A Two-Phase Handoff Scheme for Mobility Management in Wireless ATM Networks

Khaled Salah
Dept. of CS, Illinois Institute of Technology
Tellabs Operations, Inc.
ksalah@tellabs.com

Elias Drakopoulos
Dept. of CS, Illinois Institute of Technology
Lucent Technologies
edrakopoulos@lucent.com

Abstract. Mobility management in Wireless ATM networks poses a number of technical issues. An important issue is the ability to manage and reroute on-going connections during handoff as mobile users move among base stations. We propose a two-phase handoff management scheme using permanent virtual paths reserved between adjacent Mobility Enhanced Switches (MES). The virtual paths are used in the first phase to rapidly reroute user connections. In the second phase, a distributed optimization process is initiated to optimally reroute handed-off connections. The paper also describes an adaptive optimization scheme to achieve high reserved bandwidth utilization. We analytically calculate and study the bandwidth requirement for the reserved virtual paths and handoff blocking probability. We also study the impact of processing and signaling load due to the second-phase route optimization. Both ATM CBR and VBR traffic types were considered for mobile users.

Keywords: MOBILITY MANAGEMENT, ATM, WIRELESS NETWORK, HANDOFF PROCEDURE

1. Introduction

In future mobile communication networks, Wireless ATM (WATM) technology promises support for multimedia traffic such as voice, video, and data with QoS guarantees . A key feature of any wireless network is the ability to support and manage the mobility of a user while maintaining communication. This requires the implementation of handoff management. In handoff management, connection routes need to be modified as users move during the life time of a connection. The rerouting must be done fast enough with minimal disruption to traffic.

For the purpose of this paper, the network model shown in Figure 1 is adopted. This model has been used in project Magic WAND (Wireless ATM Network Demonstrator) [1] and is being used as a reference network configuration in the ATM Forum [2].

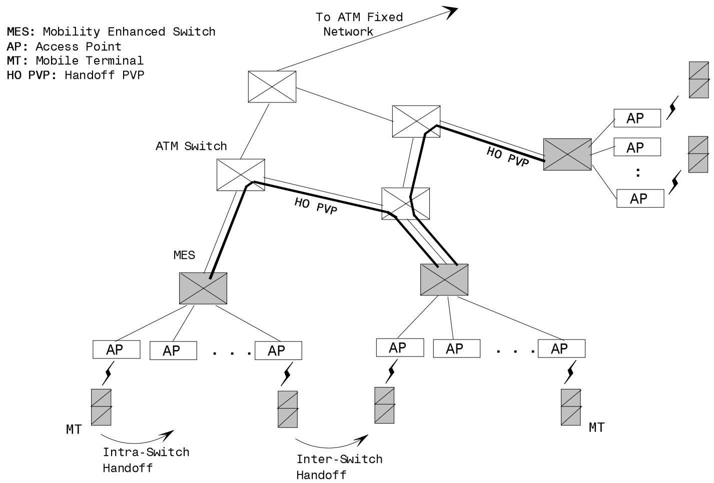

Figure 1 WATM network architecture

In order to solve the problem of managing and rerouting user connections in WATM handoff, number of handoff management schemes have been proposed. Two of the most well-known schemes are path extension [3, 4, 5] and path rerouting [6, 7, 8]. In path extension, the connection is extended from the old AP (Access Point) to the new AP. Pre-provisioned connections are typically established between APs in order to reduce connection setup time. While this scheme promises low rerouting latency, the resulting route is often not optimal. Also, it increases the complexity of the AP. The AP must be capable of managing pre-provisioned connections, and it must have buffering and switching capabilities to all adjacent AP links. Increasing complexity of the AP will lead to increase in the total system cost as the AP will be one of the most widely deployed nodes. In path rerouting, a portion of the connection is rerouted at a Crossover Switch (COS). The COS is a rerouting point where the new partial path meets the old path. The idea is to re-use as much of the existing connection as possible, creating only a new partial path between the COS and the new AP. The scheme provides only partial route optimization and requires an implementation of a COS selection algorithm during handoff. The handoff latency of this scheme depends largely on the time involved in selecting the COS and the delay involved in setting up new connection segments for the establishment of the new partial path. This delay will be highly variable and will depend on the number of intermediate switches and the processing load at each switch. The delay is more noticeable in the inter-switch handoff as the number of intermediate switches increases.

In this paper, we present an alternative solution in which we overcome these drawbacks. In the new scheme, Handoff Permanent Virtual Paths (HO PVPs) are provisioned between adjacent MESs to rapidly reroute user connections during inter-switch handoffs eliminating the connection processing load and delays at intermediate switches. Therefore, the handoff latency is minimal. The rapid reroute of user connections is followed by a non-realtime second phase in which a distributed route optimization procedure is initiated to find optimal paths. This scheme keeps AP complexity and cost low. The AP is simple and doesn't require having switching or buffering capabilities. It requires only mapping capabilities of user cells received on the wireless link to the wired link connected to the MES. The AP also doesn't need to manage pre-provisioned connections. Also, provisioning HO PVPs between adjacent MESs is more efficient in terms of bandwidth and management resources. It is more expensive to provision and manage permanent connections between adjacent APs or between border APs and their adjacent MESs.

The rest of the paper is organized as follows. In Section 2, the first phase of the proposed scheme is described along with signaling protocols for both Intra- and Inter- Switch handoffs. Section 3 describes the route optimization of the second phase. Section 4 presents an analytical model to evaluate the proposed scheme. Section 5 studies performance results. Section 6 proposes an adaptive optimization service rate to improve bandwidth utilization. Finally, Section 7 concludes the paper.

2. Description of the proposed scheme

In this section, we describe how the proposed two-phase handoff management scheme can be applied to Intra-Switch handoff as well as Inter-Switch. Intra-Switch handoff occurs when an MT (Mobile Terminal) moves from an AP connected to an MES to another AP connected to the same MES. Inter-Switch handoff occurs when an MT moves from an AP connected to an MES to another AP connected to a different MES. See Figure 1. Intra-Switch handoff requires only one new connection segment to be established between the MES and the new AP, and the resulting route is optimal, assuming the original path to the MES was optimal. Since the new AP is directly connected to the MES, the HO PVP is not involved. Therefore for the Intra-Switch handoff, there will be no need to execute the handoff in two phases. However, Inter-Switch handoff becomes more involved as more new connection segments need to be set up and managed. The number of new connection segments is dependent on the network topology and may span number of ATM switches . With the use of HO PVP between adjacent MES, the management of establishing new connection segments is simplified. Only two new segments need to be established and managed: one is within the HO PVP and the other is between the new MES and the new AP.

A signaling protocol for Intra- and Inter -switch handoffs is shown in Figure 2. The protocol for Intra-switch handoff can be described briefly as follows. During a call setup the user communication path to the MT is established. When the MT moves to a new cell, it determines, using signal strength measurements, a handoff needs to be executed. So, it sends to its MES (via its AP) a HO_REQUEST message requesting a handoff to a new AP. The MES upon reception of the HO_REQUEST allocates a new connection segment for the new AP. The MES requests the new AP (using RR_ALLOCATE message) to allocate radio resources according to expected QoS and bandwidth requirement. The new segment allocation is completed when RR_COMPLETE message is received by the MES. The MES then returns to the MT a handoff response message via the old AP. The handoff response message includes the new connection id and possible QoS modifications. The MT then establishes a new radio link with the new AP. Buffering functions need to be performed at the MT and MES to coordinate switching of traffic to ensure in-order delivery of cells and no cell loss. An example of switching and buffering between two nodes will be illustrated in Section 3. Finally, old connection and radio resources are released.

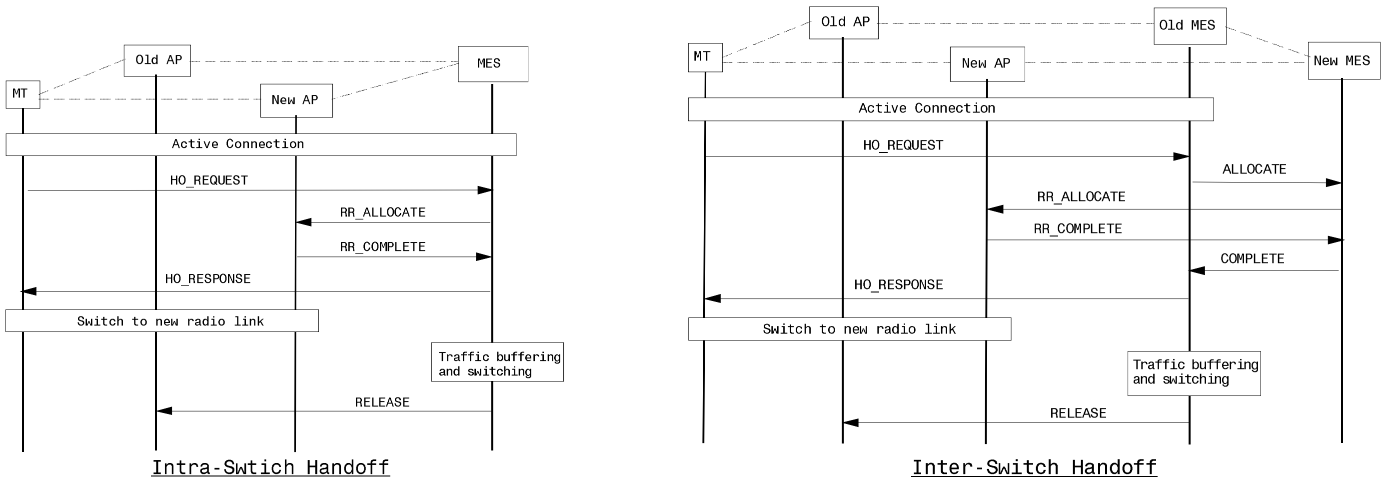

Figure 2 Handoff signaling protocol

In case of Inter-Switch handoff, the signaling protocol is similar except the new MES is involved. When the old MES determines that the new AP is connected to an adjacent MES. The old MES sends ALLOCATE message to the new MES. The new MES allocates two connection segments: one between itself and the new AP and the other within the HO PVP. After a successful Inter-switch handoff, a request for route optimization is initiated. The route optimization procedure is described next.

3. Route Optimization

In order to optimize the connection route resulted from the rapid rerouting using HO PVP, a non-realtime route optimization is executed by the new MES. We propose a distributed route optimization procedure in order to distribute processing load and minimize signaling at a centralized node. The protocol for the route optimization procedure is described in the following steps, as depicted in Figure 3:

1. The new MES requests path information of the handed-off connection from the old MES. Path information is requested using an ID that uniquely identifies the handed-off connection. The ID is provided to the new MES during handoff in the HO_REQUEST message. The requested information includes connection QoS parameters, source and destination ATM addresses, and a list of addresses for all candidate crossover nodes along the path. A crossover node in this case is basically a regular ATM switch which has the added functionality of coordinating traffic switching and buffering with the new MES. The list of candidate crossover nodes is built during connection original establishment. Current ATM Forum and ITU-T standards for UNI and NNI signaling can support building such a list. Call SETUP and CONNECT messages can carry such information as the original connection segments are built hop by hop. If the MT, the local host, is the called/destination node, the MES will extract the list from the SETUP message. However if the MT is the caller/source node, the MES will extract the list from the CONNECT message. A crossover node along the path processes the SETUP or CONNECT message and adds its address to the message using additional IEs (Information Elements). A non-crossover node merely processes the message and passes it to the next node. A crossover node adds its address to the message if the message has one or more crossover IEs. The initial crossover IE is added by the crossover node nearest to the remote host. If the remote host is the caller, the IE is added in the SETUP message, otherwise it is added in the CONNECT message. The crossover node nearest to the remote host uses location management information and addressing to determine if the end host is mobile or fixed. The list of candidate crossover nodes is kept in hierarchical order, i.e. the first node on the list means that the node is nearest to the remote host.

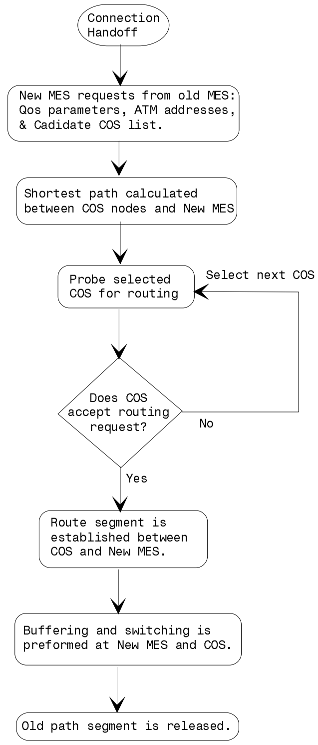

Figure 3 Flow chart of the route optimization process

2. Based on path information received from the old MES, the new MES performs COS discovery. This scheme is similar to Prior Path Knowledge COS discovery scheme proposed in [12], however no centralized connection server is used in our proposed procedure. In order to find the optimal path, the shortest path from the new MES to all candidate crossover nodes in the list is calculated. Since the PNNI routing scheme is a link-state routing scheme (and not a "distance-vector" scheme), this operation can be computed using the existing PNNI protocol [13]. The candidate crossover node with the shortest path will be selected as the crossover node. If multiple candidate crossover nodes have the same shortest path (e.g. minimum-hop count), then the node nearest the remote host will be selected.
3. The new MES then probes the selected crossover node for optimization rerouting. A crossover node receiving the rerouting message will accept or deny the request based on its own knowledge of network topology and state. If the selected crossover node denies the request, another crossover node (one next to the best) is probed.
4. The new MES then builds the best route to the selected crossover node in the from of a hierarchically complete source route known as a Designated Transit List, or DTL, as specified in [13]. The establishment of the new connection segment between the selected crossover node and the new MES can be initiated by either the crossover node or by the new MES. In order to minimize signaling of path information to the crossover node and allow for faster selection of another crossover node in case of segment setup failure, the establishment of the new segment is initiated by the new MES.
5. After the new segment has been set up, buffering and switching functions need to be performed at the new MES and crossover node to ensure lossless rerouting. The new MES and crossover node will use in-band signaling prior to connection switch-over. For example in the ingress direction (towards the crossover switch), when the new MES receives successful segment establishment from the crossover node, it sends a special "Tail" signal cell after the last user cell on the old connection segment. "Tail" signals are special cells sent on the same VC as the user cells (in-band signals). They could be RM (Resource Management) cells. If user cells arrive at the crossover node on the new segment prior to the reception of the "Tail" signal, they will be buffered. These buffered cells will be sent after the reception of the "Tail" signal. Similarly, switching and buffering can be done in the egress direction (towards the new MES.) In-band signaling was used in [11] to implement lossless handoff.
6. Lastly, the old path segment is released. This may include the release of the connection segment within the HO PVP, if it is not part of the new segment. Since the HO PVP is a critical resource, releasing its connections need to be done first. Also database information about the connection is deleted from the old MES and stored in the new MES with updates to connection parameters and the list of candidate crossover nodes

It is worth noting that the optimization phase can be transparent to both the AP and MT, unless there is a need for QoS re-negotiation or a need for bandwidth adjustment which requires the MT involvement.

4. HO PVP Bandwidth and Optimization Rate

Two important design parameters in the proposed scheme are the required bandwidth for HO PVPs and the processing load for route optimization at the MES. In this section, we analytically study these parameters. In [14], the handoff call arrival rate in a cell is given as follows:

$$\lambda_h = \frac{(1-P_0)[1-R^*(\mu_M)]\lambda_0}{\mu_M \; E(R)\,[1-(1-P_f)\,R^*(\mu_M)]}, \tag{1}$$

where:

- P_0 : The originating call blocking probability
- P_f : The handoff blocking probability, (i.e. the probability that call is dropped due to lack of bandwidth.)
- λ_0 : The originating arrival call rate in a cell follows a Poisson process.
- $1/\mu_M$: The mean of holding time of a call T_M . T_M has exponential distribution.
- $E(R)$: The mean residual time R of a call in a cell. The cell residual time is the time the MT resides in a cell before it moves out to another cell. R has a general distribution. The cell residual times, $R^{(1)}, R^{(2)}, R^{(3)} \cdots$, resulting from the movement of the MT, are all random variables which are independent and identically distributed.
- $R^*(s)$: The Laplace-Stieltjes transform (LST) of the random variable R .

In addition, the following assumptions are made:

1) Each call uses one connection. Every call/connection has an identical bandwidth requirement.
2) Each connection is bi-directional. This means a connection has two virtual circuits or channels or two VCs.
3) Resource allocation never causes call blocking for originating calls or during route optimization.
4) Radio resources are sufficient not to cause blocking during handoff.
5) All inter-switch handed-off connections require route optimization.

Under the above assumptions, the handoff blocking probability P_f due to the failure of allocating connections in the HO PVP can be expressed using Erlang-B formula:

$$P_f = \frac{\dfrac{[\lambda_S\, E(T_S)]^{N_S}}{N_S!}}{\displaystyle\sum_{n=0}^{N_S} \frac{[\lambda_S\, E(T_S)]^n}{n!}}, \tag{2}$$

where N_S is the number of connections in the HO PVP, λ_S is the total inter-switch handoff request rate, and $E(T_S)$ is the expected holding time of a connection in the HO PVP.

Next we find λ_S . We assume a generic environment consists of hexagonal-shaped cells with uniform movement in all six directions. The handoff rate across any cell boundary, contributed by one cell, is $\lambda_h/6$. As shown in Figure 4, there are three cell boundaries contributing to the total inter-switch handoff. Therefore

$$\lambda_S = 3\cdot 2\cdot \lambda_h/6,$$

$$\lambda_S = \lambda_h .$$

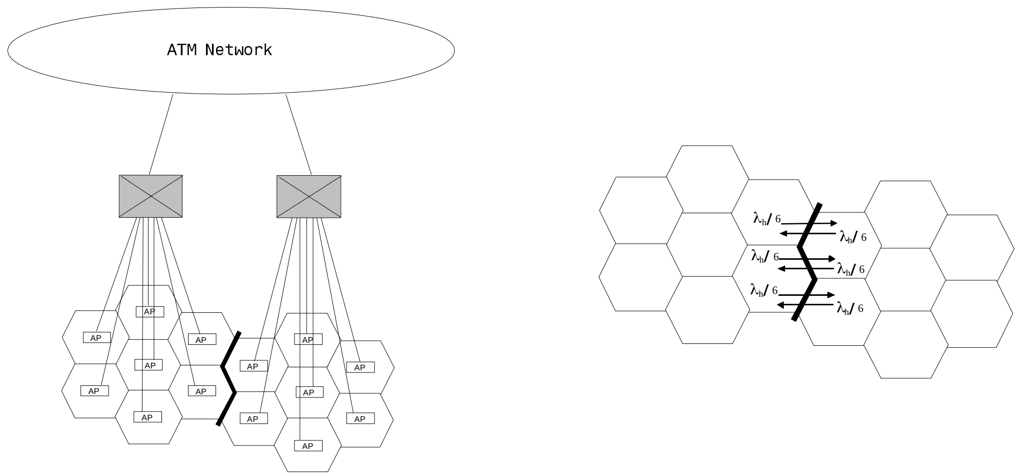

Figure 4 Inter-switch cell boundaries and handoff rates

Now we find $E(T_S)$, which is the average connection holding time in the HO PVP. Suppose the MT moves across one of the inter-switch cell boundaries and has a successful first-phase handoff, i.e. a new connection got established in the HO PVP. This connection will remain established until it is released due to one of the following: 1) call completion, 3) route optimization, or 3) handoff blocking. Hence, the connection holding time T_S within the HO PVP can be written as:

$$T_S = \min(T_M, T_Z, T_R),$$

where:

- T_M is the holding time of a call/connection. Since T_M has exponential distribution, $F_{T_M}(t) = 1 - e^{-\mu_M t}$.
- T_Z is the route optimization time of one connection for a single HO PVP. The route optimization process can be approximated by an $M/M/1$ queue with a random (Poisson) arrival rate λ_Z and a random (exponential) service time distribution with mean optimization service rate of μ_Z. μ_Z is the mean optimization rate for a single HO PVP. As we've seen in Section 3, every MES performs route optimization for the "incoming" handed-off connections (i.e. for handed-off connections towards the MES.) Handed-off connections towards the other MES are handled by the neighboring MES. Therefore the optimization request rate at one MES for a single HO PVP can be expressed as $\lambda_Z = \lambda_S / 2$. The distribution function of T_Z is given by $F_{T_Z}(t) = 1 - e^{-(\mu_Z - \lambda_S)t}$. For simplicity, it is assumed that the route optimization will always result in releasing the connection.
- T_R is the total sojourn time of N cells where MT generating the call resides before handoff blocking.

The distribution of T_S can be expressed as

$$F_{T_S}(t) = 1 - [1 - F_{T_R}(t)]\, e^{-(\mu_M + \mu_Z - \lambda_Z)t}.$$

By the definition of LST properties,

$$E(T_S) = -T_S^{*'}(0), \text{ and}$$

$$T_S^*(x) = \int_0^\infty e^{-xt} dF_{T_S}(t).$$

Let $v(x) = \mu_M + \mu_Z - \lambda_Z + x$, then

$$T_S^*(x) = \frac{v(0)}{v(x)} + \left[1 - \frac{v(0)}{v(x)}\right] T_R^*(v(x)).$$

Next we find $T_R^*(v(x))$. Remember that T_R is the total residual time of *N* cells before handoff blocking. This means $T_R = R^{(1)} + R^{(2)} + R^{(3)} + \cdots + R^{(N)}$. R is the cell residual time in a cell. Note that *N* is the number of cells the MT resides in before the handoff blocking. Therefore *N* is a random variable and has a geometric distribution. And thus

$$P(N=n) = P_f(1-P_f)^{n-1}, \quad n = 1,2,3...$$

The LST of T_R is given by

$$T_R^*(s) = N[R^*(s)]$$

where $N[R^*(s)]$ is the generating function of the random variable *N*, and described as

$$N[R^*(s)] = \frac{p_f\, R^*(s)}{1-(1-p_f)R^*(s)}.$$

Therefore

$$T_S^*(x) = \frac{v(0)}{v(x)} + \left[1 - \frac{v(0)}{v(x)}\right]\left(\frac{R^*(v(x))p_f}{1-(1-p_f)R^*(v(x))}\right).$$

Taking the derivative of $T_S^*(x)$ and evaluating x at 0, we get

$$E(T_S) = \frac{1-R^*(\mu_M + \mu_Z - \lambda_Z)}{(\mu_M + \mu_Z - \lambda_Z)[1-(1-P_f)R^*(\mu_M + \mu_Z - \lambda_Z)]}.$$

R has a general distribution. If R has an exponential distribution, then

$$R^*(s) = \frac{\mu_R}{s+\mu_R},$$

and $E(T_S)$ can be simplified to:

$$E(T_S) = \frac{1}{(\mu_M + \mu_Z - \lambda_Z) + \mu_R P_f}. \qquad (3)$$

Special Case:

Let us consider a special case when the route optimization process is turned off. This means that the connection within the HO PVP is released due to two of the following conditions: 1) call completion or 2) handoff blocking. Hence, the connection holding time T_S can be written as:

$$T_S = \min(T_M, T_R).$$

Carrying out the previous derivations, we get

$$E(T_S) = \frac{1}{\mu_M + \mu_R P_f}. \qquad (4)$$

Applying numerical operations to Eq. (1), (2), (3), and (4), one can find N_S and P_f.

5. Numerical Examples

In this section we study the performance of the proposed scheme as a function of system offered load. In particular, we examine the required bandwidth for HO PVP and the processing load required for route optimization for a single HO PVP at the MES. We assume the mean cell residual time of 4 minutes and a mean call holding time of 2 minutes. Originating calls are assumed to be blocked with probability of 0.01, while handoff blocking probability is assumed to be 0.001. Mean route optimization times are chosen to be 1.3 to 0.6 Sec. We assume these times are sufficient to carry out processing and signaling load involved in the optimization procedure explained in Section 3. Also these times include VC setup delays for a bi-directional connection. According to [15], a single VC setup latency through one node ranges from 10 ms to 125 ms.

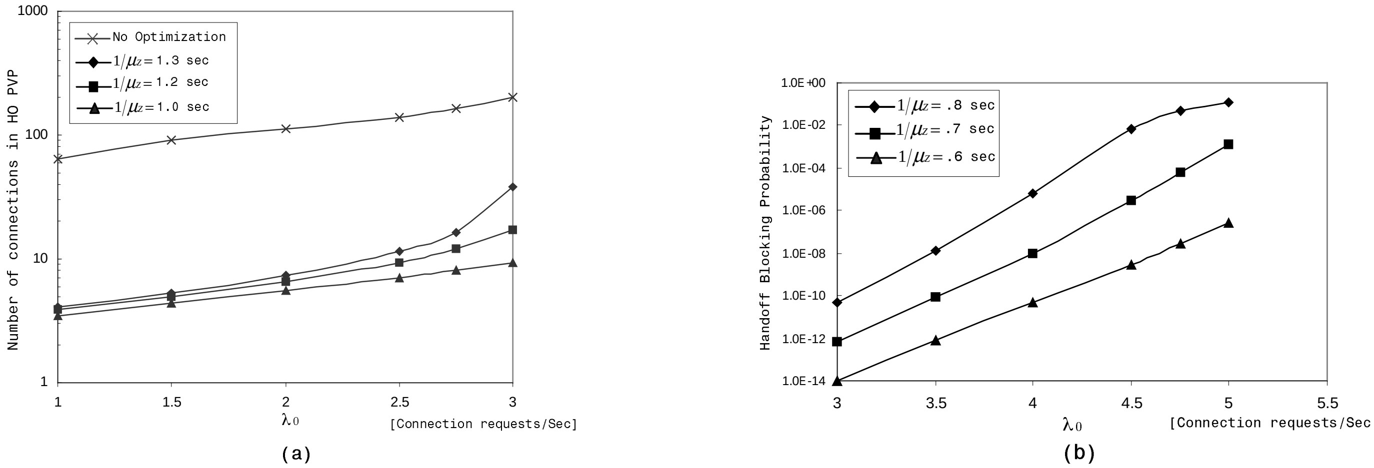

Figure 5 Required HO PVP bandwidth and handoff blocking probability

We first study the required HO PVP bandwidth in terms of number of connections as a function of the originating call rate. Figure 5a shows the required HO PVP bandwidth for different values of the mean route optimization time and when the route optimization process is turned off. The figure illustrates the tradeoff that exists between HO PVP bandwidth and optimization rate. In heavy load region $(\lambda_0 > 2.5)$, the HO PVP bandwidth increases considerably as the optimization rate decreases. While in light load region $(\lambda_0 < 2.5)$, increasing the optimization rate results only in marginal reduction in the reserved bandwidth. We next study the handoff blocking probability for different mean route optimization times and different range of the originating call rate, as depicted in Figure 5b. In this case we assume the maximum number of connections that HO PVP can hold is 15. The figure illustrates the relation between the handoff blocking probability and the optimization service rate. Since the optimization releases the connections within the HO PVP, it results in decreasing the handoff blocking probability. The faster the optimization rate is, the smaller the blocking probability becomes.

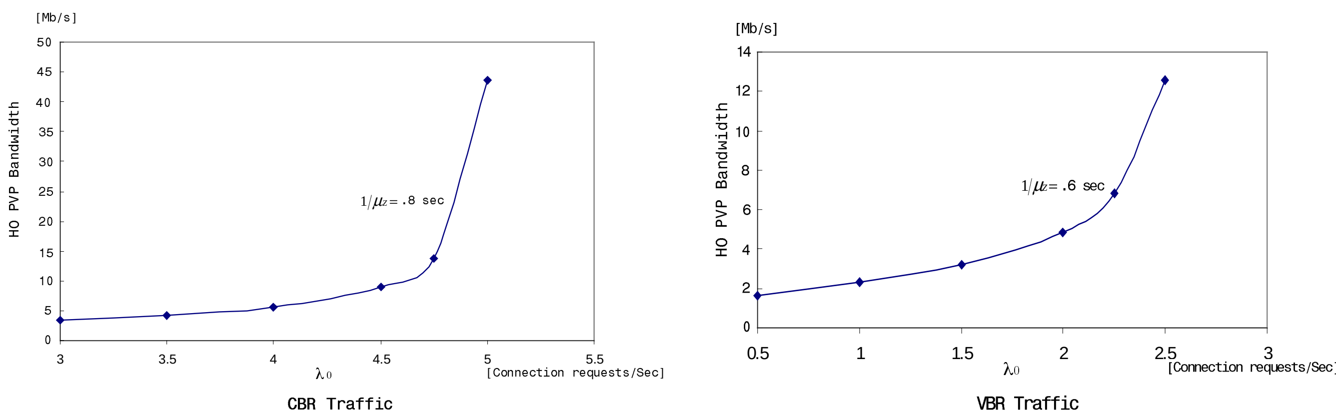

Figure 6 HO PVP bandwidth for CBR and VBR traffic

Figure 6 illustrates the bandwidth usage for different type of ATM traffic: Constant Bit Rate (CBR) and Variable Bit Rate (VBR). For CBR traffic, we consider the MTs carry voice traffic with mean cell residual time of 4 minutes a call holding time of 2 minutes. Each call requires a bandwidth of 64 kb/s. This means each call has 2 VCs and each VC has 32 kb/s. Using peak bandwidth allocation method, one can calculate the required bandwidth. See Figure 6a. For VBR traffic, we assume a mean cell residual time of 12 minutes a mean call holding time of 15 minutes. Also, connections have average bit rate B_{mi} of 512 kb/s and bit rate variance σ_i^2 of 256 kb/s. The equivalent bandwidth can be using the Stationary Approximation method [16], and it is given by

$$\text{Equivalent Capacity} \cong \mathrm{M} + \alpha\sigma$$

where $\mathrm{M} = \sum_{i=1}^{n} \mathrm{B}_{mi}$, $\sigma^2 = \sum_{i=1}^{n} \sigma_i^2$, and $\alpha = \sqrt{-2\ln(\text{Ploss}) - 2\ln(2\pi)}$. Ploss is the ATM cell loss probability and is assumed to be 10^{-5}. Figure 6b plots the required bandwidth**.** A smaller optimization service rate was chosen for VBR traffic (than that of CBR traffic) in order to achieve the stability condition $\lambda_z / \mu_z < 1$. λ_z increases because the mean cell residual time is smaller than the mean call holding time, (i.e. the MT likelihood of visiting other cells during a call increases.)

It was depicted from both Figure 5 and 6 the reserved bandwidth becomes small under light load. In other words, the utilization is poor under such condition. Poor utilization was due to the fact that the optimization service rate was constant, (i.e. the same for heavy load as for light load.) In light load, the holding time of connections in the HO PVP becomes highly influenced by optimization service rate more than call completion or handoff blocking. We next propose an adaptive optimization service rate scheme that addresses this issue.

6. Adaptive Optimization Service Rate:

In order to achieve a better utilization for the reserved bandwidth and decrease the processing and signaling load at the ATM switches due to constant service rate for route optimization, it would be more appropriate to have the optimization rate adapts to the changes in network conditions. In real life the optimization rate is dependent on several network parameters: optimality of the current path, reserved bandwidth utilization of HO PVP, handoff blocking probability, connection QoS, connection lifetime (being old or new), number of hops, loop detection, etc. However, it would be difficult to model such a system based on all of these parameters. Also from implementation point of view, the MES would have more processing load as it needs to monitor all of these parameters. A simple parameter would be the reserved bandwidth utilization.

To have the service rate adapt to changes in the bandwidth utilization, we must allow the optimization service rate to decrease when the utilization decreases. Also, when the utilization increases, the optimization service rate should relatively increase. Obviously, the increase of the service rate in the latter case is not infinite, but has a limit. The limit is some constant maximum rate. Such adaptive service rate μ_n can be expressed as

$$\mu_n = \begin{cases} \left(\frac{n}{B}\right)^{\alpha} \mu & (0 \le n < B) \\ \mu & (n \ge B) \end{cases}$$

where μ is maximum optimization service rate, n is the current bandwidth, and B is a threshold of the reserved bandwidth and is equal to 0.8 of the maximum reserved bandwidth. Note that $\left(\frac{n}{B}\right)$ represents the utilization of the HO PVP.

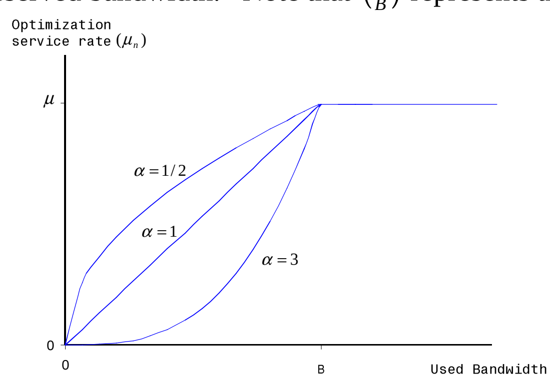

Figure 7 Adaptive optimization rate and used bandwidth

The parameter α is a tunable parameter. It controls how fast the service rate can change in relation to the used bandwidth (or bandwidth utilization.) See Figure 7. To illustrate this more, if α =1, the rate is proportional to the used bandwidth. For $\alpha < 1$, the service rate becomes more aggressive, i.e. more responsive to changes in the utilization. And for $\alpha > 1$, the service rate is less aggressive. Note for $n \geq B$, the optimization service rate μ stays constant at its maximum. An analytical and simulation work of this adaptive scheme is underway.

7. Conclusion

We have proposed a two-phase handoff management scheme for Wireless ATM networks. Control signaling and management protocols to support the two phases were described. The proposed handoff scheme does not require a complex AP or impose stringent latency requirement on COS selection algorithm, but utilizes reserved virtual paths between adjacent MES to rapidly reroute user connections. Optimal paths are accomplished in the second phase using a distributed rerouting optimization process carried out by the new MES. The required bandwidth for the HO PVP and the load at MES associated with optimization process were studied analytically. Both ATM CBR and VBR traffic types were considered. We also proposed an adaptive optimization scheme to achieve high reserved bandwidth utilization. Our results indicate that a simple fast handoff phase followed by a route optimization phase can be sufficient for supporting handoff in WATM networks.

References

[1] J. Mikkonen and J. Kruys, "The Magic WAND: a wireless ATM ATM access system", Proceedings ACTS Mobile Telecommunication Summit, Granda, Spain, 1996.

[2] Baseline Text for Wireless ATM Specifications, BTD-WATM-01.07, ATM Forum, WATM WG, April 1998.

[3] P. Agrawal, et. al, "SWAN: A Mobile Multimedia Wireless Network," IEEE Personal Communications Magazine, April 1996

[4] M. Karol, et. al, "Handoff Scheme for Mobile ATM Networks," ATM Forum/96-1499/WATM.

[5] S. Lee and D. Sung, "A New Fast Handoff Management Scheme in ATM-based Wireless Mobile Networks", GLOBECOM '96.

[6] A. Massarella, "Wireless Mobile Terminal/Network Anchor Switch Handover Model," ATM Forum/97-0265/WATM.

[7] P. Shieh, T. Tedijanto, and R. Rennison, "Handover Schemes to Support Mobility in Wireless ATM," ATM Forum/96-1622/WATM.

[8] A. Acharaya, et. al, "Signaling for Connection Rerouting for Handoff Control in Wireless ATM," ATM Forum/97-0338/WATM.

[9] ITU Study Group 11, Q.2931, Caluse 1, 2, and 3. S. Shiraishi and H. Yao, June 1994.

[10] ATM User-Network Interface Specification, Version 3.0 ATM Forum, Prentice Hall, 1993.

[11] H. Mitts, et al., "Lossless Handover for Wireless ATM," ACM/Blatzer Mobile Networks and Appls., Dec. 1996.

[12] C-K Toh, "Crossover Switch Discovery Schemes for Fast Handovers in Wireless ATM LANs", ACM Journal on Mobile Networks & Applications - Special Issue on "Routing in Mobile Communication Networks", Vol 1, No 2, Nov. 1996.

[13] Private Network-Network Interface Specification Version 1.0 (af-pnni-0055.0000), ATM Forum, March 1996.

[14] Y. Lin, S. Mohan, and A. Noerperl, "Queueing priority channel assignment strategies for PCS hand-off and initial access," IEEE Trans. Veh. Tech., vol. 43, pp 704-712, Aug. 1994.

[15] The ATM Report, "Inside: The ATM Report Buyer's Guide to ATM Backbone Switches," February, March, April 1997.

[16] R. Guerin, H. Ahmadi, and M. Naghshineh, "Equivalent capacity and its application in high-speed networks," IEEE J. Selected Areas Comm., vol. 9, no. 7, pp958-981, Sept. 1991.