OFDM Systems for Brazilian Digital Television channels

Daniel L. Hatae, Marcio Eisencraft, Cristiano Akamine,
Carlos E. S. Dantas, Magno T. M. Silva, and Maria D. Miranda
Mackenzie Presbyterian University
São Paulo, Brazil
{daniel.hatae, marcioft, akamine, cdantas, magnotmsilva, mdm}@mackenzie.br

***Abstract*— The digital television standard to be used in Brazil is in its definition stage. A comparative analysis among the transmission/reception techniques is important to set up the standard. In this paper, we consider the simultaneous transmission with multiple orthogonal carriers - OFDM (Orthogonal Frequency Division Multiplex), used in Europe and Japan and the single carrier transmission with fractionally DFE (Decision Feedback Equalizer), usually employed in the American standard receivers. To investigate the performance of these techniques, the Brazilian digital TV channel models are used.**

***Index Terms*— OFDM, Decision Feedback Equalizer, Brazilian Digital Television Channels, Channel Estimation.**

I. INTRODUCTION

The choice of transmission/reception techniques influences the Digital Television (DTV) standard adopted in each country. These standards can be classified into two groups. One uses single carrier transmission, as American DTV standard defined by ATSC (Advanced Television Systems Committee) [1]. The other considers multiple orthogonal carriers, like the Japanese and European standards, known respectively as DVB (Digital Video Broadcasting) and ISDB (Integrated Services Digital Broadcasting) [2], [3].

The transmission channel plays an important role in the technique to be adopted. From 1999 to 2002, the DTV Laboratory of Mackenzie Presbyterian University was responsible for various experimental tests in order to supply technical elements to the Brazilian Association of Radio and Television Broadcasting Stations and the Telecommunication National Agency to take a decision about the standard. The terrestrial versions of ATSC, DVB, and ISDB were analysed. In the occasion, five characteristic channels of metropolitan region of São Paulo city were modeled. These models are used as reference in several studies for evaluation and improvement of existing transmission systems (see e.g. [4]-[7]).

In this paper, we compare OFDM to single carrier for the Brazilian DTV channel models [8], [6]. In the single carrier case, DFE and oversampled DFE adapted with the LMS (Least-Mean-Square) algorithm is used. In the OFDM systems, the channel is estimated by the Least Squares (LS) and the Minimum Mean Square Error (MMSE) methods with the ISDB and DVB pilot spacing [9], [10], [2], [3]. It is relevant to notice that the objective is not to compare the already existing DTV standards, but the techniques used by them. We consider simplified situations in order to obtain the technique operation limits.

The paper is organized as follows. In Section II the most important aspects of the problem formulation, considering the OFDM transmission and the single carrier using DFE are revisited. Simulation results and concluding remarks are presented respectively in sections III and IV.

II. PROBLEM FORMULATION

A. OFDM Systems

The OFDM increases the transmitted symbol duration without changing the transmission efficiency [10], [9]. A block diagram of a typical OFDM system is shown in Figure 1.

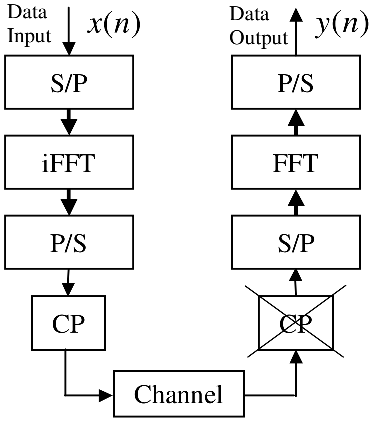

Fig. 1. Block diagram of a typical OFDM system; CP: Cyclic Prefix.

By convenience, the signals $x(n)$ and $y(n)$ transmitted and received at the carrier frequency f_k, with $k = 0, 1, \ldots, N{-}1$, are represented respectively as $X(f_k)$ and $Y(f_k)$. The channel frequency response and the additive white Gaussian noise in frequency f_k are denoted respectively as $H(f_k)$ and $W(f_k)$. The carrier orthogonality implies

$$Y(f_k) = H(f_k)X(f_k) + W(f_k), \tag{1}$$

that is, the received sample at the k^{th} carrier is the product of the signal $X(f_k)$ by the channel response $H(f_k)$ added to noise.

The considered OFDM systems are comb-type, where part of carriers are always reserved as pilot for each symbol. The pilot carrier information is used to compensate the channel effect through estimation techniques like LS, MMSE and LMS [10], [9], [11], [12]. These techniques estimates the channel frequency response at each pilot frequency and an interpolation method is used to obtain the channel response at the other carrier frequencies. In this paper we consider the LS and MMSE estimators [9]. The channel frequency response is estimated by the LS method as

$$\widehat{H}_{LS}(f_p) = \frac{Y(f_p)}{X(f_p)}, \tag{2}$$

and by the MMSE method as

$$\widehat{H}_{MMSE}(f_p) = \mathbf{R}_{HY}\mathbf{R}_{YY}^{-1}Y(f_p), \tag{3}$$

where f_p represents the pilot frequencies. The matrices $\mathbf{R}_{HY}$ and $\mathbf{R}_{YY}$ are respectively the cross-correlation between the channel frequency response and the received signal and the autocorrelation of the received signal at the pilot frequencies. Both can be approximately estimated [11], [9].

B. Decision Feedback Equalizer

Among the single carrier reception techniques, DFE is the most used [13]. The algorithms for adaptation of the DFE feedforward filter coefficients can be implemented in the symbol rate, or using oversampling [14]-[17]. In latter case, the signal that arrives to the receiver is sampled with a higher rate than that of the symbols. An important result of oversampled equalizers is that, under certain circumstances, they can reach the perfect equalization condition [14]. The 3rd and 4th generations of ATSC receivers use the oversampled DFE [18], [17].

Figure 2 shows a communication system model with oversampled DFE, denoted by DFE-T/2. The i.i.d. signal $a(n)$ is transmitted through an unknown communication channel, modeled by the subchannels $C_p(z)$ and $C_i(z)$, whose transfer functions are given by

$$\begin{aligned} C_p(z) &= h_0 + h_2 z^{-1} + \cdots + h_{2N-2} z^{N-1} \\ C_i(z) &= h_1 + h_3 z^{-1} + \cdots + h_{2N-1} z^{N-1}, \end{aligned}$$

being h_0, h_1, $\cdots$, h_{2N-1} obtained from the sampling of continuous time channel model with twice the symbol rate. The output channel signals, $u_p(n)$ and $u_i(n)$, suffer intersymbol interference and noise effects. In the receiver, these signals are filtered by $F_p(z)$ and $F_i(z)$, each one with $M_f/2$ coefficients, forming the oversampled feedforward filter. The past decisions are fed back and filtered by an FIR feedback filter $B(z)$ with M_b coefficients taps, obtaining the output signal $y_b(n)$. Then, a linear combination of the filters' outputs enters to the decision device. The DFE must mitigate the channel effects and recover the signal $a(n)$ for some delay τ_d. The oversampling is explained in details in [14] an its use in DFE was considered, for example, in [16] and [17].

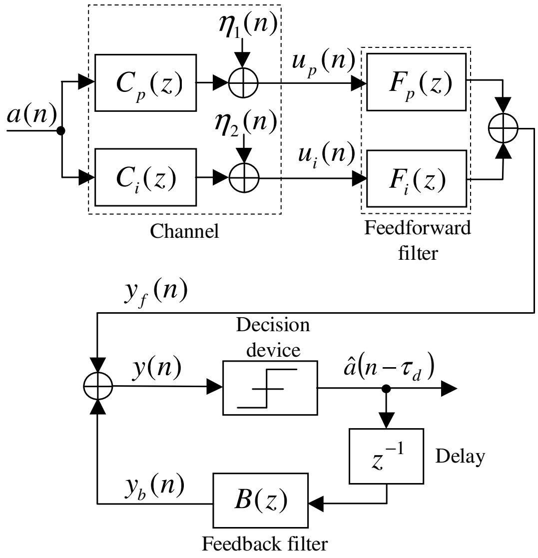

Fig. 2. Communication system model with oversampled DFE.

III. Simulation Results

In the simulations, we consider the transmission of binary signals (BPSK - Binary Phase Shift Keying) through the Brazilian DTV channels, whose impulsive response non-null coefficients are shown in Table I. The channel Brazil A represents a typical reception by external antenna and Brazil D by internal antenna, presenting more difficult equalization. Brazil B and Brazil C represent intermediate situations between A and D. Brazil E simulates a Single Frequency Network reception [19].

TABLE I

Impulsive Response of the Brazilian channels.

Brazil A	ℓ	0	2	25	34	66	67
	h_ℓ	1.00	0.20	0.15	0.18	0.21	0.15
Brazil B	ℓ	0	3	39	49	107	143
	h_ℓ	1.00	0.25	0.63	0.45	0.18	0.08
Brazil C	ℓ	0	1	5	17	26	31
	h_ℓ	0.72	1.00	0.65	0.99	0.75	0.86
Brazil D	ℓ	2	7	25	34	66	67
	h_ℓ	0.99	0.65	0.74	0.86	1.00	0.72
Brazil E	ℓ	0	11	23	-	-	-
	h_ℓ	1.00	1.00	1.00	-	-	-

We consider the carrier and pilot scheme of DVB and ISDB 8K mode, a cyclic prefix of $N/16$, and linear interpolation. In the case of single carrier with DFE, we consider $M_f = 16$ coefficients in the feedforward filter (with or without oversampling) and $M_b = 48$ coefficients in the feedback filter. These coefficients are adapted with the LMS algorithm, assuming the step-size $\mu = 0.001$.

Bit Error Rate (BER) curves as function of signal-to-noise ratio (SNR) for the considered channel models are shown in Figure 3 a) - e). In all channels, for $\mathrm{SNR} > 16\mathrm{dB}$, the oversampled DFE outperforms the other schemes. However, for lower SNR, the OFDM systems offer some advantages for the channels Brazil C, D, and E, whose equalization is more difficult. The DFE without oversampling presents good performance only for channel Brazil A, not working properly for channels C and D.

The OFDM system performance for the carrier and pilot scheme of DVB and ISDB are almost the same for all channels and different values of SNR. Thus, we can conclude that pilot spacing is not determinant for the system behavior in all these channels, which do not take in to account Doppler effect.

The LS and MMSE estimators present similar performances, independently of the considered channel. The channel estimation provided by LS method is close to the best that can be achieved, that is, the MMSE estimation. More computationally complex interpolation methods were also tested, but similar performances were observed, showing that the proximity between pilots is good enough.

Figure 3-f) shows mean-square error (MSE) curves for the channel Brazil D, using DFE-T/2 and DVB-MMSE. We consider $\mathrm{SNR} = 25\mathrm{dB}$ and an average of 80 experiments. To facilitate the visualization, the MSE signals were filtered by a moving-average filter with 16 coefficients. Both schemes converge to approximately the same MSE level. However, DFE-T/2 presents slower convergence than DVB-MMSE, what can compromise its performance in time-variant channels. It is important to notice that OFDM presents some detection errors when the channel estimation is close to strong spectral nulls. These errors do not appear in the figure due to the moving-average filter.

IV. CONCLUSIONS

In this paper, we showed a comparison between the oversampled DFE, and OFDM systems. In the simulations, we considered Brazilian DTV channel models, which characterize the metropolitan region of São Paulo.

From the simulation results, we can observe that:

- In terms of BER, for channels Brazil C, D, and E, the considered OFDM systems present interesting results, mainly if the SNR is lower than 15dB. However, this situation does not correspond to a realistic case, because the operation of DTV systems occurs for $\mathrm{SNR} > 15\mathrm{dB}$.
- In the reception with oversampled DFE and in the transmission/reception with OFDM and LS or MMSE estimation, the MSEs converge on average to similar values. However, for the OFDM, the MSE presents higher variance, what causes errors in some carriers.

It is relevant to notice that the OFDM potential was not completely exploited in the simulations. The DVB and ISDB coding schemes must be taken in to account for bettering the OFDM system performance. OFDM equalization techniques should also be considered [12], [20]. Moreover, in practical situations, the fractionally DFE is blindly adapted. In this case, there is a better use of the channel bandwidth, but its performance is limited by the supervised case.

REFERENCES

[1] ATSC Digital Television Standard, *ATSC Standard A/53*, May 21th, 2004.

[2] ETSI, "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for digital terrestrial television," *Standard ETSI EN 300 744 v1.4.1*, European Telecommunications Standards Institute, Jan. 2001.

[3] ARIB STD-B31 V. 1.2, "Transmission System for Digital Terrestrial Television Broadcasting ARIB Standard," *Association of Radio Industries and Businesses*, Jan. 24th , 2002.

[4] Y. Wu *et al.*, "An ATSC DTV receiver with improved robustness to multipath and distributed transmission environments," *IEEE Transactions on Broadcasting*, v. 50, n. 4, p. 32-41, Mar. 2004.

[5] Z. Yang *et al.* "A coding and Modulation scheme for HDTV services in DMB-T," *IEEE Transactions on Broadcasting*, v. 50, n. 4, p. 26-31, Mar. 2004.

[6] ITU Radiocommunication Study Groups, "Guidelines and techniques for the evaluation of DTTB systems," *ITU-R Document 6E/TEMP/131-E*, Mar. 2003.

[7] S. Moon, J. Kim, and D. Han; "Spatial diversity technique for improvement of DTV reception performance", *IEEE Trans. on Consumer Electronics*, vol. 49, no. 4, pp. 958-964, Nov. 2003.

[8] SET/ABERT, "Digital Television Systems - Brazilian tests - Final Report Part 1," *Report of SET/ABERT Group Tests*, ANATEL, São Paulo, May 2000.

[9] R. D. J. van Nee and R. Prasad *OFDM for Wireless Multimedia Communications*, Artech House Publishers, 2000.

[10] O. Edfors, "Low-complexity algorithms in digital receivers," *Doctoral Thesis*, Lulea University of Technology, Lulea, Sept. 1996.

[11] S. G. Kang, Y. M. Ha, and E. K. Joo, "A comparative investigation on channel estimation algorithms for OFDM in mobile communications," *IEEE Trans. On Broadcasting*, v. 49, n. 2, p. 142-149 , June 2003.

[12] L. C. L. Acácio and V. H. Nascimento,"Pre-FFT equalization in DVB-T systems," *Proc. of International Workshop on Telecommunications - IWT 2004*, p. 25-31, Santa Rita do Sapucaí, Aug. 2004.

[13] M. Ghosh, "Blind decision feedback equalization for terrestrial television receivers," *Proc. IEEE*, v. 86, p. 2070-2081, Oct. 1998.

[14] J. R. Treichler, I. Fijalkow, and C. R. Johnson Jr. "Fractionally spaced equalizers," *IEEE Signal Processing Magazine*, p. 65-81, May 1996.

[15] S. Haykin, *Adaptive Filter Theory*, 3th ed., Prentice Hall, New Jersey, 1996.

[16] L. L. Szczecinski and A. Gei, "Blind decision feedback equalisers, how to avoid degenerative solutions," *Signal Processing*, v. 82, p. 1675-1693, 2002.

[17] L. Qin *et al.* "Fractionally Spaced Adaptive Decision Feedback Equalizers with Applications to ATSC DTV Receivers," *IEEE Transactions on Consumer Electronics*, v. 50, p. 999-1003, Nov. 2004.

[18] R. A. Casas, "An integrated VSB/QAM/NTC/BTSC receiver: recent advanced in television designed," *Proceedings of the 53th Annual IEEE Broadcast Symposium*, Oct. 2003.

[19] J. Wang *et al.* "A new implementation of single frequency network based on DMB-T," *Proc. of International Conference on Communication Circuits and Systems (ICCAS'2004)*, pp. 246-249, vol. 1, June 2004.

[20] S. Armour, A. Nix, and D. Bullm, "Complexity evaluation for the implementation of a pre-FFT equaliser in an OFDM receiver", *IEEE Transactions on Consumer Electronics*, p. 428-437, Aug. 2000.

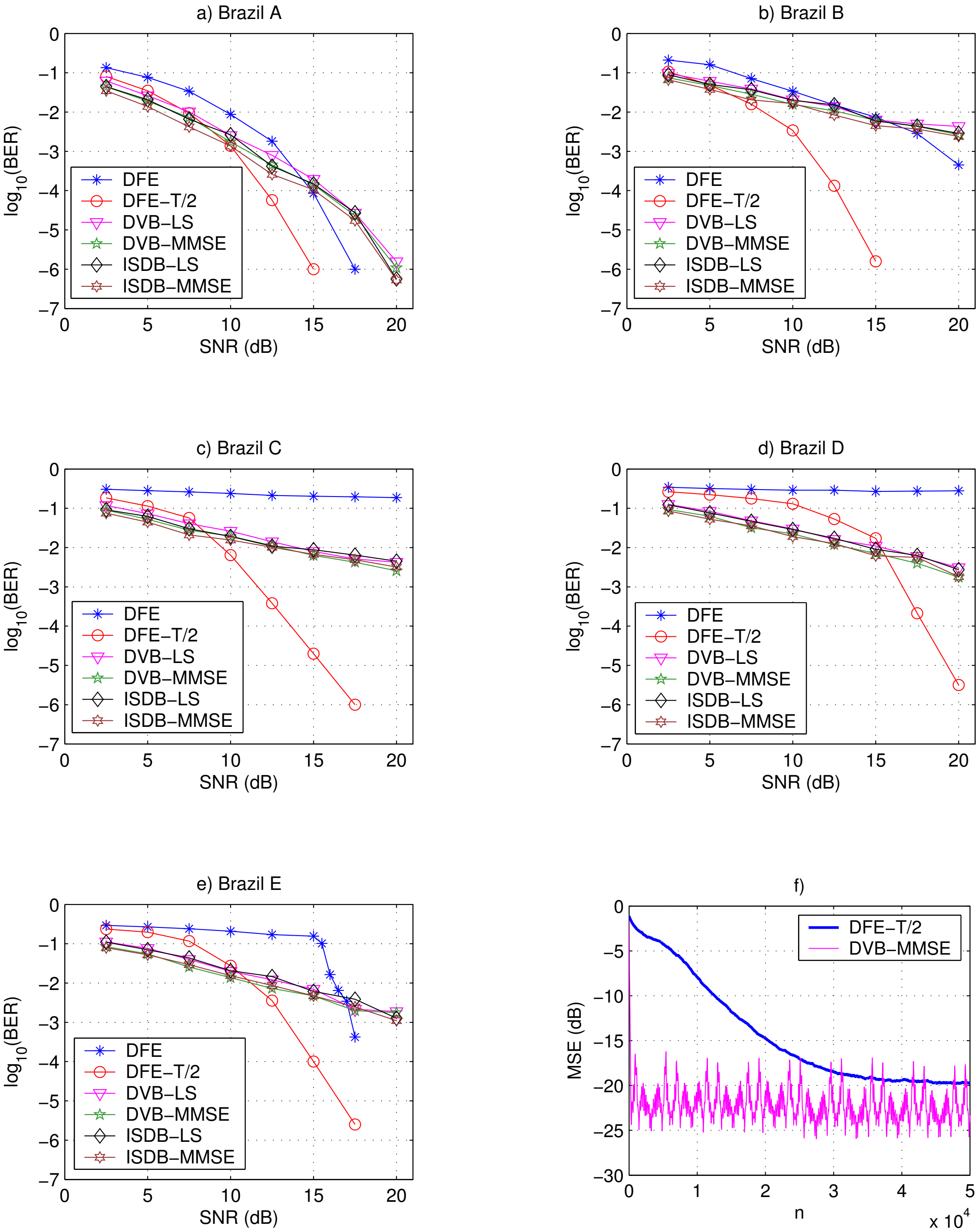

Fig. 3. Simulation results: a) - e) Decimal logarithm of BER for the Brazilian DTV channels; f) Mean-square error (MSE) for Brazil D.