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Performance Analysis on Error Correction Scheme for Wireless Sensor Network over Node-to-node Interference

Sang-Min Choi, Byung-Hyun Moon*, Jeong-Tak Ryu, Se-Hyun Park

Abstract : In this paper, we study a problem of providing reliable data transmission in wireless sensor network(WSN). A system with forward error correction9FEC) can provide an objective reliability while using less transmission power than a system without FEC. We propose the use of LDPC codes of various code rate (0.53, 0.81, 0.91) of FEC for WSN. Node-node-node interference is considered in the simulation in addition to AWGN in the channel. It is shown that the rate of 0.91 LDPC coded system obtained 7dB gain in signal to noise ratio over a system without FEC

.**Keywords** : Wireless Sensor Network, Error Correcting Codes, LDPC Code, Node-to-node Interference

Ⅰ. Introduction

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.

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 in a sensor node

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

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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 LDPC codes of various code rates0.53, 0.81, 0.91) for FEC to provide reliable communication while reducing power usage in the WSN when node-to-node interference is present in addition to AWGN noise in the channel.

Ⅱ. IEEE 802.15.4

Task group 4 in IEEE 802.15 Wireless Personal Area Network working group had established a new standard that can be used in wireless sensor network. In 2003, the IEEE 820.15.4 draft 18 was approved. The operating frequencies of IEEE 802.15.4 are 868/915MHz and 2.4Ghz. In both frequencies, direct sequence spread spectrum (DSSS) with BPSK/OQPSK modulation scheme is used. Table 1 shows the frequency bands and the spreading parameters.

Table. 2. Frequency bands and spreading parameters for IEEE802.15.4

PHY (MHz)	frequency band (MHz)	Spreading Parameter	
		Chip rate (kchip/s)	Modulation
868/915	868-868.6	300	BPSK
	902-928	600	BPSK
2450	2400-2483.5	2000	O-QPSK

In Figure 1, the packet structure of IEEE 802.15.4 is shown. It consists of 6 bytes of header and 0-127 byte of data.

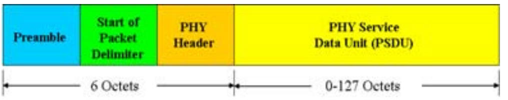

Fig. 1. PPDU of WSN using IEEE 802.15.4 PHY

Ⅲ. 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:

$$E_b = E_t + E_r + \frac{E_{dec}}{k} \qquad (1)$$

where Edec represents the decoding energy per packet, Et and Er are the required energy for transmitting and receiving, respectively,

$$E_t = \frac{(P_{te} + P_O)\frac{n}{r} + P_{tst}T_{tst}}{k} \qquad (2)$$

$$E_r = \frac{P_{re}\frac{n}{r} + P_{rst}T_{rst}}{k} \qquad (3)$$

Pte/Pre represents the power consumption in transmitter/receiver electronics. Ptst/Prst represents the power consumption in the start-up and r represents the data rate.

Equation (1) can be rewritten as follow:

$$E_b = k_1 + k_1\frac{n}{k} + + \frac{k_2 + E_{dec}}{k} \qquad (4)$$

where k1 can be thought as of useful energy for communication of a information bit and k2 as the start-up energy consumption. The energy efficiency as computed as follows:

$$\eta_e = \frac{k_1 k}{k_1 n + k_2 + E_{dec}} \qquad (5)$$

and the energy efficiency factor is defined as follows:

$$\eta = \eta_e(1 - PER) \qquad (6)$$

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 k1 and k2 are assumed to be equal to 1.85μJ/bit and 24.86μJ respectively. In order to determine the value of η in (6), Edec and PER need to be identified.

To find the value of the Edec, we used the results of [3].

$$E_{dec} = (3nj + n)E_{add} + (3ni + 6nj - 10n)E_{\mu lt} \qquad (7)$$

where Eadd is energy consumption per bit addition and Emult is energy consumption per bit multiplier[3]. i and j is weight of row and column of parity check matrix.

The figure 2 shows decoding energy of LDPC codes.

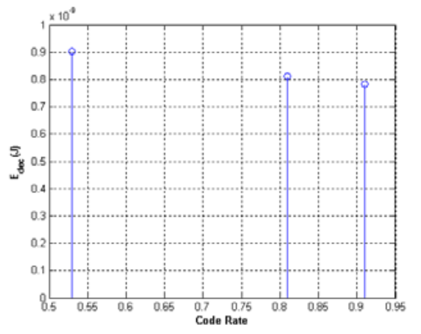

Fig. 2. Decoding energy per packet (iteration =1)

Ⅳ. Interference Signal and WSN using Error Correction Scheme

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 from sensor nodes.

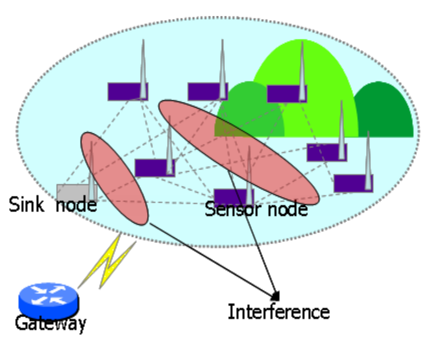

Fig. 3. Node-to-node interference of WSN

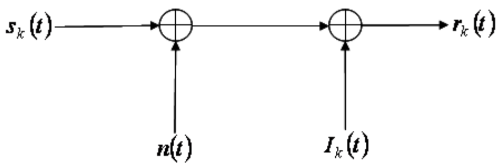

Fig. 4. AWGN channel model with node-to-node interference

Received data from k-th sensor node is in equation (8).

$$r_k(t) = s_k(t) + n(t) + I(t) \quad (8)$$

where sk(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 (9) and (10) respectively.

The transmitted signal DSSS-BPSK modulation and can be written as

$$s_k(t) = Ab_k(t)c_k(t)\sin(2\pi f_c t)\mathrm{b} \quad (0 \leqq t \leqq T) \quad (9)$$

where bk(t) is data, taking values of ±1, ck(t) is the spreading signal

$$I(t) = \sum_{i=1}^{n} s_i(t) - s_k(t), \quad (1 \leqq k \leqq n) \quad (10)$$

where si(t) is signals of I-th sensor node and sk(t) is transmitting data of k-th sensor node.

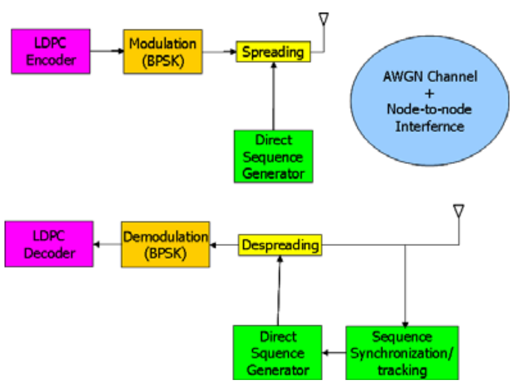

Fig. 5. Proposed system using Error Correction Scheme

2. WSN using Error Correction Scheme

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 error correction scheme(convolutional code, LDPC codes) as follow:

The parameter of FEC 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 3. Code parameters

	(N,M)	Rate	Column Weight
LDPC Code	(1064,500)	0.53	3
	(1064,200)	0.81	3
	(1064,100)	0.91	3
Conv. Code	Generator		(7,5)
	Constraint Length		3
	Rate		0.5

V. 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 and convolutional code used in the simulation is R=0.53, 0.81, 0.91 and N=1064.

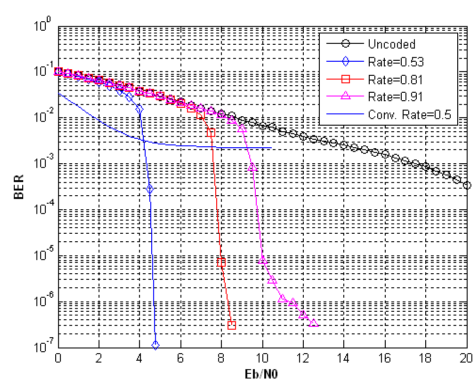

Fig. 6. BER performance of WSN using LDPC codes (nodes = 7)

Figure 6 depicts the BER curves of WSN

using error correction scheme over node-to-node interference. It is shown that the WSN with the code 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. But convolutional code had a error floor region and bed Performance over node-to-node interference.

Figure 7 depicts the PER curves of WSN using error correction scheme 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. Also, it is shown that the WSN with LDPC codes has PER than lower than the WSN with convolutional code at code rate=0.5. Therefore, the WSN with LDPC codes has low retransmission rate.

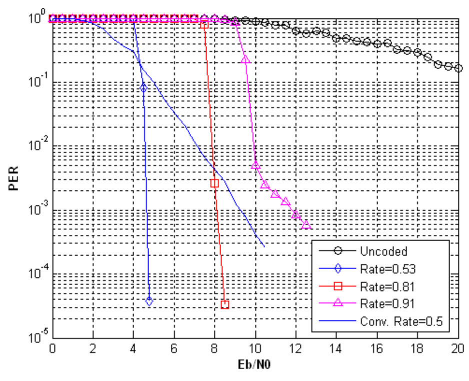

Fig. 7. PER performance of WSN using LDPC codes (nodes = 7)s

Ⅵ. Conclusion

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.

Reference

[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 Correcting Codes Based on Very Sparse Matrices", IEEE Trans, on Inform, Theory, vol.45, pp399 431, March 1999.

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