Adaptive Two-level Unequal Error Protection Convolutional Code Scheme for Wireless ATM Networks

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Abstract— **Because the wireless asynchronous transfer mode (ATM) networks are often constrained with the limited link bandwidth and error prone characteristics, forward error correction (FEC) is needed to improve their bit error rate performance. In this paper, a two-level punctured convolutional code (PCC) scheme is constructed to apply to wireless ATM cell header and various payloads with the flexible unequal error protection (UEP). Since their perforation matrices can be programmable, the code rates of PCCs are applicable to the different sensitivity of source encoded symbols, even if only the same encoding and decoding hardware is used. Finally, the performance on Gaussian and fading channels is analyzed, which shows significant reductions in cell loss rate (CLR) and good balances for CLR and the payload bit error rate (BER).**

I. Introduction

In recent years, due to increasing attention to the terminal mobility, the wireless interfaces of asynchronous transfer mode (ATM) networks have been very important, as shown in Fig.1 [1]. In a wireless ATM, ATM cells are transmitted via radio frames between a base station (BS) and a mobile station, which includes a terminal equipment (TE) and a radio module (RM). The wireless interface of ATM networks is a band-limited channel with much higher error rate than the wired one. Then, forward error correction (FEC) is needed not only in end-to-end but also in link-by-link connection [2].

A tradeoff between quality (coding gain) and capacity (coding rate) is very important in designing FEC systems. In multimedia wireless ATM interface, the header and various payloads to be transmitted have different importance or error protection needs, expressed by source significance information (SSI). In this situation it is desirable that channel coding provides unequal error protection (UEP), matched to the different sensitivity of source encoded symbols. One UEP scheme having two different FEC codes for the header and payload is proposed [3], which is applied to AWA system [4]. The variable-rate FEC method controlled by media is proposed to increase total utilization efficiency in multimedia systems [5].

However, these schemes only use block codes (BCs), the other important codes — convolutional codes (CCs) are not discussed. In this paper, firstly we propose a wireless multirate FEC frame, and then construct the adaptive two-level UEP code scheme by punctured convolutional codes (PCCs) for it. The performance was analyzed for Gaussian and fading channels, and the characteristic results about cell loss rate (CLR) and bit error rate (BER) are obtained.

II. Wireless ATM cell

According to the B-ISDN protocol reference model [6], ATM cell header error control (HEC) is a single-bit error correction and multiple-bits error detection cyclic redundancy code (CRC), and only employed in the ATM cell header and not in the cell payload in order to avoid incorrect forwarding due to header errors. The HEC controls 8 redundant bits out of 40 bits in a cell header.

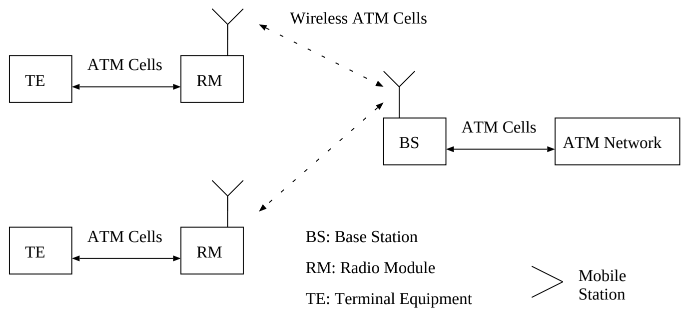

Fig. 1. The construction of wireless ATM

But in the wireless ATM network, the above HEC alone is not sufficient. For mitigating the effect of radio channel errors before cells are released to the ATM network layer, the wireless ATM needs a custom data link control (DLC) layer protocol [7]. 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 wire-line networks must be avoided. In [7], after compressing essential ATM header information, only two bytes containing virtual channel identifier (VCI) and control information are included in wireless ATM header. The wireless header also incorporates a packet sequence number required to support DLC error recovery over moderately large cell error bursts, and includes fields to enable other wireless network function, such as service type definition, segmentation and reassembly and hand-off support. In general, header bits in ATM cell are considered to be more important than payload bits. In order to ensure correct delivery and a low loss rate, we assign the code (FEC1) with a low local coding rate R_1 to be used for the header. At the same time, the code (FEC2) for the payload is designed to be with a higher rate R_2 than the one of FEC1 for effective transmission. From the above discussions, in this paper, we replaces the standard ATM header with the wireless ATM header, which includes the wireless data packet header, the compressed ATM header, and FEC1 and FEC2, as outlined in Fig.2.

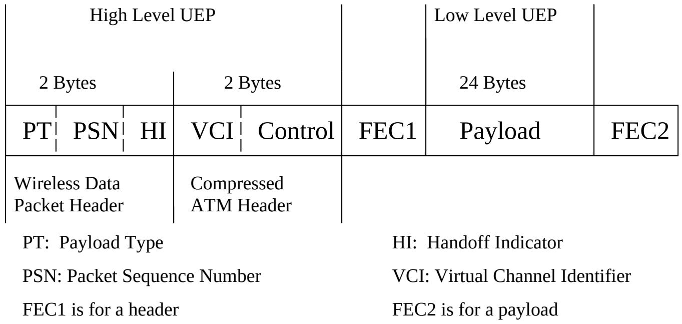

Fig. 2. DLC packet format of wireless ATM cell (using two coding rate FEC)

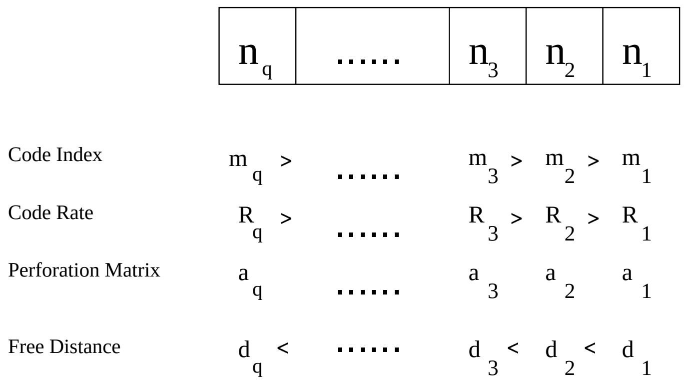

Fig. 3. Data frame with information bits grouped according to their values of SSI

III. The multirate convolutional codes

To simplify the decoding complexity of high rate CCs, the PCCs were suggested in 1979 [8]. The PCCs ($R=\frac{l}{nl-m}$) are produced by being periodically (for each nl bits) punctured m bits from $R=\frac{1}{n}$ low rate CCs (called as the original code). Many of PCCs are shown to be almost as good as the best known regular codes. For example, almost no loss in the minimum distance is caused by using a punctured code. By a virtue of their polynomial generator matrices and upper bounds on the constraint length, the good PCCs that are same as those good known regular nonsystematic and systematic high rate CCs may be constructed [9].

After adding a rate-compatibility restriction to the puncturing rule, PCCs are able to implement a multirate CC encoder/decoder simply [10]. In Fig.3, the ordered information bits are shifted into a shift register of q rates code. During the n_1 information bits, R_1 code with the perforation matrix a_1 is used for multiplexing. As soon as the first bit of the second group enters the encoder, the perforation matrix a_2 will be used. After another n_3 information bits or encoder shifts, the matrix is switched to a_3. At the p-th step n_p/R_p code bits are transmitted per n_p information bits with the perforation matrix a_p and rate R_p . The frame is terminated after the group n_q by shifting $(K-1)$'s "0" bits into the shift register, where K is the constraint length of the original code. Thus, transmitting $(K-1)/R_q$ overhead code bits is necessary for proper termination of the trellis. The procedure is easier to follow when n_p is an integer multiple of the puncturing period l. The overall code rate is then:

$$R=\frac{\sum_{p=1}^{q} n_p}{\sum_{p=1}^{q}\frac{n_p}{R_p}+\frac{K-1}{R_q}}. \quad (1)$$

When the original code is $R_0=\frac{1}{3}$ CC and $l=8$, a set of PCCs with UEP capabilities can be derived, which rates are $R_p=\frac{l}{3l-m_p}=\frac{8}{24-m_p}$. The results of $K=4,5,6,7$, $R_p=\frac{8}{24-m_p}$ PCCs, where $m_p=0,1,\cdots,15$ are obtained [10]. For all rates, the encoder uses the same shift register. Only the perforation matrix is changed. From these results, we construct a new FEC scheme for the wireless ATM in the next section.

IV. Two-level UEP code scheme for wireless ATM

A. Two coding rate FEC scheme for wireless ATM

The realization of two coding rate FEC scheme in the wireless interface of ATM is shown in Fig.4. Only the transmission from RM to BS is illustrated for simplicity. After the payload of the wired ATM is divided into two (24 bytes), the wireless headers are added, then, the HEC is replaced by FEC1 and FEC2 in RM. In BS, after the decoder of FEC1 and FEC2, the HEC is inserted so as to become the normal ATM cell. There is a same procedure in the transmission from BS to RM. The wire-line portion of this system is assumed to be error free so that the encoding and decoding model of two rate PCCs is simplified, as shown in Fig.5.

Let the coding rates of FEC1 and FEC2 be R_1 and R_2 ($R_1<R_2$), respectively. Obviously, from the selection of R_1 and R_2, various overall rate R values in the wireless ATM can be obtained. Supposing FEC1 be $R_1=\frac{8}{12}$ PCC and FEC2 be $R_2=\frac{8}{10}$ PCC, we have:

Header sequence ($A_1^{(i)}$) are the most important bits (MIB: SSI is bigger), using $R_1=\frac{8}{12}$ PCC from $R=\frac{1}{3}$ and $K=7$ original CC, where $l_1=8, m_1=12$ and $n_1=32=4l_1$;

Payload sequence ($A_2^{(i)}$) are less important bits (LIB: SSI is smaller), using $R_2=\frac{8}{10}$ PCC from $R=\frac{1}{3}$ and $K=7$ original CC, where $l_2=8, m_2=14$ and $n_2=192=24l_2$.

Then, the overall code rate is:

$R=\frac{32+192}{32\frac{12}{8}+192\frac{10}{8}+6\frac{10}{8}}=\frac{448}{591}\doteq 0.758.$

Let the data sequence from a sender be:

$$A^{(1)},A^{(2)},\ldots,A^{(i)},\ldots \quad (2)$$

where $A^{(i)}$=($A_1^{(i)}$,$A_2^{(i)}$), and the encoded data sequence $B^{(i)}=(B_1^{(i)},B_2^{(i)})$ by $R=\frac{1}{3}$ CC encoding is:

$$B_1^{(i)}=(B_{1,1}^{(i)},B_{1,2}^{(i)},\cdots,B_{1,4}^{(i)}) \quad (3)$$

$$B_{1,j}^{(i)}=(b_{1,j,1}^{(i)},b_{1,j,2}^{(i)},\cdots,b_{1,j,24}^{(i)})$$

$$B_2^{(i)}=(B_{2,1}^{(i)},B_{2,2}^{(i)},\cdots,B_{2,24}^{(i)}) \quad (4)$$

$$B_{2,j}^{(i)}=(b_{2,j,1}^{(i)},b_{2,j,2}^{(i)},\cdots,b_{2,j,24}^{(i)})$$

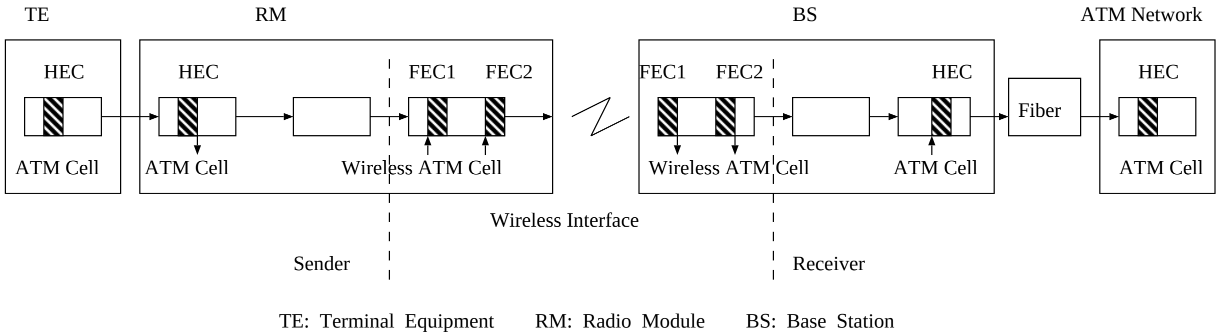

Fig. 4. The realization of two rate FEC scheme in the wireless ATM networks

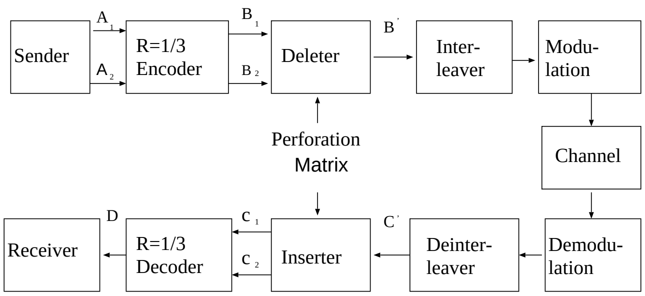

Fig. 5. The encoding and decoding of two rates PCCs

Suppose the perforation matrix of R_1 PCC be :

$$\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

and the perforation matrix of R_2 PCC be :

$$\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}.$$

After deleting, output data sequence $B'^{(i)} = (B_1'^{(i)}, B_2'^{(i)})$ becomes:

$$\begin{aligned} B_1'^{(i)} &= (B_{1,1}'^{(i)}, B_{1,2}'^{(i)}, \cdots, B_{1,4}'^{(i)}), \\ B_{1,j}'^{(i)} &= (b_{1,j,1}^{(i)}, b_{1,j,2}^{(i)}, b_{1,j,4}^{(i)}, b_{1,j,7}^{(i)}, b_{1,j,8}^{(i)}, b_{1,j,10}^{(i)}, \\ &\quad b_{1,j,13}^{(i)}, b_{1,j,14}^{(i)}, b_{1,j,16}^{(i)}, b_{1,j,19}^{(i)}, b_{1,j,20}^{(i)}, b_{1,j,22}^{(i)}), \end{aligned} \tag{5}$$

where $j = 1, \cdots, 4$, and:

$$\begin{aligned} B_2'^{(i)} &= (B_{2,1}'^{(i)}, B_{2,2}'^{(i)}, \cdots, B_{2,24}'^{(i)}), \\ B_{2,j}'^{(i)} &= (b_{2,j,1}^{(i)}, b_{2,j,2}^{(i)}, b_{2,j,4}^{(i)}, b_{2,j,7}^{(i)}, b_{2,j,10}^{(i)}, \\ &\quad b_{2,j,13}^{(i)}, b_{2,j,14}^{(i)}, b_{2,j,16}^{(i)}, b_{2,j,19}^{(i)}, b_{2,j,22}^{(i)}), \end{aligned} \tag{6}$$

where $j = 1, \cdots, 24$.

After the transmission of $B'^{(i)}$ via channel, deinterleaver outputs $C'^{(i)} = (C_1'^{(i)}, C_2'^{(i)})$ are:

$$\begin{aligned} C_1'^{(i)} &= (C_{1,1}'^{(i)}, C_{1,2}'^{(i)}, \cdots, C_{1,4}'^{(i)}), \\ C_{1,j}'^{(i)} &= (c_{1,j,1}^{(i)}, c_{1,j,2}^{(i)}, c_{1,j,4}^{(i)}, c_{1,j,7}^{(i)}, c_{1,j,8}^{(i)}, c_{1,j,10}^{(i)}, \\ &\quad c_{1,j,13}^{(i)}, c_{1,j,14}^{(i)}, c_{1,j,16}^{(i)}, c_{1,j,19}^{(i)}, c_{1,j,20}^{(i)}, c_{1,j,22}^{(i)}), \end{aligned} \tag{7}$$

where $j = 1, \cdots, 4$, and:

$$\begin{aligned} C_2'^{(i)} &= (C_{2,1}'^{(i)}, C_{2,2}'^{(i)}, \cdots, C_{2,24}'^{(i)}), \\ C_{2,j}'^{(i)} &= (c_{2,j,1}^{(i)}, c_{2,j,2}^{(i)}, c_{2,j,4}^{(i)}, c_{2,j,7}^{(i)}, c_{2,j,10}^{(i)}, \\ &\quad c_{2,j,13}^{(i)}, c_{2,j,14}^{(i)}, c_{2,j,16}^{(i)}, c_{2,j,19}^{(i)}, c_{2,j,22}^{(i)}), \end{aligned} \tag{8}$$

where $j = 1, \cdots, 24$.

Then, by the inserter, we have $C^{(i)} = (C_1^{(i)}, C_2^{(i)})$:

$$\begin{aligned} C_1^{(i)} &= (C_{1,1}^{(i)}, C_{1,2}^{(i)}, \cdots, C_{1,4}^{(i)}), \\ C_{1,j}^{(i)} &= (c_{1,j,1}^{(i)}, c_{1,j,2}^{(i)}, \times, c_{1,j,4}^{(i)}, \times, \times, c_{1,j,7}^{(i)}, c_{1,j,8}^{(i)}, \\ &\quad \times, c_{1,j,10}^{(i)}, \times, \times, c_{1,j,13}^{(i)}, c_{1,j,14}^{(i)}, \times, c_{1,j,16}^{(i)}, \\ &\quad \times, \times, c_{1,j,19}^{(i)}, c_{1,j,20}^{(i)}, \times, c_{1,j,22}^{(i)}, \times, \times), \end{aligned} \tag{9}$$

where $j = 1, \cdots, 4$ and $\times$ represents an inserted dummy bit, and:

$$\begin{aligned} C_2^{(i)} &= (C_{2,1}^{(i)}, C_{2,2}^{(i)}, \cdots, C_{2,24}^{(i)}), \\ C_{2,j}^{(i)} &= (c_{2,j,1}^{(i)}, c_{2,j,2}^{(i)}, \times, c_{2,j,4}^{(i)}, \times, \times, c_{2,j,7}^{(i)}, \times, \\ &\quad \times, c_{2,j,10}^{(i)}, \times, \times, c_{2,j,13}^{(i)}, c_{2,j,14}^{(i)}, \times, c_{2,j,16}^{(i)}, \\ &\quad \times, \times, c_{2,j,19}^{(i)}, \times, \times, c_{2,j,22}^{(i)}, \times, \times), \end{aligned} \tag{10}$$

where $j = 1, \cdots, 24$.

Afterwards, through (3,1,7) decoder, decoded bit sequence D are sent to the receiver.

In the above course, it is assumed that bit synchronization and cell synchronization have been achieved. The decoder first decodes the header, if it succeeds, the quality of service (QoS) information identified in the header is extracted and used to determine the code rate used to decode the payload.

Using variable rate PCCs can also make the encoding rate (R_2) to be assigned to each service having a different need of error protection. For example, we can set $R_1 = \frac{8}{16} = \frac{1}{2}$ and $R_a = \frac{8}{10}$ for Audio, $R_d = \frac{8}{12}$ for Data, $R_v = \frac{8}{14}$ for Video. Its advantage is that only one encoder and one decoder circuits are needed for

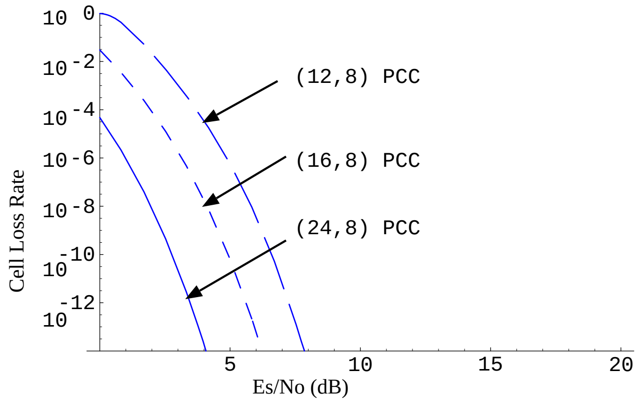

Fig. 6. The CLR analytic upper bound as a function of SNR (for $R_1 = \frac{8}{12}$, $R_1 = \frac{8}{16}$, $R_1 = \frac{8}{24}$) over Gaussian channel

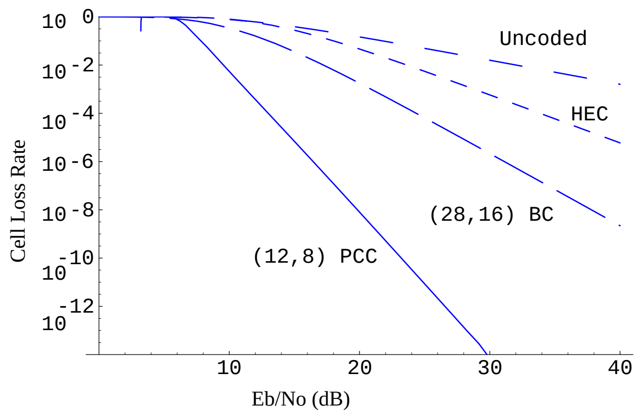

Fig. 7. The CLR versus E_b/N_0 analytic upper bound for $R_1 = \frac{8}{12}$ over fully interleaved Rayleigh fading channel

FEC1 and various FEC2 even if their code rates, and thus the levels of error protection are different, since the perforation matrix can be programmable. But in this case, the encoded length of wireless ATM packet becomes variable.

B. Performance of Cell Loss Rate and Bit Error Rate over Gaussian and Rayleigh fading channel

One of the most important performance parameter in ATM cell transport is CLR, which is defined by the ratio of total lost cells to total transmitted cells. When a header portion contains errors that can not be corrected, the cell will be misdirected and regarded as lost cell outcome.

If an $(nl-m,l)$ PCC with the minimum free Hamming distance d_f is applied to the header, the probability of a cell loss for coded systems is given by:

$$P_{coded} = 1-(1-P_c)^{32}, \tag{11}$$

where P_c is the bit error probability of wireless ATM header after using PCC, which can be upper bounded by [11]:

$$P_c \le \frac{1}{l}\sum_{d=d_f}^{\infty} c_d P_d, \tag{12}$$

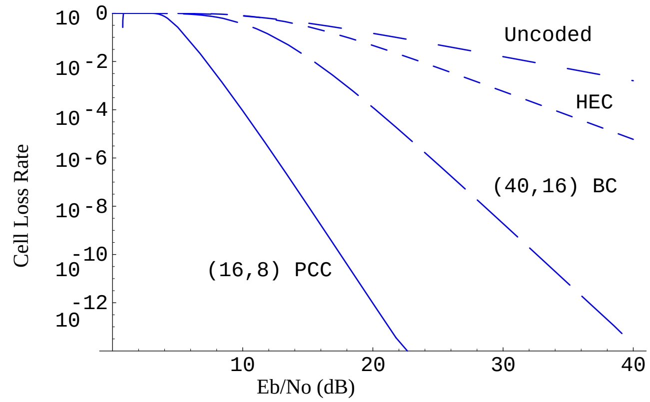

Fig. 8. The CLR versus E_b/N_0 analytic upper bound for $R_1 = \frac{8}{16}$ over fully interleaved Rayleigh fading channel

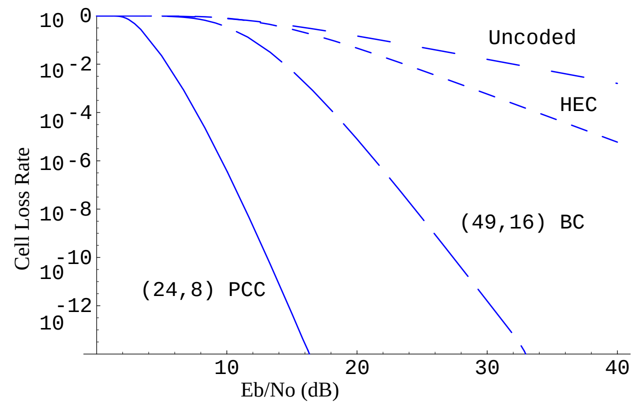

Fig. 9. The CLR versus E_b/N_0 analytic upper bound for $R_1 = \frac{8}{24}$ PCCs over fully interleaved Rayleigh fading channel

where c_d is the total number of error bits produced by the incorrect paths, and P_d is the probability that the wrong path at distance d is selected. For binary phase-shift keying (BPSK) over Gaussian channel with soft decision on C', P_d is expressed by:

$$P_d = \frac{1}{2}erfc(\sqrt{dE_s/N_0}), \tag{13}$$

where E_s/N_0 is the signal-to-noise ratio (SNR) per coded bit. The CLR analytic upper bounds as functions of E_s/N_0 over Gaussian channel (the constraint length of PCC original code is 6) are shown in Fig.6.

Supposing that ideal interleaving produces independent data errors. For BPSK over Rayleigh fading channel with soft decisions on C' and full channel state information(CSI), P_d can be upper bounded by [10]:

$$P_d \le \frac{1}{2}(\frac{1}{1+RE_b/N_0})^d, \tag{14}$$

where $E_b/N_0 = E_s/RN_0$ is the SNR per uncoded bit.

Let P_b be the probability of bit error for a Rayleigh fading channel, for an uncoded header (4 bytes), the probability of a cell loss is given by:

$$P_{uncoded} = 1-(1-P_b)^{32}, \tag{15}$$

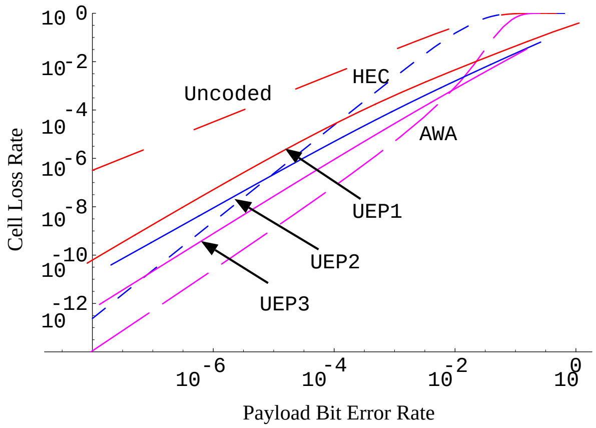

Fig. 10. The CLR versus payload BER analytic upper bound

For a header with HEC, the probability of a cell loss is given by:

$$P_{HEC} = (1-P_0)(1-P_0) + P_0(1-P_0-P_1), \tag{16}$$

where the probability of no error in one cell header $P_0 = (1-P_b)^{40}$, and the probability of single-bit error in one cell header $P_1 = 40P_b(1-P_b)^{39}$.

If an (n,k) t-error correcting block code is applied to the header, the probability of a cell loss is given by:

$$P_t = \sum_{i=t+1}^{n} {}_nC_i(1-P_b)^{n-i}P_b^i. \tag{17}$$

Fig.7 to Fig.9 depict the CLR versus E_b/N_0 analytic upper bound over a Rayleigh fading channel. The solid lines represent the result of $R_1 = \frac{8}{12}, \frac{8}{16}$, and $\frac{8}{24}$ PCCs, the constraint length of their same original code is 6. The dashed lines represent the results of uncoded one, HEC and three different BCs, respectively [5]. The figures show that adding PCCs over the header greatly decreases the number of cell loss, therefore increases the QoS of the system. For example, the (12,8) PCC realizes about 30 dB gain over the uncoded system, 21 dB gain over the HEC system and 10 dB gain over the (28,16) BC [5] at a CLR of 10^{-4}. For each result in these figures, there is a 50%, 100% or 200% increase in bandwidth for the header of PCC and BC. Obviously, the schemes using PCCs have better CLR performance than the scheme of [5] with the same increase in required bandwidth.

On the other hand, it is extremely efficient from the viewpoints of coding gain and coding rate to create the same balanced design for CLR and the payload BER as the HEC for a wired ATM [3]. Fig.10 shows the relationship of the payload BERs and CLRs over a fully interleaved Rayleigh fading channel. The dashed lines represent the result of uncoded for header and payload, the result of HEC for the header and uncoded for the payload, and the result of AWA system, respectively. The solid lines represent UEP1 with $R_1 = \frac{8}{12}$ and $R_2 = \frac{8}{10}$, UEP2 with $R_1 = \frac{8}{16}$ and $R_2 = \frac{8}{12}$, UEP3 with $R_1 = \frac{8}{24}$ and $R_2 = \frac{8}{16}$, respectively. Obviously, the balance about CLR and BER performance is very good as the HEC when PCCs are applied for the wireless ATM networks.

V. Conclusions

In this paper, a UEP code scheme using PCCs is put forward, which is considered to be suitable for the wireless ATM. The ATM cell header is protected by a relatively powerful PCC to ensure correct delivery and low cell loss. The payload is protected by relatively high transmission PCCs having different coding gains. In such a way, a whole family of codes with different rates is available using the same encoder and the same Viterbi decoder except for only the puncturing rule being changed. The CLR and BER are analyzed, which are better than the previous FEC scheme with the same increase in required bandwidth. Besides, they are good balance designs for CLR and payload BER.

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