Improved LDPC Decoding Speed Using Past Decoding Information

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Abstract

In this work, a new LDPC decoding architecture for DVB-S2 is proposed. Based on the traditional LDPC decoding algorithm, low-pass filtering on probability decisions is used in order to suppress radical changes. This results in improved performance gain either as decreased number of required iterations or as higher error correction capability under severe channel conditions. Simulation results for different modulation schemes are used to demonstrate the improved performance of the proposed approach.

Keywords: LDPC, decoding architecture, DVB-S2.

1. Introduction

Error Correction Codes (ECC) are being used in all applications where reliable data transmissions has to be achieved over noisy channels. Error correction is an integral part of any transmission system, but it may increase its complexity significantly depending on the raw BER (bit error ratio), experienced at the channel, and the target BER that has to be provided to the user. Increased error correction capabilities may also be achieved by adding more parity information (increased overhead) and/or a more iterative decoding steps which result to increased latency.

Low-Density Parity-Check (LDPC) codes are ECCs that have characteristics which make them suitable for a variety of applications, from storage devices to satellite communications [1]. Their inglorious beginning after their invention in 1962, was followed by a sincere appreciation about thirty years later, mainly due to their performance, which can be very close to the capacity of a variety of channels [2].

In this work, we present an enhancement to the traditional LDPC decoding process that results to better decoding capabilities and/or less decoding iterations for a given decoding performance. The proposed decoding enhancement has been applied to a satellite communications system that is based on the DVB-S2 specifications [4]. The new decoding approach is based on memory elements introduced in each variable/check node. These memories are associated with previous probability estimations and are used in the current estimation for achieving faster convergence to its final value. That results to less iterations in order to successfully decode messages than the traditional LDPC decoders. This advantage begins to emerge in low channel SNRs and it also accomplishes successful decoding in many cases where the traditional LDPC decoding fails.

In [5] a new LDPC decoding algorithm is proposed in order to reduce complexity and make it simpler for implementation. A new demapping/decoding method which is based on decreased correlation of coded bits within a symbol is introduced in [6]. A new class of iterative bit flipping decoding algorithms which results in improved coding gain and decoding speed is proposed in [7].

This paper is organized as follows. In Section 2, we present the theoretical background on LDPC codes and its applicability on the DVB-S2 specification, emphasizing on the initial LDPC decoding algorithm on which our system is based. In Section 3, we present the enhancement we made in the LDPC decoder's architecture and details about its filtering characteristics. Simulation results acquired by the proposed architecture are shown and analyzed in Section 4. They are also compared with the performance results of the traditional decoding approach and the resulted improvement is also demonstrated. Finally, in Section 5 we give a concise description of our on-going work on this approach.

2. LDPC and Satellite Communications

LDPC codes provide near-capacity performance on symmetric memoryless channels, while keeping their complexity relatively low, which makes their use attractive on a large group of data transmission and storage channels. LDPC codes can be described in terms of their parity check matrix or using Tanner graphs. Since the graphical representation is more easily conceivable, we use it in order to describe the decoding process.

Tanner graphs are bipartite graphs, that is, graphs whose nodes can be divided into two sets, with edges connecting only nodes from different sets. The two types of nodes in a Tanner graph are the variable nodes (VN) and the check nodes (CN). In a Tanner graph of a LDPC code, there is an edge between VN(i) and CN(j), whenever $h_{ij} = 1$ (h_{ij} is an element of the parity check matrix H). In Fig. 1 is shown a Tanner graph of an LDPC decoder with 5 VNs and 3 CNs. Decoding of LDPC is based on an iterative belief propagation scheme. Each node is a processing unit that transmits and receives messages only to its adjacent nodes. In Soft Decoding, messages exchanged between the nodes are basically the probability of a specific codeword digit to be '0' (or '1').

In every iteration, all VNs compute a decision (probability) and send it to each of its adjacent CNs, based on the information given by the set of connected CNs. At the same iteration, every CN computes a response based on VNs' inputs.

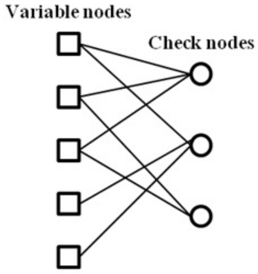

Fig. 1 Tanner graph of an LDPC decoder

The LDPC decoder starts a new iteration, unless the current iteration results to an error-free dataword or the maximum number of allowed iterations has been reached. The decision of each node is based exclusively on the messages received from its adjacent nodes at the current decoding round.

2.1 DVB-S2

Digital Video Broadcasting – Satellite – Second Generation (DVB-S2) is an international specification for digital satellite transmissions developed by the DVB Project [4] and has been designed as a successor for the popular DVB-S system [3]. DVB project has selected a set of modulation schemes as well as various tools for channel coding and error correction that shall be used in order to transfer data over a satellite communication channel efficiently and with guaranteed quality of service. More specifically, DVB-S2 supports four modulation modes: QPSK, 8PSK, 16APSK and 32APSK depending on the C/N required.

In order to correct the errors induced by the noisy satellite channel, DVB-S2 uses a powerful Forward Error Correction scheme (FEC), which is a large LDPC code concatenated with an outer BCH code. The BCH code is mainly used in order to avoid the error floor problems of LDPC at low bit-error rates.

Both modulation and coding characteristics can be dynamically selected on a frame by frame basis by using the Adaptive Coding and Modulation (ACM) technique. ACM allows each individual user to adjust the transmission parameters depending on the channel characteristics.

2.2 LDPC for DVB-S2

In 2003, the DVB-S2 selection committee chose an irregular LDPC code to be included in the specification. LDPC's performance beat other turbo codes that were examined in terms of performance and complexity. The block sizes supported by DVB-S2 are 16200 (short) and 64800 (normal). Also, the code rates specified in the standard are 1/4, 1/3, 2/5, 1/2, 3/5, 2/3, 3/4, 4/5, 5/6, 8/9 and 9/10. A brief description of the decoding algorithm is defined in [4]. Fig. 2 shows the basic decoding architecture per LDPC node. The FIR part is related with the proposed enhancement and is not included in the basic decoding architecture. This part is analyzed in the next Section. Below we describe the basic decoding steps. We define as q_{ij} the message sent by VN(i) to CN(j) and as r_{ji} the message sent by CN(j) to VN(i).

- **Initialization:** All VNs send their q_{ij} messages to the associated CNs. Since at this time there is no other information, they send $q_{ij}(1) = \Pr(c_i = 1|y_i)$, where y is the received message and c is an error free codeword. Respectively, $q_{ij}(0) = 1 - \Pr(c_i = 1|y_i)$
- **CN update:** All CNs calculate their output messages:

$$r_{ji}(0) = \frac{1}{2} + \frac{1}{2}\prod_{i' \in V_j \backslash i}(1 - 2q_{i'j}(1)) \quad (1)$$

$$r_{ji}(1) = 1 - r_{ji}(0) \quad (2)$$

which means that they compute the probability that there is an even number of 1's in all VNs except i, in order to satisfy the j-th parity check equation.

- **VN update:** The VNs compute their output messages:

$$q_{ij}(0) = K_{ij}\Pr(c_i = 0|y_i)\prod_{j' \in C_i \backslash j} r_{j'i}(0) \quad (3)$$

$$q_{ij}(1) = K_{ij}\Pr(c_i = 1|y_i)\prod_{j' \in C_i \backslash j} r_{j'i}(1) \quad (4)$$

where constants K_{ij} are used in order to ensure that always $q_{ij}(0) + q_{ij}(1) = 1$.

- **Hard decision making:** In addition, VNs make also an estimation of the variable $\hat{c_i}$. If the probability $Q_i(0) = K_i\Pr(c_i = 0|y_i)\prod_{j \in C_i} r_{ji}(0)$, is larger than $Q_i(1) = K_i\Pr(c_i = 1|y_i)\prod_{j \in C_i} r_{ji}(1)$, then the estimation is $\hat{c_i} = 0$, otherwise $\hat{c_i} = 1$. If these estimations satisfy all parity check equations then the decoder terminates, otherwise it continues with another iteration, until the maximum number of iterations has been reached.

3. Enhanced LDPC Decoding Architecture

In our work we investigate the effect of previous LDPC decoder decisions in each iteration. Based on the observation that message values q_{ij} and r_{ji} have significant fluctuations from iteration to iteration, we introduced low-pass filtering in the outbound edges of each Tanner graph node, in order to decrease the observed fluctuations. As a result, we also observed better decoding performance (initially in terms of number of iterations for proper decoding) under severe channel conditions. For that purpose, we currently use a first order low pass FIR filter. The block diagram of these filters is shown in Fig. 2. A message m_{in}, which represents either q_{ij} or r_{ji} , is stored in a memory element and weighted with a factor a. In the next decoder iteration, the decision takes into account also the respective result of the previous iteration, properly weighted. The following describes the new probability estimation approach in iteration k:

- **CN update:**

$$r_{ji}(0)[k] = a\left[\frac{1}{2} + \frac{1}{2}\prod_{i' \in V_j \backslash i}\left(1 - 2q_{i'j}(1)\right)\right] + \\ + (1 - a) \cdot r_{ji}(0)[k-1] \quad (5)$$

- **VN update:**

$$q_{ij}(0)[k] = a\,[K_{ij}\Pr(c_i = 0|y_i)\prod_{j' \in C_i \backslash j} r_{j'i}(0)] + \\ + (1 - a) \cdot q_{ij}(0)[k-1] \quad (6)$$

$$q_{ij}(1)[k] = a[K_{ij}\Pr(c_i = 1|y_i)\prod_{j' \in C_i \backslash j} r_{j'i}(1)] + \\ + (1 - a) \cdot q_{ij}(1)[k-1] \quad (7)$$

4. Performance results

Our experimental scenario is based on a DVB-S2 system, mainly using Q-PSK and 8-PSK constellations for data transmission in a AWGN channel. The advantages of the proposed architecture stand out in low SNR values, because this characteristic results in lower number of decoding iterations. In our analysis, we focus on code rate 1/3 with short datawords.

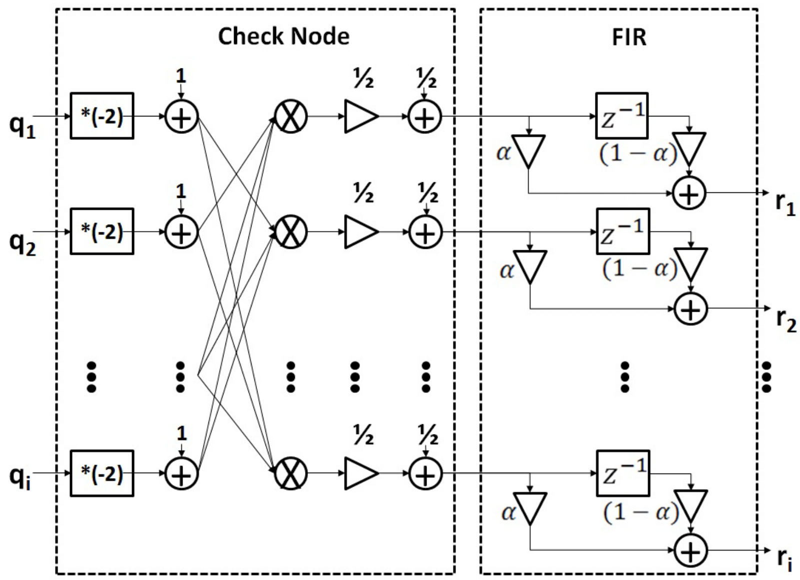

Fig. 2 Check node example with FIR filters at its outputs

In Fig. 3 we show the cumulative probability of successful decoding for three channel SNRs with QPSK. In this experimental scenario, we have set to 100 the maximum number of iterations before the decoder fails. In Fig. 3A we see that with SNR=1dB both the LDPC and the enhanced LDPC decoders will successfully decode the received messages in no more than 40 iterations, but it is clear that the enhanced decoder precedes the typical, memoryless decoder. By increasing the channel noise, as in Fig. 3B, SNR=0.5dB is used. We can see that with 0.4 probability, the typical LDPC decoder will reach the maximum number of iterations without success, while the enhanced decoder will succeed with up to 80 iterations performed. By further decreasing the SNR to 0.25db, as in Fig. 3C, we observe that for all attempts the traditional LDPC decoder fails while the enhanced decoder fails in only 10%. Fig. 3D demonstrate the effect of SNR on the performance of enhanced LDPC decoder. Fig. 4 shows similar results for 8-PSK modulation. Again, the improved performance of the proposed decoder is clearly demonstrated.

5. Conclusions

In this paper, we presented the architecture and performance results of an improved version of the traditional LDPC decoder by using low-pass FIR filters at the outputs of the decoder's nodes. Our performance results show that there is a significant improvement in the decoding speed and the ability of a specific code rate to decode messages in very noisy channels.

In order to continue our investigation on the enhancement of LDPC decoding, we'll experiment with all code rates, constellations and SNR values. We would also like to examine the possibility of dynamically adjusting the factor α and for estimating the best possible value for each modulation/coding rate pair of DVB-S2. Last but not least, the reduction of the memory elements required is a vital challenge in order to make the decoder less complex. Initial results show that applying this filtering only in specific nodes, comparable results can be achieved.

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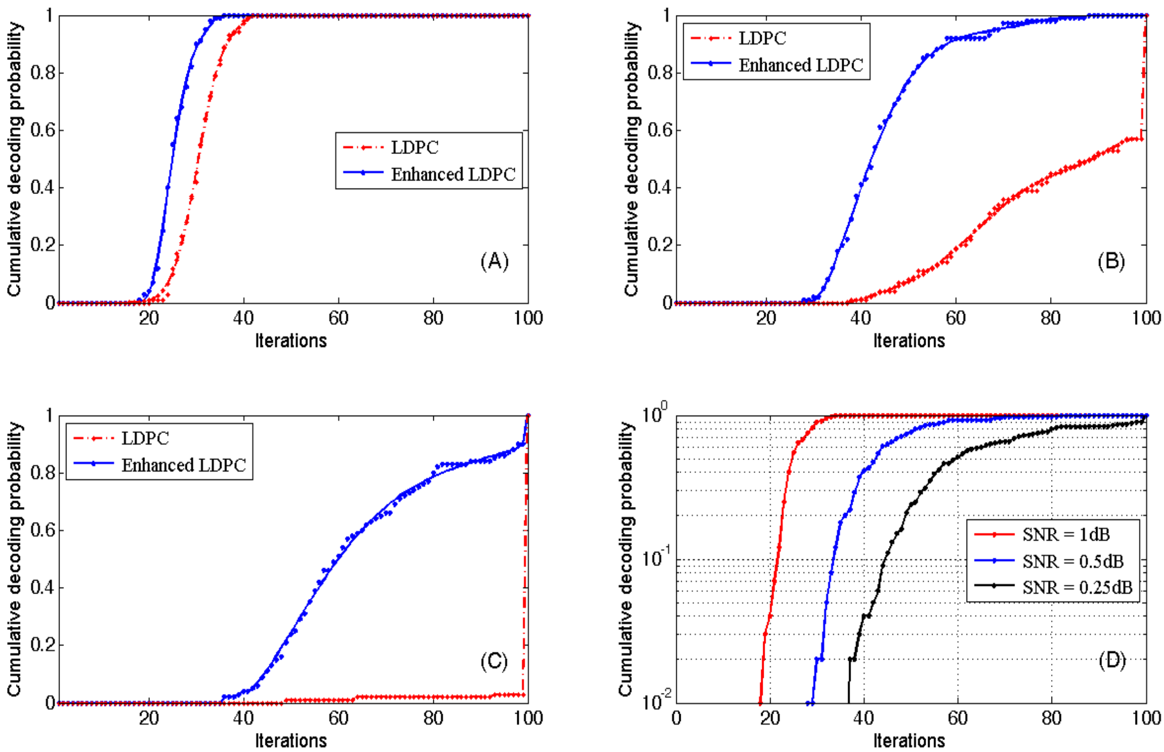

Fig. 3 Cumulative decoding probabilities for QPSK and SNR = 1dB (A), 0.5dB (B), and 0.25dB (C). The effect of SNR on the performance of enhanced LDPC decoder is shown in (D).

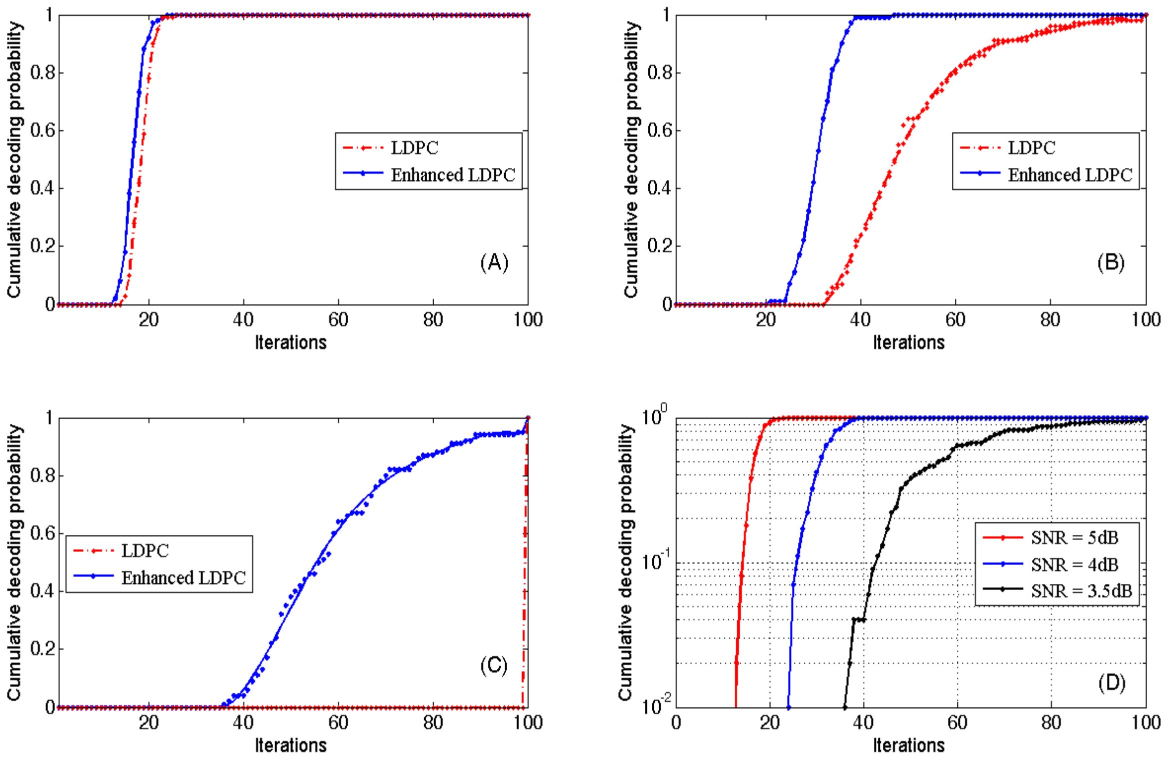

Fig. 4 Cumulative decoding probabilities for 8-PSK and SNR = 5dB (A), 4dB (B), and 3.5dB (C). The effect of SNR on the performance of enhanced LDPC decoder is shown in (D).