INTERNATIONAL JOURNAL FOR TRENDS IN ENGINEERING & TECHNOLOGY
VOLUME 4 ISSUE 2 – APRIL 2015 - ISSN: 2349 - 9303

Survey on Error Control Coding Techniques

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Abstract - Error Control Coding techniques used to ensure that the information received is correct and has not been corrupted, owing to the environmental defects and noises occurring during transmission or the data read operation from Memory. Environmental interference and physical effects defects in the communication medium can cause random bit errors during data transmission. While, data corruption means that the detection and correction of bytes by applying modern coding techniques. Error control coding divided into automatic repeat request (ARQ) and forward error correction (FEC).First of all, In ARQ, when the receiver detects an error in the receiver; it requests back the sender to retransmit the data. Second, FEC deals with system of adding redundant data in a message and also it can be recovered by a receiver even when a number of errors were introduce either during the process of data transmission, or on the storage. Therefore, error detection and correction of burst errors can be obtained by Reed-Solomon code. Moreover, the Low-Density Parity Check code furnishes outstanding performance that sparingly near to the Shannon limit.

Index Terms-Error control coding (ECC), Forward Error Correction (FEC), Reed-Solomon (RS) code, Redundancy,Low- Density Parity Check (LDPC) code.

1 INTRODUCTION

Error detection and correction helps in transmitting data in a noisy channel to transmit data without errors. Specifically, Error detection refers to detecting errors if any, received by the receiver and correction is to correct errors received by the receiver [5].

Error correction and detection achieved by two methods:

(i) Automatic Repeat Request
(ii) Forward error correction

First of all, Automatic Repeat Request is an error control technique whereby an error detection scheme combined with requests for retransmission of incorrect data. Second, Forward error correction is an error correction method, correcting the errors without retransmission of data and adding redundancy to the message, to recover the original data in the receiver.

Especially, In Forward error correction, the receiver does not ask to retransmit the data again and also error is corrected and suitable for simplex communication such as broadcasting.

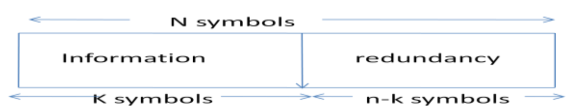

Fig.1.systematic block encoding for error correction.

Figure 1 show that systematic block encoding for error correction.ECC can be divided into two classes.convolutional codes and Block codes. Convolutional codes are processed on a bit by bit basis and here the sequence of messages modified into the sequence of codes. Hence, the encoder needs memory as the bestow code is the combination of the present and the past message. In addition, they are suitable for hardware implementation and also Viterbi decoder allows optimal decoding.

First of all, Block codes are processed on a block by block basis. Second, no memory required for block codes and these codes called as repetition codes, hamming codes, cyclic redundancy check & BCH codes. Specifically, LDPC & Turbo codes have recent constructions that can provide almost optimal efficiency.

2 ERROR DETECTION SCHEMES

2.1 Parity Check

Error detection means that detecting errors and it can be achieved through parity bits or CRC. Of course, one extra bit added to the message to create the number of 1's either, even in the case of even parity or odd in case of odd parity.

The drawback of this method, if a single bit error takes place, then the receiver can detect it by counting the number of 1's. But when more than one bit is in error it is sparingly difficult for the receiver to detect the error.

2.2 Checksum

The Checksum has to be determined in the transmitter and sent with the real data. However in receiver, checksum is done and compare with the received checksum .Besides that, a mismatch is an indication of the error.

The drawback of this scheme as data and checksum has received with an error and then the detection may not be possible.

2.3 Cyclic Redundancy Check

At first, the message interpreted as polynomial and it can be divided by a generator polynomial. Then the reminder of the division added to the actual message polynomial to form a code polynomial. Besides that, the code polynomial is invariably divisible by the generator polynomial. This property has been checked by the receiver. If failed to satisfy this property the received code word has error. Finally, it was complex but efficient error detection scheme.

3 ERROR CORRECTION SCHEMES

3.1 Hamming code

Hamming codes are the first class of block codes for error correction. Besides that, it can be used to detect single and double bit errors and corrects single -bit errors.

Design of hamming code as (n,k,t) code refers to an 'n' bit codeword having 'k' data bits and 'r'(n-k) redundant bits having capability of correcting 't' bits in the error('t'- corrupted bits).the hamming rule defined as

$$2^k \geq n+k+1$$

Rule1:

(i)All bit positions that are of the form 2^j are used as data bits.

(ii)The remaining positions can be used as message bits(like 3,5,6,7,9,10,11,12,13,14,17,18…….)
To illustrate that, code will be in the form of

P1 P2 D3 P4 D5 D6 D7 P8 D9 D10 ……………..

Where P1, P2, P4, P8 are parity bits
D3, D5, D6, D7 are data bits

The drawback of this scheme, if more than one bit has an error then it will cause a system to malfunction.

3.2 BCH Code

BCH code can be the form of a large class of puissant random error correcting cyclic codes. Binary BCH codes discovered by Hocquenghem in 1959 and independently by Bose & Chaudhuri in 1960.Additionally BCH code have the generalization of hamming codes for multiple error correction.

These codes are imperative for two reasons:

1. Simple decoding scheme.
2. The class of BCH code is quite large. Indeed, for any positive integers r and t with $t \leq 2^{r-1}-1$, there is a BCH code of length $n=2^r-1$ that is t-correcting and has dimension $k \geq n-rt$.

3.3 Reed-Solomon code

Specifically, RS code used for the successful forward error correction code in practice today. Consequently, It can correct multiple and long burst errors with a relatively high code rate and the number of errors in the code can correct depends upon the amount of parity bits added. In any number of bits within the symbol are corrupted, after that RS code can correct the entire symbol [6].Figure 2 shows that RS(n,k) code in systematic form.

RS code can correct errors in the wide range of systems in digital communications. RS codes widely used in Compact Discs, DVDs, Barcodes and wireless and mobile communications. Accordingly it is also used in satellite communications and broadband modems.

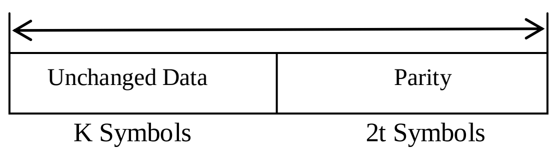

Fig.2 RS (n,k) code

A t-error correcting RS code with symbols from GF (q) has following parameters:

Block length: $n = q-1$
Number of parity-check digits: $n-k = 2t$
Minimum distance: $d_{min}=2t+1$

Construct a t- error correcting RS code of length q-1 with entries in GF (q).find the primitive element α€GF(q).The dimension of the code is k=q-2t-1.

Error correction capacity= (length-dimension)/2.

For encoding process, initially find the generator polynomial

$$g(x) = \prod_{i=1}^{2t} (x - \alpha^i) \quad \text{............ (1)}$$

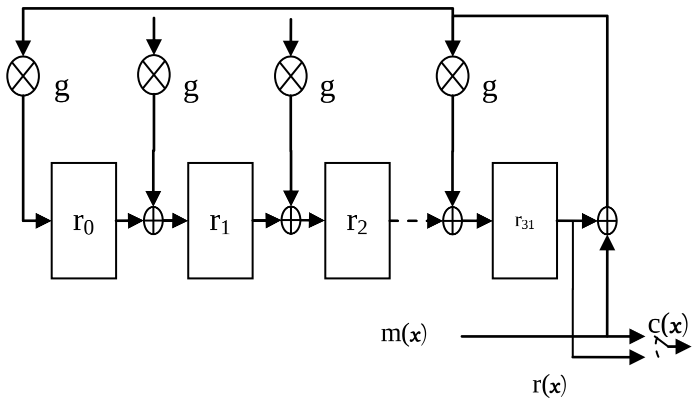

Fig.3 LFSR Encoder circuit for an RS code

The message polynomial M(X) is the order of k-1,

$M(x)=M_{k-1}\, x^{k-1}+\ldots\ldots+M_1x+M_0$ ....(2)

Where each of the coefficients M_{k-1}, M_1, M_0 …………….. as m-bit message symbol.

First of all, to encode the information, the message polynomial multiplied by X^{n-k} and the result is divided by g(x), the remainder called as parity check polynomial P(x).

Finally, Codeword as formed in systematic form.

$C(x) = M(x) + P(x)$…………….(3)

In decoding the process, errors can be added with the coded message polynomial E(x).

The received polynomial is

$R(x) =C(x) +E(x)$…………..(4)

Where $E(x) =E_{n-1}x^{n-1}+\ldots\ldots+E_1x+E_0$………(5)

The decoding steps are,

i) Syndrome calculation: error detection

ii) Key equation solver -To find the coefficients of the error locator polynomial.

iii) Chien search algorithm-To find the roots of the error locator polynomial.

iv) Forney algorithm- To find the value of the errors.

As a result, we can correct the received codeword by XORing the received vector with the error vector.

3.4 Low Density Parity Check Code

At first, LDPC (Low-Density Parity Check) codes are a class of linear block code. The term "Low-Density" refers to the characteristic of the parity check matrix which contains only a few '1's in comparison to '0's. Especially, LDPC codes are arguably the best error correction codes in existence at bsetow. LDPC codes were first introduced by R. Gallager in his PhD thesis in earlier 1960 and soon forgotten due to the introduction of Reed-Solomon codes and the implementation issues with limited technological know how at that time. In addition, the LDPC codes were rediscovered in mid-90s by R. Neal and D. Mackay at the Cambridge University [1].

As a result, it has better block error performance which exactly close to Shannon limit.

An (n, k) block code takes k bits (message bits) at a time and produces n bits (code bits).adding the redundancy make that the errors correction.

$u= [u_0\ u_1\ u_2\ldots\ldots u_{k-1}]$

$c= [c_0\ c_1\ c_2\ldots\ldots c_{n-1}]$

Where u be collection of k message bits,

c be the collection of n encoded bits called as a codeword.

Code rate: r =k/n.

Codeword encoded through the generator matrix,

C=u*G

For every generator matrix, there exist many parity check matrices that satisfy

$G*H^T=0$

Where $G= [I_k\ \ P]$

$H = [P^T\ \ I_{n-k}]$

P = Parity check matrix

LDPC Code represented by parity check matrix H that must satisfy

$c.H^T= 0$

where codeword denoted as c.

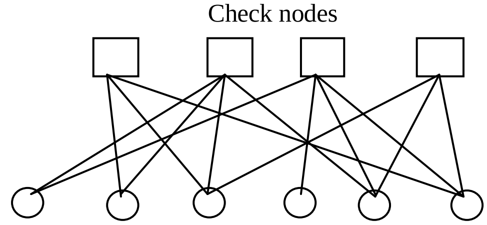

Fig. 4 Tanner graph representation of a parity check matrix.

Figure 4 shows that tanner graph representation of a parity check matrix. Here, Decoding can be the decision process which finds a codeword that minimizes the probability of decoded error based on a received word.

Decoding algorithms are,

1. Sum product algorithm
2. Bit flipping algorithm
3. Min sum algorithm

Nowadays LDPC code used in DVB-S2 & Wi-MAX standard. Furthermore LDPC code can be used along with RS codes for OFDM application for high data rates. As a result, LDPC code as the strong candidate for 4G or 5G error correcting code.

3.5 Convolutional Code

In particular, Convolutional codes differ from block codes, the encoder contains memory and n encoder outputs at any time unit depends not only on the k inputs but also m previous inputs.

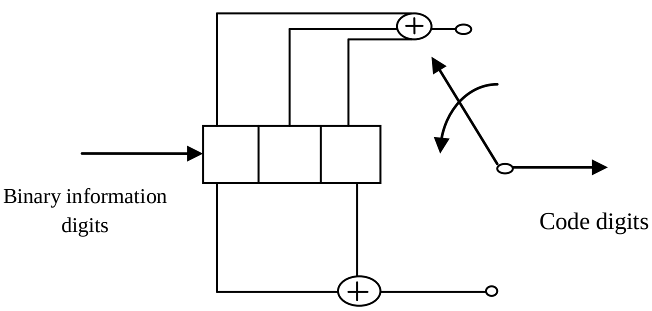

Fig.5 convolution code

In Figure 5, Convolutional code is generated by passing message sequence to be transmitted through a linear finite state shift register. Shift register contains k (k-bit) stages and linear algebraic function generators. Furthermore, Encoding is achieved by three methods, state diagram, trellis diagram and tree diagram.

In particular, Trellis diagrams are difficult but generally preferred over both tree and state diagrams because they represent linear time sequencing of events. The performance of the convolutional codes depends upon the decoding algorithm and also the distance properties of the code.

Different ways to decoding the convolutional codes.

1. Sequence decoding
   -fano algorithm
2. Maximum likelihood decoding
   -Viterbi decoding

F. Turbo codes

Turbo codes are the class of FEC codes developed in 1990.It is the concatenation of two convolutional codes. Hence, it can be concatenated either in serial, parallel or hybrid manner. In addition, Turbo codes yield better performance at low signal to noise ratio.

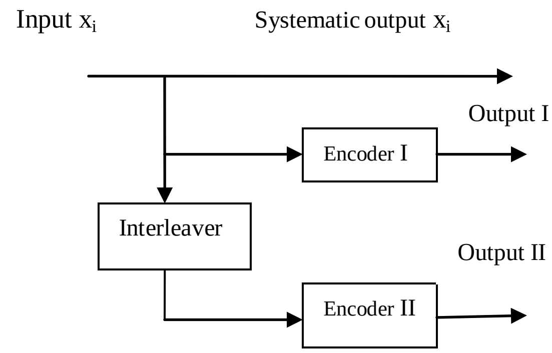

Fig.6 Block Diagram of the Turbo encoder

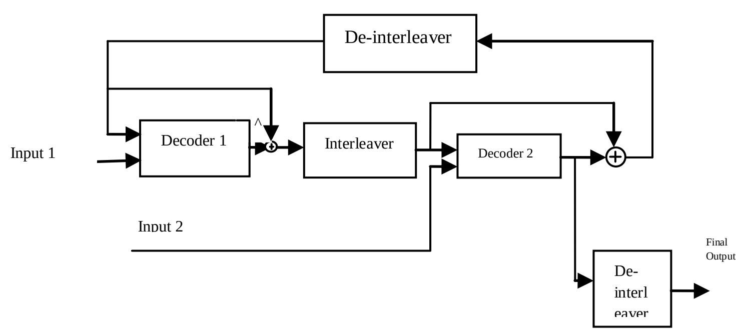

Fig .7 Block Diagram of the turbo decoder

In Figure 7, two component decoders are linked by inter-leaver in a structure manner similar to that of encoder.

Two suitable decoder methods are

i) Soft output viterbi algorithm

ii) Maximum posteriori probability

Usually, turbo codes are used for many commercial applications, including third-generation cellular systems UMTS and CDMA 2000.

4 CONCLUSION

To summarize that Hamming code correct only single bit error. RS code corrects both burst errors and random errors.BCH targets only single bit errors. However it is better than RS code, when we given the same parity check bits for both RS and BCH code. In particular, code with higher redundancy, can usually correct more errors because code rate is low. If more errors can be corrected, then the communication system operate with a lower transmit power and high data rate.

LDPC& turbo code has the same performance which is sparingly close to the Shannon's theorem. But LDPC does not require long inter-leaver to achieve better performance. In contrast, due to usage of inter-leaver, Turbo code has high latency than the LDPC code. To conclude that LDPC code have significantly lower complexity at performance, S/N ratio and code lengths.

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