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Serial Min-max Decoding Algorithm based on Variable Weighting for Nonbinary LDPC Codes

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Abstract

In this paper, we perform an analysis on the min-max decoding algorithm for nonbinary LDPC (low-density parity-check) codes and propose serial min-max decoding algorithm. Combining with the weighted processing of the variable node message, we propose serial min-max decoding algorithm based on variable weighting for nonbinary LDPC codes in the end. The simulation indicates that when the bit error rate is 10^-3, compared with serial min-max decoding algorithm, traditional min-max decoding algorithm and traditional minsum algorithm, serial min-max decoding algorithm based on variable weighting can offer additional coding gain 0.2dB、0.8dB and 1.4dB respectively in additional white Gaussian noise channel and under binary phase shift keying modulation.

Keywords: *min-max decoding algorithm, variable weighting, serial decoding*

1. Introduction

Since the LDPC code was discovered in 1962 [1], more and more researchers devote themselves to the encoding and decoding project about LDPC codes and they have achieved remarkable success [2-6]. The discovery of nonbinary LDPC codes [7] opens up a new research area about the development of LDPC code. Finding a very effective method to encode and decode nonbinary LDPC code becomes a new issue explored by more and more scholars. We get sum-product decoding algorithm for nonbinary LDPC codes by extending the decoding algorithm [8] of binary LDPC code to Galois field, which shows computational complexity of 0(q^2) because of vast sum and product operations. This influences the use of LDPC codes, so the sum-product decoding algorithm based on Fast Fourier Transform (FFT) was proposed by Davey and Barnault, which owns the complexity of 0($q\log_2 q$) and involves vast product operations for hardware implementation. After that, Wymeersch proposed sum-product decoding algorithm based on log-domain [9] which presents the computational complexity of 0(q^2). In order to further reduce the computational complexity, Declercq proposed extended minsum algorithm. Then it was in [10], the author proposed a kind of min-max decoding algorithm which does not need any sum operations greatly reducing the computational complexity in check node processing. Based on [10], we propose serial min-max decoding algorithm by changing the message scheduling order, which effectively improves the convergence speed of the message and the bit error performance. By referring to the paper [11], we finally propose serial min-max decoding algorithm based on variable weighting for nonbinary LDPC codes by weighting variable node processing, which effectively reduce the correlation between the variable nodes and further improves the bit error performance.

The whole structure of the paper is as follows. In the first part, we tell the serial min-max decoding algorithm for nonbinary LDPC codes. And in the second part, we introduce the serial min-max decoding algorithm based on variable weighting for nonbinary LDPC codes. Then we depict concrete performance simulation in the third part. Finally, we draw a conclusion in the fourth part.

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2. Serial Min-max Decoding Algorithm for Nonbinary LDPC Codes

Nonbianry LDPC code is a kind of linear block code which is defined by its parity-check matrix H that owns a low density of nonzero elements from GF(q). The sparseness of the matrix is good for encoding and decoding. A MXN parity-check matrix can be treated as a bipartite graph: the M rows of the matrix represent the M check nodes of the bipartite graph and the N columns represent the N variable nodes. In the field of decoding, traditional decoding algorithm is such message passing algorithm based on parallel processing, which is called sum-product decoding algorithm. But the computational complexity of this algorithm is considerable. It was in [10], the author proposed the min-max decoding algorithm for nonbinary LDPC codes, which greatly reduces the computational complexity by showing a very small performance loss. According to the detailed analysis on [10], we propose serial min-max decoding algorithm for nonbinary LDPC codes by changing the message scheduling order, which effectively improves the bit error performance with no increasing of the computational complexity. In order to further improve the performance, referring to paper [11], we propose serial min-max decoding algorithm based on variable weighting for nonbinary LDPC codes. The simulation shows that the bit error performance can be further improved, which is good for hardware implementation.

For clearly depicting serial min-max decoding algorithm of nonbinary LDPC codes, we denote some following notations.

·N(m)={n: $h_{mn} \neq 0$}, set of neighbor variable nodes of the check node m. In other words, all the nonzero elements of the m-th row of the parity-check matrix H.

·N(m)\n, set of neighbor variable nodes of the check node m except the variable node n.

·M(n)={m: $h_{mn} \neq 0$}, set of neighbor check nodes of the variable node n. In other words, all the nonzero elements of the nth column of the parity-check matrix H.

·M(n)\m, set of neighbor check nodes of the variable node n except the check node m.

· f_n^a , the log-domain information when the nth variable node is a.

· Q_{mn}^a, the variable node log-domain information from the nth variable node to the m-th check node when the nth variable node is a.

· R_{mn}^a , the check node log-domain information from the m-th check node to the nth variable node when the nth variable node is a.

The decoding process is as follows:

Initialization

Do as the following formula to get initial information.

$$f_n^a = \log(pr(x_n = s_n \mid channel) / pr(x_n = a \mid channel)) \tag{1}$$

s_n means the most possible value of the nth variable node.

Then set k=1 and $Q_{mn}^a = f_n^a$.

(1) Decide whether k reaches the biggest iteration maxiter or not. If it is yes, then exit the whole process; otherwise set n=1 and goto step (2).
(2) During the first k iteration, update variable information in n=1,2, ⋯N order. Decide whether n is bigger than N or not? If the answer is yes, then goto step (8), otherwise goto step (3).
(3) Do an exchange of information vector from variable node. For example, if we know Q_{mn}^a , then $Q_{mn}^{'a}$ means the information to check node m across h_{mn} ,where $Q_{mn}^{'a}$ is equal to $Q_{mn}^{ah_{mn}}$ .The most important thing is that all the arithmetic is in Galois field.
(4) Check node processing
Do as the following formula.

$$R_{mn}^{a} = \min(\max_{\substack{n' \in n(m)\backslash n \\ b' \in V: x_n = a}} (Q_{mn'}^{b'}))$$ (2)

V means the vector sets that meets the m-th check equation.

(5) Do an opposite exchange of information vector. It is the opposite process of step (3). Do as the formula $R_{mn}^{'a} = R_{mn}^{ah_{mn}^{-1}}$.

(6) Variable node processing
Do as the following formula:

$$\nabla_{mn}^{a} = f_n^a + \sum_{m' \in M(n)\backslash m} R_{m'n}^{'a}$$ (3)

then perform the formula in the next line.

$$\Delta_{mn} = \min_{a \in GF(q)} (\nabla_{mn}^{a})$$ (4)

Get the information from variable node by the formula (5).

$$Q_{mn}^{a} = \nabla_{mn}^{a} - \Delta_{mn}$$ (5)

(7) Do as the formula n=n+1.

(8) Collect all the variable node information using the formula (6).

$$Q_n^a = f_n^a + \sum_{m' \in M(n)} R_{m'n}^{'a}$$ (6)

Decide each variable node x_n using the formula $\hat{x}_n = \arg\min_{a \in GF(q)} (Q_n^a)$, then decide whether $H * x^T$ is equal to zero, if the answer is yes, then exit all the process; otherwise goto step (9).

(9) Do as the formula k=k+1,then goto step (1).

Serial min-max decoding algorithm of nonbinary LDPC codes indicates that the check node processing can get updated information faster, so that the convergence speed can be improved effectively.

3. Serial Min-max Decoding Algorithm based on Variable Weighting for Nonbinary LDPC Codes

Nonbinary LDPC code is an extension of binary LDPC code in Galois field.The composition of parity-check matrix of nonbinary LDPC codes derives from the binary parity-check matrix whose nonzero entries are replaced by nonzero entries in Galois field. But it is inevitable for binary matrix which is made up of random methods to show short cycles, which results in the oscillation of LLR and degrades the bit error performance. So in order to reduce the impact, it was in paper [11], the author proposed an algorithm based on variable weighting, which is used to combine with serial min-max decoding algorithm in the paper. The process is as follows.

Do as the formula (7).

$$Q_{mn}^{new} = \lambda_1(\nabla_{mn}^{a} - \Delta_{mn}) + \lambda_2 Q_{mn}^{old}$$ (7)

When the message tends to be convergent, Q_{mn}^{new} and Q_{mn}^{old} are almost the same. So we can get $\lambda_1 = 1 - \lambda_2 = \lambda$, and the formula (7) can be replaced by the following formula.

$$Q_{mn}^{new} = \lambda(\nabla_{mn}^{a} - \Delta_{mn}) + (1-\lambda)Q_{mn}^{old} \tag{8}$$

λ can be called weighting factor ,so it can be called serial min-max decoding algorithm based on variable weighting. The simulation indicates that the weighting factor λ can be 0.9 , which shows good performance in the medium signal-to-noise ratio region.

4. Performance Simulation

For the convenience of analysis ,we choose 0.5-rate regular nonbinary LDPC code whose code length is 200 ,which is in additive white Gaussian noise channel and under binary phase shift keying modulation [12]. Then we make a comparison among serial min-max decoding algorithm based on variable weighting、serial min-max decoding algorithm、traditional min-max decoding algorithm and traditional minsum decoding algorithm. The result is as follows.

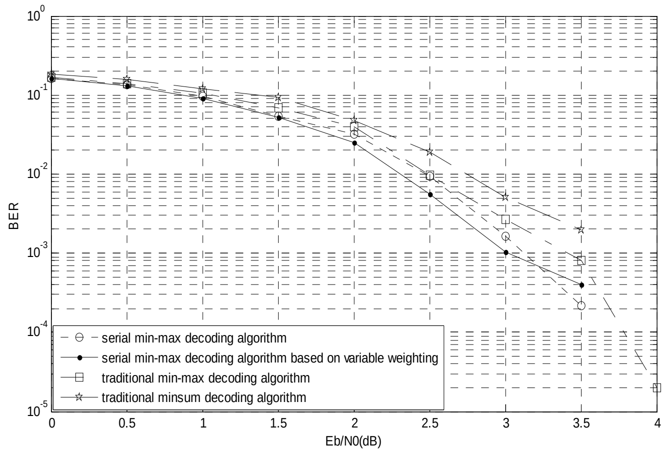

Figure 1. The Relational Graph between Bit Error Rate (BER) and Signal-to-noise Ratio Eb/N0(dB)

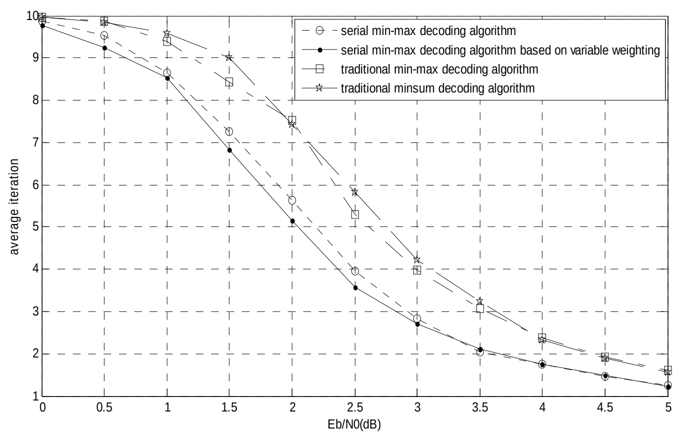

Figure 2. The Relational Graph between Average Iteration and Signal-to-noise Ratio (Eb/N0(dB))

What we can find from Figure 1 is that at the same signal-to-noise ratio, the performance of serial min-max decoding algorithm based on variable weighting outperforms serial min-max decoding algorithm whose performance is better than traditional min-max decoding algorithm and traditional minsum decoding algorithm. When the bit error rate is 10^-3, compared with serial min-max decoding algorithm, traditional min-max decoding algorithm and traditional minsum algorithm, serial min-max decoding algorithm based variable weighting can offer additional coding gain 0.2dB、0.8dB and 1.4dB respectively. Figure 2 shows that the average iteration of serial min-max decoding algorithm based on variable weighting is less than that of serial min-max decoding algorithm whose average iteration is less than traditional min-max decoding algorithm and traditional minsum decoding algorithm. In a word, serial min-max decoding algorithm based on variable weighting is optimal not only in performance but also in average iteration.

5. Conclusion

We perform an analysis on traditional min-max decoding algorithm. And then we propose serial min-max decoding algorithm based on variable weighting combining with the variable node weighted process. The simulation indicates that the proposed algorithm is optimal not only in performance but also in average iteration. So it has a good application prospect and can be a solution for hardware implementation to decode nonbinary LDPC code in the future.

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