireless networks that are able to support their connectivity. Hence, it is natural to extend ATM to wireless environment. However, several challenging issues must be addressed before the goal of integrating the wired and wireless networks is achieved.<sup>2</sup>

As the *mobile terminal* (MT) travels between wireless cells, the task of forwarding data between the wired network and the mobile host must be transferred to the new wireless cell's *base station* (BS) or *access point* (AP). This process is called a *handoff* and it must ensure that end-to-end connectivity is maintained in the dynamically reconfigured network topology. Handoff is achieved via signalling messages exchanged between the BSs, the MT and the switches in the wired network.

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Several schemes have been proposed in the literature that extend the current UNI 4.0<sup>3</sup> signalling protocol to support handoffs. The handoff schemes proposed for *wireless ATM* (WATM) have been broadly classified in Toh<sup>4</sup> into full re-establishment, path extension, virtual tree and incremental re-establishment-based schemes. There are several, sometimes conflicting, requirements to be satisfied by a handoff algorithm such as a low handoff latency, scalability, *quality of service* (QoS) guarantees, buffer tradeoff and data integrity.<sup>5</sup> The performance of these schemes was analytically compared in terms of several of these in Banh *et al.*<sup>6</sup>

The full re-establishment scheme<sup>7</sup> requires the entire connection from the source to the old BS to be released and a new connection to the new BS to be set up. This is slow, inefficient and not transparent as the destination host has to be aware of the handoff.

In path extension,<sup>8</sup> handoff is performed by extending the route of a connection from the old BS to the new BS. This makes it easier to ensure data integrity. However, after a number of handoffs, loops and sub-optimal routes will tend to occur. To counter this, some form of route optimization will have to be performed periodically.

Virtual tree-based handoff schemes<sup>9</sup> create multiple connections for a single user connection to all possible handoff candidate base stations. This type of re-routing is fast as it predicts handoff events and pre-establishes connections. This may lead to significant wasted resources for handoffs that never occur. In addition there is also the problem of ATM cell duplication.

Incremental re-establishment schemes require the establishment of a new partial path which connects to a portion of the original connection path. This allows the reuse of existing circuits and results in seamless handoffs as the destination host is unaware and is not involved in the handoff process. Examples of this type of re-routing are available elsewhere.<sup>4, 7, 10, 11</sup> The re-routing of the path requires the selection of a suitable switch that is called the *crossover switch* (COS) where the old and the new subpaths converge. The new route can be close to optimal depending on the selection of the COS which can be fixed or dynamically selected for each connection. Dynamic selection of COS is illustrated in Fig. 1 which shows a wireless access network consisting of two BS connected to a network of ATM switches. A fixed *correspondent terminal* (CT) is communicating with the MT over a *virtual channel* (VC) that initially passes through BS1 and is shown with thick lines in Fig. 1. When the MT moves to enter the cell served by BS2, the optimal route to reach it is through SwitchC as shown by the dashed lines in the figure. SwitchA is selected as the COS as it is the convergence point of the old and the new routes and it is at this point that switching of cells to the new path takes place.

In this paper, the implementation and performance evaluation of a handoff scheme based on Acharya *et al.*<sup>12</sup> and Li *et al.*<sup>13</sup> and its integration with an open signalling system is presented. Open signalling is advocated by OPENSIG, a special interest group that works towards open standards in network signalling that allow third-party software creation as well as network programmability. Open signalling abstracts the functionality of diverse resources in the network to realize various networking services such as end-to-end connection setup with QoS guarantees. These resources are modeled as objects that interact through well-defined interfaces over distributed object-oriented computing platforms such as the *Common Object Request Broker Architecture* (CORBA). This allows a variety of network control algorithms to be

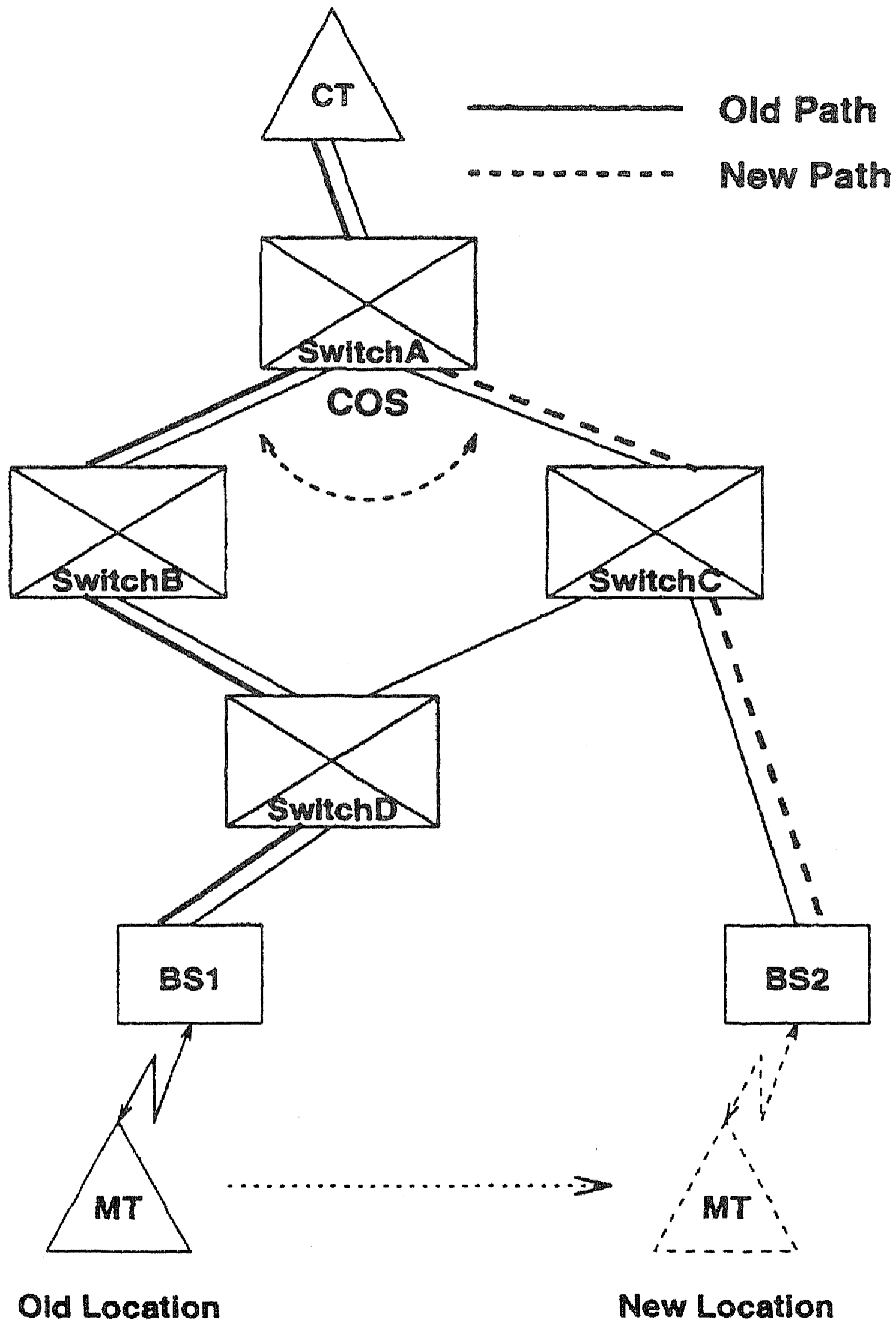


FIG. 1. An example of COS selection where Switch A is selected as the COS when the MT is handed over from BS1 to BS2.

implemented in a flexible manner. CORBA is used across all fixed network components. Though it can be deployed all the way up to the mobile terminal, the CORBA overhead may be too heavy for the scarce and unreliable wireless medium. The telecom domain task force of the OMG is currently working on the necessary changes required in CORBA to support wireless and mobile access. Instead of CORBA, one may choose DCOM as the distributed computing platform. The choice of CORBA for the reported work is purely based on its availability on Unix machines which are used in the ATM network. Open signalling is being standardized by the IEEE Project P1520 on Application Programming Interfaces for Networks.<sup>14</sup>

A simple UNI signalling stack was first implemented and later augmented with the handoff control messages and procedures. This was then integrated with a Handoff Manager that was implemented using Orbix, a commercial CORBA implementation. The Handoff Manager uses SNMP to communicate with commercial ATM switches and effect a handoff. An experimental system was set up to test the implementation and measure the handoff latency, transition delay and packet loss. The experiments demonstrated that such a set up could be used to implement handoffs effectively. The measured results indicate that handoff is accomplished with handoff latencies of around 92.4 ms, transition delay of around 18.5 ms and a low packet loss depending on the traffic characteristics.

The implementation of the handoff control procedures as well as the design of the Handoff Manager is detailed in Section 2. The experimental set-up and the results obtained are analyzed in Section 3. Finally, some conclusions are drawn in Section 4.

## 2. Handoff implementation

The handoff control messages and procedures are based on Acharya *et al.*<sup>12</sup> where the primitives for handoff were presented as incremental additions to the existing UNI signalling protocol. Hence, it was necessary to first study and implement a prototype UNI signalling stack before these extensions could be considered.

### 2.1. UNI signalling

The UNI Signalling Specification 4.0<sup>3</sup> provides call-and-connection control procedures at the ATM User to Network Interface. These procedures are defined in terms of messages and their information elements that are used to characterize the ATM connection. The UNI 4.0 is based on the BISDN signalling protocol specified by the ITU-T.<sup>15</sup>

For this prototype, the essential call-control states and messages were identified. The structure of the UNI messages is particularly suited to an object-oriented implementation as the information elements present within them may occur in any order and different messages are made up of the same types of information elements. This implementation of the encoding and decoding of messages can be easily extended to include new messages when required. The UNI signalling states and procedures were implemented as two entities, a *user* and a *network* that performed the functions of the two sides of a UNI, respectively.

The UNI signalling messages are transferred via the *signalling AAL* (SAAL) which provides for a reliable transport between peer entities. It consists of three layers, the Common Part

**Table I**  
**New messages for handoff control**

New message	Functions
Handoff Request	Select COS, set up new subpath
Handoff Response	Connect new path, indicate new path ready
Handoff Confirm	Inform COS to enable new path
Handoff Confirm Complete	Response to Handoff Confirm and release old subpath
Handoff Join	Complete connection through BS2 by joining the wireless link between BS2 and MT
Handoff Join Complete	Connect wireless path

which is as specified for the AAL Type 5, the *Service Specific Connection Oriented Protocol* (SSCOP) which ensures the reliable transfer of data and finally the *Service Specific Coordination Function* (SSCF).

This layered structure of the signalling stack was implemented using an object-oriented design with each layer modeled as an object. These objects were then integrated and the entire signalling stack was tested for compliance by setting up a VC to the UNI signalling module on the Fore ASX 200, a commercial ATM switch. The SSCOP connection was established and the correct sequence of messages was exchanged over this connection.

## 2.2. Signalling for Handoffs

In order to effect a handoff operation, the new signalling messages that were proposed in Acharya *et al.*<sup>12</sup> are required and are shown in Table I. These messages and procedures were implemented and integrated with the UNI signalling system.

## 2.3. Handoff manager

One of the disadvantages of an incremental re-establishment handoff algorithm is that all the switches in a network have to support the augmented signalling protocol. In order to overcome this difficulty and at the same time facilitate the programmability of the network, a Handoff Manager entity was implemented using the distributed programming approach of CORBA.

It was thus possible to run the Handoff Manager on any node connected to the network while freeing the switches from the additional load of handling handoff requests and responses. The Handoff Manager is modeled as a centralized controller that manages the re-routing and COS selection functions. It receives handoff requests from the BSs via CORBA calls on its methods and processes them according to the handoff algorithm used. It re-routes connections using the Dijkstra's shortest path algorithm<sup>16</sup> to obtain the optimal routes and also to select the COS. It then communicates with the switches via SNMP to map the new routes into their VC routing tables.

## 2.4. Handoff emulation

Work is in progress on defining standards for wireless ATM air interfaces. Thus, there is a lack of commercially available wireless ATM hardware products. Due to this limitation, the implementation of the handoff procedure in this project concentrates on the wireline part and the

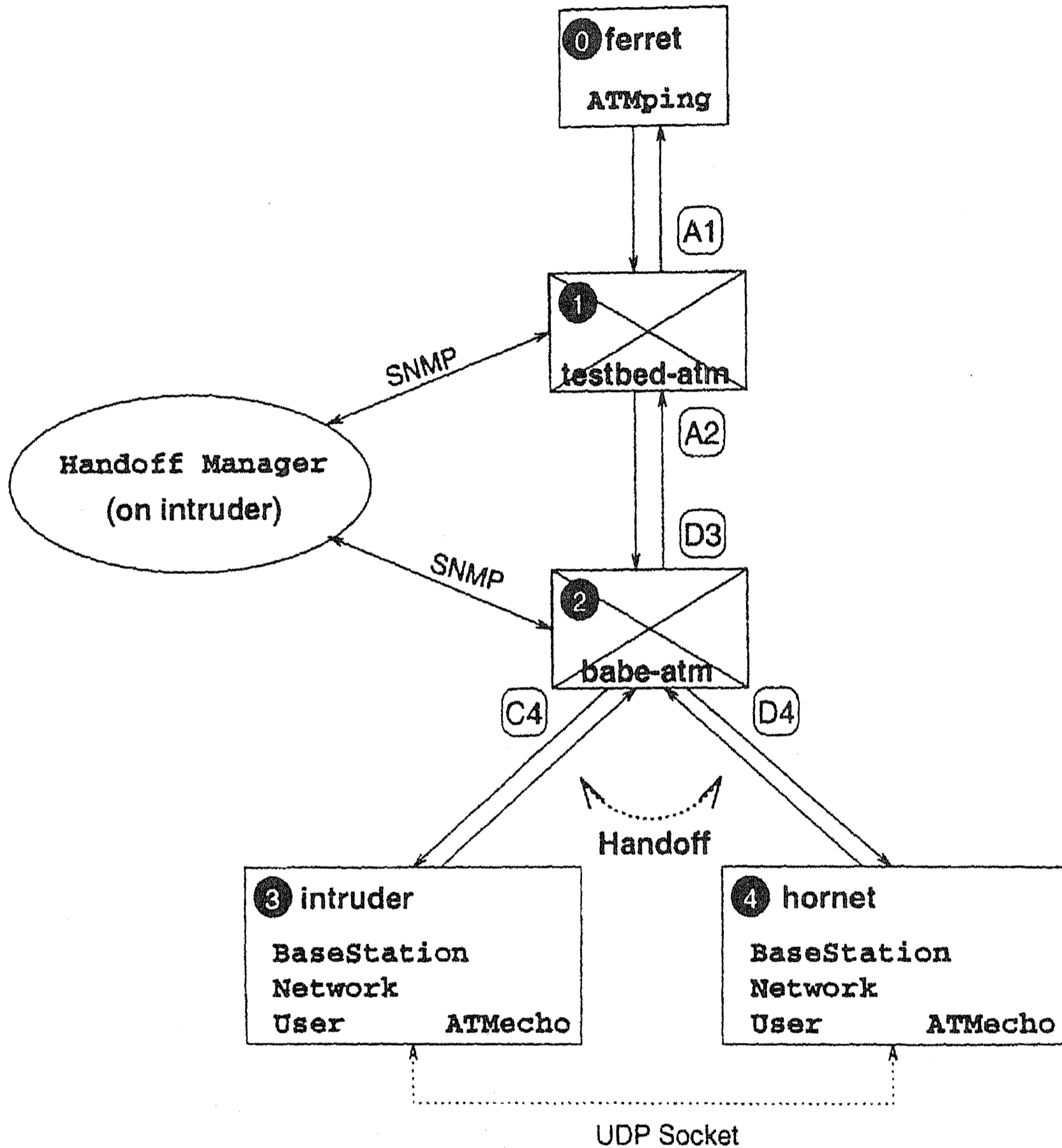


FIG. 2. System configuration of the experiment.

handoffs are emulated in software. The *handoff emulation system* is shown in Fig. 2. The workstations which are labeled in the figure as *intruder* and *hornet* act as the BS during the emulated handoff.

The interacting software processes are shown in Fig. 3. The MT is emulated by a process which contains the *user* side of the UNI signalling stack augmented with handoff messages. The *user* communicates with the *network* side via a UNIX socket. This UNIX socket repre-

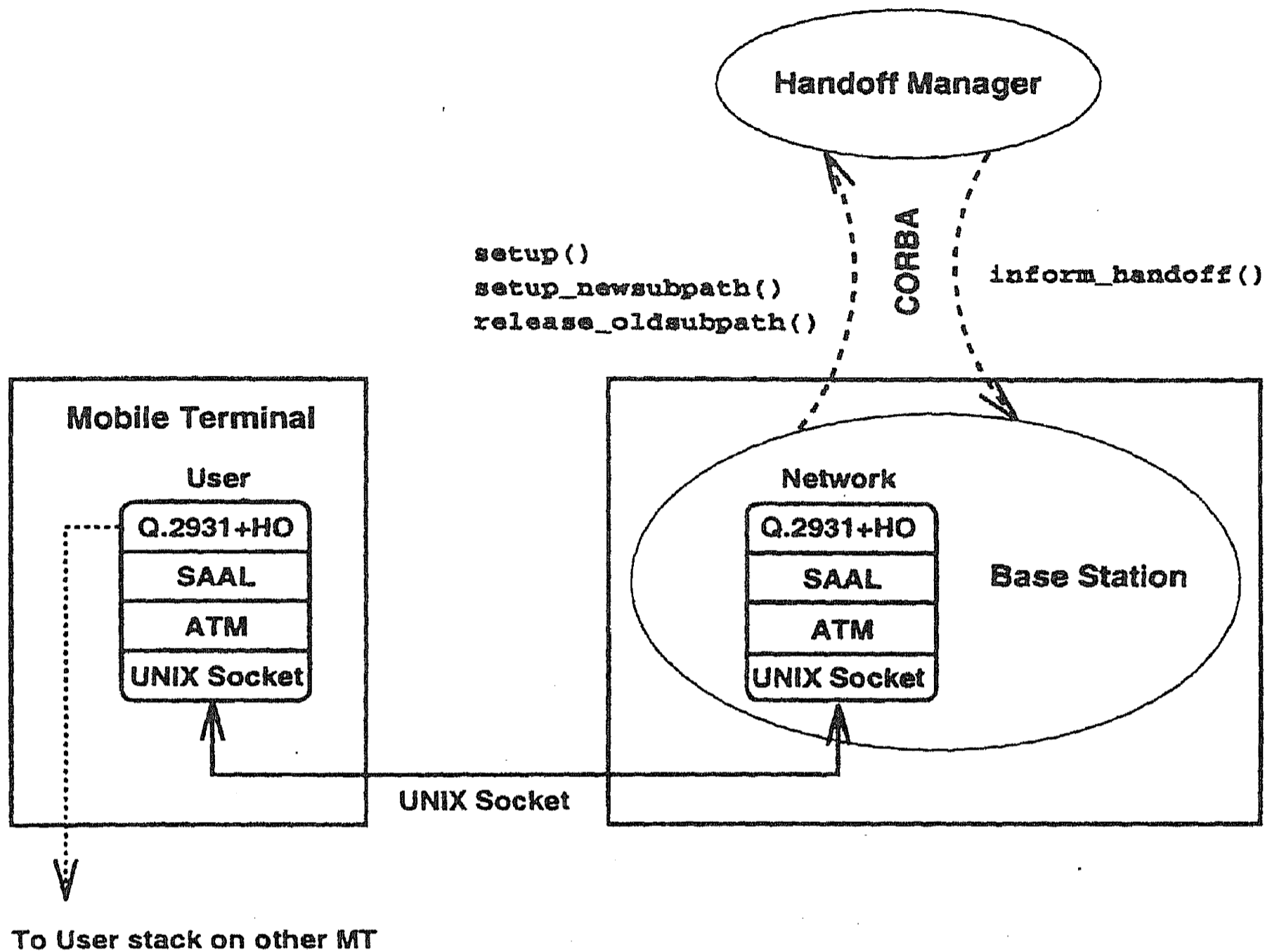


FIG. 3. Interaction between processes on a BS and an MT.

sents the radio link for the emulation of handoff in the prototype. The *network* side receives the messages and processes them according to the procedures in UNI 4.0. The sequence of messages exchanged between the entities is shown in Figure 4.

The *network* calls the `setup()` method of the Handoff Manager in order to create an initial VC. The MT can request a handoff operation by transferring a Handoff Request message across the emulated radio link. On receiving this message, the *network* side calls on the `setup_newsubpath()` method of the Handoff Manager. The Handoff Manager computes the new route for the connection and selects the COS. It then sets up the new subpath by sending SNMP messages to the switches on the route. After the new subpath has been created, the Handoff Manager informs the new BS about the connections that have been handed-off by means of a `inform_handoff` call to the new BS. When the new subpath has been created, the *network* transfers a Handoff Response message to the *user*. The *user* replies with a Handoff Confirm message to indicate that it is ready to switch to the new BS. At this time, the MT stops transmitting cells to the current BS. The *network* invokes the `release_oldsubpath()` call on the Handoff Manager which deletes the old subpath and switches the data to the new subpath. The *network* informs the *user* that it may now switch to the new BS by sending a Handoff Confirm Complete message.

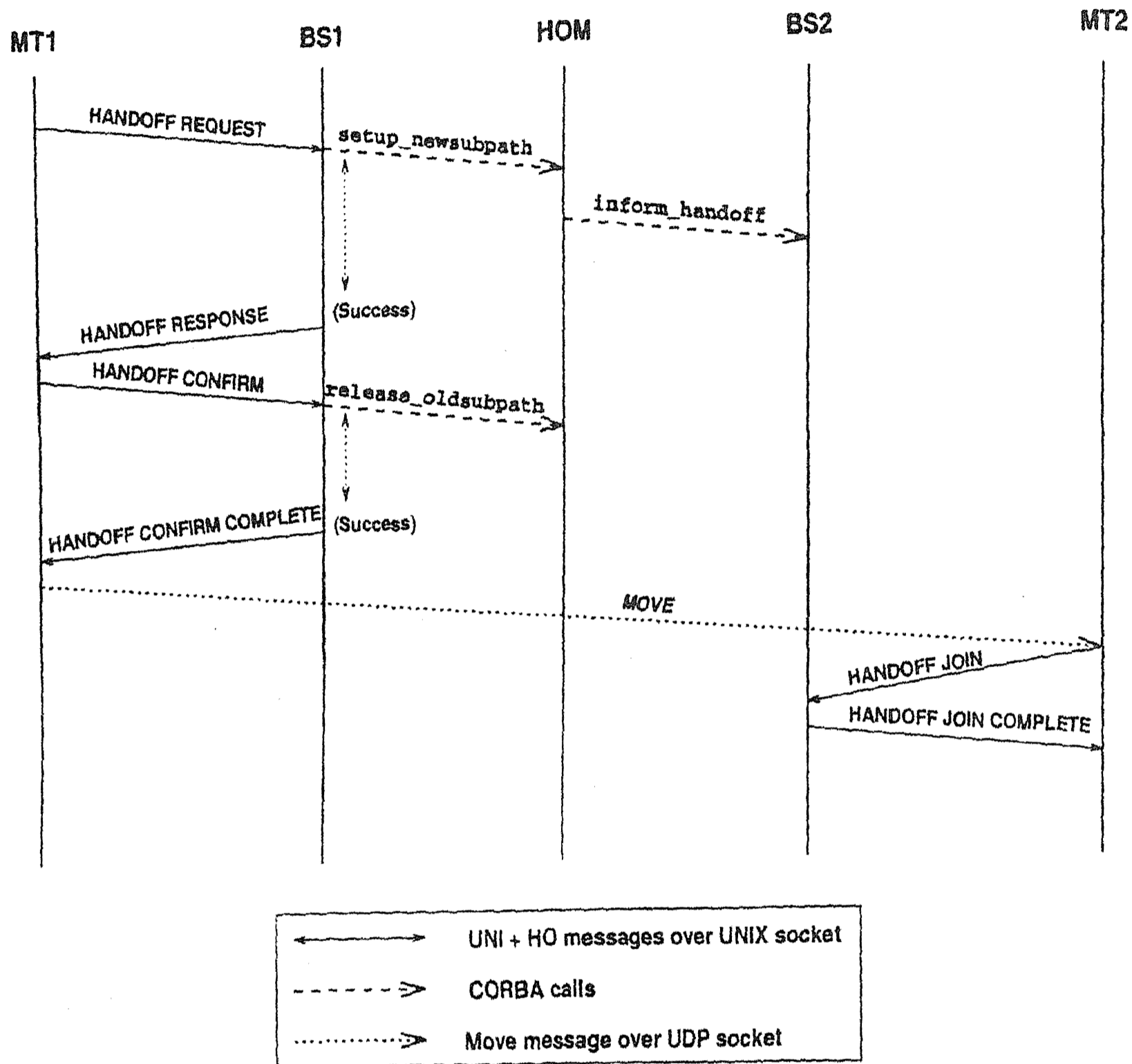


FIG. 4. Handoff procedure.

Now, the MT must switch to the radio port on the new BS and start communicating with the new BS. This procedure is emulated in software by the *user* entity on the old BS sending a 'Move' message to the *user* entity on the new BS over a UDP socket set up for this purpose. On receiving this message, the second *user* process starts signalling to the *network* process in the new BS. The first *user* process stops communicating with the *network* process to signify that the MT has moved to the new location and is no longer within the coverage area of this BS.

### 3. Experimental results

The experiments were carried out on the handoff emulation system in order to characterize the *handoff latency*, the *transition delay* and the *packet loss*. The experimental setup and procedure is similar to that described in Li and Yuan.<sup>17</sup>



**Table II**  
**Configuration of machines in the experimental set-up**

Machine name	Configuration
ferret	Sun SPARCstation-10 with two TMS390Z55 CPUs @50MHz, 132Mb RAM, SunOS 5.3
intruder, hornet	Sun Ultra-1 with UltraSPARC CPU @167 MHz, 64Mb RAM, SunOS 5.5
babe-atm	Fore ASX-200 ATM Switch, 8 OC-3 155Mbps ports, ForeThought 4.0.2
testbed-atm	Fore ASX-200BX ATM Switch, 8 OC-3 155Mbps ports, ForeThought 4.1.0

The configuration of the machines shown in Fig. 2 is tabulated in Table II. The two switches, *babe-atm* and *testbed-atm* run the SunOS 4.1.3 operating system as well as the SNMP agent daemon. The three workstations used are *intruder* and *hornet* and *ferret* that are equipped with Fore SBA-200E ATM Network Adapters and are connected to the switches as shown. Figure 2 also shows the software processes that are running on each machine.

### 3.1. The ATMPing application

To characterize the packet loss due to a handoff, it was necessary to transfer data over the VCs that were handed off and determine the number of lost packets per handoff. The ATMPing and ATMecho applications as described in Yuan *et al.*,<sup>10</sup> were implemented for this purpose.

The ATMecho application continuously reads from the incoming VC and echoes the data to the outgoing VC. It also has a feature whereby on receiving a signal from the User process, it stops echoing the packets and starts discarding them. This feature is used while emulating the ceasing of transmission and reception between the time the MT leaves BS1 to the time when it completes registration with BS2.

The ATMPing application is used to generate traffic of a desired nature. It sends out packets at regular intervals after numbering them with a sequence number and time stamping them. It receives the echoed packets and determines the round trip time as well as the number of packets that were lost during the handoffs.

### 3.2. Results and comparison

On start up, a duplex VC connection was set up between one of the MTs and the CT. Then, the ATMPing and ATMecho applications were started on the CT and MT ends of this connection, respectively. Next, a sequence of handoffs was initiated where the connection was handed off repeatedly between the two BSs after regular intervals of 1 s. The messages shown in Fig. 4 were exchanged between the entities for each connection during each handoff.

A packet loss can occur in three situations. First, the VC routing table change occurs within the cell stream that belongs to one AAL PDU. This results in part of the packet being sent to the old BS and the other part arriving at the new BS. Therefore, AAL reassembly cannot be performed successfully at both BS due to a failed checksum and both the BSs reject the entire packet. Second, since the packets are sent and echoed via a duplex VC link, and the VCs are changed one after the other, it may be possible that the routing change occurs after the packet

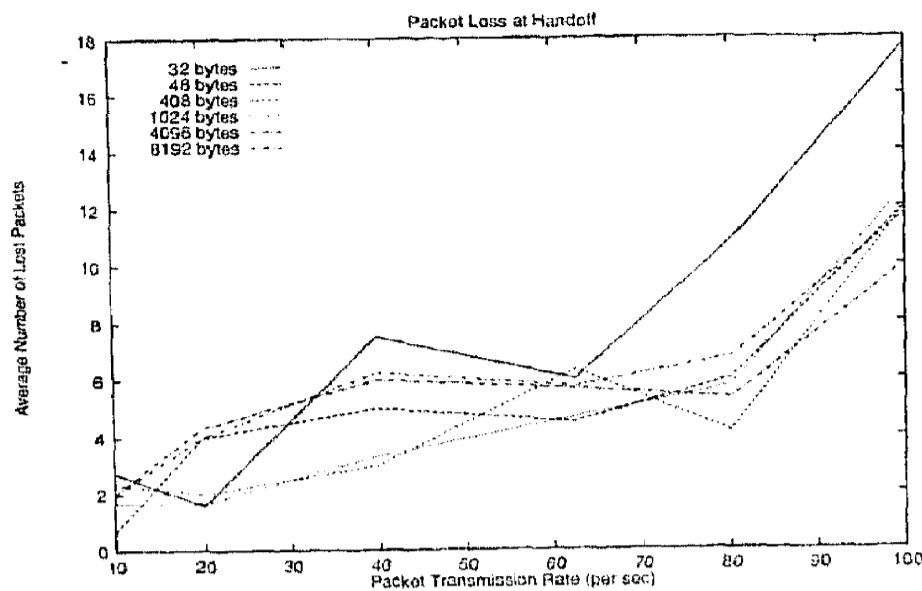


FIG. 5. Packet loss when using AAL 3/4.

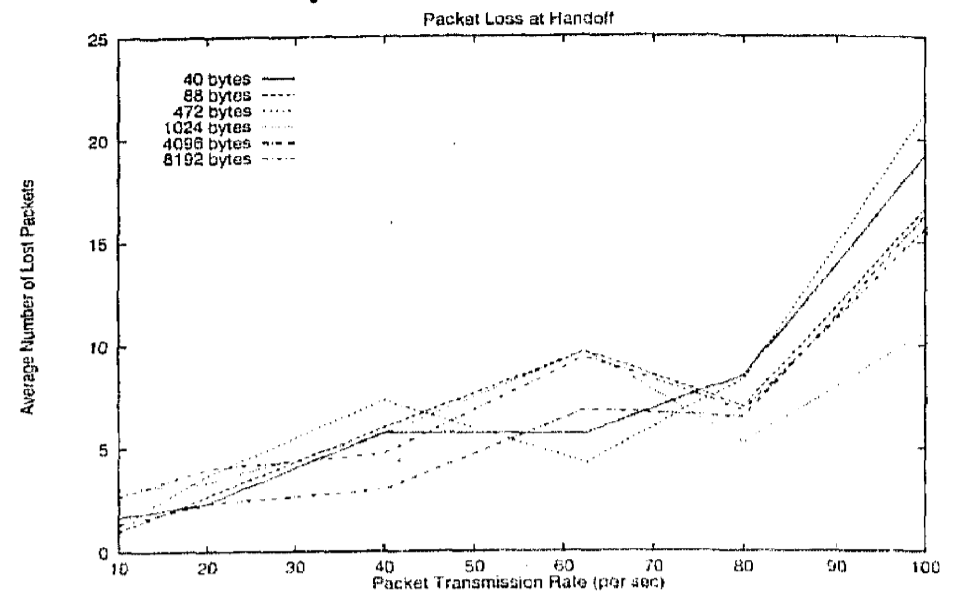


FIG. 6. Packet loss when using AAL 5.

has exited the switch (towards the old BS) and before the old BS can echo it back. A third instance of packet loss is when the MT is in the process of shifting from BS1 to BS2. The data path has been already shifted to BS2 but the ATMecho process on BS2 discards packets until the User process finishes registering with BS2.

For a given packet transmission rate, the average packet losses were calculated over a total of 20 handoff operations. The traffic profile was varied by changing the packet size, the packet transmission rate as well as the AAL type used to transport the packets. The packet loss as a function of the transmission rate was plotted for AAL 3/4 and AAL 5 in Figs 5 and 6, respectively, for different packet sizes.

As can be seen from the plots, as the packet rate is increased, there is a general trend towards an increase in the number of packets lost. This can be expected because a larger packet rate implies that the number of cells crossing the switch towards either BS is larger and will result in a larger number of the cells being lost due to the three factors mentioned before. This is also borne out by the fact that if the packet rate is held constant while the packet size is increased, effectively increasing the number of cells per second, then the number of lost packets also increases.

It is also observed that the number of lost packets when AAL 3/4 is used to transport them is greater than when AAL 5 is used. This may be due to the fact that AAL 3/4 has a greater overhead, especially for short messages. In addition to an overhead of 8 bytes added to every packet in the Convergence Sublayer, the SAR also adds 4 bytes to every cell. AAL 5, on the other hand, only adds an 8-byte CPCS trailer to every message. The computation of the 10-bit CRC for each cell in AAL 3/4 also contributes to a larger processing delay for these packets.

The *handoff transition* delay is the transition delay for changing the VC routing table on the switch for the two VCs of the duplex connection. This could not be measured directly as access to the internal structures of the switch was not possible. Since the VC routing entries were changed via SNMP, an approximation of the transition delay could be obtained by measuring the time delay between the sending of the SNMP SetRequest-PDU and the receipt of the GetResponse-PDU indicating a success. The control of the switch via SNMP allowed the

change of only one VC routing table entry at a time. The average time required for this was measured to be 18.46 ms. A large part of this is due to the round-trip times of the SNMP PDUs themselves.

The *handoff latency* was measured as the delay between the start of the handoff process, i.e. the sending of the Handoff Request message by the MT to the receipt of the Handoff Confirm Complete message. It depends on the number of signalling messages, their propagation delay in the wired network and the loading of the processors in the wired network. The handoff latency has a direct bearing on the buffer requirements at the BS and the MT which must be minimized as far as possible to reduce the overall cost of the system. For the experimental set-up used in this study, the propagation delay for messages between the User and Network processes was negligible as they were transferred over a UNIX socket. However, there may be a considerable delay associated with the CORBA calls that are made as well as the transfer of messages across UDP sockets. The very first handoff request will require the creation of all the CORBA objects and the associated initializations. Thus, the time delay for such a 'cold start' will be considerable and was measured to be around 1.4 s. Once all the servers are in operation, subsequent handoff requests have on the average shorter handoff latencies of 92.42 ms.

As mentioned earlier, a set-up at the NEC C&C Research Laboratories was used to measure the parameters as described in Yuan *et al.*<sup>10</sup> and the results are presented in Li and Yuan.<sup>17</sup> However, the NEC system used an extension of Fore System Simple Protocol for ATM Network Signalling (SPANS) to perform handoffs. The SPANS module on a Fore ASX-100 switch was modified to accept the new messages and to directly access the VC route table of the switch and write to it. This enabled the system to have a low handoff transition delay of below 1 ms. In contrast, the transition delay of the system under study is much larger at 18.46 ms due to the overheads of the SNMP communication. An alternative solution to the control of the switch could be to use the *General Switch Management Protocol* (GSMP)<sup>18</sup> that provides messages to add and delete a branch to an existing ATM connection that could be used to set up and release the subpaths in handoffs.

The packet loss statistics of this system compare favorably with the NEC system, with a similar increase in packet loss with an increase in the transmission rate. The handoff latency of the NEC system was 14.5 ms. The corresponding latency for this system is 92.42 ms, which is much larger due to the larger transition delay that occurs four times for the handoff of a single duplex connection. However, the approach followed in this paper is more general as we use SNMP to control the switches.

In order to study the effect of the handoff latency on the packet loss rate, the experiments described earlier were conducted with a variable delay introduced between the time that the MT receives a Handoff Response message and the time that the MT responds with a Handoff Confirm message. By increasing this variable delay, the handoff latency can be increased and correspondingly the packet loss rate increases. This is seen in Fig. 7 which plots the packet loss rate against the handoff latency. From this plot, it is possible to calculate the packet loss rate for a system with a given handoff latency and this can enable the designer to dimension the buffer size.

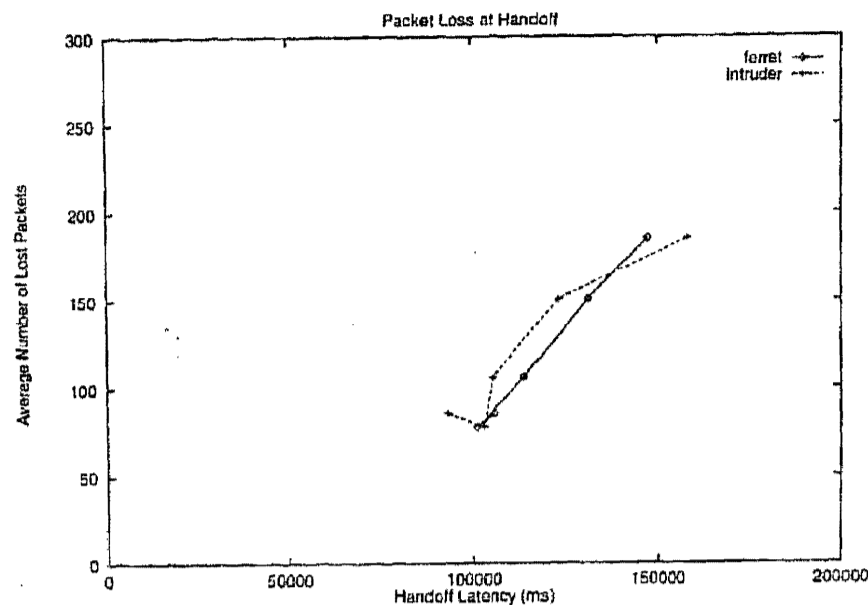


FIG. 7. Packet loss rate as a function of handoff latency.

#### 4. Conclusions

Mobility support in ATM networks will become increasingly important due to the demand for high bandwidth access for mobile end systems. In this paper, the design and implementation of a framework for handoff management in a wireless ATM network is presented. A prototype UNI signalling stack incorporating signalling extensions for mobility is implemented. The handoff is performed by a Handoff Manager which is a CORBA entity controlling the switches via SNMP. This approach is flexible, versatile and WATM mobility management can be realized using commercially available ATM switches. The transition delay for changing the VC routing table on the switch via SNMP is measured to be 18.46 ms. This is relatively very high and the major component of this delay is the propagation time of the SNMP PDU and its processing time. The handoff latency, measured to be 92.42 ms, is relatively high with the major contribution being the large transition delays. The packet loss for various traffic conditions due to a series of handoffs is measured and analyzed. It is found that fewer packets are lost when using AAL 5 as compared to AAL 3/4. An important future direction of this work is the integration of the signalling system with WATM hardware. In such a network, the end-to-end performance using a wireless link during handoffs and the impact of degradation in the wireless link on the connection could be evaluated.

#### Acknowledgements

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