A Unifying Methodology for Handovers of Heterogeneous Connections in Wireless ATM Networks

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Abstract

The aim of Wireless ATM is to provide multi-media services to mobile users. While existing research on Wireless ATM are focussed on handovers of unicast connections, handovers of multicast connections have not been investigated. While conventional multicast join and leave operations occur over the same path, this is not the case during mobile host migrations in a Wireless ATM network. In this paper, we reveal how handovers of multicast connections can be achieved in a manner irrespective of whether these multicast trees are source-, server- or core-based. More importantly, we demonstrate how the enhanced hybrid handover protocol incorporating crossover switch discovery can be used to support handovers of heterogeneous (i.e., unicast and multicast) connections in a uniform and unified manner, for Wireless ATM LANs employing either the centralised or distributed connection management scheme.

Keywords: Handovers; Multicasting; Switch Discovery and Wireless ATM.

1 Motivation

While current research efforts on handovers are centred on unicast mobile connections, little attention is devoted to handovers of multicast connections. The extension of IP multicast to resolve the problems of multicasting to/from mobile hosts (MHs) is investigated in [1]. However, their environment is not based on Wireless ATM. While traditional multicasting only allows receivers to be dynamic, this is no longer true in a mobile network. Because multicast connections are point-to-multipoint and multipoint-to-multipoint in topology, migration by any member of the multicast group can result in severe traffic flow interruptions if the handover operation is not performed properly. In the worst case, improper handovers may result in other group members loosing their connections. Hence, there is a need for a uniform, unified, efficient and dynamic handover protocol that can support handovers of both unicast and multicast connections in a Wireless ATM network.

This paper presents the **first** treatment into achieving a uniform and unified handover paradigm. It reveals a methodology for handovers of both unicast and multicast connections. It is organised as follows. Section 2 presents an introduction to multicasting while Section 3 discusses briefly on mobility management. A wireless cell clustering strategy and the principles of crossover switch discovery are discussed in Section 4. Section 5 discusses the roles of multicast routing while Section 6 describes mobile connection establishment. Handovers of unicast and multicast connections are described in Section 7 and 8 respectively. Finally, Section 9 provides a discussion on related issues. The symbol '$\rightarrow$' is used in this paper to refer to the path from one node to another.

2 Introduction to Multicasting

2.1 Definition of Multicast

Traditional communications take place between two parties or end hosts and the resulting connection is basically point-to-point, i.e., unicast. However, communication among multiple parties are now common, especially in conferencing applications. Hence, the ability to simultaneously connect to a subset of end hosts and send replicated data to these hosts is known as *multicasting*. Multicasting, also known as *selective broadcast*, refers to both point-to-multipoint and multipoint-to-multipoint communications. The former provides unidirectional traffic flow from the *sender*, commonly known as the *source* or *root*, to the *receivers* or the *leaves* of the multicast tree. The latter, however, can be constructed from multiple point-to-multipoint connections.

Multicast is usually implemented by the network, where data or packets are replicated and distributed to multiple receivers. In a connectionless network [6], multicasting basically involves replicating packets and routing them to the receivers. However, in a connection-oriented network [3], such as ATM networks, a multicast connection needs to be established prior to communication. A *multicast group* is defined as a set of senders and receivers who are involved in a multi-party communication session.

2.2 IP Multicast

IP multicast is fundamentally different from ATM multicast. Many of the existing IP multicast routing protocols such as MOSPF [11] and DVMRP [5] are source-based, i.e., they built trees rooted at the source. For MOSPF, a multicast tree is built by setting up shortest paths from the source to its destinations. MOSPF computes a separate path for each $\{$ source, destination, type of service (this refers to minimum delay, maximum throughput, maximum reliability, minimum monetary cost and normal service) $\}$ tuple, using Dijkstra's algorithm. In DVMRP, a "broadcast and prune" approach is used to derive a shortest-path and sender-rooted multicast tree. For a multicast group with $\mathcal{N}$ senders and $\mathcal{G}$ receivers, $\mathcal{N}$ multicast trees have to be setup. This is obviously inefficient and has scalability problems, especially if the underlying network is ATM.

2.3 ATM Multicast

In ATM multicast, several proposals have been made. In the ATM Forum UNI (User-to-Network Interface) perspective, ATM multicast can be achieved via:

- **Multicast Server** - Nodes wishing to transmit onto a multicast group establish point-to-point connections with the multicast server. The server is then connected to all nodes, via a point-to-multipoint connection, which wish to receive the multicast packets.
- **Overlaid Point-to-Multipoint Connections** - This is essentially a point-to-multipoint overlaying technique where all nodes in a multicast group establish a point-to-multipoint connection with each other node in the group, resulting in a mesh of connections. Hence, all nodes can transmit to and receive from all other nodes.

While the multicast server approach is efficient in terms of network resource consumption, a potential bottleneck exists at the multicast server, especially when the number of senders increases. On the other hand, the overlaid approach has severe scalability problem (since $\mathcal{N}$ multicast trees have to be built for $\mathcal{N}$ senders in a multicast group) and poor network resource utilisation efficiency (since the concept of shared delivery trees is not employed).

A recent proposal is the Core-Based Tree (CBT) [2] approach. While CBT was originally developed for IP multicast, CBT for ATM has been extended and proposed in [3]. As the name implies, CBT is not source-based but core-based. In CBT, a single delivery tree is constructed per multicast group, independent of the number of senders. Hence, while CBT may not suffer from poor scalability and network utilisation efficiency as in source-based trees, it may face traffic concentration problems, especially for large numbers of senders, since all the source traffic must travel on the shared delivery tree [4]. In this paper, we aim to address handovers of multicast connections which are built from either source-, server- or core-based trees.

3 Mobility Management

3.1 Location Management

In a connection-oriented Wireless LAN, there must exist means to support location and connection management. A location server may exist in a Wireless LAN so as to provide location tracking and query resolution functions. MHs' movements are normally detected by base stations which then update the database of the location server.

3.2 Handover Management

Handover is regarded as the most important operation in a wireless network since it allows communication sessions to continue without severe interruption. Instead of using the packet encapsulation and redirection techniques (as in Mobile IP protocol [7]), handovers in a Wireless ATM LAN require changes in virtual connections. Depending on the handover scheme used, the resulting handover signalling traffic can be substantial. Several handover schemes have been proposed, such as connection extension [15], full re-establishment [8], partial re-establishment [8], multicast join/leave [8] and multicast group [14]. This paper is concerned with handovers using partial re-establishments, where a new partial path is established from the new base station to a node in the original connection path. Hence, this method requires the discovery of the crossover switch, the setting up of the new partial path and the tearing down of the old partial path.

3.3 Connection Management

Since a Wireless ATM network is a connection-oriented network, a virtual circuit has to be established prior to any data transfer. The connection management scheme can be performed in a centralised or distributed manner. In the former approach, all connection requests are directed to a connection server. The connection server then derives a feasible route and interacts with the switches and base stations in the route for possible call admission [10]. The latter approach, however, uses a hop-by-hop call setup scheme, where call setup packets are forwarded from one switch to another, with call admissions performed at each base station and switch encountered [16].

4 Cell Clustering & Switch Discovery

4.1 Wireless Cell Clustering

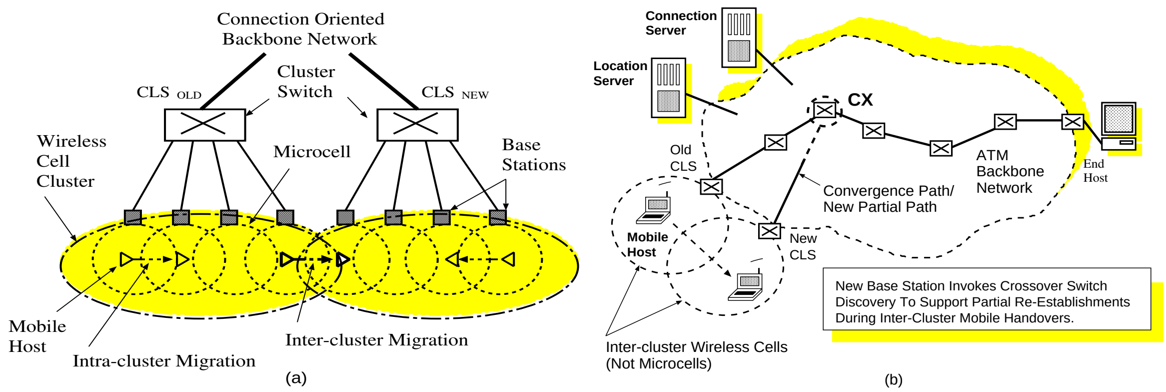

Figure 1: Intra/inter Cluster MH Migrations and Crossover Switch Discovery.

To support distributed handover management with the capability of transferring handover control, a wireless cell clustering methodology [16] is employed. This clustering scheme is derived as a result of observing the mobility profiles of mobile users. A study on the mobility profiles of Active Badge [12] users at the University of Cambridge Computer Laboratory reveals that mobility is mostly local, i.e., users seldom migrate across location domains (a location domain here refers to a floor in a building).

As shown in Figure 1a, a group of base stations (BSs) are connected to an ATM switch, known as the cluster switch (CLS). Hence, MHs' migrations within the coverage of the CLS result in *intra-cluster* handovers while those between wireless clusters result in *inter-cluster* handovers. While intra-cluster handovers can be performed very quickly, inter-cluster handovers are slower since the handover management entity may reside on a backbone ATM switch instead of the CLS. Hence, this forms the main motivation for crossover switch discovery. The proposed clustering scheme has also resulted in localised (where handovers occurring within a wireless region are handled by a nearby handover management entity) and independent handovers (where source and destination MHs handovers are performed in a mutally independent manner).

4.2 Crossover Switch Discovery

To support fast inter-cluster handovers, several crossover switch (CX) discovery mechanisms [18] have been proposed. Briefly, the purpose of CX discovery is to locate a suitable CX so that a new partial path can be established from the new BS (BS_{NEW}) to the CX. In addition, the CX is held responsible for performing connection re-routing during inter-cluster handovers.

While P-NNI routing supports ATM connection setup, CX discovery utilises existing routing and QoS information to derive an appropriate partial path so that mobile QoS requirements can be fulfilled during handovers. Five CX discovery schemes (*loose select*, *prior path knowledge*, *prior path resultant optimal*, *distributed hunt* and *backward tracking*) have been proposed, simulated and their performance evaluated and outlined in [18].

In *loose select* discovery, the new BS established a new path towards the destination node with no regard to existing path nodes. If the new path 'intersects' with the old path, the intersecting node is the crossover node. In *prior path knowledge* discovery, information about existing path nodes (i.e., possible CXs) is obtained by querying the connection server. With this information, BS_{NEW} derives all possible partial paths (i.e., $BS_{NEW}\rightarrow$CXs) and selects the partial path that fulfils QoS requirements.

The *prior path resultant* CX discovery is derived from *prior path knowledge* discovery with the exception that only those nodes that result in new paths that are either shorter or equal to existing path prior to handovers are considered. In *distributed hunt* CX discovery, however, BS_{NEW} initiates a broadcast to locate all possible CXs within the LAN. Again, among all possible partial paths, the partial path that fulfils QoS requirements is selected. Finally, in *backward tracking* discovery, each node in the existing path will progressively verify if it can reach both old and new BSs. The backtrack starts at the node closest to the old BS and continues along the existing path until a crossover node is found.

This paper is concerned primarily with handovers employing either the *prior path knowledge* or *distributed hunt* discoveries. Because this paper is also concerned with multicast connections, the roles and characteristics of existing multicast routing schemes are elaborated in the next section.

5 Multicast Routing

There are two main functions provided by a multicast routing protocol: (a) to derive a multicast tree (based on certain QoS constraints) so that a multicast connection can be established and (b) to handle problems associated with dynamic multicast groups. Because multicast trees can be source-, server- or core-based, it is essential to highlight the characteristics of these multicast routing schemes.

5.1 Routing For Call Setup

Several multicast routing algorithms to support multipoint communications have been proposed. Some of these algorithms have high computation and communication complexities. Existing multicast routing algorithms may be classified [20] into: (a) minimum steiner tree (MST), (b) shortest path tree (SPT) and (c) constrained multicast tree (CMT). Their characteristics are summarised in Table 1.

As mentioned earlier, our work emphasizes the mobility aspects in a Wireless ATM network. Regardless of the nature of the multicast trees, i.e., whether they are source-, server- or core-based, we intend to propose a handover protocol that is applicable to all these trees.

Minimum Steiner Tree	Shortest Path Tree	Constrained Multicast Tree
• Constructs minimum spanning tree per source group pair. • Based on near-optimal steiner tree heuristic algorithms. • May utilise global or local cost information. • Minimise cost but not delay.	• Further classified into source-, core- and hybrid-based trees. • Examples of source-based SPTs are DVMRP and MOSPF. • An example of core-based SPT is CBT. • PIM combines source and core based SPT to consider QoS requirements. • RBM [4] combines features of PIM and RSVP [9].	• Combines the features of SPT and MST. • Considers both cost and delay during multicast tree derivation. • CMT is source based and it requires global information available at the source. • Global information is provided by ATM P-NNI routing protocol.

Table 1: Summary of the Characteristics of MST, SPT and CMT Multicast Routing Schemes.

5.2 Routing For Dynamic Host Memberships

Another function of a multicast routing protocol is the ability to support dynamic host memberships. This is especially true for a multi-party conferencing session over an ATM network, where group members may decide to join or leave the multicast group at any time. The importance of the ability to support dynamic host memberships has motivated work on "Leaf Initiated Join (LIF) Extensions" [13] by the ATM Forum Signalling Subworking Group. Host membership changes may affect the pre-established optimal multicast tree, especially in terms of end-to-end delay and the total cost of all the routes from the multicast source to its destinations. Although none of the existing multicast routing algorithms are designed to support mobile handovers, it will be seen later that similar scenarios exist in a Wireless ATM network environment, where once a mobile multicast tree is established, MH handovers are performed in a manner which requires minimum modifications to the existing optimal multicast tree.

6 Mobile Connection Setup

6.1 Mobile Unicast Connection Setup

Prior to the discussion on mobile multicast connection setup, we present in this section how mobile unicast connection setup is performed. In [16], mobile unicast connection setup is based on a hop-by-hop approach where once a MH issues a call setup request to its current BS, this BS has to allocate a wireless channel, perform a location-to-address resolution (by consulting the location server to locate the BS which is currently servicing the target host) and forward this request to the CLS. Thereafter, hop-by-hop virtual channel routing is used to forward this packet over a minimum-hop route to the BS serving the target MH. The remote end BS then allocates a wireless channel and passes this packet to the target MH. If the target host decides to accept the call, it returns an acknowledgement back to the sender, in a hop-by-hop manner, over the same traversed path. These hop-by-hop data-link associations are known as *mobile associations* while the concatenation of these associations from the sender MH to the target host results in a *mobile connection*.

6.2 Mobile Multicast Connection Setup

For ATM multicast connections, there exists three methods to perform multicast setup. They can be source-, server- or core-based. As shown in Figure 2, we illustrate a source-based mobile multicast connection establishment for a multicast group having a single source and two receivers.

Here, we introduce the concept of "distribution point" (DP). A DP is an ATM switch which performs a minimum dualcast (i.e., the ability of a switch to send duplicated packets/cells to two receivers) action for a multicast connection. ATM cells are duplicated and distributed by the DP to each of the groups' receivers. For source-based trees, in order to establish a multicast connection, the sender must first know who the receivers are and this is achieved by consulting a multicast server. With the group membership, topology and QoS information available, a multicast routing algorithm is then used to compute the multicast tree. DPs are then identified once the tree is derived. In a Wireless ATM LAN employing a centralised connection management scheme, the source may then instruct the connection server to establish the multicast connection. For those Wireless LANs that employ a distributed connection management scheme, the source will have to send out multicast connection setup packets to each of the group receivers, in a hop-by-hop manner, over the selected path. Note that for server- and core-based trees, the concept of 'DPs' continues to apply.

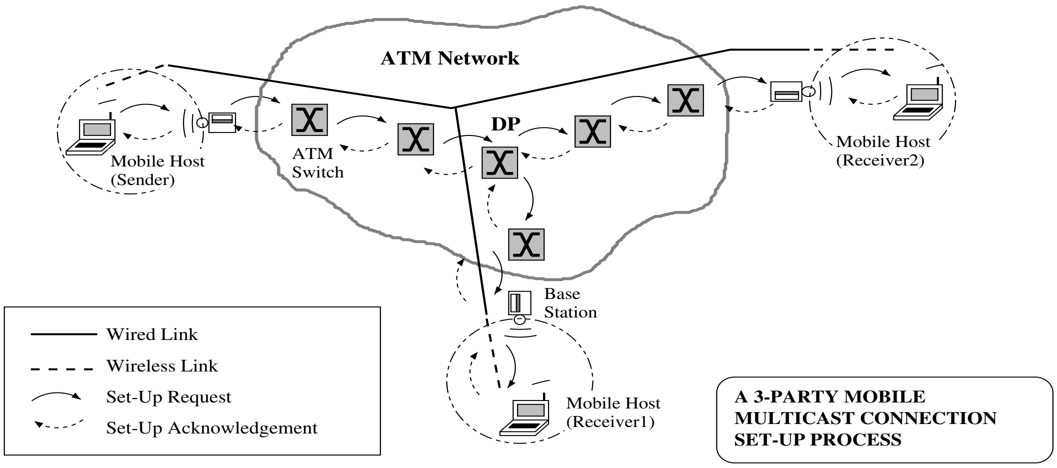

Figure 2: Mobile Multicast Connection Setup.

7 Handovers of Unicast Connections

7.1 Hybrid Handover Protocol

Before delving into the details of handovers of mobile multicast connections, a discussion on a handover protocol proposed for unicast connections in a Wireless ATM environment is necessary in order to reveal the uniformity of the handover protocol with its enhanced version.

There are several issues [16] that need to be addressed during the design of a handover protocol to support multi-media in a Wireless ATM environment. They include: (a) exploitation of locality, (b) exploitation of radio hint, (c) circuit reuse efficiency, (d) scalability, (e) mobile QoS, (f) service disruption time (continuity), (g) cell loss and sequencing, (h) exploitation of personality (i.e., mobility profiles), (i) consideration for data looping, (j) traffic flows disruption symmetry, (k) robustness of protocol, (l) queueing of handover requests and (m) service traffic characteristics. The proposed handover protocol, which employs the concept of partial re-establishments and crossover switch discovery, is summarised below.

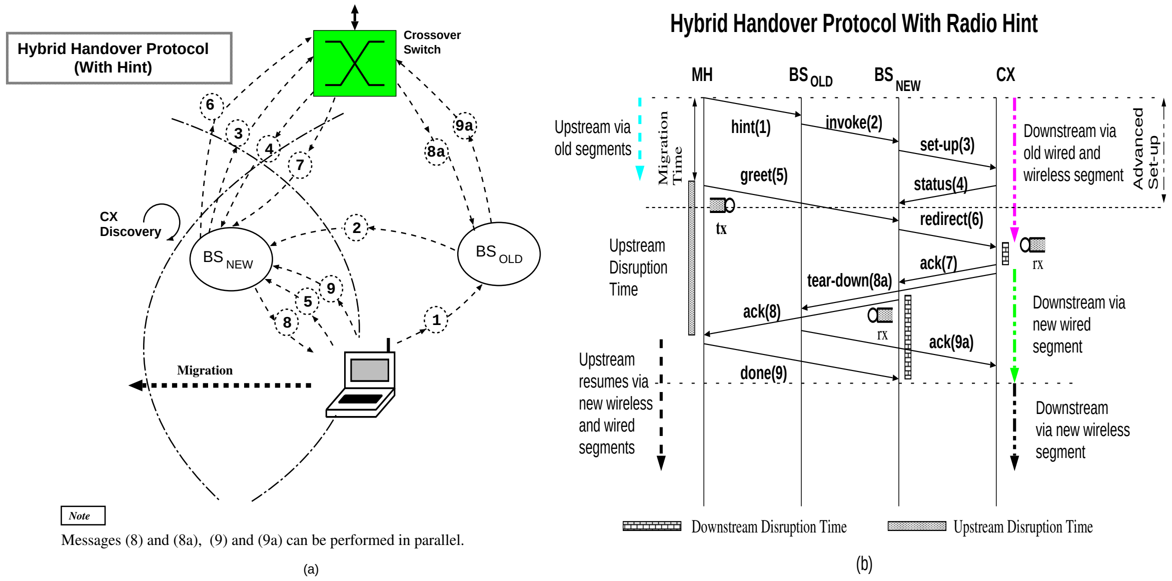

Figure 3: With-Hint Hybrid Handover Protocol Control and Data Flow Diagrams.

The proposed protocol uses a mobile-assisted handover approach and it utilises radio hint as an advance signal to trigger a handover earlier. This gives ample time to invoke CX discovery (for inter-cluster MH migrations) and to establish the partial path. As shown in Figures 3a and b, these operations are achieved through *hint*(1), *invoke*(2), *set-up*(3) and *status*(4) messages. Hence, by the time the MH enters the new wireless cell, the partial path has already been established. The MH may now signal, via the *greet*(5) message, to the BS_{NEW} to perform a handover. This message is then transformed to a *redirection*(6) message by BS_{NEW} and sent to the CX. Connection re-routing is then performed at the CX and an *ack*(7) message is returned to BS_{NEW}. The CX may then initiate a partial path disconnection via the *tear-down*($8a$) message and await the disconnection *ack*($9a$) message from the old BS (BS_{OLD}). The handover operation is completed when BS_{NEW} receives a *done*(9) message from the MH. If after sending the *hint*(1) message, the MH decides not to enter into the new wireless cell, time-out will abolish the pre-established partial paths. Likewise, after sending the *invoke*(2) message, if BS_{OLD} does not receive the *tear-down*($8a$) message, it will time-out and abort the handover process. Earlier experiments and analysis [16] revealed that this protocol exhibits symmetric upstream and downstream disruption time. The data flow diagram in Figure 3b reveals the disruption and subsequent continuation of the upstream and downstream data flows during and after a handover.

7.2 Unicast Connection Re-routing

By connection re-routing we mean the redirection of ATM cells from the old partial path to the new partial path, with consideration given to cell sequencing and loss during this process. This operation is performed by a cell redirection entity, which resides in the CXs and CLSs. Connection re-routing is achieved by first un-chaining (i.e., association un-join) the data-link tunnel between the two association points which are related to the old partial path and then re-chaining it (i.e., association join) with a new association point which is related to the new partial path. Hence, incoming ATM cells are now remapped with a new virtual channel identifier (VCI) so that it is re-routed to the new partial path. Although connection re-routing is not specified by the ATM Forum, we have demonstrated its practicality through an actual implementation [16] [17] on a Cambridge Fairisle ATM switch.

8 Handovers of Multicast Connections

8.1 Enhanced Handover Protocol

To strive for a clear and universal explanation applicable to source-, server- and core-based multicast trees, our explanation will be based on a single multicast tree with a single sender and multiple receivers.

The proposed handover scheme is an enhancement of the hybrid handover protocol and crossover switch discovery schemes proposed in [16] and [18]. By modifying the CX discovery algorithm, handovers of multicast connections can be supported in a transparent manner, i.e., without the need to re-establish a new multicast tree. This is an attractive feature since multicast tree re-establishments cause severe interruptions to traffic flows and incur a relatively long setup time.

Handovers of mobile multicast connections can be initiated at the source or receiver nodes and they are mutually independent of each other. The same handover protocol procedures apply, with the exception that the partial path deletion process is now conditional. During inter-cluster handovers, a migration by a receiver node from a wireless cell that houses other receiver nodes does not necessarily imply the need to delete the old partial path (i.e., from CLS_{OLD}→CX). This is true when the same Virtual Path/Virtual Channel (VP/VC) is being used for MHs residing in the old wireless cell. Hence, although the CX receives a *redirection* message from BS_{OLD}, CX will not delete the old partial path if this path is still valid. BS_{OLD} will now issue a *passive tear-down acknowledgement* message to the CX. This, therefore, avoids pruning off (i.e., loss of connectivity to) valid multicast group members from the multicast tree. However, if different VPs/VCs are used for each MH residing in the old wireless cell, then this partial path tear-down process does not pose a problem.

8.2 Enhanced CX Discovery Algorithm

Unlike CX discovery for unicast connection handovers, the goal of the enhanced CX discovery algorithm is to locate a CX where both the connection re-routing and partial path deletion operations can be performed together in a manner such that other branches of the tree will not be undesirably pruned during handovers of multicast connections. In addition, the nodes to be considered for convergence must now reside in the $CLS_{OLD} \rightarrow DP_x$ path (so that the direction of data flow remains unchanged after a handover), not the original source-to-destination path as in the case for unicast connection handovers.

An enhanced version of the *prior path knowledge* discovery algorithm is discussed here. Since the *distributed hunt* algorithm has similar CX selection procedures as the *prior path knowledge* discovery, its enhanced version is omitted in this paper. As shown in Table 2, all possible $CLS_{NEW} \rightarrow CX$ paths are computed and the CX that yields the least hop $CLS_{NEW} \rightarrow CX$ is selected. However, if multiple CXs have the same minimum-hop $CLS_{NEW} \rightarrow CX$ paths, then the CX nearest to the DP_x will be selected. Although the original *prior path knowledge* algorithm chooses the CX nearest to the CLS_{OLD} for convergence, simulation results obtained in [18] confirm that choosing CX away from the CLS_{OLD} yields higher circuit reuse efficiency and produces a higher percentage of shorter resultant paths. Therefore, this approach is adopted. In addition, to limit the complexity associated with the CX discovery algorithm so that explanation can be simplified, we have chosen to omit details as to how QoS are being considered by the CX discovery algorithm. However, interested readers can refer to [19].

Enhanced CX Discovery Algorithm For Inter-Cluster Handovers

Let M be the multicast tree, and $V(M) = \{m_1, m_2, ...m_x\}$.
Let DP_x be the DP nearest to the old CLS, i.e., CLS_{OLD}.
Let the old partial path $CLS_{OLD} \rightarrow DP_x$ be O, where O is a subgraph of M and $V(O) = \{o_1 = CLS_{OLD}, o_2, ..., o_y = DP_x\}$

Prior Path Knowledge Discovery (Multicast Version) Computation

Begin
Given knowledge of the existing path nodes in O,
For each $O_i \in V(O)$, where $\{i = 1, 2, ..., y\}$,
Begin
  Compute minimum-hop convergence paths from $CLS_{NEW} \rightarrow O_i$.
  Let these routes be M_i.
  If (No. of minimum-hop paths among M_i=1)
    $CX = O_j$, where $CLS_{NEW} \rightarrow O_j$ is the least-hop convergence path.
  else
  Begin
   Among multiple convergence paths with the same minimum-hop count,
   Select $CX = O_k$, where O_k is the node nearest to DP_x.
  End
End

Table 2: The Enhanced CX Discovery Algorithm.

8.3 Deriving An Appropriate DP_x

Prior to deriving an appropriate CX during inter-cluster handovers of multicast connections, the DP_x associated with the old partial path has to be determined. This demands knowledge of the multicast tree topology. Since a multicast tree can be source-, server- or core-based, we will explain in the following text methodologies to maintain multicast tree topology maps and the algorithm required to derive the DP_x.

8.3.1 Source-Based Trees

The derivation of a DP_x requires an up-to-date multicast tree topology map. For a Wireless ATM LAN using source-based trees and a centralised connection management scheme, this map is maintained and constantly kept refreshed at the connection server. However, if a distributed connection management scheme is employed, no connection server is present. Since the connectivity of the multicast tree is known at the source during multicast connection setup, it will therefore have a topology map of this tree. This information may then be multicast to all the receivers' BSs once the multicast tree is established. Hence, with the tree topology map, DP_x associated with a particular MH can be derived.

However, the DP_x associated with a MH can change over time since the connectivity of a multicast tree changes when receivers join and leave the multicast group. Under the distributed connection management scheme, whenever a receiver wishes to join or leave a multicast group, the sender is informed and a new branch is established to the new receiver. The sender then

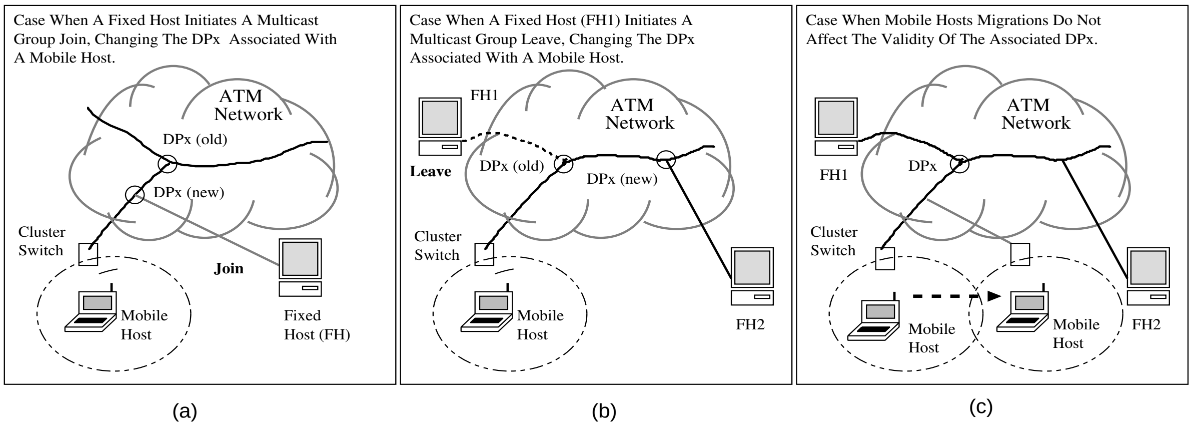

Figure 4: Effects of Multicast Leave, Join and MH Migrations on the Validity of DP_x.

multicasts the new connectivity map of the multicast tree to the rest of the receivers. With the centralised connection management scheme, however, all changes in tree connectivities are known at the connection server. Hence, no additional messaging is required to maintain up-to-date tree topology maps. Although inter-cluster MH migrations also affect the connectivity map of a multicast tree, it does not affect the validity of a DP_x. Figures 4a, b and c explain the above-mentioned points.

8.3.2 Server-Based Trees

The server-based tree approach requires all senders to establish point-to-point connections to the multicast server. The multicast server then establishes a point-to-multipoint connection to all receivers in the multicast group. Since this approach is already centralised, we propose that a connection server to be present to establish such connections. Both the multicast and connection servers may reside in a single machine. The connection server approach, therefore, eliminates the difficulty in maintaining up-to-date tree topology map when compared to those Wireless ATM LANs employing the distributed connection management scheme.

8.3.3 Core-Based Trees

In CBT, since the multicast tree originates from the core, we expect the core to maintain a connectivity map of the tree. Whenever tree topology changes as a result of host membership changes, the cores may then update each other in order to derive a consistent and updated tree topology map. Queries can then be made by the BSs to the nearest core to derive the tree map during inter-cluster handovers of multicast connections. With this map, BS_{NEW} may then proceed to derive the DP_x and subsequently invoke CX discovery.

8.3.4 Algorithm For Deriving DP_x

Summarising, irrespective of whether the multicast tree is source-, server- or core-based, so long as an up-to-date topology map of the multicast tree is maintained, BS_{NEW} can execute the algorithm outlined in Table 3 to derive the DP_x. This is the requisite necessary for the enhanced CX discovery algorithm to locate an appropriate CX.

Algorithm For Deriving DP_x By Backtracking From BS_{OLD}.
Let M be the multicast tree.
Let T_{MAP} be the topology map of M.
Let DP_x be the DP nearest to CLS_{OLD}.
BS_{NEW} executes the following during inter-cluster mobile multicast handovers :
Begin
Let successor = BS_{OLD}.
Repeat
With T_{MAP}, backtrack from the successor node.
Update new successor.
Until (successor has an edge degree ≥ 2, i.e., successor=DP_x)
End

Table 3: Algorithm For Deriving DP_x.

8.4 Multicast Connection Re-routing

During a handover, a connection re-routing operation is needed to re-route the data path. Figures 5 and 6 show that both receiver and sender inter-cluster multicast-connection handovers have similar characteristics, i.e., both connection re-routing and old partial path deletion operations are performed at the CX and in particular, the handover does not affect the orientation of the traffic flow in the multicast tree. If the CX is not DP_x, the c onnection re-routing process is similar to the case of handovers for unicast connections and is achieved via association join and unjoin operations. However, if the chosen CX happens to be DP_x, then the connection re-routing process comprises of multicast-leave (to prune the old branch from the multicast tree) and multicast-join (to join a new branch to an existing multicast tree) operations. Similar to unicast connection re-routing, the cell redirection entity to implement multicast-join and multicast-leave operations at the ATM layer can be achieved through an ATM multicast fabric.

8.5 Inter-Cluster Handovers of Multicast Connections

Having explained how multicast-connection handovers can be supported, we now present the detailed protocol procedures for handover of multicast connections.

8.5.1 Handover of a Sender in a Multicast Tree (Centralised)

With reference to Figures 3a, 3b and 5, the protocol procedures are outlined below.

- When the migrating MH crosses wireless cluster boundaries, it sends a handover *hint*(1) message to BS_{OLD}, so that advance handover procedures can be performed. BS_{OLD} then sends an *invoke*(2) message to BS_{NEW}, which subsequently results in BS_{NEW} querying the connection server for a topology map of the multicast tree.

- With this tree map, BS_{NEW} proceeds to locate a DP which is nearest to the sender, i.e., DP_x. With DP_x, the CX discovery process is invoked. BS_{NEW} inspects its routing table for the minimum-hop routes from BS_{NEW} to the nodes in the $CLS_{OLD} \rightarrow DP_x$ path.

- The CX discovery process proceeds to locate the CX with the minimum-hop path from BS_{NEW}, among all possible CXs. As mentioned earlier, to support partial re-establishments

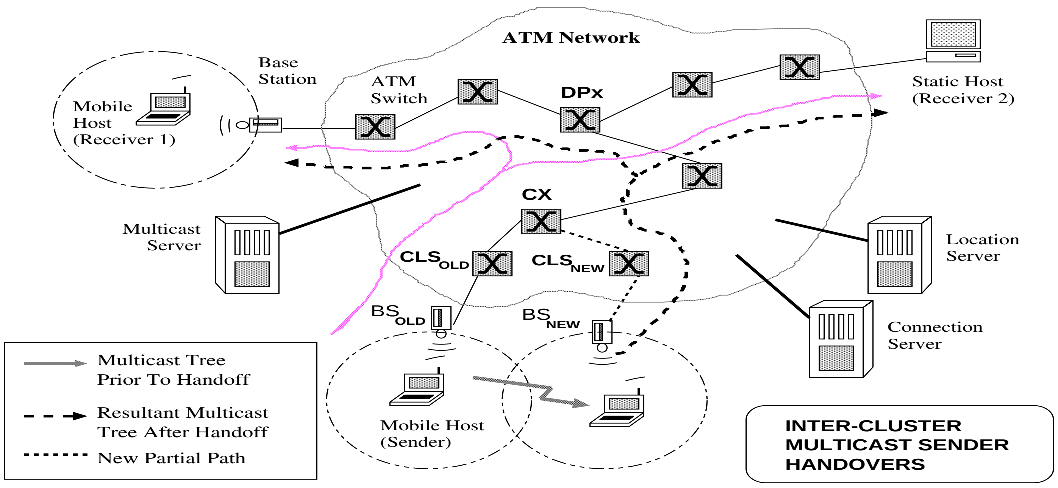

Figure 5: Inter-Cluster Sender Handover.

and to avoid reconstructing the multicast tree, a CX must be a node on the $CLS_{OLD} \rightarrow DP_x$ path.

- Having located the CX, the BS_{NEW} requests the connection server to establish the partial path from BS_{NEW} to CX. When the partial path is established, BS_{NEW} awaits the MH to signal a *greet*(5) message once the MH has entered well into the new wireless cell.

- Upon receiving the *greet*(5) message, BS_{NEW} sends a *redirection*(6) message to the CX. To activate the appropriate connection re-routing operations, the CX must first know if it is the DP_x. This is made known to the CX in the *redirection*(6) message since BS_{NEW} is aware of the identity of CX and DP_x. If CX is DP_x, it performs multicast leave and join operations on the old and new partial paths respectively. Otherwise, it executes association unjoin and join operations. This effectively re-routes the connection.

- The CX proceeds to relinquish the old partial path. The deletion operation can be performed in parallel with the *redirect* and *greet acknowledgement*(7)(8) messages. As mentioned earlier, the partial path deletion operation is not always executed.

8.5.2 Handover of a Sender in a Multicast Tree (Distributed)

Referring to Figures 3a, 3b and 5, this subsection presents the protocol procedures for a Wireless ATM LAN employing a distributed connection management scheme. In this scheme, each ATM switch is required to maintain a connection table, which contains its current list of active connections. Instead of *prior path knowledge* discovery, the *distributed hunt* discovery is used here.

- When BS_{NEW} receives an *invoke*(2) message from BS_{OLD}, it broadcasts a CX query packet throughout the LAN to locate all the possible CXs. Nodes receiving the CX query will check their connection tables to ascertain if they are CXs. All possible CXs will then generate a reply to the BS_{NEW}.

- To determine the appropriate DP_x, BS_{NEW} will require the multicast tree connectivity map. The derivation of this map has been mentioned previously in Section 8.3.

- Having discovered all the possible CXs (only CXs in the $CLS_{OLD} \rightarrow DP_x$ path are considered) and computed DP_x, the BS_{NEW} inspects its routing table to locate the CX with the minimum-hop $BS_{NEW} \rightarrow CX$ route. BS_{NEW} then sends the CX *setup*(3) control packet to its next succeeding node, using the hop-by-hop routing and connection setup approach, until the setup request packet arrives at the CX.

- CX then returns an *acknowledgement*(4) message to the BS_{NEW}. The partial path is said to be established when BS_{NEW} receives CX's reply. When the MH issues a *greet*(5) message to BS_{NEW}, it results in BS_{NEW} sending a *redirection*(6) message to the CX. This invokes the multicast leave and join operations at the CX (if CX is DP_x), or the association unjoin and join operations (if otherwise).

- Having performed the redirection, CX proceeds to delete the old partial path. This can be done in parallel with the *redirect* and *greet acknowledgement*(7)(8) messages. Again, the deletion can be active or passive. The handover operation is completed when BS_{NEW} receives a *done*(9) message from the MH.

8.6 Handover of a Receiver in a Multicast Tree - Centralised or Distributed

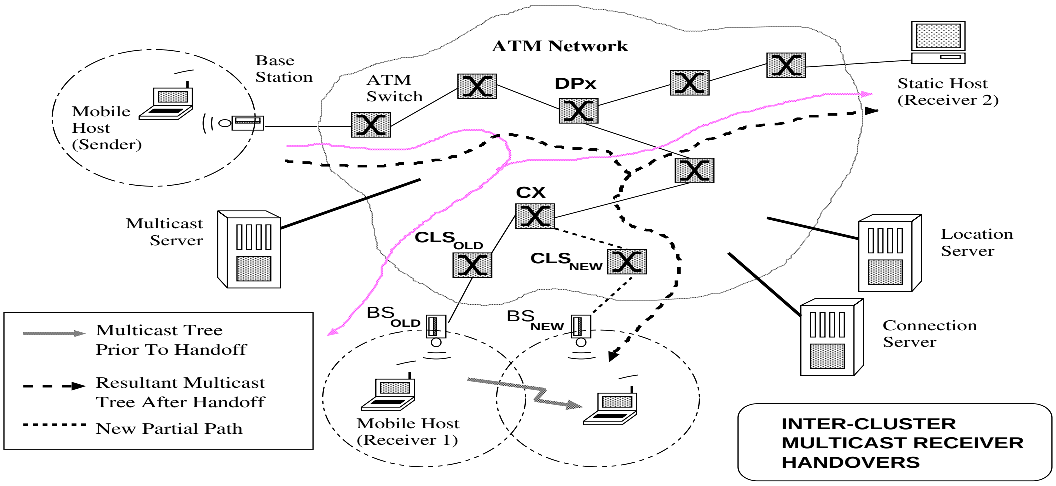

Figure 6: Inter-Cluster Receiver Handover.

The procedures for handover of a receiver in a multicast tree are almost identical to those of the sender. As shown in Figure 6, CX remains as a node in the $CLS_{OLD} \rightarrow DP_x$ path and the connection re-routing operations are similar to those for sender handovers (whether CX is DP_x or not). As before, if the centralised connection management scheme is used by the Wireless LAN, consultation with the connection server is necessary during CX discovery. Otherwise, no connection server is required for the distributed connection management scheme since each node maintains a connection database. The protocol control and data flow diagrams are the same as those in Figure 3.

8.7 Intra-Cluster Handovers of Multicast Connections

Intra-cluster handovers of multicast connections are easier to manage than inter-cluster handovers since the CLS is also the CX, which is only a single hop away from the BSs. This implies that the handover operation can be performed very quickly, unlike inter-cluster multicast-connection handovers.

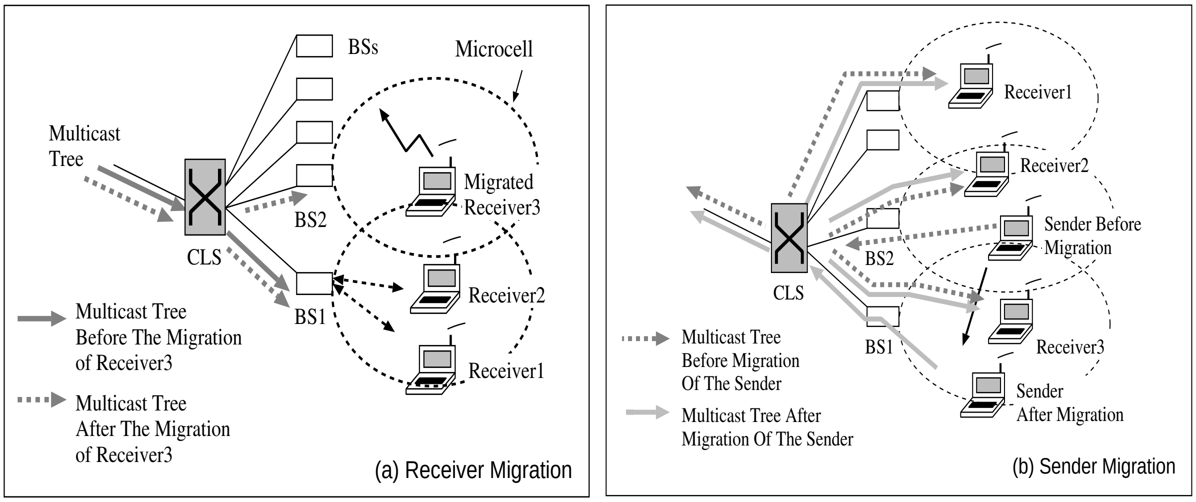

Figure 7: Intra-Cluster Handover of Multicast Connections.

In unicast-connection handovers, the old partial path must always be deleted once the new partial path is established and the connection re-routing operation is invoked. As explained earlier, for multicast-connection handovers, a migration by a receiver or sender does not necessarily imply the need to delete the old partial path. As shown in Figure 7a, if multiple receivers are all residing in the same wireless cell, a migration of a receiver to the next neighbouring cell should not result in the deletion of the $CLS \rightarrow BS1$ path (if the same VP/VC is used for MHs residing in the old wireless cell) since BS1 is also a DP. Hence, although the BS_{NEW} issues a *redirection*(6) message to the the CLS, the latter will not delete the old partial path if the path is still valid. The CLS will now receive a *passive tear-down acknowledgement*(9a) message from BS_{OLD}. This, therefore, avoids the loss of connectivity to other valid multicast group members.

However, this is not a problem for sender's migration when both the sender and receiver reside in the same wireless cell prior to handover, as shown in Figure 7b. Finally, if different VPs/VCs are used for MHs residing in the old wireless cell, the partial path deletion process is no longer conditional.

9 Discussion

9.1 Applicability to Source-, Server- & Cored-Based Trees

While we have so far mentioned handovers of multicast connections based on a single multicast tree with a single sender and multiple receivers, how are these applicable to multicast connections derived from different multicast tree schemes? For a CBT multicast connection, our explanation is directly applicable since our multicast model is essentially that of a CBT, which is a single delivery tree irrespective of the number of senders.

For server-based trees, $\mathcal{N}$ point-to-point connections are established from $\mathcal{N}$ sources to the multicast server but only one point-to-multipoint connection is established from the server to the recipients. Hence, receivers' handovers occur over a point-to-multipoint connection, which is similar to our model. For senders' inter-cluster handovers, the same principle of convergence applies because DP_x is, in the worst case, the switch connecting the multicast server.

Finally, for source-based trees, because $\mathcal{N}$ point-to-multipoint trees are established for $\mathcal{N}$ senders, this implies that the handover process (irrespective of sender or receiver handovers) involves changing the partial paths for $\mathcal{N}$ multicast trees. Hence, $\mathcal{N}$ tree maps are required; CX discovery has to be invoked $\mathcal{N}$ times; $\mathcal{N}$ DP_xs have to be computed per multicast group; $\mathcal{N}$ redirection and acknowledgement messages are required, etc. Source-based multicast trees, therefore, place very high computation and communication burdens on the network during handovers of multicast connections, especially when the number of senders is large. This may suggest that source-based multicast trees are unsuitable for Wireless ATM networks.

9.2 Applicability to other CX Discovery Schemes

This paper has earlier explained the enhancements required for the *prior path knowledge* and *distributed hunt* discoveries before handovers of multicast connections can be supported. It is necessary here to discuss whether other CX discovery schemes can be enhanced. Because the *loose select* discovery scheme considers only the destination node for convergence, it cannot support multicast connection handovers directly. Instead of the destination node, DP_x should be regarded as the ultimate node to converge to. In *backward tracking* discovery, the backtrack process should now only occur over the CLS_{OLD} to DP_x path, not over the complete existing path, so that handovers of multicast connections can be supported. Summarising, all the CX discovery schemes proposed for unicast connection handovers have to be augmented.

9.3 Qualitative Comparisons

In terms of qualitative performance, compared to unicast connection handovers, the additional signalling traffic incurred by multicast connection handovers is minor and this is attributed to the need to maintain up-to-date multicast tree topology maps. In terms of additional computation requirements at the BSs, this is a small amount attributed to the algorithm necessary for the derivation of DP_x. Similarly, in terms of handover delay (this is the time from initiating a handover $greet(5)$ message till a handover $done(9)$ message is received by the MH), multicast connection handovers will have relatively similar delays as those in unicast connection handovers. This is because: (a) the additional time required to derive the DP_x does not contribute to the handover delay since this process is done well in advance and (b) the time needed to perform multicast leave and join operations will be much less than the signalling time incurred over the wireless link. Nonetheless, future quantitative comparisons will be necessary.

10 Uniform and Unified Handovers

As shown by the earlier sections, the enhanced hybrid handover protocol is suitable for MHs with unicast, multicast or heterogeneous connections. The protocol employs the same principle of partial re-establishments, exploitation of locality, radio hints and CX discovery, with variations in connection re-routing operations for unicast- and multicast-connection handovers.

There is no difference in the protocol procedures for sender and receiver multicast-connection handovers since DP_x in both cases is the DP nearest to the CLS_{OLD}. Because the same protocol procedures are employed for both unicast- and multicast-connection handovers and the fact that CX discovery is required during these handovers, we arrive at a uniform and unified handover methodology for MHs in a Wireless ATM network.

Types of Handover Connections	**Partial Path Setup**	**Partial Path Setup**	**Nodes Considered For Convergence**	**Connection Re-routing Operations at the CX**
Inter-Cluster Unicast Connections	BS_{NEW}→CX	$CX \rightarrow BS_{OLD}$	$CLS_{OLD} \rightarrow CLS_{DEST}$	Association Unjoin & Association Join
Inter-Cluster Multicast Connections (if CX is not a DP)	BS_{NEW}→CX	Depends	$CLS_{OLD} \rightarrow DP_x$	Association Unjoin & Association Join
Inter-Cluster Multicast Connections (if CX is a DP)	BS_{NEW}→CX	Depends	$CLS_{OLD} \rightarrow DP_x$	Multicast Join & Multicast Leave
Intra-Cluster Unicast Connections	BS_{NEW}→CLS	CLS→BS_{OLD}	None	Association Unjoin & Association Join
Intra-Cluster Multicast Connections	BS_{NEW}→CLS	Depends	None	Multicast Leave/Join or & Association Unjoin/Join

Table 4: Summary of Handover Operations.

Types of Handovers	**Remarks on Handover Management**
Intra-Cluster Handovers (Heterogeneous Connections)	Single Convergence Point (i.e., Single CX) but Multiple Connection Re-routing Operations.
Inter-Cluster Handovers (Heterogeneous Connections)	Different Convergence Points (i.e., Multiple CXs and Multiple Connection Re-routing Operations.

Table 5: Summary of Handover Management.

Table 4 presents the summary of the partial path setup, tear-down, connection re-routing and CX discovery functions for unicast- and multicast-connection handovers. Finally, Table 5 summarises how intra- and inter-cluster handovers of heterogeneous connections are performed in a distributed or centralised manner.

11 Conclusion

While many of the existing Wireless ATM architectures are concerned with supporting handovers of unicast connections, **none** have proposed an architecture that can support both handovers of unicast and multicast connections.

In this paper, we have highlighted the problems associated with handovers of multicast connections and have revealed a methodology to support both sender and receiver handovers of multicast connections, irrespective of whether the multicast tree is source-, server- or cored-based. The methodology enables handovers to occur without re-establishing a new multicast tree and without affecting the direction of traffic flows. More importantly, we have shown how intra- and inter-cluster handovers of heterogeneous (i.e., unicast and multicast) connections can be performed in a uniform and unified manner, for Wireless ATM LANs employing either the centralised or distributed connection management scheme.

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