

Connection Routing Schemes for Wireless ATM

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Abstract

Wireless ATM, presents several interesting challenges such as managing an end-to-end ATM connection (using connection re-routing) and location management, handling high error rate performance of wireless links, maintaining the ATM cell sequence, and supporting quality of service (QoS) requirement. Recently, the design of re-routing schemes has received some consideration in the literature. However, most of these schemes do not address support for multi-connection and multicast handoffs that may be necessary for mobile multimedia computing. We discuss several rerouting schemes for wireless ATM networks and many issues including multi-connection and multicast connection handoffs and propose generic techniques that can be incorporated in rerouting schemes to support such handoffs. We also discuss how these can be incorporated in rerouting schemes such as RAC (Rearrange ATM Connection) and EAC (Extend ATM Connection).

1. Introduction

To support mobile computing an interesting approach is to use "Wireless ATM" (Asynchronous Transfer Mode), which is the extension of ATM technology to wireless networks. The use of "Wireless ATM" has been motivated by an increasing deployment of ATM technology in backbone networks and due to the need to support mobile multimedia services in the next generation wireless networks. These could include terrestrial cellular systems, emerging wireless local loop [1] and high-speed satellite systems. Wireless ATM is an emerging technology where ATM cells are transmitted over wireless channels and part(s) of the ATM connection lies in the wireless network (see Figure 1).

The term wireless ATM should be differentiated from Mobile ATM, which offers a common wired network infrastructure to support mobility of wireless terminals, independent of the wireless access protocol [2]. The introduction of ATM in wireless environment creates many interesting challenges. These include how to maintain the end-to-end ATM connection as the user moves from one location to the other, how to keep track

of the mobile location, how to provide quality of service, and the how to deal with wireless links to support the mobile computing environment. More details on wireless ATM can be found in [3-5]. We discuss several rerouting schemes for wireless ATM networks and many issues including multi-connection and multicast connection handoffs and propose generic techniques that can be incorporated in rerouting schemes to support such handoffs.

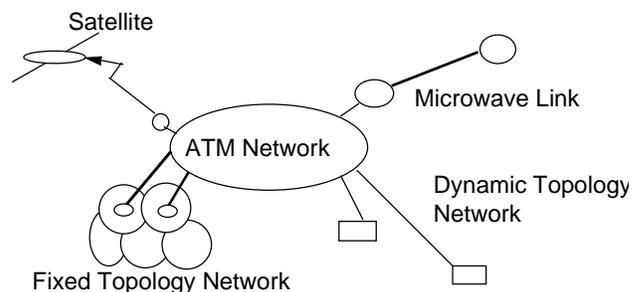


Figure 1. A wireless ATM network

The paper is organized as follows. In Section II, we present an integrated treatment of several rerouting schemes and also a classification of these schemes. In Section III, we introduce several important issues that need to be addressed by rerouting schemes. We present support for multicast and multi-connection handoffs in IV and V respectively. In VI, support for these handoffs in RAC/EAC is addressed and then we conclude in VII.

2. Connection rerouting schemes

Several rerouting schemes have been proposed in the literature [6-20] based on rearrangement of end-to-end ATM connection using the following approaches: (a) by setting up a new connection every time a mobile host moves (also called connection reestablishment) [6], (b) by forwarding of ATM cells to the current location of the mobile user (connection extension) [7, 8], (c) by keeping the path same up to a switch and modifying the path from the switch to the new location (anchor switch) [9], (d) by rerouting the connection as the mobile user moves

(dynamic rerouting) [10-13], (e) by setting paths in advance for communications in the wireless network [14-17], and (f) hybrid schemes [18, 19].

2.1. Connection reestablishment

This approach is simplest as it involves setting up a new connection every time mobile host moves to a new location [6]. This has also been termed as New Connection Every Handoff (NCEH) [18]. The advantages of this scheme include no need for routing functionalities, no modification to ATM switches, always optimal path to the mobile user. The disadvantages include lot of connection processing (more so in micro or pico cellular networks), long handoff delays, and the connection setup (and hence mobility) is not transparent to fixed ATM terminals.

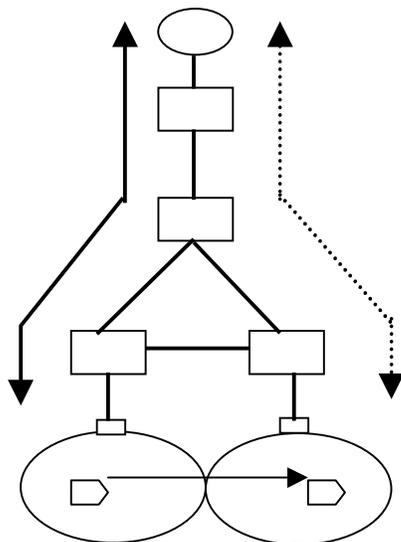


Figure 2. Rerouting using reestablishment

2.2. Connection (path) extension

This approach is also simple as path is extended from the previous location to the new location of the mobile user. The advantages include no need for routing functionalities, and no modifications to ATM switches. The disadvantages include non-optimal (or even inefficient) extended path, the need for switching and buffering capabilities at all Base Stations to perform connection extension, and possible bottleneck at BSs.

BAHAMA [7] is an ad hoc wireless ATM LAN, where portable base stations (PBS) are employed and connected in an arbitrary topology. Mobile hosts locally register with PBS, and a paging scheme is used to locate the corresponding PBS of the called mobile user. The technique employs designated “Source Home” and

“Destination Home” base stations to reroute ATM cells to new locations of mobile user(s). After a handoff the traffic is still routed through their original source and destination home base stations. However, it has been suggested that these home base stations be slowly updated to reduce the bandwidth waste. To maintain the ATM cell sequence integrity, sequence numbers are used for ATM cells in parts of the network.

SWAN [8] is a Seamless Wireless ATM Network where path extension is performed when a cell boundary is crossed. The path extension may cause inefficient routes and some provisions are presented to loop removal and rerouting. When a mobile user crosses a domain boundary then the end-to-end connection is partially rebuild.

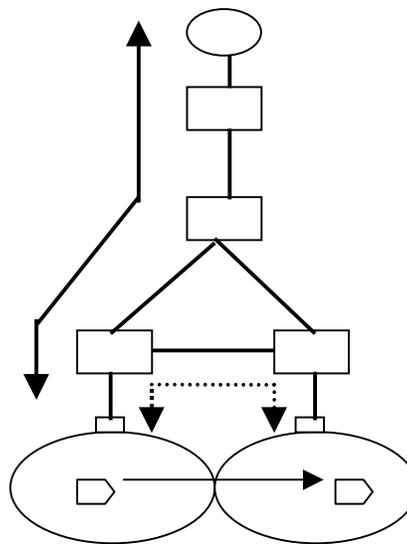
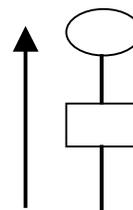


Figure 3. Rerouting using extension

2.3. Anchor routing

This approach has been used in Personal Communications Systems/cellular networks where connection from the backbone network to anchor switch is fixed and only the connection from anchor switch to new BS is modified [9]. The advantages include no changes needed at most switches and only edge (anchor) switches are modified to support connection routing. The disadvantages include non-optimal extended paths (may be better than path extension).



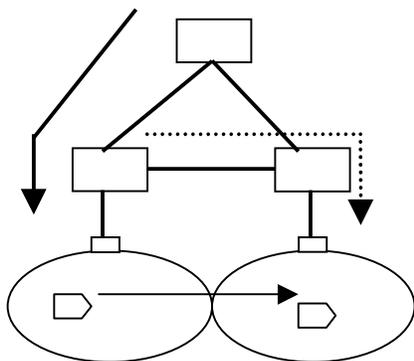


Figure 4. Rerouting using anchor switch

2.4. Dynamic rerouting

This class of routing schemes involves modification of old path to find an optimal or close to optimal new path to the new location of the mobile user. In general this class of routing schemes attempt to find a common switch between old and new path using certain criteria and then turning around the connection from the common switch to the new location of mobile user. This is also termed as crossover switch discovery or route splicing scheme. This is the richest class of connection rerouting scheme in terms of number of contributions or proposals published in the literature. Different proposals look for different switches based on considerations as optimality of the new path, minimum changes from previous path, closest to new BS, closest to the old BS, minimum delay, etc. The disadvantages include longer delays because of switch/path discovery, and the need to modify all ATM switches to support rerouting.

The concept of crossover switch discovery is introduced in [10]. Five proposed crossover switch discovery algorithms include (Loose Select, Prior Path Knowledge, Prior Path Optimal, Distributed Hunt, and Backward Tracking) and are designed for wireless ATM LANs. Its been also shown that network topology can have a significant impact on the performance of crossover switch discovery algorithm. A hybrid protocol based on incremental re-establishment was proposed [11]. To support low and high mobility and to exploit the locality in LAN environment, a multi-tier wireless cell clustering is proposed. The paper looks into handoff protocol design specifications issues such as exploitation of locality, exploitation of radio hint, resource reuse, scalability, and mobile Quality of Service (M-QoS) (M-QoS definition, QoS during handoffs, QoS Consistency, Service disruption time). The paper also looks into cell loss and sequencing, looping, traffic disruption, roaming between wireless ATM LANs. Another proposal that compares the performance of five different schemes using experimental

setup is presented in [12]. They have found that it's possible to achieve low latency, efficient routes and limited disruption of service during handoffs with even simple rerouting schemes. There have been many other proposed rerouting schemes where different criteria is used to select a crossover point (switch). Some of these can also be found in [13].

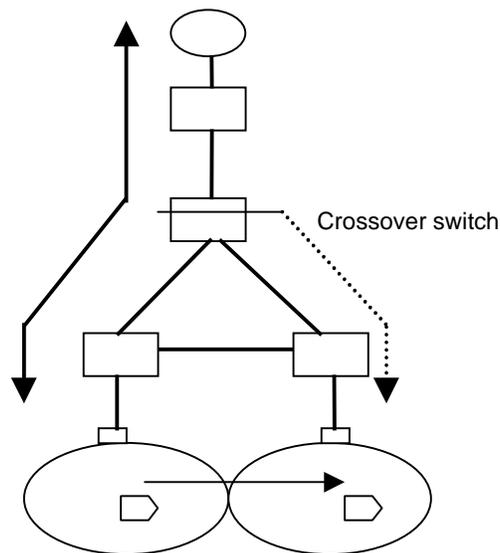
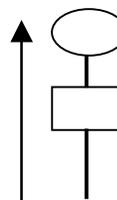


Figure 5. Rerouting using crossover switch

2.5. Rerouting by advance setup of paths

This class of routing schemes involves setting up paths in advance. There are two possible ways to do that. The first is to set up a complete tree so when mobile user moves from a location to the other, it selects a different branch of the tree by using a connection number. Since handoff only involves the selection of a new (but pre-established) path and use of the connection number related to that path, the handoff delay is small, however it may involve longer call setup delay for establishment of tree. It is possible that handoff delay may increase if mobile user is moving out of the tree coverage. The disadvantages include possible waste of bandwidth (due to excess capacity needed in the connection tree), and the need to have changes to all ATM switches to support such rerouting. The second way (and may be a more efficient way) is to use prediction to set up a path to the possible location where a mobile user is likely to move to. The advantages include less waste of bandwidth while disadvantages include increased processing due to prediction algorithm and also the cost of incorrect prediction.



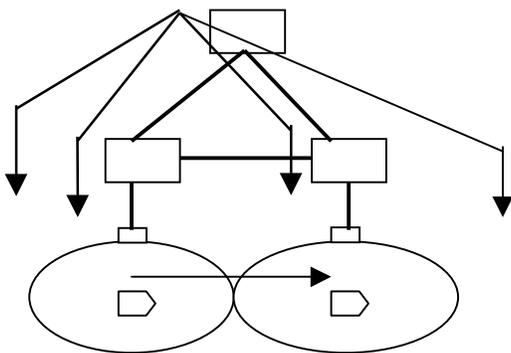


Figure 6. Rerouting using adv. path setup

A virtual connection tree approach [14] is proposed that involves allocating multiple Virtual Connection Numbers to define paths between the root of a connection tree and a distinct base station. A mobile host selects a base station (by comparing signals from nearby base stations) during the handoff by choosing one of these numbers. The network call processor comes into picture to set up a new connection through the ATM network only when the mobile user leaves a certain geographic area covered by a connection tree. Admission control required for maintaining QoS has also been proposed.

Another scheme uses dynamic tree in which routes are predetermined but not set up for potential handoffs. During a handoff, signaling with source routing is used for fast allocation of resources for supporting the handoff connection. The connection tree reconfigures after a handoff to support future handoffs [15].

A predictive mobility scheme using the movement circle and movement track models is presented [16]. The

predictive scheme employs the regular pattern detection algorithms to decompose the complicated daily movement into two parts: regular pattern part and random movement part. MC/MT predicts the regular pattern part while Markov Chain Model is used to model and predict the random part. Preliminary simulation shows that very high prediction efficiency can be achieved based on the degree of randomness in mobile users movement patterns [16].

Rapidly Deployable Radio Network (RDRN) project [17] has the objective of creating a wireless ATM network that is flexible enough at both the link and network levels to allow for rapid deployment and response to a changing environment. A cellular like system for users using directional antennas and high capacity multiple-beam network for switch-switch communications. The paper proposes virtual network configuration (VNC) algorithm for predictive network configuration. They also suggest that handoff in mobile PNNI can be supported by using VNC [17].

2.6. Hybrid schemes

Hybrid schemes combine the features of some of the above scheme. For example, connection extension is among the fastest way to perform handoff but may lead to inefficient routes. On the other hand dynamic rerouting schemes can provide optimal routes but may not provide low handoff delay that may be required for some applications. To support different applications with different delay requirement, hybrid schemes can be designed where two or more different schemes are incorporated. The design of such hybrid schemes has attracted some attention [18,19]. One such proposal combines two schemes termed RAC (Rearrange ATM

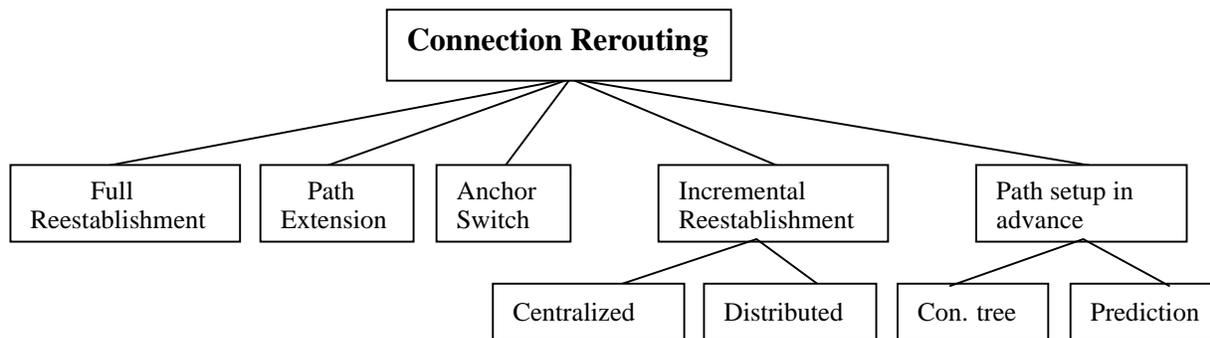


Figure 7. A Possible classification of rerouting schemes

Connection) and EAC (Extend ATM Connection), based on dynamic rerouting through ATM network and connection extension in wireless network, respectively [18]. RAC places the processing requirement for

rerouting in ATM network, and if NCP (Network Call Processor) is unable to process the request, then EAC (to extend the connection to the new location of the mobile user) is performed in wireless network using base

stations. The choice to use any one or both could be based on utilization of bandwidth, implementation complexity, or amount of rerouting load, and the type of signaling used in the ATM network.

2.6.1. RAC (Rearrange ATM Connection). In an ATM network, such connection rearrangement can be done faster if a single entity can process a connection request and inform the ATM switches about the new connection. This type of signaling arrangement has been termed as centralized signaling system and such an entity is called NCP.

NCP periodically broadcast information about its loading that can be used by a BS in determining whether to pursue RAC or not. NCP can use the following information in deciding whether to accept or refuse RAC request: (a) the queue length at NCP (or more generally, the current NCP load), or (b) resource unavailability in the new route to support QoS. In case (a), if the queue length at NCP has reached a certain limit, NCP can refuse a connection on the basis the total waiting time for RAC would increase the effective handoff duration (as experienced by the mobile user) significantly. In this case, it will be faster (although inefficient) if EAC is used. If NCP executes RAC, it finds a new route between the fixed user and the current location of the mobile user. Then it divides the switches in the old route and new route into several groups. These groups include switches that were part of earlier ATM connection but are not needed any more, switches that are still needed but with some change and switches that are still needed with no change. Then NCP can send a message to all members of a group. For e.g., NCP sends CLEAR to all switches that are not needed in the new connection. For switches that are still needed with no change, NCP do not send any message. For switches that were not involved in the earlier connection but are now needed are sent NEWCONNECTION. Switches will take necessary action by making required changes in their routing tables and the connection is rearranged.

Now we take an example to illustrate RAC (Figure 8). Assuming that a connection exists between a fixed user P and a mobile user Q using switches A, B and C and the base station X. If Q moves in the cell of base station Y, then NCP sends only REARRANGE message to the switch C, which in turn changes its routing table to accommodate the rerouted ATM connection.

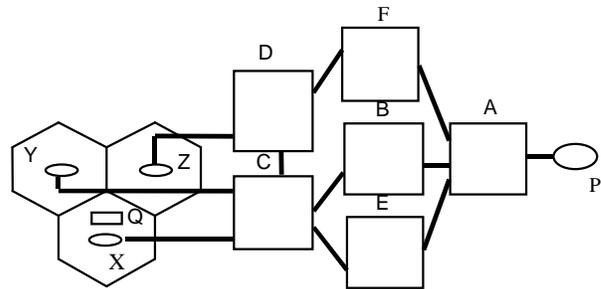


Figure 8. Rearrange ATM Connection (RAC)

However, if Q had moved to cell of Z, then NCP may have several choices of new routes. One is to use switches A, B, C and D to reach new base station Z. The second possibility is to use switches A, F, D. And so on. As it can be seen, second route uses only three switches (A, F, and D) while the first one uses four (A, B, C, and D). Let's compute the number of NCP messages and the changes needed for each of these routes. For the first route, NCP would need to send REARRANGE to switch C and NEWCONNECTION to D. So there are only two messages (changes) for the first route. For the second route, NCP would need to send REARRANGE to switch A, NEWCONNECTION to F and D, and CLEAR to B and C. So there are a total of five messages (changes) for the second route. If the NCP is programmed to optimize the number of hops (switches) every route, it would select the second route. However, if the number of changes needed to complete RAC has to be minimized, NCP would choose the first route.

2.6.2. EAC. After detecting that it's not receiving any signal from the mobile user, the current base station will locate the new base station for the mobile user. The current BS will request the new BS to extend the ATM connection and will supply the necessary information including the list of base stations that have been visited by the mobile user and are part of the extended connection. Extending connection through base stations in wireless network may cause triangular or circular routes and thus amount of traffic can increase in wireless network significantly. Therefore EAC includes the provision for detecting and removing any such routes.

Every base station, before accepting a request for connection extension, checks for triangular and circular (loop) routes that may be formed. This is done by looking into the list of base stations (supplied with extension request), that have been visited and are currently part of the extended connection. If new BS finds that one of the base stations (except the most recently visited base station) on the list is its immediate neighbor, it detects the formation of triangular routing. If possible, It will clear the triangular route with the co-operation of other base stations. The scheme works as follows for circular route formation: if the base stations

finds that it has been visited before and is currently part of the extended connection, it detects the possible loop formation. It will clear the loop after it receives all the ATM cells already in the loop. A marker ATM cell is inserted in the route to indicate that there are no more ATM cells in the route.

3. Issues not addressed by rerouting schemes

There are some issues that have not been addressed (or needs to be addressed in more details) by most rerouting schemes.

3.1. Rerouting for multicast handoffs

Multicasting for wireless ATM is an interesting issue as researchers are still looking into how to support efficient and reliable multicasting in regular ATM networks. Various solutions for multicasting support have been proposed (such as VC mesh, multicast server etc.) but all of these assume stationary ATM users. We feel that a rerouting scheme should be able to provide handoff support for multicast connections. We discuss some general schemes for multicast connection rerouting in section IV.

3.2. Rerouting for multi-connection handoff

A mobile user may be involved in several simultaneous one-to-one connections, say downloading a file while talking to someone. In addition to these, a mobile user may have subscribed to one or more information services that send messages once in a while. When mobile user moves to a new location the handoff will involve not just one but several connections. There are several issues that may arise when a connection rerouting scheme is extended to support multiple connection. We will discuss some of these issues in section V.

3.3. Impact of heterogeneous environment

Connection rerouting schemes assume one of the three scenarios as far as mobility support in ATM switches is concerned (a) no change in the ATM switches, (b) every ATM switch supports mobility, or (c) edge switches (ATM switches at the edge of wired ATM network) supports mobility. One important factor that needs to be addressed is what may happen when some switches have functionality to support mobility while others don't. Or what happens when several different ATM networks are interconnected where some of these networks support mobility and others don't. It's also possible that some switch support multicasting and mobility both and some support one or the other or none of these two.

3.4. Interworking of heterogeneous networks

The rerouting schemes presented in the literature also do not address the interworking issues of heterogeneous wireless ATM networks that arise when different networks based on different rerouting schemes are interconnected. For these purposes, we propose that wireless ATM networks may be implemented with generic rerouting schemes. It's possible to divide most of the rerouting schemes into two classes for implementation purposes. Full reestablishment, extension, anchor, and dynamic schemes can be integrated into a generic scheme where a crossover switch is selected based on a certain criteria. By using different criteria, all of these can be implemented into one generic scheme, and we name it to Generic Reactive Rerouting Scheme (GRRS) as the connection is rerouted in reaction. Other rerouting schemes such as virtual connection tree, dynamic tree, prediction based rerouting, and other schemes that setup a connection in advance can be integrated into one and can be termed as Generic Proactive Rerouting Scheme (GPRS). So we have put major rerouting schemes into two generic schemes. In GPRS, use of prediction scheme can be considered a special case of virtual connection tree where only one branch of the tree is set up (using prediction) for connection rerouting. Virtual connection tree can be thought of a simple prediction scheme where we cover all possible places the mobile user may go next. By allocating bandwidth in advance or after the mobile user has actually reached to the new location (where a tree branch is set up for rerouting), we could cover other major rerouting schemes such as dynamic tree that involves bandwidth allocation only after the mobile user has actually moved.

There are several possible situations (although the number of permutations and combinations of rerouting schemes in different networks have been reduced by making two generic schemes) such as one where networks are using same generic rerouting scheme and second one where they are not. The second case is more complex and need to be addressed by researchers. We could make some comments here about a situation where two networks are interconnected and one is using GPRS and the other using GRRS. One possible way is to use GRRS all the way to the point of interconnection and from there to the mobile user GPRS can be used. When there is a major change (or after several minor changes) in the route in one network, the other network can be notified and its part of the route can be modified accordingly. Even, in cases where both interconnected networks are not using generic schemes but one is using generic rerouting scheme and the other is using one of the four possible rerouting schemes (of the generic scheme), then interworking issues are simplified. If all

networks that need to be interconnected are using the integrated (generic) rerouting then a particular rerouting scheme can be selected based on resources, type of connection, and other factors.

3.5. Impact of failure

A wireless ATM networks may suffer base station failure, ATM switch failure, link failure, and/or failure of mobile devices. Connection rerouting schemes proposed in the literature do not address these issues. For example, if a rerouting scheme uses connection extension involving previous and new base station, and assuming the previous base station fails before the connection is extended, how can we still perform connection rerouting. Similarly, the failure of switches (crossover or switches on the path) will impact rerouting.

4. Rerouting for multicast connection

Multicasting can be defined as the problem of creating, maintaining and updating efficient multicast tree(s). The multicast tree needs to be updated after users leave or join, after there is a change in connectivity or the load of the underlying network. There are two general approaches to multicast trees, one using tree rooted at every sender and branching to all receiver, the other one using a shared tree [20]. Multicasting for wireless ATM is an interesting issue as researchers are still looking into how to support efficient and reliable multicasting in regular ATM networks. ATM only supports point-to-multipoint connection and multipoint-to-multipoint connections can be setup as a group of point-to-multipoint connections. Various solutions for multicasting support in ATM have been proposed (such as VC mesh, multicast server etc.) but all of these assume stationary ATM users. We feel that multicasting for mobile users should be supported in wireless ATM networks. Therefore, a rerouting scheme should be able to provide handoff support for multicast connections. There are several issues that we feel are important for multicasting in wireless ATM networks. These include cost of updating/maintaining multicast tree, impact of admission control, and scalability issues.

In general multicasting schemes proposed for ATM networks can be extended to support mobile users. One point that must be made here is that due to mobility, the updating of multicast tree(s) would be a major issue as it has the potential of wasting significant amount of network bandwidth if proper updating is not performed after handoffs of mobile users. But updating of tree, especially in case of fast mobility or lot of users, may require significant amount of overhead. For example, if a

source based tree is used for multicasting where a mobile user is the source and is connected to several receivers using shortest path tree, then after the mobile user moves to a new location and the tree is not updated, then amount of bandwidth in use by the multicast tree may increase. However, if the tree is updated after the handoff then amount of overhead required in updating may be significant. On the other hand, if a shared tree is used for multicasting then after a handoff, the length of multicast tree (and hence the amount of network resources in use) may increase if tree is not properly updated. A multicast tree may also be subject to admission control after a mobile user moves to a new location where the base station can not provide requested amount of bandwidth/resources. The type of connection rerouting scheme used in wireless ATM networks will also impact the scalability of multicast tree in terms of number of users, network size and frequency of change.

We assume a generic multicasting scheme is used where a single multicast tree is used to support multicast communications. Our focus is more on the rerouting and possible ways to update the multicast tree. The tree may have to be updated as users join and leave. We propose several general techniques that can be used in maintaining multicasting for mobile users.

4.1. Rerouting with possible tree updating

One is to reroute connections after a handoff in such a way that it partially or fully updates the multicast tree. We call these as Rerouting with Possible Tree Updating. Rerouting with possible tree updating can be implemented in several different ways. These differ in how the connection rerouting is done after a handoff.

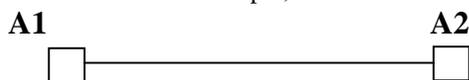
Find a shortest path to the core. After a handoff, mobile user is connected via a shortest path to the current core. The new shortest path may or may not use part of the old shortest path (the path before the handoff).

Find a shortest path to the tree. After a handoff, mobile user is connected to the existing tree at any point using a shortest path.

Find a shortest path to a future core. If the new core can be predicted, then mobile user is connected to the new core by using a shortest path.

4.2. Rerouting followed by tree updating

The second general scheme is based on the concept of rerouting be independent of updating of multicast tree. In this, rerouting is done using a certain criteria and after N handoffs or T time or after the length of multicast tree



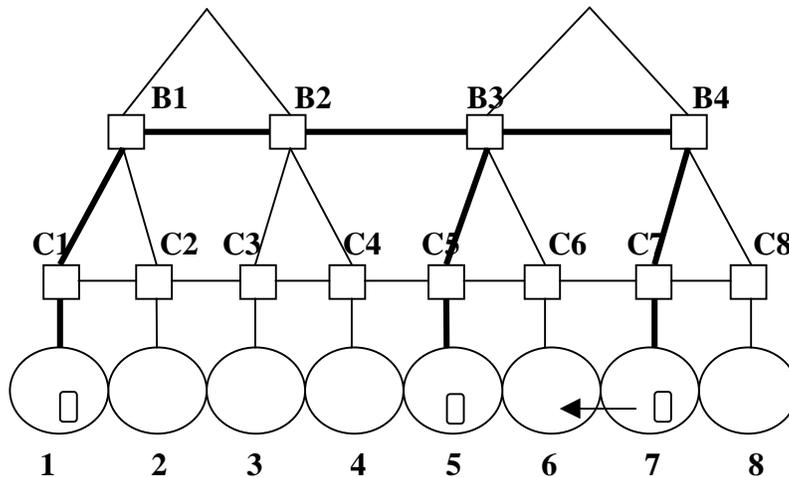


Figure 9. Multicast tree in wireless ATM network

reaches Q hops, the multicast tree is updated to reduce the network resources in use by the multicast tree.

4.3. Rerouting as leave & join

The third technique is to treat handoff (or 1 of every N handoffs) as a leave and join operation. This will cause new connection to be setup after a handoff and so the multicast tree update cost may be reduced.

Assuming that initially mobile users are at locations 1, 5, and 7. The core of the tree then would be at switch B3 (the distances to 1, 5, and 7 are 4, 2, and 3 hops respectively). If the mobile user who was at location 7 moves to 6, then possible choices for rerouting include (a) connecting to B3 via C6 (shortest path to the core), (b) connecting to C5 via C6 (shortest path to the tree), (c) extending the existing connection (B3-B4-C7) to C6. In case (a), the distances from core are 4, 2, and 2. In case (b), the distances are 4, 2, and 3. In case (c), the distances are 4, 2, and 4. So the length of multicast tree depends on how rerouting is done. Some rerouting schemes such as shortest path to the core or tree may partially update the tree. Connection rerouting schemes such as extension may increase the amount of resources and thus may not be suitable for multicasting.

We can count overhead of each of these schemes as the number of signaling messages and the number of hops a message needs to travel. The total overhead of a multicast rerouting scheme should include both the overhead of connection rerouting and the cost of updating the resultant tree. Therefore, a scheme that may perform well in unicast connection rerouting may not perform well for multicast rerouting as the updating cost of the resultant tree may be high.

5. Rerouting for multiple connections

A mobile user may be involved in several simultaneous one-to-one connections, say downloading a file while talking to someone. In addition to these, a mobile user may have subscribed to one or more information services that send messages once in a while. This scenario leads to a situation where a mobile user may have several connections. When mobile user moves to a new location the handoff will involve not just one but several connections. The schemes presented in the literature for connection rerouting (or handoff) address single connection handoff. In theory these schemes can also perform handoffs involving several connections. However there are several issues that may arise when a connection rerouting scheme is extended to support multiple connection. In this section we discuss these issues and their possible impact.

5.1. Parallel vs serial rerouting

When a mobile user is involved in several connections that need to be rerouted after a handoff, one important consideration is whether or not these connections can be rerouted simultaneously. If yes, then we have to consider issues like amount of loading as now a switch is asked to support many new (rerouted) connections. Also what happens if switches in the new (rerouted) path can support some but not all connections. Also then the impact of a switch failure would be more on a mobile user if all of his/her connections use the same set of switches.

5.2. Handoff Processing and delay

In case of serial processing of multiple connections, the handoff delay may become a concern as the total delay seen by a user is sum of rerouting delay for each connection.

5.3. Handoff delay for real-time traffic

If multiple connections are rerouted serially without considering the type of traffic they are carrying then it may be possible that real-time traffic may experience more delay than the other traffic types.

5.4. QoS & admission control

In case of multiple connection handoff, the new base station may not have the sufficient bandwidth to support all connections. In that case, the new base station may consider renegotiation of bandwidth or possible blocking of one or more connections, especially the one needing a lot of bandwidth.

5.5 Cost of inefficient routing

In wireless ATM networks, since the resources are limited, the choice (or performance) of a connection rerouting scheme impacts the bandwidth use (or misuse). This problem can be multiplied by several fold when multiple connections are involved in a handoff.

5.6. A scheme for multiple connection handoffs

We propose that rerouting for multiple connections as part of a single handoff should be based on the expected QoS of traffic carried by these connections. For example, if a connection involves real-time traffic then a simple and fast rerouting scheme can be used. Complex and more efficient rerouting scheme should be used with connections involving traffic that can tolerate some delays. Wireless networks can be implemented with one of the two generic rerouting schemes such as GRRS or GPRS and then the choice of a rerouting scheme (such as extension, incremental reestablishment etc.) can be made based on several factors. For example, if GPRS scheme is employed, then if the user's mobility pattern is very random the switches could use virtual or dynamic tree schemes that involve several connections to cover all possible movement of a user. If the user's mobility pattern is static or not very random, then switches could use prediction schemes for connection rerouting.

The advantages of choosing rerouting scheme based on a connection include lower delay for real-time traffic, efficient routing for delay-tolerant traffic, and distribution of traffic load on several different paths. This will also reduce the impact of switch and/or link failure on mobile user as all of his/her connections will not be affected if a switch and/or carrying one or some of the rerouted connections fail. One example of routing is shown in Figure 10.

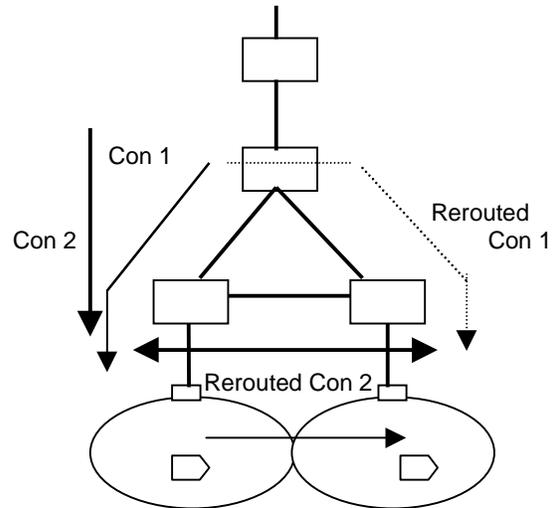


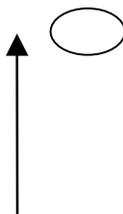
Figure 10. Multi-connection handoff rerouting

In addition to selecting the rerouting scheme based on the traffic, we also propose that a priority scheme be used to select which connection should be handoff first and so on. The factors that can be considered could be (a) type of traffic, (b) handoff delay history for the connection, (c) bandwidth of connection.

If the new base station can not support all connections of a mobile user who just moved to its coverage, then the base station can temporarily reduce bandwidth allocation to one or more connection to allow other connections of the mobile user to be continued. This reduction may not impact the QoS perceived by the mobile user. For example, if a mobile user is involved in a voice conversation and the base station reduces bandwidth allocation to his/her other connection involving file download, the user may not perceive the increased delay in file transfer.

6. Multi-connection and multicast handoffs in RAC/EAC

RAC uses Network Call Processor that maintains information about all switches in its network. This kind of architecture has some advantages as far as multi-connection and multicast handoffs are concerned. One is that most processing is done by NCP so the ATM switches are relieved of processing multicast and multi-connection handoffs. Second is that a generic rerouting scheme (such as GRRS or GPRS) can be employed or modified or changed at NCP without changing ATM switches. Third is that NCP may be able to combine processing with connection rerouting with multicast tree updating, thus reducing the overall cost of supporting multicasting in wireless ATM networks. Fourth advantage may include simplified interconnection with



other wireless ATM networks. If other networks use NCPs, then interworking issues are simple. If other networks use PNNI architecture (where nodes have group leaders that pass routing and loading information to other group leaders and so on) then NCP can be considered as a group leader as it has the information necessary to act as a group leader. For multi-connection handoff, NCP can select different routes for different connections based on factors such as handoff delay, acceptable cell loss during handoff, etc. NCP can determine the core of a multicast tree before rerouting connection and thus reducing the multicast tree update cost. For EAC, implementing multi-connection handoff and multicasting means that now EAC may attempt connection extension (for some connections needing low handoff delays) without attempting RAC first. The cost of inefficient routes is even more with multi-connection and multicast handoff, so the provisions of EAC such as prevention, detection and removal of triangular and loop routes [19] may even become more useful.

7. Conclusion

Recently, the design of connection re-routing schemes has received some consideration in the literature. However, these schemes do not address support for multiple connections and multicasting that may be necessary components in supporting mobile multimedia computing. This paper presents general schemes to support into multi-connection and multicast connection handoffs.

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