Design And Implementation of Coupled Turbo Codes With Code Block Coupling For Error Detection And Correction In Wireless Networks

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Abstract- *The Internet of Things framework has seen swift transformations regarding its applications and global user base. The necessity for reliability in ensuring excellent service quality is paramount, considering the characteristics of data transmission via wireless media. The emergence of high-performance chips with compact sizes and low power consumption, capable of executing reasonably sophisticated algorithms, has become essential for Internet of Things applications. This research study concentrates on the design and implementation of turbo code blocks utilizing the BCJR method to couple the bits within the composite transport block. The information and parity bits are to be integrated to enhance information exchange within the transport block, hence significantly decreasing the mistake rate in the error waterfall phase. 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].

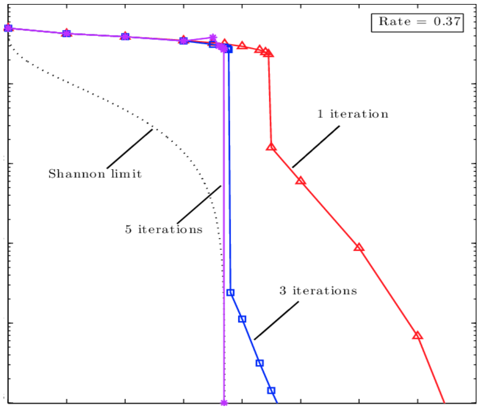

Fig.2 Typical error performance of Shannon's limit

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.

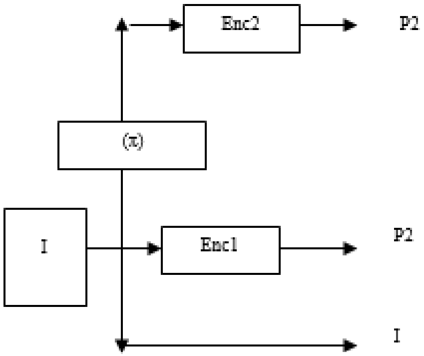

Fig.3Turbo encoder

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.

Transmitted Bits	B0	B1	B2	B3	B4	B6	B7
	1	0	1	0	1	0	1
	1	1	0	1	0	1	1/0
Received Bits	B0	B1	B2	B3	B4	B6	B7

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 [25].
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 [26].
3. Lesser iterations are also needed to minimize the latency (delay) of the system as IoT networks can be used for time critical applications [27].
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 [28].

Typically two deciders are employed for decoding in the cascading manner. The BCJR based algorithm is used for the decoding of the codes [29].

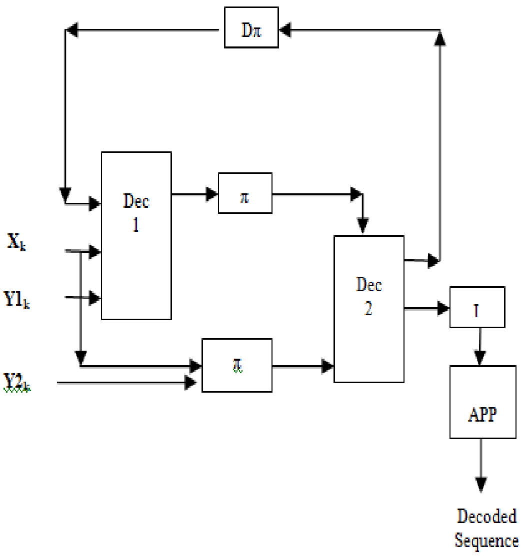

Fig.6 The turbo decoding mechanism

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) [30].

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 [31]. 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 [32]. 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 [33].

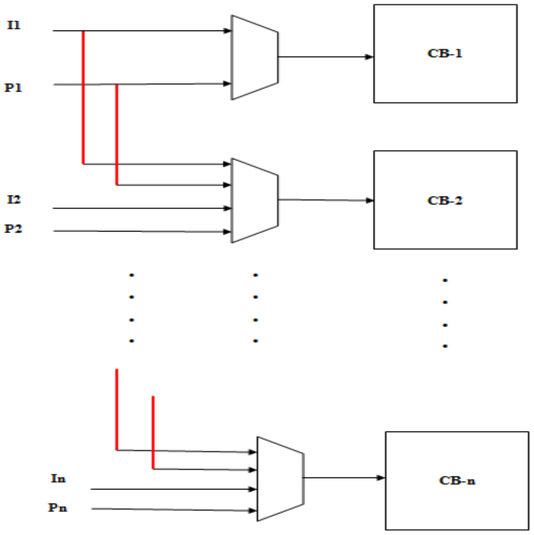

Fig.7 The proposed approach

In the proposed approach, both information and parity bits are coupled. Previous approaches do not have a method to couple both I & P [34].

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 [35].

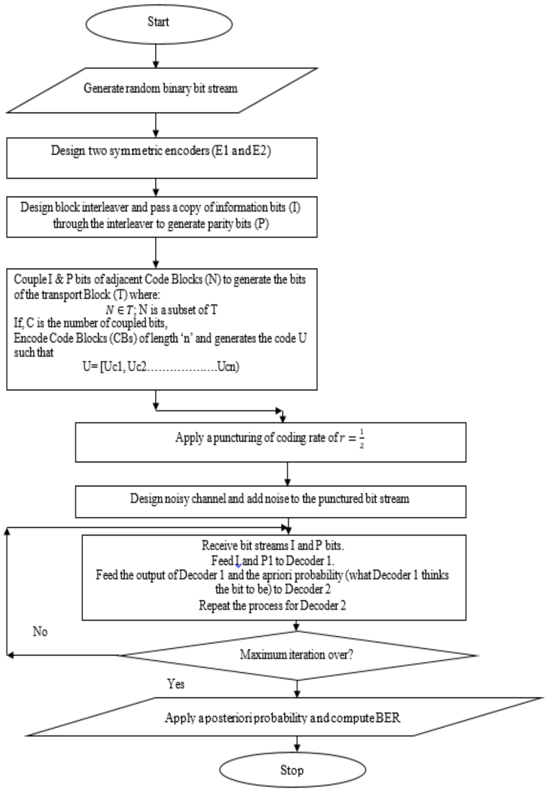

Fig.8 Proposed Flowchart

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

Inference from the spatial coupling logic:

Conventional turbo codes have already demonstrated excellent error correction capability and near-Shannon-limit performance, making them widely used in wireless communication, satellite systems, and modern communication standards [36]. However, conventional turbo codes still suffer from certain limitations such as high error floors, slower convergence during iterative decoding, and performance degradation under highly noisy channel conditions [37]. To overcome these drawbacks, researchers introduced the concept of spatial coupling into turbo coding structures, resulting in significant improvements in error correction performance and decoding stability [38].

Spatially Coupled Turbo Codes improve upon this limitation by introducing coupling among neighboring turbo code blocks. Instead of encoding each block independently, portions of information bits or parity bits are shared across adjacent blocks [39]. This coupling creates a chain-like interconnected structure where decoding information from one block influences neighboring blocks [40] The coupling mechanism allows reliable information to propagate gradually throughout the entire coupled system, thereby improving the overall decoding process. The interconnected structure essentially transforms isolated local decoding into a collaborative global decoding process [41].

One of the most important mechanisms behind the superior performance of SCTCs is the phenomenon known as threshold saturation [42]. In conventional turbo codes, the iterative decoding threshold remains significantly away from the optimal Maximum A Posteriori (MAP) threshold. This means that conventional turbo codes require relatively better channel conditions to achieve reliable decoding [43]. In contrast, spatially coupled turbo codes push the belief propagation decoding threshold much closer to the MAP threshold. Consequently, SCTCs can achieve successful decoding even under noisier channel environments while operating very close to the Shannon channel capacity limit [44].. This threshold saturation effect is one of the key reasons why SCTCs provide significantly lower BER compared to conventional turbo codes [45].

Another major advantage of spatially coupled turbo codes is the wave-like decoding propagation mechanism. In SCTCs, boundary blocks are typically initialized with higher reliability during the decoding process [46]. These reliable blocks decode earlier and then gradually assist neighboring blocks by propagating accurate extrinsic information across the coupled chain. This process creates a wave-like movement of reliable decoding information throughout the code structure [47]. As the decoding wave progresses, uncertain bits in neighboring regions are corrected more effectively. Conventional turbo codes do not possess this global reliability propagation capability because their decoding remains confined within individual blocks [48].

The improvement in extrinsic information exchange also contributes significantly to the superior performance of SCTCs [49]. In conventional turbo codes, soft information exchange occurs only between constituent decoders within a single block. However, in spatially coupled turbo codes, multiple neighboring blocks participate in iterative information sharing [50] This results in richer and more reliable extrinsic information during the decoding process. The enhanced diversity of information exchange improves soft decision estimation, accelerates convergence, and reduces the probability of incorrect decoding decisions [51]..

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.

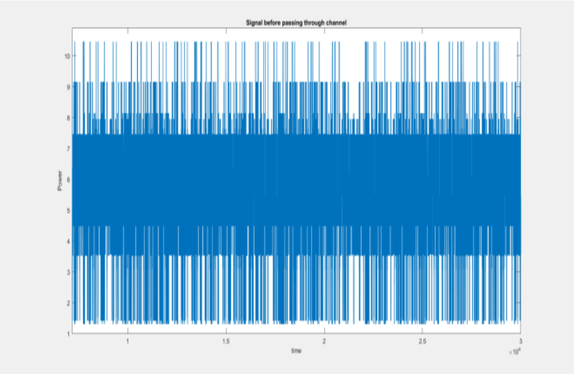

Fig.9 binary bits

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

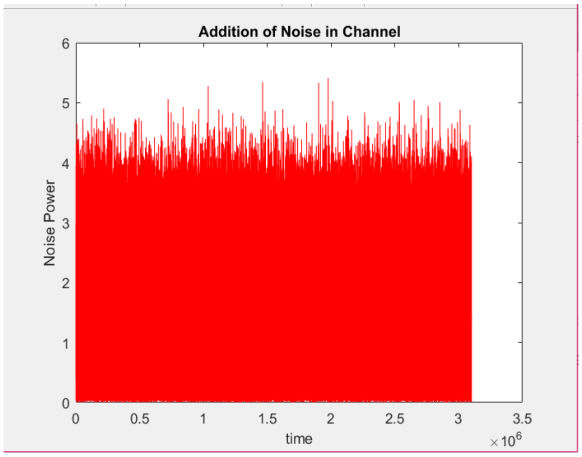

Fig.10 Addition of disturbance

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.

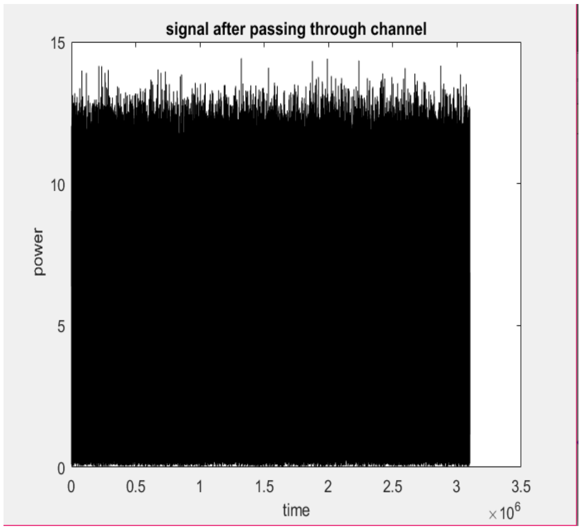

Fig.11Effect of noise addition.

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.

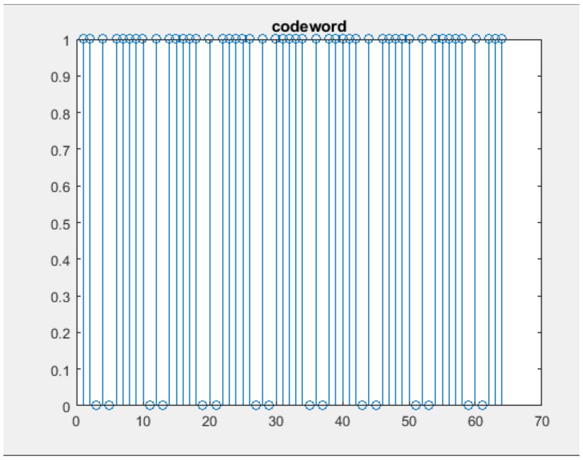

Fig.12 Formation of the turbo Code-word

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

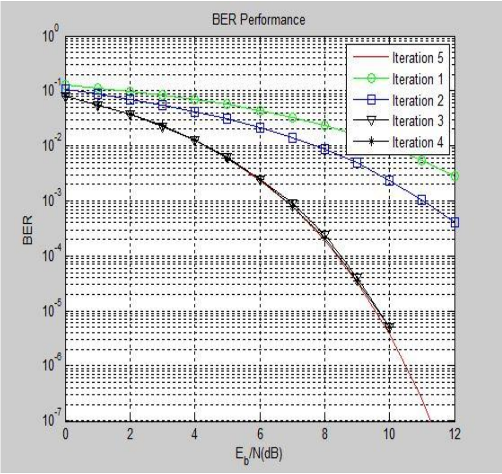

Fig.13 error as function of iterations.

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.

V. CONCLUSION

Wireless and IoT networks have seen rapid alterations in terms of their applications and global user base. The imperative for dependability in delivering superior service quality is crucial, given the attributes of data transmission through wireless channels. The advent of high-performance CPUs that are compact and energy-efficient, capable of running somewhat complex algorithms, has become crucial for Internet of Things applications. This research study focuses on the design and implementation of turbo code blocks using the BCJR algorithm to link the bits within the composite transport block. The integration of information and parity bits aims to improve information sharing within the transport block, hence substantially reducing the error rate in the error waterfall region.

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