A NOVEL HANDOFF SCHEME FOR WIRELESS ATM NETWORKS

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ABSTRACT

Mobility support and management in Wireless ATM networks poses a number of technical issues. An important issue is the ability to manage and reroute active connections during handoff as mobile users move among base stations. We propose a novel two-phase handoff 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. In this paper, we address various control issues related to signaling and implementation of such a scheme including how to achieve optimal paths. We analytically calculate and study the handoff blocking probability and the bandwidth requirement for the reserved virtual paths. 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 user connections.

KEYWORDS:

MOBILITY, HANDOFF, SIGNALING, ROUTE OPTIMIZATION, WATM, ATM, WIRELESS

1. INTRODUCTION

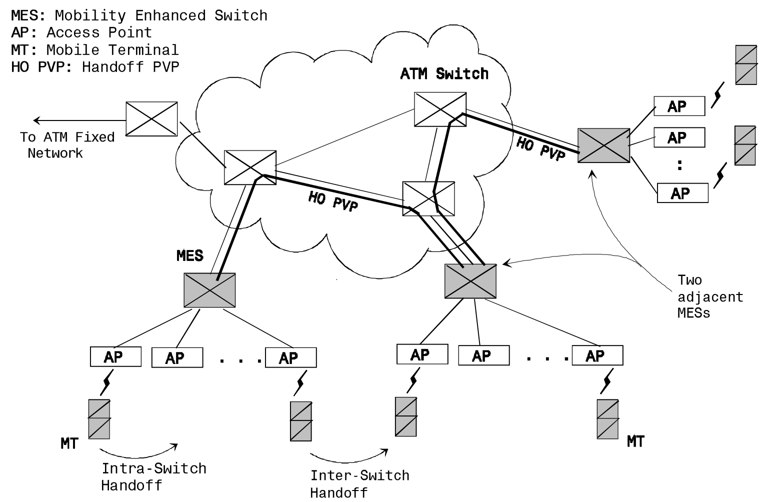

Figure 1: WATM network architecture

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. During handoff, connection routes need to be modified as users move during the lifetime 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].

In order to solve the problem of managing and rerouting user connections in WATM handoff, a number of handoff 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 and how to achieve optimal paths. Section 4 presents an analytical model to evaluate the proposed scheme. Section 5 studies performance results. Finally, Section 6 concludes the paper.

2. DESCRIPTION OF THE PROPOSED SCHEME

In this section, we describe how the proposed two-phase handoff 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 many 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. Finally, old connection and radio resources are released.

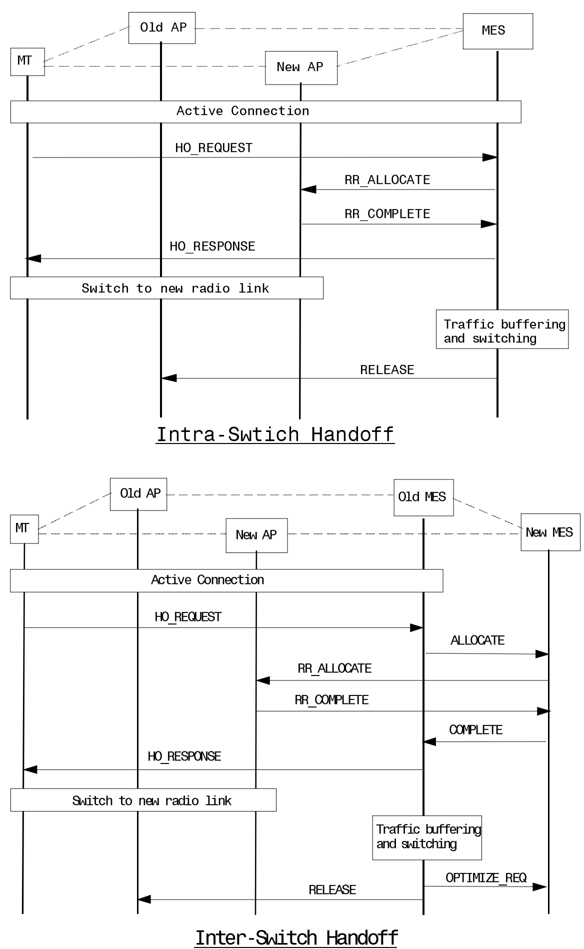

Figure 2: Handoff signaling protocol

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 and managed 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:

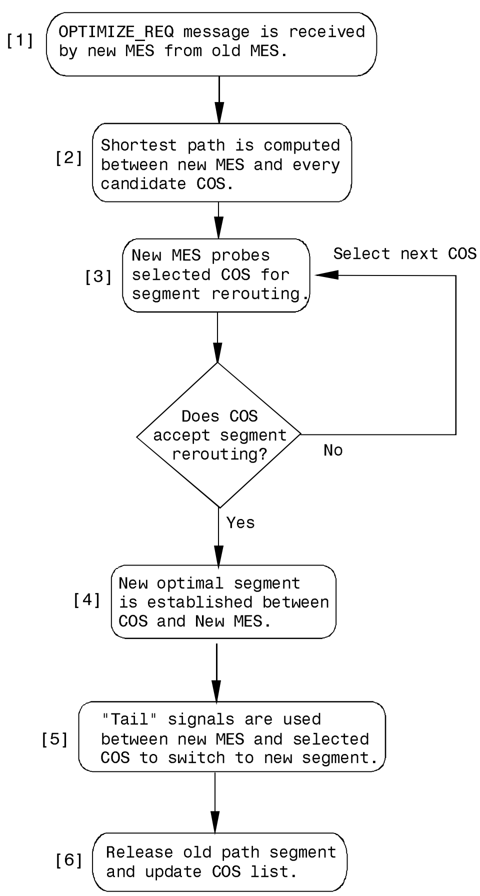

Figure 3: Flow chart of the route optimization process

STEP 1. The optimization process starts when receiving the OPTIMIZE_REQ message from the old MES indicating a successful first-phase handoff. The OPTIMIZE_REQ message will include a list of candidate COSs. The list of candidate COSs will be used by the new MES to find the optimal path. The optimal path will be the shortest path between the new MES and one of the candidate COS found in the list. It is worth mentioning that the COS in our proposed scheme is basically a regular ATM switch which has the added functionality of supporting signaling extensions for mobility and coordinating traffic switching with the new MES, i.e. has hardware that supports switching to new path using "Tail" signals. The concept of "Tail" signals or "Marker" cells was introduced by [9] to switch user data from an old VC to a new VC. The marker cells are sent in-band on the same VC segment as the user cells. The marker cells should be distinguishable by hardware from the user cells; they could be special Resource Management (RM) cells.

The list of candidate COS gets built during original connection establishment. Current ATM Forum and ITU-T standards for UNI and NNI signaling can support building such a list [10,11]. Call SETUP and CONNECT messages can carry such information as the original connection segments get built hop by hop.

New types of IE (Information Element) to support building the list of COSs need to be defined for SETUP and CONNECT messages. These new IEs would be honored and acted upon only by the COS and MES nodes and ignored but passed along intermediate node. We also define the notion of an "edge" COS. An edge COS is the nearest mobility enhanced node to the fixed host.

Depending on the type of the called and calling parties, there are three different scenarios to consider for building the COS list: 1) Mobile to Fixed, 2) Mobile to Mobile, and 3) Fixed to Mobile.

Mobile to Fixed: This refers to the case when the calling party of a connection is the MT and the called party is a fixed host, as shown in Figure 3. In this case, the MES creates a "COS LIST request" IE and adds it to the SETUP message. The "COS LIST request" IE has an originating type field, indicating whether the calling party is a mobile or a fixed host. The originating type is set by the MES and edge COS for mobile and fixed hosts, respectively. Whenever the "COS LIST request" IE is created, the address of the MES or edge COS is added as the first entry in the COS list. Every intermediate COS (or possibly MES) along the connection path examines the IEs in the SETUP message. If a "COS LIST request" IE is found, then the COS adds its address to the IE and passes the SETUP message to the next node in the path. This continues until the SETUP message reaches the edge COS. The edge COS extracts the COS list from the SETUP message and adds its own address to it. The edge COS also examines the originating type. For this scenario where the originating type is "mobile", the edge COS must return the COS list in the CONNECT message. So, after the fixed host replies to the edge COS with a CONNECT message, the edge COS creates a "COS LIST reply" IE containing the COS list formed by the SETUP message. The edge COS sends the "COS LIST reply" IE with the CONNECT message to the next node in the reply path. The CONNECT message finally reaches the MES with a complete COS list. The MES extracts the COS list and stores it in its database.

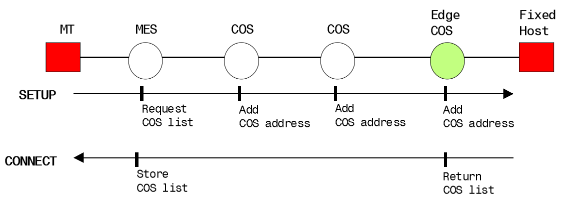

Figure 3: Building COS list from MT to fixed host

2) Mobile to Mobile: This is the same as to the Mobile to Fixed scenario. However, since the called party is also a mobile host, the MES of the called MT needs to store the COS list also in its local database, as illustrated in Figure 4.

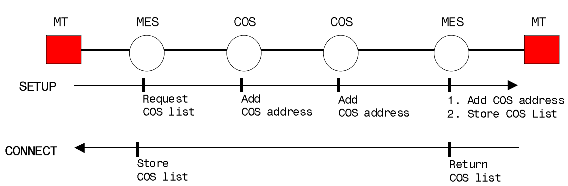

Figure 4: Building COS list from MT to MT

3) Fixed to Mobile: This refers to the case when the calling party is a fixed host and the called party is the MT, as illustrated in Figure 4. At the time of originating the call by the fixed host, the edge COS examines the destination address. If the destination address is that of a mobile address, the edge COS creates a "COS LIST request" IE with "fixed" originating type and adds it to the SETUP message. The COS list is then built hop by hop with each COS adding its address to the "COS LIST request" IE of the SETUP message until it reaches the MES of the called MT. The MES extracts the COS list from the SETUP message and stores it into its local table. Since the originating type is "fixed", the MES does not return the COS list in the CONNECT message.

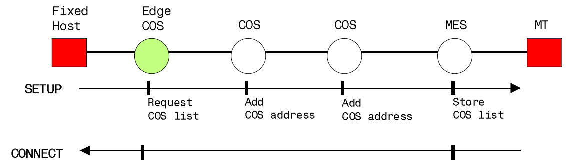

Figure 5: Building COS list from fixed host to MT

STEP 2. Based on path information, passed by the old MES to the new MES, which included the list of candidate COSs, the new MES performs COS discovery in order to find the optimal path. Refer to Figure 6. The COS discovery is simple. The new MES computes the shortest path to all candidate COS nodes in the list. Since the PNNI routing scheme is a link-state routing scheme, this operation can be accomplished using the existing PNNI protocol [12]. The candidate COS node with the shortest path will be identified as the selected COS node. If multiple candidate COS nodes have the same shortest path, then the COS nearest the called party will be selected. For this latter case, the new MES can identify the COS nearest to the called party by examining its link-state database.

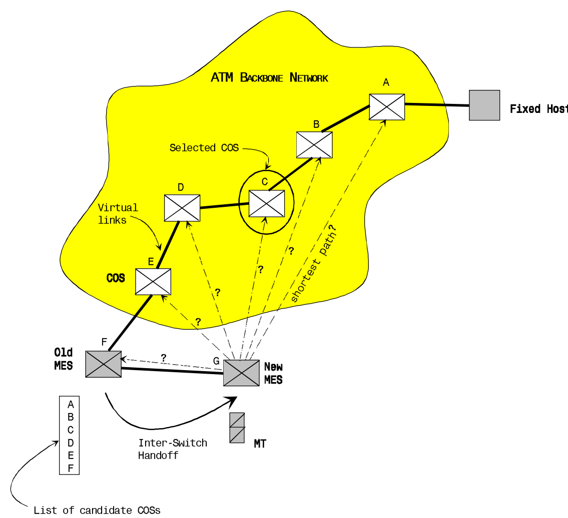

Figure 6: COS Discovery

It is worth noting that this proposed scheme for building the COS list has a number of advantages:

- Unlike the "Prior Path Knowledge" COS discovery algorithm [13], the scheme overcomes the need for a centralized server and keeps building the list of COSs distributed at the MESs serving the calls.
- Unlike the "Distributed Hunt" COS discovery algorithm [13], information about calls is maintained and stored only in the MESs and not at multiple nodes in the network.

- The scheme makes use of existing signaling messages.
- The scheme does not introduce an extra signaling load since building the list is done during the original call establishment.

STEP 3. The new MES then probes the selected COS node for segment rerouting. A COS node receiving such a request will accept or deny the request based on its current resources and load. If the selected COS node denies the request, another COS node (one next to the best) is probed.

STEP 4. The new MES then builds the best route, "new optimal segment", to the selected COS node in the from of a hierarchically complete source route known as a Designated Transit List, or DTL, as specified in [12]. The establishment of the new connection segment between the selected COS node and the new MES can be initiated by either the COS node or by the new MES. In order to minimize signaling of path information at the COS node and allow for faster selection of another COS node in case of segment setup failure, the establishment of the new segment is initiated by the new MES.

STEP 5. After the new segment has been set up, "Tail" signals will be utilized between the new MES and selected COS to switch to the new segment. The latency to switch to the new optimal segment should not cause any service disruption. It is all done in hardware.

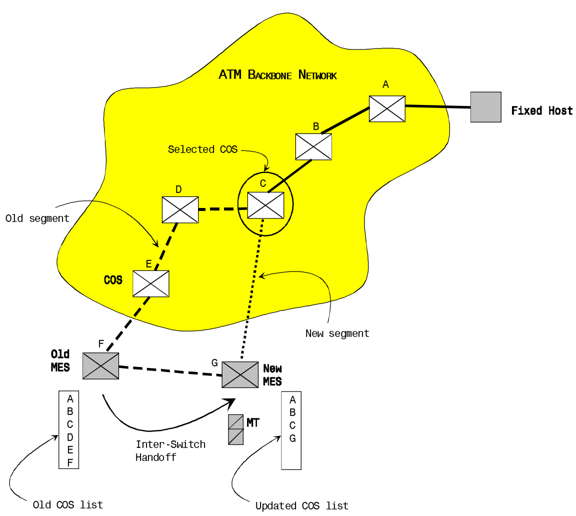

Figure 7: Switching to new segment and updating COS list

STEP 6. Lastly, the old 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. In addition, the list of candidate COSs is updated to reflect changes to the connection path after optimization. New COSs along the new segment are added to the list and old COSs along the old segment are deleted. Refer to Figure 7.

It can be noted 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's involvement.

Based on the description of the route optimization procedure above, signaling and processing load would be imposed on the WATM network. In particular, processing load would be imposed on the MES and crossover nodes, and signaling messages would be exchanged between new and old MES as well as between new MES and crossover nodes. We will study this optimization overhead in relation to the required HO PVP bandwidth. The optimization overhead will be represented by the optimization rate μ_z .

4. HO PVP BANDWIDTH AND ROUTE OPTIMIZATION RATE

The performance of the two-phase handoff scheme is studied in this section using analysis. 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 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:

$$P_f = \frac{\dfrac{[\lambda_S E(T_S)]^{N_S}}{N_S!}}{\sum_{n=0}^{N_S} \dfrac{[\lambda_S E(T_S)]^n}{n!}}, \qquad (1)$$

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.

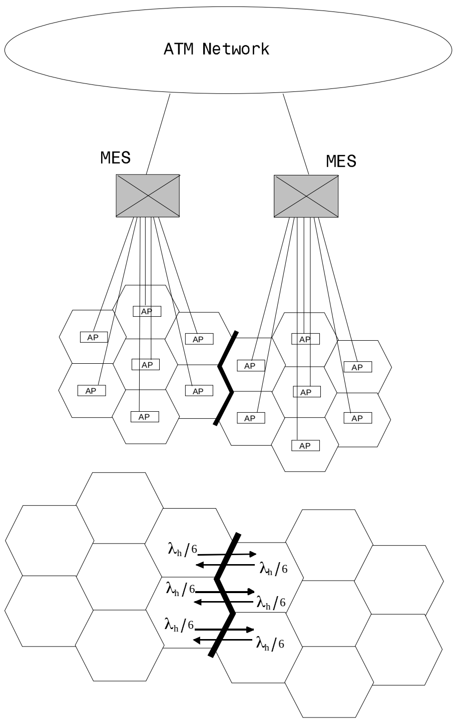

Figure 9: Inter-switch cell boundaries and handoff rates

First we find λ_S, the total inter-switch handoff request rate. In [14], the handoff call arrival rate in a radio cell is given as follows:

$$\lambda_h = \frac{(1-P_0)[1-R^*(\mu_M)]\lambda_0}{\mu_M \; E(R)\,[1-(1-P_f)\,R^*(\mu_M)]}, \quad (2)$$

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 call arrival rate in a cell. It 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, $R^{(1)}, R^{(2)}, R^{(3)} \dots$, 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 .

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 9, there are three cell boundaries contributing to the total inter-switch handoff. Therefore $\lambda_S = 3 \cdot 2 \cdot \lambda_h/6$, and hence $\lambda_S = \lambda_h$.

Now we find $E(T_S)$. 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 followings:

1. Route optimization (executed at a mean rate of μ_Z).
2. Call holding time expiration.
3. Handoff blocking as a result of MT journey.

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. According to our proposed route optimization procedure, the initiation of optimization for handed-off connections within a single HO PVP is performed by the two adjacent MESs. Hence, μ_Z is distributed between these two adjacent MESs. We assume that μ_z is divided evenly between the adjacent MESs, with each MES having a mean optimization service rate of $\mu_z/2$. As for λ_S , it is also divided evenly among these two MESs. This is so because every MES performs route optimization for the "incoming" handed-off connections. The term "incoming" refers to handed-off connections towards the MES. Handed-off connections towards the other MES will be considered "departing" connections and will be handled by the other adjacent MES. At the

inter-switch cell boundaries the incoming and departing handoff rates are equal, since movement within a cell was assumed to be uniform. So for each MES, the mean optimization request rate is $\lambda_S/2$. Therefore, one can approximate the optimization process by two independent or parallel *M/M/1* queues with each having a mean service rate of $\mu_Z/2$ and a mean arrival rate of $\lambda_S/2$. Hence, the two independent *M/M/1* queues are equivalent to one *M/M/1* queue with $\rho = \lambda_S/\mu_Z$. 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 6 minutes and a mean call holding time of 3 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.

We first study the required HO PVP bandwidth in terms of the number of connections as a function of the originating call rate. Figure 10(Left) 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 $(\lambda_0 > 1.25)$, the HO PVP bandwidth increases considerably as the optimization rate decreases. While in light load region $(\lambda_0 < 1.25)$, 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 10(Right). 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, the smaller the blocking probability.

Figure 11 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 15 minutes and a call holding time of 6 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 11(Left).

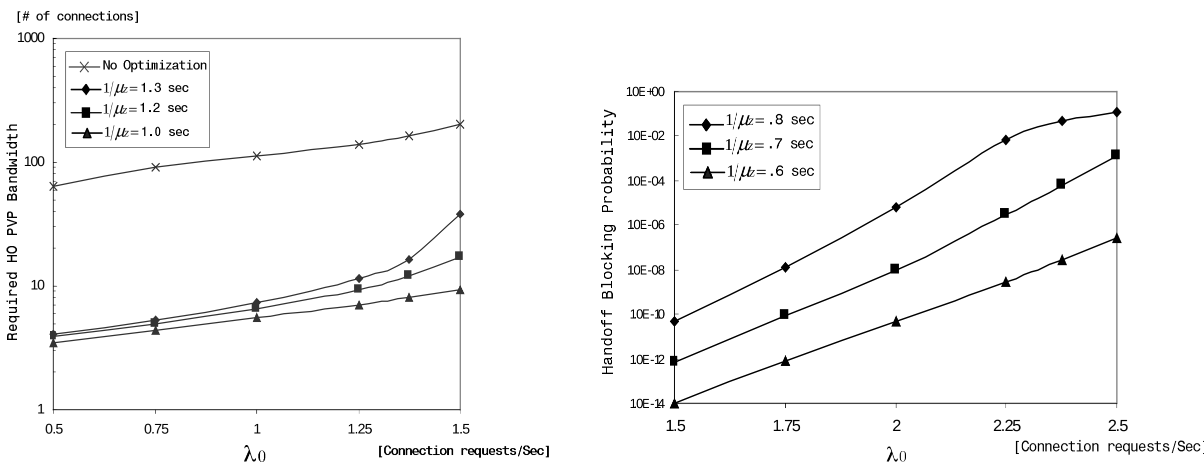

Figure 10: Required HO PVP bandwidth and handoff blocking probability

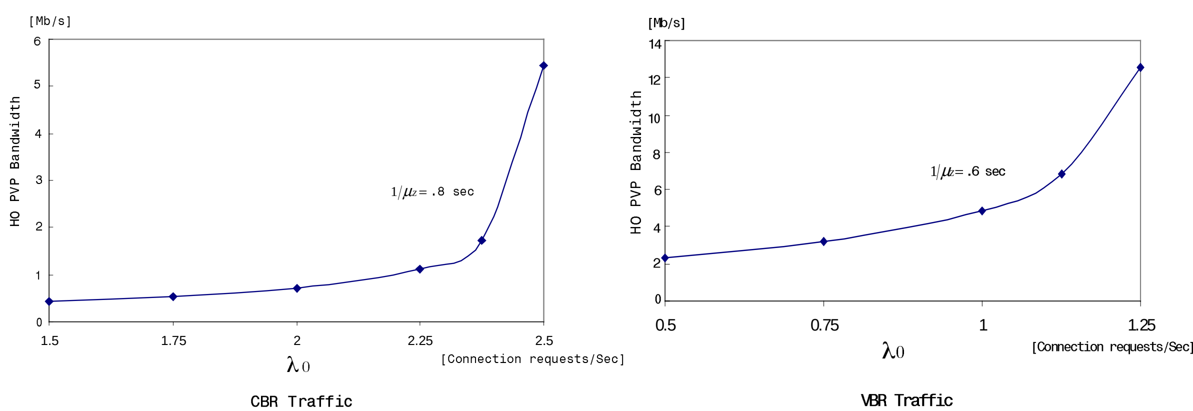

Figure 11: HO PVP bandwidth for CBR and VBR traffic

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 computed 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 $\alpha = \sqrt{-2\ln(\mathrm{Ploss}) - 2\ln(2\pi)}$. Ploss is the ATM cell loss probability and is assumed to be 10^{-5}. Figure 11(Right) 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.)

6. SUMMARY AND CONCLUSIONS

We have proposed a novel two-phase handoff scheme for Wireless ATM networks. We addressed various control and management issues related to signaling and implementation including how to achieve optimal paths. 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. Our results indicate that a simple fast handoff phase followed by a route optimization phase can be sufficient for supporting and managing mobility in WATM networks.

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