Chapter 6
HARQ Scheme I in the DLC Protocol of Wireless ATM

This chapter applies the hybrid ARQ scheme with RCPC codes to the DLC protocol of wireless ATM networks. This scheme is based on the successive parity transmission so as to achieve the enhanced throughput performance.

6.1 Introduction

In wireless ATM networks, audio, video and data can be transmitted at all. Their requirements for bit error, capacity and delay are different from each other. Time-sensitive services, such as audio and video, can only use FEC schemes. In the FEC scheme I of Chapter 4, there are corresponding FEC-H and FEC-P for one VC, and two schemes with different quality levels are defined: the PC-UEP1 scheme with $R_H = \frac{1}{3}$ CC and the PC-UEP2 scheme with $R_H = \frac{1}{2}$ PCC, where R_P for both schemes is changeable. The CC with coding rate $\frac{1}{3}$ is a parent code. PCCs with the coding rate $\frac{1}{2}$ and any R_P are obtained by puncturing the parent code. In this case, when one or more bit errors are detected in header, the cell is discarded.

In order to guarantee high reliability to any kinds of services, especially to time-insensitive services, such as data, HARQ schemes should be applied to exploit both the predictable performance of FEC codes and the rate flexibility of ARQ protocols. Then, 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.

Figure 6.1 depicts the data transmission using RCPC codes, where a noiseless feedback link is available so that the receiver can reliably inform the transmitter whether the transmitted packets can be successfully decoded. RCPC codes are constructed from a rate $\frac{1}{3}$ convolutional code, and a family of higher rate codes are formulated by puncturing successively greater numbers of code symbols. These codes have practical utilities in that the system requires a single rate $\frac{1}{3}$ convolutional encoder and a Viterbi decoder. The transmitter and the receiver need only share a puncturing table so that the transmitter determines which code symbols to transmit at a given

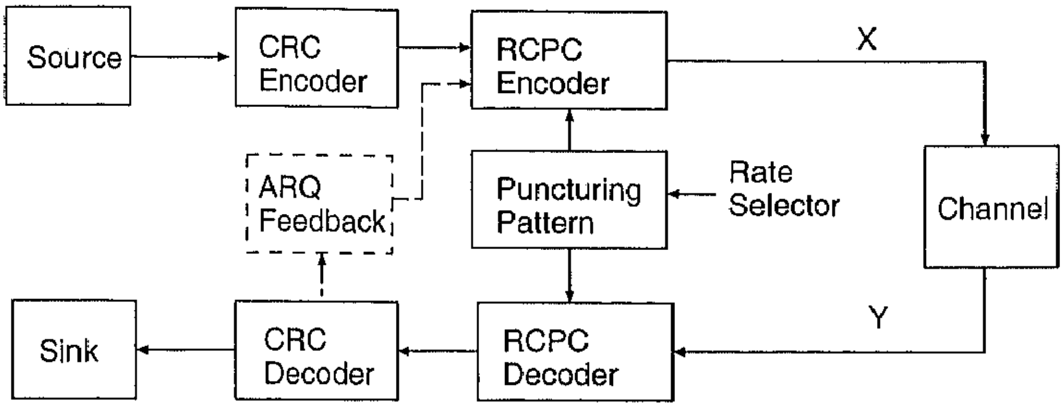

Figure 6.1: **Data transmission using RCPC codes**

time, and the receiver may insert erasures for all code symbols that have not yet been received. The rate compatibility requirement of these codes restricts the puncturing rule so that all of the code symbols of a high rate punctured code are used by the lower rate codes, i.e., the high rate codes are embedded in the lower rate codes. In this manner, the transmitter need only transmit supplemental code symbols to get to the next lower rate code.

6.2 Adaptive HARQ Scheme Using RCPC Codes

In HARQ scheme, a high rate block code CRC is used for error detection with a certain retransmission protocol, such as Stop and Wait (SW), Go-Back-N (GBN), Selective Repeat (SR) and even more complicated ones [51]. In SR-ARQ system, codewords are transmitted continuously and the transmitter only resends those codewords that are negatively acknowledged so as to have higher throughput than other retransmission protocols. Since the primary concerns in this chapter are the performance comparison between HARQ protocols using fixed rate FEC codes and RCPC codes, the evaluation of SR-ARQ would be sufficient to demonstrate the performance differences. Then, an ideal SR-ARQ system is assumed, which has an infinite buffer size and a perfect error detecting code.

There are various kinds of data, e.g., text data, drawing data, numerical data, filed video data or facsimiles, their requirements are not the same either. Therefore, the adaptive HARQ schemes (PC-HA1 and PC-HA2) are applied to the DLC protocol based on the PC-UEP1 and PC-UEP2 schemes, respectively. These schemes are called HARQ scheme I. As shown in Figure 2.10, the FEC utilizes RCPC code, which coding rate R_s is between R_H and R_P, and s=1,2 for the PC-HA1 and PC-HA2

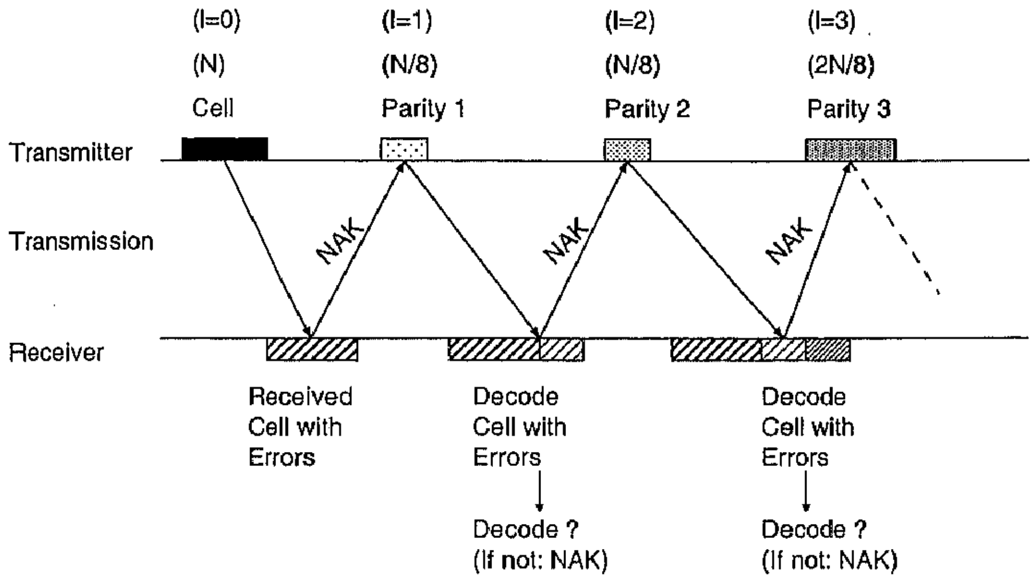

Figure 6.2: Retransmission procedures of a wireless ATM cell

schemes.

- For the PC-HA1 scheme, let the initial coding rate be $\frac{8}{9}$, which is equal to the lowest R_P of FEC scheme I. Then, $R_1 \in \{\frac{8}{9}, \frac{8}{10}, \frac{8}{12}, \frac{8}{14}, \frac{8}{16}, \frac{8}{18}, \frac{8}{20}, \frac{8}{22}, \frac{8}{24}\}$. The additional parity bits per byte one step are selected via the index set {1, 1, 2, 2, 2, 2, 2, 2, 2}. The transmitted parity length (bits per byte) $l_i \in$ {1, 2, 4, 6, 8, 10, 12, 14, 16}. Then, the maximum number of retransmission per circle I=9, and the maximum parity bit number per byte $l_9 = L$=16.

- For the PC-HA2 scheme, the initial coding rate is $\frac{8}{9}$ too. Then, $R_2 \in \{\frac{8}{9}, \frac{8}{10}, \frac{8}{12}, \frac{8}{14}, \frac{8}{16}\}$. The additional parity bits per byte one step are selected via the index set {1, 1, 2, 2, 2}. The transmitted parity length (bits per byte) $l_i \in$ {1, 2, 4, 6, 8}. Then, I=5, $l_5 = L$=8.

HARQ schemes using RCPC codes [65] fall into the class of incremental redundancy codes, in which parity bits are incrementally transmitted to adaptively meet the error performance requirements of the system. The information from multiple erroneous copies is combined to recover the correct cell, and the coding rate for error correction is varied according to the system parameters, such as channel SNR, round delay and buffer size at the receiver. The HARQ scheme in this thesis does not repeat information or parity bits even if the transmission is unsuccessful, but transmits additional redundancy bits of a lower rate RCPC code until the code is able to decode, as shown in Figure 6.2. Because of the cell-by-cell transmission in ATM, retransmissions are based on single ATM cell (length: N). In terms of the above schemes, parities 1, 2, and 3 have $N/8$, $N/8$, and $2N/8$ bits, respectively. Since none of the already transmitted code bits are thrown away but used to improve FEC decoding, the proposed schemes conclude to increase the throughput from an information theoretic standpoint.

In these schemes, each RCPC code with rate R_s comes from $R = \frac{1}{3}$ original CC, then, the HARQ protocol performs the following steps:

1. Encode 416 information bits in accordance with the $(432, 416)$ error detection block code. The parity length (k=16) is sufficient to guarantee a negligible probability of undetected cell errors.

2. Add t "0"s to properly terminate the encoder memory and the decoder trellis for the block of 432 bits.

3. Input the encoded block with $N = 432$ bits into the rate $\frac{1}{3}$ CC encoder. Store the resulting two parity streams at the transmitter, possibly in matrices for potential transmission. Let q=0 , where q represents the number of all code symbols being transmitted (reaching the lowest code rate $\frac{1}{3}$).

4. Initialize l (e.g., set l=1), so that the initial rate of the transmission is $R_1 = \frac{8}{9}$. Then, N information bits and $N/8$ parity bits are sent.

5. Keep sending the additional parity bits to achieve the coding rate corresponding to l.

6. Attempt to decode the code with rate R_l using the code symbols received thus far, and insert erasures for all those symbols not yet received. If there is an all-zero syndrome, output the 416 decoded information bits and send a positive acknowledgment (ACK) to the transmitter. Otherwise, when one or more bit errors are detected in either the header or the payload, send a negative acknowledgment (NAK) to the transmitter.

7. At the transmitter, if an ACK is received, reset the protocol and proceed to step 1. Otherwise, if a NAK is received as shown in Figure 6.2, increment l to the next appropriate value, then switch to the next lower rate and proceed to step 5.

8. If decoding is not successful after the transmission of all code symbols (i.e. $l = L$), $q \leftarrow q + 1$. When $q < Q$, the protocol resets, then commence with step 3 and retransmit the entire codeword. The receiver may reset its receive

buffers. If $q \geq Q$, discard this cell. Then, a higher order protocol could take over the error control.

The parameter Q is defined as the maximum number of all code symbols being transmitted. When Q becomes larger, the extremely low CLR could be obtained, but longer delays may occur.

6.3 Throughput Analysis

In order to realize the bandwidth-efficient and energy-efficient, it is desirable to increase throughput performance. Average throughput (T_{AV}) is one of the most important merits for the HARQ scheme.

When SR retransmission protocol is applied to the HARQ scheme, the total throughput becomes:

$$T_{AV} = \frac{(4+48) \times 8}{(4+48) \times 8 + k + t} \cdot R_{AV} = \frac{416}{416 + k + t} \cdot \frac{8}{8 + l_{AV}}, \tag{6.1}$$

where l_{AV} represents the average numbers of additionally transmitted bits per byte. R_{AV} is the effective coding rate of FEC code. Due to the overhead of k parity check bits and t terminating bits with $k + t \ll 416$, the throughput is slightly smaller than the effective FEC coding rate.

Let $P_F(l_i)$ be the probability that the FEC decoding at the i-th step results in errors which are detected by CRC, then we have:

$$\begin{aligned} l_{AV} &= \sum_{i=1}^{I} l_i P(\text{success after } i \text{ steps}) + l_I P(\text{failure after } I \text{ steps}), \\ &= \sum_{i=1}^{I} l_i P(\text{success after } i\text{-th step}) \cdot P(\text{failure at steps 1 through } i-1) \\ &\quad + l_I P(\text{failure at step 1 through } I) \\ &= \sum_{i=1}^{I} l_i (1 - P_F(l_i)) \cdot \prod_{j=0}^{i-1} P_F(l_j) + l_I \prod_{j=0}^{I} P_F(l_j). \end{aligned} \tag{6.2}$$

where I decoding attempts are assumed to have statistically independent outcomes. $P_F(l_i)$ can be upper bounded by:

$$P_{\text{coded}}(l_i) = 1 - (1 - P_c(l_i))^{(4+48)\times 8 + k + t}, \tag{6.3}$$

where $P_c(l_i)$ is calculated by (4.12). If the protocol terminates after I transmissions, the cell loss probability is simply $P_F(L)$.

When t=4 (i.e., the encoder memory length), k=16 for achieving a very low error probability [39], and Q=1 for simplicity, Figure 6.3 is obtained over AWGN

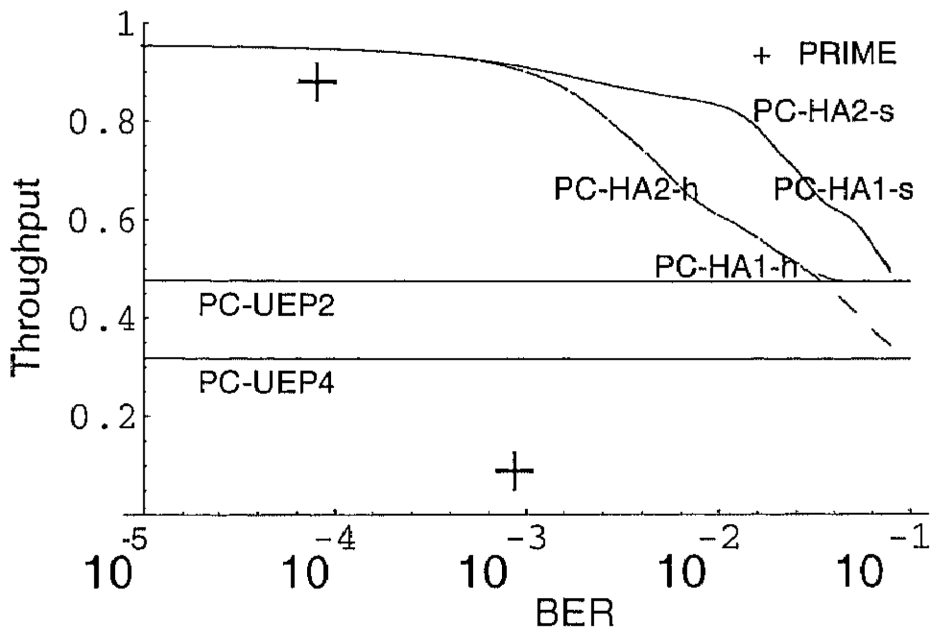

Figure 6.3: **HARQ throughput with RCPC codes on Gaussian channel with soft and hard decisions**

channel, which is calculated by the lower bound method, i.e., substituting $P_{\text{coded}}(l_i)$ for $P_F(l_i)$. From this figure, we know the PC-HA1 scheme has about the same throughput as the PC-HA2 scheme according to soft or hard decisions for the lower BER. The benefits of soft decisions are clearly observable. These HARQ schemes have higher throughputs than the correspondences—PC-UEP4 and PC-UEP2 schemes. The throughput of Partial selective Repeat superIMposEd on GBN-ARQ (PRIME-ARQ) with the managed sequence number N_{MSN} of 8 in the AWA system [51] is also shown in this figure. Obviously, they have lower throughputs than HARQ schemes.

Figures 6.4 and 6.5 depict the results of CLR and throughput, respectively, which are obtained analytically under the fully interleaved Rayleigh fading environment. Though PC-HA1 and PC-HA2 have about the same throughputs, PC-HA1 has better CLR performance than PC-HA2 in case of both soft decision (the solid lines) and hard decision (the dashed lines). The HARQ schemes also reach the same CLR as the FEC schemes by the higher throughputs.

Note that the initial coding rate is selected as $\frac{8}{9}$ here. For higher throughput, $\frac{16}{17}$ can be defined as the initial coding rate. $\frac{8}{10}$ can be defined as the initial coding rate for less delay.

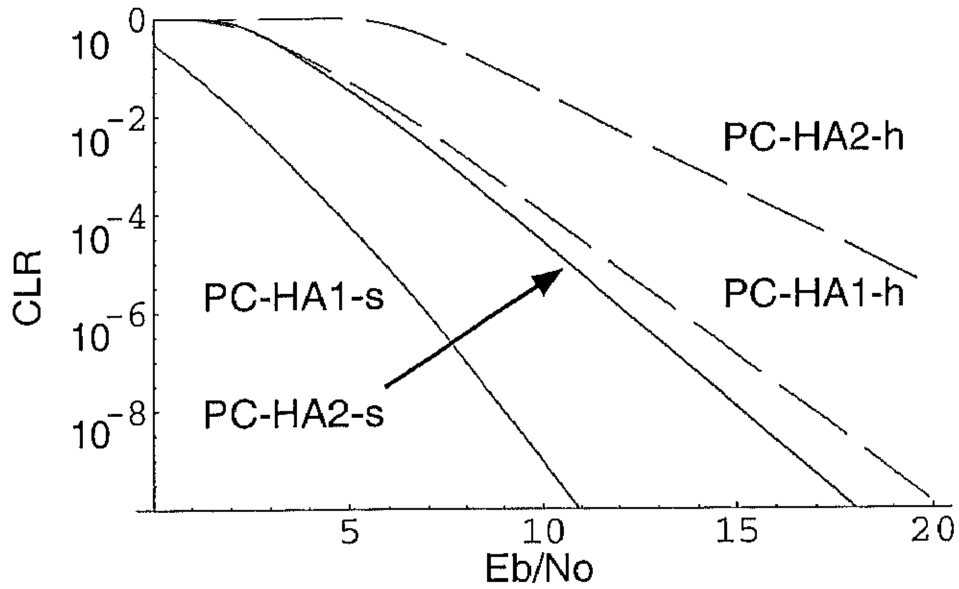

Figure 6.4: HARQ cell loss rate with RCPC codes on Rayleigh channel with soft and hard decisions

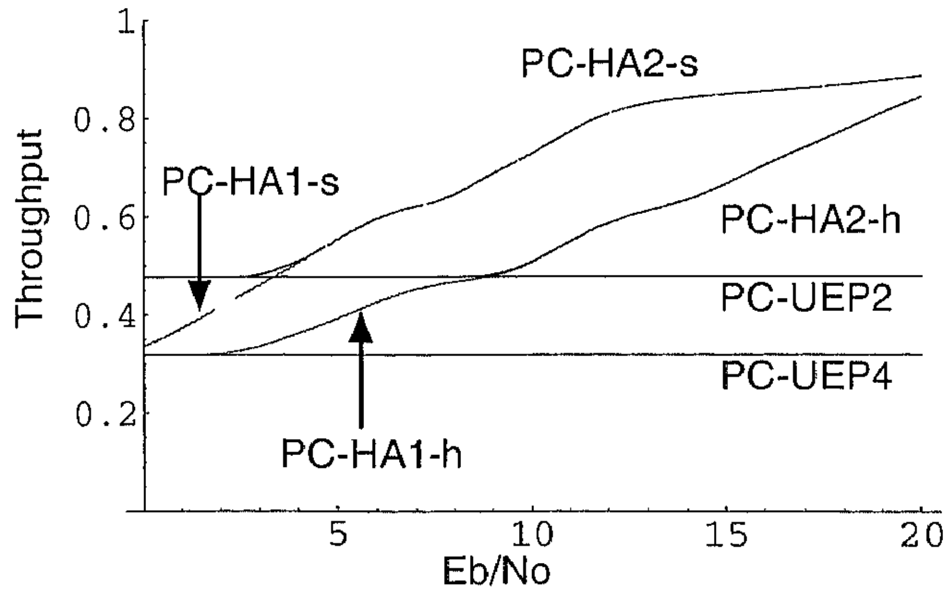

Figure 6.5: HARQ throughput with RCPC codes on Rayleigh channel with soft and hard decisions