Wireless Interworking Architectures to Support Mobile IP over ATM

Ravi Jain[1], Subhashini Rajagopalan, Li Fung Chang and Vijay Varma
Applied Research
Bellcore

Abstract. *The growing demand for mobile and wireless access to Internet services has generated interest in how to use broadband infrastructures to provide such services. In this paper we provide, as a first step, an introductory presentation of alternative architectures for providing wireless Internet access, and in particular, mobile IP service, when the fixed backbone network, either in the Internet or the Public Switched Telephone Network (PSTN), contains ATM entities. All the architectures use an Interworking Function (IWF), which encapsulates the functions of protocol adaptation, inter-BSC handoff, encryption, authentication and packet routing and addressing. The first architecture we consider provides wireless Internet access service only, without integration with voice services or provision for non-Internet data services (e.g. messaging or fax), and uses a centralized IWF. The second architecture is similar but uses a distributed IWF. We then consider two architectures where voice and data services are integrated. In Architecture 3, voice and data services share the radio system only, with switching and other functions being provided separately for each service. Architecture 4 not only allows voice and data to share the PSTN switching resources, but also considers the interworking of ATM switches in the PSTN backbones with narrowband PSTN switches as well as Internet ATM transport.*

1. Introduction

The work described in this paper is driven by two main considerations. The first is that the demand for mobile and wireless data services, and in particular, mobile and wireless Internet services, has been growing dramatically. The second is that projected demand for high-bandwidth and multimedia applications has led to Asynchronous Transfer Mode (ATM) technology being considered or being actively deployed in network backbones. It seems likely that there will be significant opportunities to utilize ATM technology to provide mobile and wireless access to Internet services in future. However, to do so it is necessary to develop the architectures and protocols by which the wireless and wired ATM infrastructures can be interworked and made to interoperate seamlessly and efficiently.

There are currently efforts underway in the Internet and ATM communities to develop protocols for mobile Internet Protocol (IP) [1] service and for IP over ATM backbones, but there is no effort currently underway for doing both, i.e., mobile IP over ATM. In this paper we present alternative architectures for providing wireless Internet access, and in particular, mobile IP service, when the fixed backbone network, either in the Internet or the Public Switched Telephone Network (PSTN), contains ATM entities. A previous document, SR-3695 [7], describes methods which can be used to provide *discrete* Internet access to mobile users who use wireless access, i.e. users who plug into the access network, e.g., an enterprise wireless LAN, obtain Internet access, and terminate the session before moving to a new location where they repeat the process. In the present paper we focus on providing *continuous* mobile IP service to wireless users. The methods described in SR-3695 [7] also do not allow Internet traffic to be delivered to the user without the user first setting up a PPP session; we avoid this limitation also. The architectures developed in the present paper can serve as baselines for more detailed design of the protocols for providing mobile IP over ATM.

An assumption we make, which distinguishes our work from other work on mobile IP services is that wireless data services in general, and mobile IP service in particular, may need to co-exist with wireless voice services, and be provided using as much of the wireless voice infrastructure as possible. We observe that Mobile IP service can be provided using some of the same AIN elements and databases, e.g. the Signaling System 7 (SS7) network and the Home Location Register or Visitor Location Register databases, which are used for providing PCS or cellular service (see [15] for further background). In this paper, we consider the situation where the backbone network (in the Internet, the PSTN, or both) evolves to become an ATM network. The ATM backbone network will be introduced to provide a whole range of broadband service offerings, e.g., video on demand, to fixed residential and business customers. Wireless voice and data services (to fixed or mobile users) will then be integrated with this emerging ATM backbone network in order to further utilize the investment in ATM, as well as to take advantage of Quality of Service (QoS) and other capabilities that ATM offers.

We also assume that as the PSTN backbone network evolves to ATM, it may be cost-effective to carry signaling as well as user information over the same physical ATM transport. We have discussed this scenario in detail in previous work and presented a series of short-term, medium-term and long-term architectures for evolution from the current PSTN architecture to one based upon an ATM backbone [5] [16] (see also [9].) In the present paper, however, we will only consider medium-term architectures where user information is transported over the ATM backbone, but signaling is still carried over the existing Common Channel Signaling (CCS) Signaling System 7 (SS7) network.

This paper is organized as follows. In Section 2 we present the architectural alternatives. In Section 2.1 we present architectures where only wireless Internet service is provided, without providing the end user with voice service at the same time.Section 2.2 presents architectures where integrated voice and data services are offered to the end user. In Section 3 we end with a summary.

1. Address correspondence to: Ravi Jain, Applied Research, Bellcore. 331 Newman Springs Rd, Red Bank, NJ 07701. Phone: (908) 758-2844. Fax: (908) 758-4371. Email: rjain@bellcore.com.

0-7803-4198-8/97/$10.00 © 1997 IEEE

2. Architectural Alternatives

Traditionally, data services have been provided in analog cellular systems using voiceband modems, which involves converting digital data to analog before transmission. We call this method of providing data service *non-interworked voiceband data over analog cellular.* Clearly, a better use of the digital channel is *interworked data over digital cellular*, or *interworked data service*, i.e., to carry the user's digital data directly over the digital wireless channel.

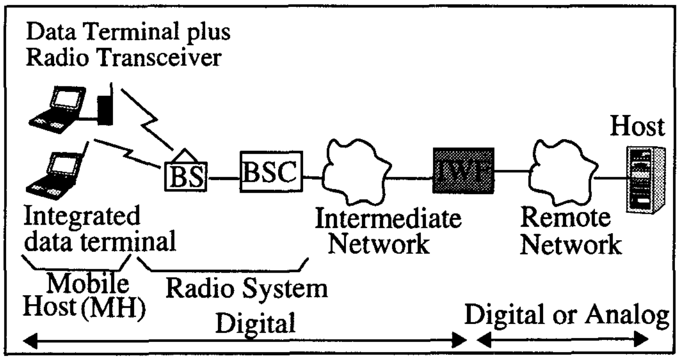

Figure 1 Architecture Framework

The basic architecture for providing wireless data services is then shown in Figure 1. In this paper, MH stands for Mobile Host, BS for Base Station, and BSC for Base Station Controller. Among other requirements of interworked data service (see [5] [6]), an *Interworking Function* (IWF) is required. The intermediate network is required in order to support inter-BSC handoff. The basic architecture shown in Figure 1 allows for many options in the choice of the intermediate network (e.g. a TCP/IP LAN, a circuit-switched data connection running LAPB via an ISDN switch, or an X.25 connection over a protocol such as LAPB via an ISDN switch and a packet switch.) The radio system could also consist of a wireless LAN; the base stations are then typically connected to a wired enterprise LAN interfaced via the IWF to the remote network. Although not a basic assumption, for concreteness we assume the peripheral switch (as well as interior switches in the Internet) is an ATM switch; the modifications required if it is not are fairly obvious. We assume that a protocol similar to IP-over-ATM [2] [3] [4] is being used.

One of the basic issues that arises when developing architectures for mobile IP over ATM is to decide where the ATM connection terminate: at the mobile host, the BS or the BSC, or at the IWF. If ATM terminates at the MH, we avoid the problem of translating the link address between the fixed infrastructure and the radio system. However, the relatively large overhead of ATM cell headers (over 10%) reduces wireless bandwidth efficiency unless techniques such as header compression, or packing ATM cells into larger units [13] [14], are used. Another issue is that as the MH moves from cell to cell, its ATM address will change, entailing procedures and protocols for managing ATM addresses. We therefore assume that ATM transport is not used over the wireless link. Thus ATM could be terminated at the BS

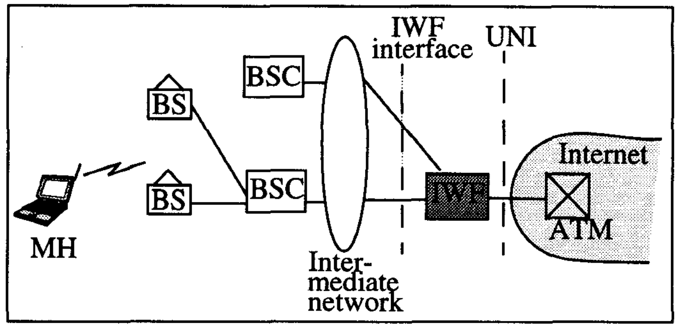

Figure 2 *Architecture 1*: Internet service overlay with a centralized IWF

or BSC or at the IWF. To keep BS and BSCs simple, dedicated for their particular function, and inexpensive, we will assume that the logical functions involved in maintaining the ATM interface are located at the IWF. If the IWF is centralized, these logical functions can be shared by multiple BSCs.

A similar issue that arises is whether any entity in the radio system has an IP address. Clearly, IP itself terminates at the mobile host. Considerations similar to those for the ATM interface, as well as a desire to conserve the current IP address space, lead us to assume that only the IWF will have an IP address.

2.1 Internet service overlay

Our first architecture, *Architecture 1* (Figure 2), is one where the complications of interworking wireless voice and Internet service are avoided. In this architecture the MH has an IP address, but not a PSTN phone number. Obviously the drawback with this architecture is that it is highly restrictive; not only does it not offer wireless voice access, even non-Internet wireless data services (e.g., reception of a fax from a standard fax machine via the PSTN) are not feasible. (It may be possible to send a fax via the Internet, using special software to convert fax data to IP packets and back, but we still regard this as basically an Internet data service.) In addition, this architecture relies upon installing a complete radio system overlay (base stations, BSCs, associated communications and power wiring, etc.) which duplicates that needed for PCS and wireless voice. Nonetheless, this architecture may be useful in some situations. One possibility is as a near-term approach for capitalizing on exploding demand for Internet service in an area where voice PCS has not yet been introduced. Another possibility is as a wireless local loop to replace the second phone lines installed in residences for Internet access.

If this architecture is used the IWF acts as an Internet gateway as well as provides interworking between the BSC and the ATM switch. As an Internet gateway, it is responsible for identifying different mobile hosts by their IP addresses and delivering IP packets to and from them. As an IWF, it is also responsible for converting the communications to and from the BSC (which are not over an ATM transport) to the format and addressing for transmission to the ATM switch.

In addition, support for encryption and authentication functions is needed. Encryption is required so as to protect the user information sent over the wireless medium. Different radio system protocols (GSM [10], PACS [11], etc.) will use different encryption schemes, and the IWF may be required to support multiple encryption schemes. Authentication is also required for the wireless access by the user. Note that this authentication is in addition to the end-to-end authentication required when the user accesses Internet services. For example, if the user opens a *telnet* session to a remote host, the remote host will authenticate the user for access to the host, as it would for a wired user. However, the wireless access medium itself is a resource whose use needs to be authenticated.

To summarize, the IWF functionality includes the following:

- It adapts data protocols on the radio system to those on the wired system. This includes adapting the radio system protocol to ATM transport in the wired infrastructure, and mapping addresses from one to the other.
- It provides for handoffs between Base Station Controllers (BSCs), and makes them invisible to the wired system. This includes acting as an anchor during inter-BSC handoffs, and may include providing buffering for data packets to prevent or minimize loss during handoff.
- It provides mechanisms for routing data packets to and from the mobile user. We will assume that, in general, it also acts as an IP gateway.
- Encryption and authentication functions

It is also possible for the IWF to perform the functions of the Foreign Agent entity required in the Mobile IP protocol [1]. Alternatively the Foreign Agent functionality can be placed in a (default) router in the Internet which is connected to an ATM switch.

A slight modification of this architecture would distribute the IWF functionality amongst multiple BSCs (see *Architecture 2*, Figure 3.) The BSC acts as an Internet gateway as well as provides interworking, handoff, encryption and authentication functionality. The intermediate network is used for the inter-BSC handoffs required as well as for connecting the BSC to the Internet. Since we have assumed that the Internet access switch is an ATM switch in this architecture, it may be advantageous if the intermediate network is also an ATM network to avoid further interworking.

The choice between Architecture 1 and Architecture 2 is influenced by several factors. Architecture 1 is desirable if Internet traffic is relatively low and it is economical to concentrate the intelligence required for interworking and IP gateway functions; in this case the BSC can be relatively simple. This may have implications not only for the capital costs of BSCs but also operational and maintenance costs, since upgrades and modifications to the IWF need not be made at geographically distributed BSC sites. It is envisioned that the design of the IWF in Architecture 1 would be highly modular, with most of the IWF functions being independent of the radio system technology. Inter-BSC handoffs may be somewhat easier to manage in Architecture 1 than in Architecture 2, since the centralized IWF provides a single anchor point during the

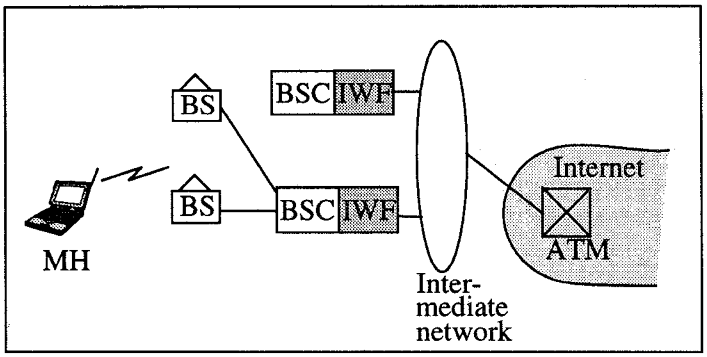

Figure 3 *Architecture 2*: Internet service overlay with a distributed IWF

handoff process. On the other hand Architecture 2 may be preferable if the volume of Internet data traffic is so high that a centralized IWF would be a bottleneck, or if the PCS Service Provider (PSP) desires to own or control the IWF functions.

2.2 Mobile voice and data service

We now consider architectures where the user can be offered both voice and Internet data service, as well as, possibly, other non-Internet data services. The user's terminal may consist of two separate devices (a voice handset and a laptop or palmtop computer) or a single integrated device; we will refer to both of these possibilities generically as the MH. In general, the MH will have a home IP address, as well as a PSTN phone number.

One issue that arises in this situation is of voice-data demultiplexing. For communication originated by the MH, we assume that the protocols on the air interface allow the BS or BSC to distinguish between voice and data transmissions, and route them accordingly (as in GSM [10], PACS [11] and CDMA [12].) For communications originated by remote hosts, (i.e., voice call or data packet delivery to the MH), the MH will be addressed by (at least) two separate logical addresses: its phone number for voice calls and an IP address for Internet traffic. For non-Internet data (e.g fax or short message delivery to the MH), there are several possibilities, including using a different number for each service, using prefix dialing (e.g. *FX dialed before the MH's phone number indicates that the call is a fax call), or two-stage dialing (the call is routed to an intermediate server, which prompts the caller for more information to determine the nature of the call.) See [6] [7] for further discussion.

2.2.1 Voice and data service using shared radio infrastructure

In *Architecture 3* (Figure 4) the radio system infrastructure is used to transport both voice and data, but different portions of the fixed infrastructure are used for voice and data. We use an IWF for interfacing the base station controllers to the ATM switch because, as in the architectures of Section 2.1, we do not assume that they can "speak ATM", i.e., have the capabilities to carry out the ATM protocols.

The BSCs have an interface both to the narrowband (i.e., non-ATM) PSTN as well as to the IWF. The PSTN access switch is an ISDN switch, and the connection between the BSC and the PSTN access switch is over an ISDN line. The connection between the BSC and the IWF can be over any suitable public or private network of sufficient bandwidth (typically, at least 56 kbps would be required). In this architecture, since the BSCs support PCS voice channels in addition to the data channels, typically they would maintain functions for encryption and authentication of the user for the voice channel resource. It may be possible to use these functions for the authentication and encryption of the data channels also, freeing the IWF from these responsibilities.

Note that a single IWF can support multiple BSCs. The IWF is shown as part of the fixed infrastructure. The IWF can also be used to allow PCS Service Providers (PSP) with different air interface protocols to be connected to the same ATM switch.

In this architecture the mobile host can be provided with both voice and data services. The top part of Figure 4 shows mobility management and mobile voice call origination and delivery being supported by the infrastructure and protocols in the PSTN for PCS service (see also [8]), and the bottom part of the figure shows mobility management and mobile IP service being supported by the Internet infrastructure and mobile IP protocol.

Voice calls to and from the mobile host are routed in the usual manner via the PSTN and the access switch. That is, for voice calls, the mobile host registers at the Visitor Location Register (VLR) and Home Location Register (HLR) databases via the SS7 signaling network. Calls are delivered to the user by consulting the HLR, which points to a VLR, which in turn obtains a Temporary Local Directory Number (TLDN) or other routing number in order to route the call via the usual call routing mechanism to the access switch and from there to the mobile host [15].

With the provision of voice service, non-Internet data services can be provided using non-interworked data, or, preferably, fully-interworked service for fax and short message transmissions [7]. Internet data service is provided using the mobile IP protocol, with the IWF (or some other entity) assuming the role of the Foreign Agent. The MH can then receive or originate Internet data traffic while enjoying continuous Internet connectivity.

2.2.2 ATM Backbone in the PSTN

So far the architectures we have considered have used ATM transport in the Internet, but not in the PSTN, where non-ATM switches are assumed. We now consider this situation, in *Architecture 4* (Figure 5).

In our previous work [5], we have described an evolutionary approach to introducing ATM switches into the PSTN. In the first near-term approach, ATM switches are only introduced selectively at a few points in the network. The other AIN elements, such as STPs and SCPs, as well as many access and tandem switches, remain narrowband. The existing SS7 signaling network is used for communicating with these narrowband entities, and the existing SS7 protocols are used, but the ATM transport can be used for signaling amongst the ATM

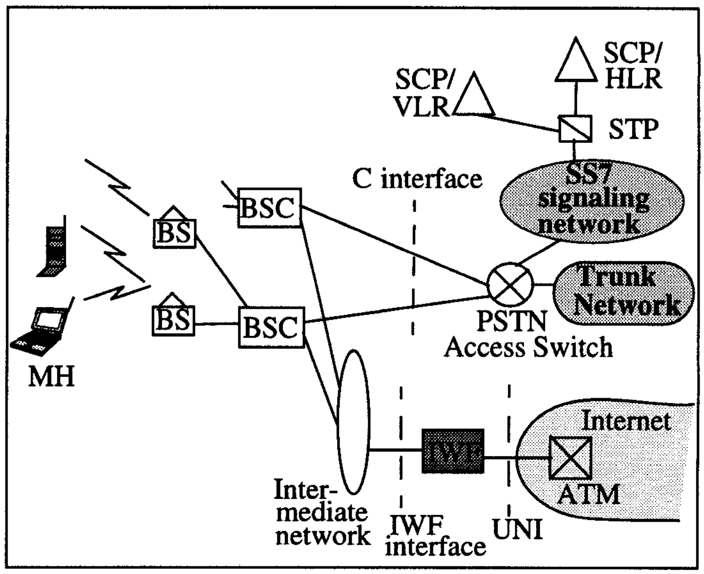

Figure 4 *Architecture 3:* Wireless voice and data over shared radio system

switches. We consider a similar approach for providing mobile IP services when the PSTN contains ATM switches. In our approach the access switch, which connects to the radio system, remains a narrowband ISDN switch, while ATM switches are used "deeper" in the network backbone. This is consistent with a scenario where ATM deployment is driven by wireline high-bandwidth applications, like video, rather than wireless.

This architecture differs from Architecture 3 in that the BSCs have direct connections only to the narrowband switch, and not to the IWF. The physical link between the BSC and the narrowband switch is typically an ISDN line, as is the link between the IWF and the narrowband switch. The ATM switch is now shown as an ATM switching system, since the switch itself needs adapters in order to interface with the narrowband switch as well as the narrowband SS7 network; these adapters are called the Interworking Unit (IWU) and the SS7 interface, respectively. The mobility management databases for voice delivery (HLR and VLR) remain unchanged. The IWF in this architecture acts as an IP gateway and also converts communications received from the BSC over the ISDN line to be suitable for transmission over ATM, and vice versa. It can also provide the Foreign Agent functionality required for mobile IP. As for Architecture 3, it is possible that the authentication and encryption functions typically provided by the BSC for the voice channels can also be used for data, freeing the IWF from this task.

The interworking of the BSC and the IWF for supporting IP is similar to that described in [7]. Either the V.120 protocol, or the X.25 protocol running over LAPB/LAPD, is used over the ISDN channels. The Internetworking Control Protocol (ICP) developed in [7] is used on top of V.120 or X.25.

In this architecture, it may be possible to utilize the database functions used for PCS voice delivery, i.e., the HLR, VLR and SS7 infrastructure, for mobile IP data delivery also. For example, it may be possible to leverage the HLR/VLR databases to use them for Home Agent/Foreign Agent functionality. In that

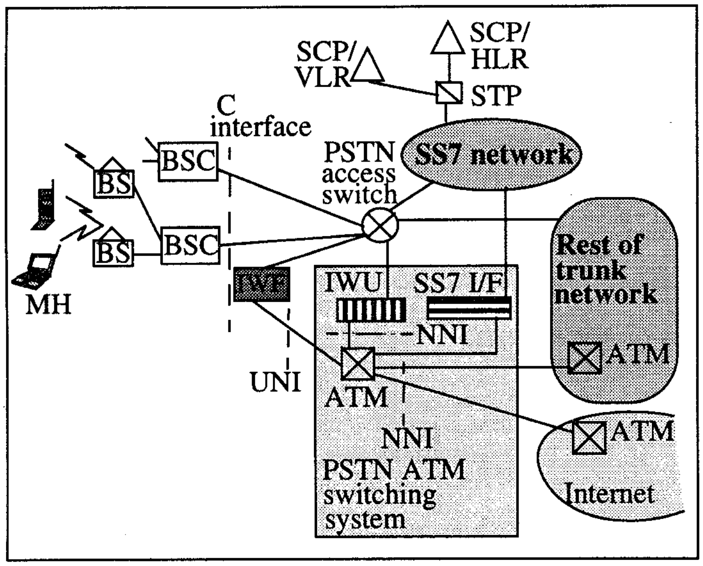

Figure 5 *Architecture 4:* Wireless voice and data over shared radio and switching system

case these databases may have interfaces to the Internet, or may connect to the Internet via the SS7 interface shown in the ATM switching system.

Architecture 4 differs from Architecture 3 in two basic respects. Firstly, in Architecture 4 the intermediate network connecting the BSCs to the IWF is explicitly assumed to be a PSTN network (via an ISDN switch.) This reduces the number of interfaces that the BSC must support, simplifying their design and potentially reducing their cost. Secondly, Architecture 4 explicitly considers integration of the PSTN switching facilities for transport of Internet traffic, and specifically considers the use of ATM backbone switches in the PSTN. However, Architecture 3 may be used in the nearer term still, before ATM is widely deployed in the PSTN or the interworking of narrowband PSTN switches with ATMswitches has been fully achieved.

3. Summary

We have presented a series of architecture alternatives for providing wireless access to Internet data services when the backbone is an ATM network. This paper follows upon previous work on wireless access to data services [5] [6] [7], as well as mobile IP and IP over ATM protocols currently being developed in the Internet community.

All the architectures we have presented involve an Interworking Function (IWF) which provides interworking between the protocols used in the radio system and those used in the fixed ATM backbone, as well as support for inter-BSC handoffs, and authentication and encryption, The IWF may also provide the functions of an IP gateway as well as of the Foreign Agent in the Mobile IP protocol. In general, the IWF may be centralized, allowing its functionality to be shared by multiple BSCs, or it may be distributed amongst the BSCs.

The architectures developed in the present paper can serve as baselines for more detailed design of the protocols for providing mobile IP over ATM.

Acknowledgments. We thank the other members of the mobile IP and interoperability team, especially Will Leland, Tony McAuley, and Bala Rajagopalan, for useful discussions.

References

[1] C. Perkins (Editor), "IP Mobility Support," *IETF RfC 2002,* Oct. 1996.

[2] M. Laubach, "Classical IP and ARP over ATM," *IETF Internet Draft,* Dec. 1996.

[3] M. Perez, F. Liaw, A. Mankin, E. Hoffman, D. Grossman and A. Mallis, "ATM Signalling Support for IP over ATM," *RFC 1755,* February 1995.

[4] D. Katz and D. Piscitello, "NBMA Next Hop Resolution Protocol (NHRP)", *Internet Draft of ROLC Working Group,* Jan. 1996.

[5] S. Rajagopalan and L. F. Chang, "Signaling Architecture Evolution for Broadband PCS Internetworking", *Proc. Intl. Conf. Univ. Pers. Comm.,* 1997.

[6] D. Harasty, L. F. Chang and A. R. Noerpel, "Architecture Alternatives for Wireless Data Services", *Proc. IEEE Intl. Conf. Universal Pers. Comm.,* Oct. 1994.

[7] Bellcore, "Data Access Services for PCS Service Providers", *Special Report SR-3695,* Issue 1, Dec. 1995.

[8] Bellcore, "Personal Communications Services (PCS) Network Access Services to PCS Providers", *Special Report SR-TSV-002459 Issue 2 Revision 1,* Dec. 1994.

[9] Bellcore, "Alternatives for Signaling Link Evolution", *Special Report SR-NWT-002897 Issue 1,* Feb. 1994.

[10] Michel Mouly and M. - B. Pautet, *The GSM System for Mobile Communications,* M. Mouly, 49 rue Louise Bruneau, Palaiseau, France, 1992.

[11] ANSI J-STD-014, "Personal Access Communications System Air Interface Standard", 1996.

[12] ANSI J-STD-008, "Personal Station - Base Station Compatibility Requirements for 1.8 - 2.0 GHz Code Division Multiple Access (CDMA) Personal Communications Systems", 1995.

[13] D. Raychoudhary and N. Wilson, "ATM-Based Transport Architecture for Multiservice Wireless PCNs," *IEEE Journal of Sel. Areas Comm.,* Oct. 1994.

[14] H. McTiffin et al, "Mobile access to an ATM Network Using a CDMA Air Interface," *IEEE Journal of Sel. Areas Comm.,* June. 1994.

[15] R. Jain, Y.-B. Lin and S. Mohan, "Location Strategies for Personal Communications Services," in *Mobile Communications Handbook,* (ed. J. Gibson), CRC Press, 1996.

[16] R. Jain, S. Rajagopalan, and L. F. Chang, "Phone Number Portability for PCS Systems with ATM Backbones Using Distributed Dynamic Hashing", *IEEE J. Sel. Areas Comm.,* Jan. 1997.