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Wireless LAN Emulation over ATM Networks

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Abstract

In this paper, the main issues of wireless LAN Emulation over ATM networks are addressed and investigated. One of the most important issues is to support the transparent services for the mobile terminals. We show that the conventional LAN Emulation service, defined by the ATM Forum, for the legacy LANs (Ethernet/FDDI/Token ring) is not efficient enough to handle the handoff of the wireless LANs. The communication path will be elongated as the mobile terminals move into the neighboring cells. This is undesirable since an elongated path not only consumes too much bandwidth but also introduces additional delay. To overcome this problem, a seamless handoff scheme is proposed for the ATM-based wireless LANs. This scheme not only meets the basic handoff requirements (data continuity and transparency), but also offers a shorter path. A path migration scheme is also suggested to migrate an inefficient path to a better one, if any. The effectiveness of the proposed handoff/migration schemes to the wireless LAN Emulation service is demonstrated via simulation. Simulation results show that the proposed handoff/migration schemes perform much better than the conventional LAN Emulation scheme in terms of the average number of hops consumed per virtual connection.

Keywords

ATM, handoff, path migration, wireless LAN emulation

1 INTRODUCTION

With the rapid proliferation of portable computers, the availability of license-free frequency bands and the promise of reduced costs for office rearrangement, wireless local area networks (LANs) have become an emerging technology for today's computer and communication industries. A user no longer is required to maintain a fixed position in the network and "computing anywhere, at any time" is becoming a reality. Mobility and portability will create an entire new class of applications and possibly, new massive markets combining personal computing and consumer electronics. Accordingly, the IEEE project 802 formed working group 802.11 to establish a recommended international standard on medium access control (MAC) methods and physical layer (PHY) specifications for wireless LANs [2].

The basic building block of a wireless network is a *cell* called a basic service area (BSA). Each cell is covered by a base station (BS), which exchanges radio signals with wireless mobile terminals (MTs). A group of MTs within a BSA that are associated with each other to communicate forms a Basic Service Set (BSS). Wireless LANs have limited ranges and are designed to be used only in local environments. In order to interconnect different BSSs, the wireless LAN should be further connected to a more extensive wireline (infrastructure) network such as LAN, WAN and the Internet, etc. In this interconnection, the BSs provide a wireless communication link between the MTs and the infrastructure network.

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A typical example of the infrastructure networks is the asynchronous transfer mode (ATM) based switching network [4], [9]. It can provide enormous switching capacity and is the target transport technique for implementing the B-ISDN. Differing from those shared-medium LAN access methods, ATM is a connection-oriented service, i.e., data may not be sent until a virtual channel connection (VCC) is established. A typical network configuration of interconnected wireless LANs based on ATM network is shown in Figure 1; where each square box represents an ATM switch. Each of the BSs here acts like a wireless LAN-to-ATM converter. Currently, there are two approaches for integrating ATM and LAN traffic: router option and bridging solution. The former approach results in network layer to be implemented directly over ATM, e.g., the IP over ATM [13]. This approach offers the efficiency by avoiding unnecessary complexity of the data link layer. However, there are many network layer protocols, such as IP, IPX, Appletalk, SNA, DECnet etc., and each one must be interfaced to ATM individually. The latter approach is to define an ATM MAC layer that is totally independent to upper layer protocols, and compatible with Ethernet, token ring and wireless LAN MACs. The process of mapping connectionless to connection-oriented communication is the so-called ATM LAN Emulation (LE) service developed by the ATM Forum to be standard [6].

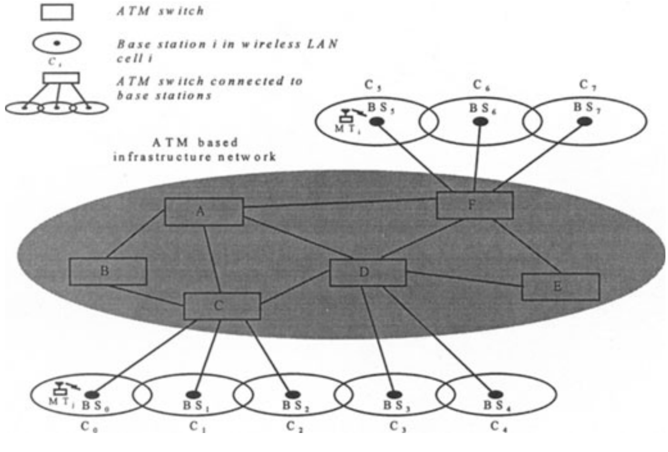


Figure 1 A typical wireless LAN interconnection via ATM based switching network.

The LE service defined in the ATM Forum uses the available bit rate (ABR) bandwidth [12], [14]-[15] and a VCC is established between the two bridges connect the two LANs. One of the properties of such service is that all the ATM cells of the frames transmitted between two LANs are assigned with the same VPI/VCI. The cells of a frame are reassembled by the destined bridge which then further forwards the frame to the destination station according to the destination MAC address. This means that the ATM switches along the VCC do not have the capability to distinguish the cells from different frames. Since terminal mobility is one of the important characteristics of a wireless LAN, the handoff/roaming impact on LE service should be addressed carefully. Generally, the mobility can be classified into two categories: intra-switch mobility and inter-switch mobility. An ATM switch might connect several BSs, each of which covers one wireless LAN cell. Assume that an MT_i is moving from C_i to C_j. Then the mobility is called an intra-switch mobility if BS_i and BS_j are connected to the same ATM switch. Otherwise, it is called an inter-switch mobility.

It is interesting that the mechanism of sharing a VCC by all the frames transmitted between a pair of LANs, as defined in the ATM Forum, is not suitable well for the wireless LAN due to the terminal mobility. For example, as shown in Figure 1, consider an extremely simple case where two mobile terminals MT_i and MT_j within cells C_5 and C_0 respectively are communicating to each other. Assume now MT_j moves into C_1 (an intra-switch mobility). Then it is clear that the ATM cells for the MT_j "should be" forwarded into BS_1 by the ATM switch C. However, since the ATM switches do not have the capability to distinguish which cells on the VCC should be forwarded, the only way to provide a seamless handoff is to establish another VCC (say, $VCC_{0,1}$) from BS_0 to

BS_1. In other words, the *BS_0* will first reassemble the cells for the *MT_j*, check the destination address (now moved out), and then segments the frame into cells and forwards the cells into the new established $VCC_{0,1}$ again.

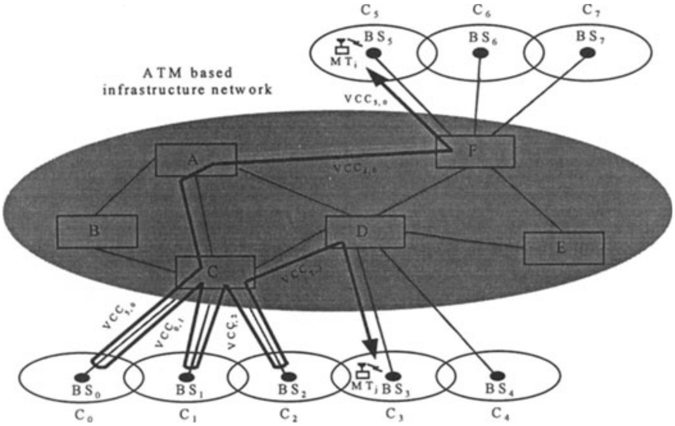


Figure 2 An example of intra- and inter-switch mobility.

This approach is quite simple and the original scheme for interconnecting the legacy wireline LANs can be applied directly. Nevertheless, as we can see, the communication path (or the $VCC_{5,0}$) is elongated as ($VCC_{5,0}$, $VCC_{0,1}$). The phenomenon of path elongation will be more serious for the inter-switch mobility. For example, if *MT_j* further moves into *C_2* and *C_3*, then the communication path between *MT_i* and *MT_j* might be elongated as ($VCC_{5,0}$, $VCC_{0,1}$, $VCC_{1,2}$, $VCC_{2,3}$) as shown in Figure 2. Therefore, it is desirable to have some mechanism to migrate an elongated path to a shorter one, if any. For example, two of the possible shorter and better paths for this elongated path are *(BS_5, F, A, D, BS_3)* and *(BS_5, F, D, BS_3)*.

In this paper, we will address the main issues of wireless LAN Emulation over ATM networks. One of the most important issues is the providing of transparent services for the mobile terminals. To do this, we propose a seamless handoff mechanism for the ATM based wireless LANs. For an intra-switch mobility, the handoff can be achieved by simply informing the corresponding ATM switch to change the data path from one port to another internally. For an inter-switch mobility, the handoff can be done by establishing a shorter VCC, if any. A path migration is also suggested to migrate an inefficient path to a better one, if any. The proposed handoff/migration schemes are evaluated by simulation. Simulation results demonstrate that the proposed schemes perform much better than the conventional LAN Emulation scheme, provided by the ATM Forum, in terms of the average number of hops consumed per virtual connection.

This paper is organized as follows. In Section II, we give an overall description to wireline LE service over ATM networks. The issues for the wireless LE service over ATM networks are discussed in Section III. The proposed seamless handoff scheme as well as the path migration mechanism are also addressed. The simulation model and simulation results are reported in Section IV. Finally, some concluding remarks are given in Section V.

2 WIRELINE LAN EMULATION

The goal of LAN emulation is to use ATM's connection oriented fabric to emulate the connectionless nature of a LAN. All the devices on the Ethernets and token rings require no modification; they simply plug into a legacy ATM-LAN bridge. The bridge is operated in layer 2 that accepts native LAN frames and slightly modifies them by adding an LE header (same as the LECID described below) and stripping off the 4-byte frame check sequence [6]. Finally, the bridge sends them out onto the ATM network as AAL5 protocol data units [5], [10]. In this section, we briefly describe the LE components and the interactions among them.

2.1 LE components

The ATM Forum LAN Emulation Sub-working Group has defined a number of different components in an emulated LAN network, which include LE clients (LECs), an LE server (LES), a broadcast and unknown server (BUS) and an optional LE configuration server (LECS) [6]. The LEC is the entity in end system which performs data forwarding, address resolution, and other control functions. It is always built within ATM workstations or ATM bridges. The LES provides a facility for registration and resolving MAC addresses and/or route descriptors (for token ring) to ATM addresses. The BUS handles data to broadcast address and to any multicast address. It may also handle *initial* unicast data which are sent by a source LEC before a direct virtual connection to the destination LEC is setup. The LECS implements the assignment of individual LECs to different emulated LANs. It also provides configuration information to LECs to locate LES for joining an emulated LAN.

2.2 LE connection types

An LEC has separate VCCs for control traffic and for data traffic. These VCCs form a mesh of connections between the LECs and other LE components.

- Configuration Direct VCC is a bi-directional point-to-point VCC between an LEC and the LECS to obtain the ATM address of the LES.
- Control Direct VCC is a bi-directional point-to-point VCC between an LEC and the LES for sending control traffic.
- Control Distribute VCC is a unidirectional point-to-point or point-to-multipoint VCC from the LES to the LECs for distributing control traffic.
- Data Direct VCCs are bi-directional point-to-point VCCs and established between each pair of LECs who need to exchange unicast data traffic.
- Multicast Send VCC is a bi-directional point-to-point VCC between an LEC and the BUS. This VCC is setup using the same process as for the Data Direct VCC.
- Multicast Forward VCC is a unidirectional VCC from the BUS to the LECs for distributing data from the BUS. This can be either a point-to-multipoint or point-to-point VCC.

2.3 Functions of LAN Emulation Service

LEC initialization

For an LEC to join an emulated LAN, it first has to find the ATM address of the LES, which can be done in several ways [6]. Once the LEC has the ATM address of the LES, it needs to determine what type of emulated LAN it is about to join and the maximum data frame size allowed on the LAN. To do this, the LEC creates a bi-directional Control Direct VCC to the LES via signalling procedures. After a successful LE-JOIN process, the LES assigns an LE client identifier (LECID), that is unique among all the LECs joined to the same emulated LAN, to the LEC. After completing the JOIN phase, the LEC setups a Multicast Send VCC to the BUS.

Address resolution

Address resolution is used to translate a MAC address to an ATM address. When an LEC has a frame for transmission and the corresponding ATM address of the destined LAN is unknown, the LEC issues a LAN emulation address resolution protocol request (LE-ARP-Request) to the LES via the Control Direct VCC. In order to transmit the frame as soon as possible, while the LEC is waiting for a response from the LES, it sends the frame to the BUS. When the LES receives an LE-ARP-Request, it forwards this LE-ARP-Request frame to all proxy LECs (bridges). Only the one with the requested MAC address will respond this request with the ATM address of the bridge.

Flush message protocol

The flush message protocol allows the source station to avoid the possibility of delivering frames out of order when there are two paths between the source and the destination. To do this, the sender first issues an LE-FLUSH-Request down to the old path, then sets some appropriate table entries so that any further frame for the given LAN destination will be buffered (or discarded if buffer is not enough) at the sender without transmitting. The LE-FLUSH-Response must be returned to the sender by the receiving client via Control Direct VCC or

Control Distribute VCC. Once the sender receives the LE-FLUSH-Response, it knows that the old path is clear of data for a given LAN destination, and uses the new path to transmit the buffered frames.

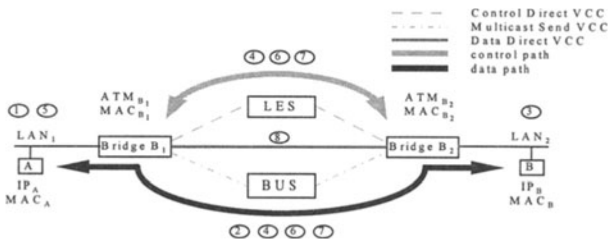


Figure 3 The procedure of using the LE services.

Data transfer

Now we use an example to describe the procedure of transmitting a frame over an emulated LAN. Assume two LANs (LAN_1 and LAN_2) are interconnected to an ATM network via two bridges B_1 and B_2, respectively (as shown in Figure 3). There are two end stations *A (ES A)* and *B (ES B)* which are located at LAN_1 and LAN_2, respectively. Also assume that station *A (B)* has a MAC address MAC_A (MAC_B) and an IP address IP_A (IP_B). Since bridge B_1 (B_2) attached to the ATM network, it has an ATM address ATM_{B_1} (ATM_{B_2}) and a MAC address MAC_{B_1} (MAC_{B_2}). By address learning process [1], assume bridge B_1 (B_2) also learned the MAC_A (MAC_B). We describe the procedure of transmitting a message from station *A* to station *B* when station *A* only knows the IP address of station *B* (a typical case in the real world). Therefore, the first step for transmission is to find the MAC_B from the IP_B. Then station *A* can transmit the frames accordingly. Following are the detailed steps to achieve this goal under the LAN Emulation environment:

1. *ES A* issues an IP-ARP-Request (with IP_A, MAC_A, IP_B) to look for MAC_B. This request is received by Bridge B_1.
2. Bridge B_1 forwards this request to LAN_2 via the BUS and Bridge B_2.
3. *ES B* replies an IP-ARP-Reply (with IP_A, MAC_A, IP_B, MAC_B). This reply is received by Bridge B_2.
4. Since Bridge B_2 does not know the corresponding ATM address of MAC_A, it forwards this reply to LAN_1 via the BUS and Bridge B_1. In the meantime, Bridge B_2 issues an LE-ARP-Request to the LES to find the corresponding ATM address of MAC_A. The LES returns ATM_{B_1}. Bridge B_2 then establishes a bi-directional Data Direct VCC to Bridge B_1.
5. As *ES A* receives this reply, it begins to transmit a frame (with MAC_A, MAC_B) to *ES B*. This frame is first received by Bridge B_1.
6. Since Bridge B_1 does not know the corresponding ATM address of MAC_B, it forwards the frame to LAN_2 via the BUS and Bridge B_2 again. In the meantime, it issues an LE-ARP-Request (with MAC_B) to the LES. The LES returns ATM_{B_2}. Bridge B_1 found that a Data Direct VCC is already established between Bridges B_1 and B_2 (by step 4).
7. To use the Data Direct VCC, Bridge B_1 first issues an LE-FLUSH-Request to Bridge B_2 via the BUS. Bridge B_2 returns an LE-FLUSH-Response to indicate all the frames on the old path (B_1-BUS-B_2) are cleared.
8. When Bridge B_1 receives this response, it switches the path to B_2 from B_1-BUS-B_2 to B_1-Data Direct VCC-B_2. The followed frames from *ES A* to *ES B* will be delivered along the new path.

Based on the above description, we can observe that, basically, only *one* Data Direct VCC is required between each pair of LANs for carrying LE data frames. The reason is that it is unrealistic to predict the bandwidth requirements of bursty data traffic in advance; and therefore a service that dynamically shares the available bandwidth between all active end stations is required. This service is referred to as available bit rate (ABR) service [12], [14]-[15].

In summary, (1) the LE service is one kind of ABR service class. (2) For data transfer, only one Data Direct VCC is needed between each pair of LANs.

3 WIRELESS LAN EMULATION

In this section, a seamless handoff scheme will be proposed to resolve the intra- and the inter-switch mobility. For an intra-switch mobility, no path elongation is required. That is, the routing overhead due to mobility has been minimized. As for an inter-switch mobility, the elongated path is kept as short as possible. In addition, a shortest-path based migration is performed, if necessary, to eliminate the elongated path due to an inter-switch mobility.

3.1 The seamless handoff scheme

Recall that a seamless handoff should meet the following requirements:

- data continuity,
- transparent to other MTs,
- less routing load (elongated path) to infrastructure network.

In order to offer the seamless handoff, we recognize that any pair of communicating MTs, instead of any pair of LANs in traditional LAN Emulation described above, should establish an individual Data Direct VCC. Based on this property, the mobility transparency and the elongated path reduction are easier to obtain. In the following, we will describe the seamless handoff scheme for the intra- and inter-switch mobilities. First of all, some routing databases and virtual connection (VC) types within the *BSs* and ATM switches are introduced.

Routing databases and VC types

MT pair-VCC mapping database (MVD): Recall that each pair of communicating MTs has an individual virtual connection, which is identified by a virtual path/channel identifier (VPI/VCI). Thus a *BS* has to maintain an MT pair-VCC mapping database (MVD) for frame forwarding.

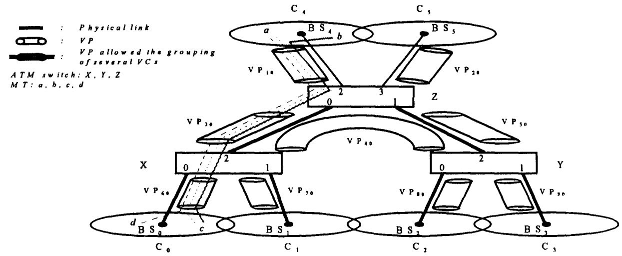
ATM switch routing database (SRD): At each switching node, the incoming VCC (IN-VCC) and incoming port (IN-PORT) of an arriving ATM cell are used as indices in the switch routing database (SRD) to uniquely identify the outgoing port (OUT-PORT) and the outgoing VCC (OUT-VCC) associated with the next link. Thus, at each switching unit, the mapping tuple (IN-VCC, IN-PORT, OUT-VCC, OUT-PORT) uniquely defines a VCC.

Signalling VC: It is a predefined VPI/VCI value (VPI=0, VCI=5) for supporting of demand (switched) channel connections. These connections are established in real time using signalling procedures [3], [7]-[8].

Handoff VC: Here we define a handoff VPI/VCI value to carry the messages of handling a mobility. The handoff VC is a point-to-point connection between a *BS* and an ATM switch or between two ATM switches.

Intra-switch mobility

For the sake of simplicity, we use the term "mobile connection" to refer the virtual connection between any pair of MTs. These mobile connections are dynamically established by the LE/Signalling protocols. Consider a veracious representation of a mobile connection topology shown in Figure 4. In this example, we have three ATM switches *X, Y, Z* and six cells $C_0, C_1, C_2, ..., C_5$. Base stations (BS_0, BS_1), (BS_2, BS_3), and (BS_4, BS_5) are connected to ATM switches *X, Y*, and *Z*, respectively. Initially, there are three mobile connections *(a, c)*, *(a, d)*, and *(b, c)*. Each mobile connection is identified by a sequence of VPI/VCI values; each of which is assigned in the physical link between two adjacent switching points along the path. That is, the sequences of VPI/VCI values for mobile connections *(a, c)*, *(b, c)* and *(a, d)* are (10/700, 30/400, 60/100), (10/800, 30/500, 60/200), and (10/900, 30/600, 60/300), respectively. The VPI value is based on the assignment of virtual paths between two ATM switches or between an ATM switch and a *BS* [9]. Note that since it is possible that more than one MT take the handoff process simultaneously, a way to resolve the MT distinguishing problem within an ATM switch is necessary. This can be done by assigning each of the MTs within the area "serving" by an ATM switch with a unique VCI value. The VCI value here is randomly selected and used to identify an end-to-end mobile connection only. The corresponding contents of the MVDs in BS_0 and BS_4 and the SRDs in ATM switches *X* and *Z* are also shown in Figure 4.



BS₀'s MT Pair-VCC Mapping Database (MVD)

MT (a, c)-60/100
MT (b, c)-60/200
MT (a, d)-60/300

Switch X's Routing Database (SRD)

IN-VCC	IN-PORT	OUT-VCC	OUT-PORT
60/100	0	30/400	2
30/400	2	60/100	0
60/200	0	30/500	2
30/500	2	60/200	0
60/300	0	30/600	2
30/600	2	60/300	0

BS₄'s MT Pair-VCC Mapping Database (MVD)

MT (a, c)-10/700
MT (b, c)-10/800
MT (a, d)-10/900

Switch Z's Routing Database (SRD)

IN-VCC	IN-PORT	OUT-VCC	OUT-PORT
30/400	0	10/700	2
10/700	2	30/400	0
30/500	0	10/800	2
10/800	2	30/500	0
30/600	0	10/900	2
10/900	2	30/600	0

Figure 4 An example of mobile connections (before mobility).

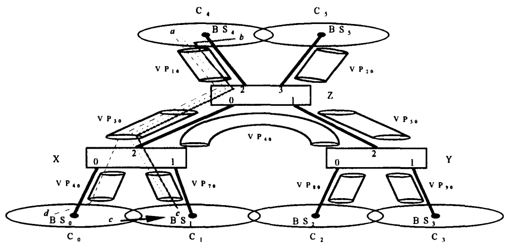
In order to perform a seamless intra-switch handoff, some handoff messages are defined and used in the proposed scheme. There are four types of handoff messages:

- **Location Message.** The moving MT initiates a location query to get the ATM address of the base station of the new cell (ATM BS_{new}) and sends it to the base station in the original cell ($BS_{original}$) via a Location message.
- **Connection Message.** The moving MT initiates a connection query to get its own MT-associated information from the $BS_{original}$, i.e., the contents in the MVD, and sends them to the BS_{new} via a Connection message.
- **Routing Message.** The $BS_{original}$ sends a Routing message with (MT-associated VCCs; ATM $BS_{original}$; ATM BS_{new}) to the attached ATM switch via the Handoff VC. Based on the user-network/network-node interface (UNI/NNI) signalling information [3], [7]-[8], then the ATM switch could identify whether the handoff is due to an intra- or inter-switch mobility. According to the MT-associated VCCs, the ATM switch could alter the corresponding tuples in the SRD for path modification, if necessary.
- **Complete Message.** Whenever the ATM switch has completed the SRD modification, it sends a Complete message with all the MT-associated VCCs to the BS_{new}.

To show the procedure of handling an intra-switch handoff, let us consider the example shown in Figure 4 again. Assume MT_c is moving from C_0 to C_1 and initiated the location and connection queries. Note that MT_c has two mobile connections with MT_a and MT_b, respectively. The steps to handle an intra-switch handoff are stated as follows.

1. MT_c issues a Location Message with the ATM address of BS_1 to BS_0, and a Connection Message with *MT (a, c)*-60/100 and *MT (b, c)*-60/200 to BS_1.
2. BS_0 then sends a Routing Message (60/100, 60/200; ATM BS_0; ATM BS_1) to ATM switch *X*.
3. ATM switch *X* modifies the corresponding tuples of the MT-associated VCCs in the SRD, and issues a Complete Message with all the associated new VPI/VCI pairs, i.e., VCCs 70/100 and 70/200, to BS_1.
4. BS_1 adds the new MT pair-VCC entries to its MVD and re-starts the procedure of data transmission.

The mobile connections and the corresponding contents in the MVDs and SRDs after an intra-switch mobility are depicted in Figure 5. Here we simply change the data path from one ATM switch port to another internally. Obviously, the routing load to ATM networks due to this intra-switch mobility is minimized and the path (VCC) is not elongated. Moreover, we don't have to change the MVD of BS_4 for such a mobility. Therefore, it is also transparent to mobile terminals MT_a and MT_b.



BS1's MT Pair-VCC Mapping Database (MVD)

MT (a, c)-70/100
MT (b, c)-70/200

Switch X's Routing Database (SRD)

IN-VCC	IN-PORT	OUT-VCC	OUT-PORT
60/100->70/100	0->1	30/400	2
30/400	2	60/100->70/100	0->1
60/200->70/200	0->1	30/500	2
30/500	2	60/200->70/200	0->1
60/300	0	30/600	2
30/600	2	60/300	0

BS4's MT Pair-VCC Mapping Database (MVD)

MT (a, c)-10/700
MT (b, c)-10/800
MT (a, d)-10/900

Switch Z's Routing Database (SRD)

IN-VCC	IN-PORT	OUT-VCC	OUT-PORT
30/400	0	10/700	2
10/700	2	30/400	0
30/500	0	10/800	2
10/800	2	30/500	0
30/600	0	10/900	2
10/900	2	30/600	0

Figure 5 An example of mobile connections (after an intra-switch mobility).

Inter-switch mobility

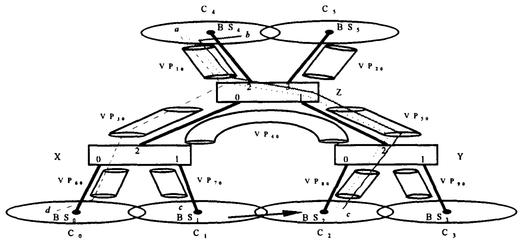
So far we have introduced the seamless handoff scheme for intra-switch mobility. Following the same idea, we try to make the elongated path due to an inter-switch mobility as short as possible. To avoid this extra reassembly and segmentation overhead, the path can be elongated from the ATM switch connects the old *BS* to the new *BS* rather than from the old *BS* to the new *BS*. For the continuity of frame forwarding at the new *BS*, we need to define a Couple Message to identify the relationship between the elongated path and the corresponding pair of MTs.

- **Couple Message.** For each of the MT-associated VCCs of the moving terminal, the ATM switch connects the old *BS* will establish a point-to-point switched virtual connection (SVC) to the new *BS* for the elongated path via the signalling protocol. The new *BS* then gets the VPI/VCI value for the elongated path. However, it does not know the relationship between this VPI/VCI value and the corresponding MT pair. Thus, after the SVC is established, the ATM switch will send a Couple message with the MT-associated VCC to the new *BS* via the new established SVC. The new *BS* then keeps the mapping between the VPI/VCI value of the elongated path and the MT-associated VCC, and the frames for the MT can be forwarded again.

To demonstrate the procedure of handling an inter-switch handoff, let us consider the example shown in Figure 5 again. Assume that the MT_c in C_1 continues roaming to C_2. Then an inter-switch handoff has to be taken which is explained as follows.

1. MT_c issues a Location Message with the ATM address of BS_2 to BS_1, and a Connection Message with *MT (a, c)*-70/100 and *MT (b, c)*-70/200 to BS_2.
2. BS_1 then sends a Routing Message (70/100, 70/200; ATM BS_1; ATM BS_2) to ATM switch *X*.
3. ATM switch *X* establishes an SVC to BS_2 for each of the MT-associated VCCs (70/100 and 70/200), modifies the corresponding tuples in its SRD, and sends a Couple Message with VCC 70/100 (70/200) to BS_2.
4. BS_2 adds the new MT pair-VCC entry into its MVD and re-starts the procedure of data transmission.
5. Whenever an ATM switch *(X)* detects the output port and input port of a mobile connection are identical (a loop occurs), it first releases the SVC established for the elongated path and sends a Routing Message to the adjacent ATM switch *(Z)* of the mobile connection. The adjacent ATM switch will establish a new SVC from it to the new *BS* for the elongated path and detect the loop condition as well. If there is no loop, the handoff procedure is done; otherwise, the procedure described before is repeated until the loop within an ATM switch is eliminated.

The possible mobile connections and the corresponding contents in the MVDs and SRDs after an inter-switch mobility are illustrated in Figure 6. We note this is also transparent to MT_a and MT_b, and the elongated path is shorter than the case of BS-to-BS elongation. This not only offers a shorter path but also provides a better bandwidth utilization.



BS₂'s MT Pair-VCC Mapping Database (MVD)

MT (a, c)-80/350
MT (b, c)-80/450

Switch Y's Routing Database (SRD)

IN-VCC	IN-PORT	OUT-VCC	OUT-PORT
80/350	0	50/150	2
50/150	2	80/350	0
80/450	0	50/250	2
50/250	2	80/450	0

BS_4's MT Pair-VCC Mapping Database (MVD)

MT (a, c)-10/700
MT (b, c)-10/800
MT (a, d)-10/900

Switch Z's Routing Database (SRD)

IN-VCC	IN-PORT	OUT-VCC	OUT-PORT
30/400->50/150	0->1	10/700	2
10/700	2	30/400->50/150	0->1
30/500->50/250	0->1	10/800	2
10/800	2	30/500->50/250	0->1
30/600	0	10/900	2
10/900	2	30/600	0

Figure 6 An example of mobile connections (after an inter-switch mobility).

3.2 Path migration schemes

Having finished the handoff operation, the elongated path due to an inter-switch mobility is kept as short as possible. However, it might not be the shortest one between the source *MT* and the destination *MT*. A path migration could be applied to migrate an inefficient path to a better one, if any. The path migration schemes proposed in [11] can be regarded as intentional migrations, which are triggered by recognizing an inefficient path. Basically, these migration schemes can be applied to the ATM-based wireless LANs. However, we still have to take care the problems of when to find a feasible better path and make a migration. In our design, we suggest that the path migration, if necessary, be done once an inter-switch handoff occurs. This is because based on the proposed seamless handoff scheme, we don't have to take care the rerouting problem for intra-switch handoffs. When an inter-switch handoff occurs, the *BS* of the new cell first establishes a VCC to the remote destined *BS* by executing some routing scheme, e.g., the shortest path scheme. Then makes a migration to the new path. The flush message protocol [6] can be used to switch the path from the old one to the new one for keeping the frame order.

The establishment and selection of a path between two ATM end stations, suggested in the ATM Forum P-NNI [7], are based on performing a shortest path (Dijkstra) computation. For the sake of simplicity, here we also suggest using the shortest path algorithm to find the new path in the migration scheme since it provides a shorter delay and consumes a minimum amount of available bandwidth to establish a virtual connection. If the new established path is "better" (in terms of delay, cost, and other metrics) than that produced via the seamless handoff scheme, then migrate it to the new one. Otherwise, keep the old path and release the new one.

Recall that a new end-to-end virtual connection has to be established for the path migration. A Partner Message is used here to carry the ATM addresses of the destined partner *BSs* to the new *BS*.

- **Partner Message.** For each of the MT-associated VCCs, the moving MT initiates a location query to get the ATM address of the destined partner *BS* (ATM $BS_{partner}$) and sends a Partner message with these ATM addresses to the *BS* in the new cell. That is, a Partner message contains all the MT-associated VCCs of the moving MT tagging with the corresponding ATM addresses, each for a destined partner *BS*.

To demonstrate the procedure of a path migration, let us consider the example shown in Figure 6. Once finishing an inter-switch handoff, the path migration mechanism could be initialized, if necessary, and the steps are stated as follows.

1. BS_2 establishes an SVC to BS_4 for each of the MT-associated VCCs (80/350, 80/450). Now there exist two paths between BS_2 and BS_4. The first one is that produced during the inter-switch handoff described before. The other is the new established path.

2. BS_2 initiates the flush message protocol for switching the path from the old one to the new one, if necessary. In this example, since the two paths have the same hop counts, the migration can either be done or just ignored.

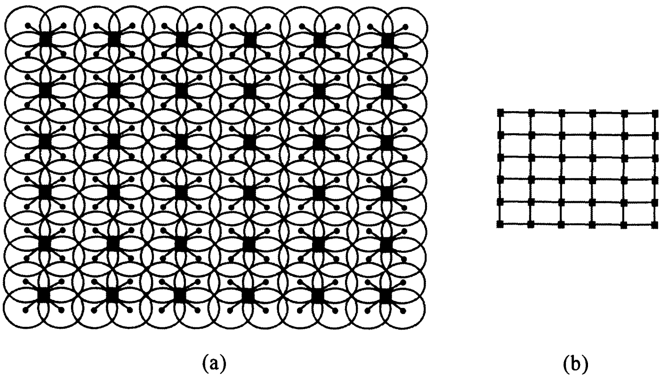


Figure 7 (a) A 12*12 Manhattan-style wireless LAN architecture.
(b) ATM switch interconnection configuration.

4 SIMULATIONS

4.1 Simulation model and assumptions

In order to evaluate the effectiveness of the proposed seamless handoff scheme and the paths migration mechanism, one experimental test was implemented. The experiment is implemented by the C programming language on an 80486 personal computer. A Manhattan-style wireless LAN model with a size of 12*12 is considered here as shown in Figure 7 (a); where each black square box represents an ATM switch which connects four base stations. The interconnection among the ATM switches is also the Manhattan-style model with a size of 6*6, as shown in Figure 7 (b). Since the wireless LAN Emulation provides the ABR service, each of the connection setup requests should be accepted [6]. The shortest path routing algorithm is exploited to establish virtual connections among mobile terminals. Here we use the hop count as the routing metric.

In our experiment, the number of new connection requests per unit time and the number of old connections released per unit time are assumed to be Poisson distributed with means E and R, respectively. The source-destination traffic of each connection request is assumed to be a uniform distribution.

Let M denote the percentage of roaming terminals per unit time. Thus, M=1% means that one percentage of the mobile terminals roams per unit time. A roaming terminal must either roams to up, down, right or left cell (randomly determined). Also assume that there are totally 144 mobile terminals uniformly distributed over the wireless LANs, i.e., one mobile terminal per wireless LAN cell. For each pair of mobile terminals only a virtual connection is established, if necessary. However, a mobile terminal may have several virtual connections, each of which with a distinct mobile terminal.

The following parameters are considered in the simulation:

1) The time interval for performance observation is selected from the 0th unit time to the 100th unit time for the experiment. From the simulation results below, we can observe that after 100 time units the proposed seamless handoff scheme outperforms the conventional handoff scheme (used in the wireline LAN Emulation).
2) M=1%, 3%, 5%, 10%, and 20%.
3) E=10. Ten pairs of mobile terminals are selected randomly per unit time and for each of them, a virtual connection based on the shortest path is established.
4) R=4. Four established virtual connections are selected randomly to release per unit time.

In order to compare the performance of the wireless LAN Emulation service with and without applying the seamless handoff scheme and the path migration mechanism, the average number of hops consumed per virtual connection is investigated. Note that the path between a *BS* and the attached ATM switch is recognized as a hop consumption in the following experiments. Thus for an intra- or inter-switch mobility, the conventional handoff scheme generates additional two hop counts per virtual connection than that of the seamless one.

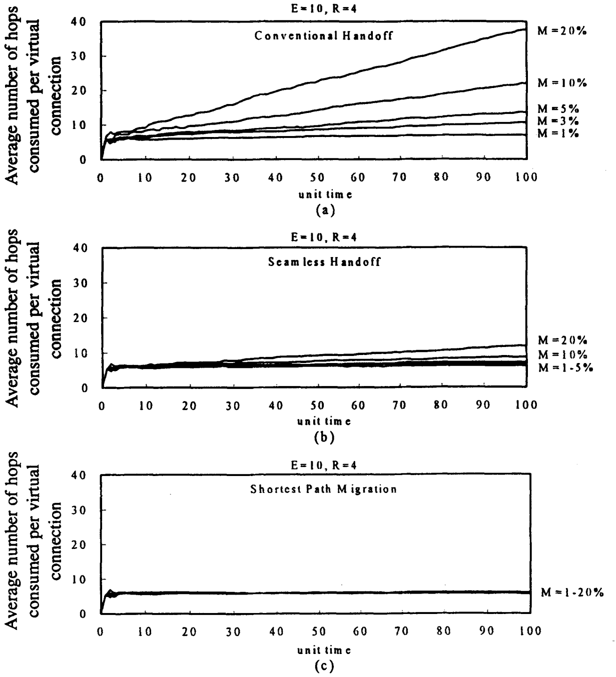


Figure 8 The average number of hops consumed per virtual connection for different handoff schemes.

4.2 Experimental results

The simulation results are depicted in Figure 8 which shows the average number of hops consumed per virtual connection (*H*) versus time in the compared schemes for different values of *M*. Figure 8 (a) shows the results obtained by the conventional handoff scheme, defined by the ATM Forum. We can see that for a system with the conventional handoff scheme, the value of *H* is increased in exponential discipline when the value of *M* is higher than 20%. That is, the elongating paths will result in a very long network delay and low network utilization. Figure 8 (b) depicts the results obtained by the proposed seamless handoff scheme. In order to see the effectiveness of this seamless handoff scheme, the suggested path migration scheme is not applied here. Surprisingly, the proposed seamless handoff scheme reduces the exponential increment of *H* to a more flat growth, even though the roaming percentage is up to 20%. This means that the design of assigning a dedicated VCC for each pair of mobile terminals can substantially lessen the roaming impact on the LAN Emulation service. Figure 8 (c) demonstrates the results obtained by applying the shortest path migration whenever a mobility, in spite of intra-switch or inter-switch, occurs. We can see that if the shortest path migration is applied directly for each handoff, the path elongation problem can be completely resolved. However, since an end-to-end virtual connection has to be setup for each mobility, the handoff overhead might be extremely high for a high value of *M*. Thus a better solution to overcome the roaming impact is to combine the seamless handoff scheme with the proposed path migration scheme once an inter-switch mobility occurs.

5 CONCLUSIONS

In this paper, the main issues of wireless LAN Emulation over ATM networks have been addressed and investigated. We show that the conventional (wireline) LAN Emulation service, in which only a VCC is established between each pair of LANs, is not efficient enough to handle the handoff of the wireless LANs due to the fact that the VCC might be elongated when mobile terminals move in and out. To overcome this problem, we suggest that a VCC should be established between each pair of communicating mobile terminals instead of each pair of LANs as defined in the ATM Forum. Based on this suggestion, a seamless handoff scheme is proposed which not only meets the requirements of data continuity and transparency, but also keeps the communication path as short as possible. A path migration scheme is also suggested to further migrate an inefficient elongated path to a better one (due to the roaming of mobile terminals), if any. Simulation results show that the proposed seamless handoff/migration schemes perform much better than the conventional LAN Emulation scheme in terms of the average number of hops consumed per virtual connection. This also implies that the proposed schemes utilize the available bandwidth in a more efficient way and provide a smaller transmission delay.

6 REFERENCES

[1] IEEE Project 802 Local and Metropolitan Area Networks Standards, IEEE Standard 802.1D MAC Bridges (1990).

[2] IEEE Project 802 Local and Metropolitan Area Networks, IEEE Draft Standard 802.11 Wireless LAN (1 December 1994).

[3] ATM Forum, ATM User-Network Interface Specification Ver. 3.0, (Prentice Hall, 1993).

[4] CCITT, I-Series Recommendation on B-ISDN, Geneva, 1991.

[5] CCITT SWG XVIII Draft recommendation I.363, "B-ISDN ATM Adaptation Layer (AAL) Specification," Jan. 1993, section 6.

[6] LAN Emulation SWG Drafting Group, "LAN Emulation over ATM-Version 1.0 Specification," Jan. 1995.

[7] P-NNI SWG, "P-NNI Draft Specification," ATM Forum/94-0471R4.

[8] P-NNI SWG, "Interim Inter-switch Signaling Protocol (IISP) Draft Version," ATM Forum/94-0924R2.

[9] Handel, R., Huber, M.N., and Schroder, S., *ATM Networks: Concepts, Protocols, Applications,* Addison-Wesley, Reading, 1994.

[10] Heinanen, J., "Multiprotocol Encapsulation over ATM Adaptation Layer 5," *RFC 1483,* Telecom Finland, July 1993.

[11] Huang, N.F. and Chen, K.S., "A Distributed Paths Migration Scheme for IEEE 802.6 Based Personal Communication Networks," *IEEE J. Select. Areas Commun.,* vol. 12, no. 8, pp. 1415-1425, Oct. 1994.

[12] Kung, H.T., Blackwell, T., and Chapman, A., "Credit-Based Flow Control for ATM Networks: Credit Update Protocol, Adaptive Credit Allocation, and Statistical Multiplexing," *Proc. ACM SIGCOMM'94,* pp. 101-114, London, Aug. 1994.

[13] Laubach, M., "Classical IP and ARP over ATM," *RFC 1577,* Hewlett-Packard Laboratories, Jan. 1994.

[14] Newman, P., "Traffic Management for ATM Local Area Networks," *IEEE Commun. Mag.,* pp. 44-50, Aug. 1994.

[15] Romanow, A. and Floyd, S., "Dynamics of TCP Traffic over ATM Networks," *Proc. ACM SIGCOMM'94,* pp. 79-88, London, Aug. 1994.

7 BIOGRAPHY

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