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(Research Article)

Cross layered adaptive rate optimized irregular LDPC for WSN

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Abstract

This paper proposes a cross layered adaptive rate optimized technique that uses irregular low-density parity-check (LDPC) codes over an additive white Gaussian noise (AWGN) channel in wireless sensor networks (WSNs). Irregular LDPC is used as error control code. Cross layer design along with error control code gives the energy balance in the network. This new algorithm uses the physical layer parameters such as coherence time of the channel, BER and SNR and the routing layer parameter such as demanded data rate to determine the rate of the LDPC coder. The algorithm adaptively changes the code rates as ¾, ½, and 1/3. We have conducted the simulations to verify our methods using MATLAB and find that the proposed scheme increases the network performance in terms of energy balance and quality of data by using irregular LDPC codes in the cross-layer environment.

Keywords: Cross layer; Wireless sensor network; Error control code; Energy balance; Code rate; Irregular LDPC

1. Introduction

In recent years, there has been an increasing demand for efficient and reliable digital data transmission. This demand has been accelerated by the emergence of large-scale, high-speed data networks for the exchange, processing, and transmission of digital information in the commercial, governmental, and military spheres. The merging of different layers of communications is required in the design of these systems. A major concern of the system designer is the control of errors with limited energy so that the data can be reliably reproduced. To achieve reliable and high data transmission in modern communication systems, error correction coding (ECC) techniques are used with effective iterative decoding algorithms, turbo codes and low-density parity-check (LDPC) codes are two powerful coding techniques [1]. The LDPC codes perform near the Shannon limit of a channel that exists for large block lengths. An interesting fact is that high performance codes are irregular.so we used irregular LDPC codes for our system.

2. Related Work

The purpose of using Error Control Coding (ECC) in WSNs is to achieve energy efficiency. Low Density Parity Check code has its rate less advantage and while comparing it with fixed rate code it attains Shannon's limit [2]. ECC provides coding gain, resulting in transmitter energy savings, at the cost of added decoder power consumption. While comparing decoder implementations for a range of ECC types, including block codes, convolutional codes, and iteratively decoded codes such as turbo codes and LDPCs, it is found that LDPC codes performed better than all other codes [3]. LDPC block codes performed better than convolutional codes when the requirements on the battery are permissive [4]. Recent works have shown that for long block-lengths, irregular LDPC codes can outperform turbo codes of the same block-length and code-rate [5]. In [6] the authors present a cross layer analysis of error control schemes considering routing, medium access, and physical layer. This paper compares ARQ and FEC schemes in WSN and proves that for more hops FEC schemes are better than ARQ scheme.

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Spatially coupled ARJA codes [11] and spatially coupled MN codes show better asymptotic performance than regular SC-LDPC codes with bounded degrees. However, it is later known that the finite-length performance of spatially coupled ARJA codes is rather worse than that of other spatially coupled codes due to their inferior scaling behavior [12]. LDPC codes have some prominent performances, which involves being close to the Shannon limit, achieving a higher bit rate and a fast decoding [13] and suitable for energy constrained environment.

It found that most of the works are identified with energy efficient error control codes for WSN and very few works referred to cross layered error control for WSN. In this work we discussed the cross layered parameters that are adaptively change the rate of the irregular LDPC code and hence achieve the desired performance.

3. Cross Layered Adaptive Rate optimized irregular LDPC (CLARIL)

One of major issues in WSN is to reduce energy consumption and ensure the reliability of data. We propose to use cross layered adaptive rate optimized irregular LDPC (CLARIL) to meet these requirements. The proposed CLARIL block diagram is shown in figure 1. In the scheme, encoding irregular LDPC is performed by LDPC encoder at the source node. The encoding data then are sent to the sink node. At the sink node, the data is decoded by LDPC decoder using MMSE decoding technique. Hu et al. [7] analyzed Source-Channel Coding Using Non-Linear Curves and MMSE Decoding. Apart from coding, transmission efficiency can also be enhanced by this decoding.

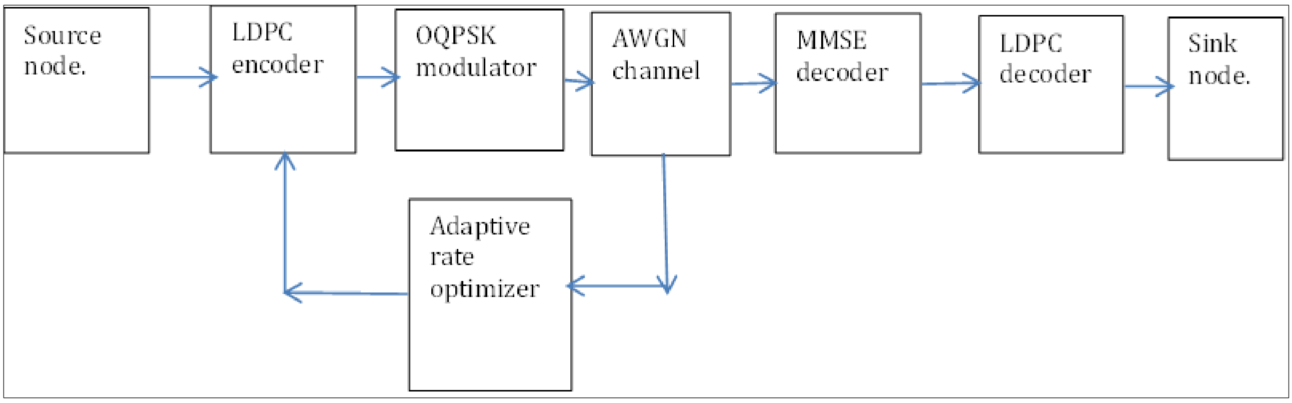

Figure 1 Block diagram of the cross layered adaptive rate optimized irregular LDPC.

3.1. Source node/ Sink node.

These are the nodes in a sensor network which are responsible for converting the environmental variables to measurable electrical variables and serve the purpose of the WSN. The sensed data is digitized using the ADC and processed by the controller before transmitting it by the transceiver unit.

3.2. LDPC Encoder/LDPC Decoder

LDPC codes are block codes with parity-check matrices that contain only a very small number of non-zero entries. It is the sparseness of H which guarantees both a decoding complexity which increases only linearly with the code length and a minimum distance which also increases linearly with the code length.

Aside from the requirement that H be sparse, an LDPC code itself is no different to any other block code. Indeed, existing block codes can be successfully used with the LDPC iterative decoding algorithms if they can be represented by a sparse parity-check matrix. Generally, however, finding a sparse parity-check matrix for an existing code is not practical. Instead LDPC codes are designed by constructing a sparse parity-check matrix first and then determining a generator matrix for the code afterwards.

The biggest difference between LDPC codes and classical block codes is how they are decoded. Classical block codes are generally decoded with ML like decoding algorithms and so are usually short and designed algebraically to make this task less complex. LDPC codes however are decoded iteratively using a graphical representation of their parity-check matrix and so are designed with the properties of H as a focus. The LDPC code parity-check matrix is called -regular if each code bit is contained in a fixed number, of parity checks and each parity-check equation contains a fixed number, wr, of code bits. For an irregular [10] parity-check matrix we designate the fraction of columns of weight i by vi and the fraction of rows of weight I by h. Collectively the set v and h are called the degree distribution of the code.

3.2.1. LDPC Construction

The construction of binary LDPC codes involves assigning a small number of the values in an all-zero matrix to be 1 so that the rows and columns have the required degree distribution. The original LDPC codes presented by Gallager [8] are regular and defined by a banded structure in H. The rows of Gallager's parity-check matrices are divided into wc sets with M/ wc rows in each set. The first set of rows contains wr consecutive ones ordered from left to right across the columns. (i.e., for i ≤ M/wc, the i-th row has nonzero entries in the ((i − 1) K + 1)-th to i-th columns). Every other set of rows is a randomly chosen column permutation of this first set. Consequently, every column of H has a "1" entry once in every one of the wc sets.

Another common construction for LDPC codes is a method proposed by MacKay and Neal. In this method columns of H are added one column at a time from left to right. The weight of each column is chosen to obtain the correct bit degree distribution and the location of the non-zero entries in each column chosen randomly from those rows which are not yet full. If at any point there are rows with more positions unfilled then there are columns remaining to be added, the row degree distributions for H will not be exact. The process can be started again or back tracked by a few columns, until the correct row degrees are obtained.

Another type of LDPC codes called repeat-accumulate codes have weight-2 columns in a step pattern for the last m columns of H. This structure makes the repeat-accumulate codes systematic and allows them to be easily encoded. Since LDPC codes are often constructed pseudo-randomly we often talk about the set (or ensemble) of all possible codes with certain parameters (for example a certain degree distribution) rather than about a particular choice of parity-check matrix with those parameters.

LDPC codes are often represented in graphical form by a Tanner graph [9]. The Tanner graph consists of two sets of vertices: n vertices for the code word bits (called bit nodes), and m vertices for the parity-check equations (called check nodes). An edge joins a bit node to a check node if that bit is included in the corresponding parity-check equation and so the number of edges in the Tanner graph is equal to the number of ones in the parity-check matrix.

The Tanner graph is sometimes drawn vertically with the bit nodes on the left and check nodes on the right with bit nodes sometimes referred to as left nodes or variable nodes and the check nodes as right nodes or constraint nodes. For a systematic code the message bit nodes can be distinguished from the parity bit nodes by placing them on separate sides of the graph.

3.2.2. LDPC Encoding Technique

Encoder uses generator matrix to encode the information bits into the code word.

$$H = \begin{matrix} 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 & 1 \end{matrix}$$

Both generator and parity check matrix are interrelated, parity check matrix is given by.

H= [A | $I\ n{-}k$]

The generator matrix is given by.

G= [Ik | AT]

Initially parity check matrix is generated; using that generator matrix is created by Gaussian elimination method. There are two types of parity matrices in LDPC coding one is Regular matrix, and another one is irregular matrix. Regular matrix is one in which column Wc is same for all columns and row weight is given by Wr = Wc (n/m) for all rows. Let us consider an 5x10 parity matrix with Wc=2 and Wr=4 as shown below

$$\begin{bmatrix} 1&0&0&1&0&0&0&1&0&1 \\ 0&1&1&1&0&0&1&0&0&0 \\ 0&1&0&0&1&1&0&1&0&0 \\ 1&0&0&0&0&1&1&0&1&0 \\ 0&0&1&0&1&0&0&0&1&1 \end{bmatrix}$$

To transfer the above parity check matrix to standard form i.e., H= [A | $I\ n{-}k$] gaussian elimination method is applied. Gaussian elimination involves elementary row operations which are interchanging two rows or adding one row to another modulo 2 and columns. The resulting parity matrix in its standard form is as shown below.

$$H = \begin{bmatrix} 1&0&1&0&1&1&0&0&0&0 \\ 1&1&0&0&0&0&1&0&0&0 \\ 1&1&1&0&0&0&0&1&0&0 \\ 1&1&1&1&1&0&0&0&1&0 \\ 0&0&0&1&1&0&0&0&0&1 \end{bmatrix}$$

Obtained parity matrix is translated to standard form generator matrix i.e., G= $[Ik \mid AT]$ as shown below

$$G = \begin{matrix} 1&0&0&0&0&1&1&1&1&0 \\ 0&1&0&0&0&0&1&1&1&0 \\ 0&0&1&0&0&1&0&1&1&0 \\ 0&0&0&1&0&0&0&0&1&1 \\ 0&0&0&0&1&1&0&0&1&1 \end{matrix}$$

Now the information message bits are encoded by multiplying it with above generator matrix i.e., C=[U][G] to obtain the code word.

3.2.3. LDPC Decoding Technique

Low-density parity-check codes are usually iteratively decoded using the belief propagation algorithm, also known as the message-passing algorithm. The highly efficient message-passing algorithm is an important factor that has contributed to the success of LDPC codes in both theoretical studies and practical applications. Suitably designed LDPC codes have been shown to perform very close to the Shannon limit when decoded using the iterative message-passing algorithm (MPA). This algorithm also features intrinsic parallel scheduling, which makes it very attractive for high throughput hardware implementations.

The message-passing algorithm operates on a factor graph, where soft messages are exchanged between variable nodes and check nodes. The variable nodes are initialized based on the channel outputs. In the first step of decoding, check nodes receive the initial beliefs from the neighboring variable nodes and in return, send the extrinsic information (information from the neighbors) to each of the variable nodes. In every iteration, each variable node receives new extrinsic information from more distant neighbors and refines its initial decision. The message-passing algorithm is exact when operating on a factor graph that is cycle free, and in practice, free of short cycles is an important criterion in the construction of good codes.

The iterative message-passing algorithm can usually reach convergence within a small number of iterations when operating on graphs containing no short cycles. The message-passing algorithm can be formulated as follows: in the first step, variable nodes xi are initialized with the prior log-likelihood ratios (LLR) defined in the following equation using the channel outputs y. This formulation assumes the information bits take on 0 and 1 with equal probability.

$L^{pr}(x_i) = log Pr(x_i{=}0 \mid y_i)/Pr(x_i{=}1 \mid y_i) = (2/\sigma^2)\, y_i$

where σ^2 represents the channel noise variance.

The variable nodes send messages to the check nodes along the edges defined by the factor graph. The LLRs are recomputed based on the parity constraints at each check node and returned to the neighboring variable nodes. Each variable node then updates its decision based on the channel output and the extrinsic information received from all the neighboring check nodes. The marginalized posterior information is used as the variable to check message in the next iteration.

3.3. Adaptive Rate Optimizer

This module finds the rate of the irregular LDPC code using cross layered parameters such as Channel Sate Information and user defined QoS requirements. An ARO is a block at the MAC. It takes the input from the routing layer and physical layer to compute the irregular LDPC code rate.

An ARO has two phases such as the channel study phase and rate transfer phase. During the channel study phase an ARO transmits test signals to its next node and collects the SNR and BER information. From the received parameters an ARO computes the coherence time Tc of the channel. From the physical layer parameters and the demanded QoS such as BER and data rate, an ARO computes the coding rate for the LDPC encoder.

3.4. OQPSK Modulator

The OQPSK (offset quadrature Phase Shift Keying) modulator maps the input binary signals to an analog signal for transmission.

3.5. Channel

The channel is the medium by which information is transmitted from the transmitter to the receiver. In WSN this is a wireless channel. The addition of noise normally occurs in the channel. In the simulations, the channel is modeled as Additive White Gaussian Noise (AWGN) channel. The resulting noise added to the system follows the zero-mean normal distribution, with variance $N_0/2$, and N_0 is the single-sided noise power spectral density.

3.6. Minimum Mean Square Error (MMSE) Detector

If the mean square error between the transmitted symbols and the outputs of the detected symbols, or equivalently, the received SNR is taken as the performance criteria, the MMSE detector is the optimal detection that seeks to balance between cancelation of the interference and reduction of noise enhancement. Let us denote.

MMSE detector as W_{MMSE} and detection operation by

$X_K = \text{sgn}\,[W_{MMSE}\, y]$

The W_{MMSE} that maximizes the SNR and minimizes the mean square error which is given by:

E [(X K −W_MMSE y) T (X K −W_{MMSE} y)]

To solve for x, we know that we need to find a matrix W_{MMSE}. The MMSE linear detector for meeting this constraint is given by:

$W_{MMSE} = (H^H H + \sigma_n^2\, I)^{-1} H^H$

$W_{MMSE} = (H{*}H + (1/SNR)\, I)^{-1} H^{*}$

MMSE at a high SNR:

$W_{MMSE} = (H{*}H + (1/SNR)\, I)^{-1} H^{*} \approx (H^H H)^{-1} H^H$

At a high SNR MMSE becomes Zero Forcing.

4. Results and discussion

4.1. Energy Consumption

The energy required for transmitting n bits is given by equation (3). The energy spent for receiving n bits is given by equation (4).

$E_{tx} = T_{start}P_{start} + n / (R) (P_{txElec}+(\alpha_{amp} + \beta_{amp}P_{tx}))$ -----------------------------(3)

Where, n – length of the codeword, R – Nominal data rate

4.2. Energy Consumed for Receiving n Bits.

$E_{rx} = T_{start}P_{start} + n / (R * R_{code}) P_{rxElec} + n*E_{decBit}$ -------------------------(4)

$E_{decBit} = E_{node} * m * l$

Where, 'E_{decBit}' is Energy consumed for decoding a single bit, 'E_{node}' is Fixed amount of energy consumed for each iteration, 'm' is number of computational nodes, 'l 'is number of Iterations.

From the obtained results it is found that as the number of bits increases the transmitting energy and reception energy increases form micro joules to mill joules. Also, that for the case of 1000bits the receiving energy is equivalent to that of transmitting energy.

4.3. Bit error rate performance evaluation

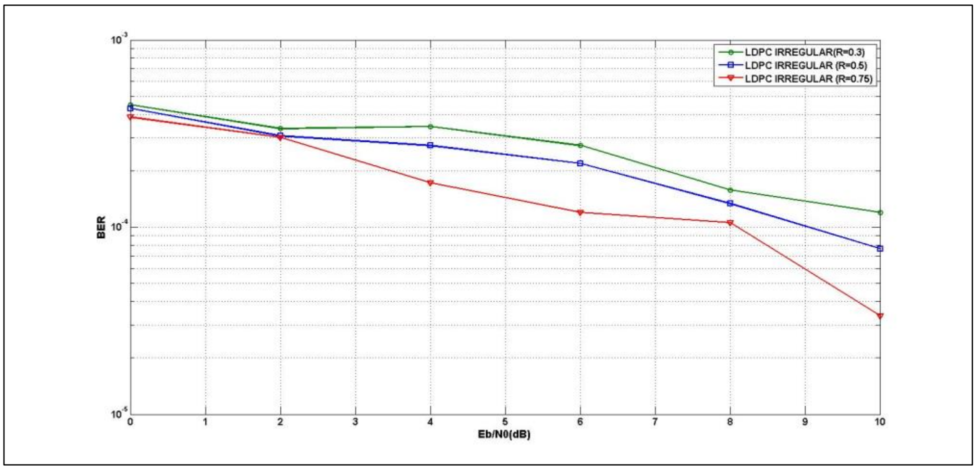

Figure 2 Performance of LDPC for various code rates

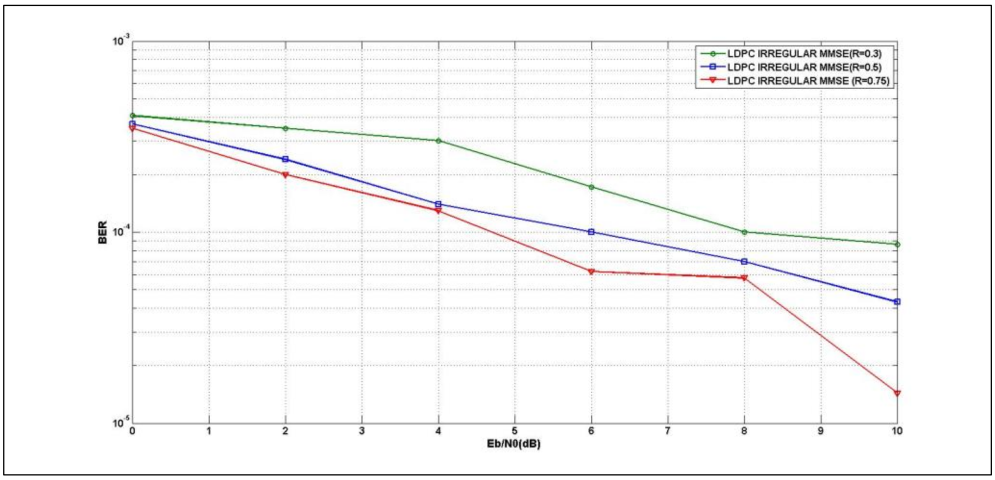

Figure 3 Performance of LDPC for various code rates with MMSE

Figure 2 shows the BER performance of the proposed algorithm. From the results it is found that as the energy per bit increases, the BER decreases for all the rates of the code. It is also found that bit error performance is better for rate 1/3 code compared to rate ¾ by about 85% at the Eb/No value of 5dB.This enhancement is at the cost of increased redundancy of the irregular LDPC code.

The performance of LDPC coder for various code rates such as 0.3,0.5 and 0.75 with MMSE decoding technique is shown in figure 3. From this we can understand that the BER performance is varied for various values of the code rate in the wireless system.

5. Conclusion

To attain energy efficiency in wireless sensor networks (WSN), we proposed cross layered adaptive rate optimized irregular LDPC as error control code for WSN. On implementation it is found that Mac Kay's method for encoding has linear encoding complexity of the order of O (n). The MPA decoding method with MMSE decoder is implemented for decoding. Also, the energy consumption for transmitting and receiving n-bits for μAMPS-1 mote is calculated for various code lengths. The proposed CLARIL adaptive changes the coding rate of the irregular LDPC coder to maintain the required QoS performance. This work can be enhanced further by fine tuning the optimizer performance using optimization algorithms.

Compliance with ethical standards

Disclosure of conflict of interest

There is no conflict of interests regarding the publication of this paper.

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