# LDPC FEC CODE EXTENSION FOR UNEQUAL ERROR PROTECTION IN 2ND GENERATION DVB SYSTEMS

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## ABSTRACT

One of the envisioned advantages of scalable video coding is its inherent suitability for achieving unequal error protection (UEP). UEP can be effectively used for graceful quality degradation under harsh network conditions. The Digital Video Broadcasting (DVB) organization recently introduced second generations of broadcast transmission technologies like DVB-T2 and DVB-S2. These technologies, due to the newly introduced and advanced tools, ensure better quality of service compared to their respective first generation counterparts. Among the important tools that directly affect the quality of service positively in these emerging technologies is the new physical layer-chained forward error correction coding. In both cases, the chained codes comprise of a Bose-Chaudhuri-Hocquenghem (BCH) code, which functions as the outer code, followed by a Low-Density Parity Check (LDPC) code as the inner code.

To allow for improved graceful quality degradation in the second generation DVB broadcast technologies, this article proposes a novel method to extend deployed LDPC codes. This code extension enables the implementation of UEP schemes in an effective manner in these DVB broadcast systems. Furthermore, the proposed solution is backward compatible to legacy receivers. The performance evaluation of the proposed method is supported by results, obtained through simulations.

***Keywords*****—** LDPC, DVB-T2, DVB-S2, SVC, UEP

## 1. INTRODUCTION

The range of devices capable of consuming advanced multimedia services is growing with every passing year. This trend opens new markets for service providers, but at the same time is forcing existing multimedia dissemination and consumption technologies to be exploited to their limits. Therefore, to fulfil the needs of evolving markets, and to provide sufficient bandwidths to enable transmitting media with the best possible quality of service, new processing and transmission technologies have emerged lately.

Recently, H.264 Scalable Video Coding (H.264/SVC) [1] was developed as an extension of the H.264/AVC [1]. The codec was designed to provide scalability at the bitstream level, with good compression efficiency. It allows free combinations of scalable modes, such as spatial, temporal and SNR/fidelity scalability. Hence, this codec is ideal for simultaneously serving terminals of differing capabilities, efficiently.

The potential of H.264/SVC video codec was recognized by Digital Video Broadcasting (DVB) organization. Hence, it was adopted as one of the codecs used for DVB broadcast services [2]. DVB also specified the second generation of DVB systems, DVB-T2 [3] and DVB-S2 [4], to improve data transmission performance.

In addition to the efficient simultaneous serving of heterogeneous terminals, building DVB services that make use of H.264/SVC may bring additional benefit. One among other benefits is the capability of providing graceful degradation using unequal error protection (UEP). For example, higher reliability of the transmitted video stream can be achieved by protecting the base layer with a stronger forward error correction (FEC) code compared to enhancement layers. Thus, enabling the base layer to act as an fallback alternative in case of harsh network conditions.

Second generation DVB broadcast systems use the same physical layer chained FEC codes. In both DVB-S2 and DVB-T2, the chained codes comprises of a Bose-Chaudhuri-Hocquenghem (BCH) code [5] which functions as the outer code followed by a Low Density Parity Check (LDPC) code [6] as the inner code. In this paper, we present a novel method to extend the LDPC code. The extension is designed to be utilized as part of the channel coding in the DVB-T2 and DVB-S2 systems so that to provide graceful degradation of the transmitted H.264/SVC content.

The rest of the paper is organized as follows. Background information is presented in Section 2. First, the paradigm of scalable media coding is described. Next, the main concept of FEC protection in second generation DVB broadcast systems is introduced. Finally, detailed information about the LDPC code, which will constitute the basis to Section 3, is provided. In Section 3, the proposed method to extend the LDPC code is described. Subsequently, the simulation setup to support our concept

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and the results are presented in Section 4. The paper is concluded in Section 5.

## 2. BACKGROUND

### 2.1. Scalable Media Coding

The concept of scalable media coding has been widely investigated in academia and industry for the last 20 years. The underlying idea is that an encoder produces a single bit-stream containing different representations of the same content with different characteristics. A decoder can then decode a subset of the bit-stream that is most suitable for the target use case and the decoder capabilities. A scalable bit stream usually consists of a base layer and one or more enhancement layers. For example, in H.264/SVC removal of enhancement layers at the receiver may lead to a decoded video sequence with reduced frame rate, picture resolution or picture fidelity. One other benefit that comes with scalable media coding is that it is well suited for robust data transmission through the application of UEP schemes.

The above mentioned characteristic has been one of the main reasons for the increased interest in scalable coding by the industry. Consequently, almost every video coding standard supports to some extent media scalability. However, in older video coding standards, scalability was always linked to increased complexity and a drop in coding efficiency when compared to non-scalable coding. Hence, simulcast has been favoured over deployment of scalability. Simulcast provides similar functionalities as a scalable bit-stream by transmissitting two or more single layer streams simultaneously (hence the name simulcast). As such, simulcast has reduced complexity compared to scalable coding. However, on the downside, it also causes a significant increase in the total overall bit rate.

Significant improvement on the front of scalable video coding came in recent years. The H.264/SVC standard, contrary to the previous specifications of scalable video codecs, is characterized by good coding efficiency and moderate complexity. Hence it can be seen as a superior alternative to the simulcast. Simulations in [7] show significantly better bandwidth usage when using H.264/SVC in comparison to simulcast. For further details about architecture, system and transport interface for H.264/SVC, the reader is referred to the Special Issue on Scalable Video Coding in IEEE Transactions on Circuits and Systems for Video Technology [8].

The scalable media coding paradigm is also applicable for other media types such as audio. An example is the Embedded Variable Bit Rate (EV-VBR) speech/audio codec G.718 [9], which has a layered design. The bit-stream of this codec consists of a core layer and four enhancement layers. Where the core layer is sufficient for successful decoding of the audio content and each of the enhancement layers provides an improvement to the reconstructed audio quality.

### 2.2. Second Generation DVB Standards

The second generation DVB broadcast standards, namely DVB-T2 and DVB-S2, were designed to replace their first generation counterparts, DVB-T and DVB-S respectively. Although these standards are designed for different transmission scenarios, DVB-T2 for terrestrial transmission and DVB-S2 for satellite transmission, both share the same logical concept of data transmission. In both systems, a physical layer data channel is divided into logical entities called physical layer pipes (PLP), where each one carries one logical data stream. Data within a PLP is organized in the form of baseband (BB) frames. On each BB frame a physical layer FEC is calculated and by appending the repair bits to the end of the BB frame, a FEC frame is created.

The DVB-T2 and DVB-S2 systems use the same physical layer chained FEC codes. First, a length $k_{bch}$ binary message is encoded into an $n_{bch}$ bit systematic BCH codeword. Next, the $k_{ldpc} = n_{bch}$ BCH codeword is encoded into an $n_{ldpc}$ bit systematic LDPC codeword. The codeword length, $n_{ldpc}$, can be either 64,800 or 16,200 bits long, producing a normal or short frame, respectively. DVB-T2 and DVB-S2 fix the length of the FEC frame encoder output. Therefore, the length $k_{bch}$ of the input to the BCH encoder and the length $k_{ldpc}$ of the input to the LDPC encoder are variable and depend on the chosen code rate (Table 1 presents the mapping between the code rate and the resulting code lengths for DVB-T2). The structure of a FEC frame is presented on Figure 1.

**Table 1.** $K_{bch}$ and $K_{ldpc}$ lengths [bits] depends on code rate and frame type specified in DVB-T2

| Code Rate | $n_{ldpc}$=16200 (short frame) | | $n_{ldpc}$=64800 (normal frame) | |
|---|---|---|---|---|
| | $k_{bch}$ | $k_{ldpc}$ | $k_{bch}$ | $k_{ldpc}$ |
| 1/2 | 7032 | 7200 | 32208 | 32400 |
| 3/5 | 9552 | 9720 | 38688 | 38880 |
| 2/3 | 10632 | 10800 | 43040 | 43200 |
| 3/4 | 11712 | 11880 | 48408 | 48600 |
| 4/5 | 12432 | 12600 | 51648 | 51840 |
| 5/6 | 13152 | 13320 | 53840 | 54000 |

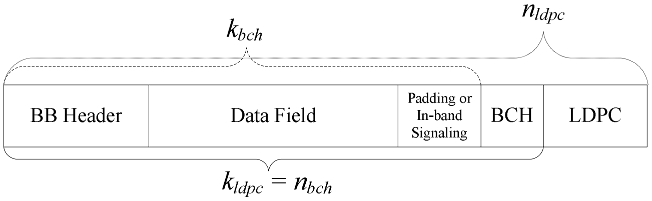

**Fig. 1.** FEC Frame structure in DVB-T2 and DVB-S2 systems

Within a PLP, the data encapsulation in BB frames is not allowed to change freely, but only at super-frame boundaries (circa every 64 seconds). Hence, changing the code rate of FEC frames within a PLP is not possible with a sufficient level of flexibility. Therefore, to overcome this limitation and to allow flexible service component specific robustness at physical layer, authors propose in this publication a novel method to extend physical layer LDPC codes used in second generation DVB systems.

This paper does not handle the rest of the processing components as they are not necessary for the topic of this paper. For further details about the physical layer structure of the DVB-T2 and DVB-S2 standards, the reader is referred to [3] and [4], respectively.

### 2.3. LDPC in DVB-S2 and DVB-T2

In the early 1960's, Gallager introduced a family of codes based on sparse bipartite graphs called Low Density Parity Check codes (LDPC) [6]. Although the codes were good in theory, they were not used in practice due to their high encoding complexity and long block lengths. However, with the advances in computing and hardware technologies as well as the development of low-complexity encoding LDPC codes, they have come back under the attention of researchers and were rediscovered again by MacKay [10] in late 1990's. Soon afterwards, it was shown in [11][12][13] that long irregular LDPC codes can be superior to turbo codes of the same length and can approach the Shannon capacity limit within a fraction of a decibel.

LDPC codes are binary linear block codes, where a $k$ bit message $d$ is encoded into an $n$ bit codeword $c$ according to

$$c = dG \qquad (1)$$

where $G$ is the $k$ by $n$ generator matrix and the matrix operations are performed over GF(2). The parity-check matrix $H$ is an $m = n - k$ by $n$ binary matrix that satisfies

$$GH^T = 0 \qquad (2)$$

A column in $H$ is associated with a bit of the codeword and each row corresponds to a parity check. A one in a row means that the corresponding bit contributes to this parity check.

Based on the characteristics of the parity check matrix, LDPC codes can be divided into regular and irregular codes. An LDPC code is regular when all rows have the same number of ones and all columns have the same number of ones, otherwise the code is irregular.

In this publication, the focus is on a special class of irregular codes called extended irregular repeat accumulated (eIRA) codes [14]. This class of LDPC code is used in the DVB-T2 and DVB-S2 systems.

In eIRA codes, the parity check matrix consists of an $(n\text{-}k)$ by $k$ sparse matrix $H_1$ and an $m$ by $m$ matrix $H_2$ (with m-1 degree 2 columns and a final degree one column) as presented in (4).

$$H = [H_1 H_2] \qquad (3)$$

$$H_2 = \begin{bmatrix} 1 & & & & & \\ 1 & 1 & & & & \\ & 1 & 1 & & & \\ & & & \cdots & & \\ & & & & 1 & 1 \\ & & & & & 1 \quad 1 \end{bmatrix} \qquad (4)$$

The generator matrix is then expressed as

$$G = \left[\, I \; H_1^T \; H_2^{-T} \,\right] \qquad (5)$$

where

$$H_2^{-T} = \begin{bmatrix} 1 & 1 & \ldots & 1 & 1 \\ & 1 & \ldots & 1 & 1 \\ & & \ldots. & \ldots & \ldots \\ & & & 1 & 1 \\ & & & & 1 \end{bmatrix} \qquad (6)$$

and the $H_1^T$ matrix is specified in the second generation DVB standards for each code rate and frame length. Multiplication by $H_2^T$ corresponds to a differential encoding operation so that encoding in eIRA code may be accomplished in two separate steps. Consequently, the LDPC FEC encoding process in DVB-T2 and DVB-S2 may be performed with relatively low complexity. First, the $n_{bch}$ bits long systematic BCH codeword is multiplied by the sparse matrix $H_1^T$ creating intermediate bits. Then the resulting bits are differentially encoded creating $m$ parity bits. The $m$ parity bits are, subsequently, combined with the $n_{bch}$ bits of the systematic BCH codeword which finally creates the $n_{ldpc}$ bits of the systematic LDPC codeword.

## 3. LDPC EXTENSION

While designing the extension, we followed a requirement for backwards compatibility. The extension should provide support for UEP at newer devices and at the same time not interfere with the data reception at legacy terminals. Therefore, the extension shall not change the structure of a FEC frame and it shall not impact the decoding process in legacy terminals.

At the transmitter side the extension is created as follows. First, the size of the Data Field from a BB frame (Fig.1) is shortened, i.e. the number of padding bits $p$ in BB frames is increased. Thus a space for transporting the additional parity bits is created. The number of padding bits $p$ depends on how many extra parity bits need to be transmitted, so as to correspond to the target code rate of the extended LDPC code. Next, extra $m_{ldpc\_ext} = p$ LDPC parity bits are calculated over $k_{ldpc\_ext}$ bits, depicted on Fig. 2. The extension encoding itself takes place just before the original DVB FEC encoding operations. Subsequently, the $m_{ldpc\_ext}$ bits are transmitted as part of the BB frame due to the space freed by padding bits. The whole structure of the FEC frame with extra LDPC parity bits is presented in Figure 2.

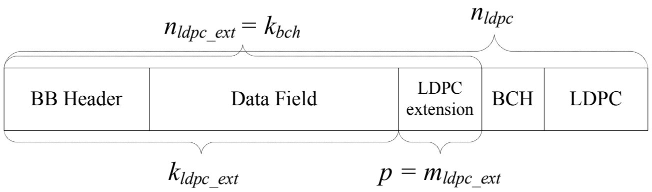

**Fig. 2.  FEC Frame structure with LDPC extension**

In the decoding process both, the original and the extension, parity bits shall be used at the same time. Therefore, a receiver with support for the extension shall be able to create one parity check matrix ($H_{new}$) containing parity check matrix of the original DVB code ($H_{ldpc}$) and parity check matrix of the extension code ($H_{ldpc\_ext}$). The structure of the $H_{new}$ matrix is depicted in Fig. 3. The $Z_{ext}$ is a zero matrix.

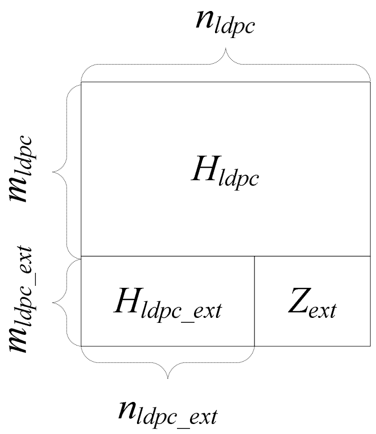

**Fig. 3.** $H_{new}$ matrix structure for method 2

The structure of $H_{ldpc\_ext}$ matrix is open. However, it may have the eIRA code structure, as presented in subsection 2.3, to assure relatively low complexity. The example structure of $H_{ldpc\_ext}$ matrix is presented in Fig. 4 where $H_{1\_ext}$ and $H_{2\_ext}$ matrices are equivalent to matrices $H_1$ and $H_2$ described in subsection 2.3 respectively..

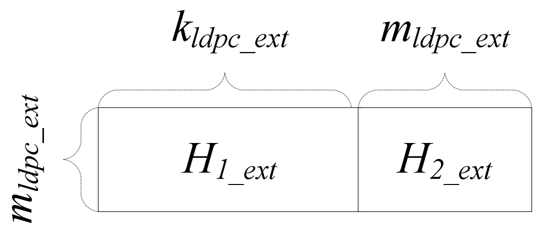

**Fig. 4.** $H_{ldpc\_ext}$ matrix structure for method 2

## 4. SIMULATION AND RESULTS

To study the performance of the LDPC extension proposed in Section 3, a set of simulations was performed. For the purpose of the simulations, a simplified DVB-T2 physical layer model implemented in Matlab was utilized. The physical layer model was limited to BB frame creation, scrambling, FEC code calculation and FEC frame creation, bit interleaving, and modulation. The simplification was done to reduce the run time of the simulations.

The simulations analyzed how the extended LDPC codes cope with transmission errors. The tests were conducted for 16200 bits long FEC frames and 16QAM modulation. An additive white gaussian noise (AWGN) channel model was used. All the error calculations were performed by averaging the individual error rates of data fields of each BB frame.

In the following, the proposed method in section 3 was tested for two use cases. In the first one the original DVB-T2 FEC with code rate 3/4 was extended to achieve a code rate of 1/2, Fig. 8. In the second one the original DVB-T2 FEC with code rate 5/6 was extended to achieve a code rate of 2/3, Fig. 9.

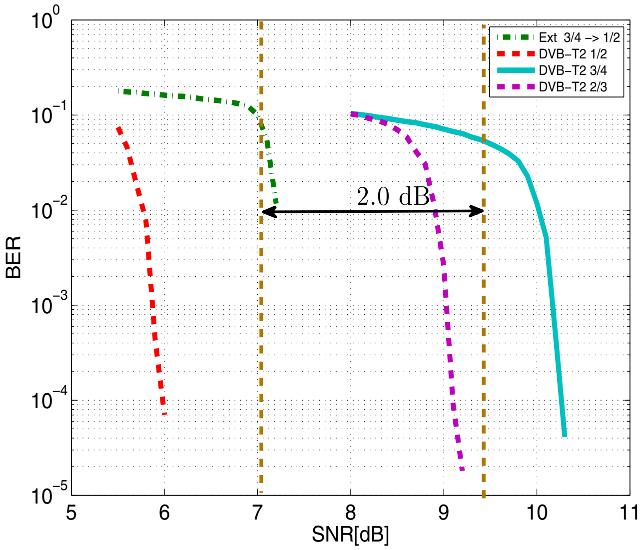

**Fig. 5 Comparison of extended LDPC code performance for code rate 3/4 to 1/2**

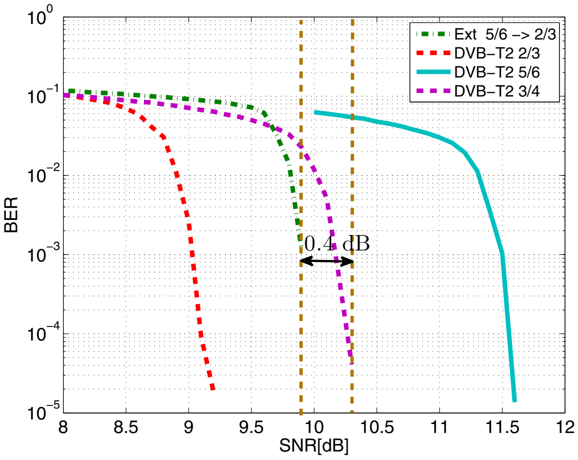

**Fig. 6. Comparison of extended LDPC code performance for code rate 5/6 to 2/3**

Foremost, it can be clearly observed that proposed LDPC extension strengthen the performance of native DVB-T2 FEC. The extended code is weaker compared to the original DVB-T2 codes with the same amount of repair data, mainly due to the non-optimized extension parity check matrix. However, it needs to be stated that the objective of the extensions is to enable the implementation of UEP schemes and not to replace existing DVB-T2 FEC codes.

When UEP is deployed, enhancement layers (EL) are protected by the original DVB-T2 code whereas the base layer (BL) data is protected by the stronger code that is constructed by employing one of the proposed methods. To understand the gain brought by deploying an UEP scheme, an average code rate was calculated to obtain the equivalent Equal Error Protection (EEP) code. For our comparison, an assumption that BL covers 33 percent of the overall bit rate was made (this corresponds to bit-rate requirements in a typical spatial scalability use case). For the first scenario, an average code rate for the equivalent EEP would be 2/3, whereas in the second scenario, an average code rate for the equivalent EEP is 7/9. During the simulations code rate 7/9 was replaced by a slightly stronger code rate 3/4. The comparison to the equivalent EEP ensures fairness as both EEP and UEP codes would use a similar amount of protection data. As a consequence, graceful degradation can be achieved by increasing the reach of the BL stream. A receiver that benefits from the UEP scheme, will be able to ensure continuous video playback for SNRs lower by 2.0 (0.4) dB compared to legacy DVB-T2 terminals.

## 5. CONCLUSION

In this paper, we provided a description and evaluation of a novel method to extend LDPC codes used in the second generation DVB systems. The results showed that by using this method the original DVB codes can be strengthened to achieve higher protection for selected parts of the transported data. The extended codes only approach but have yet to achieve similar performance as the original second generation DVB codes. However, it should be noted that the LDPC parity check matrices that were used for the extension were not optimized. Furthermore, the impacts of UEP are expected to weigh out this protection penalty. Through more optimized extension parity check matrix construction, similar performance as their standardized same code-rate counterparts may be achieved. Finally, we showed that deploying the extension for UEP scheme results in significant gains in terms of graceful degradation for the service may be achieved

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