An SCCC turbo decoder for DVB-T

Costas Chaikalis, Nicholas S. Samaras and Costas Kokkinos

Abstract—**The Digital Video Broadcasting – Terrestrial (DVB-T) standard represents the dominant solution for the implementation of digital television in Europe. DVB-T requires error control protection in order to provide the best Quality of Service at the receiver. The current error protection scheme is Reed Solomon coding combined with convolutional encoding. In this paper we propose a new channel coding scheme for DVB-T standard which uses a turbo encoder-decoder with Serial Concatenated Convolutional Codes (SCCC). Our simulation results show that an SCCC turbo encoder-decoder performs better in AWGN channels, gaining about 2.1 dB compared to the standard DVB-T encoding-decoding scheme. Moreover, our results show that the most advantageous choice for the number of iterations of the proposed channel coding scheme seems to be 8, while the best value for the SCCC encoder random interleaver seed is 12000.**

Index Terms— **AWGN channel, DVB-T, SCCC turbo encoding-decoding**

I. Introduction

DVB-T standard represents the terrestrial transmission version of DVB standards. DVB-T is defined as the functional block of equipment performing the adaptation of baseband TV signals from the output of the MPEG-2 multiplexer to the terrestrial channel characteristics. Source data, consisting of video, audio and data is multiplexed into MPEG-2 transport stream packets. The adapter receives the MPEG-2 transport stream and produces the Radio Frequency (RF) signal to be transmitted over the air. The RF signal has an 8 MHz bandwidth and is centralized between channels 21-69 of the UHF band, identical to analogue TV signal [1, 2]. The following processes are applied to the MPEG-2 data stream:

- Transport multiplex adaptation and randomization for energy dispersal
- Outer coding (i.e., Reed-Solomon code)
- Outer interleaving (i.e., convolutional interleaving)
- Inner coding (i.e., punctured convolutional coding)
- Inner interleaving (either native or in-depth)
- Mapping and modulation
- Orthogonal Frequency Division Multiplexing (OFDM) transmission

Costas Chaikalis (corresponding author) Nicholas S. Samaras and Costas Kokkinos are with the Department of Informatics Technology & Telecommunications, at TEI of Larissa, in Larissa, Greece. Their respective emails are: kchaikalis@teilar.gr, nsamaras@teilar.gr and k_kokkinos@teilar.gr.

The block diagram for a DVB-T transmitter is shown in Figure 1 [1, 2].

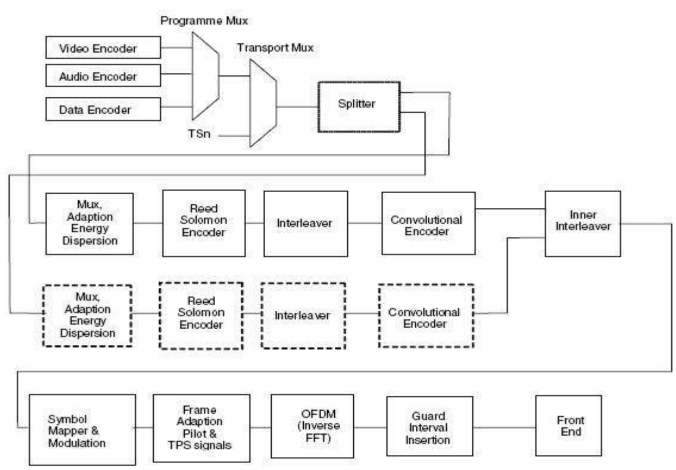

Fig. 1. DVB-T transmitter functional block diagram.

DVB-T provides adequate protection to co-channel interference and interference from neighbouring channels (Adjacent Channel Interference). Therefore a system with error correction is defined and used. Instead of single-carrier transmission, the DVB-T transmitter uses Orthogonal Frequency Division Multiplexing (OFDM) to transmit information bits. Broadcasting with OFDM provides the ability to setup networks with sparse transmitters that broadcast at the same time, through synchronization, exactly the same data at the same frequency and their signal interference does not affect the receiver significantly. Networks of this kind are known as Single Frequency Networks (SFN). DVB-T standard combines OFDM with additional coding and modulation techniques, presenting the Coded OFDM technology (COFDM) using forward error correction (FEC) coding [1, 2].

Two DVB-T modes of operation are defined: a “2K” mode and an “8K” mode. The “2K” mode, shown in Figure 1, is suitable for single transmitter operation and for small SFN networks with limited transmitter distances. “2K” mode is used in our simulations. The "8K mode" can be used both for single transmitter operation and for small and large SFN networks [1, 2].

Generally, there are two types of turbo codes: Parallel Concatenated Convolutional Codes (PCCC) and Serial Concatenated Convolutional Codes (SCCC) [3, 4, 5, 6]. The use of turbo codes in DVB-T standard has been well addressed in published literature: in [7] the concatenation of PCCC turbo codes and Reed-Solomon codes is discussed and the focus is on analyzing the performance of the new concatenated forward error correct scheme applied to an OFDM system. Simulation results compare the proposed system with the standard DVB-T system (which uses convolutional codes) on AWGN channels and the results show that performance is improved significantly by employing only a few numbers of iterations for turbo codes. A turbo decoder is proposed for DVB-T in [8] which iteratively exchanges information between the maximum a posteriori (MAP) soft-input soft-output (SISO) detector and SISO low density parity check (LDPC) channel decoder.

In [9] the simulation of transmission in Digital Video Broadcasting Satellite Services to Handhelds, OFDM mode (DVB-SH-A) standard in Gaussian and mobile fading channels (RA6, TU6) is discussed. Turbo encoder, which is used in DVB-SH (3GPP2), was modified for the simulation. Dependences of BER on SNR after turbo decoding in all tested channel models are compared.

In [10] an irregular mapping technique is proposed, where a new labeling searched via modified adaptive binary switch algorithm, mixed with a pre-fixed labeling, can provide near-optimal match to a given outer channel code. With the use of the proposed technique, the bit-interleaved LDPC coded modulation systems with iterative demapping/decoding can achieve near-capacity performance. With a slight modification on the LDPC coded modulation scheme of DVB-T2 standard, the proposed technique can improve the iterative demapping system by exploiting significant iterative gain.

In [11] three padding and puncturing schemes for DVB-S2 LDPC codes are presented. The aim is to obtain coding rates equivalent to DVB-SH specification (2/3, 1/2, 2/5, 1/3, 2/7, 1/4, 2/9 and 1/5). The performance of punctured DVB-S2 LDPC codes is compared against 3GPP2 turbo codes. Simulation results for BER and FER show that the proposed coding schemes exhibit 0.5 dB to 0.75 dB penalty loss compared to 3GPP2 codes.

In this paper we concentrate on SCCC turbo codes and we examine their performance in DVB-T standard. The paper is organised as follows: section II presents the operation of PCCC and SCCC codes, while section III describes the two simulation models used. Subsequently, section IV presents the simulation results which verify that SCCC turbo codes can be used in DVB-T. Finally, section IV presents some concluding remarks.

II. PCCC and SCCC Turbo Codes

PCCC turbo codes were introduced in [3] and the reason for their excellent error correction performance is iterative decoding. Let's see in more detail the operation of PCCC turbo codes. Using a kind of convolutional codes called recursive systematic convolutional (RSC) codes, a turbo encoding scheme can be constructed using two of them [12]. The two RSC encoders receive the same data, but the second encoder receives the data after being permuted by an inner interleaver.

An example of a PCCC turbo encoder is the UMTS turbo encoder, which can be seen in Figure 2 [12]. It consists of two 8-state RSC encoders with constraint length $K=4$ and the rate of the turbo encoder is $r_c = 1/3$. The output bit sequence of the turbo encoder is given below:

$$\begin{aligned} x_k^{(q)} &= \{x_k^{(0)}, x_k^{(1)}, x_k^{(2)}\} \\ &= x_1^{(0)}, x_1^{(1)}, x_1^{(2)}, x_2^{(0)}, x_2^{(1)}, x_2^{(2)}, \ldots, x_{k_f}^{(0)}, x_{k_f}^{(1)}, x_{k_f}^{(2)} \end{aligned}$$

where $q = 0,1,2$ for $r_c = 1/3$. The bit sequence $m_k = m_1, m_2, \ldots, m_{k_f}$ represents the input bit sequence to the turbo encoder. The systematic output sequence is $x_k^{(0)} = x_1^{(0)}, x_2^{(0)}, \ldots, x_{k_f}^{(0)}$ with $x_k^{(0)} = m_k$. The output sequences from the first and second RSC encoders are $x_k^{(1)} = x_1^{(1)}, x_2^{(1)}, \ldots, x_{k_f}^{(1)}$ and $x_k^{(2)} = x_1^{(2)}, x_2^{(2)}, \ldots, x_{k_f}^{(2)}$, respectively. The output sequence from the inner interleaver is denoted by $m_k{}' = m_1{}', m_2{}', \ldots, m_{k_f}{}'$ and it is input to the second RSC encoder. The term k_f represents the number of input bits or frame size.

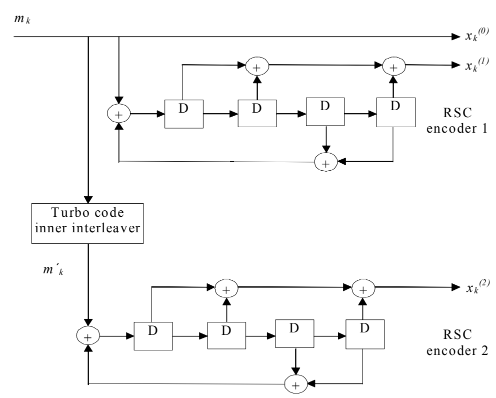

Fig. 2. UMTS PCCC turbo encoder

Figure 3 describes the operation of a PCCC turbo decoder. A decoding algorithm that accepts a-priori (or intrinsic) information at its input and produces a-posteriori information at its output is called a SISO decoding algorithm [12]. Each SISO decoder for a RSC encoder with rate $r_c = 1/2$ has three inputs: the weighted systematic received sequence $r_k^{(0)} = r_1^{(0)}, r_2^{(0)}, \ldots, r_{k_f}^{(0)}$, the parity received sequence $r_k^{(p)} = r_1^{(p)}, r_2^{(p)}, \ldots, r_{k_f}^{(p)}$ and the a-priori information $z_k^{(p)} = z_1^{(p)}, z_2^{(p)}, \ldots, z_{k_f}^{(p)}$ (where $p = 1 \; or \; 2$ for SISO decoder 1 and 2 respectively, while the turbo encoder rate is $r_c = 1/3$), which is derived from the other SISO decoder output. The soft output sequence $\Lambda_k^{(p)} = \Lambda_1^{(p)}, \Lambda_2^{(p)}, \ldots, \Lambda_{k_f}^{(p)}$ of SISO decoder p

for every symbol k is a sequence of real numbers, which is represented in terms of a-posteriori log likelihood ratios [12].

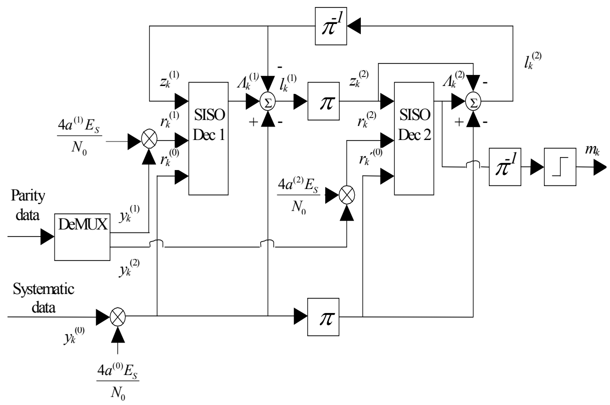

Fig. 3. PCCC turbo decoder

In [5, 6] the authors propose a method to avoid the error floor of PCCC turbo codes, namely SCCC turbo codes. The main difference with PCCC turbo codes is that the parity bits of the outer encoder are transferred to the inner encoder through an interleaver and the transfer of the information bits is optional in SCCC. At Figures 4 and 5 we can see a SCCC turbo encoder and decoder as described in [12].

Fig. 4. SCCC turbo encoder [12]

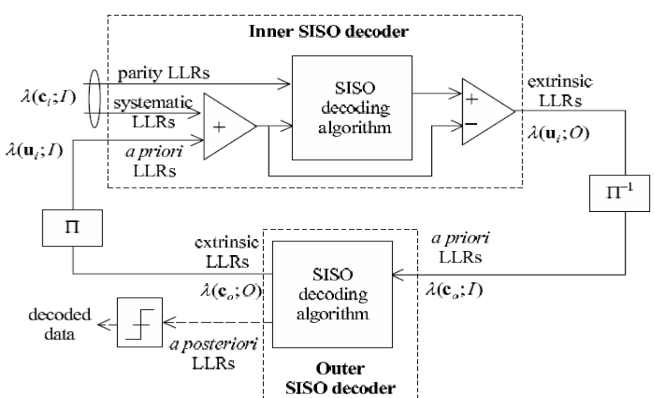

Fig. 5. SCCC turbo decoder [12]

In [12] a tutorial paper on SCCC and PCCC is presented. Particularly, it gives an overview of the implementation aspects related to PCCC and SCCC turbo decoders. Initially, the general structure of iterative decoders is considered, while the main features of the SISO algorithm that forms the heart of iterative decoders are discussed. Subsequently, it is shown that very efficient parallel architectures are available for all types of turbo decoders allowing high speed implementations.

Maximum A Posteriori (MAP) algorithm is used at the decoding of PCCC turbo codes. The same algorithm can be used for the decoding of SCCC turbo codes according to [13, 14]. The BER performance of SCCC codes varies according to constituent codes, interleaver type and size, and concatenation method. In [15] performance comparison of rate compatible PCCC and SCCC turbo codes is discussed in AWGN and frequency selective fading channels.

III. Simulation Models

A. 1st simulation model

Simulink's library contains a model which simulates DVB-T performance with a code rate of ¾. The encoding part of the 1st simulation model consists of two convolutional encoders serially concatenated with rates 1/2 and 2/3 respectively, leading to an overall code rate of 1/3 (see Figure 6) [2].

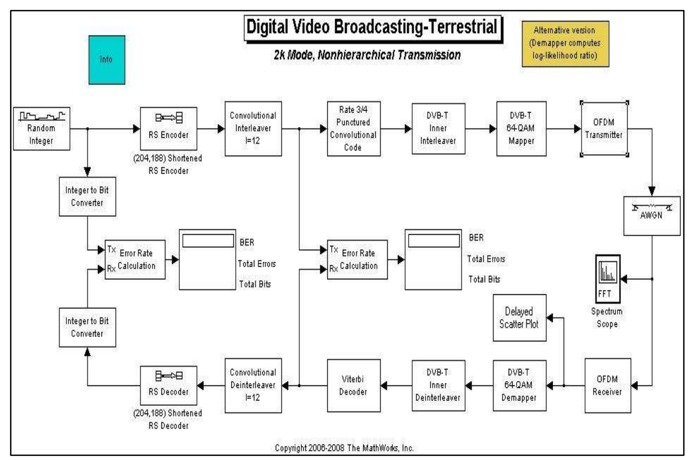

Fig. 6. Simulink 1st simulation model with convolutional and RS encoding-decoding

We are creating a simulation model that uses a rate of ½ in order to compare it with a 2nd simulation model, which is described in the following section. This is done under the following conditions:

- Removing the puncture vector at both encoder and decoder blocks.
- Changing the buffer size at Inner De-interleaving sub-block.
- Changing the model's Ts according to ETSI Standards.
- Altering the delay parameters into Viterbi decoder's block so that data will be aligned to a 1632 frame.

- Altering the Receive delay parameters at Error Calculation Blocks.
- Calculate dynamically the equivalent (for a bipolar constellation scheme) variance value which will be used to the 2nd simulation model.

B. 2nd simulation model

Based on an existing SCCC model at Simulink library named "commsccc" which uses a 1/3 rate SCCC with bipolar constellation, our goal is to construct a simulation model (named 2nd simulation model) which will be compared with the 1st simulation model (Figure 7) [2].

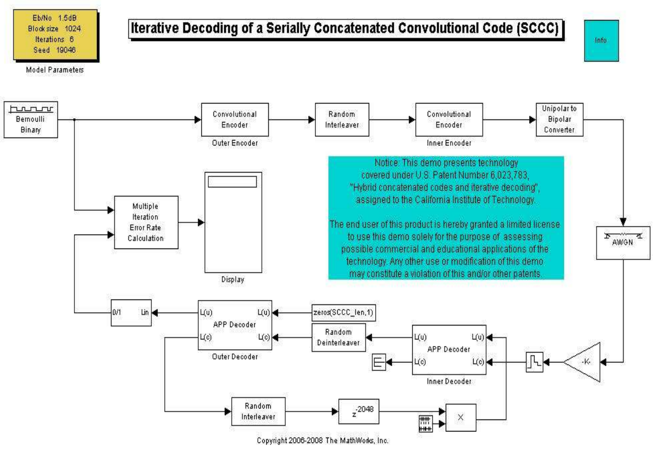

Fig. 7. Simulink SCCC encoding-decoding system

The modifications made to the simulation model of Figure 7 are:

- The "time interval" of the generator of random bits/integers between the 2 models leads to the same "sample time" at the AWGN block (period must be equal to 0.000224 sec for 2K mode).
- The amount of AWGN noise that corrupts the transmitted data is the same between the 2 models.
- The overall coding rate of the encoder/decoder if inspected as a generic subsystem, is equal to ½ which is the same as the 1st simulation model.
- A small enhancement for error calculation is added.

Figure 8 shows the reconstructed SCCC DVB-T model (2nd simulation model) which is used to obtain our simulation results.

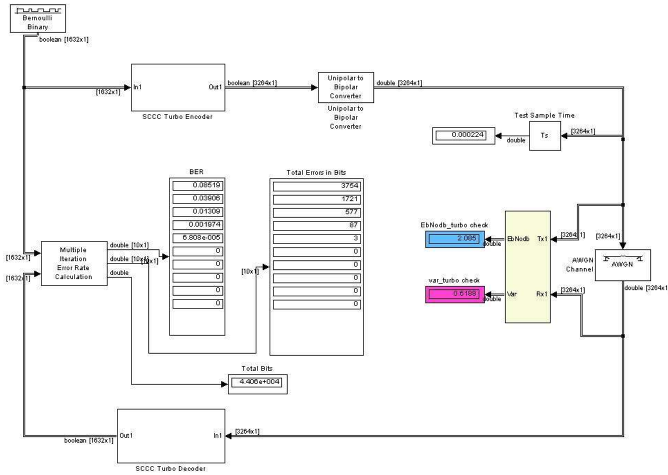

Fig. 8. Simulink 2nd simulation model with SCCC encoding-decoding

Apart from the changes that are essential for the comparison of the two simulation models, some more additions have been made to the 2nd simulation model of Figure 8 which concerns the error calculation part of the simulation model. Thus, the "Multiple Iteration Error Rate Calculation" sub-block is illustrated in Figure 9. This sub-block is now able to calculate the number of erroneous bits as well as the total number of bits compared.

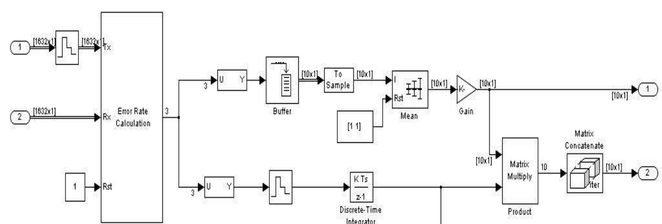

Fig. 9. Multiple iteration error rate calculation block

Furthermore, the SCCC Turbo Encoder and SCCC Turbo Decoder sub-blocks analysis can be observed at Figures 10 and 11, respectively.

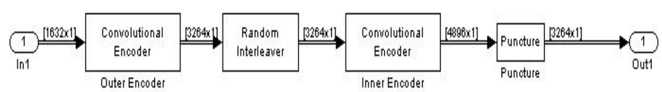

Fig. 10. SCCC encoder block

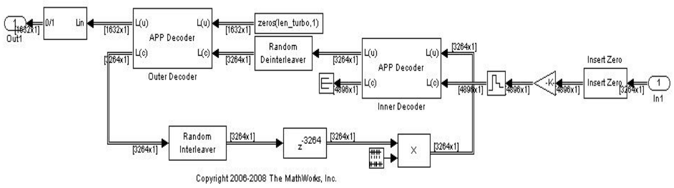

Fig. 11. SCCC decoder block

IV. SIMULATION RESULTS

The two simulation models work with the same sample time, inner code rate and constellation method, producing the same number of bits.

A. *Varying frame length*

Figures 12, 13, 14 and 15 show the simulated performance of the two DVB-T simulation models for different frame lengths. Particularly, the 1st simulation model uses convolutional coding/decoding with rate ½ over AWGN channel, while the 2nd simulation model uses SCCC turbo encoding/decoding with rate of ½. Moreover, the turbo decoder uses max-log-MAP algorithm for different number of iterations and the SCCC encoder random interleaver value is set to 19046.

Figure 12 shows the simulated performance of the 2nd DVB-T simulation model for a frame length of 632 bits and different number of iterations. At Table 1 the performance gain for every new iteration is observed at a BER of 10^{-3}. The maximum coding gain of 1.4 dB is seen for an iteration increase from 2 to 3.

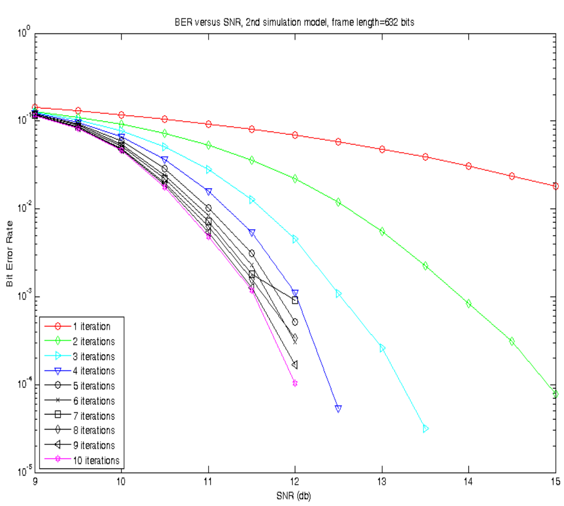

Fig. 12. BER vs SNR (dB) for the 2nd simulation model and a frame length of 632 bits

	Number of iterations							
	3	4	5	6	7	8	9	10
Performance gain	1.4 dB	0.5 dB	0.3 dB	0.25 dB	-	0.4 dB	0.15 dB	0.1 dB

Table 1: Performance gain of the 2nd simulation model for different number of iterations according to Figure 12

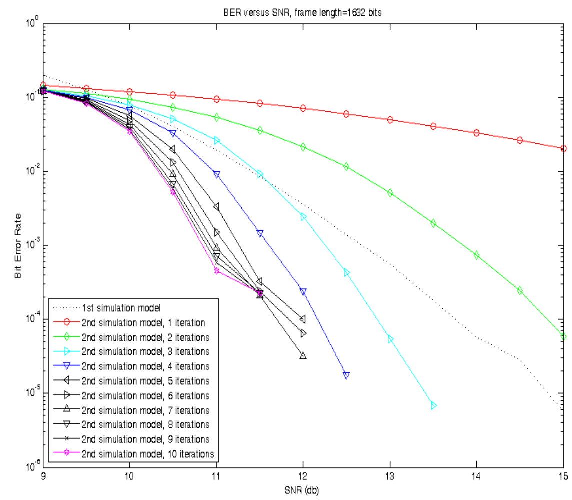

Fig. 13. BER vs SNR (dB) for the 1st simulation model (uses convolutional coding – dashed line) and the 2nd model (uses SCCC turbo coding) and a frame length of 1632 bits

Figure 13 shows the simulated performance of the two DVB-T models for a frame length of 1632 bits and different number of iterations. The comparison for the BER performance between the two simulation models is performed for different values of SNR at Table 2, where we can see the reduction of BER as SNR is increased.

SNR (db)	Convolutional Enc. / Viterbi Decoding	SCCC turbo Encoding/Decoding									
	-	Iter #1	Iter #2	Iter #3	Iter #4	Iter #5	Iter #6	Iter #7	Iter #8	Iter #9	Iter #10
9,0	1,96E-01	1,44E-01	1,30E-01	1,26E-01	1,24E-01	1,23E-01	1,23E-01	1,22E-01	1,22E-01	1,21E-01	1,21E-01
9,5	1,29E-01	1,31E-01	1,12E-01	1,05E-01	9,99E-02	9,60E-02	9,29E-02	9,01E-02	8,75E-02	8,56E-02	8,32E-02
10,0	7,59E-02	1,19E-01	9,33E-02	7,96E-02	6,74E-02	5,70E-02	4,91E-02	4,31E-02	3,91E-02	3,66E-02	3,47E-02
10,5	4,05E-02	1,06E-01	7,32E-02	5,14E-02	3,27E-02	1,98E-02	1,32E-02	9,17E-03	6,85E-03	5,83E-03	5,26E-03
11,0	1,92E-02	9,41E-02	5,40E-02	2,60E-02	9,19E-03	3,33E-03	1,51E-03	9,19E-04	7,10E-04	5,89E-04	4,51E-04
11,5	8,56E-03	8,21E-02	3,60E-02	9,24E-03	1,48E-03	3,21E-04	2,38E-04	2,09E-04	2,28E-04	2,17E-04	2,29E-04
12,0	3,54E-03	7,05E-02	2,15E-02	2,43E-03	2,36E-04	1,02E-04	6,46E-05	3,16E-05	0,00E+00	0,00E+00	0,00E+00
12,5	1,39E-03	5,99E-02	1,15E-02	4,27E-04	1,79E-05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
13,0	5,63E-04	5,01E-02	5,11E-03	5,50E-05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
13,5	1,81E-04	4,10E-02	1,99E-03	6,87E-06	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
14,0	5,77E-05	3,30E-02	7,35E-04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
14,5	2,84E-05	2,60E-02	2,43E-04	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
15,0	5,61E-06	2,01E-02	5,91E-05	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00

Table 2: BER vs SNR for the two simulation models and for different number of iterations for frame length of 1632 bits according to Figure 13

According to the results presented at Figure 13 let's compare the performance gain of the 1st and the 2nd simulation models. More specifically, the performance gain is compared at a BER of 10^{-3} with the number of iterations altered from 2 to

10 and the results are tabulated. At Table 3 we observe that there is a performance gain of 1.2 dB of the 1st over the 2nd model only in the case of 2 iterations. In all other case, namely, 3 to 10 iterations there is a performance gain of the 2nd over the 1st model of 0.4 to 2.1 dB, respectively. Furthermore, we can observe that the 2nd simulation model using the same variants increases significantly the number of bits corrected after the 3rd iteration.

The simulation results presented at Figure 13 clearly show why the proposed SCCC channel coding scheme is superior to the existing channel coding scheme used in DVB-T standard.

	Number of iterations for the 2nd simulation model								
	2	3	4	5	6	7	8	9	10
Performance gain/loss of the 2nd simulation model compared with the 1st	Loss 1.2 dB	Gain 0.4 dB	Gain 1 dB	Gain 1.4 dB	Gain 1.6 dB	Gain 1.8 dB	Gain 1.9 dB	Gain 2 dB	Gain 2.1 dB

Table 3: Performance gain/loss of the 2nd simulation model compared with the 1st for different number of iterations according to Figure 13

Figure 14 shows the simulated performance of the 2nd simulation model for a frame length of 2632 bits and different number of iterations. At Table 4 the performance gain for every new iteration is observed at a BER of 10^{-3}. The maximum coding gain of 1.5 dB is seen for an iteration increase from 2 to 3.

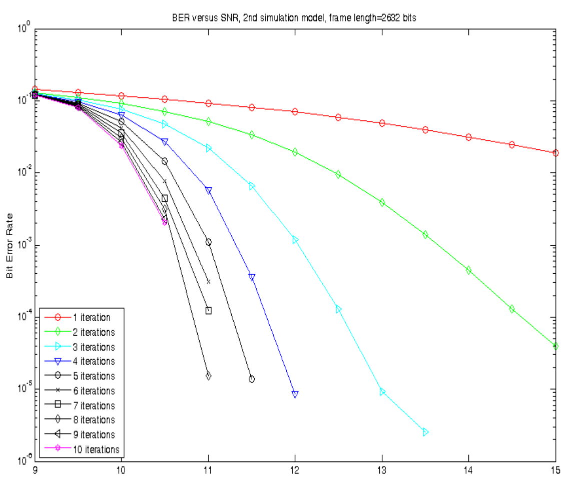

Fig. 14. BER vs SNR (dB) for the 2nd simulation model and a frame length of 2632 bits

	Number of iterations							
	3	4	5	6	7	8	9	10
Performance gain	1.5 dB	0.7 dB	0.3 dB	0.25 dB	0.2 dB	1.15dB	-	-

Table 4: Performance gain of the 2nd simulation for different number of iterations according to Figure 14

Figure 15 shows the simulated performance of the proposed simulation model for a frame length of 5000 bits and different number of iterations. At Table 5 the performance gain/loss is compared at a BER of 10^{-3} with the number of iterations. It is observed that the maximum coding gain can be up to 1.85 dB.

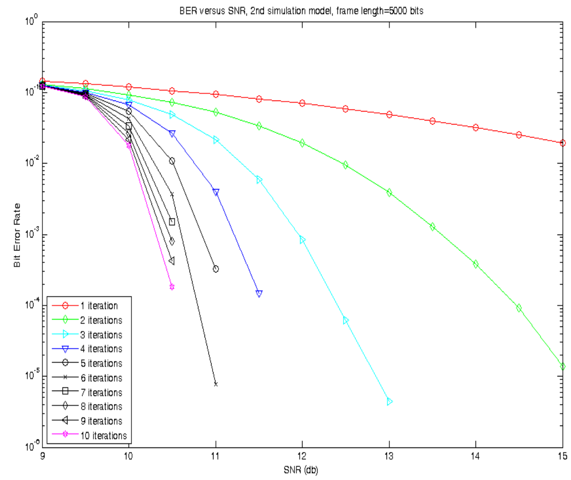

Fig. 15. BER vs SNR (dB) for the 2nd simulation model and a frame length of 5000 bits

	Number of iterations							
	3	4	5	6	7	8	9	10
Performance gain	1.7 dB	0.75 dB	0.35 dB	0.25 dB	0.1 dB	0.1 dB	0.1 dB	0.1 dB

Table 5: Performance gain of the 2nd simulation model for different number of iterations according to Figure 15

If we compare all 4 figures in terms of number of iterations for the 2nd simulation model and the SCCC turbo decoder we observe that, similarly to PCCC turbo codes, 8 iterations represent the optimum number since there is no significant performance improvement for a higher number of iterations.

B. Varying the SCCC encoder random interleaver seed value for the 2nd simulation model

For Figures 16, 17 and 18 the frame length is 1632 bits and we alter a parameter of the SCCC encoder random interleaver, namely seed value for the 2nd simulation model. Three different values are considered: 5000, 12000 and 40000. For an interleaver seed value of 5000 the BER performance is shown at Figure 16. We observe that at a BER of 10^{-3} and for 10 turbo decoder iterations, the SNR value is 10.9 dB.

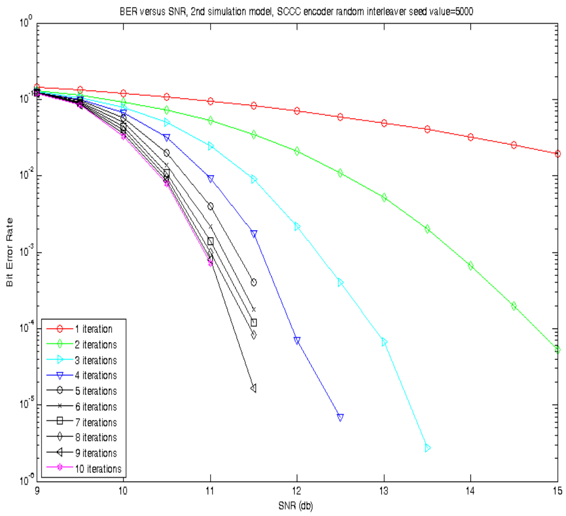

Fig. 16. BER vs SNR (dB) for the 2nd model and a SCCC encoder random interleaver seed value of 5000

For an interleaver seed value of 12000 the BER performance is shown at Figure 17. We observe that at a BER of 10^{-3} and for 10 turbo decoder iterations, the SNR value is 10.75 dB.

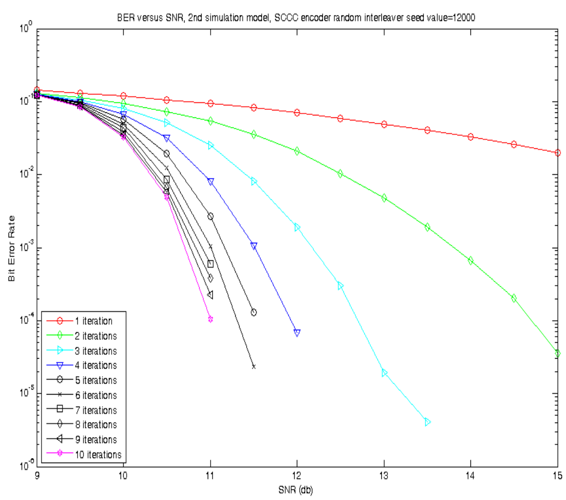

Fig. 17. BER vs SNR (dB) for the 2nd model and a SCCC encoder random interleaver seed value of 12000

For an interleaver seed value of 40000 the BER performance is shown at Figure 18. We observe that at a BER of 10^{-3} and for 10 turbo decoder iterations, the SNR value is 10.7 dB.

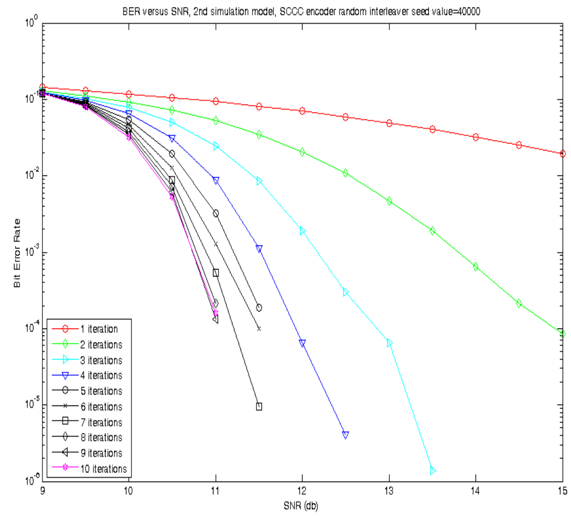

Fig. 18. BER vs SNR (dB) for the 2nd model and a SCCC encoder random interleaver seed value of 40000

Comparing the observations from the 3 figures we conclude that a SCCC turbo encoder random interleaver seed value of 12000 is reasonable to be used in a SCCC turbo encoder-decoder for DVB-T.

V. CONCLUSION

Digital television is a reality nowadays and DVB-T represents the most popular standard to be used in digital television. In terms of channel coding DVB-T uses convolutional coding combined with RS coding. SCCC turbo codes represent serial concatenation of convolutional codes with an interleaver.

In this paper the use of SCCC turbo codes in DVB-T standard is investigated. Particularly, two different simulation models for DVB-T standard are studied and compared, the first one corresponds to the original transmitter-receiver specified for DVB-T, while the second one represents the proposed model and uses SCCC turbo encoding-decoding. Our simulation results show that the SCCC turbo encoding and decoding DVB-T model performs better in AWGN channels, gaining up to 2.1 dB compared to the standard DVB-T encoding-decoding model.

Our analysis also shows that for the proposed SCCC turbo encoding-decoding scheme 8 iterations represent the most advantageous value in terms of BER performance, similarly to the published literature for PCCC turbo codes. Furthermore, for the proposed SCCC turbo encoder a seed value of 12000 is reasonable for the random interleaver in terms of BER performance.

Although the implementation of SCCC turbo coding in a DVB-T system is practically more complex compared to the standard DVB-T channel coding scheme, it results at lower BER at a given SNR (better BER performance) and thus it must be preferred especially when broadcasting at noisy environments.

Future work could focus on the trade off between BER performance and complexity and the channel coding schemes analysed in this paper. A reconfigurable channel encoding-decoding architecture for DVB-T could be studied together with specific implementation scenarios. These scenarios would focus either on performance or on complexity and the study could be done similarly to the ideas presented in [16].

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