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A Cascaded Bit Coupled Architecture for Turbo Codes for Error Detection and Correction with Puncturing

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Abstract: Internet of things (IoT) is being explored today for a wide variety of automated networks. However, once of the concerns associated with IoT is trustworthiness of data transfer which makes error detection and correction extremely important. In the proposed technique, the adjacent code block information and parity bits have been coupled so as to enhance upon the performance of the only information cup-led or partially coupled turbo coding technique. The interleaving technique has been kept as the block interleaving technique with row wise read and column wise write operations being done. Non adjacent code block coupling of the Information and Parity bits has not been employed deliberately so as to cut down on the already complex Bahl, Cocke, Jelinek and Raviv (BCJR) decoding mechanism for the turbo codes. In the proposed work, the BER analysis has been employed which clearly shows that the proposed technique attains lesser BER compared to previously existing technique which has been considered as the primary reference.

Keywords:* *Internet of Things (IoT), Trustworthiness, Information Theory, Turbo Codes, (BCJR) algorithm, recursive decoding, bit sharing, bit error rate.

I. INTRODUCTION

Turbo codes are a class of high-performance forward error correction (FEC) codes which show extremely good BER performance near the Shannon's limit. [1] For codes with

relatively large code length, the bit error rate or probability of error (P_e) approaches zero if the transmission rate is less than the channel capacity,[2] mathematically given by:

$$TR \leq Channel\ Capacity \qquad (1)$$

Here,
TR represents transmission rate through the channel. The Shannon's limit is BER of almost 10^{-5} (ideally 0) for $\frac{E_b}{N_0}$ = 0 dB for binary modulation. [11]

The turbo codes can be thought of as a parallel concatenation of Convolutional codes. The structure of the turbo encoder and decoder in a communication system is shown in the figure below.

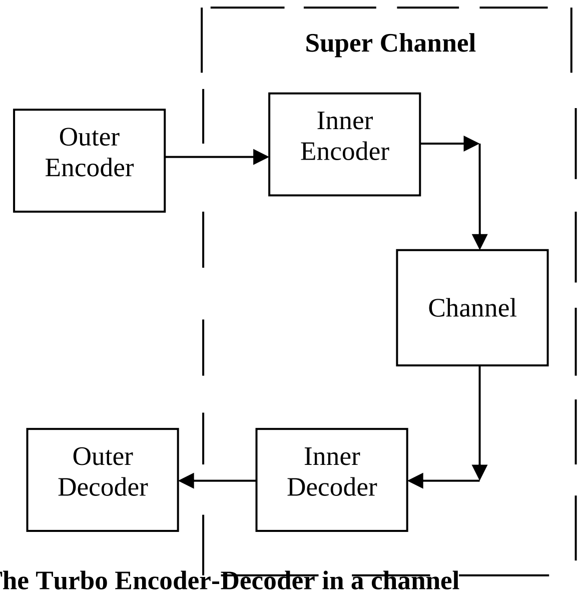

Fig.1 The Turbo Encoder-Decoder in a channel

The turbo encoding can be thought of as a two-step process comprising of the inner encoder and the outer encoder.[3] The inner encoder, channel and outer encoder is often termed as the super channel. The block diagram of the turbo encoder is shown below.

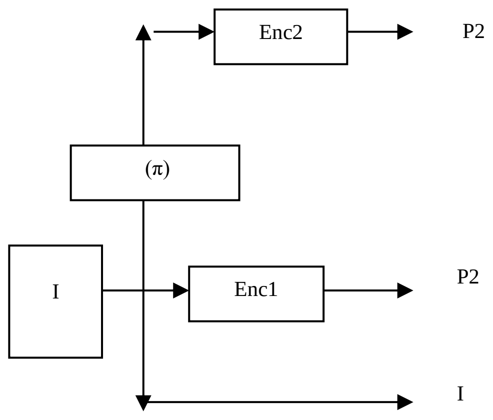

Fig.2 Turbo Code Encoding Mechanism [11]

The encoder inputs and outputs are:
Input: I
Outputs: I, P1, P2
Here,
I represents the information bits
P1 represents the Parity bit 1
P2 represents the parity bit 2
The interleaver is denoted by π

Turbo codes should look like random codes and the interleaver introduces the randomness. However, too much randomness can create a lot of decoding complexity. On the flipside, if the randomness is too low, i.e. there is too much structure in the code, then the code doesn't remain random at all.

II. TURBO ENCODING

The blocks in the turbo encoding part are:
1) Encoder 1
2) Encoder 2
3) Interleaver (π)

The information bit I is fed directly to one encoder and it's interleaved version is fed to the other encoder. The outputs of encoder 1, encoder 2 and he original information bit are fed to the channel. Often the output of encoder 1 is called parity bit 1, and the output of encoder 2 is called parity bit 2. If both the encoder structures are same, then such codes are called symmetric codes and they generally exhibit good convergence.

Encoder Structure:

The encoder structure is extremely critical for turbo code design. The encoder structure is a recursive feedback encoding mechanism. It results in large inter code distance in the trellis structure. The conventional turbo code or the systematic turbo encoder has one input and 3 outputs and hence has a coder rate of

$$r = \frac{1}{3} \qquad (2)$$

The recursive encoding structure can be understood as:

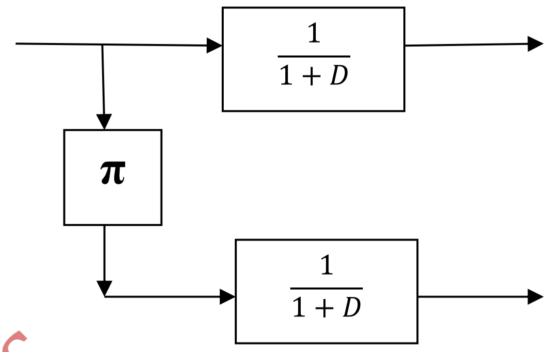

Fig. 3 Internal Encoder Structure

The recursive structure at the encoder is used in the form of the system response of $1 + D$
Generally, recursive encoder design renders better intercede distance. Moreover, the parallel concatenation is better than serial concatenation since parallel concatenation based codes terminating easily.
Considering the response of the encoder block as G(D), and the input as U(D)=1,we get:

$$U(D) = 1 \qquad (3)$$

$$G(D) = \frac{1}{1+D} \qquad (4)$$

Then, the output of the encoder1 will be:

$$V(D) = 1 + D + D^2 + \cdots \quad (5)$$

If the interleaver system function is given by

$$\pi = 1 + D^{n-1} \qquad (6)$$

Then, the input to encoder 2 will be,

$$V(D) = 1 + D^{n-1} \qquad (7)$$

Thus the interleaver spreads out the 1s in the input bit stream and feeds to encoder 2.This results in code word with large weights at the output.[7] This can be illustrated as:

Let the original information sequence be:

110000000000000

Then the interleaved bit sequence will be

1000000000000001

It can be seen that the bit 1 is spread out temporally in the code word.

The most common interleaver structure used is the block interleaver. It this structure, the interleaver is fed row-wise and data is read column wise and vice-versa.

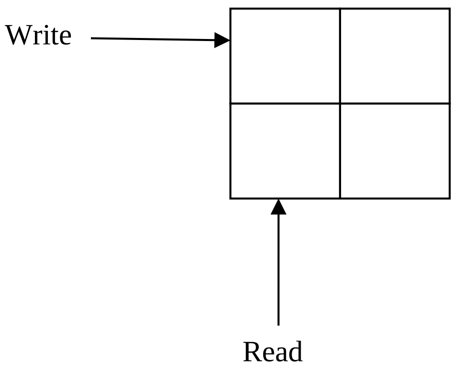

Fig.4 Block … structure

IV PUNCTURING

Puncturing is a technique of generating codes of higher rate. In this technique, some of the bits are not transmitted at every time slot. The following table illustrates the concept.[8]

Bit	Tx (Y/N)	Tx (Y/N)	Tx (Y/N)
I	Y	Y	Y
P1	Y	N	Y
P2	N	Y	N
	Time=t1	Time=t2	Time=t3

At t1, I and P1 are transmitted

At t2, I and P2 are transmitted

At t3, I and P1 are transmitted

Thus the $r = \frac{1}{3}$ code is converted to a $r = \frac{1}{2}$ code. Hence, by puncturing, higher rate codes are obtained. The receiver assumes that for the non-transmitted bit, there exists equal probability for 0/1 transmission i.e.

$$P(0) = P(1) \qquad (8)$$

V NOISY CHANNEL DESIGN

The channel assumed in this approach is the Gaussian channel with the frequency domain Power Spectral density of noise being constant.[10] Mathematically,

$$N(f) = k\forall f \qquad (9)$$

Here,

N stands for noise

k is a constant

f stands for frequency.

The time domain nature of the noise is random and resembles a random signal which is a function of time.

VI. TURBO DECODING

The turbo decoding mechanism is shown below.

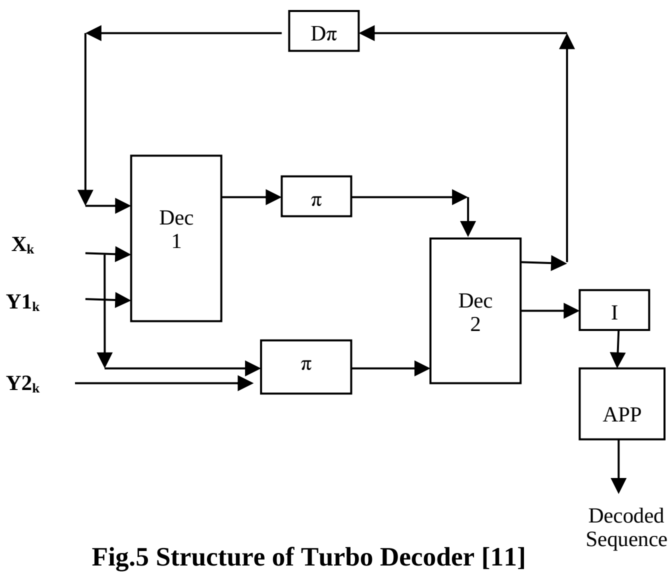

Fig.5 Structure of Turbo Decoder [11]

The turbo decoding mechanism uses two decoders working in synchronism in a recursive fashion.[5] Three inputs to both the decoders are the information bit X and the parity bit Y1 and

Y2, all of which come from the channel. The second decoder receives an interleaved version of the parity bit Y2 so as to retain the sequence of the data stream. [9] The input 4 is the apriori information of the bit that the other decoder thinks the bit to be. Hence, decoder 1 sends the estimation of a bit along with its probability to decoder 2 and the same process is repeated by decoder 2 and data is sent to decoder 1. Thus, in place of decoding the bit at one go, the decoder tries to decoder encoder 1 first followed by decoding encoder 2. The decoding is carried on recursively and stopped on setting a conditions on iterations. The final verdict about the information bit I is taken from the decoder 2 after computing the a posteriori probability (APP) using the following relations.

$$max^*(x,y) = \ln(e^x + e^y) \qquad (9)$$

or

$$max^*(x,y) = \max(x,y) + \ln(1 + e^{-|x-y|}) \qquad (10)$$

Here, x and y denote the probabilities of the bit being 0 or 1. Finally a hard decision output i.e. hard quantized output in the form of 1 or 0 is received.

VII SIMULATION AND RESULTS

The results obtained are plotted below:

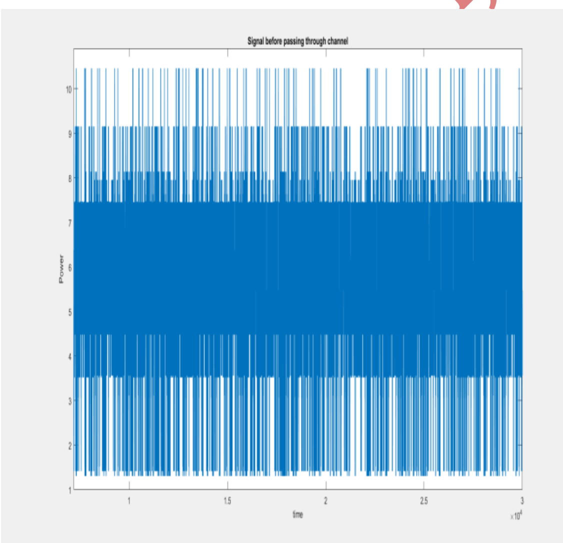

Fig.6 Original Signal before passing through channel

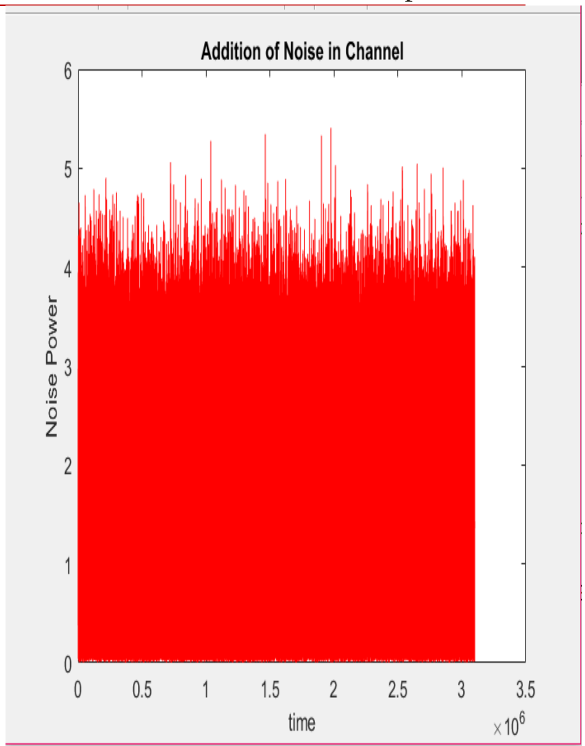

Fig.7 Addition of Noise in Channel

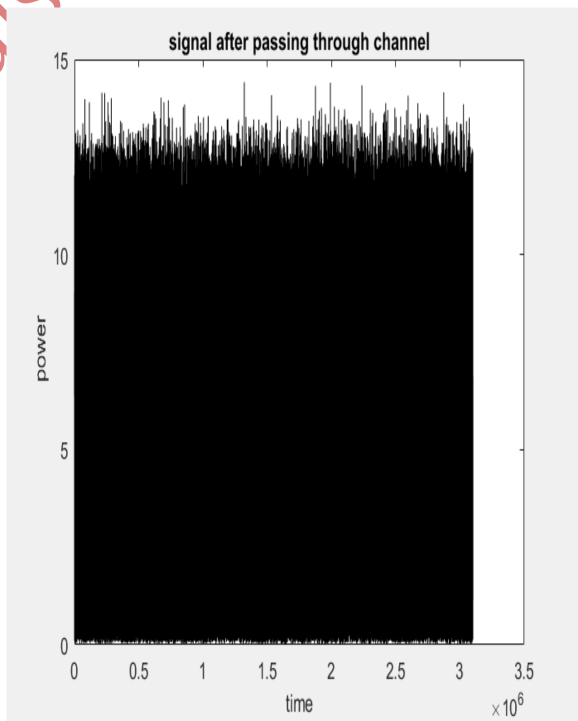

Fig.8 Signal after addition of noise

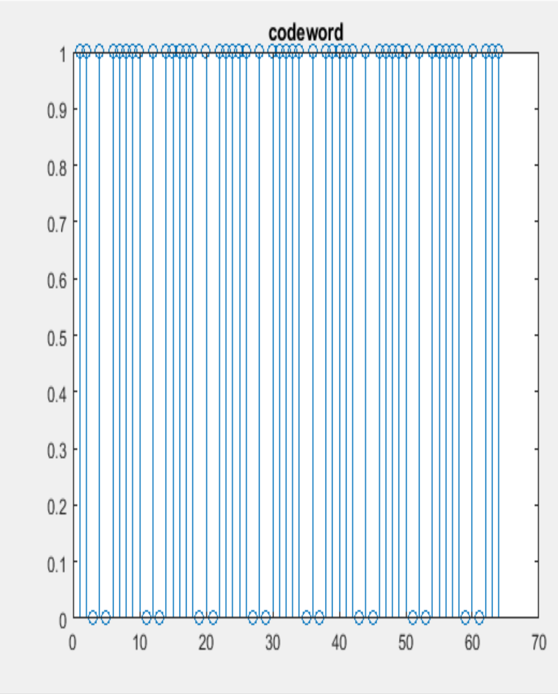

Fig.9 Codeword Generation

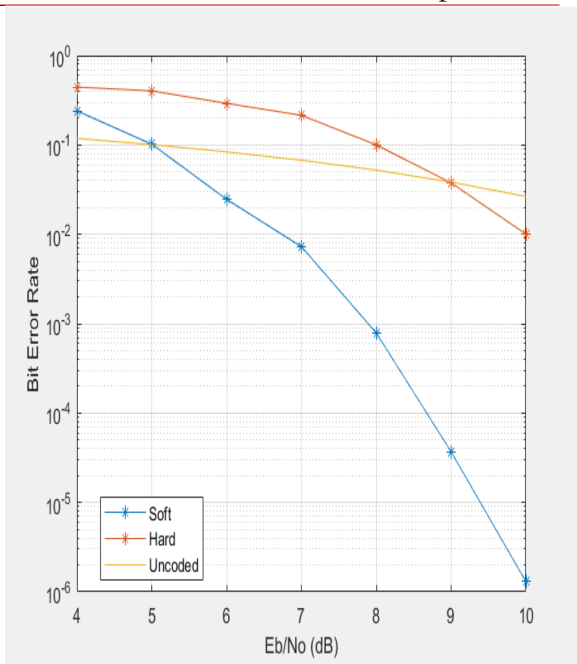

Fig.11 Comparative BER Analysis for Un-coded, Hard and Soft Decoding Structures

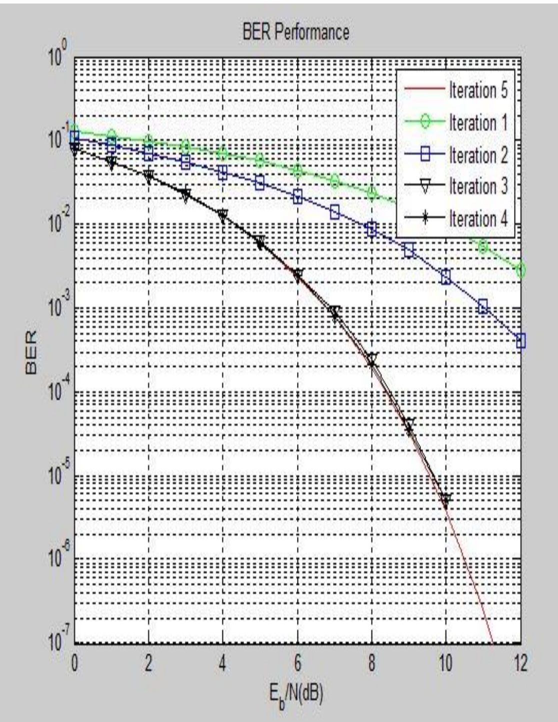

Fig.10 BER performance of system

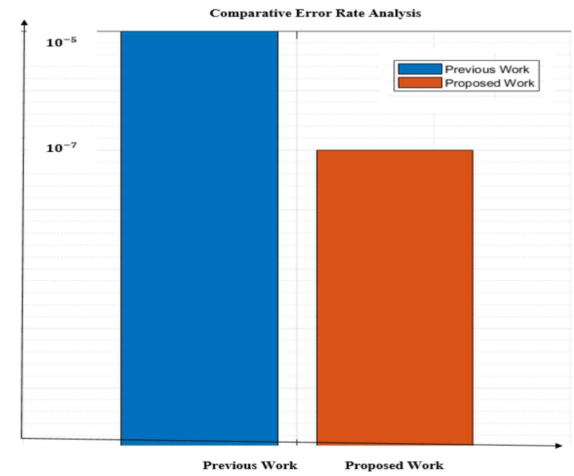

Fig.12 Comparison with Previous Work

Conclusion:

It can be concluded from previous discussions that turbo codes are effective in attaining low BER in the approaching the Shannon's limit. The system has been simulated on MATLAB. The results obtained and the related mathematical formulations that the proposed technique achieves

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