Performance Analysis on Wireless Sensor Network using LDPC Codes over Node-to-node Interference

Sangmin Choi*, Byunghyun Moon *
* School of Computer and Communication Engineering, Daegu University
sangmin@daegu.ac.kr, bhmoon@daegu.ac.kr

Abstract - Wireless sensor networks(WSN) technology has various applications such as surveillance and information gathering in the uncontrollable area of human. One of major issues in WSN is the research for reducing the energy consumption and reliability of data. A system with forward error correction(FEC) can provide an objective reliability while using less transmission power than a system without FEC. In this paper, we propose to use LDPC codes of various code rate(0.53, 0.81, 0.91) for FEC for WSN. Also, we considered node-to-node interference in addition to AWGN channel. The proposed system has not only high reliable data transmission at low SNR, but also reduced transmission power usage.

Keywords: LDPC codes, Wireless sensor network, Node-to-node interference.

1 Introduction

In recent years, the idea of wireless sensor networks (WSN) has received a lot of attention by researchers. Such a network consists of hundreds to several thousands of small nodes scattered throughout an area of interest information about the environment is gathered by the sensors and is delivered to a central base station where the user can extract the desired data.

Sensor nodes are very tiny and have limited power resource. Since applications involving WSN require long system lifetimes, energy usage must be carefully controlled. Table 1 shown the energy usage due to various types or instructions in WSN[1].

Table 1. Energy Usage

Instruction type	Energy per cycle (nJ)	Energy per instr (nJ)
Idle	1.70	1.70
Arithmetic/logic	3.41	3.41
Device	Energy per CPU cycle	Energy quantum
LED	1.89	1.89 nJ/cycle
RFM send	2.56	2050 nJ/cycle
RFM receive	2.44	1950 nJ/cycle

From Table 1 it is clear that most of the energy is used during the transmission and reception of data. Also, sensor network has possible occurred error by node-to-node interference, because sensor network has many nodes and construct dense networking.

Our goal is to reduce the transmission power usage in the WSN. This can be achieved by the following forward error correction (FEC) for reliable data transmission[1][2] [3][4]. Therefore, proper error control coding can save the power required for communication of the information on bits. WSN using LDPC codes are almost 45% more energy efficient than those that use BCH code which were shown to be 15% more energy efficient than the best performing convolutional codes[2].

We propose to study low-density parity-check (LDPC) codes of various code rate(0.53, 0.81, 0.91) to provide reliable communication while reducing power usage in the WSN over node-to-node interference in addition to AWGN channel.

2 Related Works

2.1 Physical layer and components of WSN

The physical layer (PHY) shall employ direct sequence spread spectrum (DSSS) with binary phase-shift keying (BPSK) used for chip modulation[6].

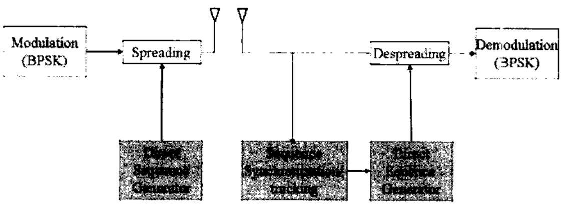

Figure 1. Modulation and spreading functions

The functional block diagram in Figure 1 is provided as a reference for specifying the PHY modulation and spreading functions. Each bit in the PHY protocol data unit (PPDU) shall be processed through the modulation and spreading functions with the preamble field and ending with the last octet of the PHY service data unit (PSDU).

It is shown PPDU of WSN in Figure 2. Size of PPDU is 1064 bits with PSDU of 1016bits.

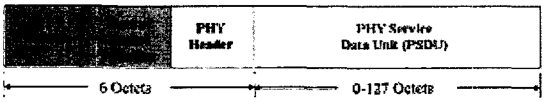

Figure 2. PPDU of WSN using IEEE 802.15.4 PHY

It is shown component of WSN in Figure 3. Sensor nodes have various sensors and sense various informantion. Sink nodes and gateway are collection of data from sensor nodes.

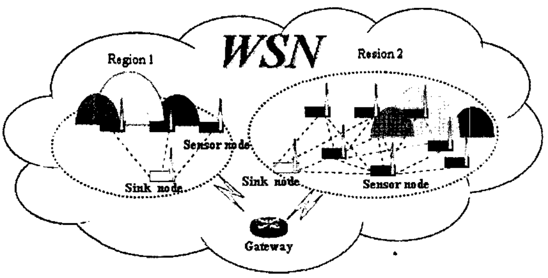

Figure 3. Components of WSN

2.2 FEC using LDPC codes

Link reliability is an important parameter in the design of any WSN due to the unpredictable and harsh nature of channels and the fact that most of the applications of the WSN require high data precision. The channel bit error rate (BER) is inversely proportional to the received signal-to-noise ratio (SNR) and the output power. To increase the reliability of the communication we can either increase the output power of the node or use a suitable error control code. The former solution is not applicable due to the limited power available for each sensor node.

LDPC codes are discovered by Gallager in 1962 and have recently been rediscovered LDPC codes exhibit a performance extremely close to the Shannon capacity formula[7][8][9]. Using error control coding increases the reliability and decrease the transmit power required. However, the additional processing required increases the energy of computation. The energy efficiency factor defined in [2], [3] and [4] can be used in a suitable metric for evaluating the efficiency of the FEC. This factor involves both the energy efficiency and the reliability factor. The energy efficiency is defined as the energy for communication of the information bits divided by the sum of total energy for communication of both the information bits and the redundant bits and the start-up and decoding energy consumption.

To compare LDPC codes as FEC with BCH codes, we use the same energy consumption characteristic as [3]. If the code rate of the LDPC code is equal to R, then for each k information bits the transmitter is sending $n=k/R$ bits. The energy required to transmit and receive on information bit and be expressed as follows:

$$E_b = E_r + E_t + \frac{E_{dec}}{k} \tag{1}$$

where E_{dec} represents the decoding energy per packet, E_t and E_r are the required energy for transmitting and receiving, respectively,

$$E_t = \frac{(P_{te} + P_O)\frac{n}{r} + P_{tst}T_{tst}}{k}$$
$$E_r = \frac{P_{re}\frac{n}{r} + P_{rst}T_{rst}}{k} \tag{2}$$

P_{te}/P_{re} represents the power consumption in transmitter/receiver electronics. P_{tstc}/P_{rst} represents the power consumption in the start-up and r represents the data rate.

Equation (1) can be rewritten as follow :

$$E_b = k_1 + k_1\frac{n}{k} + \frac{k_2 + E_{dec}}{k} \tag{3}$$

where k_1 can be thought as of useful energy for communication of a information bit and k_2 as the start-up energy consumption. The energy efficiency as computed as follows:

$$\eta_e = \frac{k_1 k}{k_1 n + k_2 + E_{dec}} \tag{4}$$

and the energy efficiency factor is defined as follows:

$$\eta = \eta_e(1 - PER) \tag{5}$$

where PER denotes the packet error rate after applying the decoding algorithm. In this experiment, as in [4], we assume RFM-TR1000 as the transceiver and k_1 and k_2 are assumed to be equal to $1.85\mu J$/bit and $24.86\ \mu J$ respectively. In order to determine the value of η in (5), E_{dec} and PER need to be identified.

To find the value of the E_{dec}, we used the results of [3].

$$E_{dec} = (3nj + n)E_{add} + (3ni + 6nj - 10n)E_{mult} \tag{6}$$

where E_{add} is energy consumption per bit addition and E_{mult} is energy consumption per bit multiplier[3]. i and j is weight of row and column of parity check metrix.

The figure 4 shows decoding energy of LDPC codes.

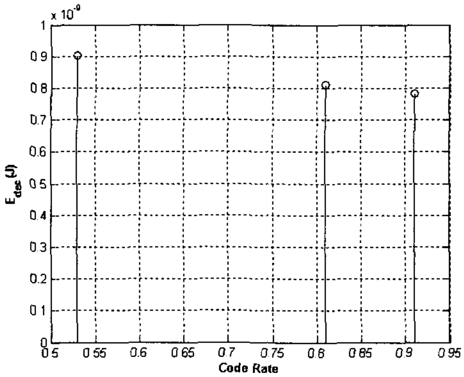

Figure 4. Decoding energy per packet (Iteration = 1)

3 Interference Signal and WSN using LDPC Codes

3.1 Interference signal

WSN compose closed network using hundred of sensor nodes. Therefore, WSN has node-to-node interference. Node-to-node interference is interference of the other sensor node, when data send to sink node or gateway form sensor nodes.

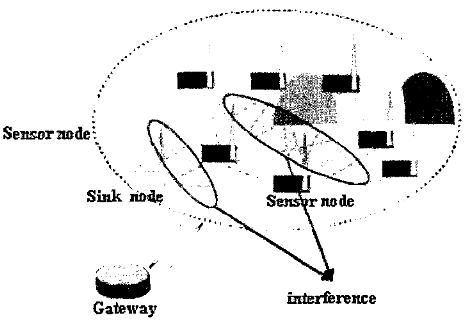

Figure 5. Node-to-node interference of WSN

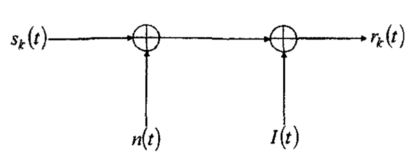

Figure 6. AWGN channel model with node-to-node interference

Received data from k-th sensor node is equation (7).

$$r_k(t) = s_k(t) + n(t) + I(t) \qquad (7)$$

Where $s_k(t)$ is the transmitted signal from the k-th sensor node. $n(t)$ denotes Gaussian Noise and $I(t)$ denotes node-to-node interference in equation (8) and (9) respectively.

The transmitted signal DSSS BPSK modulation and can be written as

$$s_k(t) = Ab_k(t)c_k(t)\sin(2\pi f_c t), \quad 0 \le t \le T \qquad (8)$$

where $b_k(t)$ is data, taking values of $\pm$ 1, $c_k(t)$ is the spreading signal

$$I(t) = \sum_{i=1}^{n} s_i(t) - s_k(t), \qquad 1 \le k \le n \qquad (9)$$

where $s_i(t)$ is signals of i-th sensor node and $s_k(t)$ is transmitting data of k-th sensor node.

3.2 WSN using LDPC codes

We propose coded data packet by LDPC codes for FEC. Packet with FEC has reliability of data and energy efficiently.

Proposed system is DSSS system using LDPC codes as follow:

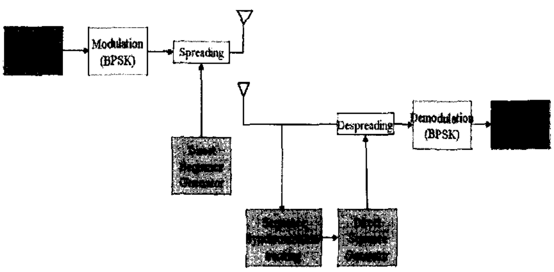

Figure 7. Proposed system using LDPC codes

The parameter of LDPC codes is shown in Table 2. LDPC codes use sparse parity check matrix with uniform number of 1's per column and row. Decoding algorithm of LDPC codes uses sum-product algorithm.

Table 2. Code parameters

	(N,M)	Rate	Column Weight
Code 1	(1064,500)	0.53	3
Code 2	(1064,200)	0.81	3
Code 3	(1064,100)	0.91	3

4 Performance Analysis

We simulated WSN using LDPC codes over node-to-node interference. The interference is simulated as 6 simultaneous transmissions of DSSS signal from 6 sensor nodes. All have the same modulation type as shown in equation (8). LDPC codes used in the simulation is R=0.53, 0.81, 0.91 and N=1064.

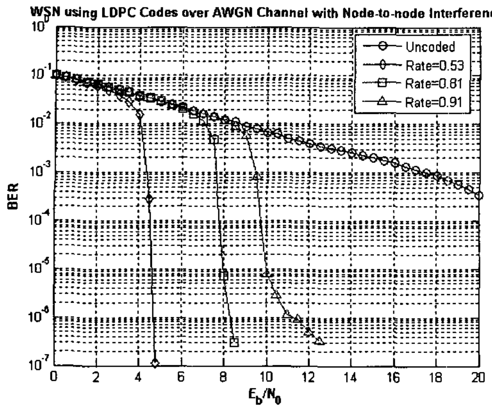

Figure 8. BER performance of WSN using LDPC codes (nodes = 7)

Figure 8 depicts the BER curves of WSN using LDPC codes over node-to-node interference. It is shown that the WSN with the rate 0.53 LDPC code obtains at least 13dB gain over the WSN without LDPC code at BER=10^{-3} for Code 1. For the Code 2 to 3, at least 9 dB and 7 dB gain were obtained, respectively.

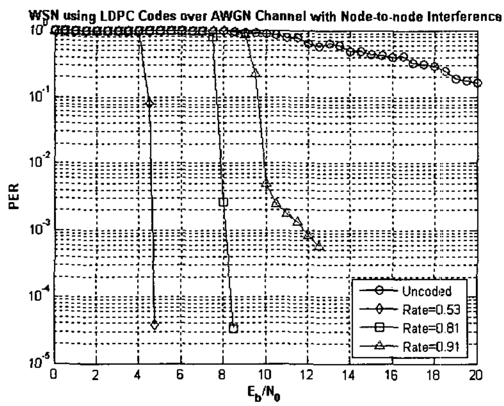

Figure 9. PER performance of WSN using LDPC codes (nodes = 7)

Figure 9 depicts the PER curves of WSN using LDPC codes over node-to-node interference. It is shown that the WSN with LDPC codes has PER that is lower than the WSN without LDPC codes. Therefore, the WSN with LDPC codes has low retransmission rate.

5 Conclusions

In this paper, the WSN using LDPC codes is proposed for high reliable data and reducing energy consumption. We use various code rate, R=0.53, 0.81, 0.91, for FEC for WSN and consider node-to-node interference in addition to AWGN channel. With R=0.53, 0.81 and 0. 91 and N=1064, the SNR of 7dB, 9dB and 13dB can reach BER of 10^{-3} respectively. The R=0.53 LDPC coded system obtained about 13dB gain over the WSN without LDPC code. It is shown that the rate of 0.91 LDPC coded system obtained 7dB gain over the WSN without LDPC codes. The WSN with LDPC codes has low power usage, because of the WSN with LDPC codes has SNR lower than the WSN without LDPC codes at same BER. Also, WSN with LDPC codes has high reliability of data at low SNR.

References

[1] Jaein Jeong and Cheng Tien Ee, "Forward error correction in sensor networks," U.C Berkeley Technical Report, May, 2003.

[2] Mina Sartipi, Faramarz Fekri, “Source and channel coding in Wireless sensor networks using LDPC codes,” IEEE Communications Society Conference on 4-7 Oct. 2004.

[3] Y. Sankarasubramaniam, I. F. Akyuildiz, and S. W. McLaughin, “Energy efficiency based packet size optimization in wireless sensor networks,” proceedings of 1st IEEE international Workshop on Sensor Network Protocols and Applications SNPA’03, 2003.

[4] Zorzi, M.; Rao, R.R, “Coding tradeoffs for reduced energy consumption in sensor networks,” PIMRC 2004. 15th IEEE International Symposium on Vol. 1, 5-8 Sept. 2004

[5] M. Goel and N. R. shanhag, “Low-power channel coding via dynamic reconfiguration,” Proc. Of International Conference on acoustics, Speech and Signal Processing, March, 1999.

[6] IEEE802.15.4-2003, IEEE Standard for Information Theory-Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer(PHY) Specifications for Low-Rate Wireless Personal Area Networks(LR-WPANs), Oct, 2003.

[7] R. G. Gallager, "Low-Density Parity-Check Codes" IRE Trans on Info. Theory vol.8, pp 21-28, Jan 1962.

[8] D. J. C. MacKay and R. M. Neal, "Near Shannon limit performance of low density parity check codes", Electron, Ldtt., vol.32, no. 18, pp 1645-1646, Aug, 1996.

[9] D. J. MacKay, " Good Error Corecting Codes Based on Very Sparse Matrices", IEEE Trans, on Inform, Theory, vol.45, pp399-431, March 1999.