Modified Packet Combining using Error Forecasting Decoding To Control Error

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Abstract-To combat error in computer / data communication networks, ARQ (Automatic Repeat Request) techniques are used. Recently Chakraborty has proposed a simple technique called packet combining scheme in which error is corrected at the receiver from the erroneous copies. The technique has a number of attractions. In the paper we propose a modified packet combining scheme that is established as more powerful than the Chakraborty's technique. We also propose to apply error forecasting decoding to control error in network. This may lead to lower delay and higher performance at the cost of extra decoding complexities.

Index Terms-:Error control, MPC, Forecasting

control

I. Introduction

In order to transfer data reliably from source to destination either BEC (Backward Error Control) or FEC (Forward Error Control) strategies are used. It is well established that BEC strategy is sufficient for wired communication, and FEC strategy is required for wireless transmission. BEC is cost effective but inherently associated with appreciable amount of delay. This is because the erroneous packet is corrected by the retransmission from transmitter. FEC is costly as it consumes higher bandwidth for using correction code, but delay is marginal in the process. To improve performance of BEC strategy several modifications of basic ARQ techniques and new techniques are suggested in literatures[1-17]. Recently Chakraborty[18-20] has suggested a very simple and elegant technique, known as packet combining technique, for error correction using BEC strategy. The technique aims to minimize delay in correction process. However, we propose a extended modified packet combining technique that will achieve higher throughput and lower transfer delay. In the proposed technique the application of error forecasting decoding[21,22] is seen to achieve further improvements.

II. Packet Combining Scheme

The BEC is cost effective but inherently associated with appreciable amount of delay. This is because the erroneous packet is corrected by the retransmission from transmitter. Chakraborty has recently suggested a simple technique where the receiver will correct limited error, one or two bit error, from the received erroneous copies. The technique proposed by Chakraborty is illustrated below:

We assume the original transmitted packet as "01010101." The packet erroneously received by the receiver as "11010101." The receiver requests for retransmission of the received erroneous packet but keeps in store the received erroneous packet. The transmitter retransmits the packet, but again the packet is received by the receiver erroneously as "00010101." Chakraborty proposed that the receiver can correct the error by using two erroneous copies for a bit wise XOR operation between erroneous copies may be performed to locate the error position, in the present example being as follows:

First erroneous copy	11010101
Second erroneous copy	00010101
XOR	11000000

The error locations are identified as first and/or second bit from the left. Chakraborty suggested that the receiver can apply brute method to correct error by changing received "1" to "0" or vice versa on the received copies followed the application of error decoding method in use. In the example the average number of brute application will be 0.5.

Chakraborty's technique is known as Extended ARQ scheme (also known as packet combining scheme). The EARQ technique is the extension work of Sindhu[23]. Chakraborty deduced that if there is no double error (double error is defined as "when two copies are erroneous, there is at least one bit position in which both copies have an error"), throughput of EARQ or modified SRQ is given as:

$$\nu(\text{chakraborty}) = 1/(1+P)$$

where P is the probability that the packet is in error. In that consideration the throughput of the conventional SWARQ[5] will be:

$$\nu\,(\text{SWARQ}) = (1 - P)$$

Hence their ration is $(1 - P^2)$. When P = 0, both are same but when P=1, the throughput of SWARQ = 0 and that of Chakraborty's technique = 0.5.

The operation of the Chakraborty's technique fails when double error occurs. The probability P(i,j) that two copies with i and j errors, respectively, have a double error is given as:

$$P(i,j) = 1- [(n - i)!\ (n-j)!/\ n!\ (n-i-j)!]$$

The EARQ technique is found suitable when the packet size is small. On the other hand, the processing of the receiver increases in the technique. Besides, the technique fails if error occurs at least at the same location of both the retained erroneous packet and the retransmitted packet.

The complexity of the bit inversion process to get correct copy is given as:

$$C = 2^{\,2n\alpha} - 2$$

where α is BER. In order to avoid the complexity, it was suggested that when number of 1s under XOR operation exceeds a certain number, N_{max}, the pair is discarded, and a retransmission is requested. In such cases,

$$P(i,j) = \begin{cases} 1-[(n-i)!\ (n-j)!/n!(n-i-j)!] & \text{if } i+j <= N_{max} \\ = 1 & \text{if } i+j > N_{max} \end{cases}$$

III. Modified Packet Combining Scheme(MPC)

We propose a Modified Packet Combining (MPC) technique. In the MPC technique, on getting a retransmission call from the receiver the transmitter can send i (i>1) copies of the requested packet. Receiver getting i copies, can now make a pair-wise xored to locate error positions. For example if i=2, we have three copies of the packet (Copy-1=the stored copy in receiver's buffer, Copy-2=one of the retransmitted copies, Copy-3=another retransmitted copy) and three pairs for xor operation:

Copy-1 and Copy-2
Copy-2 and Copy-3

Table(I) Algorithm of MPC

Comparing pairs	Number of bits in error (x)	Common copy in two consecutive (x)
Copy-1 and Copy-2	1	Copy-1 common in first two xs
Copy-1 and Copy-3	2	Copy-3 common in next two xs
Copy-3 and Copy-2	3	Copy-2 common in next two xs

Copy-3 and Copy-1

Assume that an actual packet 10100011 was received as:

Copy-1 = 10101011
Copy-2 = 10101111
Copy-3 = 10100001

when we have under xored operation:

Copy-1 xored Copy-2 (say, C_{12})= 00000100 (one bit in error)

Copy-2 xored Copy-3 (C_{23}) = 00001110 (three bits in error)

Copy-3 xored Copy-1 (C_{31})= 00001010 (two bits in error).

Now we have to define with which copy the bit inversion will start and how to proceed thereafter. We define an algorithm for the purpose as below. Make a table (see Table(I)) in ascending order of number of bits in error as indicated by the xor operation. The bit inversion and the FCS checking process shall begin with the common copy indicated in the last column of the table so prepared, and proceed down the table if required. If all the inversions do not yield any result, the receiver has to go for requesting further retransmission as in EARQ of Chakraborty et al. As per table(I) in this example, the detection of error location and consequent bit inversion will start with Copy-1 and if required will be followed by Copy-3 and then by Copy-2.

On the first retransmission and subsequent application of MPC, if the result does not yield, retransmission for the second time may be done with variable i. Second retransmission may be done with i=4 . Copies received on earlier retransmission and first transmission are kept at the receiver. With i=4 at second retransmission, we have 7 copies for comparisons and we have the followings obtained by different pairs under XOR operations:

C_{ij} for i=1 to 7 and j=1 to 7 but i≠j

i.e we are having: C_{12}, C_{13}, C_{14}, C_{15}, C_{16}, C_{17}, C_{23}, C_{24}, C_{25}, C_{26}, C_{27}, C_{34}, C_{35}, C_{36}, C_{37}, C_{45}, C_{46}, C_{47}, C_{56}, C_{57}, C_{67}. These are typically like the parameters used in topological design of users' sub network using Easu-William algorithm[24].For the purpose of correction we can follow the procedure described earlier using table like that of table(I). But in the present case we may not get common copy between two successive rows. In that case, correction process may be started with individual copy starting with the copy having lowest numbers of bit in error. We illustrate with an example.

Example:

We assume an original data 1010101001010100. We shall underline the bit(s) in error, but these are unknown to the receiver.

We assume that on first transmission the copy was received as:

Copy-1 = $101010\underline{0}001010100$

On the first retransmission with two copies (i=2), we assume that the received copies were:

Copy-2 = $\underline{0}0101010\underline{1}101010\underline{1}$

Copy-3 = $1010101\underline{1}01010100$

On the second retransmission with four copies (i=4), we assume that the copies were received as:

Copy-4 = $10101010010101\underline{1}0$

Copy-5 = $\underline{01}1010100101010\underline{1}$

Copy-6 = $\underline{0}01010100101010\underline{1}$

Copy-7 = $10\underline{0}0101001010101\underline{1}$

Thus on XOR operation between two different pairs of copies, we have the followings. On the sides of C_{ij} we have mentioned the number of locations having 1 (i.e. number of bit positions where difference in bits between comparing pairs of copies are identified) in the first bracket:

C_{12} = 1000001010000001 (4)
C_{13} = 0000001100000000 (2)
C_{14} = 0000001000000010 (2)
C_{15} = 1100001000000001 (4)
C_{16} = 1000001000000001 (3)
C_{17} = 0010001000000001 (3)
C_{23} = 1000000110000001 (4)
C_{24} = 1000000010000011 (4)
C_{25} = 0100000010000000 (2)
C_{26} = 0000000010000000 (1)
C_{27} = 1010000010000000 (3)
C_{34} = 0000000100000010 (2)
C_{35} = 1100000100000001 (4)
C_{36} = 1000000100000001 (3)
C_{37} = 0010000100000001 (3)
C_{45} = 1100000000000011 (4)
C_{46} = 1000000000000011 (3)
C_{47} = 0010000000000011 (3)
C_{56} = 1000000000000000 (1)
C_{57} = 1110000000000000 (3)
C_{67} = 1010000000000000 (3)

The list of C_{ij}s' with the ascending order of the number of 1s in them is, therefore:

C_{26}
C_{56}
C_{13}
C_{14}
C_{25}
....
....
......
......
......
C_{24}
C_{35}
C_{45}

The correcting process now be started as:

Step-I: As C_{26} is the first in the list, we shall have to apply bit inversion technique successively in copy 2 and in copy 6 for correction. But in applying, bit inversion on 9th bit location, as indicated by $C_{26,}$ on both the copies we do not get back the corrected data.

Step-II: We repeat the process with next in order of the list, C_{56}, but fail to correct.

Step-III: We repeat the process with next in order of the list,C_{13}, but fail to correct.

Step-IV: We repeat the process with next in order of the list, C14. Applying the bit inversion to the bit location 7th of Copy-1, (rule is applied first at a single location one after another for all the locations indicated in error, then with possible pairs, etc), we get the correct copy. The correcting process stops now.

The disadvantage of MPC is that more processing is required in the receiver.

The advantages of MPC over Chakraborty's scheme are:

(1) double bit error may be corrected in MPC,
(2) throughput efficiency is comparable, and
(3) by varying i, variable bit rate channel may be controlled.

IV.MPC with Error Forecasting Decoding

The error forecasting decoding has been investigated in correction of burst error. The decoding is properly applicable to the interleaving technique of correction. We propose the application of error forecasting technique in packet combining scheme. The technique is applicable to both random and burst error correction and is illustrated with an example:

A. CASE OF RANDOM ERROR

Original packet number 1 = 01010101

Received packet number 1 = 11010101 (erroneous copy 1)

Retransmitted received packet number 1 = 00010101(erroneous copy 2)

1. Apply original packet combining technique to correct error
2. Keep track of the error location for correction of the next packet if required.

Original packet number 2 = 00110011

Received packet number 2 = 01110011

3. Apply error forecasting technique to correct error in the received erroneous second packet. Assume error is in the same location as in the first packet, and change bit from 0 to 1 or vice versa. See correction is achieved or not. If correction is made, stop; and be ready to receive third packet. If correction is not achieved as per forecasting technique repeat the process for neighboring bits. For example if the error bit location in the first packet is first bit from left, check for second from left. If it is second from left, check for first and third from left.

B. CASE OF BURST ERROR

In case of burst error, the interleaving technique be used. Assume a (4,5,4) interleaving packets for the purpose of illustration in table (II) where only simple parity is applied in packet of one byte. Assume error locations on transmission as in table (III). Then we propose to apply the packet combining and forecasting as in table(IV) for correction.

Table (II): Original interleaved packets

01010101
11111111
00010001
10101010

Table (III): Burst error position assumed occurred at location x.

01xx0101
111xxx11
0xx10001
101xx010
Use parity on column

Recently a composite GBN is proposed by this author. In high error rate condition, both the multicopy GBN and truncated packet GBN may be employed together rather than either of the schemes. As and when the link is found to be in high error rate condition, any packet before transmission is to fragmented in parts so as to make mini packet and a multicopies of mini packet are to be transmitted. The application of the both the schemes adds up the benefits of both the scheme. The proposed work in this paper may be combined with composite GBN to implement a protocol for efficient error control in high error rate channel. The composite technique offers better throughput in selected environment. Only limitation is it's a bit higher complexity in implementation. The application of mini packet with multicopy apparently will increase overhead bits. But as the multicopies to be transmitted for correct reception will be less, the overhead bits increased in mini packets will be compensated.

Table(IV): Application MPC and Forecasting

0101	No error
11x0	Error detected. Call for retransmission apply MPC
x1x1	Apply forecasting in all other erroneous packets
Xx1x	
0x0x	
1x00	
0101	
1110	
0000	

V. Throughput Comparison

The throughput of both packet combing and modified packet combining will be higher than the throughput of any basic ARQ technique, namely Stop & wait, Go-Back-N (GBN) and selective repeat request. This is because in the packet combing and in the modified packet combing technique the receiver corrects the erroneous packet with the available copies of erroneous packets received earlier by the receiver, and not by the repeated retransmissions till the receiver gets correct copy as in basic ARQ techniques. The throughput depends on the bit error rate of the channel, α or otherwise on the packet error probability, P. In basic stop & wait ARQ technique, the average number of times a packet needs transmission / retransmission before it is correctly received is 1/(1-P), and the throughput is proportional to (1-P). In basic GBN the throughput is (1-P)/ [1+(N-1)P]. When the packet combining scheme or modified packet combining scheme is applied, any packet with the single or the multiple bit error may be corrected with available erroneous copies without requiring repeated retransmission till a correct copy is received. This logically amount to reducing the value of P as below:

$$P_{s\ (\text{for single bit error correction with packet combing})} = P - [\ {}^{n}C_{1}\ \alpha\ (1-\alpha)^{(n-1)}\ ]$$

$$P_{d\ (\text{for double bit error correction with modified packet combing})} = P - \sum_{1}^{2} [\ {}^{n}C_{i}\ \alpha^{i}\ (1-\alpha)^{(n-i)}\ ]$$

As $P > P_s > P_d$, the throughput will be higher both in the packet combing and the modified packet combing schemes than that in basic schemes.

VI. Conclusion

The modified packet-combining scheme is superior to the packet-combining scheme suggested by Chakraborty. The advantages are discussed. The major advantage is that by the modified packet-combining scheme, multiple bit errors will be corrected by the receiver. Besides, this advantage is achieved with the copies received at the receiver, thereby saving the retransmission delay. Of course this is at the cost of required additional memory at the receiver. The advantages in hybrid application of MPC and Forecasting decoding lies in decreasing retransmission delay, but at the cost of higher decoding complexity which remains a scope of further research.

The techniques proposed in the work may be coupled with recent schemes of selective ARQ, Truncated ARQ and integrated approaches of security and error control[25]. Particular interest will be to couple the present work with composite GBN.

References:

[1] C T Bhunia, A Few Modified ARQ Techniques, Proceedings of the International Conference on Communications, Computers & Devices, **ICCCD-2000**, 14-16, Decedmber'2000, I I T, Kharagpur, India, Vol.II, pp. 705-708

[2] C T Bhunia and A Chowdhury, ARQ Technique with Variable Number of Copies in Retransmission, Proceedings of Conference on Computer Networking and Multimedia (**COMNAM-2000**), 21-22 December'2000, Javadpur University, Calcutta, India, pp.16-21

[3] C T Bhunia and A Chowdhury, Performance Analysis of ARQ Techniques used in Computer Communication Using Delay as a Parameter, Proceedings of Conference on Computer Networking and Multimedia (**COMNAM-2000**), Jadavpur University, Calcutta, India, pp.22-24.

[4] C T Bhunia, ARQ with two level coding with generalized parity and i (i>1) copies of parts in retransmission, Proceedings of National Conference on Data Communications (**NCDC-2000**), Computer Society of India, Chandigarh, India, 7-8 April'2000, pp.19

[5] C T Bhunia, ARQ Techniques: Review and Modifications, Journal IETE Technical Review, Sept-Oct'2001 Vol18, No 5, pp 381-401

[6] R J Beniece and A H Frey Jr, An analysis of retransmission schemes, IEEE Trans Comm Tech, COM-12, pp 135-145, Dec 1964

[7] S Lin, D Costello Jr and M J Miller, Automatic repeat request error control schemes, IEEE Comm Mag, 22, pp 5-17, Dec '1984.

[8] A R K Sastry, Improving Automatic Repeat Request (ARQ) Performance on Satellite Channels Under High Error Rate Conditions, IEEE Trans Comm, April'77, pp 436-439.

[9] Joel M Morries, On Another Go-Back -N ARQ Technique For High Error Rate Conditions, IEEE Trans Comm, Vol 26, No 1, Jan'78, pp 186-189.

[10] E J Weldon Jr, An Improved Selective Repeat ARQ Strategy, IEEE Trans Comm, Vol 30, No 3, March'82, pp 480-486.

[11] Don Towsley, The Shutter Go Back-N ARQ Protocol, IEEE Trans Comm, Vol 27, No 6, June'79, pp 869-875.

[12] Dimirti Bertsekas et al, Data Networks, Prentice Hall of India, 1992, Ch-2
[13] G E Keiser, Local Area Networks, McGrawhill, USA, 1995
[14] N D Birrell, Pre-emptive retransmission for communication over noisy channels, IEE Proc Part F, Vol 128, 1981, pp 393-400.
[15] H Bruneel and M Moeneclacey, On the throughput performance of some continuous ARQ strategies with repeated transmissions, IEEE Trans Comm, Vol COM m34, 1986, pp 244-249.
[16] Y wang and S Lin, A Modified Selective Repeat Type-Ii Hybrid ARQ System and its Performance Analysis, IEEE Trans Comm, Vol Com 31, May'1983, pp. 593-608.
[17] S B Wicker and M J Bartz, Type-II Hybrid ARQ Protocol using Punctured MDS Code, IEEE Trans Comm, Vol 42, Feb-March-April'1994, pp. 1431-1440.
[18] Shyam S. Chakraborty et al, An ARQ Scheme with Packet Combining, IEEE Comm Lettters, Vol 2, No 7, July'95, pp 200-202.
[19] Shyam S Chakraborty et al, An Exact Analysis of an Adaptive GBN Scheme with Sliding Observation Interval Mechanism, IEEE Comm Letters, Vol 3, No. 5,May'99, pp 151-153.
[20] Shyam S Chakraborty et al, An Adaptive ARQ Scheme with Packet Combining for Time Varying Channels, IEEE Comm Letters, Vol 3, No 2, Feb'1999, pp 52-54.
[21] Katsumi Sakakibara, Performance Analysis of the Error-Forecasting Decoding for Interleaved Block Codes on Gilbert-Elliot Channels, IEEE Trans. On Communication, Vol 48, No 3, March' 2000, pp. 386-395
[22] J R Yee et al, Evaluation of performance of error correction codes on a Gilbert channel, IEEE Trans. On Communication, Vol 43, Aug'1995, pp.2316-2323.
[23] P S Sindhu, Retransmission Error Control with memory, IEEE Trans Comm, Vol COM 25, May'1977, pp. 473-479.
[24] V Ahuja, Design and Analysis of Computer Communication Network, McGraw Hill. 1982.
[25] C T Bhunia, Works are reported in paper format to different International Journals.