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LDPC 코드의 Linear-Congruence를 이용한 WSN 에너지 효율

(Energy Efficiency in Wireless Sensor Networks using Linear-Congruence on LDPC codes)

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요 약

최근 무선센서 네트워크는 센서 영역 안에 수많은 센서 노드로 구성되어 있으며, 각각의 센서들은 강제적인 에너지 구속조건을 가지고 있으므로 효율적인 에너지 관리는 중요하다. WSN 응용 시스템에서 FEC(Forward error correction)는 데이터 전송의 에너지 효율성과 데이터 신뢰성을 증가시킨다. LDPC 코드는 FEC 코드중 하나로 코드워드의 길이가 커지면 다른 FEC 코드 보다 많은 부호화 작업을 필요로 하지만, 샤논의 용량 한계에 접근되어 있으며, 전송에너지의 감소와 데이터 신뢰도를 증가시키는데 사용되어진다. 본 논문에서는 WSN(Wireless Sensor Network)에서의 에너지 효율성 증가와 부호화의 복잡도를 줄이기 위하여 LDPC(Low-density parity-check) 코드의 패리티 체크 행렬의 생성에 Linear-Congruence 방법을 적용하였다. 결과적으로 본 논문에서 제안된 알고리즘은 부호화 에너지 효율성과 데이터의 신뢰도를 증가시켰다.

Abstract

Recently, WSN(wireless sensor networks) consists of several sensor nodes in sensor field. And each sensors have the enforced energy constraint. Therefore, it is important to manage energy efficiently. In WSN application system, FEC(Forward error correction) increases the energy efficiency and data reliability of the data transmission. LDPC(Low density parity check) code is one of the FEC code. It needs more encoding operation than other FEC code by growing codeword length. But this code can approach the Shannon capacity limit and it is also can be used to increase the data reliability and decrease the transmission energy. In this paper, the author adopt Linear-Congruence method at generating parity check matrix of LDPC(Low density parity check) codes to reduce the complexity of encoding process and to enhance the energy efficiency in the WSN. As a result, the proposed algorithm can increase the encoding energy efficiency and the data reliability.

Keywords: Linear-Congruence, LDPC, WSN, energy efficiency, data reliability

Ⅰ. Introduction

In recent years, the wireless sensor networks have a lot of attention by many related researchers. Technology advances have made it feasible to deploy large-scale sensor networks using low-cost sensor nodes. But the each sensor nodes are very small so the energy is biggest constraint to wireless sensor capabilities[1,2]. As growing the size of sensor networks, reliability between sensor networks is decreased. To solve these problems, some kind of FEC(Forward error correction) codes such as BCH(Bose-Chadhuri-Hocquenghem) codes and RS codes has been adopted into a WSN(Wireless sensor network) by many researchers. As one of these FEC codes, LDPC codes can approach the Shannon's channel capacity limit and can be applied to increase node to node reliability and transmission energy efficiency[3-7]. But when the LDPC code that uses random parity check matrix, it needs lots of encoding energy to transform the parity check matrix.

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Furthermore, partial matrix of parity check matrix that used in encoding process should be invertible. To solve these problems, the author proposed Linear-Congruence method in triangular matrix decomposition process. Linear-Congruence method can be applied to make parity check matrix and it reduces the complexity of transformation process. And the partial matrix of parity check matrix is always invertible. For the verification of the proposed scheme, the author compared Linear-Congruence method and Random-regular method.

The organization of this paper is as follows: Section. Ⅱ illustrates the theoretical background of node to node interference. Section. Ⅲ addresses proposed parity check matrix using the Linear-congruence method. And Section. Ⅳ shows the experimental results and discussion of the proposed algorithm. Lastly, the conclusion is drawn in Section Ⅴ.

Ⅱ. Theoretical backgrounds

1. Node to node interference

The goal is minimize energy consumption in wireless sensor network. Node to node interference is affected by network traffic. So in a small WSN, node to node interference is not a problem to concern about. But in a large WSN that consists of hundred to several thousand of nodes, the node interference causes a serious problem. It decreases node to node data reliability and reduces energy efficiency. In this paper, node interference is assumed in AGWN channel.

The received signal $r_i(t)$ is given by Eq. (1).

$$r_i(t) = s_i(t) + n(t) + I(t) \quad (1)$$

Fig. 1 shows the node to node interference in AWGN channel. In Eq. (1), according to the numbers of nodes grow, the node interference is increased. And it also decreases transmission energy efficiency.

In Eq. (1), $r_i(t)$ is a received signal at i_{th} node, and $n(t)$ is an AWGN. $I(t)$ is a node interference and given by Eq. (2).

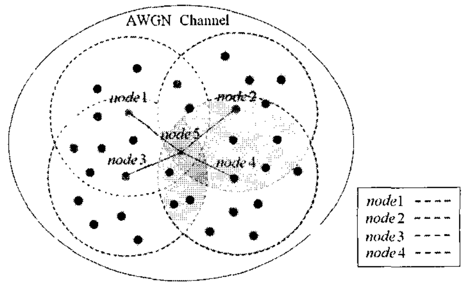

그림 1. AWGN 채널에서의 Node간의 Interference.
Fig. 1. Node to Node interference in AWGN channel.

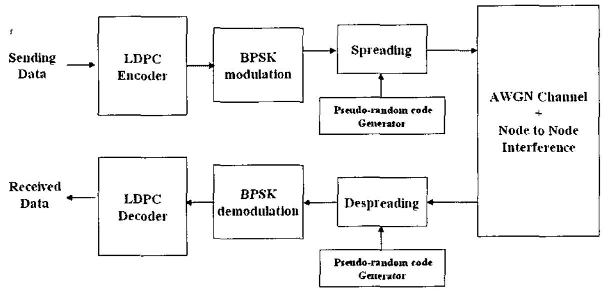

그림 2. LDPC 코드를 이용한 WSN 시스템 블록도.
Fig. 2. The block diagram of WSN system diagram using LDPC code.

$$I(t) = \sum_{n=1}^{m} s_n(t) - s_i(t) \quad 1 \le i \le m \quad (2)$$

And $s_i(t)$ is DSSS modulated original signal and given by Eq. (3).

$$s_i(t) = A b_i(t) c_i(t) \sin(2\pi f_c t) \quad (3)$$

In Eq. (3), $b_i(t)$ is an amplitude of BPSK modulation, and it takes a values of ± 1. And $c_i(t)$ is PRC(Pseudo-random code) to spread a frequency spectrum.

Fig. 2 shows a communication block diagram in AWGN channel.

2. Energy consumption model

In WSN application it needs high accuracy, node reliability is very important fact. Because of the BER of received signal is the inverse proportion with SNR and transmission energy. Also the reliability of communication channel has the inverse proportion with the node transmission energy.

LDPC code can approach the Shannon capacity limit exponentially fast in the length of the code. And it is also can be used to increase the reliability and decrease the transmission energy. When the LDPC code rate is $R=k/n$ (k: length of information bits, n: length of the codeword), the energy that consumed in communication is given by Eq. (4).

$$E_b = E_t + E_r + \frac{E_{enc} + E_{dec}}{k} \tag{4}$$

In the paper [3], the authors neglect an encoding energy, because they use BCH codes and a convolution encoder. But in case of LDPC, as the code length becomes grow, the calculation process is more complicated and it takes more encoding energy that is hard to neglect.

In Eq. (4), E_{enc} and E_{dec} means encoding and decoding energy respectively. And E_r and E_t means transmission and receiving energy respectively. It is given by Eq. (5) and (6).

$$E_t = \frac{(P_{te} + P_o)\frac{n}{R} + P_{tst}T_{tst}}{k} \tag{5}$$

$$E_r = \frac{P_{re}\frac{n}{R} + P_{rst}T_{rst}}{k} \tag{6}$$

Where k_1 and k_2 are given by Eq. (7) and Eq. (8), Eq. (4) can be rewritten as Eq. (9)

$$k_1 = \frac{(P_{te} + P_o) + P_{re}}{R} \tag{7}$$

$$k_2 = (P_{tst}T_{tst} + P_{rst}T_{rst}) \tag{8}$$

$$E_b = k_1 + k_1\frac{(n-k)}{k} + \frac{k_2 + E_{enc} + E_{dec}}{k} \tag{9}$$

The energy efficiency factor is defined as follows:

$$\eta = \eta_e(1 - PER) \tag{10}$$

The factor η_e is calculated as follows:

$$\eta_e = \frac{k_1 k}{k_1 n + k_2 + E_{enc} + E_{dec}} \tag{11}$$

In Eq. (9) the PER means packet error rate in WSN which adopts an error correction code. Because the system energy efficiency η_e in Eq. (11) is reversely proportional to E_{enc} and E_{dec}, the system efficiency is increased as the encoding and decoding energy are decreased.

3. LDPC encoding

LDPC codes have lots of advantage than the other codes, but it has a weakness in encoding process. As a one of the well-known encoding method, there is a triangular decomposition method proposed by [5]. This method uses Gaussian elimination and Greedy algorithm to generate a parity check matrix. But as the size of a matrix becomes longer, the transformation process is more complicated and the partial matrix of parity check matrix is not always invertible.

Fig. 3 shows a parity-check matrix H proposed by [5]. The parity-check matrix H is composed by six partial matrix, N is length of codeword and the M is a length of parity-check and K is a length of information bits.

The Parity check matrix H, depicted in Fig. 3 can be represented as Eq. (12), and expressed as follows:

$$H = \begin{bmatrix} T & B_1 & B_2 \\ A & C_1 & C_2 \end{bmatrix} \tag{12}$$

$$= \begin{bmatrix} I & 0 \\ -AT^{-1} & I \end{bmatrix} \begin{bmatrix} T & B_1 & B_2 \\ A & C_1 & C_2 \end{bmatrix} \tag{13}$$

$$= \begin{bmatrix} T & B_1 & B_2 \\ 0 & -AT^{-1}B_1 + C_1 & -AT^{-1}B_2 + C_2 \end{bmatrix} \tag{14}$$

In the syndrome matrix $S = HX^T$, the codeword is composed of x_a, x_b and the information bits x_c. So the relation is expressed as follows:

$$S = \begin{bmatrix} T & B_1 & B_2 \\ 0 & -AT^{-1}B_1 + C_1 & -AT^{-1}B_2 + C_2 \end{bmatrix} \begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix} = 0 \tag{15}$$

$$\begin{cases} Tx_a + B_1x_b + B_2x_c = 0 \\ (-AT^{-1}B_1 + C_1)x_b + (-AT^{-1}B_2 + C_2)x_c = 0 \end{cases} \tag{16}$$

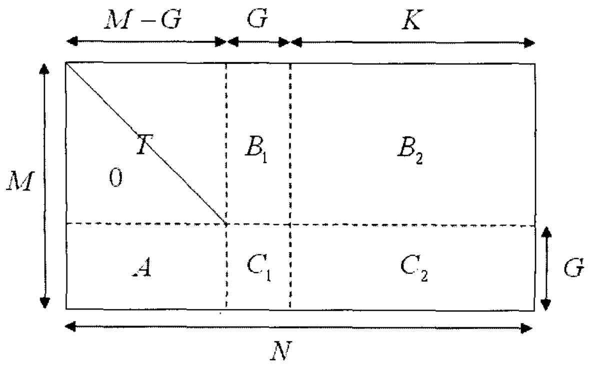

그림 3. 삼각 분해 방법을 이용한 패리티 체크 행렬.
Fig. 3. Parity-check matrix using triangular decomposition method.

In the Eq. (16) $(-AT^{-1}B_2 + C_2)x_c = \Phi$

$$\Phi x_b + (-AT^{-1}B_2 + C_2)x_c = \Phi x_b + \hat{s} = 0 \qquad (17)$$

And then it can compute the x_b by back substitution. But there are two weaknesses in this triangular decomposition method. Firstly, as the length of codeword becomes longer, the transformation process is more complicated. Secondly, the partial matrix of parity check matrix is always invertible.

Ⅲ. Proposed parity check matrix

The Linear-Congruence composition method allows that a partial matrix of parity check matrix is always invertible. To solve this problem, in this paper adopted Linear-Congruence composition method into a triangular decomposition in encoding process. If the (M×N) parity check matrix is composed of c_1, c_2 which size is (M×K), (M×N) respectively and then $H = [C_1|C_2]$. So the parity matrix P is represented as $P = C_2^{-1}C_1$ and the generator matrix is as follows:

$$G^T = \begin{bmatrix} I_k \\ P \end{bmatrix} = \begin{bmatrix} I_k \\ C_2^{-1}C_1 \end{bmatrix} \qquad (18)$$

In Eq. (18), C_2 should be invertible if it makes a generator matrix. In general parity-check matrix that generated at random with appropriate column and row weight, the partial matrix doesn't always invertible. But Linear-Congruence composition method allows that the partial matrix is always invertible and prevents the reduces decoding performance with 4-cycle.

If C_2 is a $M \times M$ regular matrix, Eq. (19) represents first row index of 1's.

$$b_1^1, b_2^1, b_3^1, \cdots, b_k^1 \qquad k = row\,weight \qquad (19)$$

Row and column index of C_2 represents as (i,j), i_{th} 1's position can be written as Eq. (20) and it is said to be Linear-Congruence matrix.

$$b_l^i = ai + b_l^i \mod M \quad l = 1,2,\cdots,k \qquad (20)$$

In Eq. (20) a and b is a positive number less than M. Fig. 4 represents Coderate 4/7 parity check matrix using Linear-Congruence composition method [7]. In Fig. 4, with a=1 from Eq. (20).

Fig. 5 shows parity-check matrix that weight of row and column is 6 and 3. B_2 and C_2 is composed of nine partial matrix which weight of row and column is both 1 and distributed randomly.

Then the T, A, B_1, C_1 are composed by Linear-Congruence method. Since the Fig. 5 assumes the form of a triangular matrix, it doesn't need additional transformation process such as Gaussian elimination and Greedy algorithm. Hence, when it encodes LDPC code using Linear-Congruence composition method, the encoding complexity is

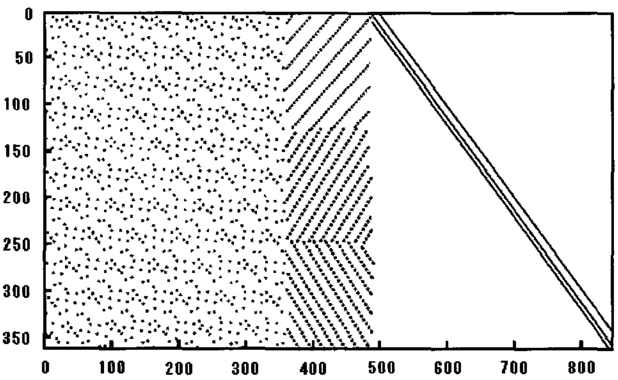

그림 4. Linear-congruence 합성 방법을 이용한 Parity-check matrix(R=4/7).
Fig. 4. Parity-check matrix(R=4/7) using Linear-Congruence composition method.

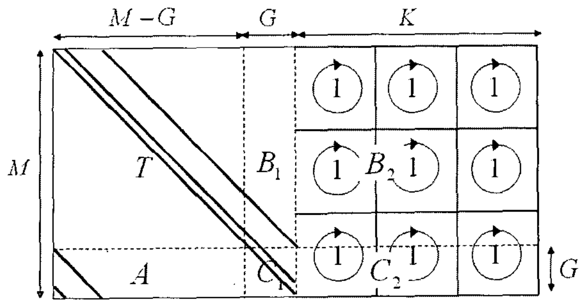

그림 5. 제안된 패리티 체크 행렬.
Fig. 5. Proposed parity check matrix.

reduce, and it means encoding energy E_{enc} is also reduced too.

Because of the partial matrix T, A, B_1, C_1 in Eq. (16) takes a shape of triangular matrix, Φ in Eq. (10) is also nonsingular matrix and could be invertible

Ⅳ. Experimental Result

In this paper, the author simulated WSN using different LDPC encoding method over node to node interference. The interference is simulated with 12 simultaneous transmission of DSSS signal from 12 sensor nodes. All have the same modulation as shown as Eq. (3).

It compared two LDPC codes performance each other, first one uses Random-regular parity check matrix and the other one uses Linear-Congruence composition method. The Random-regular parity check matrix is constructed as Fig. 6.

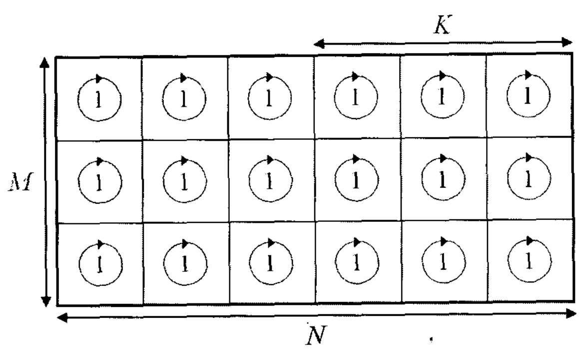

그림 6. Random-regular 패리티 체크 행렬 (행렬 가중치 (6,3)).
Fig. 6. Random-regular parity check matrix (weight of row and column is (6,3)).

표 1. LDPC 코드 파라미터.
Table 1. LDPC code parameters.

Design	(N,M)	Code rate	Row weight	Column weight
Regular LDPC	(1080,540)	0.5	6	3
Linear-Congruence	(1080,540)	0.5	6	3

표 2. 시뮬레이션 결과의 비교.
Table 2. Comparison of the simulation results.

Design	Total error from 1080 decoded data (50 iteration)			
	1 dB	2dB	3db	4db
Random-Regular	108	43	7	1
Linear Congruence	75	32	5	1

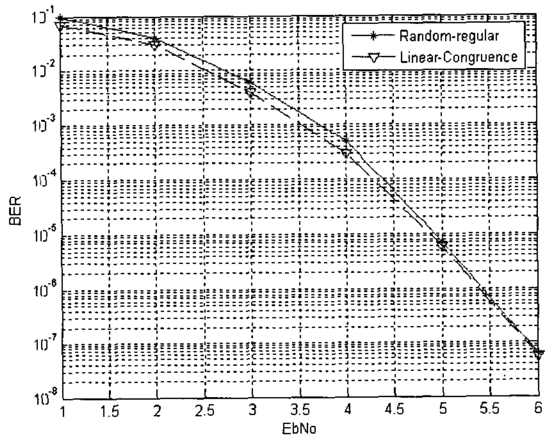

그림 7. Random-regular와 Linear-Congruence의 BER 성능 비교.
Fig. 7. Comparison of BER performance between Random-regular method and Linear-Congruence method.

And each LDPC code is simulated as table 1.

As a decoding algorithm, the author use sum-product algorithm and set the maximum iteration number by 60. In the Linear-Congruence process, the position of first column number set by $b_1^0 = 0, b_2^0 = 4/G, b_3^0 = G$ respectively. And the Table 2 shows the simulation results.

When the SNR value was selected at 1dB in Table 2, there are 108 and 75 error bits for Random-Regular parity check matrix and

Linear-Congruence matrix respectively. But as the SNR increase, error correction performance becomes nearly same.

Fig. 5 shows the graphical representation of BER relative to the change on SNR value.

V. Conclusion

In this paper, the author proposed Linear-Congruence composition method in LDPC encoding process to increase encoding energy efficiency and node to node reliability than the random regular LDPC code in WSN. The author assumed that there is a node to node interference in addition to AWGN channel and the simulated wireless sensor network is composed of 12 nodes using DSSS BPSK modulation.

Conclusively, the suggested LDPC code using Linear-Congruence method had performed better than general LDPC code using Random-regular parity check matrix.

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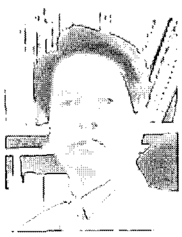
저 자 소 개



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