OFDM comparison with FFT and DWT processing for DVB-T2 wireless channels

Comparación OFDM con procesado FFT y DWT para canales inalámbricos DVB-T2.

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Abstract

Introduction− Recent studies on the FFT processing (Fast Fourier Transform) or DWT (Discrete Wavelet Transform) of the OFDM signal (Orthogonal Frequency Division Multiplexing) have shown pros and cons for DVB-T2 (Digital Video Broadcasting-Second Generation Terrestrial) radio communications; however, the benefits of both types of processing have yet to be compared for the same scenario.

Objective− The objective of this research is to compare the response of the wireless channel with AWGN noise (Additive White Gaussian Noise Channel) and Rayleigh and Rician fading in the UHF (Ultra High Frequency) band

Methodology− The transmission of DVB-T2 information with OFDM modulation and FFT and DWT processing was simulated in Matlab®, specifically in Simulink.

Results− The results of the study proved to be more efficient for DWT system than FFT system, due to the low rate of erroneous bits, spectral efficiency and reduction of the Peak-to-Average Power Ratio (PAPR), for Eb / No relations greater than 10dB.

Conclusions− In this article, we present the designs of both systems and the results of the research experience; likewise, the practical applicability of these systems is discussed, and improvements are suggested for future work.

Keywords− Wireless channel, AWGN noise, fading, broadband communications, DWT and FFT

Resumen

Introducción− Recientes estudios sobre el procesado FFT (Fast Fourier Transform) o DWT (Discrete Wavelet Transform) de la señal OFDM (Orthogonal Frequency Division Multiplexing) han demostrado pros y contras para comunicaciones de radio DVB-T2 (Digital Video Broadcasting – Second Generation Terrestrial); sin embargo, aún falta comparar las prestaciones de ambos tipos de procesamiento para el mismo escenario.

Objetivo− El objetivo de esta investigación es comparar la respuesta del canal inalámbrico con ruido AWGN (Additive White Gaussian Noise Channel) y desvanecimiento Rayleigh y Rician en la banda de UHF (Ultra High Frequency).

Metodología− Se simuló en Matlab®, específicamente en Simulink, la transmisión de información DVB-T2 con modulación OFDM y procesado FFT y DWT.

Resultados− Los resultados del estudio demostraron ser más eficientes para el sistema DWT en comparación con el Sistema FFT, por la baja tasa de bits errados, eficiencia espectral y reducción del cociente entre la potencia pico a promedio (PAPR: Peak-to-Average Power Ratio), para relaciones Eb/No mayores a 10dB.

Conclusiones− En este artículo se presentan los diseños de ambos sistemas y los resultados de la experiencia de investigación; así mismo, se discute la aplicabilidad práctica de estos sistemas y se sugieren mejoras para trabajos futuros.

Palabras clave− Canal inalámbrico; ruido AWGN; desvanecimientos; comunicaciones de banda ancha; procesado FFT y DWT; desempeño.

I. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) has been widely adopted in wireless communication. The aim of this paper is to compare the performance of an OFDM modulated signal with FFT and DWT processing when it is transmitted through a wireless channel with AWGN noise and Rayleigh and Rician fading. The OFDM scheme usually uses Fast Fourier Transform (FFT) to produce orthogonal sub-carriers; however, these systems have drawbacks in their transmission by high PAPR, low spectral efficiency and the frequency and/or time synchronization difficulty [1]. An alternative platform beside IFFT and FFT is the discrete wavelet transforms (DWT) which has been considered in Abdullah and Hussain [2]. It uses low pass filter (LPF) and high pass filter (HPF) operating as quadrature mirror filters satisfying perfect reconstruction and orthonormal bases properties.

This performance of OFDM modulated signal with FFT and DWT processing could be evaluated considering parameters such as BER, eye diagram, spectral efficiency, PAPR, and the constellation diagram; however, for this research, BER, spectral efficiency, and Peak-to-Average Power Ratio were considered. Applying wavelet packet transform with the OFDM improves the bit error rate, spectral efficiency and reduces the Peak-to-Average Power ratio performance over wireless communications. For this reason, OFDM-FFT tends to be replaced by OFDM–DWT [3].

II. Theoretical Framework

OFDM modulation is formed from the sum of N unique-carrier modulations typically QAM type using N different carrier frequencies. By this type of modulation, each symbol is transmitted occupying more time and less bandwidth regarding the unique carrier modulation, the transmission of each group of n symbols is transmitted in parallel, occupying adjacent carrier frequency, orthogonal and spaced between each other by an integer number of cycles (cyclic prefix). IFFT and FFT algorithms guarantee the orthogonally of the carriers in the receptor and minimize operations to be performed on the data. The IFFT processing, realized in the transmitter, transform the band base signal of the frequency domain to the time and the FFT makes the inverse function in the receiver.

Another processing that can be done through modulated signals OFDM is by Discrete Wavelet Transform (DWT), that is a projection of a signal over the vector space generated by the base functions (orthonormal or bi-orthogonal) that are obtained of the dilatation/contraction (according to an operator of scale change) and displacement of a passband function prototype, well localized both in time and in frequency called mother wavelet [4]. This function generates a family of Wavelets from expansions and continues translations of itself. If g is a mother Wavelet function, then the set {τt, Ds, g}, is the family generated by g for all expansions s and all displacements (t). Table 1 shows two features of the Haar Wavelet type. This family was used in the simulation by H. Paz [5].

Table 1. Definition of Time and Frequency Domain of the Haar Type Wavelet.

Time Domain	Frequency Domain
$g(t)=\begin{Bmatrix}1\\-1\end{Bmatrix}\begin{Bmatrix}-1/2\le t<0\\0\ge t\le -1/2\end{Bmatrix}$	$\hat{g}(\gamma)=2j\dfrac{sen^2\left(\pi\gamma/2\right)}{\pi\gamma}$

Source: Ecitronica Research Group

The processing through the wavelet transform is implemented quickly and recursively through the filter banks in quadrature. Detail coefficients *dj* corresponding to the high-frequency bands at the decomposition level J, are calculated as the discrete circumvolution of the in signal *x(k)* with the high-pass filter *g(k)*; and with the approximation coefficients (*dk)*, that correspond to the low frequency bands, are calculated as the discrete circumvolution in signal *x(k)* with the low-pass filter *h(k)*. These last ones, act as mirror filters in quadrature that allows perfect reconstruction of the processed signal orthonormal properties.

One advantage of FFT and DWT processing is to shape the power spectrum of the DVT-T2 signal to make it robust in AWGN noise, Rayleigh and Rician fading at the radio channel. OFDM processed WDT or FFT is currently used in ADSL: Asymmetric Digital Subscriber Line, PLC: Power Line Communications, digital TV under DRM standards: Digital Radio Mondiale and DAB: Digital Audio Broadcasting; and has been investigated by Schulze [6] and ETSI [7], [8] as the right modulation scheme for wireless noisy communication channels (Wi-Fi and WiMAX, fourth-generation telephony LTE and UWB: Ultra-Wide Band).

An OFDM variation is the introduction of a channel coding to multiplexing called COFDM (Coded Orthogonal Frequency Division Multiplexing). This scheme is characterized by its resistance to multipath effects, resistance to small changes in signal attenuation and phase distortion, networks single frequency use permission and ability to transmit a signal to mobile receivers [9].

The communication channel where an OFDM signal propagates is characterized by its impulse response of a given duration and properties over time changes. In this context, the knowledge of the propagation characteristics is a key for better use from digital communications systems to new application scenarios. Respecting to the characteristics of fading in the channel, several types are identified in the Fig. 1.

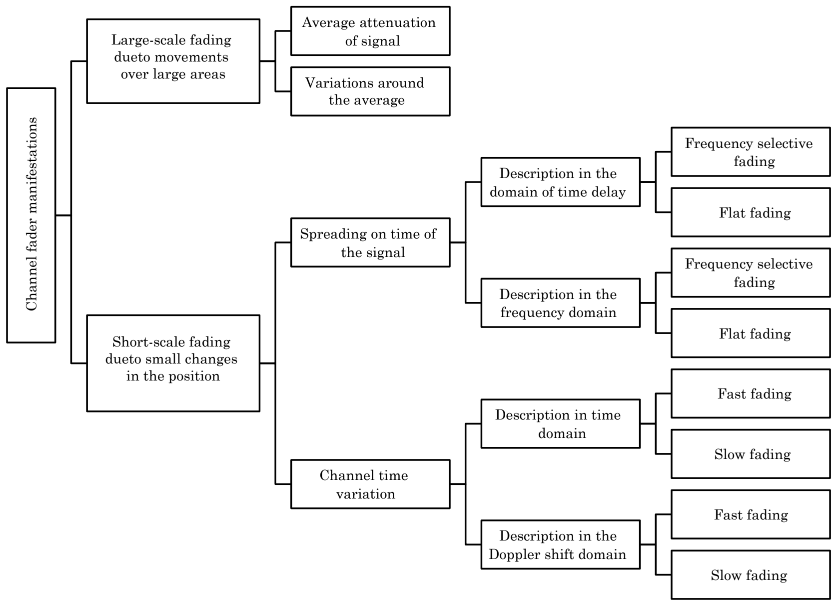

Fig. 1. Fading types in a wireless channel.
Source: Authors.

The simplest way to deal with fading is to use during transmission a big enough power or a binary speed small enough, for the ratio between the symbol energy and the noise power high enough to maintain an efficient error rate during a specified time fraction [10]. This, equivalent to design the system for the worst channel conditions are evidently inefficient because much of the time power is wasted or transmissions are at a lower rate than the one that could be obtained in the channel.

Another line, commonly used to try fading mitigation is diversity, both time (where could include error correction code too) or frequency (multicarrier or spread spectrum). In this kind of procedures, the signal is transmitted over several channels with independent fading, so that the probability for highly attenuated links is small. Although these methods can provide considerable improvements in the usefulness of the system, it is at the expense of a wider bandwidth or an increment in the equipment cost.

In any case, these technics do not try to exploit temporal selectivity of the link, but to prevent that the system became unusable during deep fading of the received signal, ending up in poor utilization of channel total capacity. Significant improvements can be obtained by techniques that adapt to the instantaneous channel state methods of reception, transmission, or both.

An interesting possibility, if a return link exists, is to allow the receiver to monitor channel conditions and request during communication, changes in the transmitted signal suited to the conditions of the link that have been measure instantly. This leads to adaptive technologies for transmission that are designed with the objective of improving the transmitted average power of the system parameters, reception error rate or spectral efficiency (transmission speed).

The effect of fading is the decreasing of the received power and a distortion of its waveform. Some factors that influence the plane and selective fading of a DVB-T2 signal, OFDM modulated, is the multipath due to reflection and signal dispersion. Likewise, variations in the time and frequency of physical channel characteristics contribute to the deterioration of the propagated signal.

A wireless channel for the digital television subbands IV and V, between 470MHz-860MHz, with background noise and presence of multipath, can be characterized by the Gaussian, Rayleigh and Rician distributions; because the variable statistical nature in time of the envelope of the received signal with flat fading (Gaussian) as well as the envelope of an individual component with multipath (Rayleigh and/or Rician), are reasonably well described by these distributions , and of which, several examples are known in wireless communications.

Gaussian distribution allows to reproduce simple and continuous mathematical models of the background noise of a radio channel that are useful to make an idea of the behavior of a DVB-T2 signal to be transmitted through a radio system with amplitude variations and small phase between the frequency components that arrive at the receiver; these variations are correlated because they are all subject to similar amounts of reinforcement or cancellation. Does not account for selecting frequency fading, ISI, nonlinearity or slow cyclic dispersion in the channel signal.

Meanwhile, in the fading channels, a process of dispersion (scattering) occurs and is characterized by a signal amplitude and phase varying randomly with respect to its long-term and mid-term. If the received signal comprises dispersed spectral components uncorrelated, the process of fading is known as Rayleigh type, since the variable statistical nature over time of the envelope of the received signal and the envelope of a single component with multipath is described quite well by that distribution [5]. Meanwhile, a significant component is present in the waveform of the received signal, such as it occurs when an impulse noise in the channel is present, the process is designated as Rician fading. This fading will be simulated in Matlab® by a random, partial or total cancellation of some spectral components of the signal due to the arrival of the signal to the receiver by several different paths and at least one of those paths with continuous changes (lengthening or shortening of the trajectory which in turn represents the variable magnitude of the impulse noise).

III. Methodology

The investigation started from a theoretical review of the propagation characteristics of an electromagnetic wave in the UHF band. The specific case of the spread of the DVB-T2 signal in the 470MHz-860MHz band was examined. Given the problems of plane and selective frequency fading of the radio channel for such communications; and following the technical recommendations for the implementation of DVB-T2 standard for digital television in Colombia, the transmitter-channel-receiver architectures were implemented for simulation in Matlab® Simulink.

Table 2. Characteristics of the Communications System With OFDM-FFT Modulation

FFT size	8192
Bandwidth (MHz)	7.61
Guard interval	1024 (1/8)
Chip interval	8192
Approximate maximum distance between transmitters (Km)	67.2
Number of carriers	6817
Another carries	Continuous pilot: 117 Scattered pilots: 524 TPS (Transmission Parameter Signalling): 68
Useful carriers	6048
Symbol duration (ns)	0.896
Guard interval duration (ns)	0.112
Total symbol duration (ns)	1.008
Spacing between carriers (KHz)	1.116
Network Solomon code rate	7/8

Source: Authors.

In the OFDM system with FFT processing, the input signal to the modulator is conformed by 64 samples per frame using two tones at 5MHz and 10MHz, respectively. The OFDM-FFT processing followed the specifications of table 2.

Meanwhile, basic input information for DWT is specified through the election of a countable set of points of the time-scale plane and of a mother Wavelet; and is implemented through quadrature filter banks, which make possible to perform the transform quickly and recursively by a decomposition tree.

The Matlab BERTool favored the analysis for different channel models: AWGN, Rayleigh Fading and Rician Fading based on the ratio of energy per bit vs the power spectral density of the noise (Eb/No). To assess the probability of system failure, a ratio of Eb/No of 0-14dB was chosen and different factors according to the channel condition into account were adding.

The analysis of the simulation results was focused on the performance of OFDM multicarrier modulation by FFT and DWT processing, with the unique-carrier modulation scheme of 16-QAM on Gaussian, Rayleigh and Rician wireless channels; these considerations have a good approximation to actual radio channel for digital television standard adopted for Colombia. With the analysis of the results obtained, some findings presented below were inferred.

IV. Results And Analysis

The behavior of the OFDM modulation with DWT and FFT processing and an Eb / No of 10 (dB) compared to an AWGN channel is shown in Fig. 2 and 3.

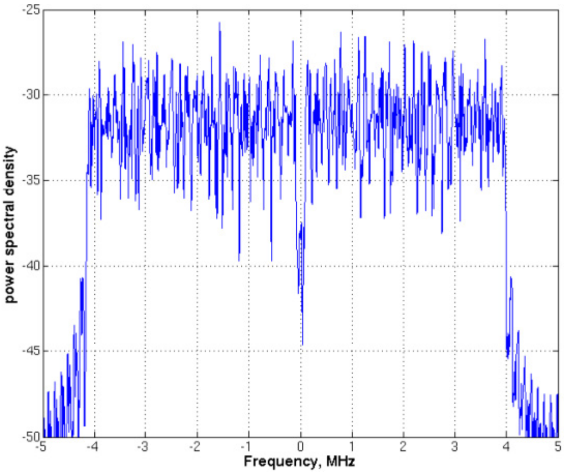

Fig. 2. Spectral power density of an OFDM 8K with FFT processing, Eb/No= 10 (dB) and guard intervals Δ=Tu/4 AWGN (10dB). Source: Matlab®, Authors.

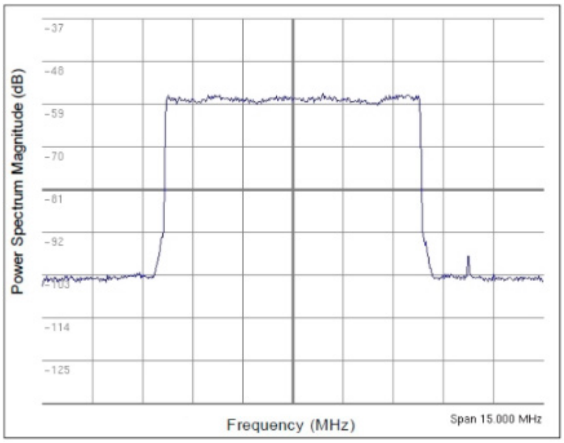

Fig. 3. Spectral power density of an OFDM 8K with DWT processing, and Eb/No= 10 (dB). Source: Matlab®, Authors.

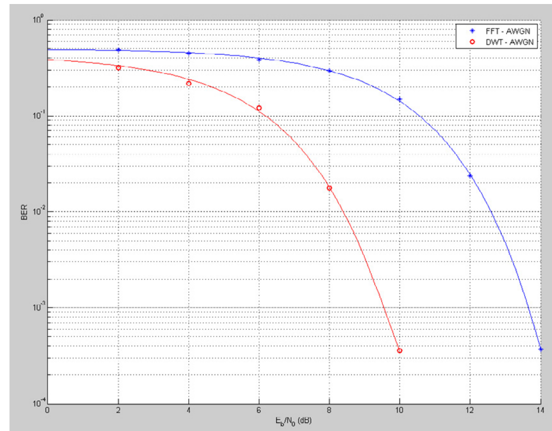

Fig. 4. BER values with relations Eb/No from 1-14dB to channels AWGN. Source: Matlab®, Authors.

In the two previous figures (2 and 3), it can be seen that the pass of a modulated signal through a channel with AWGN features, reproduce transmission situations with presence of shallow and flat noise that affects the entire spectrum of the transmitted signal; phenomenon is more impacted by the signal processing-FFT OFDM because it requires additional spectrum for adding cyclic prefix. Likewise, it is shown in Fig. 2, that when a deep fade more affects the amplitude of the modulated multicarrier signal, the symbols become very close and cannot be demodulated correctly by the receiver, therefore infers more loss of information in the system.

The best performing DWT-OFDM versus AWGN channel is evidence that it has bit error rate lower for Eb/No ratio 10dB (Fig. 4). Coincides with the results of Gupta, Torry, Vats and Garg [11].

The modeling of a Rayleigh fading channel in *Matlab* ® is generally a radio link with NLOS multipath, which is specific to DVB-T2 signals propagating in the UHF band. The effects of a multipath channel are fast, deep and cause serious damage to the multi-carrier signal; for simulating multipath phenomenon, two paths shown in Fig. 5, it is equivalent to simulate *N* different paths (with an accuracy of 80-90%) were used.

The simulation was performed with a delay time less than symbol (1nS) and with an attenuation of 3 dB additional route in respect of the reference path having flat fading. In addition, the frequency shift (Doppler Shift) was set up with the value of 290 (Hz). This value was found experimentally and represents the offset of the multipath between the transmitter and receiver.

To evaluate the behavior of the ratio Eb/No vs. the probability of system failure Jakes type the function was chosen. In Fig. 6, the DWT-OFDM multicarrier system has the wrong rate less than that produced by FFT-OFDM for the same bit error probability that decreases the bandwidth and ISI; furthermore, the curve of the second type of processing has a continuation of the almost horizontal slope; that is to say that for older SNRs 10dB, and even greater than 40dB, the error remains almost constant (BER = $10e^{-1}$).

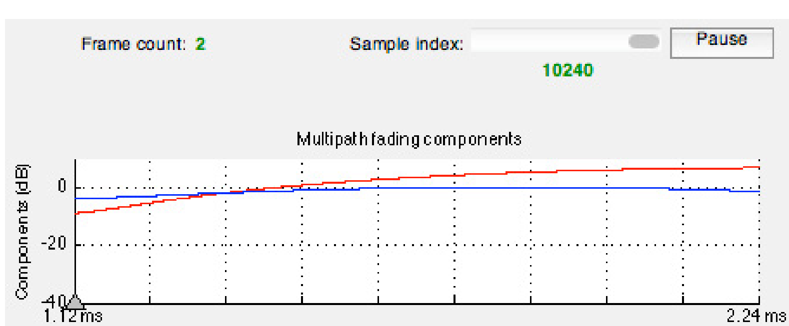

Fig. 5. Paths chosen for simulating channel with fading Rayleigh. 3dB attenuation for additional path and multipath signals lower than 1nS. Source: Matlab® Imagines, Authors.

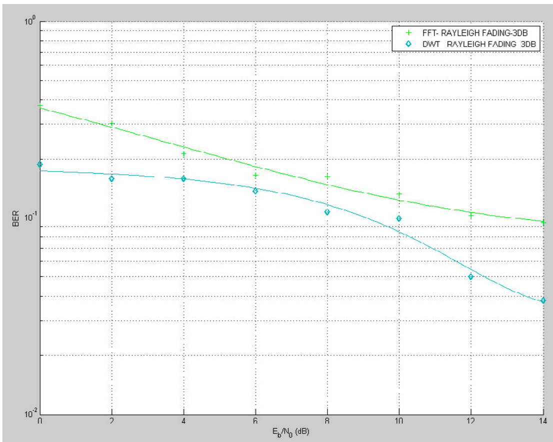

Fig. 6. BER values with relations Eb/No from 1-14dB for RAYLEIGH channels. Source: Matlab®, Authors.

To simulate the system under study in the presence of Rician fading channel is part of a channel with multipath Rayleigh's, yet another way that has a direct line of sight with the receiver, therefore, has higher gain; last leg configuration represents the greatest possible proximity between transmitter and receiver without obstacles. The existence of a direct line of sight increases efficiency for a given symbol period, as the temporal correlation between channel samples is higher and the inter-carrier interference is reduced. In this context, the higher the gain of additional travel better combat multipath fading, producing better performance and lower channel path gain, the channel behave like submit Raleigh fading. The system simulation was performed with the same parameters that were used for the Rayleigh fading, most direct path to a gain of 10 times.

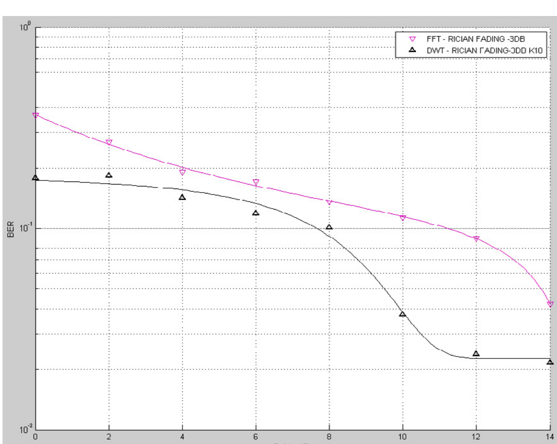

Fig. 7. BER values with relations Eb/No from 1-14dB for RICIAN channels Source: Matlab®, Authors.

As shown in the Fig. 7, the performance of DWT-OFDM processing is higher compared to FFT-OFDM, because always less error-prone evidence for the same Eb/No, but we can say that, regardless of the quality of the channel, provided there multipath fading, the transmission will not be error-free, regardless of the defendants made in the communications system DVB-T2 [12].

In summary and as shown in Table 3 and Fig. 8, the OFDM system -DWT (Haar family) shows superior performance compared to OFDM systems- FFT for channels with the presence of additive white Gaussian noise (AWGN) and Rayleigh fading. System performance is described in the bit error rate (BER) as a function of the ratio of bit energy to noise density ratio (Eb / No): for AWGN channels, the transmission of OFDM signals processed -FFT require more than 4dB (Eb/No) OFDM- DWT (Haar family) to achieve the same error probability 10^{-3}; while for Rayleigh channels, the transmission of OFDM signals processed - FFT require more than 8dB (Eb/No) OFDM-DWT (Haar family) to achieve the same error probability of 10^{-1}.

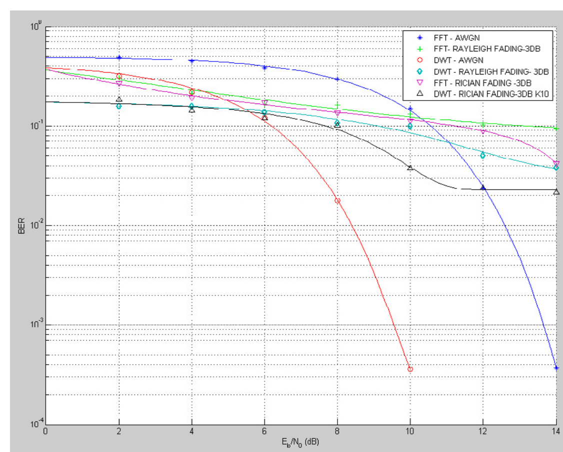

Fig. 8. BER values with relations Eb/No from 1-14dB for AWGN, RAYLEIGH, and RICIAN channels. Source: Matlab®, Authors.

In this perspective, OFDM signals transmitted-DWT (Haar family) Save 12.5% over OFDM spectrum - FFT (with cyclic prefix: CP = Ts/8 = 0.112ns) for the same bit rate (Fig. 4 and Fig. 5); consequently, their wider bandwidth could be used to transmit more services.

Moreover, the ratio between the level of peak power and average value: PAPR, for a predetermined time (one of the main problems for multicarrier modulation OFDM) for processed OFDM signals – FFT, exceed their counterparts OFDM - DWT (family Haar) by approximately 7dB to identical transmission characteristics (Fig. 4); rate plus the presence of peaks near 85% is evident. Consequently, the OFDM system - DWT (Haar family) low peak power amplifier and reduces the amount of average power used in the transmitting station, thereby enabling the amplifiers to work closer to the saturation limit. For these reasons, the Discrete Wavelet transform has been considered as an alternative platform for the replacement of IFFT and FFT [2],[3],[10],[13]. For a more rigorous comparison of practical implementation is suggested to evaluate other factors such as resource availability, system complexity, and cost.

V. Results

OFDM can be implemented digitally using FFT o DWT. The multicarrier technique with processed WDT is better in frequency selective. Independent of the processing technique used in OFDM, as N increases the peak-to-average ratio decreases. In both processed: FFT o DWT, the addition of cyclic prefix combats time dispersion: it accommodates the decaying transient of the previous symbol (ISI) and avoids the initial transient reaches the current symbol (ICI). Finally, OFDM with processed WDT or FFT can reduce adjacent channel interference with pulse shaping.

The results of the simulation of a DVB-T2 OFDM processing system - DWT (Haar family), have shown better performance (low error probability, high spectral efficiency, and better PAPR) for the presence of channels with additive white Gaussian noise (AWGN) and Rayleigh and Rician fading. Furthermore, itself adopting a correct configuration of transmission parameters DVB-T2 and incorporates some innovations in the level of compatible application with the standard [14] could meet the requirements of the table 3 that are necessary to ensure good transmission of digital television.

However, faced with the problem of fading, noise and interference of the radio channel, the DVB-T2 signal becomes robust due to the use of new error correction mechanisms (BCH + LDPC) and insertion techniques as hierarchical modulation characteristics, time interleaving, rotated constellations and space diversity transmission for antennas (Fig. 9).

For example, the DVB-T with hierarchical modulation (multi-resolution) transmission, gives the possibility of transmitting two independent data streams with different priority [8]. One of the two flows would be used to disseminate information to fixed receivers, and the other, more error protection (high priority), would be for phones. Another possibility is that high priority data intended for transmission to remote areas of the transmitter, cases in which the Eb/No less; while the low priority flow is assigned for transmissions closest to the transmitter (higher Eb/No) areas. The high priority flow is modulated with a few elements of the constellation, for example, QPSK, while 16QAM is used to modulate the low priority data. Formally, it is dealing with a 64QAM modulation scheme in the hierarchical interpretation is as a combination of two modulations, one 16QAM and QPSK another, which is designated as “QPSK in 64QAM”. The combined rate of the two partial flows is the same as that of a flow of 64QAM [15].

Table 3. Minimum Requirements Based On Dvb-T

Parameter DVB-T	Requirement
Quadrature error	9dB-13dB
Intermodulation (Shoulder) before the filter mask	It must be less than -36dB in Fc±3.2MHz.
Mask filter (after filter).	It must not attenuate over 0.3dB to ± 3.2MHz, the thresholds are: Not critical mask: -41.5dB and critical mask: -51.5dB
Spectral mask	For transmitters powers greater than or equal to 25W. It is equals to -31.5 - (-83) = 51.5dB. And lower power transmitters to 25W: 12.5 - (-39) = 51.5dB (ITU-R SM.1792, II, 2007.)
Modulation Error Ratio: MER.	≥33dB
Amplitude vs. frequency response	Must be better than ± 5dB
Frequency vs. Group delay response	Must be less than 0.1µs pp
Spurious level	Must be less than -60dBc.
Harmonics	Must be less than -80dBc
Frequency precision	Must be better than ± 100Hz
Error of constellation phase	Must be less than 0.5°
External signal input frequency for synchronization	10MHz and 1 pps.
Phase noise	Must be less than -80dB at 100Hz.
Efficiency	Minimum 20%: MER=33dB and Shoulder=36dB

Source: Commission for Communications regulation of Colombia. CRC. Yellow paper. Regulatory infrastructure. June of 2013

When the reception conditions are good, both flows are present in the receiver and it works with lower priority, but higher resolution. If the Eb/No decreases, the reception conditions deteriorate and the error rate increases 16QAM constellation, precluding satisfactory reception. In this situation, the receiver “is” with QPSK, more robust constellation, but keeping the receipt in acceptable condition. This modulation technique despite being validated by the DVB standards organization has not been currently implemented in commercial DTT networks in the world.

The robustness of the information signal can also be reinforced with DWT-OFDM processing, which could be achieved by an increase in coverage or transmission power savings (Table 4).

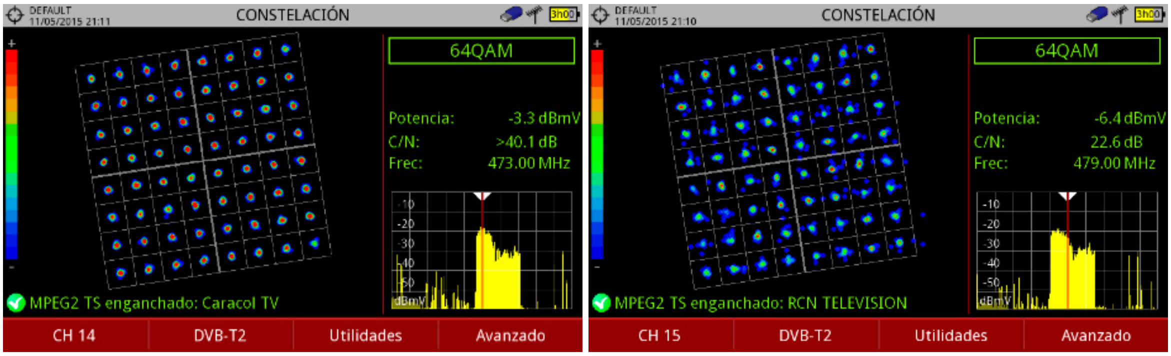

Fig. 9. 64QAM constellation diagram rotated for DVB-T2 signals from CARACOL and RCN.
Source: Authors.

Table 4. Comparison Table OFDM with FFT Processing and DWT

Parameter comparison	OFDM with FFT processing	OFDM with DWT processing
Spectral efficiency	Loss of spectral efficiency due to the guard interval. The cyclic prefix bandwidth increases by 25%.	Good spectral efficiency by allowing more channels in the same bandwidth OFDM-FFT.
Transmit Power	The multi-carrier signals with high peak power ratio to average power (PAPR). Require large signal linear amplifiers; Otherwise, performance degradation occurs and the power out of band will be enhanced.	The PAPR is limited by intermodulation distortion. The imperfection of the linearity of radio electric transmitters single carrier QAM modulation is expressed in terms of the level of the intermodulation products
Complexity of transceivers.	Independent modules for performing IFFT and FFT. Synchronization issues in the receiver. System complexity is increased by increasing the sup-carriers.	Simple: low complexity in hardware implementation, based on processing by filters. Also, easy access to memory.
Processing times	Higher: it manipulates sequence data expressed in real part and imaginary	Lower less calculation, reduction of sub-bands decompositions of the signal.
DVB-T2 signal behavior in front of channels with AWGN, with Rayleigh and Rician fading	Works better with standing waves because it is based on functions well localized in frequency but not in time, therefore, signals intermittently (Rayleigh and Rician phenomena), Fourier loses almost all temporal information.	It is more efficient to non-stationary signals because noise filtering gives better results; Also, retrieve more information about the spectrum of the DVB-T2 signal versus time, In consequence, it has a better performance against multipath fading (Rayleigh and Rician).

Source: Authors.

VI. Future work:

The increasing application of digital wireless communications needs constant development of techniques, protocols and, transmission technologies that allow greater capacity of services of communication in a hostile conduit with limited spectrum allocation, as it happens in a wireless channel.

VII. Conclusions

The choice of an optimum combination of technical parameters OFDM with DWT processing under propagation conditions with AWGN noise and Rayleigh and Rician Fading, can ensure that the signal reception of digital TV DVB-T2 adheres to the requirements of low bits error rate, spectral efficiency and reduction of the Peak-to-Average Power ratio (PAPR), for relations Eb / No greater than 10dB; however, a major problem that needs to be addressed is the high sensitivity to synchronization errors of the OFDM transmission technique with FFT and DWT processing.

An OFDM signal with FFT or DWT processing has the advantage, that when transmitting on a channel with frequency selective fading, the OFDM signal spectrum is affected only in the subcarriers that are affected by that fading. Thus, if a symbol is destroyed, lost only a ratio 1 / n bits, which is relatively small and can be recovered by using a channel coding strategy carried out in reverse order in the receiver.

A good estimate of the channel is required for the adaptation of the modulation, the dynamic allocation of spectrum, equalization at the receiver data and estimating the ratio of bit energy to noise density. Likewise, the computational cost of computing the DWT by a bank of FIR filters can be made smaller subsampled the FFT (techniques multi-rate digital signal processing) to a sample of n symbols.

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