

## Energy Performance of LDPC Scheme in Multi-Hop Wireless Sensor Network with Two base Stations Model

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### ABSTRACT

Conservation of the energy is one of the main design issues in wireless sensor networks. The limited battery power of each sensor node is a challenging task in deploying this type of network. The challenge is crucial in reliable wireless network when implementing efficient error correcting scheme with energy consuming routing protocol. In this work, we investigated the energy performance of LDPC code in multi-hop wireless sensor network. We proposed a model of two base stations to prolong the lifetime and build a reliable and energy-efficient network. Through performed MATLAB simulations, we examine the energy effectiveness of multiple base stations model on reliable wireless sensor network performance in different network dimensions.

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## 1. INTRODUCTION

The major constraint in the deployment of wireless sensor networks is the limited battery power of each sensor node and the energy restrictions due to the error correcting scheme deployment to reach high link reliability in the network [1]. In tactical WSNs, nodes which are severely energy constrained have to rely on little energy storage for potentially months or years of service [2]. For this reason, optimization techniques needed to be implemented with the existing designed protocols used by the network to minimize the energy depletion rate (EDR) of the node and subsequently extend the service life of the WSN [3]. Moreover, these types of networks are expected to be reliable, particularly in flawed communication channel [4]. Reducing the energy consumption and increasing the network lifespan of the network in hostile environment is a crucial maneuver [5].

Efficient error correcting codes (ECC) such as LDPC (Low Density Parity Check) and RS (Reed Solomon) codes are used to improve the link reliability and lower the required transmitted power [6], [7]. However, the reliability level of the LDPC codes is provided at the cost of the energy efficiency of decoding process. In fact, these codes have a large computational complexity and employ a complex iterative decoding in the receiver which raises the energy consumption [8]. The preponderance of existing research in WSNs generally includes the perspective of a single base station. To optimize the trade-off reliability-energy in multi-hop network, we proposed a two base stations model and investigated the performance of LDPC code in different network dimensions. We extended the usual WSN conception to a two-base stations framework to improve the energy efficiency of reliable sensor network. We examined the impact of deploying two base

stations in the presence of LDPC and RS schemes on the load balancing and the energy consumption of a multi-hop wireless sensor network employing MTE (Minimum Transmission Energy) routing protocol.

The rest of the paper is organized as follows: Section 2 is a literature survey about the energy analysis of the physical layer. Section 3 discusses the energetic aspect of the used error correcting codes. Section 4 describes the proposed model. In section 5, the simulation results and discussion are given. Finally, section 6 concludes the paper.

## 2. RADIO ENERGY MODEL

The first order energy model was adopted in this work to measure the radio hardware energy dissipation [8]. This model consists of three main units as shown in Figure 1. The transmitter, the power amplifier and the receiver. The transmitter dissipates energy to run the transmitter circuitry and the power amplifier for transmitting data, and the receiver dissipates energy to run the receiver circuitry for receiving data. This model introduces the energy expended to send and receive  $L$ -bit message over a distance  $D$  taking into account two propagation forms, direct propagation and multi-path propagation. The first form is a free space propagation model, direct line-sight path between the transmitter and the receiver. The second propagation form considers a non-direct transmission, where electromagnetic waves will bounce off the ground and reach the receiver from different paths at different times. In the free space propagation model, the propagation loss of transmitting power is modeled as inversely proportional to  $D^2$ , where  $D$  is the distance between the transmitter and receiver. In the multi-path propagation model, the propagation loss of transmitting power is modeled as inversely proportional to  $D^4$ .

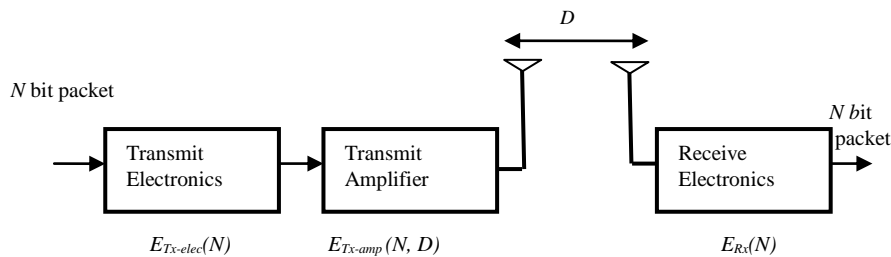


Figure 1. Radio energy model

The energy expended at transmitter is the sum of energy dissipated in the transmit electronics and transmit amplifier. This energy is defined in direct path and multiple path propagation as the following:

$$E_{Tx-dp} = E_{Tx-elec}(N) + E_{Tx-amp-dp}(N, D) \quad (1)$$

$$E_{Tx-mp} = E_{Tx-elec}(N) + E_{Tx-amp-mp}(N, D) \quad (2)$$

Decrease of transmit amplifier gain causes the minimization of the energy dissipation of sensor nodes. However, decreasing transmits amplifier energy result in degraded signal and unsuccessful transmission [9], [10]. To compensate the propagation loss during the transmission, the power amplifier can be used to amplify the transmitting power. Therefore, the transmission efficiency and optimization energy are of paramount interest in the conception of wireless sensor network.

The energy dissipation for transmitting  $N$ -bit message from the transmitter to the receiver at the distance  $D$  is described by:

$$E_{Tx-dp}(N, D) = N \cdot E_{elec} + N \cdot \epsilon_{dp} \cdot D^2 \quad (3)$$

$$E_{Tx-mp}(N, D) = N \cdot E_{elec} + N \cdot \epsilon_{mp} \cdot D^4 \quad (4)$$

The energy expended to receive the  $N$ -bit messages in the receiver circuitry is defined as:

$$E_{Rx}(N) = N \cdot E_{elec} \quad (5)$$

where  $E_{elec}$  is the energy dissipation per bit for running the transceiver circuitry in order to process the information  $N$ ,  $E_{Tx-amp}$  is the electrical energy required to transmit  $N$ -bits message over a distance  $D$ . The amplifier parameter  $\varepsilon_{dp}$  and  $\varepsilon_{mp}$  are constants corresponding to the energy per bit required in the transmit amplifier to transmit an  $N$ -bit messages with adequate SNR over a distance  $D^2$  for direct path and over a distance  $D^4$  for multi-path propagation mode. The parameters  $\varepsilon_{dp}$  and  $\varepsilon_{mp}$  can be calculated following the channel propagation model provided in [11] (Friss and two-ray ground attenuation model):

$$\varepsilon_{dp} = \frac{P_{r-thresh} \cdot (4\pi)^2}{R_b G_t G_r \lambda^2} \quad (6)$$

$$\varepsilon_{mp} = \frac{P_{r-thresh}}{R_b G_t G_r h_t^2 h_r^2} \quad (7)$$

The receiver threshold  $P_{r-thresh}$  can be determined by estimating the noise at the receiver. Where  $P_r$  is the receive power for a transmitter-receiver separation of inter-node distance  $D$ ,  $G_t$  and  $G_r$  are the gains of the transmitting and receiving antennas respectively and  $D$  is the distance between the transmitter and receiver.

The crossover distance for Friss and two-ray-ground attenuation models that defines the propagation transition from direct path to the multi-path model is defined in [11] as follow:

$$D_{crossover} = \frac{4 \cdot \pi \cdot \sqrt{L} \cdot h_r \cdot h_t}{\lambda} \quad (8)$$

where  $L \geq 1$  is the system loss factor not related to propagation,  $h_r$  and  $h_t$  are the heights of the receiving and transmitting antennas above the ground respectively and  $\lambda$  is the transmitted wavelength corresponding to the transmitting frequency ( $F_t=914MHz$ ). If the distance between the transmitter and the receiver is larger than the crossover distance  $D_{crossover}$ , the multi-path model is adopted. Otherwise, the free space model is employed to evaluate the energy dissipation [9].

### 3. ERROR CORRECTING SCHEMES : ENERGY ANALYSIS

#### 3.1. Error correcting schemes in MTE protocol

MTE is a multiple hop routing approach performs transmitting data by using other nodes that act as routers in addition to the environment sensing. The intermediate nodes route other sensor's data that is destined for the base station. The routers are chosen such that the transmit amplifier energy is minimized [12]. During each round, Euclidean distance is calculated between the node and the router nodes, the distance is compared to the crossover distance  $D_{crossover}$  in order to determine which propagation model is adopted (Eq. 8). The node's energy is decremented in proportion to the required energy for packet transmission to the next node. If a node is further from its neighbor, the power consumption for transmitting a set of sensed data is high due to the adoption of multiple paths model; this quickly drain the battery-energy of sender nodes and ultimately lessen the network lifetime. However, MTE routing is more desirable for long distance transmissions [9], [13]. It can completely improves the transmission energy saving. The inconvenience use of MTE routing is that immoderate receive energy is consumed if nodes are close to each other or the energy required for reception is high [13]. Additionally, MTE become an energy demanding protocol when the majority of the network sensor nodes operate the decoding process [12]. In order to study efficiently the effect of error correction codes on the energy efficiency of the network, we adopted the MTE algorithm as routing approach.

The employment of error correcting codes with an implemented MTE routing worsen the energy consumption, particularly when nodes employ a complex coding scheme such as LDPC [14], [15]. Over wide network dimension, the distance between the nodes is too large and the sensed environment may contain natural obstacles, the network ultimately encounters unsuccessful reception. Therefore, it is necessary to employ efficient error correction schemes that result in less error. In fact, wireless sensor networks require reliable data communication as reliability is the fundamental requisite of every communication. However, by employing error correcting codes, the link reliability improvement comes at the cost of extra energy consumption due to the encoding process at the transmitter and decoding at the receiver [14]. Efficient ECC codes provide better performance but have more complex decoders with higher energy consumption. If the extra energy consumption at the decoder outweighs the transmitted energy saving due to the use of ECC, then ECC would not be energy-efficient compared with a non-coded system [16]. Over a small distances between the network nodes, significant energy consumption in decoding process is more important than the transmit energy [15], [16]. However, the effect of path loss and fading phenomenon are not important since inter node distances are short. In the other hand, operating over large inter node distance, the radio energy is

significantly larger than decoding energy consumption and the effect of the path loss and fading phenomenon are very important which affect automatically the reliability of transmissions as well the energy consumption.

Obtained results in [8] demonstrate that LDPC and RS codes are efficient candidates for WSN applications as they feature a significant coding gain as compared with other codes. To achieve a certain desired bit error rate (BER) in WSN, RS and LDPC are considered in this work, since they present best performance of correction capacity and coding gain with satisfactory requirement of BER [17].

### 3.2. Energy analysis

In multi-hop wireless sensor networks, each node both transmit and receive coded information. Therefore, the energy model for multi hop wireless sensor networks with ECC strategy considers decoding energy for all nodes except source node and encoding energy for all nodes [18]. However, energy required in encoding is insignificant as encoding is energy undemanding operation. Thus, the coding energy in multi-hop scheme is not considered in this work.

The total energy needed to transmit and receive information in multi-hop algorithm is given as:

$$E_{Tot} = E_{Tx} + E_{Rx} + E_{Dec} \quad (9)$$

where the estimation of energy computation for each code is formulated as the following:  
Energy dissipation in RS decoding scheme:

$$E_{Dec} = (4t.M + 10t^2)E_{mult} + (4t.M + 6t^2)E_{add} + 3t.E_{inv} \quad (10)$$

Energy dissipation in LDPC decoding scheme:

$$E_{Dec} = (3j + 1)M.E_{add} + (3i + 6t.j - 10)M.E_{mult} \quad (11)$$

where  $E_{add}$ ,  $E_{mult}$  and  $E_{inv}$  denote the energy consumption per  $m$ -bit in the addition, multiplication and inversion, respectively, of field elements in Galois field  $GF(2^m)$ . They have been computed in [19] for 0.18  $\mu$ m, 2.5V CMOS based implementation. Parameter  $t$  is the correction capacity,  $M$  is the code word length,  $i$  and  $j$  are weight of row and column of parity check matrix for LDPC code. In minimum-transmission-energy algorithm, nodes route information destined for the base station through intermediate nodes. These nodes act as gateways of other nodes in addition to sensing the environment.

Therefore, each data message must go through  $m$  transmits, a distance  $r$  and  $m-1$  receives. The total energy in MTE network is given as:

$$E_{MTE} = m.E_{Tx}(N, r) + (m - 1).E_{Rx} \quad (12)$$

In case of free-space propagation:

$$E_{MTE} = N \left( (2m - 1).E_{elec} + m.\epsilon_{dp}.r^2 \right) \quad (13)$$

In case of multi-path propagation:

$$E_{MTE} = N \left( (2m - 1).E_{elec} + m.\epsilon_{mp}.r^4 \right) \quad (14)$$

The total energy  $E_{T-coded}$  in MTE network employing an error correction scheme is the summation of radio energy and decoding energy. Using Eq. (10), Eq. (11) and Eq. (12), we obtain the total energy for RS and LDPC in the case of free-space propagation:

$$E_{T-coded-RS} = N \left( (2m - 1)E_{elec} + \epsilon_{dp}.m.r^2 \right) + (4t.M + 10t^2)E_{mult} + (4t.M + 6t^2)E_{add} + 3t.E_{inv} \quad (15)$$

$$E_{T-coded-LDPC} = N \left( (2m - 1)E_{elec} + \epsilon_{dp}.m.r^2 \right) + (3j + 1)M.E_{add} + (3i + 6t.j - 10)M.E_{mult} \quad (16)$$

#### 4. PROPOSED CONFIGURATION

The base station represents the final destination for individual front nodes in the MTE network that sending periodically their own coded packet information. The base station performs the decoding operations without energy constraint due to the fact that it is assumed to have unlimited energy supply. In order to achieve optimal performance and improve the lifespan of the sensor network, we proposed the load balancing approach in MTE routing scheme by using two base stations model. The goal is to distribute the total traffic between sensor nodes over two base stations [20].

The proposed approach aims to lighten the decoding energy consumption and the energy transmission and prolong the lifetime in a reliable wireless sensor network. We investigated the load balancing from energy efficiency perspective, taking into account the implemented decoding schemes RS and LDPC in the network.

The physical layer has the largest impact on a sensor's energy level. In the proposed radio model, energy is depleted based on the magnitude of the wireless propagation distance. The node chooses the station that the transmission requires the lowered energy [21]. Therefore, the traffic load is portioned upon two networks. Some transmission links, by choosing the closest base station, systematically adopt free space model instead of multiple-path model. Each node sends their information with minimum transmission energy by employing the nearest neighbor in the optimal path toward the base station. To generate the MTE routes, the Dijkstra algorithm is employed [22]. Since nodes rely on their peers to pass information to the base station, if a peer of nodes prematurely dies due to the error correcting code employment, the wireless communication route is no longer available. If the communication route was the last viable route in the network, then the network becomes partitioned. Nodes with available energy no longer have a communication path to the base station, which creates sub-optimum network performance [22]. Furthermore, packets crossing more hops accumulate additional errors and require efficient coding schemes to effectively recover the massed errors. Additionally, large packet size is more sensitive to channel errors and requires effective coding and decoding schemes to ensure reliable reception at the base station.

The proposed model of two base stations minimizes the number of hops and the packets size destined for the BS. Moreover, it mitigates the decoding load in router nodes, particularly on hot sensor nodes. The implementation of this model in multi-hop scheme balances the traffic load of intermediate nodes, enhances the transmission reliability and network lifetime, and achieves optimal performance in the network.

#### 5. SIMULATIONS AND RESULTS

We have performed MATLAB simulation tests over multi-hop wireless sensor network employing MTE routing scheme with two base stations. We have considered a homogenous network containing 50 nodes. The simulation areas tested are rectangular fields of 200 m<sup>2</sup> and 400 m<sup>2</sup>. All nodes are dispersed around this field randomly. Table 1 shows the radio parameters used in the simulation. Both RS and LDPC codes are considered in the simulation.

In order to approach an energy dissipating sensor network and display the usefulness of multiple base stations model, we assume in this work that the radio dissipates an important radio electronic energy  $E_{elec}=50$  nJ/bit to run the transmitter or receiver circuitry (Table 1). In the proposed model, we placed a second base station distantly connected to the sensor network at the same distance as the first base station. The two base stations are placed at 100 meters from the sensor field (Figure 2). All nodes have a starting energy of 0.5 Joules and the two base stations have unlimited energy.

Figure 3 shows the total system energy over 200 m<sup>2</sup> network dimension using the error correcting codes RS and LDPC in the two base stations model.

Table 1. Simulation parameters

Parameter	Value
Transmit and Receive Electronics: $E_{elec}$	50 nJ/bit
Amplifier constant $\epsilon_{ap}$	10 pJ/bit/m <sup>2</sup>
Amplifier constant $\epsilon_{mp}$	0.0013 J/bit/m <sup>4</sup>
Message size (bits)	2000 bits
Number of nodes in the network	50
Initial node energy	0.5 J
$D_{crossover}$	87 m
Network dimension	200 m <sup>2</sup> / 400 m <sup>2</sup>
Coding schemes	RS/ LDPC
Antenna gain factor $G_t, G_r$	1
Antenna height above the ground $h_t, h_r$	1.5 m
Signal wavelenght $\lambda$	0.325 m
Bit Rate $R_b$	1Mbps

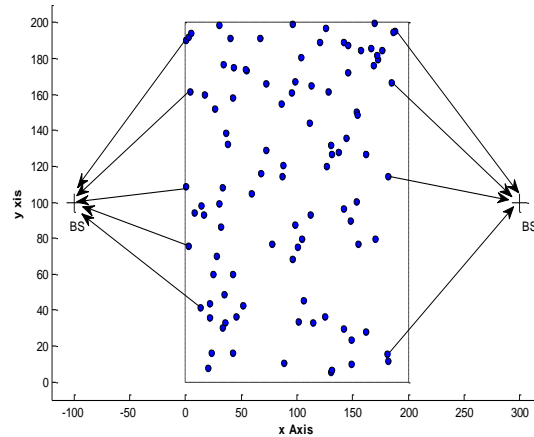


Figure 2. Multi-hop sensor network with two BS model

Table 2 represents the die-off statistics of LDPC and RS schemes in multihop network for  $200 \text{ m}^2$  and  $400 \text{ m}^2$  network dimensions for 1BS and 2BS model. Table 3 and Table 4 display the energy depletion rate in the studied network dimensions for 1BS and 2BS model. The simulation outcomes show the energy performance of RS and LDPC coding schemes in multihop wireless sensor network using one base station and two base stations.

Table 2. Die-off statistic of LDPC & RS schemes in multi-hop network

Field	% dead nodes	Uncoded (1BS)	Uncoded (2BS)	RS (1BS)	RS (2BS)	LDPC (1BS)	LDPC (2BS)
$200 \text{ m}^2$	10%	78	100	65	84	50	63
	50%	190	309	159	259	122	204
	90%	253	536	212	450	167	365
$400 \text{ m}^2$	10%	45	60	38	50	31	42
	50%	80	127	67	107	58	96
	90%	92	188	78	159	68	145

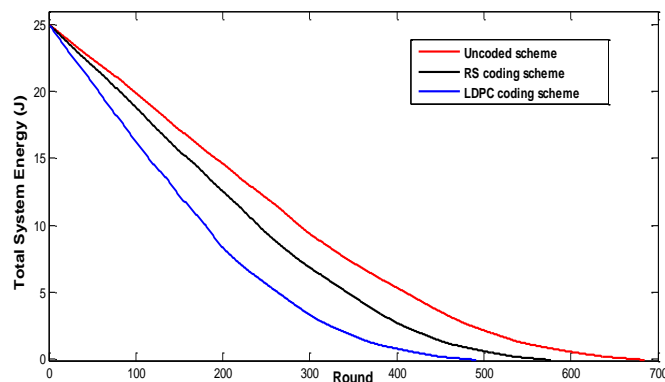


Figure 3. Total system energy with 2BS over  $200 \text{ m}^2$  network size

From Figure 3 and Figure 4, it is clear that LDPC is less energetically efficient than RS scheme. LDPC is characterized by significant energy consumption in multi-hop networks due to the use of a decoding algorithm with largest computational complexity [23]. In the network of  $200 \text{ m}^2$  dimension, the energy depletion ratio of LDPC scheme using one base station model increases of 18% and 31.4% compared to RS and uncoded scheme respectively (Table 3). However, LDPC scheme employs a complex iterative decoding process (Belief Propagation algorithm) at the receiver which intensely drains the energy of the nodes and the lifetime of the network [24]. Unlike LDPC, RS coding scheme employs a simple decoding procedure which

minimizes the energy computation consumed by the decoder in each sensor node. Nevertheless, LDPC is an efficient scheme used to improve the inter-node link reliability in multi-hop routing protocol [25]. Therefore, the energy-reliability pair is an utter constraint restricting the achievement of minimum requirement in inter-nodes communication viability and satisfactory energy efficiency in the whole sensor network [26].

Table 3. Energy depletion rate in 200 m<sup>2</sup> surface

Coding scheme	1BS	2BS	EDR reduction
RS	0.1	0.0433	56.7%
LDPC	0.1219	0.0509	58.24%
Uncoded	0.0836	0.0364	56.45%

Table 4. Energy depletion rate in 400 m<sup>2</sup> surface

Coding scheme	1BS	2BS	EDR reduction
RS	0.3086	0.1344	56.44%
LDPC	0.3571	0.1470	58.83%
Uncoded	0.2604	0.1141	56.18%

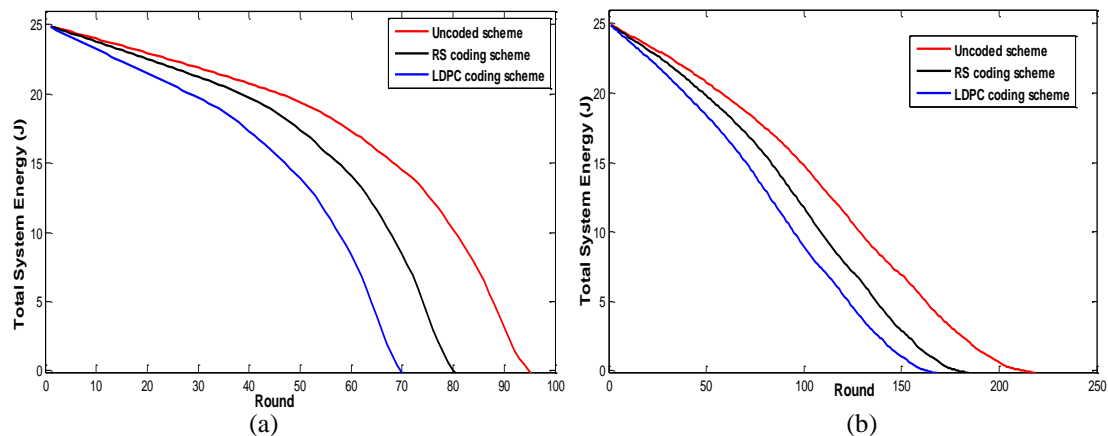
The proposed model of two base stations in multi-hop network compromises between the energy and reliability constraints. As expected the energy efficiency of the network turns into significant values after adding a second base station in the presence of LDPC and RS codes. The energy depletion proportion of RS, LDPC and uncoded schemes decreases of 56.7%, 58.24 % and 56.45% respectively compared to one base station model (Table 3).

In the proposed model, the front nodes in the network that receive all the load of sensed data share the task with the front nodes of the second base station. This lightens the transmitting load, the encoding and decoding processes and systematically improves the energy efficiency of the network. On the other hand, energy depletion ratio of LDPC scheme increases of 15% and 28.4% compared to RS and uncoded schemes respectively.

In order to evaluate the energy performance of LDPC coding scheme in large surface with two base stations model, we simulated a large network of 400 m<sup>2</sup> dimension (Table 4). Figure (a) and figure (b) show the total system energy of 400 m<sup>2</sup> network dimension using the error correcting codes RS and LDPC in one base station model and two base stations model respectively. In one base station model, the EDR of LDPC scheme increases of 13.5% and 27% compared to RS and uncoded schemes respectively. In two base stations model, the EDR of LDPC increases of 8.5% and 22.4% compared to RS and uncoded schemes respectively.

The percentage of EDR proportion of LDPC scheme compared to RS scheme decreases from 18% to 13.5% when extending the surface of the network from 200 m<sup>2</sup> to 400 m<sup>2</sup> in one base station model. The percentage of EDR proportion of LDPC scheme compared to RS scheme significantly decreases from 15% to 8.5% when enlarging the network dimension from 200 m<sup>2</sup> to 400 m<sup>2</sup> in two base stations model.

LDPC scheme accelerates the death of front nodes of the network with cascading effect, due to the weighty task of these nodes that receive all the routed data of the network and decode and code all data destined for the base station. This eventually transforms the routing topology in a certain network lifespan to direct topology where last nodes encode and transmit sensed data directly to the base station. Contrary to the LDPC, front nodes in the network using RS coding scheme conserve the decoding process at a later stage and at large scale of the network due to the energy undemanding decoding operation. The same multi-hop routing topology is retained for long time over the network where each node encodes/decodes and transmits data to other intermediates nodes.

Figure 4. Total system energy with one (a) and two (b) BS over 400 m<sup>2</sup> network size

We extended the simulation to 600 m<sup>2</sup> network dimension to observe the effect of surface dimension and the employment of two base stations on the energy efficiency of ECC schemes. As a result, the difference of energy depletion rate lessens between LDPC and RS on one hand and LDPC and uncoded scheme on the other hand. This proves that the energy performance of LDPC improves over large network dimension in multihop network in the presence of two base stations model.

## 6. CONCLUSION

In this paper, an energy performance evaluation of LDPC scheme in multihop wireless sensor networks has been carried out. A sensor network model of two base stations was proposed to optimize the energy use of LDPC scheme in reliable sensor network. The proposed model lightens the transmission burden and decoding energy consumption and significantly increases the sensor network lifespan. Extensive simulation results illustrate the efficacy of the proposed model and demonstrate the energy performance improvements of LDPC scheme for large network dimensions in the presence of two base stations. The proposed model can be adopted for large-scale monitoring applications.

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