ISSN 1009 - 3095 *Journal of Zhejiang University(SCIENCE)* V.2,No.1,P.51 - 55,Jan. - Mar., 2001
http://www.chinainfo.gov.cn/periodical; http://www.zju.edu.cn;
http://lib.zju.edu.cn/English; http://www.zjupress.com

HEADER ERROR CONTROL SCHEMES FOR COPING WITH UPSTREAM CHANNEL NOISE IN THE HFC NETWORK

CHEN Hui-fang(陈惠芳), XIE Lei(谢 磊), QIU Pei-liang(仇佩亮)
(*Dept. of Information & Electronic Engineering, Zhejiang University, Hangzhou 310027, China*)

Received Apr.18, 2000; revision accepted July 6,2000

Abstract: The Hybrid Fiber-Coax (HFC) network is being paid close attention to in recent years as a bi-directional broadband access network. To achieve seamless connection with the backbone network, an Asynchronous Transfer Mode (ATM) Network Network Interface (NNI) cell format is used as the basic transmission packet unit in the HFC system. As the transmission condition of the HFC system's upstream channel is bad, two improved header error control (HEC) schemes, i.e. the improved HEC and the cell interleaving technique, are employed to guarantee the packet integrity. Theoretical analysis of the results showed that the improved HEC and the cell interleaving technique are applicable to isolated random errors and burst errors, respectively.

Key words: HFC Networks, HEC, BCH code, Cell Interleaving Technique
Document code: A **CLC number:** TN913.24

INTRODUCTION

ATM has great superiority in certain aspects, such as resource allocation flexibility, quality of service guaranteeing, integrated traffic supporting, etc. ATM has been adopted by International Telecommunication Union (ITU) as the exchange and multiplexing techniques of the Broadband Integrated Services Digital Network (B-ISDN) (Sun et al., 1995). The HFC network based on the traditional Cable TV (CATV), a bi-directional broadband access network, has been paid close attention to by many communication communities in recent years. For the seamless link between the HFC networks and the backbone networks, it is reasonable that the ATM cell is selected as the transmission unit in the HFC network. ATM is advanced in the high performance of the fiber link. The HEC in the ATM cell header was set up to guarantee the integrity of the ATM header and to decrease the mis-insertion of ATM cell caused by virtual path identifier (VPI) and virtual circuit identifier (VCI).

The signal transmission performance in the cable distribution network of the HFC system is worse than that in the fiber link. The sub-split band locates in a part of the spectrum filled with both narrow-band noise and ingress interference (Eldering et al., 1995). The performance of the upstream channel will be affected greatly by the noise funneling. So, the HEC scheme of the cell header must be improved to deal the impact of noise on the distribution network. An improved HEC scheme is proposed to deal with with random noise problem in the HFC upstream channel. A cell interleaving technique is used for the burst noise combined with the burst transmission. The impact of two improved HEC schemes on the cell-loss and cell mis-insertion probabilities are analyzed, and the numerical results are presented.

HEC FOR ATM SYSTEM①

HEC for the ATM system is standardized in the ITU-T and ATM Forum and employs the (40, 32) Cycle Remnant Code (CRC), a single-bit error correction multiple-bit error detection code. It is very important for HEC to guarantee the routing because the functions of the ATM cell are realized based on the ATM cell header and not on the cell payload.

---

① ATM User-Network Interface Specification, in the ATM Forum.

Suppose the receiving cell header bit-stream is $R(x)$ and the HEC's generator polynomial is $G(x)$. If $R(x) \bmod G(x) = 0$, HEC indicates no errors in the ATM cell header. If $R(x) \bmod G(x) = x^i \bmod G(x)$ $(i = 0, 1, 2, \cdots, 39)$, HEC indicates single-bit errors. Other patterns mean multiple-bit errors. HEC operates in two modes: the correction mode and the detection mode. The principle of HEC is shown in Fig. 1. In the correction mode, a single-bit error can be corrected and cells with multiple-bit errors are discarded. In the detection mode, all cells with detected errors are discarded. Sometimes, when multiple-bit errors occur, if the output syndrome is $R(x) \bmod G(x) = 0$ or $R(x) \bmod G(x) = x^i \bmod G(x)$ $(i = 0, 1, 2, \cdots, 39)$, HEC indicates no error or a single-bit error in the ATM cell header, and cell mis-insertion is created.

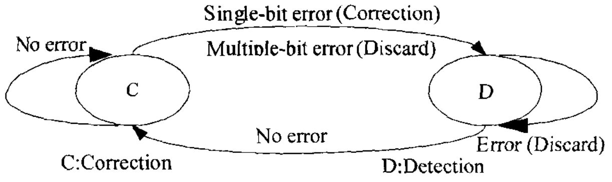


Fig. 1 Principle of HEC

In the isolated random noise condition, the probability of no error bit in the 40-bit cell header is:

$$Q_0 = \binom{40}{0} p^0 (1 - p)^{40} \tag{1}$$

Where, p is the Bit Error Rate (BER).

The probability of single-bit error in the cell header is:

$$Q_1 = \binom{40}{1} p^1 (1 - p)^{39} \tag{2}$$

As Fig. 1 shows, the steady state probabilities of the correction mode and the detection mode are:

$$P_C = \binom{40}{0} p^0 (1 - p)^{40} \tag{3}$$

$$P_D = 1 - P_C = 1 - \binom{40}{0} p^0 (1 - p)^{40} \tag{4}$$

Therefore, the cell loss probability (CLP) is:

$$P_{\text{loss1}} = P_C(1 - Q_0 - Q_1) + P_D(1 - Q_0) = 1 - (1 - p)^{40} - 40p(1 - p)^{79} \tag{5}$$

As mentioned-above, HEC regards some multiple-bit errors patterns as no error or a single-bit error in the ATM cell header, and cell mis-insertion is created. The cell mis-insertion probability (CMP) is:

$$P_{\text{mis1}} = P_C \times 2^{-8} \sum_{i=0}^{1} \binom{40}{i} \sum_{j=2}^{40} \binom{40}{j} p^j (1 - p)^{40-j} + P_D \times 2^{-8} \binom{40}{0} \sum_{j=0}^{40} \binom{40}{j} p^j (1 - p)^{40-j} = 2^{-8}[1 + 39(1 - p)^{40} - 40(1 - p)^{80} - 1640p(1 - p)^{79}] \tag{6}$$

IMPROVED HEC SCHEME OF THE HFC NETWORK

For improving the HEC's performance with isolated random noise, one method is to strengthen the HEC's correction capability, by expanding the HEC region for correction of multiple-bit errors. The shortcoming of this method is the incomplete compatibility of the ATM cell structure between the HFC networks and the backbone networks. The cell header must be transformed in the interface between the HFC networks and the backbone networks, which will increase the processing overhead.

Now, the (44, 32) or (56, 32) shortened BCH code (Aikawa et al., 1996) takes the place of the (40, 32) CRC. Two types of BCH codes can correct 2-bit errors and 4-bit errors, respectively. In the case of employing the (44, 32) BCH code, 4-bit data will be padded in the cell header and the cell has 54 bytes. In the case of employing the (56, 32) BCH code, no bit data will be padded and the cell has 55 bytes. Fig. 2 shows the transformation of the improved HEC and the standardized HEC.

Firstly, considering the (44, 32) shortened BCH code as the improved HEC, whose correction capability is 2-bit errors, that is, it cannot correct the error patterns with more than 2-bit errors. Therefore, the CLP is:

$$P_{\text{loss2}} = \left(1 - \sum_{j=0}^{2} \binom{44}{j} p^j (1 - p)^{44-j}\right)(1 - p)^{44} + \left(1 - \binom{44}{0} p^0 (1 - p)^{44}\right)(1 - (1 - p)^{44}) \tag{7}$$

When the decoder indicates the more than 2-bit error patterns that occurred as 2-bit or less that 2-bit error, cell mis-insertion is created. So, the CMP is:

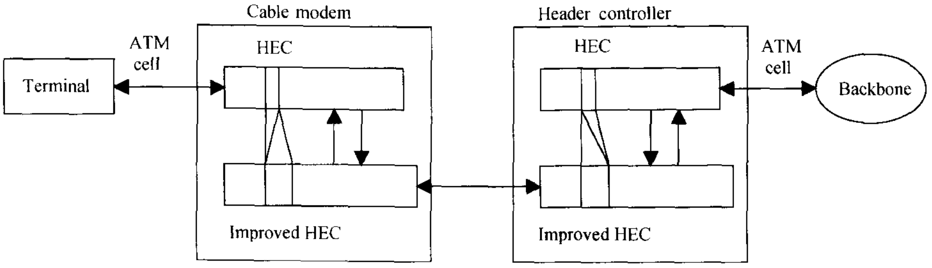


Fig. 2 Transformation of the improved HEC from the standardized HEC

$$P_{\text{mis2}} = (1-p)^{44} \times 2^{-12}\sum_{i=0}^{2}\binom{44}{i}\sum_{j=3}^{44}\binom{44}{j}p^{j}(1-p)^{44-j} + (1-(1-p)^{44}) \times 2^{-12}\sum_{j=1}^{44}\binom{44}{j}p^{j}(1-p)^{44-j} \qquad (8)$$

Considering the (56, 32) shortened BCH code as the improved HEC, its correction ability is 4-bit errors. The CLP and CMP are:

$$P_{\text{loss2}} = \left(1-\sum_{j=0}^{4}\binom{56}{j}p^{j}(1-p)^{56-j}\right)(1-p)^{56} + \left(1-\binom{56}{0}p^{0}(1-p)^{56}\right)\cdot (1-(1-p)^{56}) \qquad (9)$$

$$P_{\text{mis2}} = (1-p)^{56} \times 2^{-24}\sum_{i=0}^{4}\binom{56}{i}\sum_{j=5}^{56}\binom{56}{j}p^{j}(1-p)^{56-j} + (1-(1-p)^{56}) \times 2^{-24}\sum_{j=1}^{56}\binom{56}{j}p^{j}(1-p)^{56-j} \qquad (10)$$

Fig. 3 and Fig. 4 show the curves of the cell loss and the cell mis-insertion probabilities of the mentioned HEC schemes. As Fig. 3 and Fig. 4 show, the cell loss and the cell mis-insertion probabilities of the improved HEC are decreased obviously compared to that of the standardized HEC. When the correction capability of the BCH codes increases, the performance is improved at the expense of resource and cell transformation overhead.

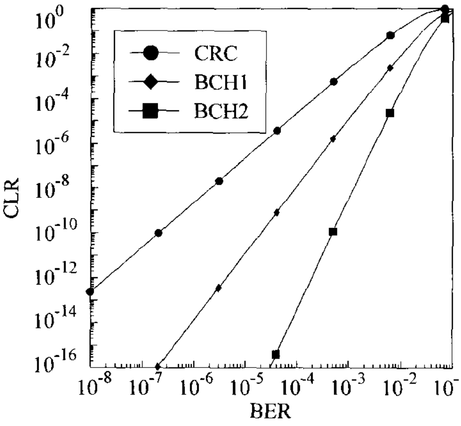


Fig. 3 Curves of cell loss probability

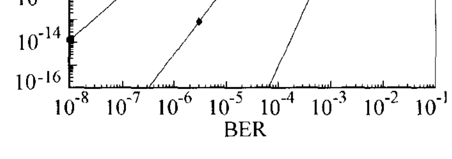
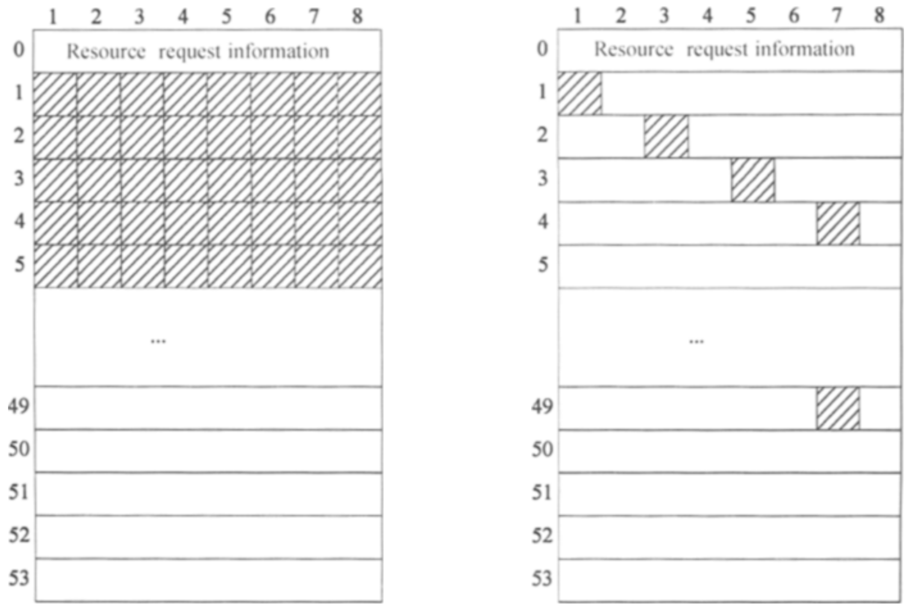


Fig. 4 Curves of cell mis-insertion probability

CELL INTERLEAVING TECHNIQUE IN THE UPSTREAM CHANNEL OF HFC NETWORK

As mentioned-above, HEC is used for guaranteeing the cell integrity. It is a single-bit error correction multiple-bit error detection code. The standardized HEC is designed under condition of low error rate and isolated random error. The burst noise exists in the upstream channel of the HFC network. The improved HEC increases the error correction capability. At the same time, it not only causes resource and hardware transformation overhead but also is not an ideal method for coping with the burst noise. To spread out the burst errors of the upstream channel and improve the HEC's function, the interleaving technique, such as the block interleaving technique which is used for spreading out the ATM cell header bit, is employed. The block interleaving technique interleaves (Sheu, 1997) headers of cells in a block unit consisting of n cells. Once transmitting, a bit will be read from one cell. This method can cope with the burst errors with burst length not longer than n. And this method has a large processing delay for interleaving and only adapt to the continuous transmission mode. So, we employ the cell interleaving technique for the burst transmitting ATM cells of the upstream channel in the HFC network.

The cell interleaving technique spreads each bit of the header field over the data field within a cell. As the payload of the ATM cell is 48 bytes and there are 40 bits in the ATM header, the maximum depth of the cell interleaving technique is $\left\lfloor \frac{48 \times 8}{40} \right\rfloor = 9$. Fig. 5 shows the principle of the cell interleaving technique. After de-interleaving at reception, any burst errors in transmission are spreaded out as isolated random errors into the data field of the cell, thus transforming most burst errors into single-bit errors. As single-bit errors in the header are easily corrected by HEC, this interleaving can reduce the cell loss and cell mis-insertion probabilities. The processing delay of this method is small. It is effective for burst errors shorter than 11 bits.



(a) (b)

Fig. 5 Principle of the cell interleaving technique

(a) cell bit stream before interleaving; (b) cell bit stream after interleaving

Now, we give analyses of the cell loss probabilities with and without interleaving.

Case 1: Assume that there are only isolated random errors and no interleaving is done. In this case, the cell loss probability can be obtained from Eq. (5).

Case 2: Consider a case of no interleaving and burst errors all assumed to be 2-bit long. The cell loss probability is:

$$P_{\text{loss4}} = \binom{40}{0} p'^{0}(1-p')^{40} \left(1 - \binom{40}{0} p'^{0}(1-p')^{40} - \frac{2}{41} \times \binom{41}{1} p'^{1}(1-p')^{40}\right) + \left(1 - \binom{40}{0} p'^{0}(1-p')^{40}\right)\left(1 - \binom{40}{0} p'^{0}(1-p')^{40}\right) \quad (11)$$

Where, p' is the 2-bit error occurrence rate. To keep the eventual bit error rate the same, we take $p' = p/2$.

Case 3: Consider a case of cell interleaving where only random errors occur. The cell loss probability is:

$$P_{\text{loss5}} = \binom{40}{0} p^{0}(1-p)^{40}$$

$$\left(1-\binom{40}{0}p^{0}(1-p)^{40}-\binom{40}{1}p^{1}(1-p)^{39}\right)+$$
$$\left(1-\binom{40}{0}p^{0}(1-p)^{40}\right)\left(1-\binom{40}{0}p^{0}(1-p)^{40}\right)$$
$$=P_{\mathrm{loss1}} \tag{12}$$

Case 4: Consider a case of the cell interleaving when burst errors all assumed to be 2-bit long. The cell loss probability is:

$$P_{\mathrm{loss6}}=\binom{80}{0}p'^{0}(1-p')^{80}$$
$$\left(1-\binom{80}{0}p'^{0}(1-p')^{80}-\binom{80}{1}p'^{1}(1-p')^{80}\right)+$$
$$\left(1-\binom{80}{0}p'^{0}(1-p')^{80}\right)\left(1-\binom{80}{0}p'^{0}(1-p')^{80}\right) \tag{13}$$

Fig. 6 of the cell loss probability obtained from Equations (5), (11), (12) and (13) shows that, when only isolated random errors occur in the channel, the cell interleaving does not affect the system performance. When only burst errors with short burst length occur, the cell interleaving improves the system performance efficiently. Assuming that the burst errors are all 2-bit long, the performance of the cell interleaving is the same as the performance with isolated random errors. That is the result of the error dispersion caused by the interleaving.

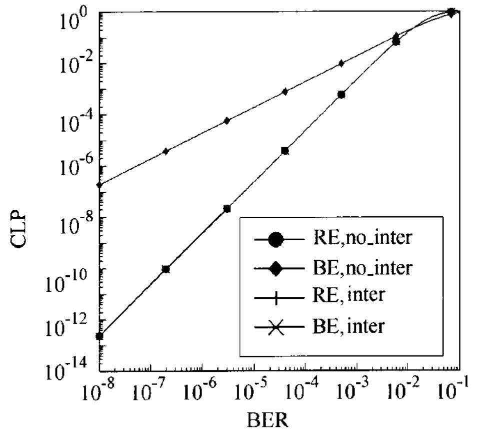


Fig. 6 The CLP in different cases

Fig. 7 of the cell loss probability corresponding to different burst error length shows that, when the burst length is short, employing the cell interleaving technique can decrease the cell loss probability obviously. When the burst length is long, employing the cell interleaving technique will degrade the performance a bit.

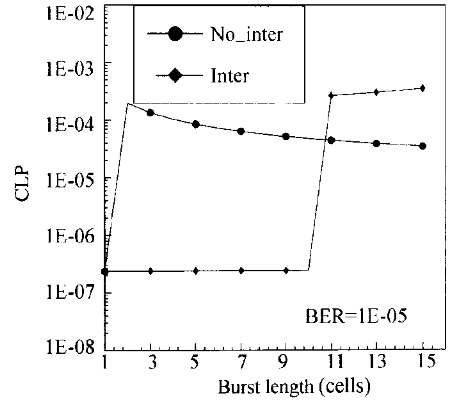


Fig. 7 CLP changing due to burst length

CONCLUSIONS

The HFC network based on CATV is a kind of bi-directional broadband access network. The transmission condition of the upstream channel in the HFC system is bad. For decreasing the cell loss and the cell mis-insertion probabilities, the functions of the HEC must be improved. There are two improved HEC methods proposed in this paper, one is the improved HEC, and the other is cell interleaving. Analysis and computation results lead to the following conclusions:

1. The improved HEC can improve the system performance by decreasing the probability of cell loss and cell mis-insertion. But this method will cause hardware transformation and resource overhead, bad compatibility and processing delay.

2. The cell interleaving technique cannot improve the performance of a system with isolated random errors. It will improve performance effectively when the burst error length is short. When the burst length exceeds the interleaving depth, this method will cause errors dispersion and the performance will degrade slightly. The processing delay of this method is larger than that of the improved HEC.

References

Aikawa, S., Motoyama, Y., Umehira, M., 1996. Forward Error Correction Schemes for Wireless ATM Systems. *IEEE ICC'96*: 454 – 458.

Eldering, C.A., Himayat, N., Gardner, F. M., 1995. CATV Return Path Characterization for Reliable Communications, *IEEE Communications Magazine*, **13**(7): 63 – 69.

Sheu, S.T., 1997. A Cell Discarding Strategy to Reduce Cell Error Rate in Wireless ATM Networks. *IEEE ATM'* **97** Workshop: 401 – 409.

Sun, H. R., Li, L. M., 1995. ATM Technique-concept, principle and applications. 1st edition, Press of University of Electronics Technology, Chengdu. p.7 – 13.