Design, Simulation and Hardware Implementation of a Digital Television System: Performance Evaluation

(Invited paper)

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Abstract— **In this paper we present the tests and performance evaluations carried out on the modulation system for the terrestrial Digital Television System (MI-SBTVD) described in [1]. All the results were obtained using computer simulated models, portraying relevant operating scenarios based on well-established channel models. The results obtained in this work have allowed us to estimate the expected system performance on working conditions as different as, for example, reception through single, fixed external antenna and single-antenna mobile reception.**

Keywords — **Broadcasting System, Digital TV, COFDM, Space-Time Code, LDPC, Performance Evaluation.**

I. INTRODUCTION

THIS paper presents a performance evaluation of the solutions proposed by the MI-SBTVD Project [1]. Among the proposed innovations in the MI-SBTVD System, the use of MIMO with up to two antennas at the transmitter and possibly more than one antenna at the receiver, associated with the use of low-density parity-check (LDPC) channel coding, which approaches Shannon's capacity limit, are the most important.

The results presented in this article are completely based on simulation models. The analysis aims at showing the performance of the system in different conditions, e.g., transmission over an additive-white-Gaussian-noise (AWGN) channel, transmission over channels Brazil-A through E [1], transmission over an AWGN channel in the presence of impulsive noise, and transmission to a mobile receiver.

The results presented in this article are only a subset of the results reported to the Brazilian Communications Ministry [9]. The choice of this subset is due to the limited space of this article.

The rest of the article is organized as follows: Section II describes the channel models used in the simulations; in Section III the simulation parameters and their possible settings are presented; the performance results and accompanying analysis are presented in Section IV; finally, our conclusions are presented in Section V.

For a more detailed description of the proposed system, we refer the reader to [1].

II. TELEVISION CHANNEL CHARACTERIZATION

ITU [4] suggests some typical channel profiles that can be used to test the system with fixed reception (Brazil-A through Brazil-E) and mobile reception (Typical Urban GSM/TU-GSM). Such profiles are adequate for tests of DTV systems because they represent a wide range of typical situations where signal reception is hindered by multipath.

For the analysis with the dynamic profile, a wide-sense-stationary-with-uncorrelated-scattering (WSSUS) model has been used. The WSSUS model has been used with all ITU profiles, not only with the TU-GSM. We tried to identify extreme cases, in terms of the influence of mobility and of greater, or lesser, path changeability on the values of the time scattering and coherence band of the channel.

For the TU-GSM channel, the correlation degree between the paths corresponding to the two transmission antennas can be adjusted at the simulator. The correlation between the Rayleigh envelopes in a system with transmission diversity is determined according to [5], [6] and [7]. Though [5] and [6] consider diversity at the receiver, the same concepts apply to diversity at the transmitter, if we admit that the channel has a reciprocal behavior.

A. Impulsive Noise Models

The models used here to represent impulsive noise are based on [3] and [4], not only because they are the most recent ones, as far as our knowledge goes, but also because they are the ones used to evaluate the performance of the DVB-T standard. On those articles, the impulsive noise is modeled as bursts of AWGN noise.

Of the six kinds of noises mentioned in [3], only three were used on the tests described here. **Test N1** and **Test N2** from [3] may be associated to external and internal reception, respectively. Besides, **Test N6** from [3] has also been used, and represents long impulsive noise bursts. Those tests are associated in this paper to the channels named **IMPUL-O**, **IMPUL-I** and **IMPUL-L**, respectively.
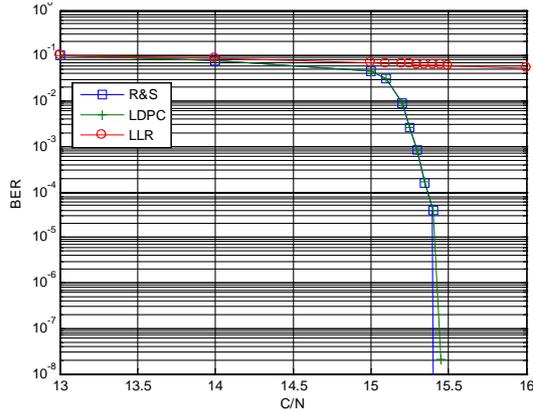
Fig. 1. Bit-error rate (BER) as a function of carrier-to-noise ratio (C/N) for the undecoded received signal, after LDPC decoding, and after RS decoding. Scenario: AWGN channel, 64-QAM modulation, and LDPC code rate 3/4.

III. SIMULATION MODELS

The tests have been performed on the complete system, comprising the transmitter, receiver and channel models. The simulation models reflect the operational functionalities described next:

- *Channel Coding* – The channel coding and decoding schemes comprise an external Reed-Solomon (RS) code and an internal LDPC code. For the preliminary tests, the LDPC simulation models used block lengths of 9k and 39k bits, and rates of 1/2, 3/4, and 7/8. The results reported here, when not specified, correspond to LDPC block length equal to 39k.

- *Temporal Interlacing* – The simulation model also uses a matrix-interlacing (temporal) scheme between the RS and the LDPC codes with adjustable block length.

- *OFDM Modulation* – The simulations were performed using a 2k-carrier OFDM scheme.

- *Guard time* – The guard time was fixed at 1/16 of the OFDM symbol period in all the simulations.

- *Space-time Coding* – The simulation model can be set up to operate in two modes: 1x1 (one transmission antenna) and 2x1 (two transmission antennas). In both cases, however, the receiver uses Alamouti's detection scheme.

- *Channel Estimation and Synchronzation* – Perfect channel knowledge and synchronism are assumed. This choice has been made in order to evaluate the system's potential, without regard to the limitations of one receiver implementation or another.

- *Channels* – The channel simulation models AWGN, Brazil A through Brazil-E, TU-GSM, IMPUL-O, IMPUL-I, and IMPUL-L were used to perform the tests.

- *Simulation Stop Criteria* – Simulations with a nonmoving receiver were stopped after the transmission of 39,168,000 bits (or 1,000 39-kbit LDPC code blocks) or after the occurrence of 40,000 bit-errors after the RS decoder, whatever comes first. On the mobile reception simulations, 3,000 LDPC blocks were used for Doppler deviation equal to 119 Hz, and 5,000 LDPC blocks were used for Doppler deviation equal to 12 Hz

- C/N_{thres} – The carrier-to-noise ratio (*C/N*) threshold is defined as the minimum ratio at which no errors are observed at the output of the RS decoder during the simulation period described previously (on the graphs, the threshold can be identified by the vertical descent of the bit-error rate).
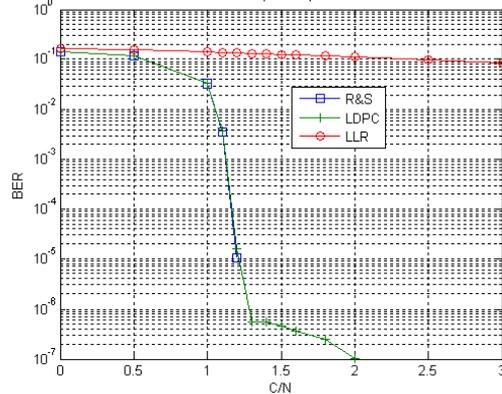
Fig. 2. BER × C/N for the undecoded received signal, after LDPC decoding, and after RS decoding. Scenario: AWGN channel, QPSK modulation, and LDPC code rate 1/2.

IV. PERFORMANCE RESULTS AND ANALYSIS

A. Performance on AWGN Channels

To evaluate the performance on AWGN channels, QPSK and 16-QAM modulation schemes were used with LDPC code rates of 1/2 and 7/8, and 16-QAM and 64-QAM were used with LDPC code rates of 1/2 and 3/4.

The minimum performance requirements specified for the system [8] stipulates that the minimum throughput must be 19 Mbps, with bit-error rate (BER) less than or equal to 3×10^{-6} for *C/N* at most 19 dB on an AWGN channel.

Using 64-QAM with LDPC code rate 3/4 and guard-interval fixed at 1/16, the net throughput is 19.33 Mbps. Fig. 1 shows that the minimum performance requirement for BER is met by the proposed system. The *C/N* threshold in this test was 15.4 dB. Hence, the BER requirement was satisfied at 3.6 dB below the 19 dB maximum allowed *C/N*.

Table I summarizes the net throughput and *C/N* threshold obtained at each simulated scenario with the AWGN channel. We notice that the scenario with 16-QAM modulation and LDPC code rate 3/4 has the same throughput of the scenario with 64-QAM and code rate 1/2, but has lower *C/N* threshold and, thus, better performance. Further investigations may determine the best compromises among bandwidth efficiency, code rate and guard time.

Fig. 3 shows the performance curves for the system after RS decoding obtained for 64-QAM modulation, guard time 1/16, 9kbit and 39kbit LDPC codes with rates 1/2 and 3/4. This last rate is used to test the conformity to the minimum acceptable performance. The *C/N* threshold for this test was equal to 15.6 dB, i.e., only 0.2 dB above the result obtained previously using the 39k-LDPC code. Hence, the minimum performance requirement is still satisfied with a margin of 3.4 dB.
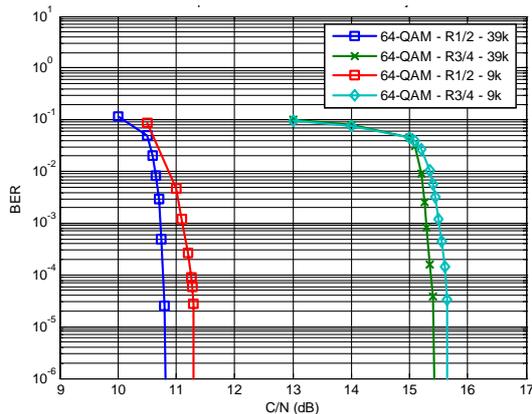
Fig. 3. System performance with 64-QAM modulation and LDPC code block lengths 39k and 9k.
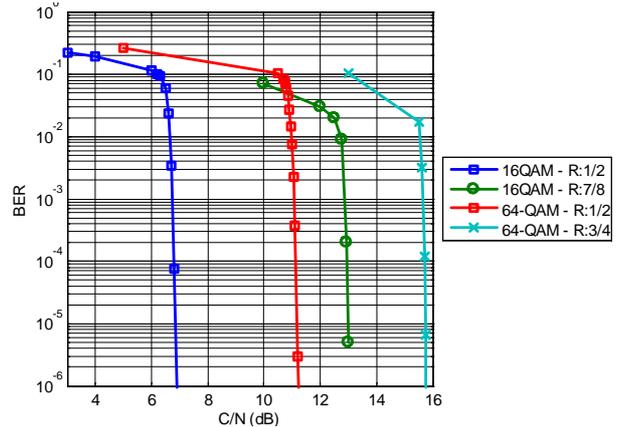
Fig. 4. System performance for channel Brazil-A.

TABLE I. SUMMARY OF THE THROUGHPUT AND $(C/N)_{\text{thres}}$ AWGN CHANNELS

	QPSK Rate 1/2	QPSK Rate 7/8	16-QAM Rate 1/2	16-QAM Rate 3/4	64-QAM Rate 1/2	64-QAM Rate 3/4
Throughput	4.23 Mbps	7.52 Mbps	8.59 Mbps	12.89 Mbps	12.89 Mbps	19.33 Mbps
$(C/N)_{\text{threshold}}$	1.3 dB	6.2 dB	6.6 dB	10.4 dB	10.8 dB	15.4 dB

B. Performance on Brazil-A through Brazil-E Channels

Since the proposed system uses two transmitting antennas by default, it was necessary to choose a phase delay profile for the two channels of the Alamouti system. The phase delays used to generate the performance curves presented in this section were chosen at random, with no loss of generality, because, in all cases studied, a difference of only about 0.6 dB was observed between the best and the worst performances.

Fig. 4 shows the performance of the system for external line-of-sight reception, corresponding to Brazil-A channel. The *C/N* threshold observed ranges from 15.75 dB, for 64-QAM modulation with code rate 3/4, down to 6.9 dB, with 16-QAM with code rate 1/2. We note that 16-QAM with code rate 7/8 has worse performance, in terms of *C/N* threshold for the same throughput, than 64-QAM with code rate 1/2, indicating that it is not very useful as a transmission mode.

The performance of the transmission system was also studied for channels B through E using the configurations above. Fig. 5 shows the results for 64-QAM modulation with code rate 3/4, which satisfies the performance requirements for all channels, from A to E.

To evaluate the efficiency of Alamouti's space-time coding scheme, the 2x1 mode was compared to the 1x1 mode using 64-QAM with rate 3/4 for channels Brazil-A through E. An example of the obtained results is presented in Fig. 6 for the channel Brazil-A. The performance improvement obtained with the use of two antennas was substantial, with gains ranging from 1.9 dB, for channel Brazil-C, up to 4 dB, for channel Brazil-B.

C. Performance on Channels with Impulsive Noise

The basic test procedure for channels with impulsive noise was to find, for each value of carrier-to-interference ratio (*C/I*), the minimum *C/N* ratio that results in a BER of at most 3×10^{-6} (Threshold of Visibility – TOV). Two channel models have been considered: one associated with systems with internal reception (noises generated by the power-supply network, or by direct induction on the receiver) named IMPUL-I channel, and another associated with systems with external reception (noises captured by the external antenna, such as the noises generated by the ignition of automobiles) named IMPUL-O channel.

Fig. 7 shows the results obtained for the IMPUL-I noise model, for 64-QAM modulation and code-rate 1/2. We note that the proposed system is able to operate with BER below TOV for *C/I* ratios greater than or equal to 26.5 dB, approximately.

It is important to note that the results presented in Fig. 7 cannot be directly compared with the results presented in [2] and [3] for the DVB-T system, since those articles did not consider the *C/I* ratio, but a ratio named by the authors as windowed *C/I*. These ratios are related according to the expression

$$\left(\frac{C}{I}\right)_w = \frac{C}{I} + 10\log\left(\frac{T_u}{BS}\right),$$

where T_u is the effective duration of the OFDM symbol and *BS* (burst spacing) is the space between bursts of impulsive noise. On the conditions of the proposed system, $(C/I)_w \approx (C/I) - 16$ dB.

Fig. 8 shows the performance of MI-SBTVD under the presence of impulsive noise considering the channel IMPUL-O, for 64-QAM modulation and LDPC code with rate 3/4, which presents throughput greater than 19 Mbps. We note that the proposed system is able to operate with BER smaller than TOV for *C/I* ratios greater than or equal to 33.5 dB, approximately.

D. Mobile Reception Performance

The channel model that represents mobile reception is TU-GSM (typical urban GSM). Two scenarios have been considered: one with low speed (around 25 kilometers per hour for the UHF channel 14), and another with high speed (around

130 kilometers per hour for the UHF channel 14).

In all figures presented in this section, the value of the *C/N* threshold is the last point on the curve. The vertical line down from that point indicates that it was not possible to observe any bit-errors beyond the threshold during the total simulation time (corresponding to 120 and 200 million transmitted bits for Doppler deviations of 12 Hz and 60 Hz, respectively).

Fig. 9 and Fig. 10 show the system performance for 16-QAM modulation with code rate 1/2 and Doppler deviations 12 Hz and 60 Hz, respectively, while Fig. 11 and Fig. 12 illustrate the performance for QPSK modulation, code rate equal to 1/2, and Doppler deviations equal to 12 Hz and 60 Hz, respectively. The figures also show the effect of the correlation between the received signals (coming from the two transmitting antennas) on the system performance.

We note that the system performance gets worse as the correlation between the received signals increases. Based on the results presented, it can be concluded that the system is able to operate with high efficiency for mobile reception using more robust modulation schemes, such as QPSK and 16-QAM.

Fig. 13 compares the performance of the system with two transmitting antennas with the case where one of the antennas is turned off (without any change at the receiver). The configuration with QPSK modulation, code rate equal to 1/2, and Doppler deviation of 60 Hz was used. Similar results to the ones shown in Fig. 13 were obtained for 16-QAM modulation, code rate equal to 1/2, and Doppler deviation 12 Hz. From these results, we observe a drop of 5-9 dB on the system performance when one of the transmitting antennas is turned off.

V. CONCLUSIONS

This article presented performance evaluation results, obtained through simulation, for the MI-SBTVD system, an innovative modulation sub-system developed in response to RFP 18-2004 from the governmental commission for the Brazilian Digital Television System (SBTVD).

The minimum performance requirements (data rate of at least 19 Mbps with at most *C/N* threshold of 19 dB over a Gaussian channel) were satisfied using 64-QAM and LDPC code rate equal to 3/4 for all cases with fixed reception (AWGN and Brazil A-E channels). Besides, good performance was observed in the presence of impulsive noise.

Feasible mobile reception was demonstrated for system set-ups with 16-QAM and QPSK modulation, combined with an LDPC code rate of 1/2, which provide data rates of 8.56 and 4.23 Mbps, respectively. *C/N* thresholds for those set-ups were between 17 and 19 dB, for 16-QAM, and 8 and 11 dB, for QPSK.

Besides being useful to evaluate the overall system performance, the simulation environment was also important in the process of decision-making for system specification. For example, the choice to use a 9-kbit LDPC code was made after the simulations showed a loss of only 0.2 dB when compared to the implementation-expensive 39-kbit code.

We may conclude that the proposed system has great potential as a modulation system for next generation digital television systems.
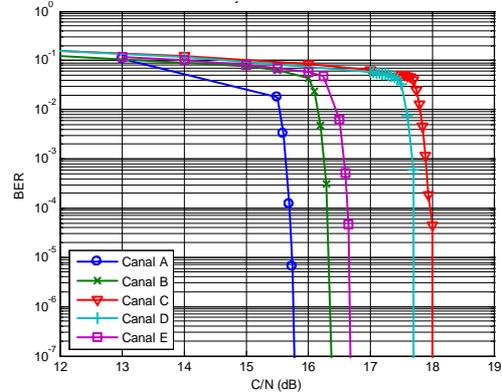
Fig. 5. System performance for channels Brazil-A through Brazil-E using 64-QAM and LDPC code rate equal to 3/4.
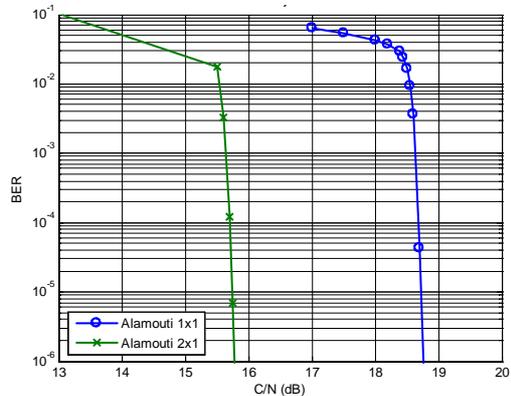
Fig. 6. Performance comparison between Alamouti 1×1 and 2×1 over channel Brazil-A.
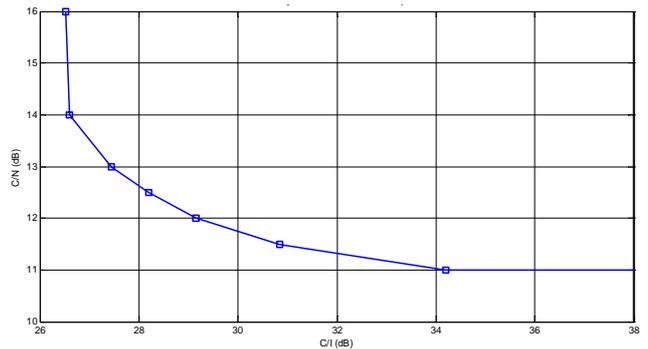
Fig. 7. Performance with impulsive noise and internal reception.
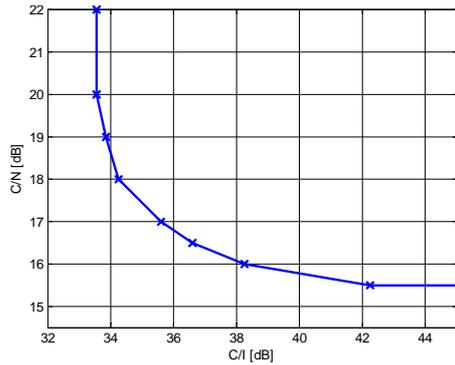
Fig. 8. Performance with impulsive noise and external reception.
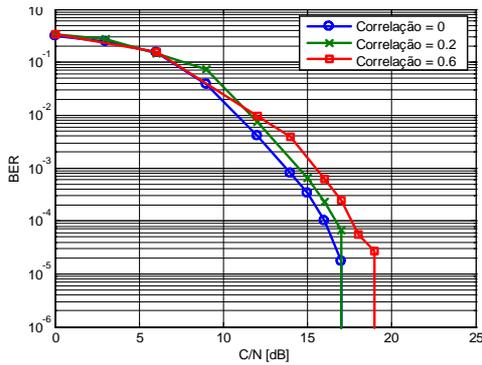
Fig. 9. Mobile reception with 16-QAM, R = 1/2 and Doppler deviation = 12 Hz
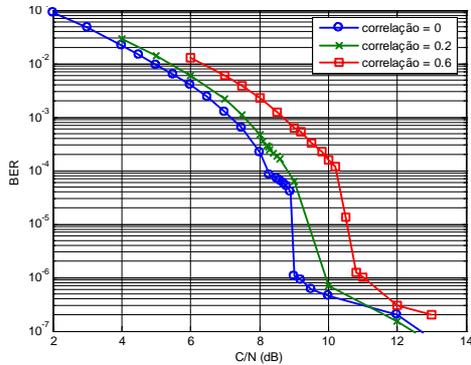
Fig. 10. Mobile reception with 16-QAM, R = 1/2 and Doppler dev = 60 Hz.
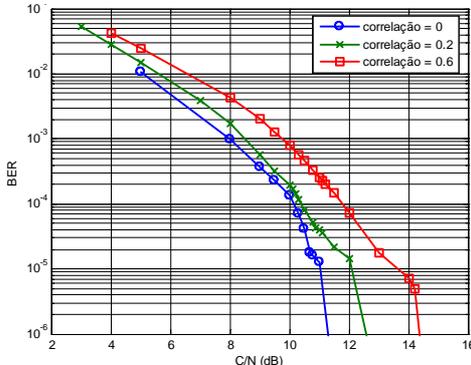
Fig. 11. Mobile reception with QPSK, R = 1/2 and Doppler deviation = 12 Hz.
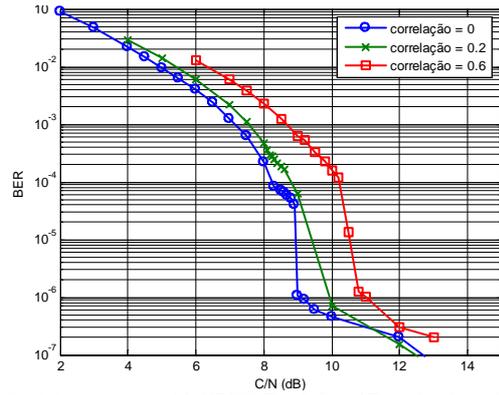
Fig. 12. Mobile reception with QPSK, R = 1/2 and Doppler deviation = 60 Hz.
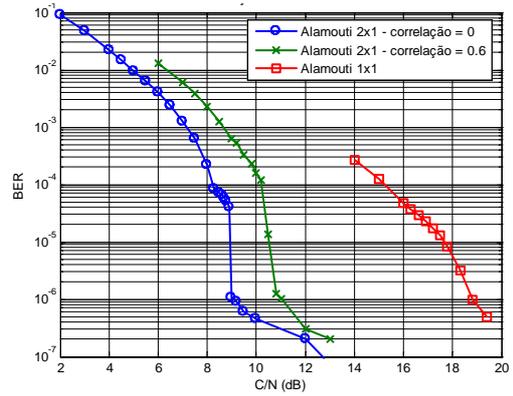
Fig. 13. Mobile reception with QPSK, R = 1/2 , Doppler deviation = 60 Hz, and Alamouti 2×1 and 1×1.

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