CHANNEL ESTIMATION FOR THE ISDB-T_B FBMC SYSTEM USING NEURAL NETWORKS: A PROPOSAL OF APPLICATION OF BACK-PROPAGATION TRAINING ALGORITHM

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ABSTRACT

Due to the evolution of technology and the diffusion of digital television, many researchers have studied more efficient transmission and reception methods. This fact occurs because of the demand of transmitting videos with better quality using new standards such 8K SUPER Hi-VISION. In this scenario, modulation techniques such as Filter Bank Multi Carrier, associated with advanced coding and synchronization methods, are being applied, aiming to achieve the desired data rate to support ultra-high definition videos. Simultaneously, it is also important to investigate ways of channel estimation that enable a better reception of the transmitted signal. This task is not always trivial, depending of the characteristics of the channel. Thus, the use of artificial intelligence can contribute to estimate the channel frequency response, from the transmitted pilots. A classical algorithm called Back-propagation Training can be applied to find the channel equalizer coefficients, making possible the correct reception of TV signals. Therefore, this work presents a method of channel estimation that uses neural network techniques to obtain the channel response in the Brazilian Digital System Television, called ISDB-T_B, using Filter Bank Multi Carrier.

KEYWORDS

Channel estimation, Artificial intelligence, ISDB-T_B, FBMC, Neural Networks.

1. INTRODUCTION

Digital TV standards in current use allow for the transmission of standard or high definition video content. However, consumers are demanding more resolution for more realistic experiences while watching TV. Therefore, researchers all over the world are working in the development of the concepts that will enable the broadcast of ultra-high definition content. These concepts include novel modulation schemes, powerful channel estimation, intelligent receptors, antenna arrays, etc. Filter Bank Multi Carrier (FBMC) is a modulation technique that has been applied as an alternative to the Orthogonal Frequency Division Multiplexing (OFDM) [1]. This trend is due to the fact that FBMC does not use the Cyclic Prefix (CP), increasing significantly the system data rate [2]. Thus, when FBMC is applied to digital television system such as Integrated Services

Digital Broadcasting Terrestrial B (ISDB-T_B) associated with channel coding and synchronization techniques such as Low Density Parity Check (LDPC) and Bootstrap, 8K transmission may be made viable. Nevertheless, the transmission of more information per second using the same frequency bandwidth leads to an increase in bit error rate if improved channel estimation algorithms, powerful error correcting codes and novel equalizers are not used. However, the channel estimation becomes a little more complex, due to the characteristics of the used filters and degrading components present on the channel [3]. In this article, an intelligent channel estimation algorithm using Neural networks is reported.

The channel estimation is a crucial stage for the perfect reception of digital TV signals because of the interferences that are generated by several sources on the channel. In the specific case of the terrestrial broadcast, these are Additive White Gaussian Noise (AWGN), multipath, and others [4]. Therefore, it is necessary to use different techniques and processes that make possible the removal and minimization of this effects, allowing the reception of the transmitted signal in an appropriated way.

Several techniques can be used to estimate the frequency response of the channel. Among them, we can highlight those that use pilots associated to interpolation methods that adequately minimize the AWGN and multipath effect [5]. However, this process is not always trivial, and can be improved with the use of Artificial Intelligence (AI).

The AI can be understood as a set of algorithms to solve complex problems, being able to resolve, to make decisions, and to develop a method of learning, according to the situation to which it is applied [6]. In this context, Neural Networks (NN)are used to solve problems through the simulation the connection between brain neurons, using specific activation and training algorithms [7].

The herein proposed channel estimation method uses a NN, trained through the Back-propagation algorithm to calculate the channel response and to permit the correct equalization in a scenario with AWGN and multi paths. This technique is applied to an FBMC version of the ISDB-T_B digital TV standard. The overall system is simulated on GNUR adio environment. The presented results show the feasibility of this new system even when transmission id performed in a channel with severe multipath interference.

2. ISDB-T_B

The Brazilian Digital Television System (SBTVD),ISDB-T_B, is the terrestrial digital TV standard adopted by 18 countries in the world. It employs a bandwidth of 6, 7, or 8 MHz and can transmit One-Segment (1SEG), Standard Definition Television (SDTV) and High Definition Television (HDTV), according to the combination chosen for the 13 Segments available. In the Figure 1 is possible to see the bandwidth segmentation used in 6 MHz. The 3 modes of operation have different parameters that are detailed in Table I [8].

Table 1. ISDB-T_B transmission parameters.

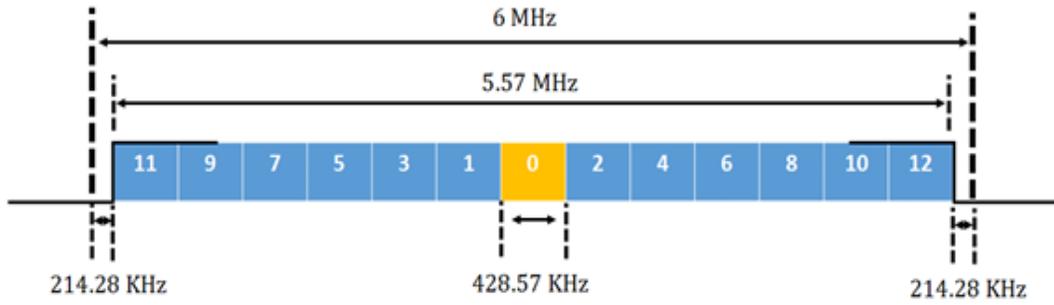| Mode	Parameters				
	Carriers	Useful Carriers	Pilots	Symbol period	IFFT
1	1405	1248	157	0,252 ms	2048
2	2809	2496	313	0,504 ms	4096
3	5617	4992	625	1,008 ms	8192

Figure 1. Segmentation of the ISDB-T$_B$ channel.

3. FBMC

The Filter Bank Multi Carrier (FBMC) modulation technique consists of dividing the available band into small equally spaced small segments [9]. For this purpose, filter banks complying with (1) are used.

$$B_k(f) = H\left(f - \frac{k}{M}\right) = \sum_{i=0}^{L-1} h_i e^{-j2\pi i\left(f - \frac{k}{M}\right)} \tag{1}$$

where, f is the frequency, M is the number of subcarriers, L is the number of filter coefficients, and $k = 0 \dots M - 1$.

Applying the Z transform, the polyphase decomposition, and making $W_M = e^{-\frac{2j\pi}{M}}$, (2) can be derived.

$$B_k(z) = \sum_{p=0}^{M-1} W_M^{-kp} z^{-p} H_p(z^M) \tag{2}$$

By expressing this equation in matrix notation, (3) is obtained.

$$\begin{bmatrix} B_0(z) \\ \vdots \\ B_{M-1}(z) \end{bmatrix} = \begin{bmatrix} 1 & \cdots & 1 \\ \vdots & \ddots & \vdots \\ 1 & \cdots & W_M^{-(M+1)^2} \end{bmatrix} \begin{bmatrix} H_0(z^M) \\ \vdots \\ z^{-(M-1)} H_{M-1}(z^M) \end{bmatrix} \tag{3}$$

The implementation of this equation is depicted in the block diagram in the Figure 2.
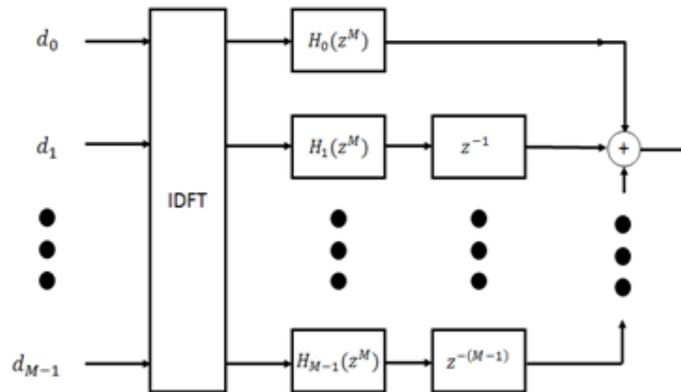

Figure 2. FBMC system model.

The filters are designed according to the zero inter-symbol interference Nyquist criterion to avoid phase and amplitude distortions [10]. FBMC employs Offset Quadrature Modulation (OQAM), so that the orthogonality is obtained between symbols and not between subcarriers [11]. Thus, it is not necessary to use the CP, making it possible to increase the data rate of the system.

4. PILOT BASED CHANNEL ESTIMATION

To estimate the frequency response of the channel, ISDB-T$_B$ performs the constant transmission of pilots. The position of the pilots depends on a Pseudorandom Binary Sequence (PRBS) sequence that has a generator polynomial equal to $x^{11} + x^9 + 1$ [8].

After the transfer function (Hp) is found using (4), where Y_p (k) anX_p (k) are the pilot amplitudes received and transmitted through the $k - th$ subcarrier, an interpolation method that can be linear, cubic, among others, is used to estimate the responses of the other subcarriers.

$$H_p(k) = \frac{Y_P(k)}{X_p(k)} \tag{4}$$

In the case of linear estimation, we use (5).

$$H(k) = (1 - a) \cdot H_p(k) + a \cdot H_p(k + 1) \tag{5}$$

where $a$is a constant determined by the relation between the distance of the position of the subcarrier where it is desired to estimate the response of the channel to the position of the nearest pilot.

In the case of cubic interpolation, (6) is used.

$$H(k) = A(a) \cdot H_p(k) + B(a) \cdot H_p(k + 1) + C(a) \cdot z(k) + D(a) \cdot z(k + 1) \tag{6}$$

where $A(a)$, $B(a)$, $C(a)$, and $D(a)$ are constants related to a and $z(m)$ is the second derivative obtained fromthe pilot information matrix [12].

5. NEURAL NETWORKS

Neural networks can be understood as algorithms that seek to simulate the functioning of the human brain, starting from the construction of small computational entities that act as a human neuron [13]. To do so, we use units called perceptrons (Figure3) which have as input parameters an input (x), a gain (w), an activation function (f) and an output (y).

Figure 3. Perceptron.

The activation function can be linear or not depending on the desired application. The most common are the logarithm and the sigmoid. Perceptrons can be combined to form layers that are interconnected to generate larger and more complex networks. For the network to work correctly, it is necessary to perform the network training, using a set of known inputs and outputs, so that the gains are properly adjusted and the actual inputs generate the desired responses [14]. Among the training techniques, one of the most used is the Back-propagation Training Algorithm.

5.1. Back-propagation Training Algorithm

This technique uses a generalization of the Least Mean Square [15]. The activation function is defined as (7).

$$f(\alpha) = \frac{1}{1-e^{-\alpha}} \tag{7}$$

Initially random weights (w) are defined for the inputs (x). Then from the desired response (d) the error is calculated by (8).

$$erro = 0.5 \cdot (d - y)^2 \tag{8}$$

where y is the output of the activation function.

Then the weights are updated, using (9).

$$w(t + 1) = w(t) - \delta \cdot erro \cdot x \tag{9}$$

where t is the previous iteration of the algorithm has been set and δ is a chosen gain. Finally, the algorithm is repeated until the desired response is obtained at the output of the system and the weights are properly adjusted.

6. PREVIOUS DEVELOPED MODEL OF ISDB-T$_B$ USING FBMC

In [2] and [16], a modified ISDB-T$_B$ system using FBMC was developed, using GNU Radio Companion (GRC) as simulation environment. The channel estimation algorithm used did not employ any Artificial Intelligence feature. For this reason, the present work expands those articles by using a different approach based on Neural Networks.

6.1. GRC

The GRC is a computational tool that allows the development of processing blocks to for simulating communications systems [17]. It is an open source and free software that makes possible the interface between the created model and software radio peripherals [18]. It uses a Graphical User Interface (GUI) that facilitates the software handling [19] [20].

The block codes are created using the C/C++ or Phyton languages and the interconnection among these blocks is described only in Phyton [21].

The processed data sources on GRC are of complex (8 bytes), float (4 bytes), int (2 bytes), or byte (1 byte) types. The used terminology of GRC is presented on Table II [22].

Table 2. GRC terminology.

Name	Definition
Block	Processing Unit with ins or outs
Port	Block in or out
Source	Data generator
Sink	Data consumer
Connection	Data flow from an output to an input
Flow Graph	Set of blocks and connections
Item	Data unit
Stream	Continuous flow of items

Name	Definition
IO Signature	In and out description

Then using GRC and programming language the system can be simulated.

6.2. Flow Graph of ISDB-T$_B$ FBMC

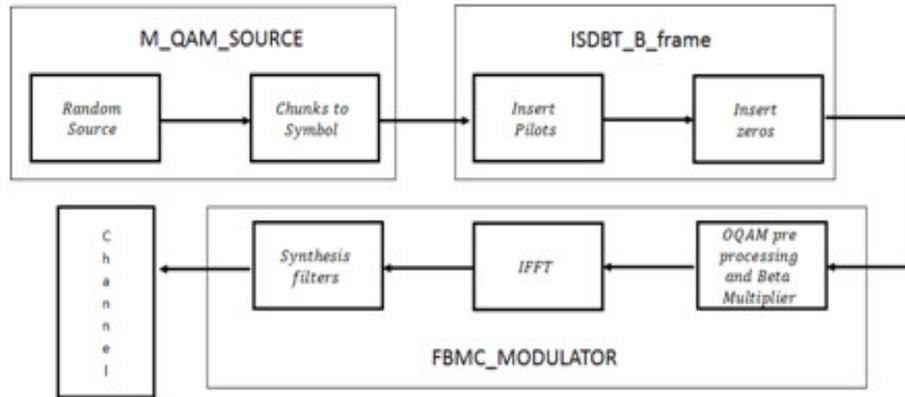The transmitter implemented on GRC is presented in the diagram shown on Figure 4.

Figure 4. ISDB-T$_B$ FBMC transmitter.

As it can be seen at the transmission side, an information source generates data that is modulated, formatted according to the standard, processed by OQAM pre-processing, multiplied by Beta, modulated through the IFFT and Synthesis filters and transmitted through the channel.

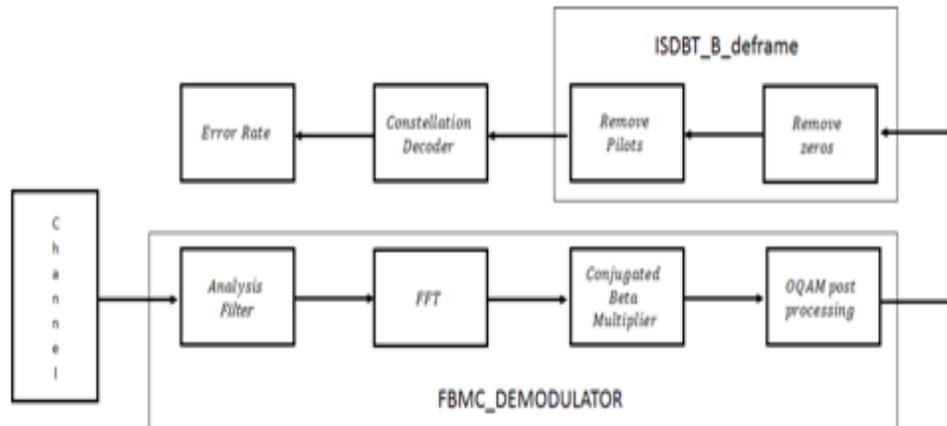The receiver diagram is shown in the Figure 5.

Figure 5. ISDB-T$_B$ FBMC receiver.

At the reception, the data goes through the analysis filters and FFT, multiplied by conjugated Beta, processed in OQAM post processing. After the zeros and pilots are removed, the data is decoded to calculate the Bit Error Rate (BER).

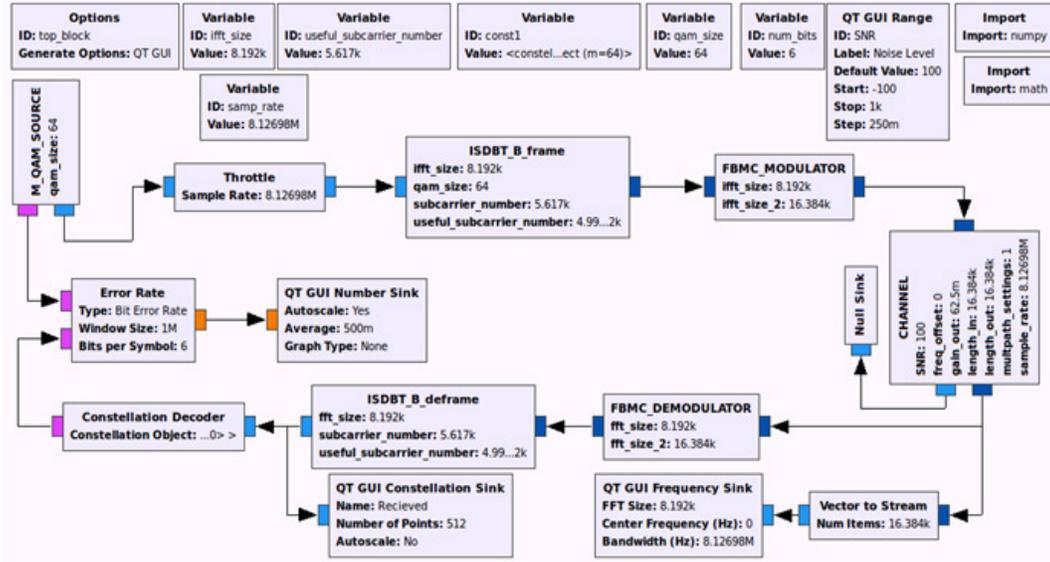The GRC environment flow graph is depicted in Figure 6.

Figure 6. Flow Graph of ISDB-T$_B$FBMC.

7. PROPOSED IA ESTIMATION METHOD

To accomplish the AI estimation, a simple NN with one perceptron for each real and imaginary part of received symbol is used. When the system initiates, four FBMC symbols are sent as training sequence and the weights of NN are trained using the Back-propagation method. Then regular operation starts and the received data symbols are equalized by the trained system.

The Flow Graph used was shown in Figure 5. Inside the "ISDBT_B_deframe" hierarchical block, three different channel estimators were implemented: the linear interpolation and the cubic interpolation, both at the time and frequency, and a neural network estimator trained with the Back-propagation technique (Figure 7).
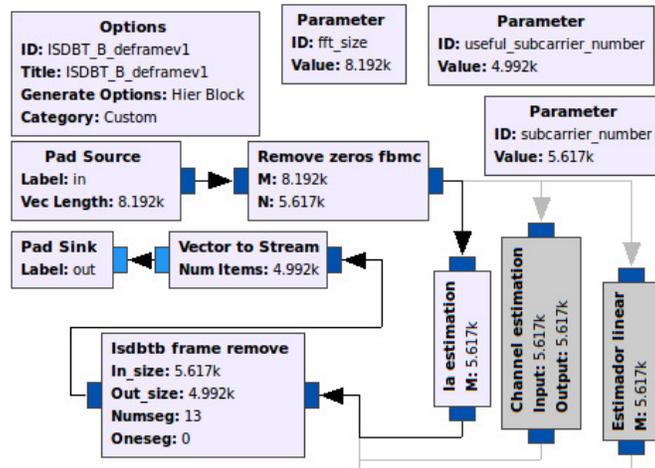

Figure 7. Content of the hierarchical block "ISDBT_B_deframe".

Thus, it was connected each channel estimator ate the system and the results could be collected.

5. RESULTS

The analysis were made using the ISDB-T$_B$ FBMC in mode 3 as in Table I. The Bit Error Rate (BER) curves were observed on two scenarios. The first is characterized by AWGN and modulation level equal to 64 (64-QAM) or 6 bits per symbol (Figure 8). The second uses the Brazil A digital TV channel model [21], which applies 6 paths with 0, 0.15, 2.2, 3.05, 5.86, and 5.93 microseconds of delay and 0, 13.8, 16.2, 14.9, 13.6, and 16.4dB of attenuation respectively, using the modulation level 4 (4-QAM) (Figure 9). In this last case, it was necessary to reduce the QAM modulation due to the long time required to perform the real-time simulation.

It can be observed that the use of neural networks brought to the system an increase of robustness at 10^{-5} BER level around to $2.1dB$ in the case only of AWGN and around to $2dB$ in the case which there is AWGN and multipath.
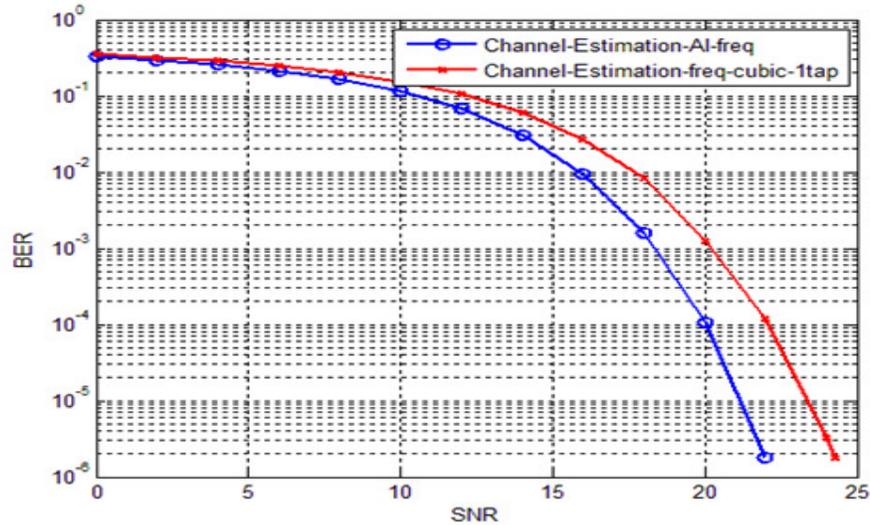

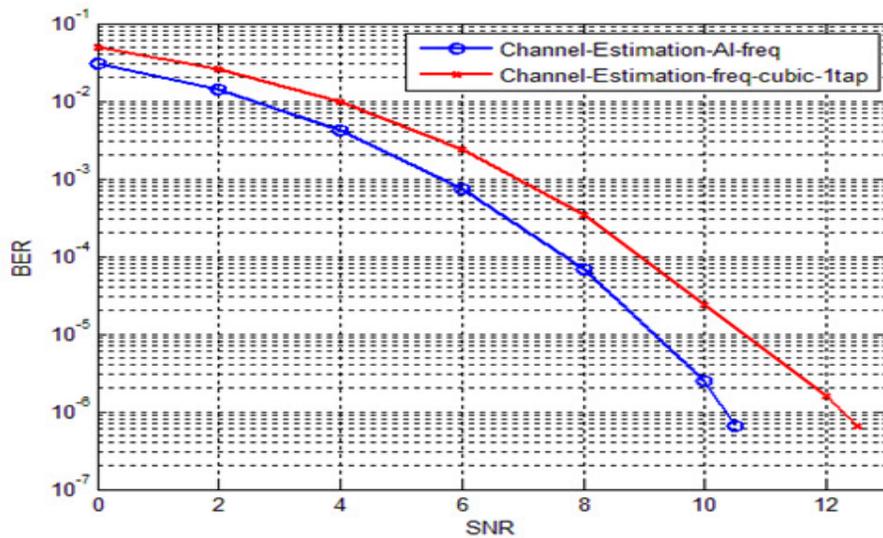Figure 8. BER curves of ISDB-T$_B$FBM Cusing 64-QAM with AWGN inserted.

Figure 9. BER curves of ISDB-T$_B$FBM Cusing 4-QAM with AWGN and multipath inserted.

6. CONCLUSION

Current digital TV standards were established to enable the broadcast of standard or high definition video. Nevertheless, nowadays consumers are demanding even higher definition content. For this reason, researchers are working on new standards that will enable a higher information transmission rate in terms of bits/s/Hz. This is the case of FBMC which was also proposed for forthcoming 5G cellular standard. But this increase in bit rate on the same frequency bandwidth implies in an increase in bit error rate if novel channel estimation and equalization are not created.

The use of artificial intelligence applied to channel estimators for FBMC opens a new field of research. The possibility of employing smart algorithms that can learn even in the presence of nonlinear interference is paramount to the success of more spectrally efficient modulation techniques.

In this paper, it was showed that the application of a simple neural network to the problem of channel estimation in the FBMC modified ISDB-Tb digital TV standard is feasible. The presented technique achieved an increase in 15%in robustnessin a channel with several multipath interferences. It was also shown that the Back-propagation training algorithm allows the estimation of the channel frequency response and contributes to minimize the bit error rate
In future, other kind of neural networks will be investigated, such as a recursive network, since it can improve the results and required computing effort.

REFERENCES

[1] Bellanger M, Mattera D, Tanda M. A filter bank multicarrier scheme running at symbol rate for future wireless systems. Wireless Telecommunications Symposium (WTS), 2015, 2015; 1–5, doi:10.1109/WTS. 2015.7117247.

[2] Almeida J. J. H, Akamine C, Lopes P. B. A proposal for the next generation of isdb-tb using fbmc in a sdr implementation on gnu radio environment. 2016 8th IEEE Latin-American Conference on Communications (LATINCOM), 2016; 1–6, doi:10. 1109/LATINCOM.2016.7811601

[3] Bellanger M. FBMC physical layer: a primer. PHYDYAS, January 2010; :1–31URL: http://www.ict-phydyas.org/teamspace/internal-folder/FBMC-Primer_06-2010.pdf.

[4] Andreas M. F. Wireless Communications. Second edition, John Wiley & Sons Ltd: California, 2011.

[5] Ishini, A. K., Akamine, C.; 2009. Técnicas de estimação de canal para o sistema isdb-tb. Revista de Radiodifusão.

[6] Russel S, Norvig, P. Inteligência Artificial. 2a ed., Rio de Janeiro: Campus, 2004.

[7] Lippmann R, An introduction to computing with neural nets, in IEEE ASSP Magazine, vol. 4, no. 2, pp. 4-22, Apr 1987. doi: 10.1109/MASSP.1987.1165576

[8] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 15601: Televisão digital terrestre - Sistema de transmissão. Rio de Janeiro, 2008.

[9]   Cherubini G, et al. Filter bank modulation techniques for very high speed digital subscriber lines. IEEE Communications Magazine, v. 38, n. 5, p. 98-104, May 2000.

[10]   Bellanger M. G. Specification and design of a prototype filter for filter bank based multicarrier transmission. Acoustics, Speech, and Signal Processing, 2001. Proceedings. (ICASSP '01). 2001 IEEE International Conference on, vol. 4, 2001; 2417–2420 vol.4, doi: 10.1109/ICASSP.2001.940488.

[11]   Siohan P, Siclet, C, Lacaille N. Analysis and design of OFDM/OQAM systems based on filterbank theory. IEEE Transactions on Signal Processing, v. 50, n. 5, p. 1170-1183, May 2002. ISSN 1053-587X.

[12]   Kang S. G, Ha Y. M, Joo E. K. A comparative investigation on channel estimation algorithms for ofdm in mobile communications. IEEE Transactions on Broadcasting, v. 49, n. 2, p. 142-149, June 2003.

[13]   Haykin S. Redes Neurais: Princípios e Prática. Bookman, 2001, Hamilton, Ontário, Canadá. 2ª Edição.

[14]   Burse K, Yadav R. N, Shivastava S. C. Channel Equalization Using Neural Networks: A Review, in IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), vol. 40, no. 3, pp. 352-357, May 2010.

[15]   Lippmann, R. An introduction to computing with neural nets, in IEEE ASSP Magazine, vol. 4, no. 2, pp. 4-22, Apr 1987. doi: 10.1109/MASSP.1987.1165576

[16]   Almeida J. H,Akamine C, Lopes P. B. A proposal for the next generation of ISDB-Tb using FBMC in a SDR implementation on GNU radio environment, IEEE Latin-American Transactions.2017, July. Available in:http://www.revistaieeela.pea.usp.br/issues/vol15issue7July2017/Vol15issue7July2017TLA.htm

[17]   Maheshwarappa MR, Bridges CP. Software defined radios for small satellites. Adaptive Hardware and Systems (AHS), 2014 NASA/ESA Conference on, 2014; 172–179, doi:10.1109/AHS.2014.6880174.

[18]   Stoica RA, Severi S, de Abreu GTF. On prototyping ieee802.11p channel estimators in real-world environments using gnuradio. 2016 IEEE Intelligent Vehicles Symposium (IV), 2016; 10–15, doi:10.1109/IVS.2016.7535356.

[19]   Larroca F, Guridi PF, Sena GG, Gonzlez-Barbone V, Belzarena P. gr-isdbt: An isdb-t 1-segment receiver implementation on gnu radio. Computing Conference (CLEI), 2015 Latin American, 2015; 1–8, doi:10.1109/CLEI.2015.7360050.

[20]   Müller A. DAB Software Receiver Implementation. Technical Report 2008. URL: http://people.ee.ethz.ch/˜andrmuel/files/gnuradio/.

[21]   Vachhani K, Mallari RA. Experimental study on wide band fm receiver using gnuradio and rtl-sdr. Advances in Computing, Communications and Informatics (ICACCI), 2015 International Conference on, 2015; 1810–1814, doi:10.1109/ICACCI.2015.7275878.

[22]   Gnuradio. http://gnuradio.org/redmine/projects/gnuradio/wiki 2016. Acessed in 07/11/2016.

[23]   ITU Radio communication Study Groups: Document 6E/TEMP/131-E, Guidelines And Techniques For The Evaluation Of DTTB Systems, 19 March 2003.

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