CODING SCHEMES FOR ENERGY CONSTRAINED IOT DEVICES

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ABSTRACT

This paper investigates the application of advanced forward error correction techniques mainly: low-density parity checks (LDPC) code and polar code for IoT networks. These codes are under consideration for 5G systems. Different code parameters such as code rate and a number of decoding iterations are used to show their effect on the performance of the network. LDPC is performed better than polar code, over the IoT network scenario considered in the work, for the same coding rate and the number of decoding iterations. Considering bit error rate (BER) performance, LDPC with rate1/3 provided an improvement of up to 2.6 dB for additive white Gaussian noise (AWGN) channel, and 2 dB for SUI-3 (frequency selective fading channel model). LDPC code gives an improvement in throughput of about 12% as compared to polar code with a coding rate of 2/3 over AWGN channel. The corresponding values over SUI-3 channel are about 10%. Finally, in comparison with LDPC, polar code shows better energy saving for large number of decoding iterations and high coding rates.

KEYWORDS

IoT, LDPC, Polar, Energy consumption.

1. INTRODUCTION

Internet of Things (IoT) is a developing vital technology for future and daily lives of people, where many sensors work with battery, actuators, and smart things are combined to the internet. Thus energy efficiency is of greatest importance to these batteries constrained IoT devices. IoT standards, and research works have motivated on the energy of device preservative topics [1]. Transmissions over wireless channels affect the transmitted data. Data transmitted over these channels will suffer from degradation due to noise and fading. Thus in last decade focus on developing transmission for these channels was the main challenge in the IoT network. The most active way to protect transmitted data is the collaboration between the transmitter and receiver during the communication; this can be done using Error Control Coding (ECC) Schemes [2]. ECC schemes have been the main focus in last few years to be worked with IoT networks. These schemes protect data by adding redundant bits to the original data. Although this results in more consumed energy and reducing the effective data rate, the gained improvements in performance make such extra loss acceptable [3].

Forward error correction schemes (FEC)are the most useful error control schemes with IoT. Many researches covered the topics related to IoT. The survey provided in [4] showed how the importance of IoT in our daily live and presentedIoT architecture and the most important protocols that were used with IoT. Zazi et.al. demonstrated and proposed a new technique that include combining two types of hybrid coding with adaptive coding and decoding schemes that worked successfully with multi-hop communications in WSNs [5]. The codes used are combination of Reed Solomon (RS) code and Low-Density Parity Check (LDPC) code. The aim

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was to decrease the decoding power depletion and to extend the lifespan of the network as well as develop the transmission with reliability. Vangala et al. published a comparative study of several polar code constructions [6]. Though, it is not recognized which construction algorithm at what design-SNR constructs the best polar codes. The results showed that all polar code construction algorithms make equally good polar codes in an AWGN channel, if the design-SNR is optimized. Kadhim et al. used a combination of FEC with Network Coding (NC) to improve the performance of WSNs and specified an energy model for the proposed system [7]. The results showed that the combination of RS and NC reduced the consumed energy by reducing the number transmissions and hence improving the transmission throughput. Kadhim et al. presented hybrid ECC schemes that worked with WSN which consist of FEC and Automatic Repeat on request (ARQ) [8]. Coding arrangement aiming to offer performance improvement for different applications in WSNs together with improved energy efficiency is introduced.Arioua et.al. presented a new combination between Low EnergyAdaptiveClusteringHierarchy(LEACH) with a Minimum TransmissionEnergy(MTE) protocolsfor multi-hop communicationin place of direct communication in cluster has enhanced the communication in the network [9]. This combination provided an important enhancement in lifespan of network and improvement in energy presentation for WSN. In the present work an arrangement of FEC are proposed to improve the performance of IoT networkwhile trying to gainan advantage in the consuming energy. The proposed coding schemes are LDPC code and Polar code. IoT network simulator also built and used to test the proposed coding scheme.

The remaining sections of the paper are organized as follows; Section-2 deals with IoT network model considered in the work together with its parameters and specifications. Details of the energy model to calculate the consumed energy also given in Section-2. Section-3 presents the simulation test results, while Section-4 provided the assessment of the results. Finally, the main concluding remarks are presented in Section-5.

2. IOT SIMULATION MODEL

The nature of IoT networks and their applications make them vulnerable to different channel impairments. These include weather and other factors such as security and unreliable communication which make the information sent more susceptible to errors. In building IoT network simulator here, there is a need to specify; network area and dimension, channel type and its parameters, number of sensor nodes, the number of packets to be transmitted through the network, and the network topology. Matlab environment is used to build IoT network simulator. LEACH protocol is considered for network routing in the simulation. The simulator here deals with the network performance measurements that cover the following performance measures: block error rate (BLER), bit error rate (BER), throughput in bit per second and the total remaining energy. The distance between nodes is taken into account when proposed a LEACH protocol to work with IoT network. The important parameters of codes are needed to be defined; Table 1 shows the coding parameters used in the simulation. The adopted parameters for the network simulation are showninTable 2.

Table 1. Parameters of used coding schemes

No.	Code Type	Code Parameters (N,K)	Code Rate (K/N)	Decoding Type	Number of Iterations in Decoding
1	LDPC	(12,8) (12,6) (12,4)	1/3 1/2 2/3	Belief Propagation	10, 20, 30
2	Polar Code	(1944,1296) (1944, 972) (1944,648)	1/3 1/2 2/3	Successive Cancelation	10, 20, 30

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Table 2.IoT network simulation parameters

No.	Parameter	Symbol	Value
1	Number of packets	N_p	10^4 Packets
2	Number of sensor nodes	N_T	320 Nodes
3	Area dimension	$D_X x D_Y$	200mx200m
4	Cluster dimension	$D_{XC} x D_{YC}$	50mx50m
5	Transmission rate	R_b	1Mbps
6	Number of clusters	N_C	16 Clusters
7	Number of nodes per cluster	N_{CN}	20 Nodes

Each node in the network implements a series of processes to handle packets and cooperate in data transmission. The consumed energy is related to the processes performed at both the transmit and receive nodes accordingly. Thus we have the communication and processing energies to be calculated. The communication consumed energy for a given node i is determined by [5,10];

$$E_{comm=}E_{TX} + E_{RX} \quad (1)$$

$$E_{TX} = (E_{elec} + E_{amp} * d^{\gamma})\text{*Packet-size} \quad (2)$$

$$E_{RX} = (E_{elec} * Packet\ size) \quad (3)$$

Where $E_{comm}$is the energy consumed in the transmission process, E_{elec} corresponds to the energy consumed by each data block for electrical transmission and reception of information. E_{amp} is the consumed energy consumed by the amplifier at the transmitter side, d is the distance between nodes, and γ is the path loss factor whose value is constant. The value of γ is considered to be 2 in the LEACH algorithm and the packet size is 1024 bytes [9].

The encoding consumed energy is that used by FEC to encode and decode the collected data. The energy that is consumed in the encoding process has been ignored due to its relatively small value compared to the decoding energy. In LDPC code, Belief Propagation (BP) algorithmis the most useful algorithm used in LDPC decoding due to its performance. The decoding complexity of BP algorithm depends on the number of real multiplications and additions being used in each decoding iteration. The following equation is used to calculate LDPC decoding energy [5].

$$E_{LDPC} = \prod_{m=1}^{L} (3N \cdot w_c + 6t \cdot N \cdot w_r - 10N) E_{mult} + (3N \cdot w_r + N) E_{add} \quad (4)$$

Where N is the code word length, L is the number of decoding iterations, t is the correction capability, $w_r$and w_c are the weights of row and column of parity check matrix for given LDPC code, E_{add} and E_{mult} denote the energy consumed per block for each addition and multiplication,respectively. Table 3 shows the values of $w_r$and w_c for the LDPC code used in the work and Table 4 shows the energy related values [5].

Table 3.Values of w_rand w_c for LDPC code

LDPC (w_c ,w_r)	Rate 1/3	Rate 1/2	Rate 2/3
w_c	6	6	6
w_r	4	3	2

Table 4. Energy parameters [10]

Parameter	Value
T_X and R_x energy (E_{elec})	50 nJ/bit
Initial node energy	3J
Addition energy (E_{add})	0.33 mJ
Multiplication energy (E_{mult})	0.37 mJ

In case of polar code, the consumed energy is determined by the required numbers of multiplications and additions for decoding iteration. This can be approximated by the following equation [11]:

$$E_{Polar} = \prod_{m=1}^{L}((NlogN)E_{mult} + (2logN + K + N)E_{add}) \qquad (5)$$

Where N is the code word length, K is the channel that used and L is the number of decoding iterations,E_{add} and E_{mult} denote the energy consumed per block for each addition and multiplication, respectively.

To find total consuming energy for any FEC code;

$$E_{Total_{cons}}=E_{comm} + E_{FEC_{dec}} \qquad (6)$$

In this work, the remaining energy is calculated to show how much energy being consumed by the coding scheme.

$$E_{rem} = E_{initial} - E_{Total_{cons}} \qquad (7)$$

$E_{initial}$,E_{rem} ,$E_{cons}$are initial, remaining and consumed energies, respectively.

The steps followed in the simulation can be represented by the following main steps:

a- Initialization step:

Set all IoT network specifications (Dimensions, No. of packets, No. of nodes and clusters), coding parameters (coding type, rate, block length, and No. of decoding iterations), transmission properties (transmission rate, wireless channel type, SNR range).

b- Transmission step:

Generate random packets to be transmitted within the network. Follow the operation of LEACH protocol in selecting the cluster head (CH) for each cluster and routing selection from source node to the network sink. For each time cycle select a random node to transmit its packet. Use the given FEC scheme to encode the data then apply binary PSK modulation to modulate the data before transmission over wireless channel model.

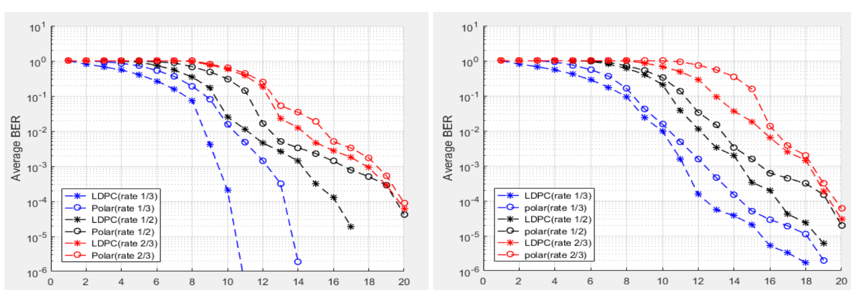
c- Reception step:

In the reception, the received samples are processed by an equalizer to compensate for the channel effect before data detection. The detected binary sequence is the fed to the decoder to recover the original transmitted binary sequence and its corresponding packet.

3. Simulation Test Results

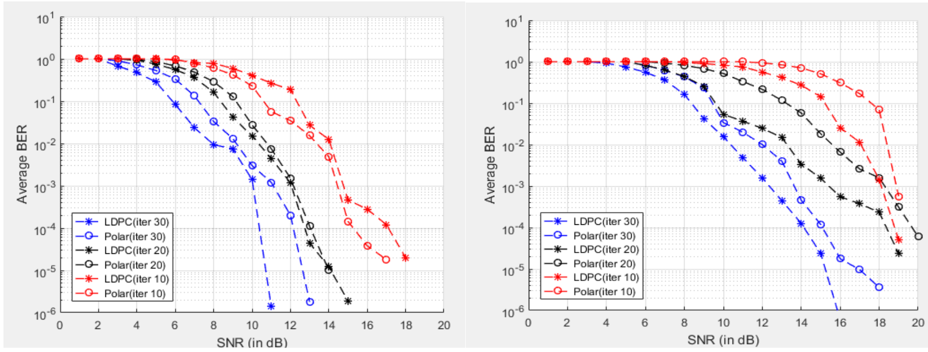
In the simulation, two different codes were used: the LDPC and polar code with different coding rates (1/3, 1/2, and 2/3) and different number of decoding iterations (10, 20, and 30). Two different wireless channels are considered an AWGN and SUI-3 channel model [12]. The latter is a frequency selective fading channel model representing moderate level of fading [13]. Bit error rate (BER), block error rate (BLER), transmission throughput, and consumed energy are the main performance measures considered for IoT networks. The performance test results for BLER, BER and throughput are shown in Figures 1 to 6 and the remaining energy results are shown in Tables 4 and 5.

The BER performance over the two channels considered in the work is shown in Figure 1 and Figure 2. The results obtained show that LDPC with low rate of 1/3 provided an improvement in SNR of about 2.6 dB over AWGN channel and 2 dB over SUI-3 compared to polar code with the same rate and the same decoding iterations of 20 at BER of 10^{-4} (Figure 1). The corresponding improvements are about 1dB (for AWGN channel), and 0.4 dB (for SUI-3 channel) when the number of decoding iterations is 30 and the rate is 1/2 as shown in Figure 2. Figures 3 and 4 show BLER performance in the network, where the performance of LDPC is better than that of polar code with same parameters. The general behavior of the codes here shows better performance of low rate codes compared to high rate. The former consume higher bandwidth. Using high number of iterations provided a better performance on the expense of extra delay in decoding.



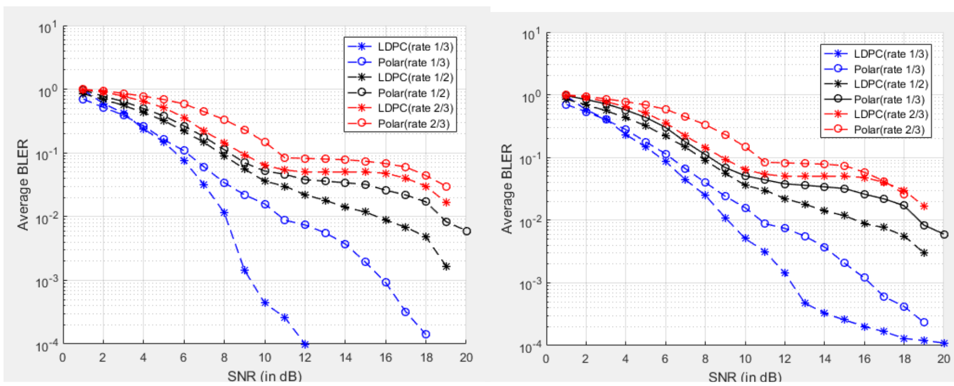
(a) AWGN (b)SUI-3

Figure 1 BER performance with 20 decoding iterations and different rates.



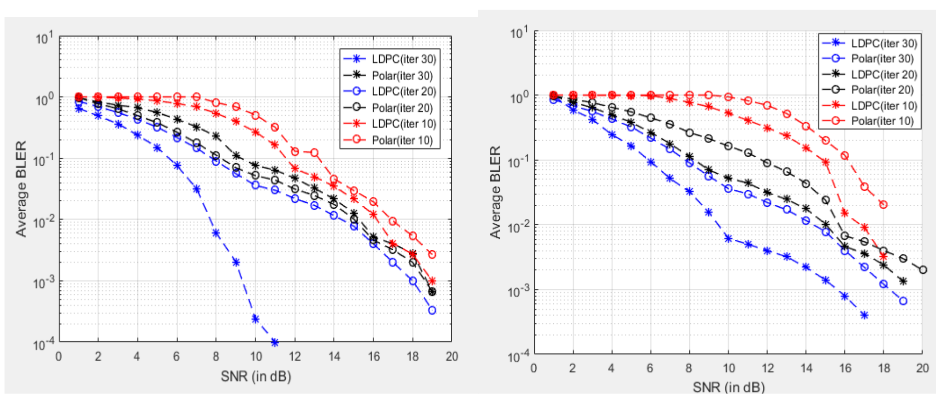
(a) AWGN (b)SUI-3

Figure 2 BER performance using rate 1/2 code and different number of decoding iterations.



(a) AWGN (b) SUI-3

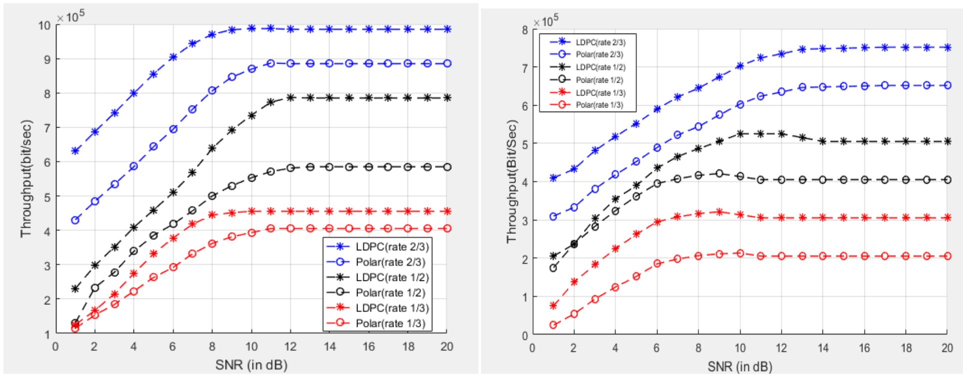
Figure 3 BLER performance with 20 decoding iterations and different rates.



(a)AWGN (b) SUI-3

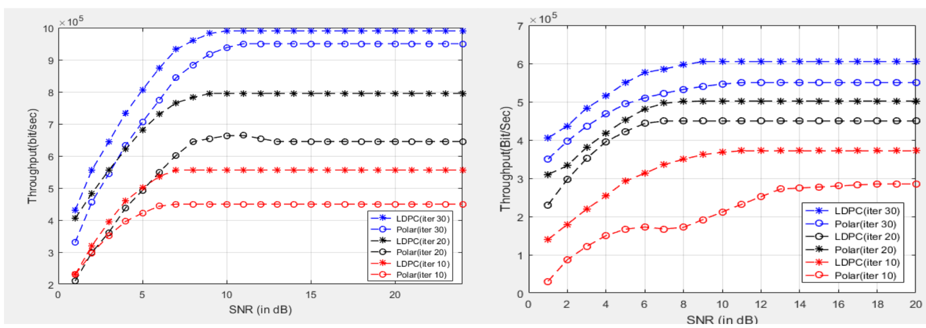
Figure 4 BLER performance using rate 1/2 code and different number of decoding iterations

Transmission throughput over the two channels shows that the high code rate gives a better performance than low rate as shown in Figures 5and 6. Rate (2/3) provided better performance compared to another rates, while high decoding iteration (30) provide a better performance than other iterations. LDPC code give an improvement in throughput of about 12% as compare to Polar code with coding rate of 2/3 over AWGN channel. The corresponding values over SUI-3 channel are about 10%. On the other hand, transmission throughput affected with decoding iteration, such improvements are being 3% for LDPC compared to polar code in case of AWGN and about 4% over SUI-3 channel.



(a) AWGN (b) SUI-3

Figure 5 Throughput performance of codes using 20 decoding iterations with different rates.



(a) AWGN (b) SUI-3

Figure 6 Throughput performance of 1/2 rate codes with different number of decoding iterations.

The remaining energy in each case is calculated. Tables 5 and 6 show high remaining energy when using Successive Cancellation (SC) decoder used with polar code. Such energy is about 2.917 J when rate 1/3 is used. As comparedto LDPC, polar code shows better energy savingfor large number of decoding iterations and high coding rates.

Table 5. Remaining energy by using LDPC code

Coding Rate	No. of Decoding Iterations		
	10	20	30
1/3	2.681 J	1.821 J	0.809 J
1/2	2.514 J	1.240 J	0.567 J
2/3	2.166 J	0.679 J	0.086 J

Table 6. Remaining energy by using Polar code

Coding Rate	No. of Decoding Iterations		
	10	20	30
1/3	2.917 J	2.234 J	0.962 J
1/2	2.572 J	1.827 J	0.723 J
2/3	2.221 J	1.162 J	0.122 J

4. CONCLUSION

Forward error correction schemes can improve the performance of IoT networks in terms of BER, BLER, throughputand save energy. A routing protocol that is already approved to be energy efficient protocol is adopted for the IoT network (LEACH protocol) leading to decrease in the energy consumption of nodes. This is combined with energy models for the coding schemes considered in the work. The simulation test results show that LDPC is performed better than polar code over IoT network when compared at the same coding rate and the number of decoding iterations. The polar code on the other hand shows better energy saving for a large number of decoding iterations and high coding rates as compared with LDPC.

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