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A Novel Modified Algorithm with Reduced Complexity LDPC Code Decoder

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Abstract: A novel efficient decoding algorithm reduced the sum-product algorithm (SPA) Complexity with LPDC code is proposed. Base on the hyperbolic tangent rule, modified the Check node update with two horizontal process, which have similar calculation, Motivated by the finding that sun-min (MS) algorithm reduce the complexity reducing the approximation error in the horizontal process, simplify the information weight small part. Compared with the exiting approximations, the proposed method is less computational complexity than SPA algorithm. Simulation results show that the author algorithm can achieve performance very close SPA. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: LDPC, Sum-product algorithm (SPA), Sun-min (MS) algorithm, Reduced complexity.

1. Introduction

Low-density parity-check (LDPC) codes were proposed by Gallager in the 1960s [1], but the technology were forgotten until the late 1900s when MacKay [2], than the LDPC code has attracted academia and industry by the excellent performance. Iterative decoding of binary Low-density parity-check (LDPC) codes has recently been shown to approach the capacity Shannon limits within 0.0045 dB [3]. The attractive feature of the LDPC code is decoding algorithm, Sum-Product Algorithm (SPA) [4] is the most efficient iterative decoding algorithm of the LDPC code, but the SPA has many communication complexity limits practice. Many SPA-based simplified algorithm are propose, such as reducing the computational complexity [5]. The min-sum algorithm (MS) [6] is one of suboptimal approximation about the SPA, which simplifies the horizontal process of the SPA. Similarly, in order to simplify the MS decoding algorithm, the normalized MS algorithm (Normalized-MS) [7], modified MS algorithm (offset-MS) is proposed [8]. Recently, many low-complexity decoding algorithms have been proposed about MS algorithm. In [7], through Jacobian approach was simplify the check node update computation based on two random values, than a dual min-sum algorithm was proposed while only the minimum value was considered[9].

In [10], achieves essentially optimal performance by applying scaling in the decoder's extrinsic information which significantly simplifies the check node update computation.

In this paper, motivated by [11], a horizontal process correction term is used to improve the decoding performance of the Min-Sum algorithms, the author modified the Check node update with two horizontal process and simplify the information weight small part which use MS algorithm is proposed. It can effectively reduce the computational complexity and can ensure the decoding efficiency.

The remainder of this paper is organized as follows. The Sum-Product Algorithm (SPA) and min-sum algorithm (MS) are introduced in Section 2, presents our proposed algorithms in section 3, simulation results and discussions are given in Section 4. Finally, we conclude this paper in Section 5.

2. SPA and MS

The SPA belongs to the family of message passing decoding algorithms which are based on the bipartite graph representation of the code, the decoding consists of iterative message passing between bit-nodes and check nodes in the graph. Next, we describe the SPA with log-likelihood ratio (LLR) messages. We denote by L_{mn}, Z_n and Z_{mn}, the bit-to-check message from bit m to check n, the check-to-bit message from check n to bit m, and the decoder output for bit m. The SPA is summarized in three steps.

2.1. Sum-product Algorithm (SPA)

Step 1: Initialization.

$$Z_{nm}(x_n) = L(x_n \mid y_n) = \frac{2y_n}{\sigma^2}, \tag{1}$$

Step 2: Iteration:
a) Horizontal step (check node update)
For each *m*, *n*

$$L_{mn} = 2\tanh^{-1}\left(\prod_{n'\in N(m)\backslash n} \tanh(\frac{Z_{mn'}}{2})\right), \tag{2}$$

b) Vertical step (bit node update)
For each *n*

$$Z_n = r_n + \sum_{m\in M(n)} L_{mn}, \tag{3}$$

For each *m*, *n*

$$Z_{mn} = Z_n - L_{mn}, \tag{4}$$

Step 3: Decision

If $Z_{mn} \geq 0$, then $x_n = 0$ and if $Z_{mn} \geq 0$, then $x_n = 1$. Otherwise, go to step 1. If a certain number of decoding iterations is reached and the algorithm does not halt, then a decoding failure is reported. SPA has better performance but with high complexity. The horizontal process calculates the hyperbolic tangent function and the hyperbolic arctangent function.

2.2. Min-sun Algorithm (MS)

The check node update computation of the min-sum algorithm is [9]. MS algorithm simplifies the horizontal process as follows.

$$L_{mn} = \prod_{n'\in N(m)\backslash n} \mathrm{sgn}(L(R_{mk}))\left(\min_{n'\in N(m)\backslash n} |L(R_{mk})|\right), \tag{5}$$

This simplification uses only minimum operations. Thus the complexity of the Min-Sum algorithm is significantly less than that of the SPA. However, this simplified structure brings some loss of performance. The performance loss can be alleviated by some modifications, which can be close to that of SPA. In this paper, the Author simplify the horizontal process, reduce the computational complexity, and better performance than MS algorithm.

3. Performance Algorithm Analysis

The SPA Horizontal step form(2), we can obtain

$$y = 2\tanh^{-1}(\tanh(\frac{x_1}{2})\tanh(\frac{x_2}{2})\cdots\tanh(\frac{x_n}{2})), \tag{6}$$

The horizontal process can be simplified to a process with only two inputs. We define the horizontal process result for the two part inputs

$$y_1 = 2\tanh^{-1}(\tanh(\frac{x_1}{2})\tanh(\frac{x_2}{2})\cdots\tanh(\frac{x_{n/2}}{2})), \tag{7}$$

$$y_2 = 2\tanh^{-1}(\tanh(\frac{x_{n/2+1}}{2})\tanh(\frac{x_{n/2+2}}{2})\cdots\tanh(\frac{x_n}{2})), \tag{8}$$

Submitting (7), (8) into (6)

$$y = 2\tanh^{-1}(\tanh(\frac{y_1}{2})\tanh(\frac{y_2}{2})), \tag{9}$$

The check node update process can be conceded two horizontal process. We just consider reduce the complex of horizontal

Then, from the Jacobi an approach [5]:

$$\begin{aligned} L(U \oplus V) &= \log(\frac{1+\exp\{L(U)+L(V)\}}{\exp\{L(U)\}+\exp\{L(V)\}}) \\ &= \mathrm{sgn}\{L(U)\}\cdot\mathrm{sgn}\{L(V)\}\min\{|L(U)|,|L(V)|\} \\ &\quad +\log(1+\exp\{-|L(U)+L(V)|\}) \\ &\quad -\log(1+\exp\{-|L(U)-L(V)|\}), \end{aligned} \tag{10}$$

Use Jacobian approach into (9)

$$\begin{aligned} y &= \mathrm{sgn}\{y_1\}\cdot\mathrm{sgn}\{y_2\}\min\{y_1, y_2\} \\ &\quad +\log(1+\exp\{-|y_1+y_2|\}) \\ &\quad -\log(1+\exp\{-|y_1-y_2|\}), \end{aligned} \tag{11}$$

If y1<y2

$$y = |y_1| + \log(1+\exp\{-|y_1+y_2|\}) - \log(1+\exp\{-|y_1-y_2|\}) \tag{12}$$

From [10], we know the second term is smaller than the third term,

$$y \approx |y_1| - \log(1+\exp\{-|y_1 - y_2|\}), \quad (13)$$

Then, we calculate the y_2 through the min-sum algorithm,

$$y_2 = \text{sgn}\{x_k\} \cdot \min\{x_k\}, k \in [1 \sim \frac{n}{2}], \quad (14)$$

We obtain the following approximation:

$$y = |y_1| - \log(1+\exp\{-|y_1 - x_k|\}), \quad (15)$$

4. Simulation Result

In this section, we report simulations that have been recorded two different code length about LDPC, which will be selected (N= 576 and N= 2304) and the code rate is R=1/2, 2/3, 3/4, 5/6. Via SP algorithm, MS algorithm and our improved algorithm, both Fig. 1 and Fig. 2 depict BER with 100 iterations.

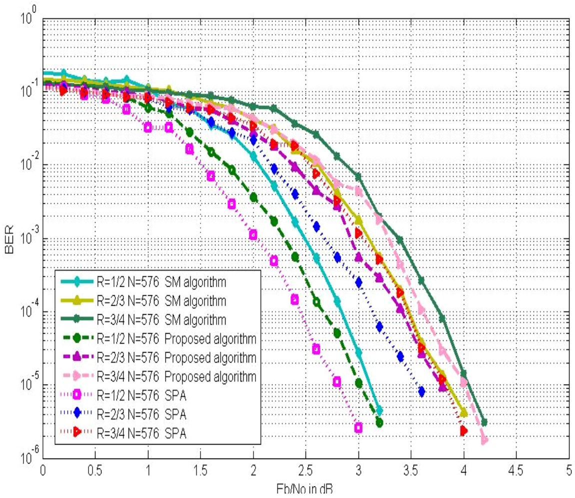

Fig. 1. LDPC code with N=576 at most 100 iterations.

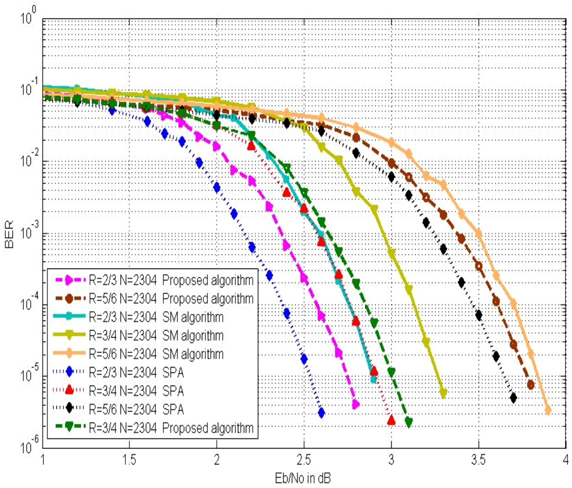

Fig. 2. LDPC code with N=2304 at most 100 iterations.

The encoded bits are binary phase-shift keying (BPSK) modulated and transmitted with AWGN channel. Both Fig. 1 and Fig. 2 show that our algorithm has better performance than the min-sum algorithm and has almost the same performance as the SPA. Our method has 0.2-0.3 dB gain with min-sum algorithm. Mathematical transformations reduce computational complexity. It comes to the following conclusion: our improved algorithm is feasible and effective.

5. Conclusions

In this article, a novel effective decoding algorithm for LDPC codes has proposed. Based on the hyperbolic tangent rule, the Check node update with two horizontal processes is modified. Two horizontal processes with different methods are calculated. Compared with the existing approximations for the SPA, the proposed method obtains less computational complexity and better performance than min-sum algorithm with small increasing computational complexity.

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