Barton, M.; Cheng, M. & Chang, L.F. “Wireless ATM: Interworking Aspects”
Mobile Communications Handbook
Ed. Suthan S. Suthersan
Boca Raton: CRC Press LLC, 1999

Wireless ATM: Interworking Aspects

Melbourne Barton
Bellcore

Matthew Cheng
Bellcore

Li Fung Chang
Bellcore

34.1 Introduction
34.2 Background and Issues
34.3 Wireless Interworking With Transit ATM Networks
Integrated Wireless–Wireline ATM Network Architecture • Wireless Access Technology Options
34.4 The PCS-to-ATM Interworking Scenario
Architecture and Reference Model • Signalling Link Evolution
34.5 QoS Support
34.6 Conclusions
Defining Terms
References
Further Information

34.1 Introduction

The ATM Forum's **wireless asynchronous transfer mode (WATM)** Working Group (WG) is developing specifications intended to facilitate the use of ATM technology for a broad range of wireless network access and interworking scenarios, both public and private. These specifications are intended to cover the following two broad WATM application scenarios:

- *End-to-End WATM*—This provides seamless extension of ATM capabilities to mobile terminals, thus providing ATM virtual channel connections (VCCs) to wireless hosts. For this application, high data rates are envisaged, with limited coverage, and transmission of one or more ATM cells over the air.
- *WATM Interworking*—Here the fixed ATM network is used primarily for high-speed transport by adding mobility control in the ATM infrastructure network, without changing the non-ATM air interface protocol. This application will facilitate the use of ATM as an efficient and cost-effective infrastructure network for next generation non-ATM wireless access systems, while providing a smooth migration path to seamless end-to-end WATM.

This chapter focuses on the ATM interworking application scenario. It describes various interworking and non-ATM wireless access options and their requirements. A generic **personal com-**

munications services (PCS)[1]-to-ATM interworking scenario is described which enumerates the architectural features, protocol reference models, and signalling issues that are being addressed for mobility support in the ATM infrastructure network. Evolution strategies intended to eventually provide end-to-end WATM capabilities and a methodology to consistently support a range of quality of service (QoS) levels on the radio link are also described.

34.2 Background and Issues

ATM is the switching and multiplexing standard for **broadband integrated services digital network (BISDN),** which will ultimately be capable of supporting a broad range of applications over a set of high capacity multiservice interfaces. ATM holds out the promise of a single network platform that can simultaneously support multiple bandwidths and latency requirements for fixed access and wireless access services without being dedicated to any one of them. In today's wireline ATM network environment, the **user network interface (UNI)** is fixed and remains stationary throughout the connection lifetime of a call. The technology to provide fixed access to ATM networks has matured. Integration of fixed and wireless access to ATM will present a cost-effective and efficient way to provide future tetherless multimedia services, with common features and capabilities across both wireline and wireless network environments. Early technical results [19, 20, 25] have shown that standard ATM protocols can be used to support such integration and extend mobility control to the subscriber terminal by incorporating wireless specific layers into the ATM user and control planes.

Integration of wireless access features into wireline ATM networks will place additional demands on the fixed network infrastructure due primarily to the additional user data and signalling traffic that will be generated to meet future demands for wireless multimedia services. This additional traffic will allow for new signalling features including registration, call delivery, and handoff during the connection lifetime of a call. Registration keeps track of a wireless user's location, even though the user's communication link might not be active. Call delivery, establishes a connection link to/from a wireless user with the help of location information obtained from registration. The registration and call delivery functions are referred to as **location management.** Handoff is the process of switching (rerouting) the communication link from the old coverage area to the new coverage area when a wireless user moves during active communication. This function is also referred to as **mobility management.**

In June, 1996 the ATM Forum established a WATM WG to develop requirements and specifications for WATM. The WATM standards are to be compatible with ATM equipment adhering to the (then) current ATM Forum specifications. The technical scope of the WATM WG includes development of: (1) **radio access layer (RAL)** protocols for the physical (PHY), medium access control (MAC), and data link control (DLC) layers; (2) wireless control protocols for radio resource management; (3) mobile protocol extensions for ATM (mobile ATM) including handoff control, routing considerations, location management, traffic and QoS control, and wireless network management; and (4) wireless interworking functions for mapping between non-ATM wireless access and ATM signalling and control entities. Phase-1 WATM specifications are being developed for short-range, high-speed, end-to-end WATM devices using wireless terminals that operate in the 5 GHz frequency

[1]The term PCS is being used in a generic sense to mean emerging digital wireless systems, which support mobility in microcellular and other environments. It is currently defined in ANSI T1.702-1995 as "A set of capabilities that allows some combination of terminal mobility, personal mobility, and service profile management."

band. Operating speeds will be up to 25 Mb/s, with a range of 30 m–50 m indoor and 200 m–300 m outdoor. The European Telecommunications Standards Institute (ETSI) Broadband Radio Access Networks (BRAN) project is developing the RAL for Phase-1 WATM specifications using the **HIgh PERformance Radio LAN (HIPERLAN)** functional requirements. The ATM Forum plans to release the Phase-1 WATM specifications by the second quarter of 1999.

There are a number of emerging wireless access systems (including digital cellular, PCS, legacy LANs based on the IEEE 802.11 standards, satellite, and IMT-2000 systems), that could benefit from access to, and interworking with, the fixed ATM network. These wireless systems are based on different access technologies and require development of different **interworking functions (IWFs)** at the wireless access network and fixed ATM network boundaries to support WATM interworking. For example, a set of network interfaces have already been identified to support PCS access to the fixed ATM network infrastructure, without necessarily modifying the PCS air interface protocol to provide end-to-end ATM capabilities [4, 6, 28]. The WATM WG might consider forming sub-working groups which could work in parallel to identify other network interfaces and develop IWF specifications for each of (or each subset of) the wireless access options that are identified. These WATM interworking specifications would be available in the Phase-2 and later releases of the WATM standards.

Some service providers and network operators see end-to-end WATM as a somewhat limited service option at this time because it is being targeted to small enterprise networks requiring high-speed data applications, with limited coverage and low mobility. On the other hand, WATM interworking can potentially support a wider range of services and applications, including low-speed voice and data access, without mandatory requirements to provide over-the-air transmission of ATM cells. It will allow for wider coverage, possibly extending to macrocells, while supporting higher mobility. WATM interworking will provide potential business opportunities, especially for public switched telephone network (PSTN) operators and service providers, who are deploying emerging digital wireless technologies such as PCS. Existing wireless service providers (WSPs) with core network infrastructures in place can continue to use them while upgrading specific network elements to provide ATM transport. On the other hand, a new WSP entrant without such a network infrastructure can utilize the public (or private) ATM transport network to quickly deploy the WATM interworking service, and not be burdened with the cost of developing an overlay network. If the final goal is to provide end-to-end WATM services and applications, then WATM interworking can provide an incremental development path.

34.3 Wireless Interworking With Transit ATM Networks

Figure 34.1 shows one view of the architectural interworking that will be required between public/private wireless access networks and the fixed ATM network infrastructure. It identifies the network interfaces where modifications will be required to allow interworking between both systems. A desirable objective in formulating WATM specifications for this type of wireless access scenario should be to minimize modifications to the transit ATM network and existing/emerging wireless access system specifications. This objective can be largely met by limiting major modifications to the network interfaces between the boundaries of the transit ATM network and public/private wireless networks, and where possible, adopting existing network standard processes (i.e., SS7, IS-41, MAP, AIN.3, Q.931, Q.932, Q.2931, etc.) to minimize development costs and upgrades to existing service providers' network infrastructure. Development of standard network interfaces that allow interworking of a reasonable subset of non-ATM digital wireless access systems with the fixed ATM network infrastructure insure that:

- Large-scale revisions and modifications are not necessary to comply with later versions of the WATM specifications to accommodate other emerging digital wireless access systems that do not require end-to-end ATM connectivity

- WATM systems are supported by open interfaces with a rich set of functionality to provide access to both ATM and non-ATM wireless access terminal devices
- WATM services can reach a much larger potential market including those markets providing traditional large-scale support for existing voice services and vertical voice features.

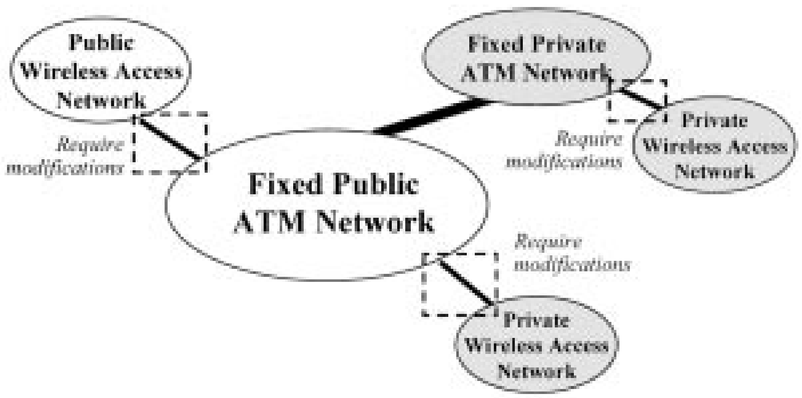


FIGURE 34.1: Wireless ATM interworking architecture.

34.3.1 Integrated Wireless–Wireline ATM Network Architecture

Figure 34.2 shows one example of a mature, multifunctional ATM transport network platform, which provides access to fixed and mobile terminals for wide-area coverage. Four distinct network interfaces are shown supporting: (1) fixed access with non-ATM terminal, (2) fixed access with ATM terminal, (3) wireless access with non-ATM terminal (WATM interworking), and (4) wireless access with ATM terminal (end-to-end WATM).

International Telecommunications Union (ITU) and ATM Forum standard interfaces either exist today or are being developed to support fixed access to ATM networks through various network interfaces. These include frame relay service (FRS) UNI, cell relay service (CRS) UNI, circuit emulation service (CES) UNI, and switched multimegabit data service (SMDS) subscriber NI (SNI). The **BISDN intercarrier interface (B-ICI)** specification [1] provides examples of wired IWFs that have been developed for implementation above the ATM layer to support intercarrier service-specific functions developed at the network nodes, and distributed in the public ATM/BISDN network. These distributed, service-specific functions are defined by B-ICI for FRS, CRS, CES, and SMDS. Examples of such functions include ATM cell conversion, clock recovery, loss of signal and alarm indication detection, virtual channel identifier (VCI) mapping, access class selection, encapsulation/mapping, and QoS selection. In addition to the B-ICI, the **private network-network interface (PNNI)** specification [2] defines the basic call control signalling procedures (e.g., connection setup and release) in private ATM networks. It also has capabilities for autoconfiguration, scalable network hierarchy formation, topology information exchange, and dynamic routing.

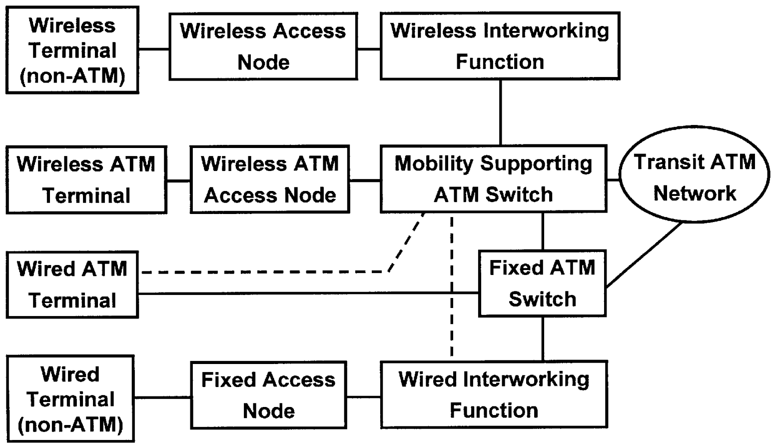


FIGURE 34.2: Wireless and wireline system integration with transit ATM Network.

On the wireless access side, existing ITU specifications provide for the transport of wireless services on public ATM networks (see, e.g., [10, 11]). For example, if the ATM UNI is at the mobile switching center (MSC), then message transfer part (MTP) 1 and 2 would be replaced by the PHY and ATM layers, respectively, the broadband ISDN user part (BISUP) replaced by MTP 3, and a common channel signalling (CCS) interface deployed in the ATM node. BISUP is used for ATM connection setup and any required feature control. If the ATM UNI is at the base station controller (BSC), then significant modifications are likely to be required. Equipment manufacturers have not implemented, to any large degree, the features that are available with the ITU specifications. In any case, these features are not sufficient to support the WATM scenarios postulated in this chapter.

The two sets of WATM scenarios postulated in this chapter are shown logically interfaced to the ATM network through a **mobility-enabled ATM (ME-ATM)** switch. This enhanced ATM access switch will have capabilities to support mobility management and location management. In addition to supporting handoff and rerouting of ATM connections, it will be capable of locating a mobile user anywhere in the network.

It might be desirable that functions related to mobility not be implemented in standard ATM switches so that network operators and service providers are not required to modify their ATM switches in order to accommodate WATM and related services. A feasible strategy that has been proposed is to implement mobility functions in servers (i.e., service control modules or SCMs) that are logically separated from the ATM switch. In these servers, all mobility features, service creation logic, and service management functions will be implemented to allow logical separation of ATM switching and service control from mobility support, service creation, and management. The open network interface between the ATM access switch and SCM will be standardized to enable multivendor operation. It would be left up to the switch manufacturer to physically integrate the SCM into a new ATM switching fabric, or implement the SCM as a separate entity.

34.3.2 Wireless Access Technology Options

Figure 34.3 identifies various digital wireless systems that could be deployed to connect mobile terminals to the transit ATM network through IWFs that have to be specified. The main emphasis is on developing mobility support in the transit ATM infrastructure network to support a range of wireless access technologies. Significant interests have been expressed, through technical contributions and related activities in the WATM WG, in developing specifications for the IWFs shown in Fig. 34.3 to allow access to the fixed ATM network through standard network interfaces. The main standardization issues that need to be addressed for each wireless access system are described below.

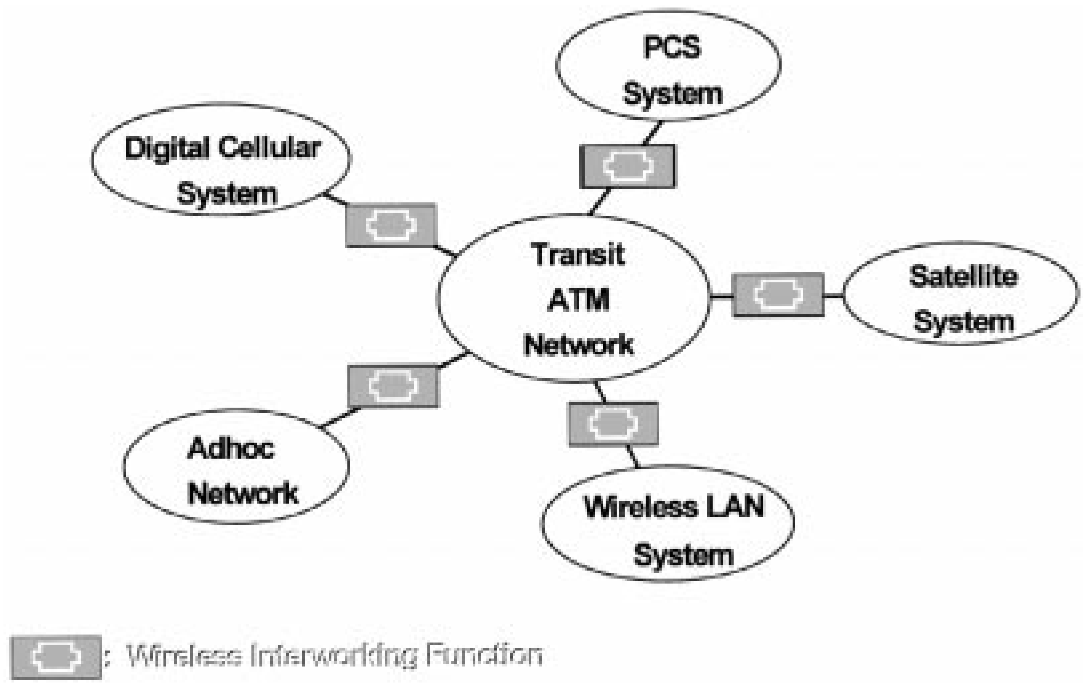


FIGURE 34.3: Various wireless access technologies supported by wireless ATM interworking.

PCS

This class of digital wireless access technologies include the low-tier PCS systems as described in Cox [8]. Digital cellular systems which are becoming known in the U.S. as high-tier PCS, especially when implemented in the 1.8-1.9 GHz PCS frequency bands, are addressed in the Digital Cellular section below. The PCS market has been projected to capture a significant share of the huge potential revenues to be generated by business and residential customers. In order to provide more flexible, widespread, tetherless portable communications than can be provided by today's limited portable communications approaches, low-power exchange access radio needs to be integrated with network intelligence provided by the wireline network.

Today, the network for supporting PCS is narrowband ISDN, along with network intelligence based on advanced intelligent network (AIN) concepts, and a signalling system for mobility/location management and call control based on the signalling system 7 (SS7) network architecture. It is expected that the core network will evolve to BISDN/ATM over time with the capability to potentially integrate a wide range of network services, both wired and wireless, onto a single network platform. Furthermore, there will be no need for an overlay network for PCS. In anticipation of these developments, the WATM WG included the development of specifications and requirements for PCS access to, and interworking with, the ATM transit network in its charter and work plan. To date, several contributions have been presented at WATM WG meetings that have identified some of the key technical issues relating to PCS-to-ATM interworking. These include (1) architectures, (2) mobility and location management signalling, (3) network evolution strategies, and (4) PCS service scenarios.

Wireless LAN

Today, wireless LAN (WLAN) is a mature technology. WLAN products are frequently used as LAN extensions to access areas of buildings with wiring difficulties and for cross-building interconnect and nomadic access. Coverage ranges from tens to a few hundreds of meters, with data rates ranging from hundreds of kb/s to more than 10 Mb/s. Several products provide 1 or 2 Mb/s. ATM LAN products provide LAN emulation services over the connection-oriented (CO) ATM network using various architectural alternatives [24]. In this case, the ATM network provides services that permit reuse of existing LAN applications by stations attached directly to an ATM switch, and allow interworking with legacy LANs. Furthermore, the increasing importance of mobility in data access networks and the availability of more usable spectrum are expected to speed up the evolution and adoption of mobile access to WLANs. Hence, it is of interest to develop wireless LAN products that have LAN emulation capabilities similar to wireline ATM LANs.

The ETSI BRAN project is developing the HIPERLAN RAL technology for wireless ATM access and interconnection. It will provide short-range wireless access to ATM networks at approximately 25 Mb/s in the 5 GHz frequency band. HIPERLAN is an ATM-based wireless LAN technology that will have end-to-end ATM capabilities. It does not require the development of an IWF to provide access to ATM. A previous version of HIPERLAN (called HIPERLAN I), which has been standardized, supports data rates from 1–23 Mb/s in the 5 GHz band using a non-ATM RAL [27]. This (and other non-ATM HIPERLAN standards being developed) could benefit from interworking with the backbone ATM as a means of extending the marketability of these products in the public domain such as areas of mass transit and commuter terminals.

Several proposals have been submitted to IEEE 802.11 to provide higher speed extensions of current IEEE 802.11 systems operating in the 2.4 GHz region and the development of specifications for new systems operating in the 5 GHz frequency band. The proposed 2.4 GHz extensions support different modulation schemes, but are interoperable with the current IEEE 802.11 low rate PHY and are fully compliant with the IEEE 802.11 defined MAC. The 5 GHz proposals are not interoperable with the current 2.4 GHz IEEE 802.11 systems. One of the final three 5 GHz proposals being considered is based on orthogonal frequency division multiplexing (OFDM), or multicarrier modulation. The other two are single carrier proposals using offset QPSK (OQPSK)/offset QAM (OQAM), and differential pulse position modulation (DPPM). The OFDM proposal has been selected. With 16-QAM modulation on each subcarrier and rate-3/4 convolutional coding, the OFDM system has a peak data rate capability of 30 Mb/s.

It is clear that a whole range of WLAN systems either exist today, or are emerging, that are not based on ATM technology, and therefore cannot provide seamless access to the ATM infrastructure network. The development of IWF specifications that allow these WLANs to provide such access through standard network interfaces will extend the range of applications and service features provided by WLANs. In Pahlavan [17], a number of architectural alternatives to interconnect WLAN and WATM to the ATM and/or LAN backbone are discussed, along with service scenarios and market and product issues.

Digital Cellular

Digital cellular mobile radio systems include the 1.8–1.9 GHz (high-tier PCS) and the 800–900 MHz systems that provide high-mobility, wide-area coverage over macrocells. Cellular radio systems at 800–900 MHz have evolved to digital in the form of Global System for Mobile Communications (GSM) in Europe, Personal Digital Cellular (PDC) in Japan, and IS-54 Time Division Multiple Access (TDMA) and IS-95 Code Division Multiple Access (CDMA) in the U.S. The capabilities in place today for roaming between cellular networks provide for even wider coverage. Cellular networks have become widespread, with coverage extending beyond some national boundaries. These systems integrate wireless access with large-scale mobile networks having sophisticated intelligence to manage mobility of users.

Cellular networks (e.g., GSM) and ATM networks are evolving somewhat independently. The development of IWFs that allow digital cellular systems to utilize ATM transport will help to bridge the gap. Cellular networks have sophisticated mechanisms for authentication and handoff, and support for rerouting through the home network. In order to facilitate the migration of cellular systems to ATM transport, one of the first issues that should be addressed is that of finding ways to enhance the basic mobility functions already performed by them for implementation in WATM. Contributions presented at WATM WG meetings have identified some basic mobility functions of cellular mobile networks (and cordless terminal mobility) which might be adopted and enhanced for WATM interworking. These basic mobility functions include rerouting scenarios (including path extension), location update, call control, and authentication.

Satellite

Satellite systems are among the primary means of establishing connectivity to untethered nodes for long-haul radio links. This class of applications has been recognized as an essential component of the National Information Infrastructure (NII) [16]. Several compelling reasons have been presented in the ATM Forum's WATM WG for developing standard network interfaces for **satellite ATM (SATATM)** networks. These include (1) ubiquitous wide area coverage, (2) topology flexibility, (3) inherent point-to-multipoint and broadcast capability, and (4) heavy reliance by the military on this mode of communications. Although the geostationary satellite link represents only a fraction of satellite systems today, WATM WG contributions that have addressed this interworking option have focused primarily on geostationary satellites. Some of these contributions have also proposed the development of WATM specifications for SATATM systems having end-to-end ATM capabilities.

Interoperability problems between satellite systems and ATM networks could manifest themselves in at least four ways.

1. Satellite links operate at much higher bit error rates (BERs) with variable error rates and bursty errors.
2. The approximately 540 ms round trip delay for geosynchronous satellite communications can potentially have adverse impacts on ATM traffic and congestion control procedures.
3. Satellite communications bandwidth is a limited resource, and might be incompatible with less bandwidth efficient ATM protocols.
4. The high availability rates (at required BERs) for delivery of ATM (e.g., 99.95%) is costly, hence the need to compromise between performance relating to availability levels and cost.

A number of experiments have been performed to gain insights into these challenges [21]. The results can be used to guide the development of WATM specifications for the satellite interworking scenario. Among the work items that have been proposed for SATATM access using geostationary satellites links are (1) identification of requirements for RAL and mobile ATM functions; (2) study of the impact of satellite delay on traffic management and congestion control procedures; (3) development of requirements and specifications for bandwidth efficient operation of ATM speech over satellite links; (4) investigation of various WATM access scenarios; and (5) investigation of frequency spectrum availability issues.

One interesting SATATM application scenario has been proposed to provide ATM services to multiuser airborne platforms via satellite links for military and commercial applications. In this scenario, a satellite constellation is assumed to provide contiguous overlapping coverage regions along the flight path of the airborne platforms. A set of interworked ground stations form the mobile enhanced ATM network that provides connectivity between airborne platforms and the fixed terrestrial ATM network via bent-pipe satellite links. Key WATM requirements for this scenario have been proposed, which envisage among other things modifications to existing PNNI signalling and routing mechanisms to allow for mobility of (ATM) switches.

In related work, the Telecommunications Industry Association (TIA) TR34.1 WG has also proposed to develop technical specifications for SATATM networks. Three ATM network architectures are proposed for bent-pipe satellites and three others for satellites with onboard ATM switches [23]. Among the technical issues that are likely to be addressed by TR34.1 are protocol reference models and architecture specifications, RAL specifications for SATATM, and support for routing, rerouting, and handoff of active connections. A liaison has been established between the ATM Forum and TR34.1, which is likely to lead to the WATM WG working closely with TR34.1 to develop certain aspects of the TR34.1 SATATM specifications.

Ad Hoc Networks

The term ad hoc network is used to characterize wireless networks that do not have dedicated terminals to perform traditional BS and/or wireless resource control functions. Instead, any mobile terminal (or a subset of mobile terminals) can be configured to perform these functions at any time. Ad hoc networking topologies have been investigated by wireless LAN designers, and are part of the HIPERLAN and IEEE 802.11 wireless LAN specifications [13]. As far as its application to WATM is concerned, low-cost, plug-and-play, and flexibility of system architecture are essential requirements. Potential application service categories include rapidly deployable networks for government use (e.g., military tactical networks, rescue missions in times of natural disasters, law enforcement operations, etc.), ad hoc business conferencing devoid of any dedicated coordinating device, and ad hoc residential network for transfer of information between compatible home appliances.

There are some unique interworking features inherent in ad hoc networks. For example, there is a need for location management functions not only to identify the location of terminals but also to identify the current mode of operation of such terminals. Hence, the WATM WG is considering proposals to develop separate requirements for ad hoc networks independent of the underlying wireless access technology. It is likely that requirements will be developed for an ad hoc RAL, mobility management signalling functions, and location management functions for supporting interworking of ad hoc networks that provide access to ATM infrastructure networks.

The range of potential wireless access service features and wireless interworking scenarios presented in the five wireless access technologies discussed above is quite large. For example, unlicensed satellite systems could provide 32 kb/s voice, and perhaps up to 10 Mb/s for wireless data services. The main problem centers around the feasibility of developing specifications for IWFs to accommodate the range of applications and service features associated with the wireless access options shown in Fig. 34.3. The WATM WG might consider forming sub-working groups which would work in parallel to develop the network interface specifications for each (or a subset of each) of the above non-ATM wireless access options.

34.4 The PCS-to-ATM Interworking Scenario

This section presents a more detailed view of potential near-term and longer-term architectures and reference models for PCS-to-ATM interworking. A signalling link evolution strategy to support mobility is also described. Mobility and location management signalling starts with the current CCS network, which is based on the SS7 protocol and 56 kb/s signalling links, and eventually migrates to ATM signalling. The system level architectures, and the mobility and location management signalling issues addressed in this section serve to illustrate the range of technical issues that need to be addressed for the other WATM interworking options.

34.4.1 Architecture and Reference Model

The near-term approach for the PCS-to-ATM interworking scenario is shown in Fig. 34.4. The near-term approach targets existing PCS providers with network infrastructures in place, who wish to continue to use them while upgrading specific network elements (e.g., MSCs) to provide ATM transport for user data. The existing MSCs in the PCS network are upgraded to include fixed ATM interfaces. ATM is used for transport and switching of user data, while mobility/location management and call control signalling is carried by the SS7 network. No mobility support is required in the ATM network. Synchronization problems might develop because different traffic types relating to the same call may traverse the narrowband SS7 network and the broadband ATM network and arrive at the destination in an uncoordinated manner. Upgrading the SS7 network to broadband SS7 (e.g., T1 speeds or higher) should partially alleviate this potential problem.

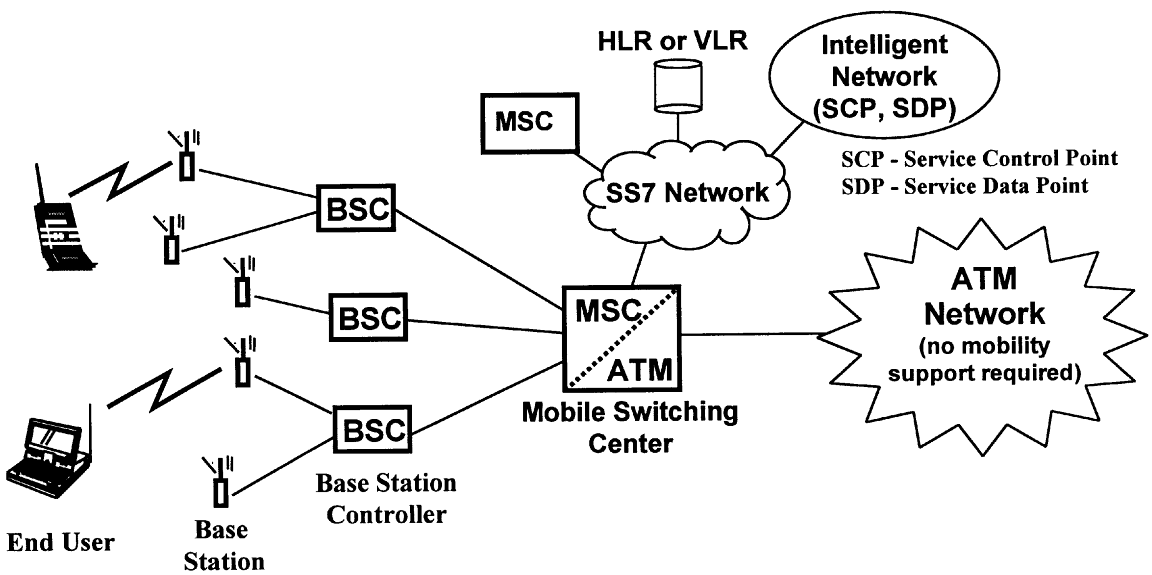


FIGURE 34.4: A near-term architecture for PCS-to-ATM interworking.

A longer-term approach for PCS-to-ATM interworking has been proposed in some technical contributions to the WATM WG. This is illustrated in Fig. 34.5, together with the protocol stacks for both data and signalling. The ATM UNI is placed at the BSC, which acts as the PCS-to-ATM gateway. The ATM network carries both data and signalling. ATM cells are not transmitted over the PCS link. Communications between the BS and BSC are specific to the PCS access network, and could be a proprietary interface. Compared with existing/emerging BSCs, additional protocol layer functionality is required in the BSC to provide (1) transfer/translation and/or encapsulation of PCS **protocol data units (PDUs),** (2) ATM to wireless PDU conversion, and (3) a limited amount of ATM multiplexing/demultiplexing capabilities.

The BSC is connected to the ATM network through a ME-ATM access switch instead of a MSC. The ME-ATM switch provides switching and signalling protocol functions to support ATM connections together with mobility and location management. These functions could be implemented in servers that are physically separate from, but logically connected to, the ME-ATM switch. The WATM WG is expected to formulate requirements and specifications for these mobile-specific functions. On the other hand, an IWF can be introduced between the BSC and the ME-ATM switch shown in Fig. 34.5. In this case, the UNI is between the IWF and the ME-ATM switch, and another standard interface (not necessarily ATM) can be used to connect the BSC to the IWF. The BSC then requires no modification, but a new entity (i.e., the IWF) is required. The IWF will perform protocol conversion and it may serve multiple BSCs.

A unique feature of this architecture is that modifications to network entities to allow for interworking of PCS with the transit ATM network are only required at the edges of the ATM and wireless access networks, i.e., to the BSC and the ME-ATM access switch. In order to minimize the technical impact of mobility on existing/emerging transit ATM networks and PCS specifications, an initial interworking scenario is envisaged in which there are no (or only very limited) interactions between PCS and ATM signalling entities. PCS signalling would be maintained over the air interface, traditional ATM signalling would be carried in the control plane (C-Plane), and PCS signalling would be carried over the ATM network as user traffic in the user plane (U-Plane). In the long term, this architecture is expected to eventually evolve to an end-to-end ATM capability.

On the ATM network side, mobility and location management signalling is implemented in the user plane as the **mobile application part (MAP)** layer above the ATM adaptation layer (AAL), e.g., AAL5. The MAP can be based on the MAP defined in the existing PCS standards (e.g., IS41-MAP or GSM-MAP), or based on a new set of mobile ATM protocols. The U-plane is logically divided into two parts, one for handling mobility and location management signalling messages and the other for handling traditional user data. This obviates the need to make modifications to the ATM UNI and NNI signalling protocols, currently being standardized. The MAP layer also provides the necessary end-to-end reliability management for the signalling because it is implemented in the U-Plane, where reliable communication is not provided in the lower layers of the ATM protocol stack as is done in the signalling AAL (SAAL) layer. The MAP functionality can be distributed at individual BSCs or ME-ATM access switches or centralized in a separate server to further reduce modifications to existing implementations. The setup and release of ATM connections are still handled by the existing ATM signalling layer. This approach allows easy evolution to future wireless ATM architectures, which will eventually integrate the ATM and PCS network segments to form a homogeneous network to carry both mobility/location management and traditional ATM signalling in the C-Plane. Issues relating to mobility support for PCS interworking with ATM networks are addressed in more detail in Cheng [7].

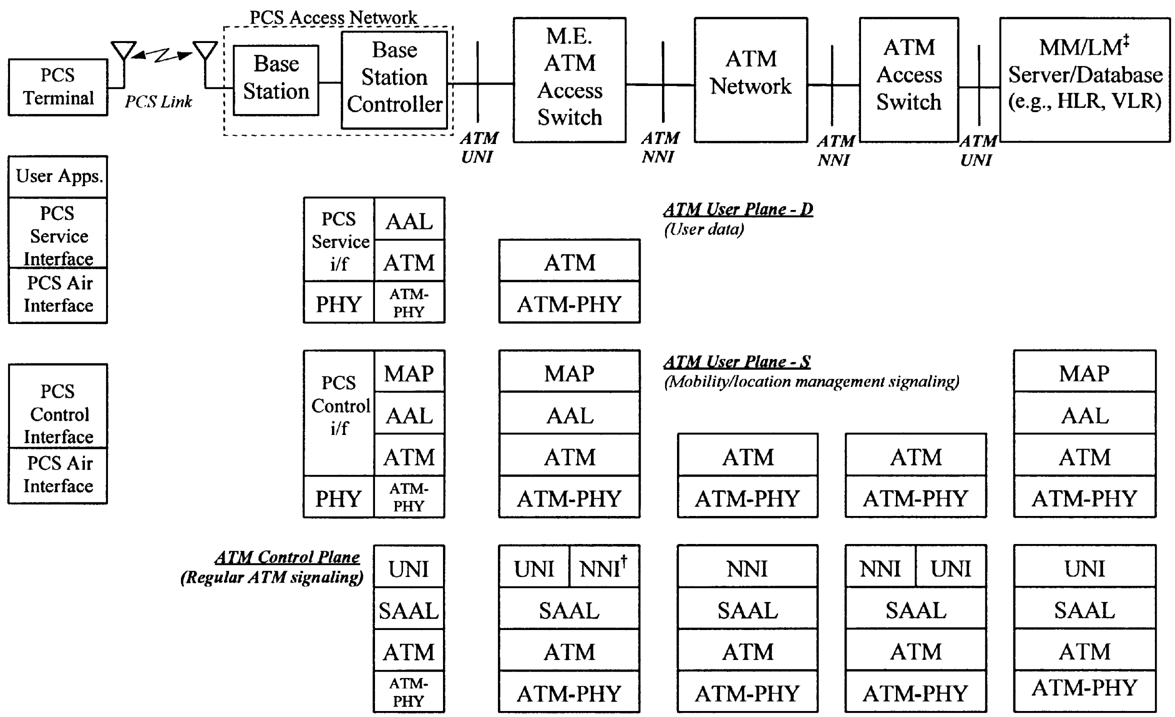


FIGURE 34.5: A longer-term architecture and reference model PCS-to-ATM interworking.

† NNI here is used in a generic sense, to refer to both public and private networks. In public networks, there will be an additional MTP3 layer between the NNI and SAAL layers.

‡ MM—Mobility Management, LM—Location Management.

34.4.2 Signalling Link Evolution

Signalling will play a crucial role in supporting end-to-end connections (without location restrictions) in an integrated WATM network infrastructure. The signalling and control message exchanges required to support mobility will occur more frequently than in wireline ATM networks. Today's CCS network, which is largely based on the SS7 protocol and 56 kb/s signalling links, will not be able to support the long-term stringent service and reliability requirements of WATM. Two broad deployment alternatives have been proposed for migrating the CCS/SS7 network (for wireline services) to using the broadband signalling platform [22].

- Migration to high-speed signalling links using the narrowband signalling platform supported by current digital transmission (e.g., DS1) facilities. The intent of this approach is to support migration to high-speed signalling links using the existing CCS infrastructure with modified signalling network elements. This would allow the introduction of high-speed (e.g., 1.5 Mb/s) links with possible minimal changes in the CCS network. One option calls for modifications of existing MTP2 procedures while maintaining the current protocol layer structure. Another option replaces MTP2 with some functionality of the ATM/SAAL link layer, while continuing to use the same transport infrastructure as DS1 and transport messages over the signalling links in variable length signal units delimited by flags.
- Alternative 2 supports migration of signalling links to a broadband/ATM signalling network architecture. Signalling links use both ATM cells and the ATM SAAL link layer, with signalling message transported over synchronous optical network (SONET) or existing DS1/DS3 facilities at rates of 1.5 Mb/s or higher. This alternative is intended primarily to upgrade the current CCS network elements to support an ATM-based interface, but could also allow for the inclusion of signalling transfer point (STP) functions in the ATM network elements to allow for internetworking between ATM and existing CCS networks.

The second alternative provides a good vehicle for the long-term goal of providing high-speed signalling links on a broadband signalling platform supported by the ATM technology. One signalling network configuration and protocol option is the extended Q.93B signalling protocol over ATM in associated mode [22]. The PSTN's CCS networks are currently quasi-associated signalling networks. Q.93B is primarily intended for point-to-point bearer control in user-to-network access, but can also be extended for (link-to-link) switch-to-switch and some network-to-network applications. Standards activities to define high-speed signalling link characteristics in the SS7 protocol have been largely finalized. Standards to support SS7 over ATM are at various stages of completion. These activities provide a good basis for further evolving the SS7 protocol to provide the mobility and location management features that will be required to support PCS (and other wireless systems) access to the ATM network.

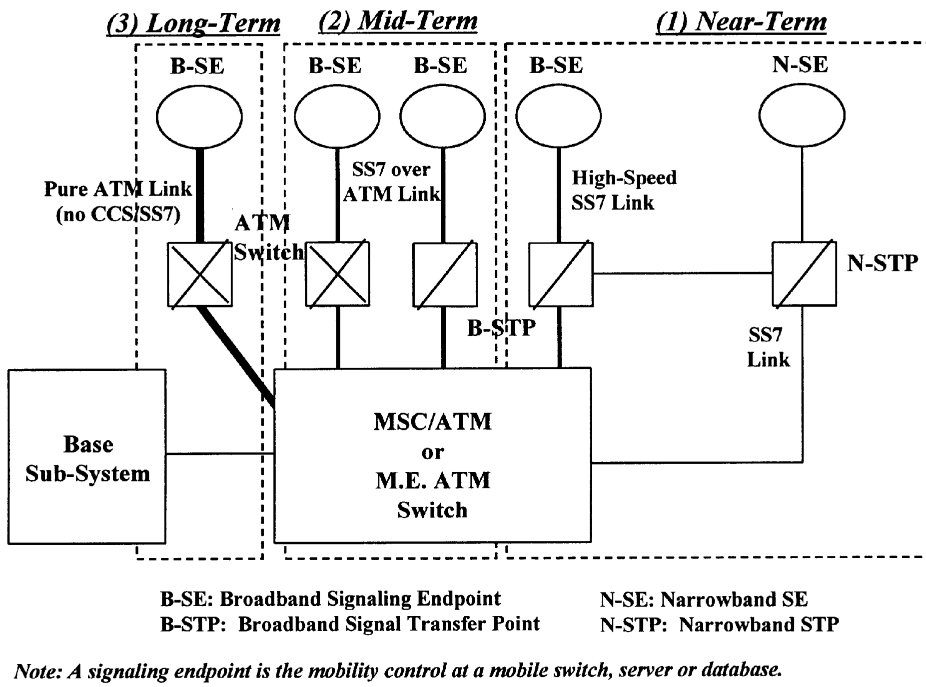
The functionality required to support mobility in cellular networks is currently defined as part of the MAP. Both IS-41 and GSM MAPs are being evolved to support PCS services with SS7 as the signalling transport protocol [14]. Quite similar to the two alternatives described above, three architectural alternatives have been proposed for evolving today's IS-41 MAP on SS7 to a future modified (or new) IS-41 on ATM signalling transport platform [28]. They are illustrated in Fig. 34.6. In the first (or near-term) approach, user data is carried over the ATM network, while signalling is carried over existing SS7 links. The existing SS7 network can also be upgraded to broadband SS7 network (e.g., using T1 links) to alleviate some of the capacity and delay constraints in the narrowband SS7 network. This signalling approach can support the near-term PCS-to-ATM interworking described in the previous subsection. In the second (or midterm) approach, a hybrid-mode operation is envisaged, with the introduction of broadband SS7 network elements into the ATM network. This results in an SS7-over-ATM signalling transport platform. Taking advantage of the ATM's switching and routing capabilities, the MTP3 layer could also be modified to utilize these capabilities and eliminate the B-STP functionality from the network. In the third phase (or long-term approach), ATM replaces the SS7 network with a unified network for both signalling and user data. No SS7 functionality exists in this approach. Here, routing of signalling messages is completely determined by the ATM layer, and the MAP may be implemented in a format other than the transaction capability application part (TCAP), so that the unique features of ATM are best utilized. The longer-term PCS-to-ATM interworking approach is best supported for this signalling approach. The performance of several signalling protocols for PCS mobility support for this long-term architecture is presented in Cheng [6, 7]. The above discussion mainly focuses on public networks. In private networks, there are no existing standard signalling networks. Therefore, the third approach can be deployed immediately in private networks.

There are several ways to achieve the third signalling approach in ATM networks. The first approach is to overlay another "network layer" protocol (e.g., IP) over the ATM network, but this requires the management of an extra network. The second approach is to enhance the current ATM network-network interface (e.g., B-ICI for public networks and PNNI for private networks) to handle the new mobility/location management signalling messages and information elements, but this requires modifications in the existing ATM network. The third approach is to use dedicated channels (PVCs or SVCs) between the mobility control signalling points. This does not require any modifications in existing ATM specifications. However, signalling latency may be high in the case of SVCs, and a full mesh of PVCs between all mobility control signalling points is difficult to manage. The fourth approach is to use the generic functional protocols (e.g., connection oriented-bearer independent (CO-BI) or connectionless-BI (CL-BI) transport mechanism) defined in ITU-T's Q.2931.2 [12]. This cannot be done in existing ATM networks without modifications, but these functions are being included in the next version of PNNI (PNNI 2.0) to provide a generic support for supplementary services. There are also technical contributions to the ATM Forum proposing "connectionless ATM" [26], which attempt to route ATM cells in a connectionless manner by using the routing information obtained through the PNNI protocol. However, the "connectionless ATM" concept is still being debated.

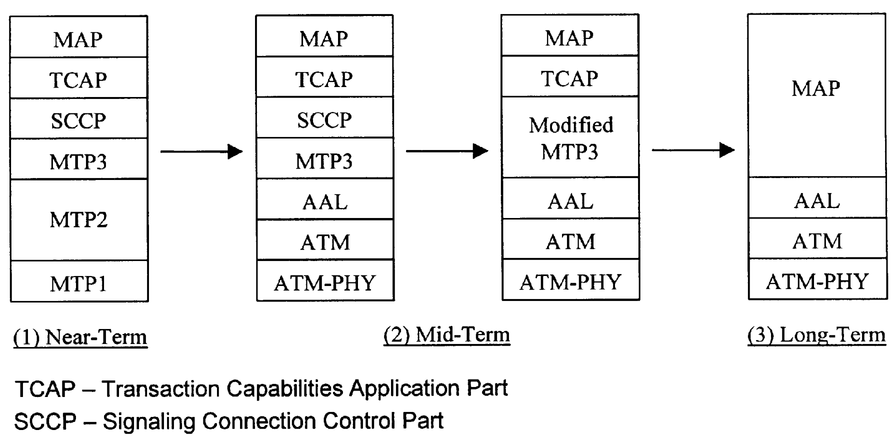
34.5 QoS Support

One immediate impact of adding mobility to an otherwise fixed ATM infrastructure network is the need to manage the changing QoS levels that are inherent in a mobile environment due to the vagaries of the wireless link, the need for rerouting of traffic due to handoff, and available bandwidth, etc. Dynamic QoS negotiation and flow control will be required to flexibly support QoS guarantees for multimedia service applications that are likely to be encountered in this environment. QoS provisioning is based on the notion that the wireless channel is likely to demand more stringent measures than the fixed ATM network to support end-to-end QoS. QoS metrics include (1) throughput, (2) delay sensitivity, (3) loss sensitivity, and, (4) BER performance. Issues relating to end-to-end QoS provisioning in multimedia wireless networks are discussed in Naghshineh [15] and articles therein. Here, the focus is on BER maintenance in the context of PCS-to-ATM interworking using forward error correction (FEC) at the radio PHY layer. This is the first step towards developing a hybrid automatic repeat request (ARQ)/FEC protocol for error control of the wireless link, with FEC at the PHY supplemented by ARQ at the DLC layer. A comparison of commonly used FEC and ARQ techniques and their potential application to WATM is presented in Ayanoglu [3].

One adaptive FEC coding scheme that has been proposed for PCS-to-ATM interworking is



(a) Architecture



(b) Protocol stack

FIGURE 34.6: Signalling link evolution for mobility/location management over a public ATM network.

based on the use of **rate-compatible punctured convolution (RCPC),** punctured Bose-Chaudhuri-Hocquenghem (BCH) or Reed-Solomon (RS) coding at the wireless PHY layer to provide unequal error protection of the wireless PDU [5]. These coding schemes can support a broad range of QoS levels consistent with the requirements of multimedia services, minimize the loss of information on the wireless access segment, and prevent misrouting of cells on the fixed ATM network. Code rate puncturing is a procedure used to periodically discard a set of predetermined coded bits from the sequence generated by an encoder for the purposes of constructing a higher rate code. With the rate-compatibility restriction, higher rate codes are embedded in the lower rate codes, allowing for continuous code rate variation within a data frame.

An example set of three wireless PDU formats that might be appropriate for a PCS system that provides access to the ATM network is shown in Table 34.1. It is desirable to establish a tight relationship between the wireless PDU and wireline ATM cell to minimize incompatibilities between them. This will reduce the complexity of the IWF at the PCS-to-ATM gateway by limiting the amount of processing required for protocol conversion. The wireless PDU can be tightly coupled to the wireline ATM cell in two ways.

1. Encapsulate the equivalent of a full 48-byte ATM information payload, along with wireless-specific overhead (and a full/compressed ATM header, if required by the mobile terminal), in the wireless PDU (e.g., PDU-3).
2. Transmit a submultiple of 48-byte ATM information payload, along with wireless-specific overhead (and a compressed ATM header, if required by the mobile terminal), in the wireless PDU (e.g., PDU-1 and PDU-2).

If the second option is used, then the network has to decide whether to send partially filled ATM cells over the ATM infrastructure network, or wait until enough wireless PDUs arrive to fill an ATM cell.

TABLE 34.1 Examples of Wireless Protocol Data Unit (PDU) Formats

PDU type	PDU header (bits)	Information payload (bits)	PDU trailer (bits)	PDU size (bits)
PDU-1	24	128	—	152
PDU-2	40	256	8	304
PDU-3	56	384	16	456

Note: Information payloads are limited to submultiples of a 48-byte ATM cell information payload.

The performance of RCPC and punctured BCH (and RS) codes have been evaluated in terms of the decoded bit BER [5] on a Rayleigh fading channel. For RCPC coding, the Viterbi upper bound on the decoded BER is given by:

$$P_b \leq \frac{1}{P} \sum_{d=d_f}^{\infty} \beta_d P_d \tag{34.1}$$

where P is the puncturing period, β_d is the weight coefficient of paths having distance d, P_d is the probability of selecting the wrong path, and d_f is the free distance of the RCPC code. Closed-form expressions for P_d are presented in Hagenauer [9] for a flat Rayleigh fading channel, along with tables for determining β_d. Since the code weight structure of BCH codes is known only for a small subset of these codes, an upper BER performance bound is derived in the literature independent of the structure. Assume that for a t-error correcting BCH(n,k) code, a pattern of i channel errors ($i > t$) will cause the decoded word to differ from the correct word in $i + t$ bit positions. For flat Rayleigh fading channel conditions and differential quadrature phase-shift keying (DQPSK) modulation, the decoded BER for the BCH(n,k) code is [18]:

$$P_b = \frac{2}{3} \sum_{i=t+1}^{n} \frac{i+t}{n} (1 - P_s)^{n-1} P_s^i \tag{34.2}$$

where P_s is the raw symbol error rate (SER) on the channel. An upper bound on the decoded BER for a t-error correcting RS(n,k) code with DQPSK signalling on a flat Rayleigh fading channel is similar in form to (34.2). However, P_s should be replaced with the RS-coded digit error rate P_e, and the unit of measure for the data changed from symbols do digits. A transmission system that uses the RS code [from GF(2^m)][2] with M-ary signalling generates $r = m/\log_2 M$ symbols per m-bit digit. For statistically independent symbol errors, $P_e = 1 - (1 - P_s)^r$. For the binary BCH(n,k) code, $n = 2^m - 1$.

Table 34.2 shows performance results for RCPC and punctured BCH codes that are used to provide adaptive FEC on the PHY layer of a simulated TDMA-based PCS system that accesses the fixed ATM network. The FEC codes provide different levels of error protection for the header, information payload, and trailer of the wireless PDU. This is particularly useful when the wireless PDU header contains information required to route cells in the fixed ATM network, for example. Using a higher level of protection for the wireless PDU header increases the likelihood that the PDU will reach its destination, and not be misrouted in the ATM network.

TABLE 34.2 Average Code Rates for RCPC Coding[a] and Punctured BCH Coding[b] for a 2-GHz TDMA-Based PCS System with Access to an ATM Infrastructure Network

Coding scheme	Average code rate (10^{-3} BER for information payload)			Average code rate (10^{-6} BER for information payload)		
	PDU-1	PDU-2	PDU-3	PDU-1	PDU-2	PDU-3
RCPC: no diversity	0.76	0.77	0.78	0.61	0.62	0.63
RCPC: 2-branch diversity	0.91	0.93	0.93	0.83	0.84	0.85
Punctured BCH: no diversity	0.42	0.44	0.51	0.34	0.39	0.46
Punctured BCH: 2-branch Diversity	0.83	0.81	0.87	0.75	0.76	0.82

[a] with soft decision decoding and no channel state information at the receiver.

[b] with and without 2-branch frequency diversity.

The numerical results show achievable average code rates for the three example PDU formats in Table 34.1. The PCS system operates in a microcellular environment at 2 GHz, with a transmission

[2] GF(2^m) denotes the Galois Field of real numbers from which the RS code is constructed. Multiplication and addition of elements in this field are based on modulo-2 arithmetic, and each RS code word consists of m bits.

bit rate of 384 kb/s, using DQPSK modulation. The channel is modeled as a time-correlated Rayleigh fading channel. The PCS transmission model assumes perfect symbol and frame synchronization, as well as perfect frequency tracking. Computed code rates are shown with and without the use of diversity combining. All overhead blocks in the wireless PDUs are assumed to require a target BER of 10^{-9}. On the other hand, the information payload has target BERs of 10^{-3} and 10^{-6}, which might be typical for voice and data, respectively. Associated with this target BERs is a design goal of 20 dB for the SNR. The mother code rate for the RCPC code is $R = 1/3$, the puncturing period $P = 8$, and the memory length $M = 6$. For BCH coding, the parameter $m \geq 8$.

The numerical results in Table 34.2 show the utility of using code rate puncturing to improve the QoS performance of the wireless access segment. The results for punctured RS coding are quite similar to those for punctured BCH coding. Adaptive PHY layer FEC coding can be further enhanced by implementing an ARQ scheme at the DLC sublayer, which is combined with FEC to form a hybrid ARQ/FEC protocol [9] to supplement FEC at the PHY layer. This approach allows adaptive FEC to be distributed between the wireless PHY and DLC layers.

34.6 Conclusions

The ATM Forum is developing specifications intended to facilitate the use of ATM technology for a broad range of wireless network access and interworking scenarios, both public and private. These specifications are intended to cover requirements for seamless extension of ATM to mobile devices and mobility control in ATM infrastructure networks to allow interworking of non-ATM wireless terminals with the fixed ATM network. A mobility-enhanced ATM network that is developed from specifications for WATM interworking may be used in near-term cellular/PCS/satellite/wireless LAN deployments, while providing a smooth migration path to the longer-term end-to-end WATM application scenario. It is likely to be cost-competitive with other approaches that adopt non-ATM overlay transport network topologies.

This chapter describes various WATM interworking scenarios where the ATM infrastructure might be a public (or private) transit ATM network, designed primarily to support broadband wireline services. A detailed description of a generic PCS-to-ATM architectural interworking scenario is presented, along with an evolution strategy to eventually provide end-to-end WATM capabilities in the long term. One approach is described for providing QoS support using code rate puncturing at the wireless PHY layer, along with numerical results. The network architectures, protocol reference models, signalling protocols, and QoS management strategies described for PCS-to-ATM interworking can be applied, in varying degrees, to the other WATM interworking scenarios described in this chapter.

Defining Terms

Broadband integrated services digital network (BISDN): A cell-relay-based information transfer technology upon which the next-generation telecommunications infrastructure is to be based.

BISDN intercarrier interface (B-ICI): A carrier-to-carrier public interface that supports multiplexing of different services such as SMDS, frame relay, circuit emulation, and cell relay services.

High-Performance Radio LAN (HIPERLAN): Family of standards being developed by the European Telecommunications Standards Institute (ETSI) for high-speed wireless LANs, to provide short-range and remote wireless access to ATM networks and for wireless ATM interconnection.

Interworking functions (IWFs): A set of network functional entities that provide interaction between dissimilar subnetworks, end systems, or parts thereof, to support end-to-end communications.

Location management: A set of registration and call delivery functions.

Mobile application part (MAP): Application layer protocols and processes that are defined to support mobility services such as intersystem roaming and handoffs.

Mobility-enabled ATM (ME-ATM): An ATM switch with additional capabilities and features to support location and mobility management.

Mobility management: The handoff process associated with switching (rerouting) of the communication link from the old coverage area to the new coverage area when a wireless user moves during active communication.

Personal communications services (PCS): Emerging digital wireless systems which support mobility in microcellular and other environments, which have a set of capabilities that allow some combination of terminal mobility, personal mobility, and service profile management.

Protocol data units (PDUs): The physical layer message structure used to carry information across the communications link.

Private network–network interface (PNNI): The interface between two private networks.

User network interface (UNI): A standardized interface providing basic call control functions for subscriber access to the telecommunications network.

Radio access layer (RAL): A reference to the physical, medium access control, and data link control layers of the radio link.

Rate-compatible punctured convolution (RCPC): Periodic discarding of predetermined coded bits from the sequence generated by a convolutional encoder for the purposes of constructing a higher rate code. The rate-compatibility restriction insures that the higher rate codes are embedded in the lower rate codes, allowing for continuous code rate variation to change from low to high error protection within a data frame.

Satellite ATM (SATATM): A satellite network that provides ATM network access to fixed or mobile terminals, high-speed links to interconnect fixed or mobile ATM networks, or form an ATM network in the sky to provide user access and network interconnection services.

Wireless asynchronous transfer mode (WATM): An emerging wireless networking technology that extends ATM over the wireless access segment, and/or uses the ATM infrastructure as a transport network for a broad range of wireless network access scenarios, both public and private.

References

[1] ATM. B-ICI Specification, V 2.0. ATM Forum, 1995.

[2] ATM. Private Network-Network Interface (PNNI) Specification, Version 1.0. ATM Forum, 1996.

[3] Ayanoglu, E., et al., Wireless ATM: Limits, challenges, and protocols. *IEEE Personal Commun.*, 3(4), 18–34, Aug. 1996.

[4] Barton, M., Architecture for wireless ATM networks. *PIMRC'95.* 778–782, Sep. 1995.
[5] Barton, M., Unequal error protection for wireless ATM applications. *GLOBECOM'96*, 1911–1915, Nov. 1996.
[6] Cheng, M., Performance comparison of mobile assisted network controlled, and mobile-controlled hand-off signalling for TDMA PCS with an ATM backbone. *ICC'97.* Jun. 1977a.
[7] Cheng, M., Rajagopalan, S., Chang, L.F., Pollini, G.P., and Barton, M., PCS mobility support over fixed ATM networks. *IEEE Commun. Mag.*, 35(11), 82–92, Nov. 1997b.
[8] Cox, D.C., Wireless personal communications: what is it?. *IEEE Personal Commun. Mag.*, 2(2), 20–35, Apr. 1995.
[9] Hagenauer, J., Rate-compatible punctured convolution codes (RCPC codes) and their applications. *IEEE Trans. Commun.*, COM-36(4), 389–400, Apr. 1988.
[10] ITU. Message Transfer Part Level 3 Functions and Messages Using the Service of ITU-T Recommendations, Q.2140. International Telecommunications Union-Telecommunications Standardization Sector, Geneva, Switzerland. TD PL/11–97. 1995a.
[11] ITU. B-ISDN Adaptation Layer—Service Specific Coordination Function for Signaling at the Network Node Interface (SCCF) at NNI. ITU-T Q.2140. International Telecommunications Union, Telecommunications Standardization Sector, Geneva, Switzerland. 1995b.
[12] ITU. Digital Subscriber Signaling System No. 2—Generic Functional Protocol: Core Functions. ITU-T Recommendation Q.2931.2. International Telecommunications Union, Telecommunications Standardization Sector, Geneva, Switzerland. 1996.
[13] LaMaire, R.O., Krishna, A., Bhagwat, P., and Panian, J., Wireless LANs and mobile networking: standards and future directions. *IEEE Commun. Mag.*, 34(8), 86–94, Aug. 1996.
[14] Lin, Y.B. and Devries, S.K., PCS network signalling using SS7. *IEEE Commun. Mag.*, 2(3), 44–55, Jun. 1995.
[15] Naghshineh, M. and Willebeek-LeMair, M., End-to-end QoS provisioning in multimedia wireless/mobile networks using an adaptive framework. *IEEE Commun. Mag.*, 72–81, Nov. 1997.
[16] NSTC. *Strategic Planning Document—Information and Communications*, National Science and Technology Council. 10, Mar. 1995.
[17] Pahlavan, K., Zahedi, A., and Krishnamurthy, P., Wideband local wireless: wireless LAN and wireless ATM. *IEEE Commun. Mag.*, 34–40, Nov. 1997.
[18] Proakis, J.G., *Digital Communications.* McGraw-Hill, New York. 1989.
[19] Raychaudhuri, D. and Wilson, N.D., ATM-based transport architecture for multiservices wireless personal communication networks. *IEEE J. Select. Areas Commun.*, 12(8), 1401–1414, Oct. 1994.
[20] Raychaudhuri, D., Wireless ATM networks: architecture, system design, and prototyping. *IEEE Personal Commun.*, 3(4), 42–49, Aug. 1996.
[21] Schmidt, W.R., et al., Optimization of ATM and legacy LAN for high speed satellite communications. Transport Protocols for High-Speed Broadband Networks Workshop. *GLOBECOM'96.* Nov. 1996.
[22] SR. Alternatives for Signaling Link Evolution. Bellcore Special Report. *Bellcore SR-NWT-002897.* (1), Feb. 1994.
[23] TIA. TIA/EIA Telecommunications Systems Bulletin (TSB)—91. Satellite ATM Networks: Architectures and Guidelines. Telecommunications Industry Association. TIA/EIA/TSB-91. Apr. 1998.
[24] Truong, H.L. et al., LAN emulation on an ATM network. *IEEE Commun. Mag.*, 70–85, May 1995.
[25] Umehira, M. et al., An ATM wireless system for tetherless multimedia services. *ICUPC'95.* Nov. 1995.

[26] Veeraraghavan, M., Pancha, P., and Eng, K.Y., Connectionless Transport in ATM Networks. ATM Forum Contribution. ATMF/97-0141, 9–14, Feb. 1997.
[27] Wilkinson, T. et al., A report on HIPERLAN standardization. *Intl. J. Wireless Inform. Networks.* 2(2), 99–120, 1995.
[28] Wu, T.H. and Chang, L.F., Architecture for PCS mobility management on ATM transport networks. *ICUPC'95.* 763–768, Nov. 1995.

Further Information

Information supplementing the wireless ATM standards work may be found in the ATM Forum documents relating to the Wireless ATM Working Group's activities (web page `http://www.atmforum.com`). Special issues on wireless ATM have appeared in the August 1996 issue of *IEEE Personal Communications*, the January 1997 issue of the *IEEE Journal on Selected Areas in Communications*, and the November 1997 issue of *IEEE Communications Magazine*.

Reports on proposals for higher speed wireless LAN extensions in the 2.4 GHz and 5 GHz bands can be found at the IEEE 802.11 web site (`http://grouper.ieee.org/groups/802/11/Reports`). Additional information on HIPERLAN and related activities in ETSI BRAN can be obtained from their web site (`http://www.etsi.fr/bran`).