Improving the QoS of Wireless and IoT Networks Employing Bit Coupled Recursive Encoder-Decoder Architecture

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Abstract: The paradigm of IoT and wireless networks consist of a large number of low-power devices communicating over unreliable wireless channels. These devices are often deployed in harsh environments where noise, interference, fading, and packet loss are common. Reliable data transmission is therefore a critical requirement in IoT systems. Error detection and correction techniques play a vital role in ensuring data integrity without excessive retransmissions. Among advanced channel coding techniques, Turbo codes are known for their near-Shannon-limit performance and are highly effective in correcting errors in noisy communication environments. The proposed technique attains lower bit error rate performance compared to the conventional un-coded and hard coded counterparts. A comparative analysis with respect to the error rate has been done so as to evaluate the quality of service of the proposed work. The lower error rate of the proposed work ensures the high quality of service and trustworthiness of the IoT system.

Keywords: Internet of things, *Turbo Codes, trustworthiness, error rate, bit sharing.*

I. INTRODUCTION

One of the major challenges of the internet of things framework is the chances of bit flips in the data to be sent. A typical IoT framework is depicted in figure 1.

Fig.1 The IoT framework

The IoT framework owing to the wireless or unguided media has to be designed such that it exhibits satisfactory quality of service [1]. The metrics may be considered to be:

1) Error Rate
2) Throughput
3) Latency

Most of the parameters though could be managed under at least one governing constraint which is [2]:

$$Data\ Rate_C \leq Capacity_C \qquad (1)$$

Here,
$Data\ Rate_C$ is the actual data rate through the channel.
$Capacity_C$ denotes the permissible channel capacity of the IoT network.

The IoT framework typically exhibits a steep fall in the waterfall region of the error curve and then a diminishing error rate [3].

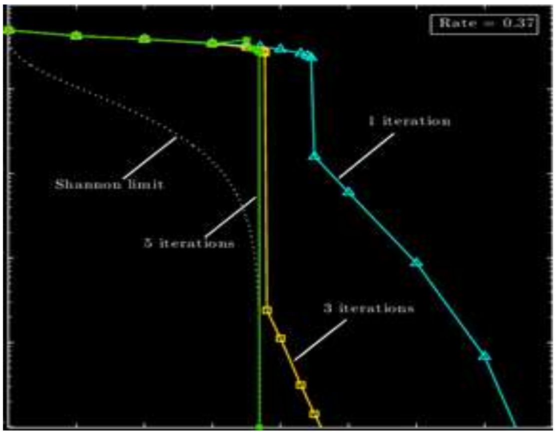

Fig.2 Typical error performance of Shannon's limit

The typical Shannon's limit is exhibited by a sharp fall in the bit error rate upto or beyond 10^{-5} for an SNR range of 0=10 dB [4]. Typically, the error drops as a function of the iterative decoding in several error detection and correction coding techniques [5]. One of the most effective error detection and correction mechanisms in this regard is the recursive turbo codes [6]-[7]. This category of codes show high adherence to the Shannon's limit [8]-[9]

The turbo encoding mechanism is typically described by the following attributes [10]:

1) Encoder
2) Decoder
3) Channel
4) Interleaver
5) De-interleaver
6) Recursive block

The encoding mechanism is depicted in figure 3.

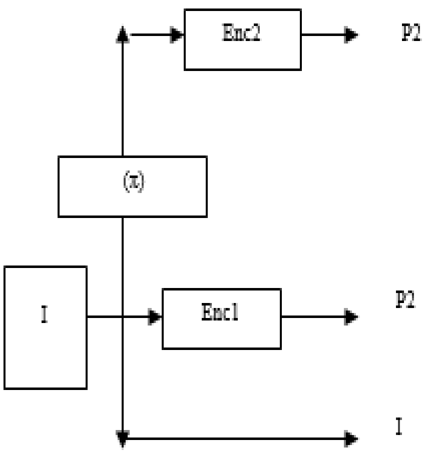

Fig.3 Turbo encoder

The turbo encoder is characterized by:
Input bits.
Parity bits
Here,
I represents the information bits
Interleaver π
Encoders

The encoding mechanism is typically performed in a way so as to enhance the reliability of the system [11]. This happens due to the fact that the encoder has three bits as the output for one bit as the input. The encoders are typically symmetric in nature or even asymmetric based on the type of encoder design [12]-[13]. The information bit shared is then passed on to render 3 bits which are [14]:

1) Same unaltered bit.
2) Encoded bit (P1)
3) Encoded bit (P2).

The difference among the bits P1 and P2 lie in the fact that both the bits are distinguished by the act of the interleaver. While the information bit 'I' directly goes to the encoder 1, the other encoder receives a modified version of the information bit [15]. The two encoders may or may not be similar. In case both exhibit a similar structure, the encoding is termed as symmetric encoding [16]. The role of the interleaver is exemplified in the next section.

II. INTERLEAVING AND PUNCTURING

The interleaving mechanism is fundamentally derived so as to reduce the burst errors in a network [17]. This can be understood through the following diagram.

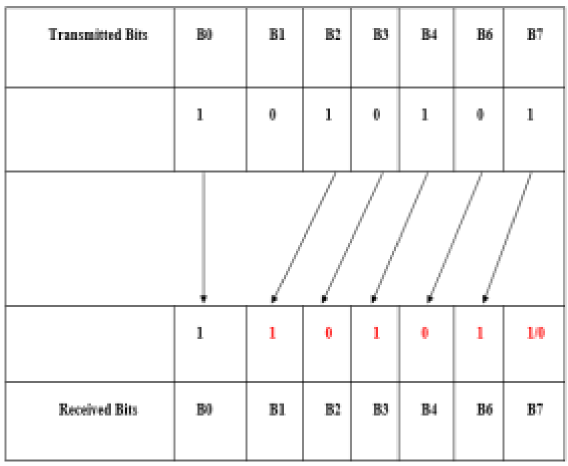

Fig.4 Burst Errors

The interleaving mechanism is fundamentally used to circumvent the domino effect of errors [18]. This can be seen form figure 4. As there is a missing bit in bit location 2, there is an error in bit 2 which is received by the receiver. The error progresses as the receiver doesn't have cognizance of the transmitters bits. This leads to a cascading progression of the bits and hence the error in one bit results in the errors in other multiple bits. This however can be mitigated in case, the error propagation mechanism is stopped [19]. The exact is done by the interleaver as the interleaver combines the bits into chunks and separates the correlation among the bits. This is however, true only for burst errors with memory and not for random errors [20].

While burst errors are bits which have a cascading effect, the random errors are the errors which can occur at any bit location at any given instance of time [21].

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

Fig.5 Puncturing

The puncturing mechanism is based on the planned non-transmission of the bits at some intervals of time. The information bit is not omitted but one of the most common techniques is to omit the parallel transmission of both the parity bits. This reduces the bit transmission rate of the system [22].

While the original coding rate is 1/3, the new coding rate remains only ½. This happens due to the suppression of one bit at a time [23].

III. TURBO DECODING

The major challenges with error detection and correction for IoT networks are [24]:

1. IoT networks are prone to noise and disturbance effects causing increase in bit error rate of the system. This decreases the reliability and trustworthiness of the system.

2. Often IoT networks are resource constrained in terms of memory and processing power. Hence coding techniques with relatively low computational complexity in terms of number of iterations are needed.
3. Lesser iterations are also needed to minimize the latency (delay) of the system as IoT networks can be used for time critical applications.

4. There exists a fundamental trade off between the number of iterations and Bit Error Rate (BER) of the system where higher iterations would result in lower BER but would significantly increase the system's latency and complexity.

Typically two deciders are employed for decoding in the cascading manner. The BCJR based algorithm is used for the decoding of the codes.

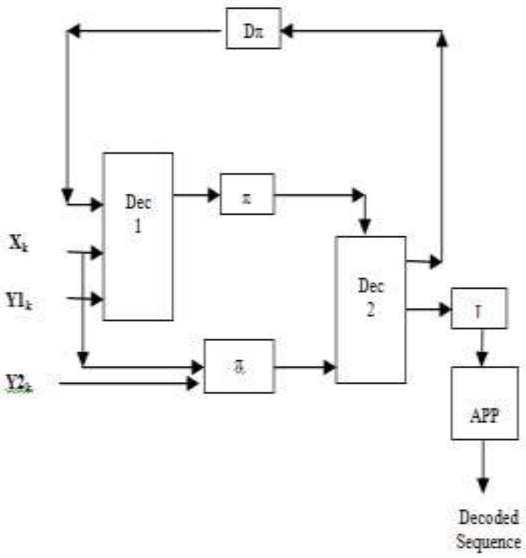

Fig.6 The turbo decoding mechanism

The figure above depicts the block diagram of the turbo decoder which comprises of two decoders. The interleaver is represented by (π) and the de-interleaver is represented by (Dπ).
The decoding process is done in a manner which incorporates both the decoders which are designated as D1 and D2. The information bit I and one of the parity bits is fed to decoders 1 and 2 respectively. Each of the decoders surmise the output based on the input information received, and the verdict of the other decider. Thus the feedback loop connects decider 1 and decoder 2's outputs in a recursive manner in which the iterative process takes place in the decoding mechanism. At the beginning of the decoding process, the output of any one of the decoders is considered to be equi-probable probabilities of 1 or zero occurring. However, the final bit pattern is considered at the output terminal of D2 [25].

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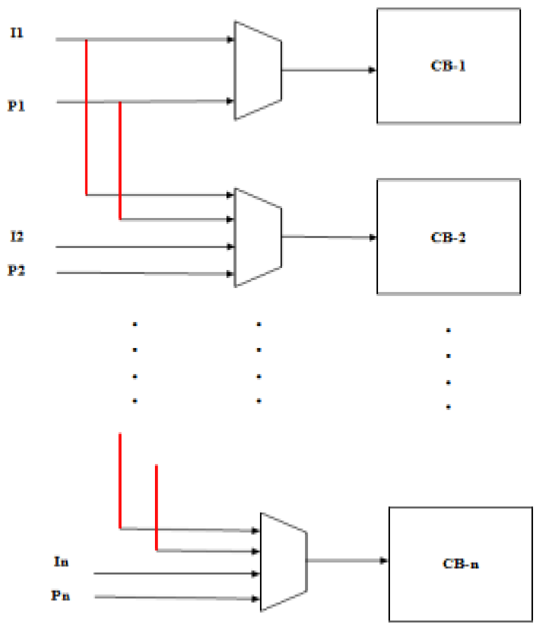

Fig.7 The proposed approach

In the proposed approach, both information and parity bits are coupled. Previous approaches do not have a method to couple both I & P.

In the proposed scheme, the information bits are designated by I and the interleaved bits are denoted by P. In this case, the n code blocks (CB) constitute a transport block (TB). The transport block vector (T) is segmented into 'n' code blocks

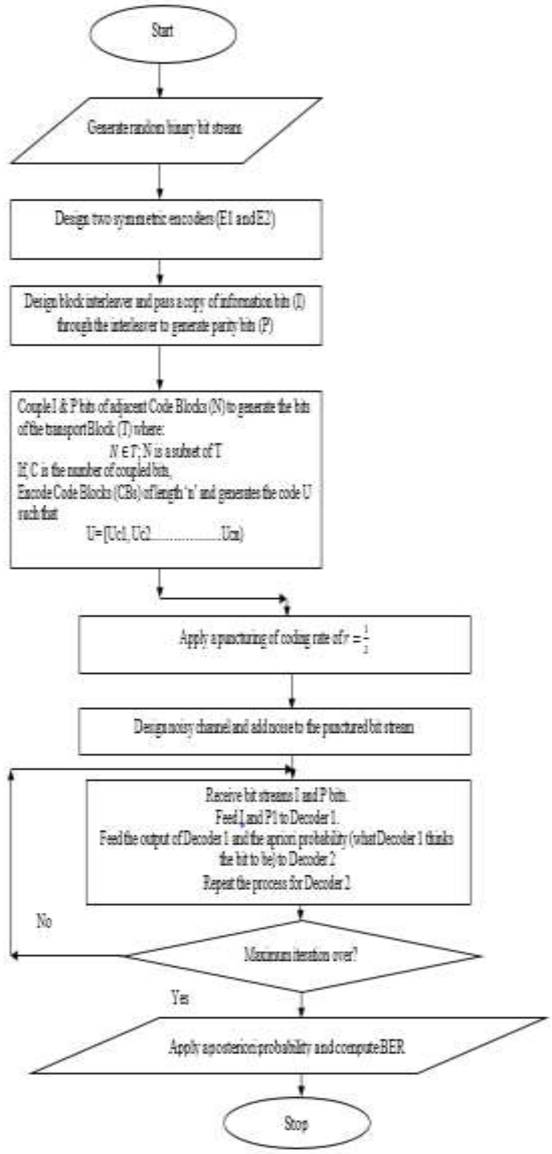

Fig.8 Proposed Flowchart

Figure 8 depicts the flowchart of the proposed system. The flowchart represents the sequential steps to implement the proposed system.

IV. EXPERIMENTAL RESULTS

The system has been designed on MATLAB. To emulate the actual data streams generated by a multitude of devices in an IoT network, random binary data has been generated.

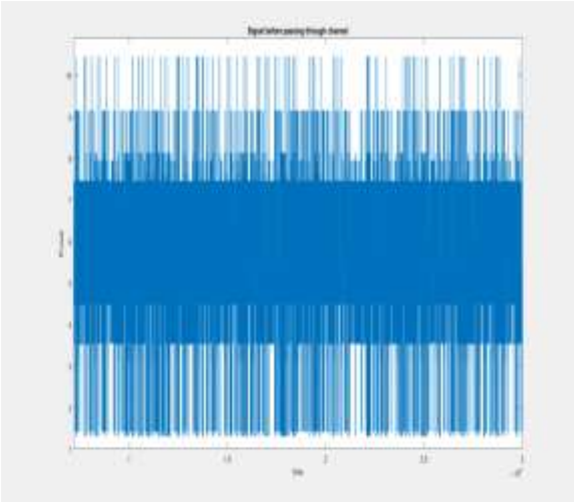

Fig.9 binary bits

Figure 9 depicts the binary data stream generated to emulate random binary data transmission.

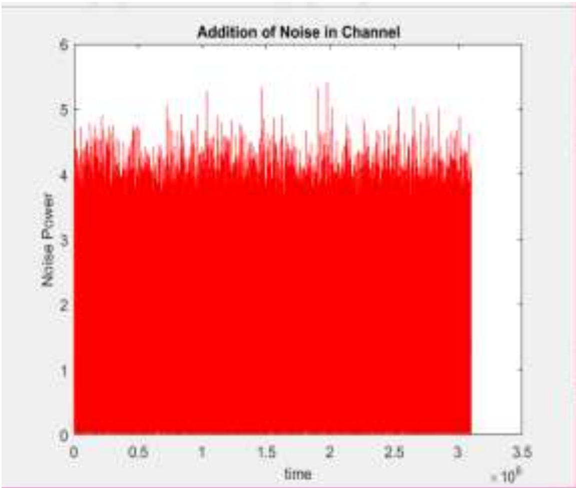

Fig.10 Addition of disturbance

Figure 10 depicts the addition of noise in the wireless channel. Random noise has been added so as to replicate the channel conditions in an actual IoT network. The random fluctuations in the noise as a function of time has been shown in the figure.

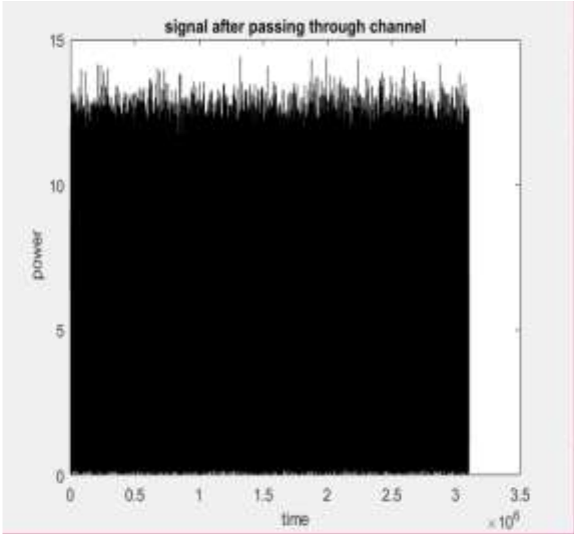

Fig.11 Effect of noise addition.

The effect of noise addition on the binary data stream in the time domain has been depicted in figure 11. It can be seen that the binary data stream has been manipulated by the addition of noise.

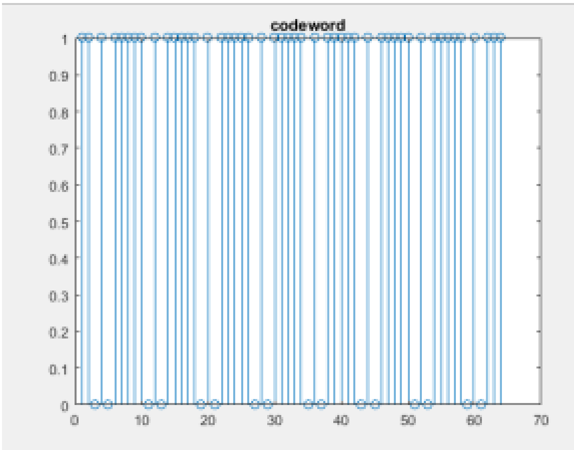

Fig.12 Formation of the turbo Code-word

Figure 12 depicts the binary code-word generated by the proposed system. The binary representation of the code word has been shown.

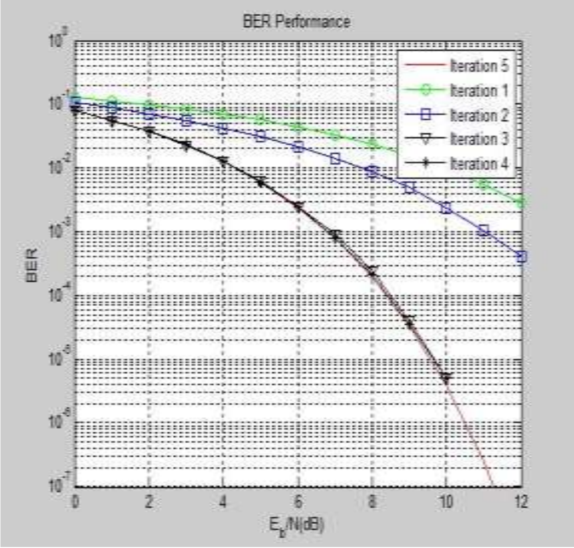

Fig.13 error as function of iterations.

Figure 13 depicts the bit error rate of the proposed system as function of iterations. It can be observed that as the iterations increase, the BER of the system continuously plummets. To represent the signal strength for binary data, the term energy per bit E_b has been used.

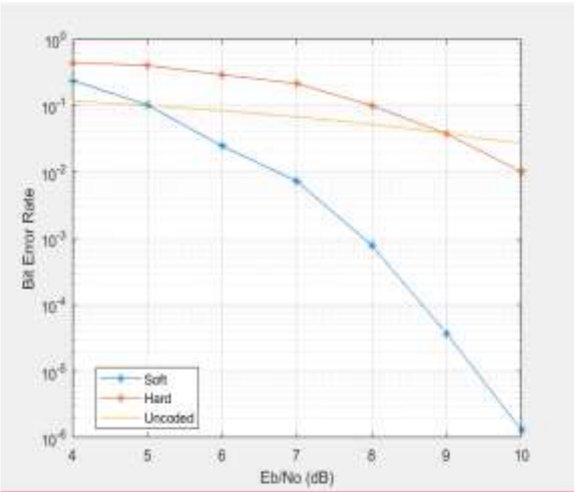

Fig.14 Coded and un-coded error rates

Figure 14 depicts the comparative analysis of the un-coded, hard coded and soft coded (Turbo) versions of binary transmission for the system. It can be clearly observed that the soft turbo coded probabilistic approach attains the steepest fall in the error rate compared to the hard coded and un-coded counterparts.

Conclusion:

IoT devices typically operate with limited power, bandwidth, and computational resources. Wireless IoT links are vulnerable to bit errors due to low signal-to-noise ratio (SNR), interference from other devices, and multipath fading. Traditional error detection methods such as parity bits or CRC can only detect errors but cannot correct them. Automatic Repeat Request (ARQ) increases latency and energy consumption. Hence, forward error correction (FEC) techniques like Turbo codes are preferred, as they allow the receiver to correct errors without requesting retransmission, making them suitable for energy-constrained IoT applications. The experimental results are gauged in terms of the iterations to attain low values of the errors for the low Shannon range SNR. The BER obtained by the proposed system is significantly less than the BER of the previous systems clearly showing improvement over benchmark models.

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