

The Research on TDMP Merged Decoding Algorithm of LDPC Codes Based on DVB-S2 Standard

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Abstract

DVB-S2 is the second generation of Digital Video Broadcasting-Satellite and LDPC (Low Density Parity Code) is the key technology in which the decoding plays an important role in determining the performance of DVB-S2 system. According to the research on the characteristics of DVB-S2 standard, this paper reports on the improvement of the Turbo Decoding Message Passing (TDMP) algorithm by adopting the idea of merging. The component codes which don't have public nodes are regarded as a new component. By changing the decoding order of component codes and removing useless waiting time, the message capacity transmitted between two adjacent component codes is increased. The performance of the proposed TDMP merged decoding algorithm is evaluated by simulation experiments. We measure decoding performance, convergence rate and the average decoding time to evaluate the system performance. The results obtained show that the TDMP merged decoding algorithm ensures the performance of decoding and good convergence, and also improves the average decoding speed and throughput.

Keywords: LDPC code, DVB-S2, TDMP, decoding rate

1. Introduction

DVB-S2 was developed on the basis of DVB-S and DVB-DSNG and is the second generation of Digital Video Broadcasting-Satellite. Since it was promulgated, the DVB-S2 has been used for television and data broadcasting services by most of Satellite radio operators. Compared with the first generation standard DVB-S, DVB-S2 has higher efficiency, wider applications, higher resource utilization and lower costs. When it comes to the system performance, the gap is only 0.7~1.0dB between DVB-S2 and the theoretical limit [1]. Because of the use of the latest techniques, including channel coding and modulation, an excellent performance of DVB-S2 has been achieved.

The most obvious feature of DVB-S2 is the concatenated channel coding of BCH and LDPC. LDPC was proposed by Gallager in 1962, and the decoding performance has the potential of approaching the theoretical Shannon limit [2-3]. Because of the large parity check matrix in DVB-S2, the decoding algorithm of LDPC is the key technology and directly determines the performance of the system. Some of the important parameters such as throughput, hardware area and power are the measurement of system performance, and therefore the study of LDPC decoding algorithm is critical. In terms of improving throughput, literature [4] has increased the decoding parallelism by fully researching on serial QC-LDPC decoding algorithm. And literature [5] focused on the pipelining system design method. Haowei, C. [6] has reduced system consumption by the sharing memory units. To improve throughput, this paper studied the decoding algorithm of LDPC codes in

3.1. TDMP Decoding Algorithm

In TDMP (Turbo Decoding Message Passing) decoding algorithm [11], the parity check matrix is divided into several component codes by row. The component codes are processed in serial and parallel way for parity nodes inside the component code. A complete iterative process consists of several sub-iterative processes of component codes. The message between two component codes can be transmitted by a reconfigurable data shuffer network unit [12]. The decoding process of TDMP is summarized as follow.

Assuming that the input message, extrinsic message, system message, posteriori message and priori message are represented as λ_l , λ_e , λ_c , λ_a and λ_o , i and j is the serial number for the component code and information bit respectively, $i = 1, 2, \dots, d$, $j = 1, 2, \dots, n$. The maximum number of decoding iteration is $imax$, and the current number of decoding is num . Assuming the transmission channel is AWGN.

1) Receiving system message and decoding initialization, setting that $i = 1$, $num=0$, $\lambda_e(i, j) = 0$.

2) TDMP sub-iterative decoding processing. We use "new" and "old" to distinguish the message produced in the current and the previous iterative process. For the i -th component code, the calculation of prior message is shown in equation (4).

$$\lambda a(i) = \lambda u(i) - \lambda e(i) \quad (4)$$

3) The calculation for $\lambda e(i)$.

Assuming that a check node in i -th component code is connected to dc variable nodes, and the variable node set is $N(m) = (n_1, n_2, \dots, n_{dc})$, so $\lambda a = (\lambda a_{n_1}, \lambda a_{n_2}, \dots, \lambda a_{n_{dc}})$.

(1) The initialization of the forward metric and backward metric;

$$A(1) = \lambda a_{n_1} \quad (5)$$

$$B(dc) = \lambda a_{n_{dc}} \quad (6)$$

(2) The calculation of forward metric $A(j)$ based on equation (7), $j = 2, \dots, dc - 1$.

$$A(j) = f(A(j-1), a) \quad (7)$$

(3) The calculation of backward metric $B(j)$ based on equation (8).

$$B(j) = f(B(j+1), \lambda a(j)) \quad (8)$$

(4) The update of extrinsic message $\lambda e, new$ and posteriori message λo .

$$\lambda e(j) = f(A(j-1), B(j+1)) \quad (9)$$

$$\lambda e(1) = B(2) \quad (10)$$

$$\lambda e(dc) = A(dc - 1) \quad (11)$$

$$\lambda o = \lambda e, new + \lambda a \quad (12)$$

4) Message transmit and the judgment of iterative progress.

Setting $i = i + 1$, if $i \leq m$, decoding is not completed, and continue to the next iteration of the component code based on TDMP.

5) The judgment for the stop of decoding. According to the dynamic iterative decoding stop criterion [13], if the criteria is met then output the hard decision. Otherwise it returns to the 2) until the stop condition is met.

In decoding algorithm, $f(a, b)$ is the main function, and in actual calculation, the nonlinear function can be simplified by the LUT.

$$f(a, b) = \log\left(\frac{1 + e^{a+b}}{e^a + e^b}\right) \quad (13)$$

3.2. The Improvement of TDMP Decoding Algorithm

The component codes are processed in serial in TDMP algorithm, when there are public nodes between two adjacent component codes, namely the message will be transmitted between the adjacent component codes. At the moment, the processing of the current component codes have to wait until the updating of previous component codes are completed, so it must to insert waiting time. If there are two or several component codes don't have public nodes, that is to say there aren't waiting time among these codes, and these component codes can be recombined into a new component codes. Based on the characteristics of parity check matrix in DVB-S2 standard, we adopt the idea of merging to improve TDMP algorithm. By changing the decoding order of component codes and removing useless waiting time, the message capacity transmitted between two adjacent component codes is increased. Thereby the decoding rate is increased. Specific process is as follows.

- 1) The preprocessing of parity check matrix \mathbf{H} . The preprocessing can be regard as the row permutation of \mathbf{H} . Interleaving the serial number in the order of $0, q, 2q \dots, 1, q+1, 2q+1, \dots$, thus getting the new check matrix \mathbf{H}' which consists of block matrix.
- 2) The mark of block matrix. The block matrix of $360 * 360$ is marked as an integer 0 or 1. If a block matrix is zero, it marks as 0 otherwise 1. After finishing the mark, we get marked matrix \mathbf{H}'' .
- 3) The detection of public nodes. Detecting the elements in each row of \mathbf{H}'' , and then put serial number of rows which don't have public node in one packet.
- 4) The merging of component codes. Based on the group result of step 3), component codes which don't have public nodes are merged. The relationship between decoding speed and the complexity of decoder should be taken into consider.
- 5) TDMP merged decoding processing.
- 6) Codeword output.

Because of merging, the structure of the parity check matrix has been changed, but the new parity check matrix \mathbf{H}' has the same code space with \mathbf{H} [4]. Actually merged process of component codes does not change the constraint conditions in LDPC code. Only the updating order of information bits and the updating capacity of sub-iteration are changed. Therefore the result of TDMP merged decoding algorithm is consistent with original decoding. Figure 3-1 shows the decoding illustration of TDMP merged decoding algorithm.

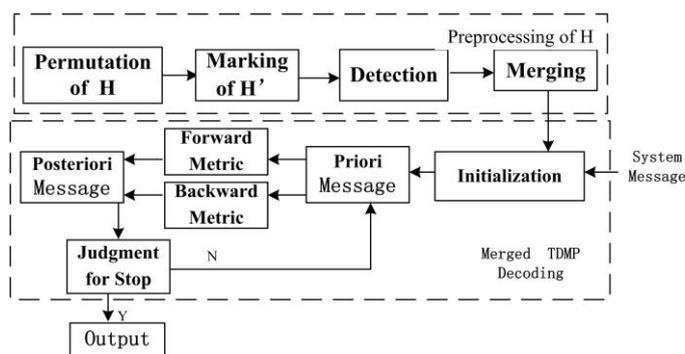


Figure 3-1. Illustrating the Decoding of TDMP Merged Decoding Algorithm

4. Simulation Analysis

In this paper, we simulated the performance of TDMP merged decoding algorithm with code rate $r = 2/3$ and code length $n = 64800$ of LDPC. Assuming that transmission channel is AWGN channel, using QPSK modulation mode. Figure 4-1 is a block diagram of the decoding simulation test platform. The TDMP merged decoding algorithm was

compared with the existed algorithms including BP algorithm, Min-Sum algorithm (MSA), normalized Min-Sum algorithm (NMSA). The normalization factor of NMSA is 0.9 that is the optimum value under this condition. The maximum iterative number of TDMP algorithm was 30 and 40 for others.

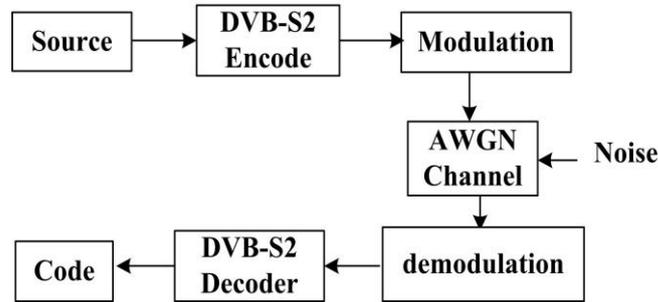


Figure 4-1. The Decoding Simulation Test Platform

Figure 4-2 is the decoding performance curves of different algorithms. Figure 4-2 shows that when the SNR < 1.0 dB the algorithm BER were similar. This is because the success for decoding probability is not high, the maximum number of iterations can't meet the required of decoding probability of success. When SNR > 1.0 dB, MS algorithm was the worst, TDMP algorithm was similar with BP. This is because the message passing mechanism of TDMP algorithm makes other sub-iterations used the updated message in a timely manner. In MS algorithm, the estimates of the node information have deviation, but in NMS the deviation will be corrected. Table 1 shows the evaluation results against SNR. Compared with MSA, the performance of TDMP merged increased 0.3dB at BER level of 10^{-4} and 10^{-5} . The simulation results show that the idea of merging does not affect the decoding performance; even in high SNR region the BER performance is better than other decoding algorithm.

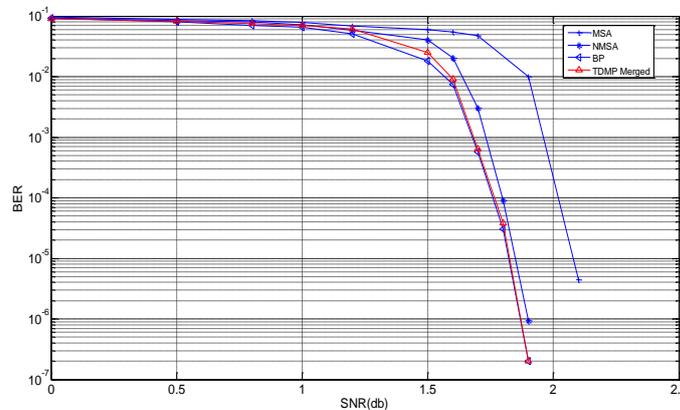


Figure 4-2. BER Curves of Different Algorithms

Figure 4-3 and 4-4 show the average number of iteration and decoding time curves of TDMP algorithm and BP algorithm, respectively. It showed that merged TDMP decoding algorithm retained the fast convergence performance from traditional TDMP.

Table 1. The Improvement Value

BER	10^{-2}	10^{-3}	10^{-4}	10^{-5}
Improvement	1.0dB	0.3dB	0.25dB	0.3dB

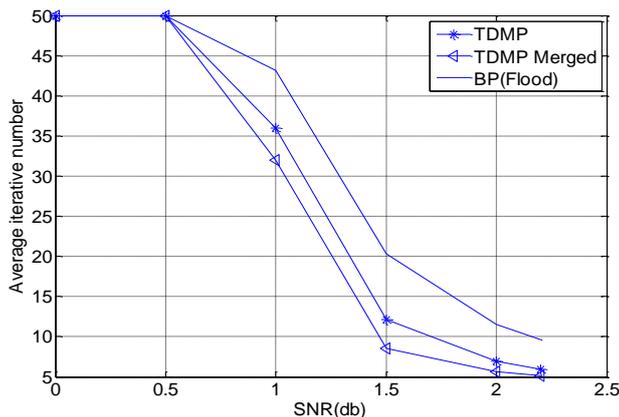


Figure 4-3. The Average Number of Iteration

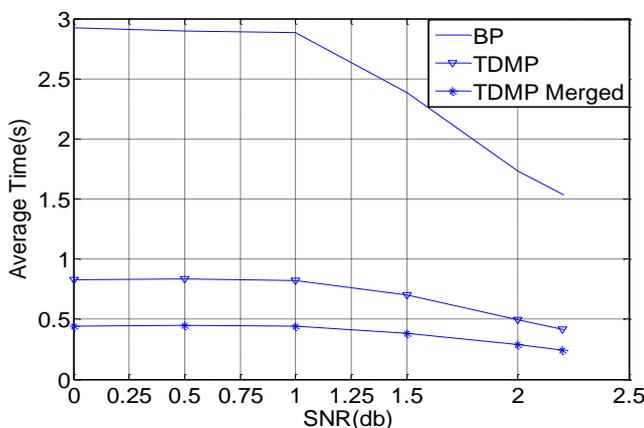


Figure 4-4. The Average Decoding Time

In Figure 4-4, when SNR was same, the average decoding time of BP was the longest, and the merged TDMP decoding algorithm was the shortest. The average decoding time of merged TDMP was 1/6 of the BP algorithm. In the low SNR region, merged TDMP decoding algorithm was 1/2 of TDMP and slightly larger than 1/2 times in the high SNR region. Thus, by adopting the idea of merging we can reduce the average decoding time manifold. Integrated the above simulation results, the merged TDMP decoding algorithm on the premise of guaranteeing the decoding performance and good convergence can improve the decoding rate and then increase the throughput of DVB - S2 system when the working frequency is constant.

5. Conclusion

These papers focused on the research of TDMP algorithm in DVB - S2, and adopt the method of merging to improve the algorithm; the performance of the improved algorithm is verified. Merged TDMP decoding algorithm can improve the decoding speed and throughput successfully on the premise of guaranteeing the decoding performance and convergence. In addition to this, merged TDMP can keep contact with Turbo decoding algorithm, and avoid large amount of resource consumption of LDPC/Turbo dual-mode decoder. Therefore merged TDMP decoding algorithm in this paper is a kind of high practical LDPC decoding algorithm both in terms of throughput and the implementation of dual-mode decoding.

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