Turbo Coded OFDM system for Video Terrestrial Broadcasting

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Abstract

In this paper we analyze the performances of a concatenated FEC scheme based on Turbo Coded and Reed-Solomon OFDM system for terrestrial broadcasting. The performances is evaluated in terms of bit error rate probability for different constituent codes block length and number of iterations. The results are compared to the DVB-T convolutional codes performances on AWGN channels. From simulation results it is demonstrated that, for a packet based system employing turbo codes with few number of iterations the system performances could improve significantly exploiting the interleaver technique in concatenated FEC systems. In conclusion using turbo codes for concatenated FEC schemes result a good solution between computing power and system complexity to archive good performances.

1 Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is a modulation technique well suited to overcome adverse effects in hostile transmission environment. This technique provides a reliable reception of signals affected by multipath propagation and selective fading, and has been adopted for digital broadcasting in DVB and in many others applications such DAB, ADSL or WirelessLAN (IEEE 802.11).

The robustness of the system resides in splitting the information to be transmitted over a large number of carriers, in such a way that the signaling rate of each of them become significantly lower than the assumed channel coherence bandwidth. Moreover to reduce the intersymbol interference a guard interval is inserted between successive symbols to cope with multipath propagation.

Despite the bandwidth reduction due to the guard interval insertion the capability of this technique rely on the combination of strong echoes at the receiver. In some cases deep fading cause a destructive combination in some carriers and enhance some others and this increase the average signal-to-noise ratio. This characteristic, combined with a strong channel coding scheme and an interleaving demonstrate very good performances.

The classical coding scheme applied for this modulation technique is based on a concatenated scheme where two coding levels are applied. The inner coder usually is adapted to the channel and the modulation and pre-process the data detecting the errors, reducing the error ratio to an acceptable value and grouping the errata packets. The second coding layer, also called outer coder, profits from the capability of the preceding code to further decrease the error rate. The performances of such coding schemes are then increased by using time and frequency interleaving techniques. Coding and interleaving applied to OFDM constitutes a very effective tool to average selective fading errors over the signal bandwidth and the time interleaved frame.

In this work a new Forward Error Correction (FEC) scheme based on Turbo codes is proposed to enhance the DVB-T performances for video broadcasting. The proposed scheme uses the same modulation parameters of DVB-T standard but achieves higher performances in terms of improved robustness against frequency and time selective fading.

The system performances are evaluated and compared using the reference AWGN DVB-T reference performances described in the *ETSI EN 300 744 v1.4.1* Annex-A [1].

The paper is organized as follow: in Section 2 the employed Turbo codes are described. In Section 3 an overview of the DVB-T modulation scheme is given. The proposed system is described in Section 4. The numerical results are presented in Section 5 and conclusions follow in Section 6.

2 Turbo Codes

In the recent past convolutional codes are widespread used in many digital communications systems because of the possibility to be decoded in real-time and high reliability in low SNR environment thanks to the Viterbi Algorithm. Moreover, the soft input implementation of this algorithm, has proved excellent capabilities in hostile transmission environment. Two class of convolutional codes has interest for implementations the: Non Systematic Convolutional (NSC) and the Recursive Systematic Convolutional (RSC). The RSC type is shown in Fig.1 with code rate $R = 1/2$, $(23, 35)$ polynomials and code memory $v = 4$. Turbo Codes, introduced by Berrou *et al* [2], are error correction schemes based on the parallel concatenation of two RSC encoders and using a feedback decoder. The main reason for the RSC choice is related with the systematic nature of these codes necessary to the parallel concatenation. The standard rate $R = 1/3$ turbo encoder is mainly composed of two RSC encoder separated by an interleaver as shown in Fig. 2

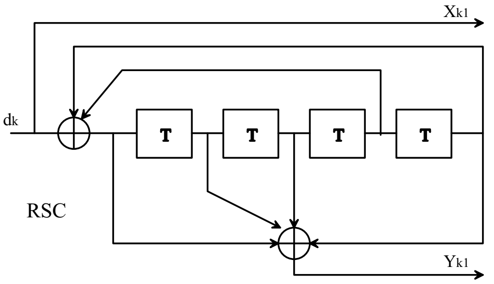

Figure 1: RSC Encoder block

The input stream X_k is feed to the first RSC to produce the first parity bit and then interleaved to produce the second parity bit. The interleaver design is one of the most critical parts because it provide randomness to the input sequence to affects the free distance d_f of the code and involve the block based code processing. Some interleaver techniques as been proposed for turbo codes: Random interleaver, Semi-Random interleaver [3], Golden interleaver [4] and Hokfelt interleaver [5].

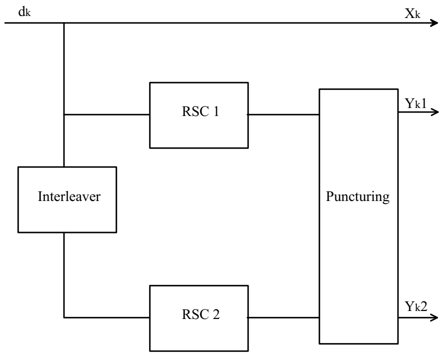

Figure 2: Rate $R = 1/3$ Turbo Encoder

The turbo-decoder is composed of two Soft-Input-Soft-Output (SISO) decoder, one for each stream produced by the singular RSC block, which process the systematic part of the code X_k, the redundancy bit associated Y_{1k} (or Y_{2k}) and the extrinsic information shared from the other encoder Z_k. Depending on the decoder implementation the process could be parallel or serial but in any cases this structure allows to iterate the decoding process (that why this coding is also called *"turbo"*). In Fig. 3 we can see the serial implementation. The optimum performances SISO algorithm with minimum symbol error probability is represented by the *Maximum A Posteriori* (MAP)[6]. Because of the complexity of the MAP algorithm, the implementation of MAP is always proposed in logarithmic domain, where the MAP becomes Log-MAP. Further simplification to Log-Map have been proposed such as a look-up table approximation and the Max-Log-MAP [7]. The other soft-output algorithm, the Soft-Output-Viterbi-Algorithm (SOVA), produce the maximum likelihood (ML) sequence estimator and can be considered a suboptimal implementations. For practical use the complexity of MAP algorithm becomes overwhelming so the simplified suboptimal algorithms are usually implemented, with minimal performance degradation.

For a systematic code the decoding process soft output $L(\hat{d_k})$ at time k can be written as:

$$L(\hat{d_k}) = L_c(X_k) + L(d_k) + L_e(\hat{d_k}) \qquad (1)$$

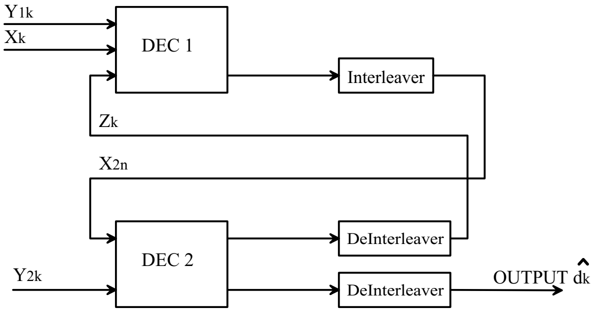

Figure 3: Serial Turbo Decoder

where $L(d_k)$ is a-priori *log-likelihood-ratio* (LLR) metric, the $L_c(X_k)$ is the channel measurement and $L_e(\hat{d})$ is called the extrinsic information gained from the decoding process and does not depend on the decoder input X_k. $L_c(X_k)$ and $L_e(\hat{d})$ and thus $L_e(\hat{d})$ can be used than as a new observation of d_k by another decoder for an iterative process.

3 DVB-T FEC

The DVB-T modulation scheme also called COFDM (Coded-OFDM) was developed to broadcast digital terrestrial TV over the existing analog TV channels with transmission error ratios between 10^{-9} and 10^{-12}. The DVB-T FEC system (see Fig.4) has been developed to work with fixed length MPEG2-TS (Transport Stream) packets. After a proper randomization to ensure the adequate binary transitions, the 188 bytes packets are Reed-Solomon coded. This outer coder adds 16 bytes and has a maximum correction capability of 8 random bytes. After this, the outer interleaving also called *Forney convolution interleaving* is performed to scatter the errors and so to make the outer coding more effective by spreading the data bytes over 12 packets.

The inner coder is a 1/2 rate convolutional code ($G_1 = 171_{oct}; G_2 = 133_{oct}$) and perform different puncturing patterns to obtain different coding robustness ($R = 1/2; 2/3; 3/4; 5/6; 7/8$) The inner interleaver consist in a bit-wise interleaving followed by a symbol interleaving. Both the bit-wise interleaver and the symbol interleaver processes are block-based and the block length depends on the OFDM mode (2K/8K carriers modes). The bit-wise interleaver , depending on the carrier modulation mode ($QPSK, 16QAM, 64QAM$) distribute the stream over different carriers to avoid selective fading to corrupt consecutive message bits. The symbol interleaver then generate a permutation between symbols to spread in frequency the symbols over a OFDM frame [1].

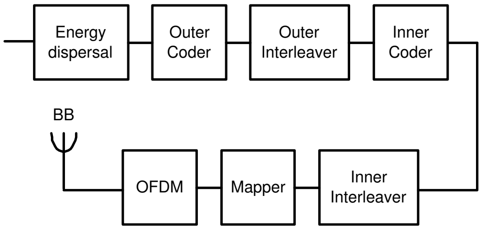

Figure 4: DVB-T FEC Block Diagram.

4 System description

The schematic of the Turbo COFDM system is shown in Fig.5. The incoming TS packets are grouped; each block of packets form an OFDM frame that starts with a synchronization symbol followed by a reference symbol. The former is used to retrieve the frame starting time and to evaluate the frequency offset and the latter is inserted to estimate the channel frequency response.

The TS packets after the energy dispersal are Reed Solomon encoded and interleaved with the same DVB-T scheme.

The turbo encoder use different generator polynomials (7,5)(15,17)(37,21)(117,121) and code rates R (1/3;2/5;1/2;2/3;3/4). The Dithered Golden interleaving technique [4] is implemented on 1632 bit blocks corresponding to a single TS packet.

The OFDM modulation (QPSK and 16QAM) is done over 2k carriers with programmable guard interval length.

The soft demapper compute the bit likelihood of the received modulated symbol $b_{k,i}$ with the simplified method proposed by F.Tosato *et al.* [8]:

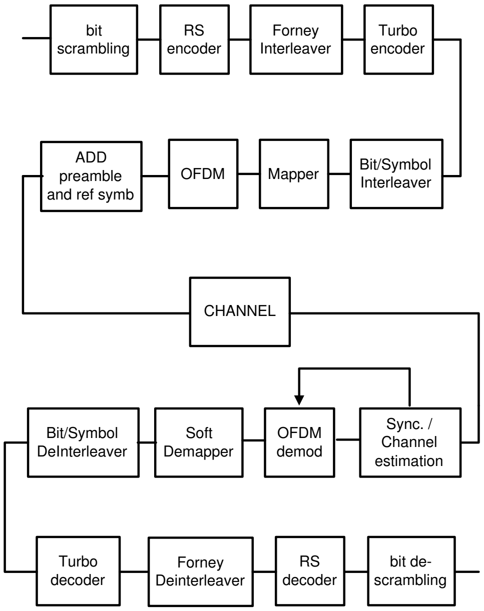

Figure 5: Turbo COFDM Block Diagram.

$$LLR(b_{k,i}) =$$

$$\frac{|G_{ch}(i)|^2}{4}\left\{\min_{\alpha I \in S_{I,k}^{0}} (y[i]-\alpha I)^2 - \min_{\alpha I \in S_{I,k}^{1}} (y[i]-\alpha I)^2\right\} \tag{2}$$

$$\equiv |G_{ch}(i)|^2 D_{I,k}\,, \tag{3}$$

where $G_{ch}(i)$ is the channel response, $(S_{I,k}^{0}, S_{I,k}^{1})$ are the subset partitions based on the Gray mapping containing the real part of the complex symbol and the $D_{I,k}$ is calculated as follows:

QAM

$$D_{I,1} = -|y_I[i]|$$

$16QAM$

$$D_{I,1} = \begin{cases} y_I[i] & |y_I[i]| < 2 \\ 2(y_I[i]-1) & y_I[i] > 2 \\ 2(y_I[i]+1) & y_I[i] < 2 \end{cases}$$

$$D_{I,2} = -|y_I[i]| + 2$$

It can be easily verified that $D_{Q,k}$ functions for the two quadrature bits are calculated with the same formulas with $y_Q[i]$ instead of $y_I[i]$.

The implemented iterative turbo decoder uses the Soft Output Viterbi Algorithm (SOVA) constituent decoder.

5 Simulation Results

The Turbo COFDM system performance is evaluated by several numerical simulations in different encoding configurations over AWGN channel. All the simulations have been done with 100 frames containing 20 packets each. It's assumed that the channel information is available at the receiver and the synchronization mechanism is considered perfect.

The impact of the Turbo coding parameters in terms of coding polynomials, number of decoding iterations, code rate and modulation scheme is investigated. The main goal is to evaluate the performances of Turbo Codes as inner coder for concatenated schemes. In the DVB-T scheme the inner coder reduces the error rate to an acceptable value (2 x10^{-4}) in order to archieve a *Quasi Error Free* (QEF) channel (BER=10^{-11}) at the output of the Reed-Solomon decoder. The role of the outer interleaver is to guarantee the correct error spreading of the grouped corrupted data coming from the convolutional encoder. The typical error distance distribution at Turbo decoder output inside each data block at BER=2 x10^{-4} is shown in Fig. 6

The corresponding cumulative distribution function (Fig.7) of the error distance probability $p_d(y)$ is calculated as:

$$P(\text{error distance} < d) = \int_0^d p_d(y)dy \tag{4}$$

and shows that most of the errors are grouped in small burst. The Turbo decoder behavior can be considered similar to the convolutional Viterbi decoder, thus the threshold of BER=2x10^{-4} can be considered a reference value to get the QEF transmission link.

In Fig. 8 the BER performances after turbo decoder for different polynomials with 3 iterations, QPSK modulation and R=1/3 are shown.

The impact of the polynomials for RSC encoders to get high coding gains is very effective especially

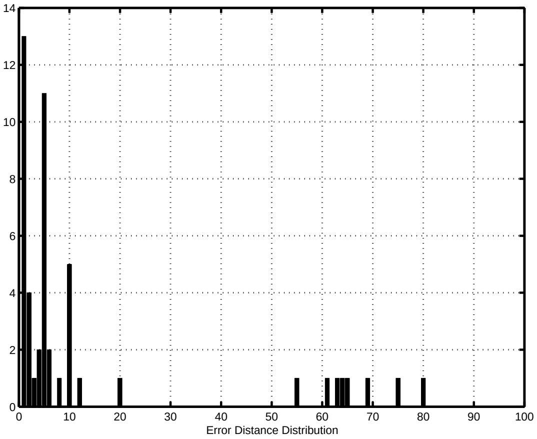

Figure 6: Error distances distribution at Turbo decoder output (limited to interval 1-100) polynomials (37,21), 5 iterations

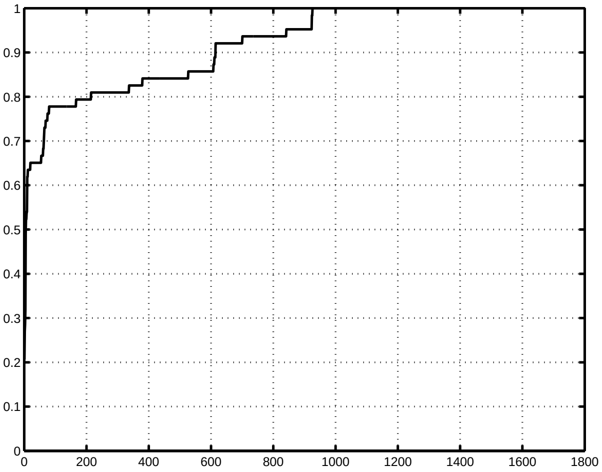

Figure 7: Cumulative Distribution Function

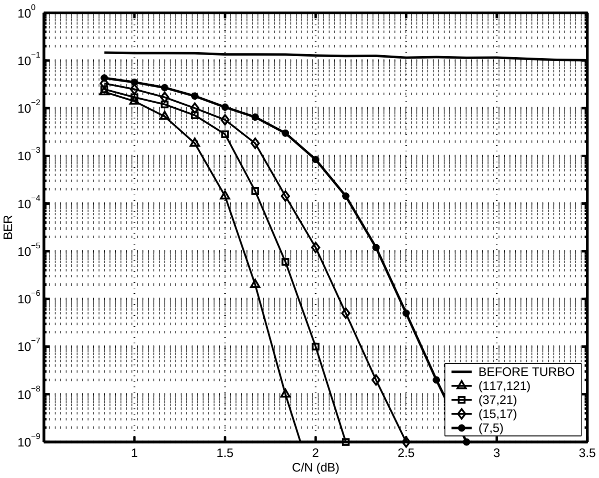

Figure 8: Performance (after Turbo Decoder) in AWGN channel, QPSK, R=1/3 and 3 iterations

with low SNR. The best result is obtained with the (117,121) code with minimum SNR to get QEF link of 1.5 dB.

In Fig. 9 the impact of the modulation scheme on the BER performances after turbo decoder is shown for (37,21) polynomial, 3 iterations and R=1/3. From this simulation we can easily notice that the loss of performances due to the multilevel modulation is around 4 dB.

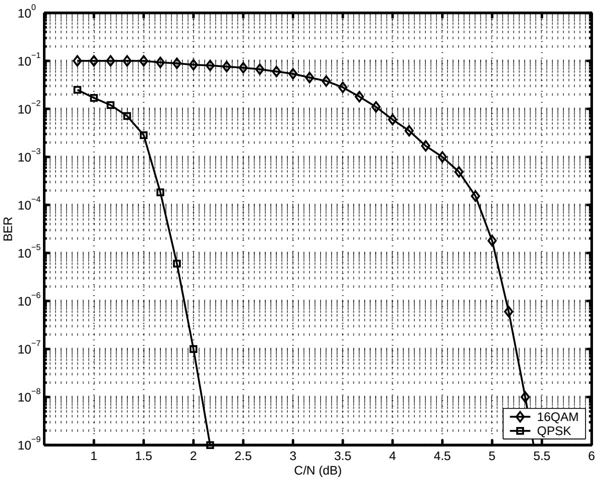

Figure 9: Performance (after Turbo Decoder) in AWGN channel, $(37,21)$, R=1/3 and 3 iterations

Fig. 10 shows the BER gain for increasing number of iterations with R=1/3 and $(37, 25)$ polynomial. The gain from 1 to 3 iterations is 1.5 dB and is only 0.3 dB if we increase the number of iterations to 5.

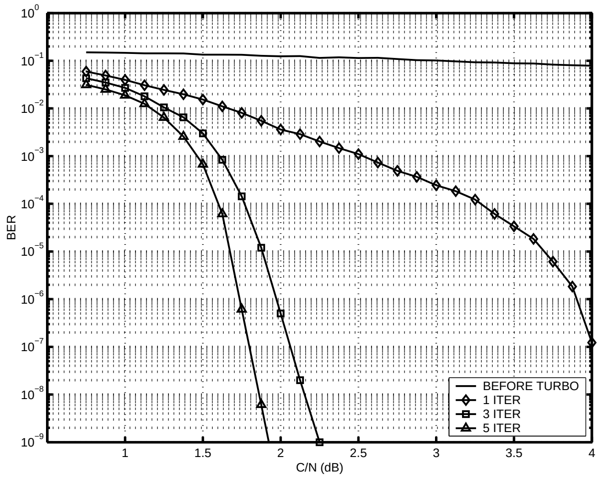

Figure 10: Performance (after Turbo Decoder) in AWGN channel, QPSK, $(37, 25)$ and R=1/3

6 Conclusions

In this paper a new concatenated FEC scheme based on Turbo Codes and Reed Solomon for OFDM system is presented. This scheme achieve the QEF performances with a SNR figure significantly lower than DVB-T ones. These performances are correlated with the number of iterations and the coding parameters. Using long memory codes increase significantly the performances but also drastically increase the decoder complexity. Increasing the number of iterations improves the BER at the Turbo Decoder output but increases the system latency and the computing power.

From these characteristics we can then conclude that turbo codes are suitable for concatenated schemes because they allow a good compromise between computing power and system complexity keeping good performances.

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