

# Analysis of ICI compensation for DVB-T2

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**Abstract**—This paper analyzes the impact of inter-carrier interference (ICI) compensation on the physical layer of DVB-T2, the new digital terrestrial television standard. We compare the performance of a well-known low complexity soft demapper for different time-interleaving depths and code rates in several realistic mobile scenarios. This paper further presents an iterative receiver design that exchanges extrinsic information between the low-density parity-check (LDPC) decoder and the ICI canceller in order to improve performance. Provided simulation results show that the proposed ICI cancellation algorithms can be necessary in several DVB-T2 transmission modes when the length of the time interleaver is limited.

## I. INTRODUCTION

Based on recent research results and a set of commercial requirements, DVB consortium has recently developed a new digital terrestrial television standard named DVB-T2. This new specification has noteworthy increased the robustness and the spectral efficiency of its predecessor (DVB-T), and although it has been designed for fixed receptors, it must allow for some mobility with the same spectrum characteristics as DVB-T. However, no research work has been published showing the performance of DVB-T2 in realistic mobile scenarios. The main remarkable novelty of the new standard lies on the error correction scheme, since DVB-T2 uses the same LDPC channel codes as DVB-S2. The proposed LDPC-based forward error correction technique offers very good performance compared to convolutional codes implemented in DVB-T, resulting in a very robust signal reception.

Regarding the modulation, the second generation digital terrestrial television standard uses the same orthogonal frequency division multiplexing (OFDM) system. As well as 2K and 8K modes, the new standard has introduced longer modes (16K and 32K) with the aim of increasing the length of the guard interval without decreasing the spectral efficiency. On the other hand, three cascaded forms of interleaving have been included: bit, time and frequency interleavers. Therefore, DVB-T2 is a complex bit-interleaved coded modulation (BICM) OFDM communication system.

DVB-T2 has been designed to offer a capacity gain of about 30%. In this way, the highest constellation size has been increased to 256 symbols (256QAM) and more efficient pilot patterns have been included. Furthermore, DVB-T2 incorporates a set of novel signal processing stages which come to offer additional robustness and diversity in challenging terrestrial broadcasting scenarios or to reduce the peak to

average power ratio (PAPR), one of the main drawbacks of OFDM systems.

It is well known that one of the major technical challenge in an OFDM based mobile communication system is its susceptibility to the Doppler frequency shift. A time-varying channel destroys orthogonality among subcarriers giving rise to inter-carrier interference (ICI) which makes more difficult the signal reception. Nonetheless, “8K” mode (8192 subcarriers) or higher are supposed to give support to mobile reception in DVB-T2, both due to the deployment of single-frequency networks (SFN) and spectrum efficiency requirements. Therefore, the effect of ICI can be very severe comparing with other OFDM communication systems.

This paper provides simulation results for DVB-T2 mobile reception in realistic scenarios and proposes two ICI suppressing algorithms in order to analyze their impact on DVB-T2: a well-known maximum a-posteriori (MAP) ICI compensating scheme [1], and an iterative version of it. ICI cancellation in relation to first generation DVB-T systems has been considered by others [2],[3],[4], but for our best knowledge this is the first time that an ICI compensation technique is applied and analyzed in the second generation terrestrial DVB specification.

The rest of the paper is organized as follows: In Section II we briefly introduce the system model. Whole Section III shows the ICI compensation algorithms implemented in this work. Section IV deals with simulation results and finally, conclusions are drawn in Section V.

## II. SYSTEM MODEL

We consider a single-input single-output DVB-T2 system, assuming perfect synchronization and channel estimation. After the inverse Fourier transform (IFFT), the transmitted signal at the symbol time  $n$  is given as

$$x(n) = \frac{1}{N} \sum_{k=0}^{N-1} X_k e^{j2\pi kn/N} \quad (1)$$

where  $X_k$  represents the data symbol transmitted at the  $k$ th subcarrier. The received discrete time-domain signal  $r(n)$  is given by

$$r(n) = \sum_{l=0}^{L-1} h(n, l) x(n-l) + z(n), \quad (2)$$

where  $x(n)$  is the transmitted signal waveform,  $h(n, l)$  is the  $l$ -th tap of the channel impulse response at time instant  $n$ , and  $z(n)$  is additive white Gaussian noise (AWGN) with complex variance  $N_0/2$ . It is assumed that there is no inter-symbol interference (ISI) between OFDM blocks, i.e., the entire channel impulse response (CIR) lies inside the guard interval. Taking the fast Fourier transform (FFT) of (2), the received signal can be expressed in frequency domain:

$$\begin{aligned} R_k &= \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} r_n e^{-j2\pi nk/N} \\ &= \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} \sum_{l=0}^{L-1} h(n, l) x(n-l) + \sum_{n=0}^{N-1} z(n) e^{-j2\pi nk/N}. \end{aligned} \quad (3)$$

Furthermore, the system can be represented in frequency domain using matrix notation as

$$R = \mathbf{H}X + Z, \quad (4)$$

where  $g(k) = H_{kk}$  is the gain for the desired symbol and  $Z_k$  is the noise at the  $k$ th subcarrier. The  $N \times N$   $\mathbf{H}$  matrix represents the frequency response of the ICI channel, where  $N$  is the number of subcarriers. It has been proved that most of the ICI energy is concentrated closed to the diagonal of this matrix, as it is shown in Fig. 1. Thus, the ICI channel memory length  $q$  is much smaller than  $N$ . In fact, for many applications, one neighboring subcarrier is only considered when suppressing ICI.

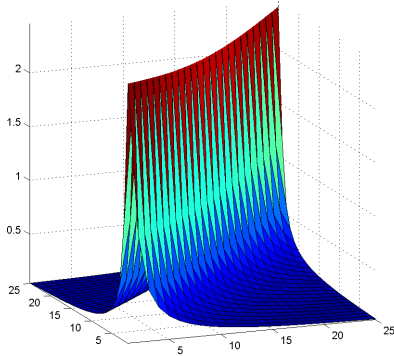


Fig. 1. First  $25 \times 25$  values of the  $\mathbf{H}$  matrix.

In our work, Jake's spectrum for each of the  $L$  channel taps is considered for Doppler frequency modelling [5]. In this case the well-known formula for the ICI power caused by Doppler is obtained by [6]

$$P_{ICI} = \frac{\pi^2}{6} f_d^2, \quad (5)$$

where  $f_d = f_D/\Delta f$  is the normalized Doppler frequency, i.e., the actual Doppler  $f_D$  divided by the sub-carrier spacing  $\Delta f$ .

### III. ICI COMPENSATION ALGORITHMS

Many ICI compensation algorithms have been presented during the last years: minimum mean square error detection (MMSE) based on successive interference cancellation (SIC) [7], low complexity zero-forcing equalization [8], low complexity block turbo equalization [9], iterative MAP detection [10], etc. We have chosen the MAP detection for ICI suppressing with the aim of modifying as little as possible the receive chain of DVB-T2. The solution proposed by [1] is one of the least complex MAP detector suggested in the literature and one of the most powerful. Fig. 2 and Fig. 4 show the soft demapper and the proposed iterative detector respectively.

#### A. Maximum-a-Posteriori detection with ICI cancellation

The ICI suppressing MAP detector [1] is composed of two stages. The first one estimates the transmitted data  $\tilde{X}_n$  using a Viterbi-like algorithm and a trellis representation of the ICI.

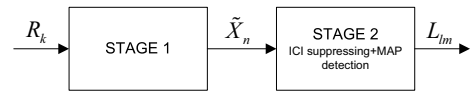


Fig. 2. Structure of the ICI suppressing soft demapper.

Based on the keen observation that only few carriers contribute significantly to ICI, we can simplify the demapping process reducing the search dimension to a few dominant terms.

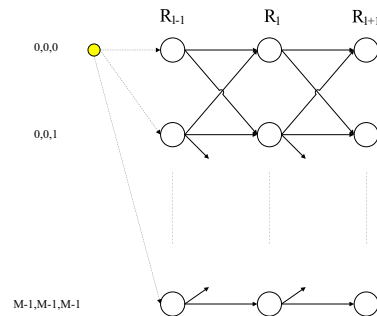


Fig. 3. Stage 1 computes symbol estimates using a Viterbi-like algorithm.

With three carriers considered for ICI ( $K = 1$ ), the trellis has  $M^3$  (one per each combination of three constellation symbols) states and three stages, representing the three received carriers considered. The branch cost in the trellis is determined by the Euclidean distance between the received symbols  $R_k$  and the three symbols. The path cost is calculated as

$$\sum_{k=l-K}^{l+K} \left| R_k - \sum_{i=k-K}^{k+K} H_{ki} X_i \right|. \quad (6)$$

Stage two computes the log-likelihood ratios using  $\tilde{X}_n$  in order to suppress ICI and exploit the frequency diversity introduced by it. Eq. 7 describes the demapping process. In our work we consider  $q = 2$ .

$$L_{lm} \approx \sum_{k=l-q}^{l+q} \log \left[ \frac{\sum_{X_l \in \mathcal{X}^+} \exp \left[ -\frac{1}{N_0} \left| R_k - \sum_{n=k-q, n \neq l}^{k+q} H_{kn} \tilde{X}_n - H_{kl} X_l^+ \right|^2 + \sum_{i=1, i \neq m}^M L_{A_i} X_{li} \right]}{\sum_{X_l \in \mathcal{X}^-} \exp \left[ -\frac{1}{N_0} \left| R_k - \sum_{n=k-q, n \neq l}^{k+q} H_{kn} \tilde{X}_n - H_{kl} X_l^- \right|^2 + \sum_{i=1, i \neq m}^M L_{A_i} X_{li} \right]} \right] \quad (7)$$

As it has already been discussed in [1], if we assume three carriers involved in the ICI ( $K = 1$ ), stage 1 requires  $NM^3$  computations, where  $M$  is the modulation order and  $N$  the number of carriers in the OFDM symbol. On the other hand, the complexity of stage 2 is a function of  $q$ , so the overall ICI suppressing MAP detector involves  $Nq^2 + NM^3$  computations.

### B. Iterative MAP detection with ICI cancellation

A more efficient iterative MAP detector has been proposed which is fed with extrinsic information generated by the LDPC decoder. The soft demapper uses the extrinsic likelihood values as a priori information ( $L_A$ ) for the demapping process. Thus, we no longer assume that all states of the constellation are equiprobable. The LLR for the  $m$ th bit associated with the  $l$ th bit can be computed using (7), being  $M$  the number of bits per symbol.

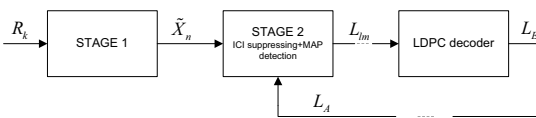


Fig. 4. Structure of the iterative ICI suppressing soft demapper.

The implementation guidelines [11] published by DVB, suggests an iterative receiver scheme based on feedback the extrinsic information generated by the LDPC decoder to the demapping process as a priori information. In our work, this turbo receiver scheme is used to implement an iterative ICI cancellator. We call external iteration the information exchange between the LDPC decoder and the MAP suppressing demapper. Internal iterations are carried out within the LDPC decoder.

## IV. SIMULATION RESULTS

DVB-T2 mobile reception has been simulated in three realistic scenarios for different time interleaving depths. On one hand, a 6-taps Typical Urban (TU6) channel is considered with the aim of simulating an urban environment for about 140 km/hr vehicle speed at 780 MHz of carrier frequency (100 Hz Doppler) with a relatively low code rate (2/3). The second scenario corresponds to the same channel model with higher code rate (5/6) and lower Doppler frequency (80 Hz). On the other hand, 180 Hz of Doppler frequency is simulated in a rural area environment (6-taps Rural Area (RA) channel) in which a vehicle could move faster (around 250 km/hr). The RA6 channel is less selective in frequency than the TU6 channel and takes into account the presence of the line of sight (LOS) component. “8K” mode with 1/4 guard interval

has been used with 16QAM modulation in these simulations and long frame size (64800 bits) for LDPC coding. 50 internal iterations are carried out. In relation with ICI suppressing MAP detector, we assume  $K = 1$  in the first stage and  $q = 2$  in the second one.

Fig. 5 depicts BER performance (after LDPC decoding) of DVB-T2 in these three scenarios for different time interleaving depths (1, 5 and 10 FECs). As it has been mentioned earlier, simulation results prove that both LDPC coding and time interleaving show very good performance against Doppler frequency shift.

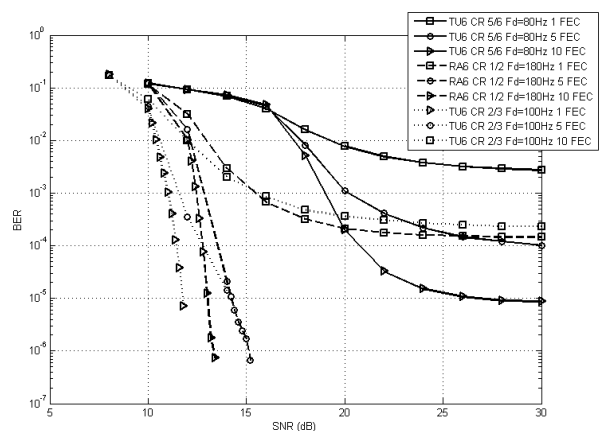


Fig. 5. BER performance of DVB-T2 over TU6 and RA6 channel using different code rates (CR) and time interleaving depths.

In the first and the third scenarios, the time interleaver is able to remove the typical error floor produced by the Doppler frequency. Nevertheless, even with an interleaving depth of 10 FECs, the error floor could not be removed in the second one.

Fig. 6, 7 and 8 describe the BER performance of the ICI suppressing demapper for the three proposed scenarios respectively. For ICI suppressing simulations we have contemplated the shortest time interleaving depth (1 FEC). We observe that there is a significant improvement in the first and second scenarios, but the ICI suppressing demapper is not able to delete the error floor. Further external iterations do not significantly enhance the performance. Otherwise, in the third scenario, quasi-error free (QEF) performance is achieved with ICI suppressing, what means that signal reception is possible without using time interleaving.

The performance gain introduced by the ICI suppressing demapper is similar in the first and the second scenario. However, Fig. 8 shows that the proposed algorithm is more powerful in less selective channels. Since stage 1 computes estimates using a viterbi-like algorithm, the less selective the

channel is, the better the performance of the ICI suppressing demapper is, i.e., estimated symbols are more accurate and the ICI suppressing is better in the second stage.

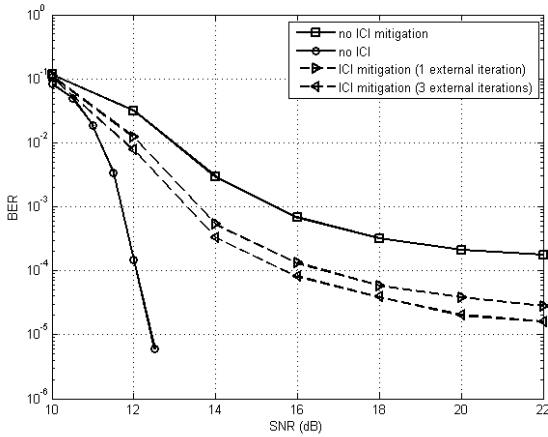


Fig. 6. BER performance of ICI suppressing demapper over TU6 channel.  $F_d=100\text{Hz}$  and CR 2/3.

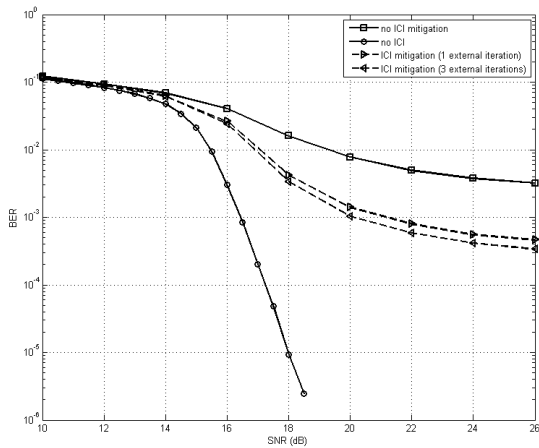


Fig. 7. BER performance of ICI suppressing demapper over TU6 channel.  $F_d=80\text{Hz}$  and CR 5/6.

## V. CONCLUSION

As a result of the inclusion of time interleaving and the LDPC coding scheme, DVB-T2 achieves an outstanding performance against inter-carrier interference. This paper analyzes BER performance of an ICI compensation system in several candidate scenarios. A well-known soft ICI cancellation scheme has been proposed and evaluated for DVB-T2 considering several channels and transmission parameters. Simulation results show that the implementation of an ICI suppressing receptor could be a good option for short time interleaving transmission modes and could help improving BER performance in any case. We have also verified that the performance of this ICI cancellation scheme is better in less selective scenarios like rural areas.

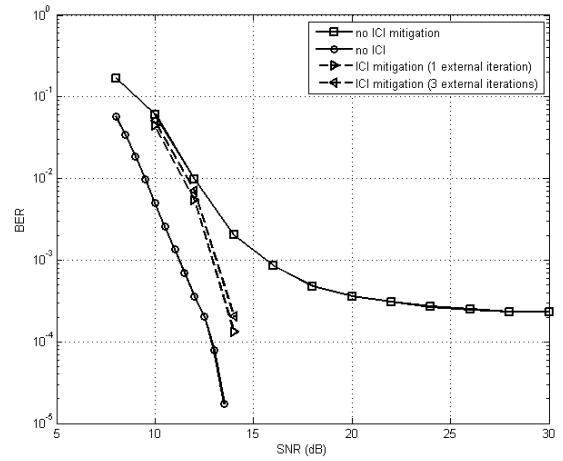


Fig. 8. BER performance of ICI suppressing demapper over RA6 channel.  $F_d=180\text{Hz}$  and CR 1/2.

## VI. ACKNOWLEDGEMENTS

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## REFERENCES

- [1] F. Peng and W. Ryan, "A low-complexity soft demapper for OFDM fading channels with ICI," *IEEE Wireless Communications and Networking Conference*, pp. 1549–54, 2006.
- [2] S. Tomasin, A. Gorokhov, H. Yang, and J.-P. Linnartz, "Iterative interference cancellation and channel estimation for mobile OFDM," *IEEE Trans. on Wireless Communications*, vol. 4, no. 1, pp. 238–45, 2005.
- [3] M. Poggioni, L. Rugini, and P. Banelli, "DVB-T/H and T-DMB: physical layer performance comparison in fast mobile channels," *IEEE Trans. on Broadcasting*, vol. 55, no. 4, pp. 719–30, 2009.
- [4] L. Wilhelmsson, J. Svensson, A. Nevalainen, and M. Faulkner, "Some results on implementing low-complex ICI cancellation for DVB-H," *IEEE 65th Vehicular Technology Conference - VTC2007-Spring*, pp. 2931–2935, 2007.
- [5] W. C. Jakes, *Microwave Mobile Communications*. Wiley, 1974.
- [6] M. Spath, S. A. Fochtel, G. Fock, and H. Meyr, "Optimum receiver design for wireless broad-band systems using OFDM - Part I," *IEEE Transactions on Communications*, vol. 47, no. 11, pp. 1668–1677, 1999.
- [7] S. U. Hwang, J. H. Lee, and J. Seo, "Low complexity iterative ICI cancellation and equalization for OFDM systems over doubly selective channels," *IEEE Transactions on Broadcasting*, vol. 55, no. 1, pp. 132–9, 2009.
- [8] C.-Y. Hsu and W.-R. Wu, "Low-complexity ICI mitigation methods for high-mobility SISO/MIMO-OFDM systems," *IEEE Transactions on Vehicular Technology*, vol. 58, no. 6, pp. 2755–68, 2009.
- [9] K. Fang, L. Rugini, and G. Leus, "Low-complexity block turbo equalization for OFDM systems in time-varying channels," *IEEE Transactions on Signal Processing*, vol. 56, no. 11, pp. 5555–66, 2008.
- [10] D. Liu and M. Fitz, "Iterative map equalization and decoding in wireless mobile coded ofdm," *IEEE Transactions on Communications*, vol. 57, no. 7, pp. 2042–51, 2009.
- [11] DVB, "Implementation guidelines for a second generation digital terrestrial television broadcasting system (DVB-T2)," Document A133, February 2009.