Wireless Intelligent ATM Network and Protocol Design for Future Personal Communication Systems

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***Abstract*—This paper presents a wireless network infrastructure for future personal communication system, which is referred to the wireless intelligent ATM (WIATM) network, to provide wireless broad-band integrated services. The WIATM network takes advantages of the ATM-cell relay paradigm for integrated services through a radio link with Quality of Service (QoS) guarantee. The design of the WIATM network architecture is an independent wireless network, which is consistent with the inherent cellular/PCS network architecture, as a wireless customer premises equipment/network (CPE/CPN) to access the ATM transport network in the B-ISDN infrastructure. An independent network architecture design separates the wireless access network from the ATM backbone network; this provides flexibility for wireless resource management with low rate source codecs with minimal tolerable QoS considered to increase the spectral efficiency, and mobility support by taking advantage of the functionalities of the IS-41 circuit-switching handoff procedures. The protocol design of the air interface is to meet the QoS requirements of wireless B-ISDN services and to be compatible with that of B-ISDN UNI. A hybrid concatenated error control scheme distributed through the protocol layers is used to target individual QoS requirements of different services. The convolutional coding and interleaving in the wireless physical layer protocol are used to guarantee QoS of voice services. A concatenated coding with additional 36 bit BCH code in the wireless ATM layer, which replaces the VCI/VPI of the ATM header field, improves the QoS up to the requirement of video services. The VCI/VPI field in WIATM is an overlapped routing information routing with the address control by radio port controller, and is thus not needed in the wireless ATM layer protocol. The retransmission scheme for data service only is added in the wireless data link layer, which is on top of wireless AAL, to meet its QoS requirement. Examples of signaling flows for call registration, call setup, and supporting handoff are shown in the design of the wireless network layer protocol. The AIN (advance intelligent network) signaling functionalities are considered for multimedia service control in the access network and interconnection to the ATM network. A parent–child creative basic call state model (BCSM) for wireless integrated services is introduced in both call origination and termination.**

***Index Terms*—AIN, ATM, BCSM, B-ISDN, CDMA, cellular, error control, handoff, mobility support, multimedia, network architecture, PCS, protocol, signaling control, SS7, TDMA, wireless.**

I. Introduction

RECENT studies of "wireless ATM" have focused on the communication aspects with ATM as the backbone transport network. Wireless ATM is considered as a wireless access network to interconnect the mobile users to the ATM network. Problems in wireless ATM concentrate on the effects of the packet mode information transport in the wireless environment, which is characterized by unreliable sharing access with finite resource and mobility. Several wireless network architectures [1]–[7] have been proposed to interconnect inherent cellular/PCS systems or wireless LAN's to the ATM network. The flexibility of the radio interface design is considered to be compatible with existing cellular/PCS systems, and to provide for future multimedia services such as data, video, or integrated services. Other proposed wireless ATM network architectures [8]–[10] focus on the wireless extension of the B-ISDN terminals for seamless ATM connection. The air interface design of [8]–[10] applies ATM cell transport through radio link for broad-band integrated services. Modified or enhanced functionalities of the B-ISDN UNI (user–network interface), such as ATM and AAL layer protocols, are suggested to improve the wireless connectivity, which includes error control to improve the error performance and mobility support. Analytical studies in error control for wireless multimedia services include [2]–[4], [8], and [11]–[13]. The channel coding in the wireless physical layer, such as forward error correcting (FEC), convolutional coding, interleaving, concatenated coding, multicarrier modulation and diversity reception, and ARQ retransmission in the link layer, are considered to meet the target BER of individual service requirement. Mobility support in wireless ATM is discussed in [14]–[21]. Focuses of mobility support include handoff protocol design, rerouting for handoff, and location management. Reference [22] discusses the current available technology of PCS and ATM for the mobile multimedia scenario. Additional functions required in the ATM layer of the B-ISDN protocol to support mobility in the design of extending ATM terminals to wireless environments are discussed in [16].

Also, there are several works investigating the AIN-capable signaling control in wireless ATM. Focuses of the AIN signaling control in wireless ATM are the design of the platforms of the service control and to support mobility [1], [9], [23]–[26] and resource management [26]. The separation of functions and physical equipment in the AIN service control provides sophisticated and efficient network control for multimedia services in the design of the wireless ATM network. There are a number of other references on wireless ATM as well.

Our objective is to design a wireless network to provide wireless B–ISDN services for future personal communication systems. The design of the WIATM network combines three reference models of inherent networks; they are the cellu-

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lar/PCS network (wireless), AIN (intelligent), and the ATM network (ATM)—hence the terminology WIATM. The evolution from ISDN to B-ISDN emphasizes issues of high-speed network design for broad-band integrated traffic with highly diverse service rates. The ATM network features high-speed information transport and high efficiency of the switching capacity for the transport of broad-band integrated traffic by combining the advantages of traditional circuit-switching and packet-switching networks. The limitation of resources, the unreliable radio channel, and the mobility of users characterize wireless communication. Thus, the requirement of QoS is redefined with more tolerance toward errors in cellular/PCS. Communication techniques, such as modulation, channel coding, diversity reception, and sophisticated antennas, are implemented to battle the received signal degradation through the unreliable radio link and to increase the system capacity. The enhanced signaling protocol in UNI is designed to support the mobility in cellular/PCS. The developing AIN is considered for signaling control to enhance the capability of user–network access for wireless multimedia services. In particular, the AIN signaling control is highly feasible for the target personal communication system which demands a sophisticated network signaling control mechanism for user–network interaction and mobility. Further, AIN-capable signaling control is included in the ITU standard B-ISDN signaling protocol. In general, emphasis is placed on taking advantage of well-developed standards where appropriate.

The system design of the WIATM network starts by laying out the overall picture of the wireless network architecture. The interworking between wireless ATM and the ATM backbone network is discussed next for end-to-end information flow. In particular, the mobility support in wireless ATM strongly connects to the wireless network architecture and the interworking functionalities. Henceforth, a clear picture of the role of WIATM in the B-ISDN infrastructure is displayed. The design of the air interface targets improvement of the radio connectivity, which includes the error performance and mobility support. A digital signaling protocol in the air interface and AIN-type signaling control are considered for multimedia personal communication systems. The role of wireless ATM and its general issues are presented in Section II. The architecture of the WIATM network and internetworking are shown in Section III. The air interface design for user information transport and guarantee QoS is presented in Section IV. The signaling control protocol to support mobility is shown in Section V, and concluding remarks are given in Section IV.

II. Why Wireless ATM?

A. The Role of Wireless ATM

Wireless ATM is considered as the wireless subdomain of the B-ISDN infrastructure shown in Fig. 1. The subdomain is in the sense of extending the user–access network, which is in terms of the customer premise equipment (CPE) of the ATM network, to the wireless environment.

From Fig. 1, the ATM network is the backbone translation for ATM network end-to-end virtual circuit setup. The CPE is considered as a subscriber loop, which has routing capability inside the loop and provides the mobile user with access to the ATM network. The CPE's include the telephone network, wide-area network (WAN), local-area network (LAN), private ATM network or B-ISDN terminals, and the wireless network. The network termination (NT) is a transport network endpoint, which contains the interworking functions to interconnect the CPE's and the ATM network. The interworking functions contain the signaling capability to perform routing in the ATM network and user–network access inside the CPE. The well-known ATM Forum is organized to standardize the physical equipment and the connection specifications, such as the protocol design routing algorithm (e.g., P-NNI) and mobility support, inside the domain of the CPE. Wireless ATM has the role of a wireless access network, as wireless CPE of the ATM network.

B. Wireless Transport Mechanism for B-ISDN Services

"Wireless ATM" originates by applying the ATM-type transport mechanism through the radio link for B-ISDN services. Advantages of the ATM-cell relay paradigm are the flexibility of the resource management of the bursty mixed traffic, and the QoS control and guarantee of each traffic. The mixed traffic is output of the B-ISDN services, which are characterized by integrating the highly diverse rate-bearer services, such as low-rate voice and data services, and high-rate data, image, and video services. Also, the B-ISDN services demand variable measure of the performance parameters, such as delay tolerance, delay jitter, and bit-error rate. Hence, wireless ATM exploits the ATM-cell transport mechanism on the radio design for the B-ISDN services through the radio link.

There are several alternatives for the radio design for B-ISDN services. For simplicity, the B-ISDN bearer services are categorized into high- and low-rate services. Fig. 2 shows three alternatives for the radio design for B-ISDN services. The mapping and set partitioning and the signal block diagram for three alternatives are shown in columns (A) and (B) of Fig. 2, respectively. The set partition presents resource sharing (radio with MAC) or logic separation (bearer services). Mapping is to integrate diverse bearer services to a radio.

The three alternatives in Fig. 2 are the following.

a) *Traditional circuit switching*—The radio contains two separate sets of access control, each of which responds for a fixed rate-bearer service. The two-set access control could be two different frequency carriers (ODFM), two different frequency bands (FDMA), two time slots (TDMA), or two spreading codes (CDMA).
b) *Segment circuit switching*—The radio contains a low-rate radio channel subset as a unit. The number of units is different to distinguish between low-rate and high-rate services. The small unit could be subband (FDMA), small time slot (TDMA), multiple codes (CDMA), or hybrid.
c) *ATM*—The high-rate and low-rate services are categorized into five classes of services, with each class

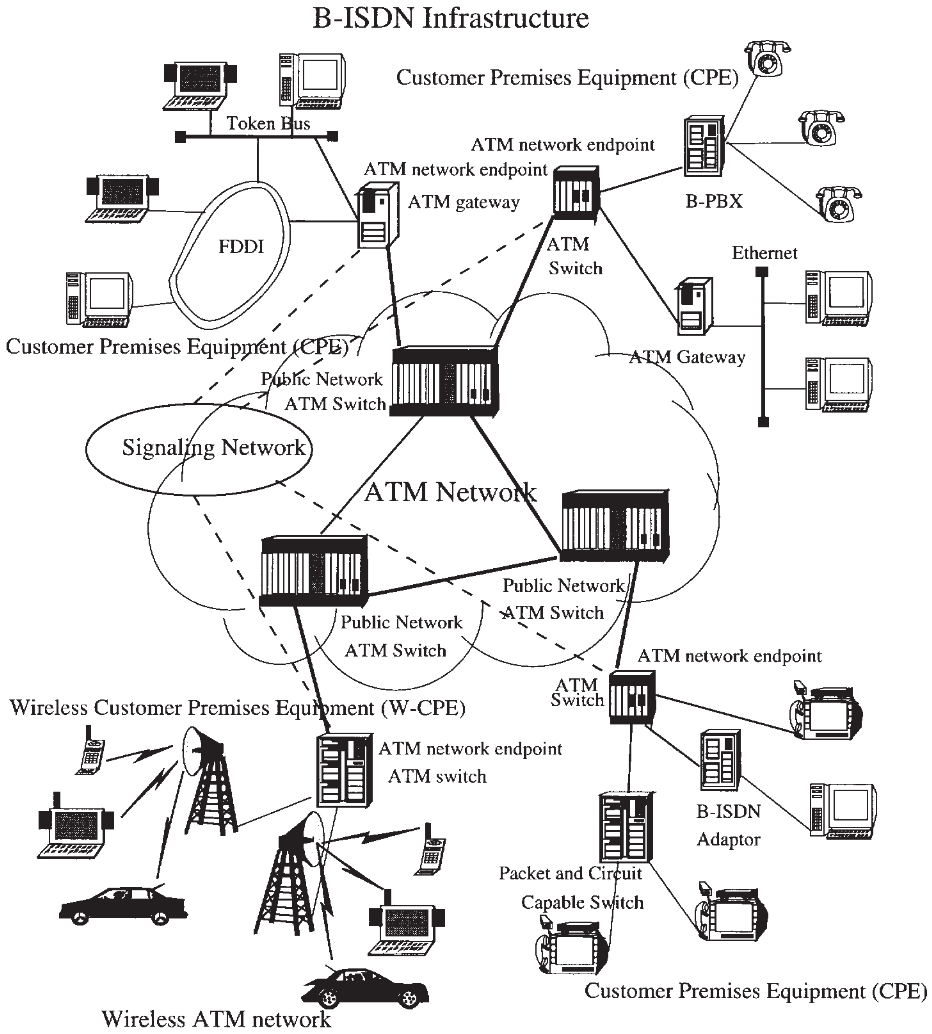

Fig. 1. B-ISDN infrastructure.

Each class of services with variable rate is segmented into fixed size cells. The radio integrates all cells.

The radio resource in (a) has to be divided into two parts for high-rate and low-rate access control. Hence, the resource utilization in (a) is low and inefficient. In (b), the radio resource is managed based on the demanding numbers of units. The physical equipment in (b) requires multiple numbers of parallel receivers or series time slots. The spectral efficiency in (b) decreases as the source gets highly bursty. Also, the admission control is inflexible in (b). For the ATM-cell relay paradigm in (c), the high-speed radio spatially multiplexes all cells from each class of service. The bursty characteristic of the multimedia source reflexes on the transport mechanism, and is best for the performance control. The radio resource utilization is high and efficient in (c).

C. Issues in Wireless ATM

Two factors affect the cost of the network infrastructure; they are the location of the ATM network termination point (NT), which supports full capability of SS7 for number translation to set up ATM end-to-end virtual connections, and the the wireless side to support SS7's capabilities to interpret the global network topology and to set up the end-to-end connection. The functional distribution between the mobile switches and base stations of the air interface design is also cost effective.

The next issue is how to increase the wireless system capacity, which is in terms of optimizing spectral efficiency for integrated narrow-band/broad-band traffic. Specifying lower rate-bearer services with minimal tolerable QoS, such as low-rate voice codec or low-resolution video, for a wireless network with given available bandwidth can increase the number of users in the system. The effect of the overhead redundancy, which is the ratio of the information field and the total packet length, is also another issue in resource management. All of the traffic parameters, such as QoS parameters, ATM traffic descriptor, and AAL parameters, are subject to change based on the new specified lower rate-bearer services, necessitating the modification of the protocols of the ATM layer, AAL, and network layer because these protocols contain the traffic parameter elements which are mandatory.

Most notable in wireless ATM is how to improve error performance through the unreliable radio link and guarantee

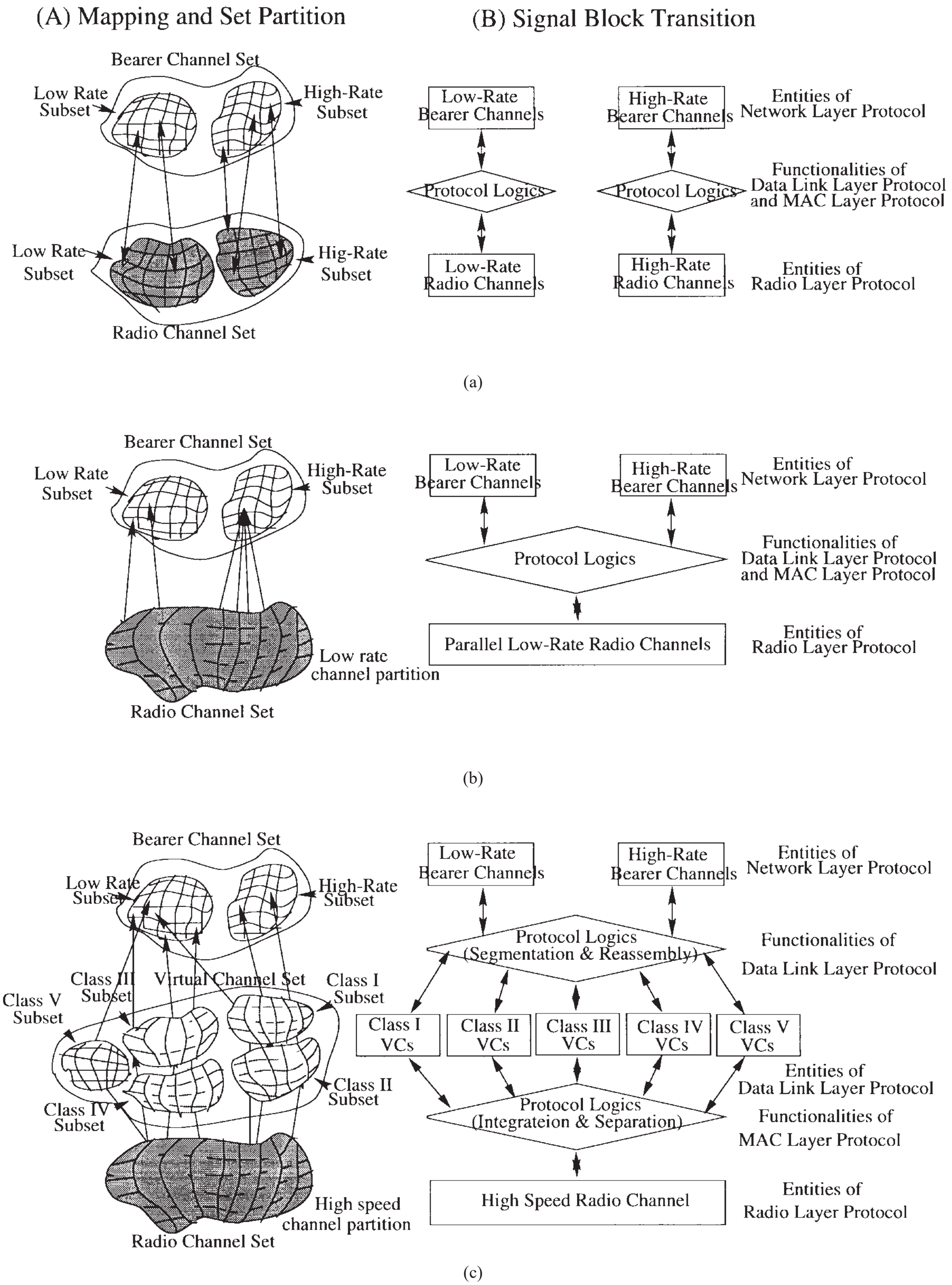

Fig. 2. Radio design for B-ISDN services. (a) Direct transformation for both high-rate and low-rate bearer channels to radio channels. (b) Direct transformation for high-rate and low-rate bearer channels to parallel low-rate radio channels. (c) Two-step transformation for high-rate and low-rate bearer channels to high-speed radio channels.

mechanism and the selection of modulation, coding, receivers, diversity, and MAC protocol provide different solutions for service performance control. The error control schemes, by introducing redundancy, which increases the service bandwidth

The signaling control and how to support mobility in wireless ATM are other issues. For signaling control, the enhancement of the ITU Q.2931 protocol is required. The specifications of the bearer capability and traffic parameters connection type to support mobility has a significant impact on the system design, especially for ATM-type cell transport. The call forwarding scheme or new connection during the interswitch handoff are two alternatives, and are based on the design of a wireless network architecture.

III. The Wireless ATM Network Architecture

The wireless network architecture contains the network structure design, the distribution of functionalities, the air interface design and its protocol stack, and the design of the interworking functions to interconnect to the ATM transport network. The distribution of the functional blocks in the wireless network is based on the network control strategy to determine the capabilities for user-to-network and network-to-network access. The air interface design delivers the requirement of the reliable radio connectivities for information transport and signaling control based on the characteristics of the wireless environment. The interworking functions convert the information elements in the wireless network to standard formats of the ATM network. In addition, it also connects the wireless signaling control elements to the signaling network for settlement of the end-to-end connection.

A. Issues in Wireless Network Architecture Design and Mobility Support

The design strategy of the WIATM network architecture is stretched out from Fig. 1. In Fig. 1, wireless ATM is a wireless access network (W-CPE) to interconnect to the ATM backbone network. Since the wireless communication has its own specific characteristics, the WIATM network is designed to have an independent network architecture, which is same as the inherent cellular/PCS network and is also shown in [1] and [3]. An independent network architecture design separates the wireless access network from the transport network. The separation between the access network and the transport network enables flexible system design, best for mobile communication. The advantages of an independent network architecture include a lower rate voice source codec being used to optimize the bandwidth utilization, flexible system design to improve the performance through unreliable radio link, and call admission control to guarantee the QoS of each user. In addition, the QoS specification in a cellular/PCS system is set at the minimal tolerable quality to further increase the system capacity. In particular, the flexibility of the independent network architecture design enables customized peer-to-peer protocols running and routing the algorithm inside the wireless network, such as a TCP/IP protocol for the wireless ATM LAN. Also shown in Fig. 1, the wireless CPE design requires minimal signaling capability for routing and mobility support inside the wireless subscribers loop (W-CPE), including connection setup during handoff and interconnection to the ATM network. This implies that no modification is required for the B-ISDN NNI protocols to support mobility in the wireless ATM network. The drawback of the independent architecture is that the complexity of the interworking function increases, where the information format is converted and the

We summarize the WIATM network architecture and several previous works [1], [8], [9], [3] in Fig. 3. The proposed network architectures in Fig. 3 are designed based on a cellular-like system environment, which is different from that of a wireless ATM LAN. Reference [1] proposes an ATM access network with packet handler for information transport of the inherent cellular/PCS system. The proposed network architecture in [8] is to extend the ATM terminals with enhancement to wireless environment for future PCN's. An ATM-UNI compatible air interface with additional PCN overhead is designed for the wireless access identification and error control. Reference [9] proposes a subnet structure of a wireless ATM network to integrate wireless access with the ATM network and B-ISDN UNI compatible air interface design. In [3], an independent wireless access network design provides flexibility in frame structure conversion between the CDMA frame and the ATM cell. A flexible radio interface design can support an IS-95 CDMA terminal and the ATM-type terminals, with variable rate up to 256 kbit/s. Two hybrid ARQ error control schemes also mentioned in [3] to improve the QoS of the nonreal-time services. The thick solid lines in Fig. 3 show the connections at the worst scenario during the interswitch handoff stage in each proposed architecture. New end-to-end connections are required in the architectures of [8] and [9]. A preestablished VCI/VPI connection for fast handoff is proposed in [1]. An independent network architecture design in WIATM enables us to apply the call forwarding strategy in IS-41 [27] for the interswitch handoff. The call forwarding is based on maintaining the connection from the ATM network at an anchor switch and setting up a tandem connection to the new switch inside the wireless network during the interswitch handoff. The call forwarding mechanism for interswitch handoff in wireless ATM reduces the cell loss caused by additional delay from user mobility and call control complexity, such as storage of control state parameters which include handoff state and billing information.

B. Error Control in WIATM

The BER and the delay tolerance are two important indexes of the QoS in wireless communication. The QoS parameters, which consist of cell loss ratio, cell loss priority, mean delay, and variance of delay, are specified during the ATM connection establishment for a given level of QoS guarantee. However, the unreliable radio channel and limited available bandwidth in wireless communication restrict the QoS to the minimal achievable level in order to optimize the spectral efficiency. This implies that the current QoS parameters, which are defined based on a reliable high-speed channel, are infeasible for wireless ATM alone. Also, the limited bandwidth in wireless communication results in defining low rate-bearer services. The ATM traffic descriptor, which includes the mean and peak cell ratio, and the AAL parameters are subject to change with low rate-bearer services. The independent network architecture design in WIATM acknowledges the demand to define a separated set of QoS and traffic parameters for wireless ATM. References [8] and [11] list tables of applications, traffic parameters, and QoS parameters for wireless multimedia

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