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A Fast Handoff Management Scheme in ATM-Based Personal Communication Networks *

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Abstract. Future wireless personal communication networks will likely have infrastructures based on asynchronous transfer mode (ATM) networks. It is a challenge to support seamless, fast handoffs in such an environment. We propose a fast handoff management scheme using permanent virtual connections (PVCs) reserved between neighboring base stations (BSs). In the proposed scheme, the handoff can be quickly performed by rerouting the communication path via the PVCs. Handoff calls are distributively controlled only by the corresponding BSs without the involvement of any ATM switches. ATM cell sequence integrity during handoff can be maintained by the BSs. In order to dimension the PVC, we analytically derive the probability of handoff blocking due to the lack of PVCs. We give some numerical examples of PVC dimensioning. The proposed scheme can be utilized in the future IMT-2000 networks accommodating various narrowband services in the range of several kbps to several hundreds kbps.

Keywords: wireless ATM, handoff, permanent virtual connection.

1. Introduction

Following the first-generation analog voice wireless networks and the second-generation digital voice/data networks, third-generation wireless mobile networks accommodating multimedia traffic such as voice, video, image, and data have been intensively studied in both UMTS [1, 2] and IMT-2000/FPLMTS [3, 4] standardized by ETSI and ITU, respectively. It is promising to envision the infrastructure of these future wireless networks being based on ATM networks which accommodate various multimedia services. ATM Forum [5] has been studying a topic called the ‘wireless ATM,’ whose two main issues are the ‘mobile ATM’ and the ‘radio access layer.’ The former deals with the higher layer control/signaling functions needed for generic mobility support, and the latter with the radio link protocols for wireless ATM access. Toh [6] addressed the protocol and architecture aspects of wireless ATM and ad-hoc networks.

One of the important issues in designing personal communication networks is the handoff function. Handoff management maintains the connection between two communicating parties while either party moves across the boundaries of cells controlled by the corresponding BSs. Handoff should be performed fast and seamlessly, since the long connection delay of isochronous traffic during handoff is most unpleasant and short disruptions in the connection can result in substantial information loss in personal communication networks with high transmission rates. Handoff control functions should be simple. Otherwise, the micro- or picocellular architecture increasing the number of handoffs may cause bottlenecks due to control

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overload. In addition, several operations are required to maintain the cell sequence integrity of the ATM cells delivered during handoff in ATM-based wireless communication networks.

Acampora [7, 8] proposed a new concept, known as the virtual connection tree (VCT), which avoids the need to involve the network call processor for every handoff attempt in ATM-based personal communication networks. When a mobile connection is admitted to the cellular ATM network, a set of virtual connections is assigned in a VCT accommodating a specified region, called the neighboring mobile access region, in which several or many BSs are placed. Mobile user connections may be handed off to any BS within this region, without involving the network call processor. However, the VCT method has several drawbacks. A large control load is needed to initialize an entire VCT during the call setup phase. A large amount of wireline link resources are reserved to support one call. Inter-VCT handoff calls require another VCT establishment in a new VCT region, which may cause long connection delays.

Yu [9, 10] proposed the mobile virtual circuit (MVC) and the source-routing mobile circuit (SRMC) to overcome the drawbacks of the VCT method. The MVC and the SRMC are also virtual tree-based schemes. They obtained efficient allocation of communication resources at the cost of some handoff processing delay. Routes for all potential handoff connections are predetermined during the call processing. However, wireline link resources are allocated for only one connection. A set of potential handoff connections, or the virtual tree, is also reestablished in post-handoff processing in order to solve the problem of call delay caused by inter-VCT handoffs. However, the frequent reconfiguration of the virtual tree may require considerable ATM switch control load.

Akyol [11] proposed a procedure called the nearest common node rerouting (NCNR) to reroute user connections due to a handoff event. However, finding the nearest common node is rather complex. This scheme also needs to allocate wireline link resources for every handoff event.

In this paper, we propose a new handoff management scheme in ATM-based personal communication networks. In the new scheme, PVCs are reserved between neighboring BSs for handoff calls. Handoff processing is very simple and quickly performed. ATM switches have no role in processing handoff calls. Only the BSs are involved in handoff processing. Also, the ATM cell sequence integrity can be maintained by the BSs. The new scheme can be utilized in the future IMT-2000 networks accommodating various narrowband services.

The rest of this paper is organized as follows. In Section 2, we describe a new handoff management scheme based on PVCs and explain its merits. In Section 3, we compare the new scheme with the VCT scheme. In Section 4, we deal with calculating the required amount of reserved PVCs, or PVC dimensioning. Finally, we draw conclusions in Section 5.

2. Description of the Proposed Scheme

Generally, we need a connection admission control (CAC) to set up a new connection in ATM networks. The CAC is a software function in switches that are responsible for determining whether a connection request is admitted or denied. Various techniques for determining connection admission have been reported [12, 13]. In those techniques, we can find a trade-off between statistical multiplexing gain and complexity. The determination of connection admission is made by allocating resources to specific connections or refusing new requests when resources are unavailable. The resources in question are typically trunk bandwidth,

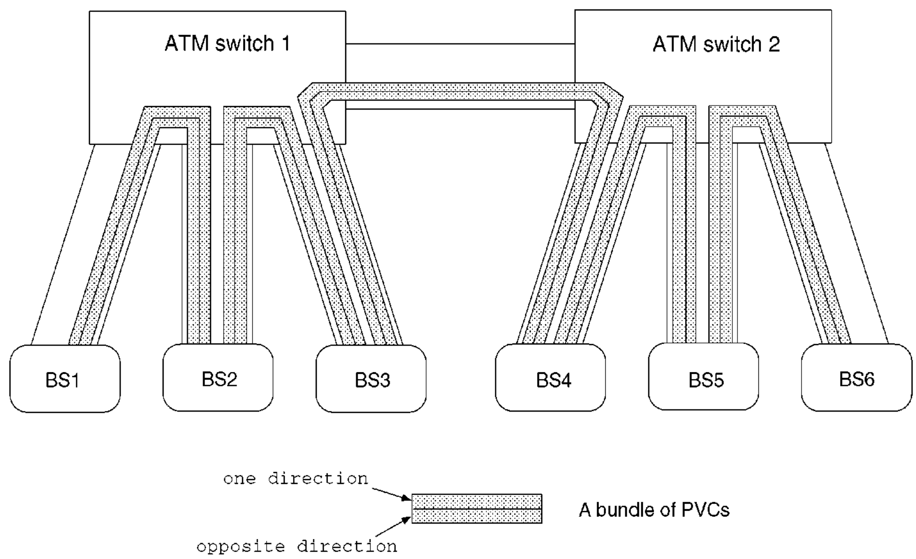


Figure 1. PVCs reserved between neighboring BSs.

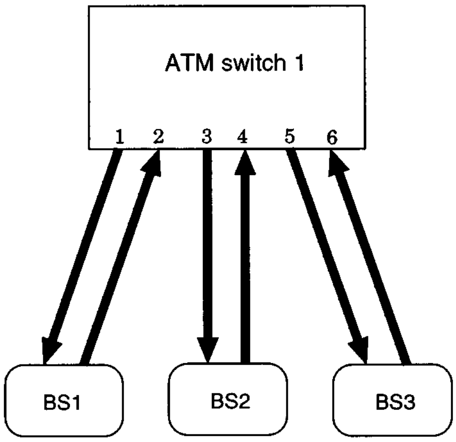
buffer space, and internal switch resources. The resources can be allocated link by link or node by node in order to set up a virtual connection. A connection is established only if resources are available on every link of its path, in both directions. For accepted requests, the CAC determines routing (including lookup table updatings), UPC/NPC parameters, and resource allocation [14]. The CAC commonly requires considerable processing time and load.

For a handoff call, we need to reestablish a new connection for rerouting the call. If we use a CAC to reestablish the connection in the wireline link for the handoff call, it may cause a long connection delay during the handoff processing. Thus we propose a new scheme in which handoff calls can be performed fast without CAC.

The control/management planes in the B-ISDN protocol reference model provide the means to support permanent virtual connections (PVCs) as well as switched virtual connections (SVCs) [14]. Virtual connections may be virtual path connections or virtual channel connections. In our methodology, the wireline link resources are reserved in the form of PVCs between neighboring BSs, as shown in Figure 1, so that handoffs can be quickly executed without the involvement of ATM switches. The PVCs between neighboring BSs may be reserved through either only one ATM switch (e.g. between BS1 and BS2 in Figure 1) or two or more ATM switches (e.g. between BS3 and BS4 in Figure 1).

Figure 2 illustrates an example of a lookup table showing how PVCs can be established. Between BS1 and BS2 (BS2 and BS3), one permanent virtual path connection (PVPC) including 20 permanent virtual channel connections (PVCCs) from BS1 to BS2 (from BS2 to BS3) and one PVPC including 20 PVCCs from BS2 to BS1 (from BS3 to BS2) are provided. The bandwidth of a PVPC (the number of PVCCs in a PVPC) can be adjusted according to varying traffic conditions in a network management level.

We now describe the handoff procedure for a mobile call in the proposed scheme. During a call setup, the communication path to a mobile terminal is established using an SVC between the ATM switch and BS1 placed in the cell where the mobile terminal is currently roaming, as shown in Figure 3(a). The communication path after completing the corresponding handoff procedure is shown in Figure 3(b).



A lookup table of ATM switch 1 for PVCs

Input			Output		
Port number	VPI	VCI	Port number	VPI	VCI
2	121	101	3	122	101
⋮	⋮	⋮	⋮	⋮	⋮
2	121	120	3	122	120
4	211	101	1	212	101
⋮	⋮	⋮	⋮	⋮	⋮
4	211	120	1	212	120
4	231	101	5	232	101
⋮	⋮	⋮	⋮	⋮	⋮
4	231	120	5	232	120
6	321	101	3	322	101
⋮	⋮	⋮	⋮	⋮	⋮
6	321	120	3	322	120

Figure 2. An example of a lookup table showing PVC establishment.

Figure 4 shows the signaling procedure during a handoff call. If the mobile terminal needs a handoff call to a new BS, it sends the new BS a handoff request (H/O req.) message including its own address and that of the current BS. If the new BS receives the handoff request message from the mobile terminal, it then checks if there is an available PVC (from the new BS to the current BS) reserved between the current BS and itself. If there is, it transfers to the current BS the PVC allocation notification (PVC alloc. noti.) message including the identifier of the PVC to be used for the handoff call. The current BS also checks if there is an available PVC (from

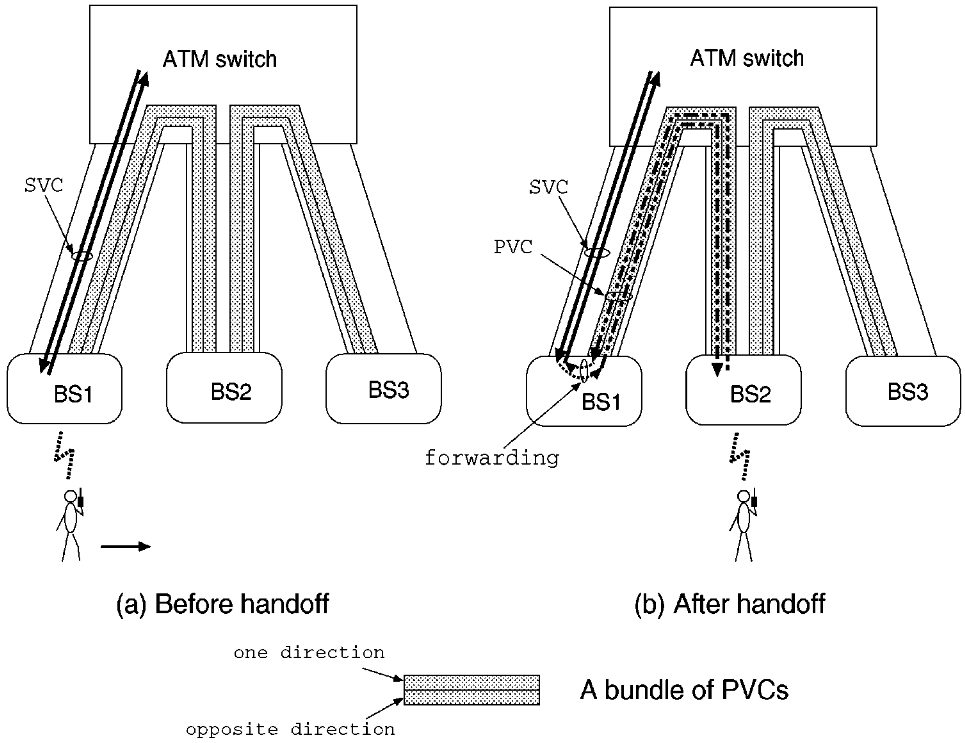


Figure 3. Handoff connection based on PVCs.

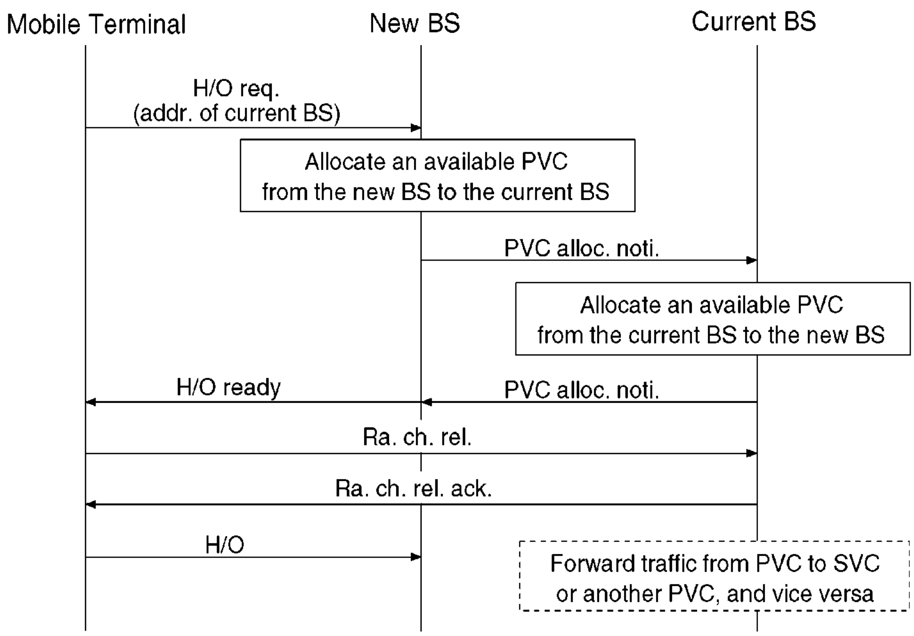


Figure 4. Signaling procedure during a handoff call.

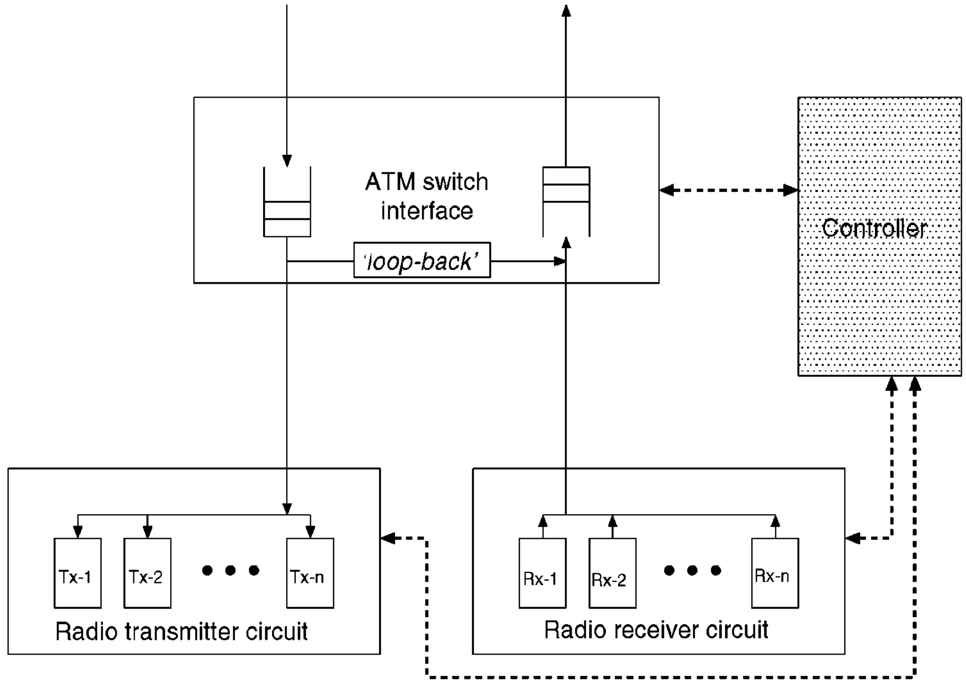


Figure 5. Configuration of the base station.

the current BS to the new BS). When the new BS receives the PVC (from the current BS to the new BS) allocation notification (PVC alloc. noti.) message from the current BS, it transfers the handoff ready message to the mobile terminal. The mobile terminal transmits the radio channel release (Ra. ch. rel.) message to the current BS. After sending the acknowledgement for the radio channel release (Ra. ch. rel. ack.) to the mobile terminal, the current BS forwards the traffic coming from the SVC to the PVC, and vice versa.

Each BS has the capability of managing the PVCs reserved between itself and the adjacent BSs (e.g. selecting an available PVC). The forwarding function required during handoff processing consists of ATM cell header translation and loop-back.

Figure 5 shows the structure of the BS under consideration in the proposed scheme. The BS discriminates the destination of the ATM cells by translating the VCI and VPI of the ATM cell header coming from the ATM switch. If the ATM cell is identified as being destined to a mobile terminal within the coverage of the BS, it is sent to the radio transmitter communicating with the mobile terminal. If the ATM cell is identified as being transmitted via a PVC or an SVC, the VCI and VPI of the ATM cell are translated into the corresponding VPI and VCI, and the resulting ATM cell is looped back.

The proposed scheme can perform fast handoffs, because rerouting the communication path for handoff calls does not require a complex CAC which may incur an unacceptably long connection delay. In addition, handoff calls are distributively controlled by BSs without the involvement of any ATM switches. Thus, the increase in the handoff rate does not affect the control load of the ATM switches.

Besides, in the proposed scheme, ATM cell sequence integrity can be maintained during handoff processings by a simple BS function. Ayanoglu [15] also proposed a method to locally maintain the ATM cell sequence integrity in the BSs. To maintain ATM cell sequence integrity,

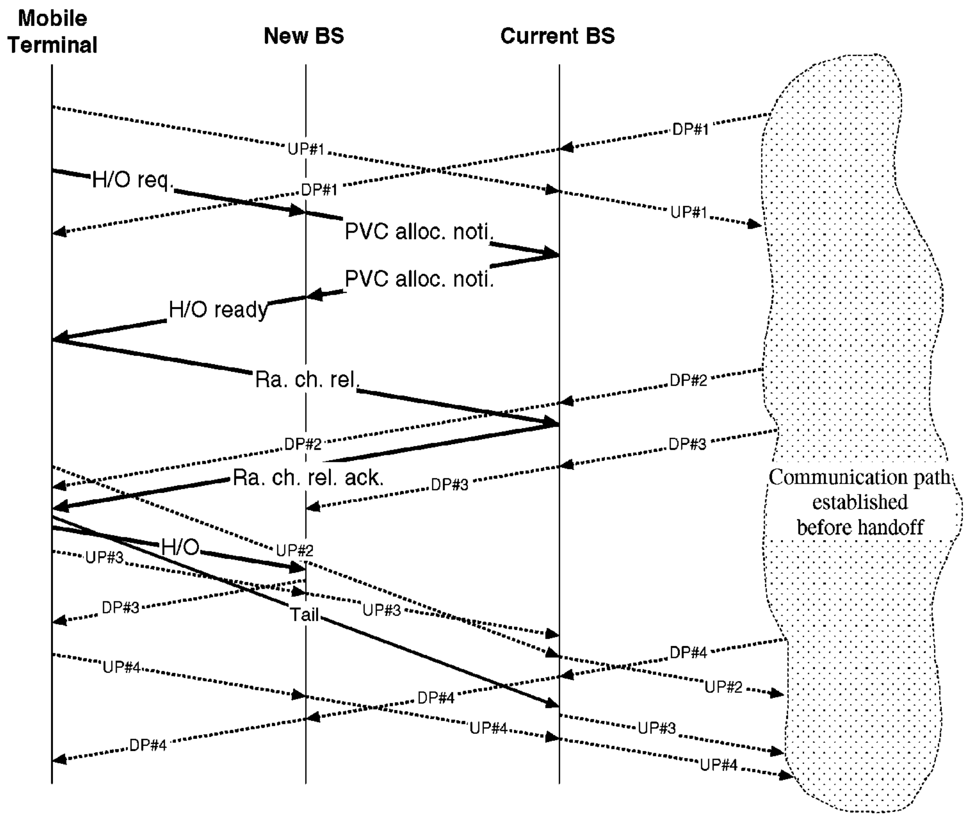


Figure 6. A flow of signaling and traffic messages.

he used sequence number for downlink ATM cells and a ‘Tail’ signal for uplink ATM cells. However, using sequence numbers results in an additional overhead on every downlink ATM cell. Our proposed scheme can maintain the downlink ATM cell sequence integrity without using sequence numbers. For uplink ATM cell sequence integrity, our scheme uses a ‘Tail’ signal as the method Ayanoglu [15] does. We now explain how to maintain ATM cell sequence integrity in more detail by referring to Figure 6.

First, we consider the downlink (from BSs to a mobile terminal) ATM cells. After sending the radio channel release acknowledgement (Ra. ch. rel. ack.) message to the mobile terminal (MT), the current BS forwards the incoming ATM cells destined to the MT to the new BS. The new BS does not transmit the downlink ATM cells (DP#3) to the MT but puts them into a buffer until receiving the handoff (H/O) message from the MT. After receiving it, the new BS transmits the downlink ATM cells in the buffer to the MT on a first-in-first-out (FIFO) basis. Therefore, the MT can receive the downlink ATM cells by maintaining their cell sequence without any cell loss.

Next, we consider the uplink (from an MT to BSs) ATM cells. Just before sending the handoff (H/O) message to the new BS, the MT transmits a ‘Tail’ signal to the current BS. Until receiving the ‘Tail’ signal, the current BS holds the uplink ATM cells coming in via the PVC. After receiving the ‘Tail’ signal from the MT, the current BS starts to transmit the uplink ATM cells (UP#3) coming from the new BS towards the ATM switch. Therefore, the current BS sequentially transmits the uplink ATM cells towards the ATM switch.

3. Comparison with the VCT Scheme

A well-known conventional handoff scheme without CAC is the virtual connection tree (VCT) scheme [7, 8]. A serious disadvantage of the VCT scheme is significant overloading on call processors required to allocate bandwidth for initializing an entire VCT when a call is set up. On the other hand, our proposed scheme does not need any additional burden during an initial call setup.

In the VCT scheme, a root ATM switch placed at the top of a VCT monitors uplink (leaf to root) ATM cells to recognize a handoff occurrence. If a handoff is detected, the root ATM switch updates a lookup table for correctly switching downlink (root to leaf) ATM cells to a new BS. A root ATM switch covers a large number of micro-cells. Thus the rate of lookup table updating due to handoff occurrence in the root ATM switch is very high. This may cause overloading on the root ATM switch. In our proposed scheme, when a handoff occurs, a lookup table in a BS with which the mobile terminal communicated just before the handoff is updated. The proposed scheme distributes handoff processing load to BSs.

In the proposed scheme, ATM cells may be loop-backed several times to ATM switches as a result of successive handoffs. Loop-backed ATM cells need header translations in ATM switches. Header translation is hard-wired, or implemented by hardware instead of software, because PVCs are preassigned in the header translator. Thus the header translations make little contribution to the processing load of ATM switches.

We now consider the effect of the proposed scheme on ATM cell delay. It takes one ATM cell time (2.7 μsec on a 155 Mbps transmission line) to translate an ATM cell header. Considering even the buffering time, the time interval needed for an ATM cell to pass through an ATM switch or a BS is estimated to be less than a few tens of ATM cell times. When an ATM cell is loop-backed to ATM switches several times, the total ATM cell delay added by introducing our proposed scheme is at most a few hundreds of ATM cell times (a few hundreds of μsec on a 155 Mbps transmission line). This is not significant for voice services.

4. PVC Dimensioning

In the proposed scheme, the wireline link resources should be reserved for PVCs between neighboring BSs. In this section, we deal with the dimensioning problem of PVCs. First we derive the probability of handoff blocking due to the lack of PVCs, and then utilize this result to dimension the PVCs.

4.1. Probability of Handoff Blocking Due to the Lack of PVCs

We now analytically calculate the handoff blocking probability due to the lack of PVCs. We begin with the following assumptions:

1. The call holding time, T_M, is exponentially distributed with mean $1/\mu_M$.
2. The originating arrival calls in a cell occur according to a Poisson process with rate λ_o.
3. The time interval, R, during which a mobile terminal resides in a cell, called the cell sojourn time, has a general distribution. Also, the cell sojourn times, $R^{(1)}$, $R^{(2)}$, $\cdots$, consecutively induced by the movement of the mobile terminal are independent and identically distributed.

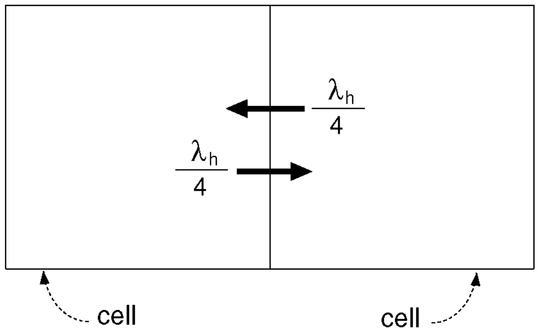


Figure 7. Handoff rates across a cell boundary.

Under the assumptions 1.–3., the handoff call arrival rate in the cell is given by [16]

$$\lambda_h = \frac{(1 - P_o)\{1 - R^*(\mu_M)\}\lambda_o}{\mu_M \mathrm{E}(R)\{1 - (1 - P_f)R^*(\mu_M)\}}, \tag{1}$$

where P_o denotes the originating call blocking probability, $R^*(s)$ the Laplace-Stieltjes transform (LST) of the random variable R, $\mathrm{E}(R)$ the expectation of R, and P_f the handoff blocking probability. If R is exponentially distributed with rate μ_R, then λ_h can be simplified as

$$\lambda_h = \frac{\mu_R(1 - P_o)}{\mu_M + \mu_R P_f}\lambda_o. \tag{2}$$

Moreover, we make the following additional assumptions:

4. Square-shaped cells are arranged in a plane.
5. Only voice calls are considered.
6. A pair of PVCs supports a two-way call.
7. The mobile terminal during a single call passes a particular cell boundary only once. This means that not more than one PVC in a cell boundary can be associated with one call.

The handoffs across one boundary may happen in two directions, as shown in Figure 7. The total handoff request rate across one cell boundary is given by

$$\lambda_P = 2 \cdot \lambda_h/4 = \lambda_h/2 \quad .$$

Suppose that a call has just been handed off successfully across the cell boundary. The interval from that instant to the time when the call is terminated by either a call completion or handoff blocking is $T_P = \min(T_R, T_M)$ where T_R is the total sojourn time of N cells before the handoff blocking, i.e., $T_R = R^{(1)} + R^{(2)} + \cdots + R^{(N)}$. Here N denotes the number of cells in which the mobile terminal generating the call resides before the handoff blocking, and is a random variable with the geometric probability distribution $\mathrm{P}(N = n) = P_f(1 - P_f)^{n-1}$, $n = 1, 2, \cdots$.

To make the meaning of the variables clear, we take the example shown in Figure 8. Two roaming paths are shown in the given microcell structure. User 1's call is initiated at $t1$ and then a handoff is requested across the cell boundary AB at $t2$, and the call is completed successfully at $t3$. In this case, $T_P = \min(T_R, T_M) = T_M = t3 - t2$. User 2's call is initiated at $t4$ and three consecutive handoffs are successfully made. However, it is terminated at $t6$ due to handoff blocking. In this case, $T_P = \min(T_R, T_M) = T_R = R^{(1)} + R^{(2)} + R^{(3)} = t6 - t5$.

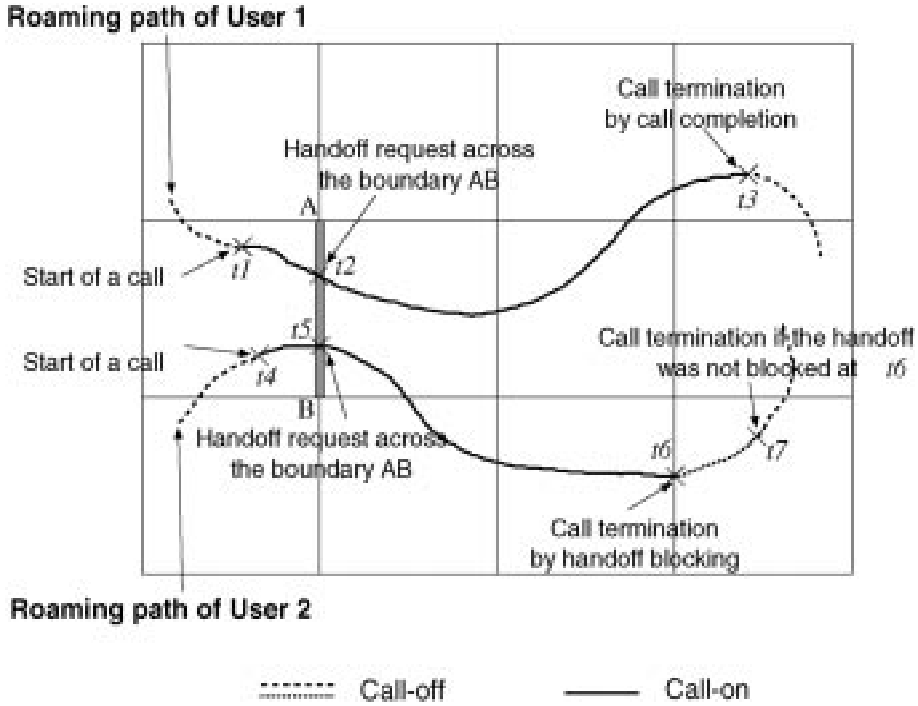


Figure 8. An example of roaming paths.

The PVC holding time, T_P, implies the interval from the instant that a PVC is allocated to a handoff call to the time that it is released. We now consider its distribution. The LST of T_R is given by

$$\begin{aligned} T_R^*(s) &= \mathrm{E}[e^{-s(R^{(1)}+R^{(2)}+\cdots+R^{(N)})}] \\ &= \sum_{n=1}^{\infty} \left(\mathrm{E}[e^{-sR}]\right)^n \mathrm{P}(N=n) \\ &= N[R^*(s)] \quad , \end{aligned} \tag{3}$$

where $N[z]$ is the generating function of the random variable N described as

$$N[z] = \frac{zP_f}{1-z(1-P_f)} \quad .$$

The distribution of T_P is written as

$$F_{T_P}(t) = F_{T_R}(t) + \{1 - F_{T_R}(t)\}(1 - e^{-\mu_M t}) \quad , \tag{4}$$

where $F_{T_R}(t)$ and $F_{T_M}(t)$ are the distributions of T_R and T_M, respectively. The LST of T_P is expressed as

$$\begin{aligned} T_P^*(s) &= \int_0^{\infty} e^{-st} dF_{T_P}(t) \\ &= \frac{s\,T_R^*(s+\mu_M) + \mu_M}{s+\mu_M} \\ &= \frac{\{sP_f - \mu_M(1-P_f)\}R^*(s+\mu_M) + \mu_M}{(s+\mu_M)\{1-(1-P_f)R^*(s+\mu_M)\}} . \end{aligned} \tag{5}$$

Also, the mean of T_P is given by

$$\mathrm{E}(T_P) = \frac{1 - R^*(\mu_M)}{\mu_M\{1 - (1 - P_f)\ R^*(\mu_M)\}}. \tag{6}$$

If R is exponentially distributed, Eq. (6) can be simplified as

$$\mathrm{E}(T_P) = \frac{1}{\mu_M + \mu_R P_f}. \tag{7}$$

The probability of handoff blocking due to the lack of PVCs is obtained as

$$P_f^{(\mathrm{PVC})} = \frac{\{\lambda_P \mathrm{E}(T_P)\}^{N_P}/N_P!}{\sum_{n=0}^{N_P}\{\lambda_P \mathrm{E}(T_P)\}^n/n!}, \tag{8}$$

where N_P denotes the number of PVC pairs reserved between two neighboring BSs.

P_f in Equations (1), (2), (6), and (7) reflects blockings due to the lack of radio channels as well as PVCs. Thus, Equation (8) is the implicit expression of $P_f^{(\mathrm{PVC})}$. If the probability of handoff blocking due to the lack of radio channels, $P_f^{(\mathrm{radio})}$, is even larger than $P_f^{(\mathrm{PVC})}$, P_f is approximately equal to $P_f^{(\mathrm{radio})}$. In that case, which seems to occur in real situations, Eq. (8) becomes the explicit form of $P_f^{(\mathrm{PVC})}$. The value of $P_f^{(\mathrm{PVC})}$ which is evaluated assuming $P_f \simeq P_f^{(\mathrm{radio})}$ is a little larger than (or an upper bound of) the exact value of $P_f^{(\mathrm{PVC})}$, because both λ_P and $\mathrm{E}(T_P)$ increase with that assumption.

4.2. Numerical Examples of PVC Dimensioning

Figure 9 shows the probability of handoff blocking due to the lack of PVCs for different traffic loads and mobilities (E(R)).

We assume that the mean call holding time is 2 minutes, that $P_f^{(\mathrm{radio})}$ is equal to 0.001, and that the cell sojourn time is exponentially distributed. We here use the approximation of $P_f \simeq P_f^{(\mathrm{radio})}$. Thus, the values of $P_f^{(\mathrm{PVC})}$ shown in the figure are upper bounds.

Figure 10 illustrates the number of PVC pairs required for a pair of two neighboring BSs for meeting the two given probabilities of handoff blocking due to the lack of PVCs, $P_f^{(\mathrm{PVC})}$. For example, we consider the micro-cell size to be $120m \times 120m$, the mean speed of the mobile terminal 30 m/min, and the traffic load 30 Erlangs/cell.

Then the required number of PVC pairs for a pair of two neighboring BSs is 20 for $P_f^{(\mathrm{PVC})} \leq 0.0001$.

5. Conclusions

We proposed a new, fast handoff management scheme using PVCs in ATM-based personal communication networks. Since rerouting the communication paths for handoff calls does not require a complex CAC but utilizes reserved PVCs, we can manage fast handoffs. The additional advantages of the proposed scheme are that handoff processing does not involve the control function of any ATM switches and the BSs can maintain ATM cell sequence integrity.

The proposed scheme makes the handoff processing quite simple and fast at the expense of reserving the wireline link resources for the PVCs. However, what is important in realizing ATM-based personal communication networks with high terminal mobility and narrow band

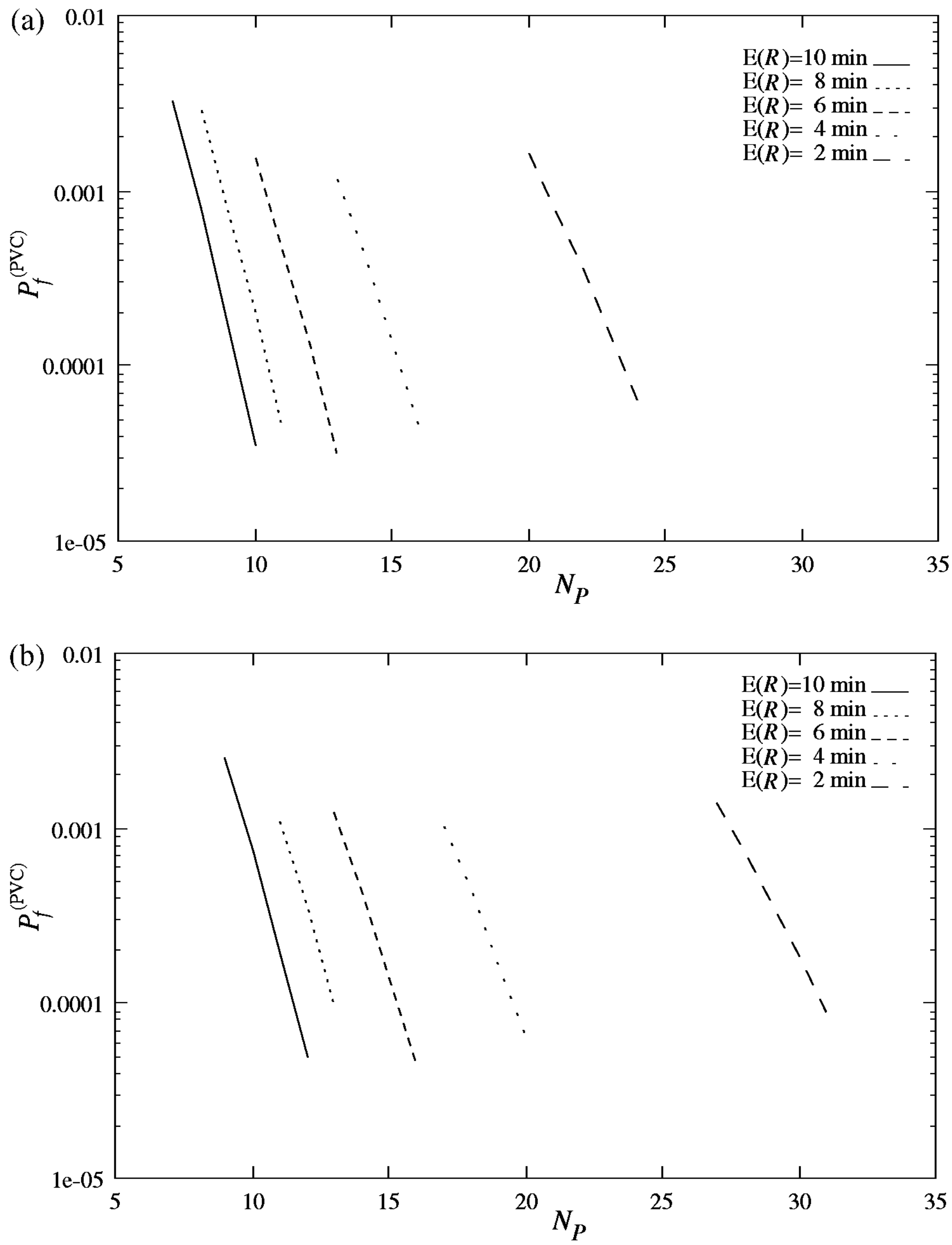


Figure 9. Probability of handoff blocking due to the lack of PVCs.

services is to reduce the complexity of the control functions rather than the wastage of the wireline link resources. The proposed scheme can be utilized in the future IMT-2000 networks accommodating various narrowband services in the range of several kbps to several hundreds kbps. In ATM-based mobile communication networks with very high wireline transmission link speed (over several Gbps), the proposed handoff scheme can also apply to wideband services.

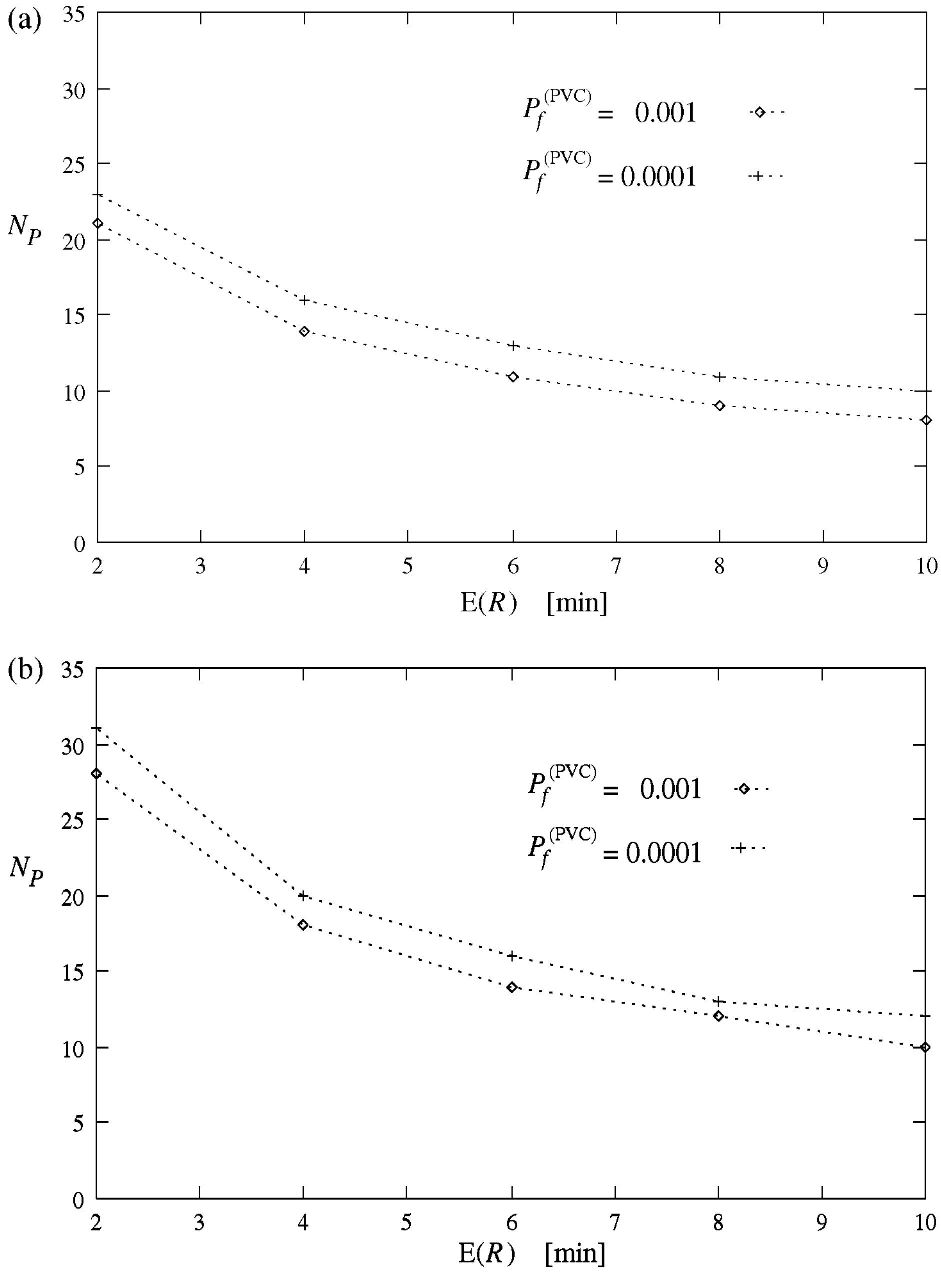


Figure 10. PVC dimensioning.

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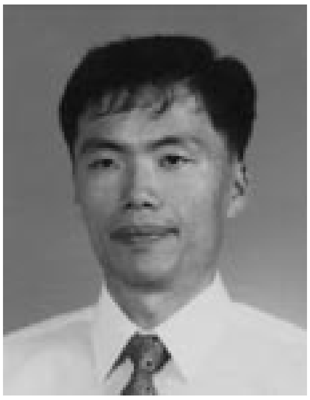
References

1. J.-P. Katoen, “Functional Integration of UMTS and B-ISDN,” in *Proc. IEEE VTC*, Chicago, IL, 1995, pp. 160–164.
2. J.A. Korinthios, H. Mitts and E.D. Sykas, “Scenarios for Integration of the Universal Mobile Telecommunication System into Broadband ISDN,” in *Proc. IEEE VTC*, Stockholm, Sweden, 1994, pp. 1596–1600.
3. Special issue on IMT-2000: Standards efforts of the ITU, *IEEE Personal Commun.*, Vol. 4, Aug. 1997.
4. M.H. Callendar, “Future Public Land Mobile Telecommunication Systems”, *IEEE Personal Commun.*, pp. 18–22, Fourth Quarter, 1994.
5. ATM Forum, “Wireless ATM”, Orlando, FL, June 1996.
6. C-K. Toh, *Wireless ATM and Ad-hoc Networks: Protocols and Architectures*, Kluwer Academic Publishers: Boston/London/Dordrecht, 1997.
7. A.S. Acampora, “Wireless ATM: A Perspective on Issues and Prospects”, *IEEE Personal Commun.*, Vol. 3, pp. 8–17, 1996.
8. A.S. Acampora and M. Naghshineh, “An Architecture and Methodology for Mobile-Executed Handoff in Cellular ATM Networks”, *IEEE J. Select. Areas Commun.*, Vol. 12, pp. 1365–1375, 1994.
9. O.T.W. Yu and V.C.M. Leung, “B-ISDN Architecture and Protocols to Support Wireless Personal Communications Internetworking”, in *Proc. PIMRC*, Toronto, Canada, 1995, pp. 768–772.
10. O.T.W. Yu and V.C.M. Leung, “Extending B-ISDN to Support User Mobility over an ATM-Based Personal Communications Network”, in *Proc. GLOBECOM*, Singapore, 1995, pp. 2289–2293.
11. B.A. Akyol and D.C. Cox, “Rerouting for Handoff in a Wireless ATM Network”, *IEEE Personal Commun.*, Vol. 3, pp. 26–33, 1996.
12. H.G. Perros and K.M. Elsayed, “Call Admission Control Schemes: A Review”, *IEEE Commun. Mag.*, pp. 82–91, 1996.
13. ITU-T, Study Group 2, *Draft Recommendation E.73X*, Geneva, May 1996.
14. D.E. McDysan and D.L. Spohn, *ATM: Theory and Application*, McGraw-Hill: New York, 1995.
15. E. Ayanoglu, K.Y. Eng and M.J. Karol, “Wireless ATM: Limits, Challenges, and Proposals”, *IEEE Personal Commun.*, Vol. 3, pp. 18–34, 1996.
16. Y.-B. Lin, S. Mohan and A. Noerperl, “Queueing Priority Channel Assignment Strategies for PCS Hand-Off and Initial Access”, *IEEE Trans. Veh. Technol.*, Vol. 43, pp. 704–712, 1994.



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