ISSN: 2278 – 909X
International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE)
Volume 6, Issue 3, March 2017

ENERGY EFFICIENT WIRELESS SENSOR NETWORKS USING RAPTOR CODES

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Abstract----**In this paper, we have explored the energy efficiency of Raptor codes; a first known class of fountain codes in an energy constrained network. Transmission power is adjusted dynamically to overcome unreliability over lossy links in wireless sensor network. One of the most felicitous key for this reliability issue is using Forward Error Correction (FEC) codes. This paper investigates the energy bagged by one such FEC code called Raptor codes in the Binary Erasure Channel scenario. We analysed the performance of Raptor codes in terms of energy by varying the precoder in it. The network parameters such as Bit Error Rate (BER), Throughput and Energy Spent per Bit are considered for our study. The simulation results show that Raptor code with BCH as a precoder outperforms Raptor code alongside LDPC as a precoder.**

Keywords— **Raptor codes, LT codes, Erasure channel, Energy Efficiency, Forward Error Correction ,Wireless Sensor Networks.**

I. INTRODUCTION

Recent developments in wireless communication technologies such as Bluetooth and Zigbee have led to great interest in wireless sensor networks (WSNs). Sensor nodes are constructed only by using sensor devices with wireless communication facilities [1]. Energy conservation is one of the most important issues in WSN, where nodes are likely to rely on limited battery power. If the transmission power is not sufficiently high there may be single or multiple link failure. Further transmitting at high power reduces the battery life and introduces excessive inter node interference. The advantage of wireless sensor networks hold over traditional wireless sensing technology lies in the mesh networking scheme they employ. Due to the nature of RF communication, transmitting data from one point to another using a mesh network takes less energy than transmitting directly between the two points. This decreases the overall signal-to-noise ratio of the system, increasing the amount of usable data. For all these reasons and more, wireless sensor networks offer many possibilities previously unavailable with traditional sensor technology [2]. WSN deployment sites frequently abound with non-line-of-sight (NLOS) communication, electromagnetic disturbances and moving objects. IEEE 802.15.4 standard, targeting low-power low-rate radios, does not provide any advanced error-control mechanisms. Instead, it combines error detection by Cyclic Redundancy Check (CRC) with Automatic Repeat Request (ARQ). This concept not only lacks proactive means for error correction, but it also results in increased communication latency. Another approach to improve transmission reliability is Forward Error Correction (FEC), based on recovering from errors by adding redundancy to the original data. In modern wireless communication systems, forward error correcting codes are employed for efficient transmission of data in noisy environments. Although additional redundancy reduces transmission efficiency, FEC is still a more preferable solution, because it may improve both reliability and latency [3].

A new class of sparse graph channel codes known as Fountain codes have been introduced for reliable transmission over communication networks modeled as erasure channels. The main classes of Fountain codes are Luby Transform (LT) codes and Raptor codes. LT codes [4] are the first realization of rateless erasure codes that we call universal erasure codes. Rateless codes in the sense that, potentially limitless sequence of encoding symbols can be generated as many symbols as needed on the fly. These are very efficient as the data length grows. In the decoder, the data can be recovered even if the data was lost or erased during transmission. Adequate number of encoding symbols can be generated on the fly and transmitted over the erasure channel until the decoder wins back the data. The LT codes are often referred to as near optimal codes because the decoder can recover the data from nearly minimum number of encoding symbols.

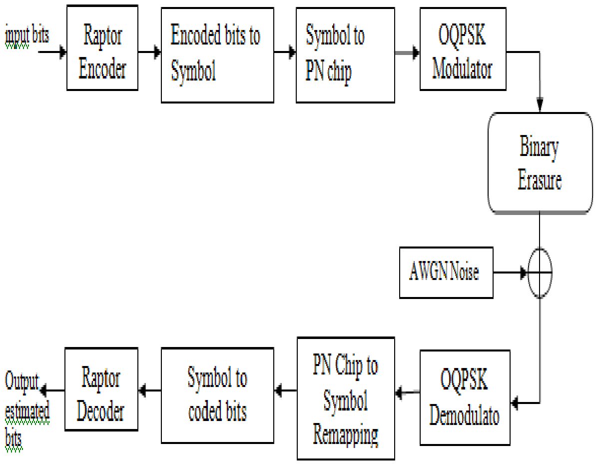

Fig.1. Block Diagram of IEEE 802.15.4 Raptor Coded RF Transceiver

In [5], the author introduced Raptor codes, an extension of LT codes with linear time encoding and decoding. The Raptor code is nothing but the precoder with a LT code. The concept behind Raptor code is the input symbols are precoded initially with a binary linear code and then given to the LT code. The precoder will produce number of intermediate symbols and the intermediate symbols are given to LT encoder to generate a codeword. Those codes were sent over the erasure channel to the decoder.

II. RELATED WORK

The performances of Raptor code with two different decoding algorithms on erasure channel was investigated in [6]. In [7], the author proposed a new algorithm for decoding that can be used for Raptor codes on erasure channel and not considered the energy efficiency of Raptor codes. In [8], the decoding complexity and erasure decoding performance between Raptor code and RS code were analyzed. They proved that the degree distribution can be preserved if the packets to be XORed are chosen according to a certain probability in [9]. The author designed an efficient decoding algorithm for Raptor code that was compatible in a hardware platform was done in [10] and they have not considered the energy owned by Raptor codes. They proposed a new decentralized Precoding aided rateless codes and compared its achievable BER performance with Raptor codes in [11]. The author analyzed the application of Raptor codes performance in the P2P Streaming domain and evaluated the feasibility of using Raptor codes to improve the performance of P2P networks in [12] and not the amount of energy used. In [13], they proposed a distributed network coding scheme based on Raptor codes and analyzed the BER performance under Rayleigh fading channel and they have not considered the network lifetime. The author investigated the energy conservation of LT codes under erasure channel in IEEE 802.15.4 complaint WSN in [14].

Majority of the earlier work considered Raptor codes especially Raptor decoding technique to reduce the decoding complexity and the analysis does not include energy efficiency of the network. Likewise, most of the earlier work compared various decoders for Raptor codes and not the encoder part. Moreover, performance analysis of wireless sensor network mentioned here lacks consideration of IEEE 802.15.4 Zigbee standard. Henceforth, this paper compares two different precoder for Raptor codes having encoders kept at the source node (transmitter). The decoding takes place at the sink node (receiver) which is not energy constrained. Thus, the proposed scheme is independent of decoding energy and complexity.
The main contribution of the paper can be twofold: They are (i) Energy Efficiency analysis of IEEE 802.15.4 Zigbee Transceiver using Raptor codes, and (ii) BER analysis of the network using Raptor coded IEEE 802.15.4 Zigbee RF Transceiver over Binary Erasure Channel.

The rest of the paper is catalogued as follows: The system model is detailed in Section III. The simulation model and its results are conferred in Section IV. Section V comes up with the conclusion.

III. SYSTEM MODEL

The system model depicts an IEEE 802.15.4 Zigbee RF transceiver based Wireless Sensor Network scenario which makes use of forward error correction technique. IEEE 802.15.4 standard was adopted by Zigbee for WSN technology. The sensor node uses IEEE 802.15.4 standard Zigbee transceiver under 2.4 GHz frequency band. Zigbee is used in applications that require a low data rate, long battery life and secure networking. We constructed a whole communication model to analyze the performance of Raptor code with two different precoder over Binary Erasure Channel (BEC). The block diagram of Raptor coded Zigbee RF transceiver system is shown in Fig.1.

The message source is assumed to have *M* number of bits to be transmitted. The input bits are given to the Raptor Encoder, which has two levels of encoding. The spreading and modulation of encoded bits from Raptor encoder will be done in next block. To imitate the Zigbee symbol, the codeword from Raptor encoder will be bunched to four symbols to be transmitted. The transmitted Zigbee symbols will be set to Pseudo Noise (PN) sequence chip mapping. The symbols will select one of the 16 nearly orthogonal PN sequences to be transmitted. The mapping of symbols to chips is achieved through 32-chip PN sequences. The PN sequences are related to each other through cyclic shifts and the successive selected PN sequences are concatenated and sent to the OQPSK modulator. The modulated signal will be sent over the channel which gets impaired by white noise. We adopt as our model of errors the *Erasure channel* introduced by Elias [15], in which each codeword symbol is lost with a fixed constant probability α in transit independent of all the other symbols. The receiver section of IEEE 802.15.4 standard Zigbee transceiver consists of the blocks to perform operations that are contra to that of the transmitter, such as OQPSK demodulation, chip to symbol remapping, and Zigbee symbol to bit regrouping followed by decoding.

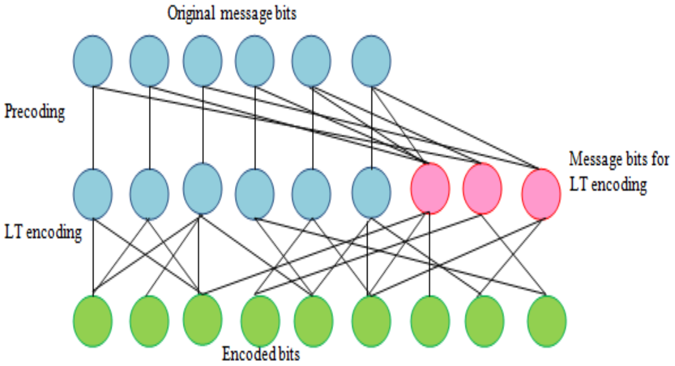

Fig.2.Raptor Encoding

A.Design Of Raptor Encoder

Raptor codes are a significant theoretical and practical improvement over LT codes. Concatenation of an inner code followed by outer code is known as Raptor codes. The inner code takes the result of the pre-coding operation and generates a sequence of encoding symbols. The inner code is a form of LT codes. Each encoding symbol is the XOR of a randomly chosen set of symbols from the pre-code output. The number of symbols which are XORed together to form an output symbol is chosen randomly for each output symbol according to a specific probability distribution [16] which is shown in Fig.2. Raptor codes, as fountain codes in general, encode a given message consisting of a number of symbols, M, into a potentially limitless sequence of encoding symbols such that knowledge of any M or more encoding symbols allows the message to be recovered with some non-zero probability. The probability that the message can be recovered increases with the number of symbols received above M becoming very close to 1, once the number of received symbols is only very slightly larger than M. A symbol can be any size, from a single byte to hundreds or thousands of bytes. This rate less property makes them a preferred choice when the communication channel conditions are unknown or vary extensively.

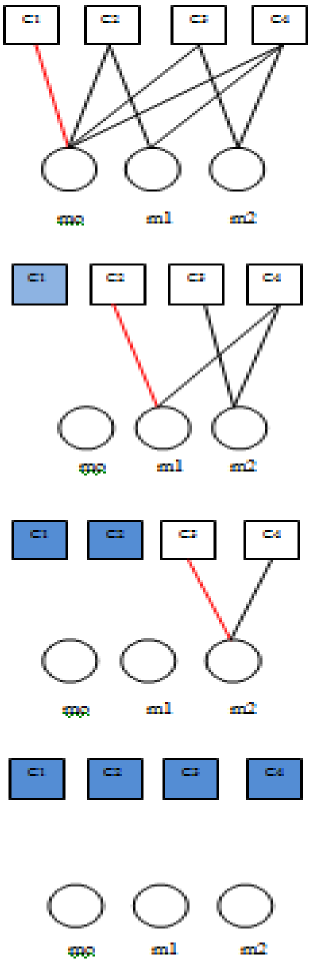

Fig.4. Raptor decoding

Each codeword is a linear combination of d symbols from the message M. The degree d is chosen at random from a degree distribution $r(d)$. Raptor codes require $O(1)$ time to generate an encoding symbol. Decoding a message with a belief propagation decoding algorithm requires $O(k)$ time for the appropriate choice of inner/outer codes. The key idea of Raptor codes is to relax the condition that all input blocks need to be recovered [17]. If an LT code needs to recover only a constant fraction of its input blocks, its decoding complexity is $O(k)$, i.e., linear time decoding. Then, we can recover all input blocks by concatenating a traditional erasure correcting code with an LT code. This is called pre-coding in Raptor codes, and can be accomplished by a modern block code such as LDPC codes. In this paper, the Raptor code 1 referred to the use of LDPC as a precoder and Raptor code 2 exemplifies the use of BCH as a precoder as shown in Fig.3.

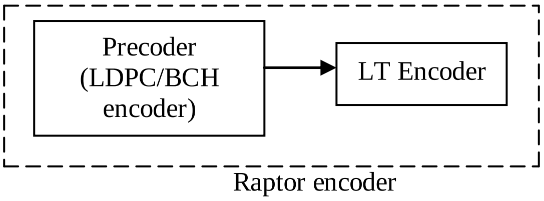

Fig.3. Block diagram of Raptor encoder.

Pre-code used in this paper for Raptor code 1 is the randomized LDPC (Low-Density Parity-Check) code. Low-density parity-check (LDPC) codes were invented by Gallager in 1963. The low-density parity-check codes are codes specified by a matrix containing mostly 0's and relatively few 1's.The parity check matrix represents a set of linear homogeneous modulo 2 equations called parity-check The equations and, the set of code words is the set of solution of these equations. The use of parity check codes makes coding relatively simple to implement [18].

Another type of precoder implemented in this paper is Bose Chaudhuri Hocquenghem (BCH) codes to be used in IEEE 802.15.4 RF transceiver based sensor nodes. BCH codes are a large class of powerful cyclic codes. BCH codes are also known as simple block error correction codes. A binary BCH code is determined by its generator polynomia1, g(X). For any positive integers m ($m \geq 3$) and t ($t \leq 2^{m-1}$), there exists a binary BCH code with block length n and parity check length of n-k where k is the number of information bits [19]. During transmission, symbol errors are introduced. The location and the magnitude of the errors are given by the error polynomial e(X).

The precoder followed by LT code is a Raptor code. The output or intermediate symbols from the precoder will be given to the LT code as input. The process of generating an encoding symbol is conceptually very easy [20]. We want a distribution that on average guarantees that just one message symbol is uncovered at each iteration. Such a distribution is the Soliton. Due to the random fluctuations around the mean behaviour, the

Soliton distribution behaves poorly in practice. If in one of the steps, there is not a degree one codeword, the decoding process stops. The Robust Soliton distribution tries to solve this problem by introducing two new parameters, c and δ, to obtain an expected number of degree one codeword symbols at each step. The Robust Soliton distribution ensures that the expected size of the ripple is large enough at each point in the process so that it never disappears completely with high probability [21].

B. Design Of Raptor Decoder

When using the encoding symbols to recover the original input symbols of the data, the decoder needs to know the degree and set of neighbours of each encoding symbol [22]. LT decoding makes use of Belief Propagation decoding algorithm in this paper. The decoder finds an output symbol such that the value of all but one of its neighboring input symbols is known. By bitwise XOR operation, the values of unknown input symbols can be recovered and the edges incident to that output symbols are detached. If all M input symbols are recovered, it issues a single-bit feedback indicating success of the decoding [23]. The decoding algorithm used for LDPC precoder is Maximum Likelihood Decoding. It minimizes the probability of decoding error and thus measures the effectiveness of a code. LDPC codes under ML decoding can tightly approach the bounds down to very low error rates, even for short block sizes [24]. Low-density parity-check (LDPC) codes have attracted much attention as the good error correcting codes achieving the error rate. There are several methods for decoding BCH codes. One of the most efficient methods is Berlekamp's algorithm [25] & [26]. This algorithm uses the syndromes calculated from the received vector to find an error location polynomial of minimum degree which produces the most likely code word from the received vector. The roots of the error location polynomial determine the error locations. Once the roots are found, the inverses of these roots give the error locations. The error location values denote the bits in the received vector that need to be inverted to give the code word estimate.

IV. SIMULATION MODEL AND ITS RESULTS

The simulation results are obtained using MATLAB. The procedure for simulating Raptor coded IEEE 802.15.4 Zigbee Transceiver is given below:

1. The information data bits are given to the Raptor encoder to get the encoded bits.
2. Every four bits of coded binary data stream generated is grouped to form a Zigbee Symbol **s**.
3. Each of these 16 Zigbee symbols is mapped to the 32-chip PN sequence.
4. The chip sequence is then sent as an input to the OQPSK modulator where half-sine pulse shaping of incoming chips is performed. 5. The modulated signal is later transmitted through a wireless channel where the channel noise is being added to the transmitted signal.
6. The decision about the transmitted signal from the received signal is made by computing the minimum of the Euclidean distance between the received and the reference signal.
7. The estimate of the transmitted symbols is obtained from the estimated chip sequence which is available at the demodulator output.
8. Finally, the estimates of the transmitted symbols are sent to the Raptor decoder to obtain decoded bits.

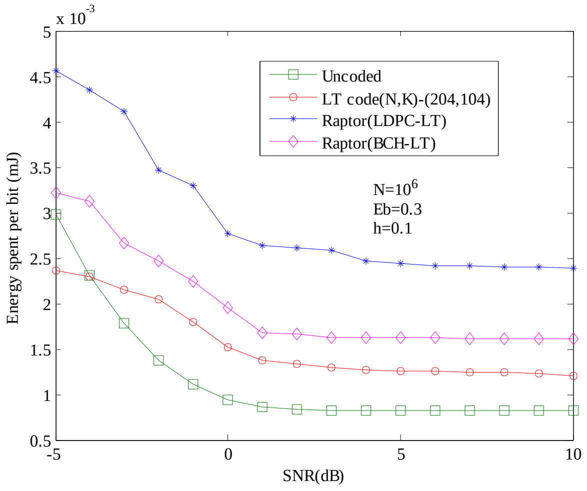

Fig.5. Energy spent per bit by IEEE 802.15.4 Zigbee Tranceiver using LT codes,Raptor code ampng LDPC and Raptor code with BCH

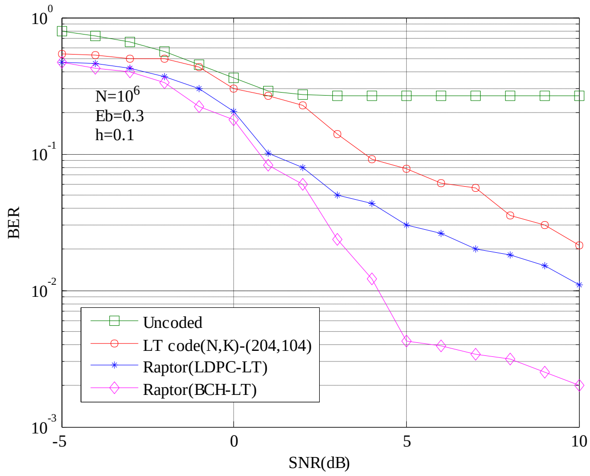

Fig.6. BER analysis for IEEE 802.15.4 Zigbee RF Transceiver using LT codes,Raptor code with LDPC and Raptor code with BCH.

9. The BER is obtained by dividing the bit error count by the total number of bits transmitted.
10. The energy spent per bit for Raptor code and LT code was obtained [27].

The simulations were carried for 10 runs for each transmission by repeating from step 5 to 10.Thus the average value of BER and EPB were found out for each SNR (dB) and for various Erasure probabilities were plotted. This helps to reduce any arbitrary randomness of the channel and also to check the consistency of the results of the simulation.

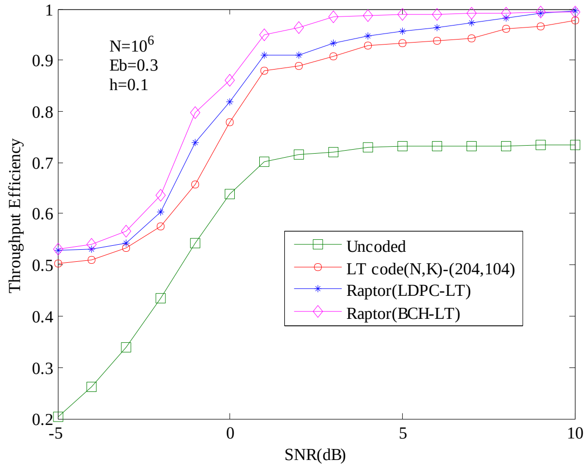

Fig.7.Comparison of Throughput Efficiency in IEEE 802.15.4 RF Transceiver using LT codes, Raptor codes.

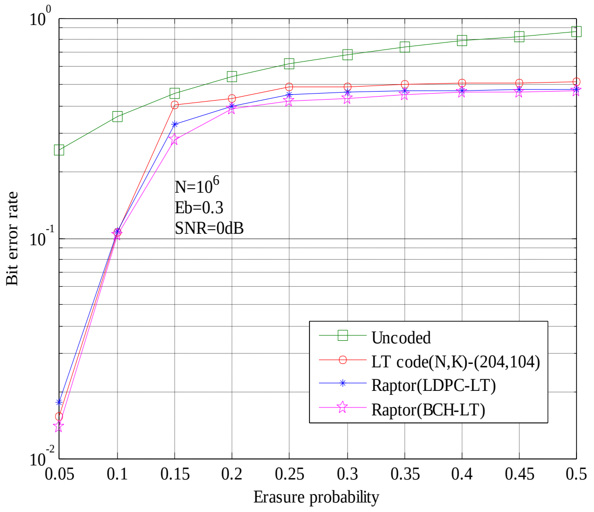

Fig.8. comparison of BER performance of LT codes and Raptor code with two different precoder for various erasure probabilities

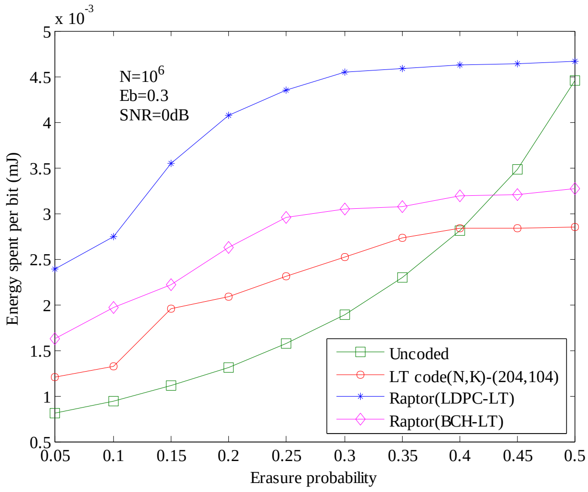

Fig.9. Energy spent per bit in IEEE 802.15.4 Zigbee Transceiver using LT codes, Raptor code with LDPC and Raptor code among BCH.

The network is analyzed under Binary erasure channel conditions and the metrics considered for the analysis are BER, Energy spent per successfully received bit and throughput. To be more precise, the simulation model proposed in this paper aims to improve link reliability in terms of BER and hence the energy efficiency of the network.

The binary erasure channel is just a theoretical model rather than a realistic model. The erasure channel can be used to model data networks, where data is transmitted in the form of packets, which either arrive correctly or are lost for many reasons such as, buffer overflow or packet checksum mismatch. In BEC, bits are either received correctly or are lost. The BEC is represented by a parameter ε, which is called channel erasure probability.

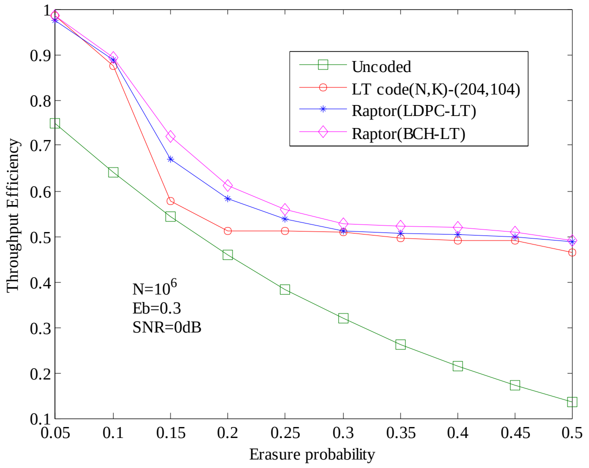

Fig.10. Throughput Efficiency Comparison of LT codes and Raptor codes for various erasure probabilities

Fig.5. shows the BER analysis of sensor network using FEC codes. It is observed that Raptor code with BCH as precoder outperforms all the other codes considered here for comparison. Raptor code with BCH as precoder achieves BER of 10^{-2} for SNR values above 4dB. Similarly, the energy spent per successfully received bit is also analyzed for a WSN using FEC codes and is shown in Fig.6. The amount of energy spent by the network nodes is directly proportional to the amount of redundant bits in the codeword. Therefore, for a given SNR, say 0 dB, Raptor with LDPC as precoder has spent higher energy (nearly 4.5mJ) compared to Raptor with BCH as a precoder (3.3mJ) .The performance of Raptor code with BCH as precoder is better in terms of energy spent by the nodes.

The throughput efficiency analysis for the Raptor coded WSN was illustrated in Fig.7. Throughput can be defined as the total number of bits received per second by the destinations of all the multi-hop flows in the network. For purposes of energy consumption comparisons, the metric we use is the total transmission and reception energy consumed per successfully received bit. The Raptor code which uses BCH code as precoder outperforms LT codes, uncoded and Raptor with LDPC as precoder.

Fig.8. follows Fig.5. It depicts the BER performance of coded wireless sensor network using LT codes, Raptor code with different precoder. Fig.9 shows energy spent by the nodes per successfully received bit as a function of Erasure probability for a network (i) without any error control scheme, (ii) LT code (N,K)-(204,104), (iii) Using LDPC as precoder for Raptor code and (iv) Using BCH code as precoder for Raptor codes. Among FEC techniques used, it is observed that LT code consumes low energy as compared to Raptor codes with different precoder, and hence is selected as the best choice of error control technique to be used in a WSN. Fig.10. follows Fig.7. In Fig.7, the Raptor code with BCH as precoder outperforms LT code, uncoded and Raptor with LDPC as precoder.

Fig.11, illustrates the percentage reduction in bit error rate over uncoded transceiver. From the figure it is clear that Raptor code with BCH as precoder overrides the other two FEC techniques. Higher the redundancy in the codeword, higher will be the error correcting capability of the code. So, the Raptor code among BCH as precoder can be used for high quality of information transmission such as video streaming, 3GPP, DVB etc, in an indoor environment where energy is free.

Fig.12 shows the percentage of excess energy consumed by the network nodes over an uncoded network. The excess energy consumed by the network is defined as the amount of additional energy spent by the network nodes using error control mechanisms for successful reception of the bit when compared to an uncoded network. The percentage of the excess energy consumed by the network for various error control strategies when compared to the uncoded network can be determined in terms of Energy spent by the coded network (E_{coded}) and Energy spent by the uncoded network ($E_{uncoded}$) as shown below.

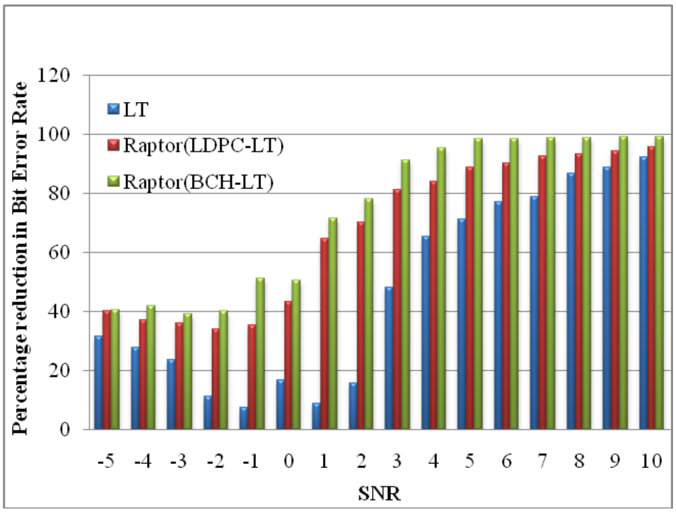

Fig.11. Percentage reduction in Bit Error Rate over uncoded transceiver

$$\text{Excess Energy Consumption (\%)} = (E_{coded} - E_{uncoded}) / E_{uncoded} \quad X\ 100$$

The comparison is made among the networks (i) using LT codes, (ii) using BCH as precoder in Raptor codes, and (iii) using LDPC as precoder in Raptor codes. It is observed that to achieve an improved performance, Raptor with LDPC as precoder consumes nearly 200% more energy than an uncoded network for SNR values, so it not of our choice. Whereas LT proves to be the best for higher and lower SNR values as the energy consumed is only 20% more than uncoded network. Therefore, LT code is selected as energy efficient error control method to be adopted for a WSN in energy constrained environment which can be used to transmit low quality of information when compared to Raptor codes.

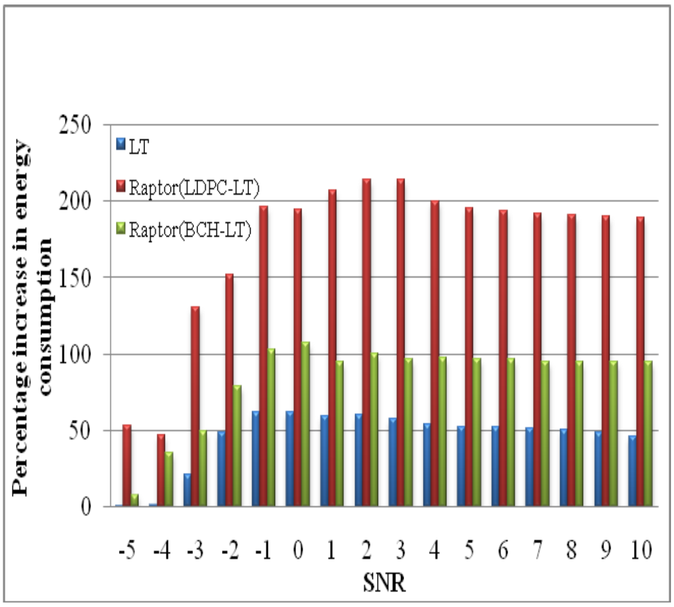

Fig.12. Percentage increase in energy consumption over uncoded transceiver.

V. CONCLUSION

Energy conservation is a critical challenge in resource constrained WSN. The use of FECs to improve the network lifetime of IEEE 802.15.4 sensor network is proposed in this work. For this purpose, Raptor codes and LT codes, a class of rate less codes (also called fountain codes) are considered for this study. The Raptor code with two different precoder is also analysed. The FEC technique such as Raptor code with BCH as precoder used in IEEE 802.15.4 Zigbee transceiver improves reliability of the link at the cost of increased energy consumption by all nodes. As mentioned earlier, LT codes can be used in an energy constrained outdoor environment for data transmission with low quality. But, high quality of data transmission in WSN can be done using Raptor codes by sacrificing some amount of energy in an environment where energy is not constrained.

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