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Layer decoding of LDPC codes for DVB-S2

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Abstract In the most common form of message-passing decoding, the LDPC decoder are performed by so-called two-phase message-passing algorithm(TPMP). For TPMP, the messages are updated iteratively at two different phases, first check node and then variable node.

In this paper, the layer decoding algorithm is applied for DVB-S2 to reduce the iteration number compared to TPMP. This paper shows in detail how to exploit the partly parallel layer schedule for DVB-S2. Simulation results show that the layer decoding performs well based on the proposed layer schedule, which sustains the partly parallel structure and fasts the convergence speed almost 2 times than TPMP.

1. Introduction

DVB-S2 is a second generation standard of digital broadcasting for satellite application, which is defined by European Telecommunications Standard Institute [1]. The forward error correction stage defined in DVB-S2 provides error correcting capability close to Shannon limit. This is enabled by including low density parity check codes (LDPC) [2,3].

The LDPC codes could be decoded iteratively using belief propagation (BP) method, which is viewed as an instance of a message passing (MP) scheme. For a LDPC code, the rows and columns of parity check matrix H are mapped to check nodes and variable nodes of a so-called tanner graph. The tanner graph corresponds to the specific parity check matrix H. In MP decoding process, the massages are passed along the edges iteratively between the variable nodes (VN) and check nodes (CN) in Tanner graph. The messages exchanging order between the two types node is called schedule. In general, the two phase message passing (TPMP) schedule is widely known, which involves check-node update and variable-node update as two serial phases. The widely used algorithm in check-node update process are sum-product algorithm (SPA)[4], normalized min-sum algorithm (NMSA) [5] and offset min-sum algorithm(OMSA)[6].

One of the reasons for the powerful error correcting capability of LDPC codes in DVB-S2 is the long codeword length of 64800 bits. However, the long codeword length leads to high complexity as well for implementing the LDPC decoder. To yield a perfect decoding performance, the DVB-S2 LDPC decoder has to iterate 40 times for TPMP decoding schedule. In addition, up to 300000 data are scrambled and calculated at each of iteration. The huge data operation and large number of iteration yield long decoding latency and severe power consumption. Therefore, a highly efficient LDPC decoding verification is a real challenge. The author of [7] introduced the concept of turbo decoding message passing schedule (also called as layered decoding), which is able to reduce the iteration number without degradation of decoding performance. In contrast to TPMP schedule, this paper calls layer decoding for LDPC codes as LDMP schedule. In general, an appropriate layer grouping method is needed to be considered for a specific LDPC code for efficient implementation. We call this layer grouping method as layer schedule process.

The main contribution of this work consists in consideration of an efficient layer schedule for the LDMP decoding of DVB-S2 system. The proposed layer schedule can be also applied to support all the code rates as specified in DVB-S2 standard.

The rest of the paper is organized as follows. Section 2 describes LDMP decoding. In section 3, the LDMP decoding with OMS algorithm and layer schedule for DVB-S2 standards are proposed. Based on the proposed layer architecture, section 4 shows the simulation results. Finally, section 5 offers the conclusions of this paper.

2. LDMP decoding

Both of TDMP and LDMP decoding are iteratively MP process between the CN and VN of Tanner graph, in which the decoder seeks a codeword c to maximizes $P(c|y, Hc = 0)$ given the received messages

	VN										
Layer H1	1	0	0	1	0	0	0	1	0	0	CN
	0	0	1	0	1	0	0	0	1	0	
	0	1	0	0	0	1	0	0	1	0	
Layer H2	1	0	1	0	0	0	1	0	0	0	
	0	0	1	1	0	0	0	1	0	0	
	1	0	0	0	1	0	1	0	0	0	

Fig.1 Example of layer schedule for LDMP

$y=(y_0,y_1,\cdots,y_m,\cdots,y_{N-1})$ with $y_m \in \Re$. Messages in these two MP decoding schemes are represented in the form of Log Likelihood Ratio (LLR).

In the TPMP decoding, the messages are computed in two phases at each iteration, check-node update and variable-node update. In the first phase of one iteration, messages in CN are updated using the messages from VN which are obtained in previous iteration. Then in the second phase, the updated messages of CN are passed to VN and are added up in the VN node for the decoder processing of next iteration.

For LDMP, one iteration is split into sub-iterations and each sub-iteration process one layer. A layer can be made of one or several CNs. The sub-iteration consists in updating all the VN connected to the CN of one layer. Then the updated VN messages are utilized to the CN update of subsequent layer in current iteration. Fig.1 depicts a size of 6×10 parity check matrix with two layer schedule sample. Each layer is made of 3 CNs.

Fig.2 depicts the message passing order of LDMP. The detailed algorithm of LDMP decoding is described in follows.

1) In the step of initialization, a VN is represented by a soft value Z_n (corresponding to nth VN), which is initialized by the channel LLR. Set $L_{mn}^{(0)}=0$ and iteration counter i=1.

$$Z_n^{(0)}=\log\left(\frac{P(v=0)}{P(v=1)}\right) \qquad (1)$$

The number of superscript in the left variable of (1) represents the iteration number.

2) In each sub-iteration of LDMP, the message update is done in two steps. First, Update message $L_{mn}^{(i)}$ (sent from

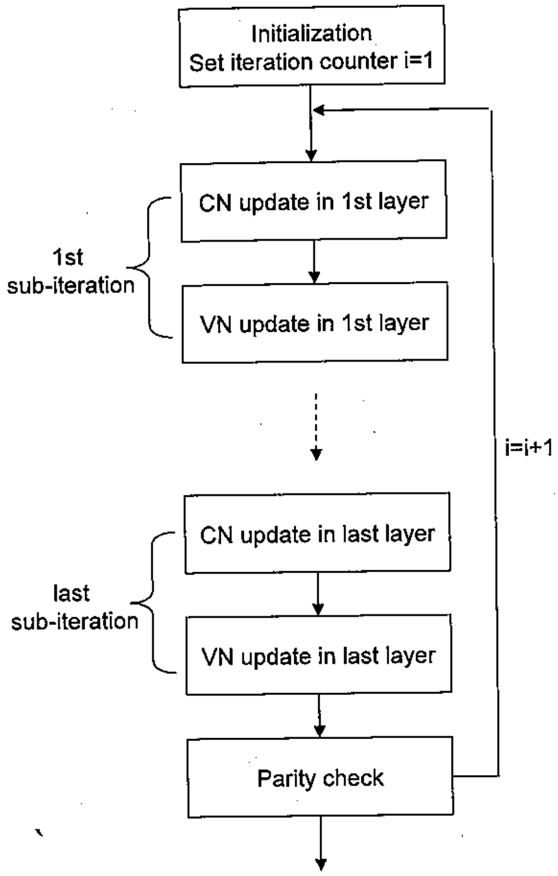

Fig.2 Layer decoding architecture

CN m to VN n) for each (m,n) with $H_{mn}=1$, by

$$L_{mn}^{(i)}=2\tanh^{-1}\left(\prod_{j\in N_{m,n}}\tanh\left(\frac{Z_{mj}^{(i)}}{2}\right)\right) \qquad (2)$$

Where, the $Z_{mj}^{(i)}$ is the message sent from variable node j to check node m, which can be calculated by (3),

$$Z_{mj}^{(i)}=Z_j^{(i)}-L_{mj}^{(i-1)} \qquad (3)$$

The second step is the VN soft value $Z_j^{(i)}$ update, which is different processing from TPMP decoding. For TPMP, the VN soft value is calculated as (4), which is decided by initialization value and the messages from CN obtained in previous iteration,

$$Z_n^{(i)} = L_n^{(0)} + \sum_{m \in \mathbf{M}_n} L_{mn}^{(i-1)} \tag{4}$$

For LDMP, the VN soft value is updated concurrently by layer processing.

$$\begin{aligned} Z_n^{(i)} &= L_n^{(0)} + \sum_{m \in \mathbf{M}_n'} L_{mn}^{(i)} + \sum_{m \in \mathbf{M}_n''} L_{mn}^{(i-1)} \\ &= Z_n^{(old)} + L_{mn}^{(i)} - L_{mn}^{(i-1)} \end{aligned} \tag{5}$$

3) Go to next sub-iteration and repeat process of step 2 until all layer processed.

4) Make a hard decision by

$$c_n^{(i)} = \begin{cases} 0, & Z_n^{(i)} >= 0 \\ 1, & Z_n^{(i)} < 0 \end{cases} \tag{6}$$

If $H^T \bullet c_n^{(i)} = 0 \; or \; i == I_{\max}$, terminate the decoding. Otherwise, set $i = i + 1$ and then repeat decoding from step 2).

For LDMP, several CNs may be grouped together to form a layer. It is better that the column weight within a layer does not exceed one. In other words, a given VN is connected at most to a single CN of a layer.

3. Proposed layered schedule with OMS algorithm

3.1 Check node update with OMS algorithm

The check node update processed as e.q. (2) is viewed as optimal solution, which is so-called SPA algorithm. For lower computation in the step, several simplified derivations of SPA were revealed. MSA can be viewed as a simplified derivation of SPA, while OMSA and NMSA are viewed as improved version of MSA with a little additive process. This paper applies OMSA as DVB-S2 check node update algorithm. As shown in section 4, the OMSA provides sub-optimal decoding performance which is close to SPA. The check node updated based on OMSA is shown in (7), Where, the offset value β could be fixed for a specific code. A simple approach to determine the value is able to rely in density evolution, which can be found in [5].

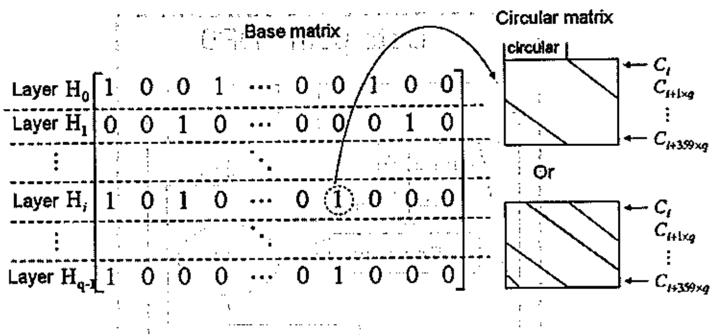

Fig.3 Layer group of DVB-S2

$$L_{mn}^{(i)} = \prod_{j \in N_{m,n}} \operatorname{sgn}\left(Z_{mj}^{(i-1)}\right) \times \max\left(\left(\min_{j \in N_{m,n}} \left|Z_{mj}^{(i-1)}\right| - \beta\right),\ 0\right) \tag{7}$$

3.2 Proposed layered schedule (data path)

In this section, the layer group method (layer schedule) will be presented to suitable for the layer decoding. For the codeword length with 64800, DVB-S2 standard defined 11 code rate ranging from R=1/4 up to 9/10. As the huge data processing of the long codeword length codes, partly parallel architecture are feasible, hence only a subset P of the nodes are instantiated. The parity check matrices of the all LDPC codes defined in DVB-S2 are architectureaware. As shown in Fig.3, 360 CN is grouped together to form a layer. For a given LDPC(N,K) code, where N and K represent codeword length, and information length respectively, the number of layers thus equals to $q = (N - K)/360$.

In Fig.3, the layer structure consists of a base matrix, in which the place with 1's represents a circular matrix with size of 360×360 . For a given H_i layer, the 360 simultaneous CN corresponds to 360 real CN (assuming marked as C_x) of original parity check matrix. These real C_x are defined by (8),

$$x = i + n \times q, \qquad n = 0, 1, \cdots, 359 \tag{8}$$

Where, i corresponds to H_i layer.

As a result, one iteration of the layer decoding worked in the proposed structure is thus split to q sub-iteration. Check node update or variable node update could be partly parallel processed in each sub-iteration. The center of the architecture is thus formed by the data path as shown in Fig.4. Fig.5 shows the high-level block architecture which consists of 360 basic data path. The

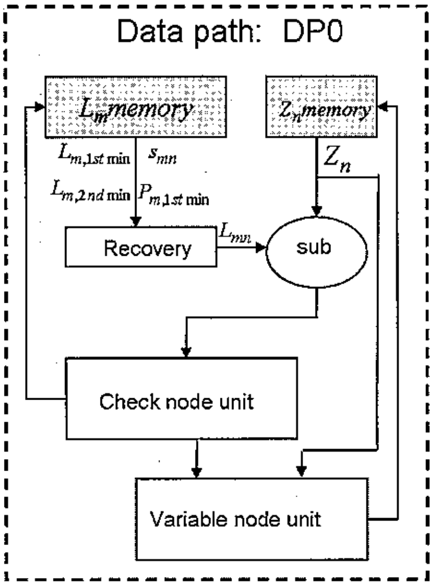

Fig.4 Data path of one sub-iteration

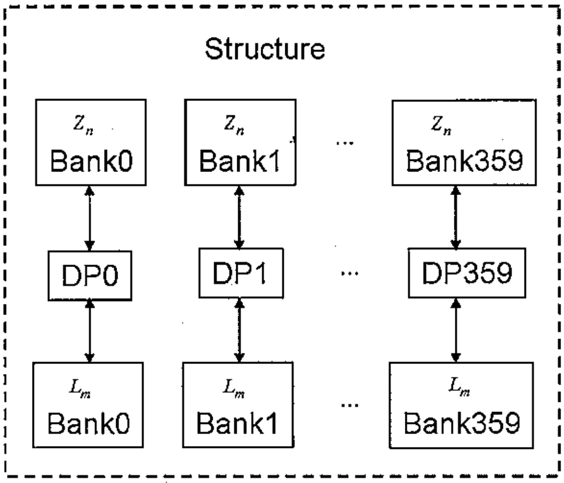

Fig.5 High level architecture

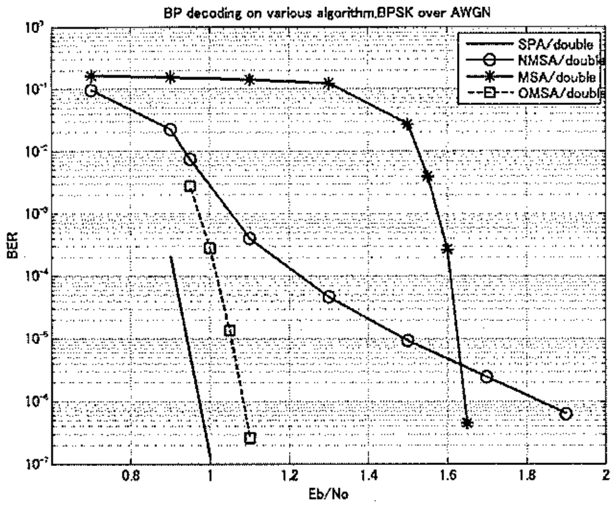

Fig.6 Performance of MP decoding on existing various algorithm

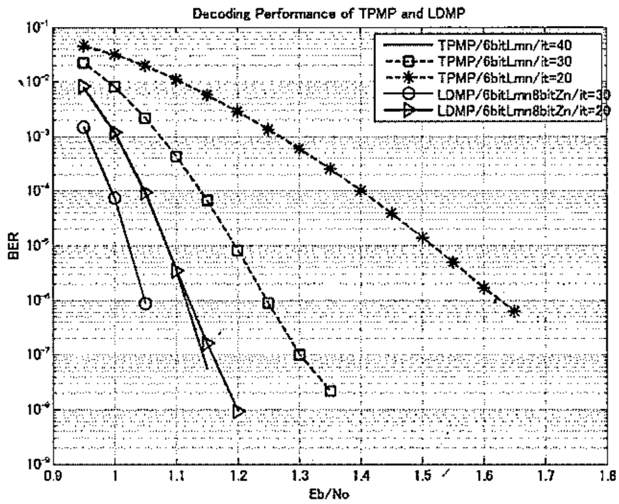

Fig.7 Performance of layer decoding

depicted architecture is time multiplexed simultaneously from first to last layer. In addition, the proposed architecture supports all code rate in shared hardware architecture.

4. Simulation results

The decoding performance is verified by the BER performance in terms of Eb/No using computer simulation. In our simulations, signal is assumed as modulated by BPSK and propagated through AWGN channel.

Fig.6 shows the BER performance of MP (BP) decoding by using the check node update on existing various algorithm for the DVB-S2 LDPC codes. Compared to the optimal algorithm SPA, the performance loss of MSA is about 0.65dB. The performance is improved by NMSA, however the NMSA incurs a high error floor. Furthermore the performance of NMSA is even worst than MSA at high Eb/No region. It is distinct that the performance of OMSA is most close to SPA, only about 0.1dB loss and the error floor of with BER<=10^{-7} at high Eb/No region is not found.

Fig.7 shows the effectiveness of layer decoding (LDMP) based on our proposed layer schedule. In the proposed decoding schedule, the check node update uses OMSA algorithm. In order to highlight the effect of LDMP, the two phases MP decoding schemes (TPMP) with maximum iteration number 40, 30 and 20 iteration number are set as reference. For TPMP, the variable information Z_n and check node information L_{mn} are all quantized to 6bits width. For LDMP, the two kinds of information are quantized to 8bits. Based on this figure, it is found that the LDMP is able to reduce about half maximum iteration number compared to the TPMP decoding without degradation of decoding performance.

5. Conculsions

Layer decoding with OMS algorithm is employed to enhance the throughput and reduce power consumption for the LDPC decoder in DVB-S2 standard. Simulation results show that the layer decoding performs well based on the proposed layer schedule, which sustains the partly parallel structure and fasts the convergence speed almost 2 times compared to TPMP.

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