Chapter 2
Wireless ATM Networks

Chapter 2 describes the wireless ATM protocol stack and four wireless ATM systems that are mainly considered as accesses to an ATM backbone network. Then, the standardization works and the frame structure are illustrated. At last, in order to satisfy various conflicting requirements, two formats of Wireless ATM cell are proposed according to the FEC and HARQ schemes.

2.1 Wireless ATM Protocol Stack

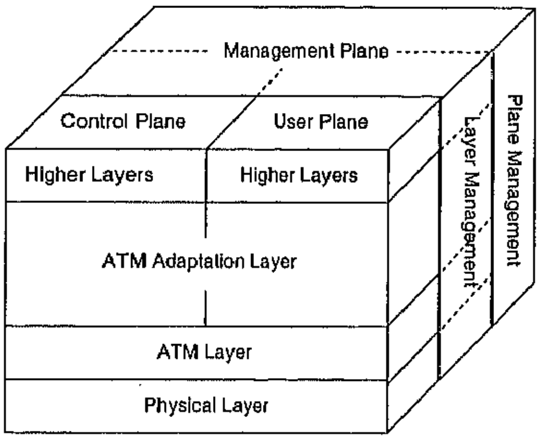

Figure 2.1: The ATM protocol reference model

In present, the ATM technology plays an increasing important role in the broadband networks, because its connection-oriented packet switched transport allows the connection specific guarantee of capacities and delays. ATM networks can provide a variety of services at a wide range of the bit rate by means of a single transport mechanism. Then, the operator of an ATM network has to install, operate and maintain only one common service integrating network instead of the previous multiple service specific networks. The ATM protocol model consists of user, control and management planes, as shown in Figure 2.1. The management plane includes layer

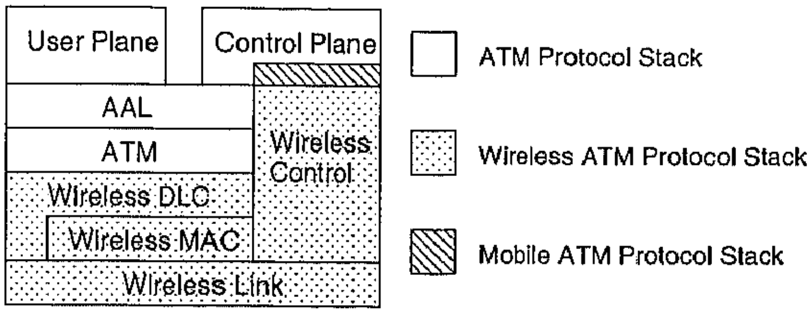

Figure 2.2: **Wireless ATM protocol stack overview**

management and plane management. The former handles the specific operation and maintenance information flows for each layer, and the latter is responsible for providing the coordination between all planes. Both the user plane and the control plane all adopt a layered structure. For the planes, the physical layer and the ATM layer are common. They include all associated mechanisms, such as the flow control and the recovery method from errors. Individual functions are included in each plane of the ATM adaptation layer (AAL) as well as high layers.

Wireless ATM is to achieve the efficient and reliable packet transmission by a wireless method [18]. To ensure transparent communications between the wired and wireless networks, wireless ATM network has a protocol stack fully harmonized with that of the standard ATM. Unreliable behaviors of a wireless link as well as accesses to the shared wireless resources lead to the requirements of additional functions at an ATM air interface, and additional layers must be introduced in the ATM protocol stack. The resulting stack contains a wireless physical layer with wireless modems, a media access control (MAC) layer and a DLC layer below the ATM layer, as shown in Figure 2.2 [19]. In the protocol stack, the standard AAL and ATM layers are used for network level functions. The wireless DLC maintains quality of service (QoS) on a virtual channel (VC) basis. Depending on the types of the provided service, the channel quality, capacity and utilization, the DLC layer may implement a variety of means including FEC, ARQ and the flow pacing to optimize the services provided to the DLC users [20]. The wireless MAC implements an allocation of wireless resources to VCs and terminals, which takes into account many factors such as channel quality, the number of terminal devices and the medium sharing with other wireless subnetworks. The functions of the wireless control protocol include terminal migration, handoff and other wireless resource management related operations. In addition, it is necessary to add mobile ATM protocol to the existent control/signaling protocols in order to provide mobile communication services over an ATM infrastructure.

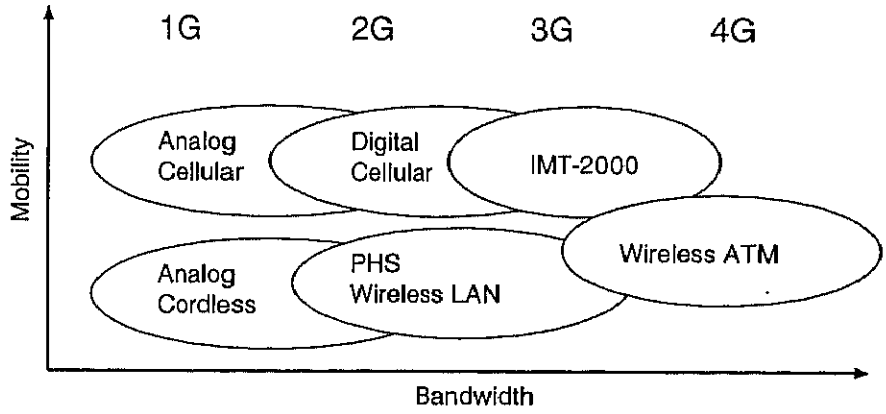

Figure 2.3: Deployment scenario of mobile communication services

2.2 Wireless ATM Systems

There are two patterns in the deployment scenario of mobile communication services as shown in Figure 2.3 [21]. One is the cellular deployment and the other is the cordless or LAN deployment. In the former, IMT-2000 (International Mobile Telecommunications 2000) is the current study target. In the latter, multimedia mobile accesses including wireless ATM are being studied, which can be considered as one part of 4G (Fourth generation mobile communication system).

In order to realize an "all ATM" network in the local and wide area by the wireline and wireless connection, wireless ATM systems are conceivable in a large variety of applications, such as public or private access networks for substitution of cable-based infrastructure (Radio in the Local Loop), indoor or outdoor broadband and multimedia cellular radio systems, wireless ATM-LANs or ad-hoc networks. This large range of applications leads to a variety of wireless ATM systems differing in the types of services and the terminal mobility, according to each specific scenario. Table 2.1 shows the four systems of them. These projects mainly study the basic technologies of wireless ATM networks.

- Magic WAND (Wireless ATM Network Demonstrator) [22][23]: This is a joint European project to develop a demonstration of mobile terminals for the multimedia information accesses using a fast and wireless ATM network. The MAC and DLC layers have been combined in one layer, bearing the name MASCARA (the mobile access scheme based on the contention and the reservation for ATM), which has an ARQ-based cell loss recovery.

- WATM (Wireless ATM) net[24][25]: This system is an ATM network for the

Table 2.1: **Comparison among wireless ATM systems**

Wireless ATM Systems	Magic WAND	WATMnet	BAHAMA	AWA
Researcher	European Union ACTS	U.S. NEC CC Lab	U.S. Bell Lab	Japan NTT
Frequency(GHz)	5.2 (17)	5	5	25
Data rate(Mbps)	20 (50)	25.6	20	80.64
Modulation	OFDM	QPSK	OFDM	DQPSK
MAC and DLC	MASCARA GBN-ARQ	TDMA-TDD ARQ	DQRUMA FEC and ARQ	TDMA-TDD FEC and PRIME-ARQ

personal communication, which incorporates a QoS control method based on time-of-expiry-based scheduling policy.

- BAHAMA (Broadband Adaptive Homing Asynchronous transfer Mode Architecture) [26]: This wireless ATM local area network (LAN) utilizes a new MAC protocol referred to as distributed queuing request update multiple access (DQRUMA). This simple demand-assignment protocol achieves the near optimal delay and throughput performance so as to have broad applications.
- AWA (ATM Wireless Access) [27]–[29]: This system concentrates on the wireless accesses to an ATM network for private LAN or wide area network (WAN) applications as well as the public environments. It is designed for supporting terminal mobility with still or quasi-still usage. The radio frequency transmission rate of AWA can reach 80.64 Mbps.

Obviously, these wireless ATM systems can be called radio ATM systems due to their working at the super high frequency (SHF) band. The design of another kind of wireless LAN—indoor infrared LAN that supports the ATM protocol is also considered to realize the wireless access to the fixed broadband integrated service digital networks (B-ISDN) [30].

2.3 Standardization on Wireless ATM

International Telecommunications Union-Telecommunications standards sector (ITU-T) has proposed many recommendations on ATM, such as "I series." It is also very important to standardize the specifications of broadband wireless access systems based on ATM. The standardization efforts include service concepts, architectures, radio access networks and network controls, which are being made all over the world.

In 1996, ATM Forum approved to establish a new working group "WATM-WG" to develop the specifications to apply ATM to wireless access systems for mobile/nomadic

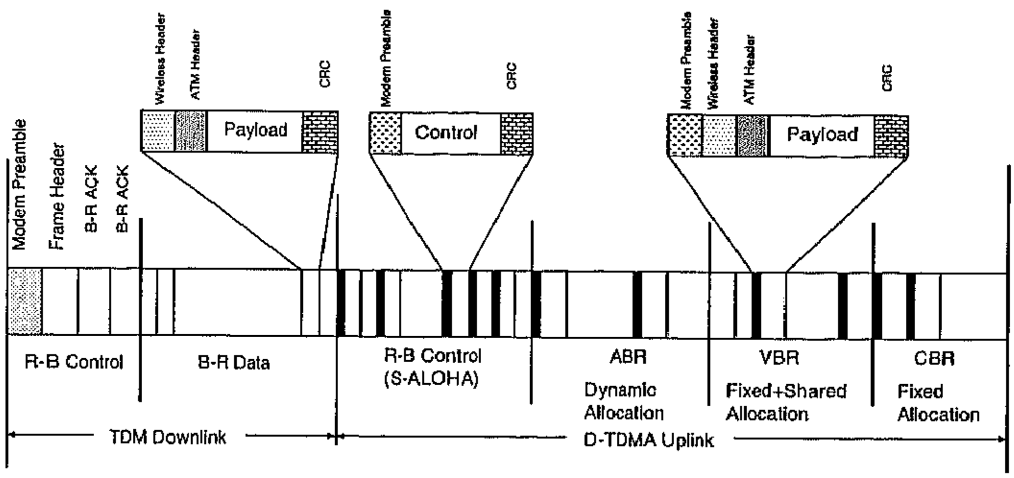

Figure 2.4: **Wireless ATM frame structure**

multimedia services [31]. At the same time, ETSI-BRAN (European Telecommunications Standards Institute-Broadband Radio Access Networks) initiated the standardization work to develop the specifications of HIgh PErformance Radio Local Area Networks (HIPERLAN) type 2, 3 ,4, which is an ATM based radio access system using 5 GHz band in Europe [32].

ATM Forum's WATM-WG has been dealing with two technical areas, i.e., radio ATM and mobile ATM. In order to accelerate the specification development, ATM Forum and ETSI-BRAN established liaison relationship for harmonization. As a result, the ATM Forum's WATM-WG is dealing with mobile ATM specifications, i.e., mobile ATM, and ETSI-BRAN is developing radio access layer specifications, i.e., radio ATM.

In Japan, to study the future mobile communications, the Ministry of Post and Telecommunications (MPT) established a Multimedia Mobile Access Communication system Promotion Council (MMAC-PC) in December 1998 in conjunction with the Association of Radio Industries and Businesses (ARIB). This council proposed two system concepts, i.e., a high speed wireless access system supporting public and private services, and an ultra high speed wireless LAN for corporate networks. More than hundred members are participating in MMAC-PC to develop the technical specifications as a candidate of Japanese standard for the proposed systems. The AWA system is one of the prototype candidates for MMAC.

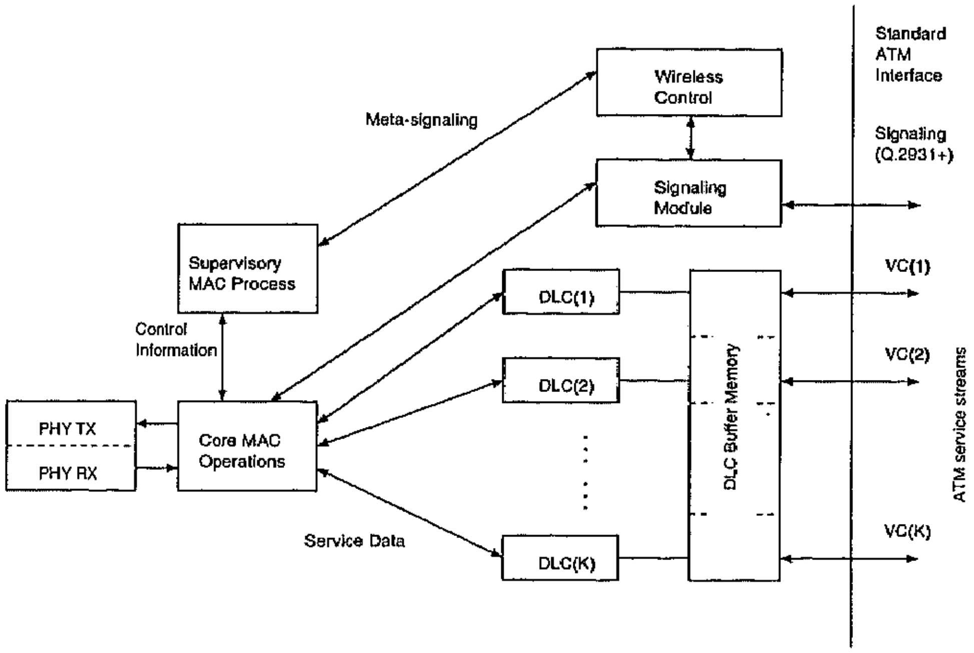

Figure 2.5: **Architecture of MAC and DLC protocol layers**

2.4 Wireless ATM Frame Structure

Currently there is no standard for wireless ATM. The frame structure, shown in Figure 2.4, is based on the NEC's WATM net prototype. Other prototype may have small variation. In order to support the changing traffic needs, the boundaries between the subframes are varied gradually with time. Downlink transmissions are the time divided modulation (TDM) multiplexed in a single burst from a base station to remote stations, while uplink transmissions use the dynamic time divided modulation address (D-TDMA).

Downlink consists of a Base-to-Remote (B-R) control region and a B-R data region. At the former, a modem preamble is provided for frame synchronization and equalization. A frame header is applied to transmit its identifier and information about the positions and sizes of all subframes in the current frame. Then, B-R acknowledgment information and other wireless network control messages are included. The B-R data region contains downlink data cells. Uplink has a Remote-to-Base (R-B) control region and three R-B data regions. R-B control region is used by the remote stations to transmit the control message to the base station in a contention access (Slotted ALOHA) mode. Uplink data and R-B acknowledgment messages are transmitted in the R-B data region. The transmission in this region is either allocated on a frame-by-frame basis (in the case of available bit-rate (ABR)/unspecified

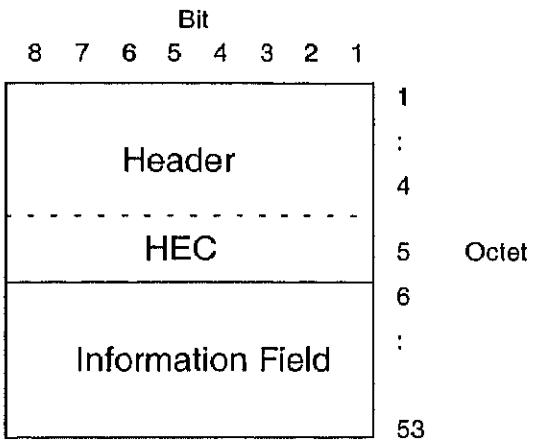

Figure 2.6: **Standard ATM cell of B-ISDN**

bit-rate (UBR) transmissions, constant bit-rate (CBR)/variable bit-rate (VBR) retransmissions and R-B acknowledgments) or isochronously preassigned in the case of the CBR default allocations.

Figure 2.5 shows the architecture of MAC and DLC protocol layers, where each service VC from the ATM interface is associated with a dedicated DLC process. This process in turn communicates with the MAC layer for transmission over wireless link. The MAC functions can be decomposed into a supervisory MAC for high level functions such as slot allocation and QoS control, along with a core MAC for high speed functions such as multiplexing and transmitting/receiving. Besides, the CBR VCs are assigned slots periodically according to their bit-rate, VBR VCs are assigned slots with the aid of a usage-parameter-control-based statistical multiplexing algorithm, and the ABR/UBR VCs are handled on a burst-by-burst basis with the dynamic reservation of their slots at the MAC layer to support retransmitting cells.

2.5 Wireless ATM Cell

ATM cell is the basic element of the ATM layer. A cell consists of a 5 octet header including a 1 octet header error control (HEC), and a 48 octet information field, whose structure is shown in Figure 2.6 [7]. The cell header at a B-ISDN user-network interface (UNI) differs from that at a B-ISDN network node interface (NNI) in the use of bits 5–8 of the first octet.

According to the B-ISDN protocol reference model, the HEC is a physical layer function, which controls 8 redundant bits out of 40 bits in a cell header. The HEC code is a single-bit error correction and multiple-bits error detection cyclic redun-

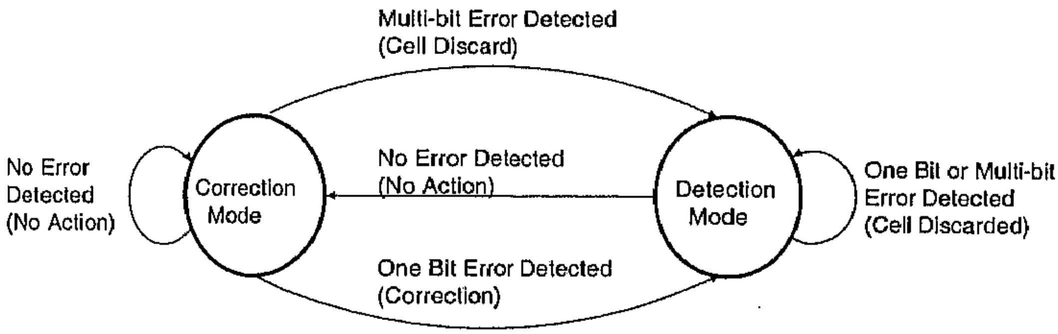

Figure 2.7: **Dual mode operation of the HEC algorithm**

dancy code (CRC), and only employed for the ATM cell header in order to avoid the incorrect forwarding due to header errors. The HEC works in two modes, as shown in Figure 2.7. In the normal (default) mode, a receiving side operates for a single bit error at the "correction mode" state. If a single bit error is detected, then the error is corrected, and the state at the receiver switches to the "detection mode" state. In case that multi-bit error is detected, the cell is discarded and the state also switches to the "detection mode" state. In the "detection mode" state, all cells with the detected header errors are discarded. As soon as a header with no error is examined, the receiver switches back to the "correction mode" state. The transmitter therefore calculates the HEC value using the polynomial generated by the header bits (excluding the HEC field) multiplied by 8 and dividing this polynomial by $x^8 + x^2 + x + 1$. The reminder of this division will be transmitted as the 8 bit HEC field. In addition, the HEC is applied to the cell delineation when cells are directly mapped into a time divided multiplex payload.

But in wireless ATM network, the error correction ability of the above HEC alone is not sufficient. To mitigate the effect of radio channel errors before cells are released to the ATM network layer, wireless ATM needs a custom DLC layer protocol. In general, error detection/retransmission protocols and FEC methods are recommended in it.

From the smaller number of users and the scarcity of bandwidth in wireless networks, the relatively large addressing overhead of ATM being designed for large wireline networks must be avoided. That is to say, the reduced VC identifier (VCI) space should be acceptable for the more limited addressing requirements of a single wireless channel, and can be expanded to the standard ATM form at BS. As illustrated in Figure 2.8, a wireless medium-specific data packet header is added after compressing the essential ATM header information into an abbreviated network layer header.

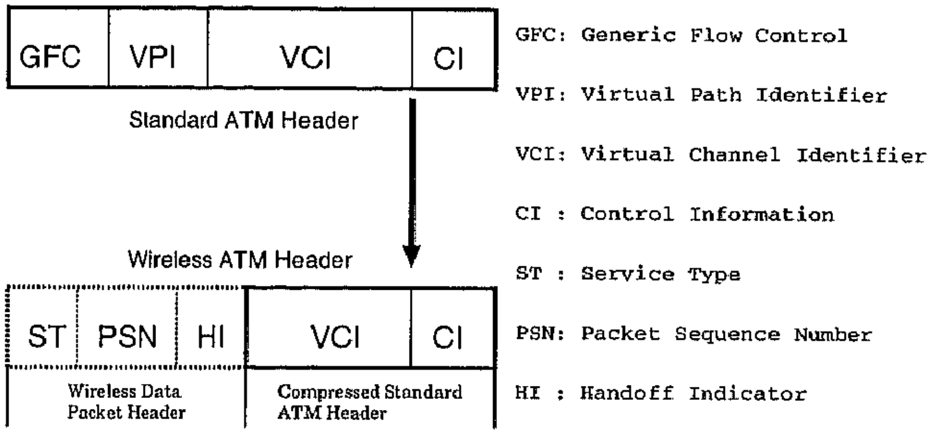

Figure 2.8: Wireless ATM header format

The compressed ATM header is to use only two bytes containing 12-bit VCI and 4-bit control information (CI). CI includes a payload type (PT) and the cell loss priority (CLP). The PT indicates whether the content of the cell is carrying the user information to be delivered transparently through the network or the special network information. The CLP distinguishes different cells in terms of their QoS. As the other part of wireless ATM header, the wireless header incorporates a packet sequence number (PSN), a service type (ST), and a handoff indicator (HI). The PSN is applied for the segmentation and the reassembly of a packet so as to realize retransmission. The ST includes the supervisory/control, CBR, VBR, and ABR/UBR data burst, which can be used to simplify the base station protocol processing and resource allocation, to enable the segregation and the priority of data types without reference to the VC-level call setup information. The HI represents the last and first data link packets before and after handoff.

That is to say, a header tells the ATM layer what to do with a cell. Then, the header bits in a wireless ATM cell are considered more important than the payload bits like an ATM cell.

The general aim of a wireless ATM network is to provide the tetherless extensions of fiber-optic based ATM network capabilities in a relatively transparent, seamless and efficient manner so as to support a reasonable range of service classes, bit-rates and QoS levels associated with ATM. Now, many new services such as e-mail, client-server data, digital audio and some video/multimedia applications may be expected in addition to the conventional telephony. Recent estimates for the bit-rate and QoS of typical applications are given in Table 2.2. Note that almost all of the new services to be transported will have more than one service components, each of which

Table 2.2: **Typical application requirements for next-generation broadband wireless networks**

Applications	QoS	Bit-rate range (Kbps)	Data	Teletex	Audio	Standard video	HD video
Voice telephony	Low–med. cell loss OK Isochronous	2.4–32			X		
Video telephony	Low–med. cell loss OK Low delay	64–384	X		X	X	
Digital audio	Low cell loss required Low delay jitter	128–512	X		X		
Standard TV	Low-med. cell loss OK Low delay	1–6K	X	X	X	X	
Digital HDTV	Low-med. cell loss OK Low delay	15–20 K	X	X	X	X	X
General computer data	Low cell loss required Med. delay OK	0.1–1 K	X				
E-mail	Low cell loss OK High delay OK	9.6–128	X				
High speed data	Very low cell loss required Med. delay OK	1–10 K	X				

Table 2.3: **Specifications of the stream and packet services**

Specifications	Time-sensitive services	Time-insensitive services
Prioritized quality	Transmission delay	Cell loss ratio
Transmission priority	Prioritized	Not prioritized
Retransmission	Not provided	Provided
Services	CBR/VBR	UBR/ABR

transports a specific type of information. For example, simple telephony is composed of a single audio component, whereas the High Definition TV (HDTV) is composed of 5 different service components. In an ATM network all these individual components can be transported over individually separate virtual channels, identified by a different VCI/VPI in the header of the respective ATM cells. However, some restrictions must be taken into account between those different virtual channels, mainly with respect to the prioritized quality.

This thesis classifies the QoS for wireless ATM into two kinds: the time-sensitive (stream mode) and the time-insensitive (packet mode) services as shown in Table 2.3. The time-sensitive services include CBR services with selectable fixed bandwidth and real-time-VBR (rt-VBR) services with the statistically multiplexed bandwidth allocation. The time-insensitive services include ABR and UBR packet data services. For each different service type, the DLC layer in wireless ATM should provide an appropriate error control mechanism to protect against the relatively poor physical level characteristic of a wireless medium. The format of input ATM cells is converted into the different format of wireless ATM cells according to their wireless QoSs.

High Level UEP	R_H	Low Level UEP	R_P
Header: Wireless Data Packet Header / Compressed Standard ATM Header	FEC-H	Payload	FEC-P
4 Bytes	Parity	48 Bytes	Parity

Figure 2.9: **DLC packet format of wireless ATM cell (using FEC schemes)**

For the stream mode services, FEC schemes in the DLC protocols should be applied to correct and filter out the erroneously received ATM cells before they enter the low error rate fixed network. The FEC can also be applied to improve the TDMA synchronization characteristics [33]. Therefore, the DLC must maintain an acceptable isochronous throughput and delay in the cell stream passed to the ATM layer. When one or more bit errors are detected in a header, the cell is discarded. Alternatively, if some buffering delay can be tolerated such as the packet mode services, the HARQ schemes are applied to enhance their CLR and throughput performance. In this case, a cell is retransmitted to compensate the bit errors or discarded when one or more bit errors are detected in either the header or the payload.

The variable rate error control for wireless ATM networks was firstly proposed by [8], which is an UEP scheme having two different block codes for a header and a payload. At the same time, the variable-rate method controlled by media is applied to increase the total utilization efficiency in multimedia systems [34]. Then, two-rate block code scheme is applied to the AWA system [9][35]. In this thesis, the standard ATM header is replaced with the wireless ATM header, which includes a wireless data packet header and a compressed ATM header. In the FEC schemes, the HEC in the standard ATM header is substituted by FEC-H and FEC-P, as outlined in Figure 2.9, where the code (FEC-H) for a header is assigned with a low local coding rate R_H in order to ensure a correct delivery and a low loss rate. At the same time, the code (FEC-P) for a payload is designed to be with a higher rate R_P than the one of FEC-H for the effective transmission. In Chapters 4 and 5, PC-UEP (FEC scheme I) and the PT-UEP (FEC scheme II) are realized using RCPC and RCPT codes, respectively.

However, the FEC scheme causes an unnecessary overhead and thus reduces the throughput under good channel conditions. On the other hand, the received payloads that result in decoding failure are passed on to the user without any changes so as to make their QoS poor when an FEC strategy is used. Since the channel state

Header	Payload	CRC	FEC
4 Bytes	48 Bytes	k Bits	parity

Figure 2.10: DLC packet format of wireless ATM cell (using HARQ schemes)

temporarily varies, it is preferable to correct the frequent error-patterns and the less-frequent error-patterns by the FEC and ARQ technologies, respectively. In this case, this thesis adopts a wireless ATM cell format in Figure 2.10, where the CRC check bits are appended in order to detect the errors in the header and the payload, and the FEC is used to enhance the error correction ability when retransmission happens. This thesis proposes PC-HA (HARQ scheme I) and PT-HA (HARQ scheme II) using RCPC and RCPT codes to reach high throughputs in Chapters 6 and 7. It should be clear at this point that the transmission packet size is variable.

Generally, the payload length of an ATM cell is 48 bytes. However, depending on the achievable channel speed, the type of low-speed applications (e.g., 8 Kbps voice codec, e-mail messaging, etc.), and the relative importance of the high wireless channel efficiency, it may be necessary to compromise on these requirements and use wireless data-link packets with payloads that are the integer submultiples of an ATM cell (e.g., 16 or 24 bytes).