Rotated Constellations for DVB-T2

D. Perez-Calderón[#], C. Oria[#], J. García[#], P. López[#], V. Baena[#], I. Lacadena[*]

[#] *Electronic Engineering Department, University of Seville*

Escuela Superior de Ingenieros. Avda. Descubrimientos s/n. 41092. Sevilla, Spain

{dperez, cinta.oria, josegargo, plopez, baena}@gte.esi.us.es

[*]*SIDSA, PTM Torres Quevedo, 1 E-28760 Tres Cantos, Madrid, Spain*

lacadena@sidsa.es

Abstract— **In this paper, the performance of the rotated constellation technique is analyzed in the context of the forthcoming Second Generation Digital Video Broadcasting (DVB-T2) standard. This technique increases the robustness of the DVB-T2 receiver in severe multipath propagation scenarios. Although the rotated constellations improve the performance of the system in all the simulated multipath channels, this improvement is particularly great in channels with erasure events where for some coding rates the non-rotated constellations are not able to correctly decode the received information.**

***Keywords*— DVB-T2, constellation rotation, digital television, OFDM, fading channels.**

I. Introduction

The availability of frequencies in the UHF band after the upcoming full analog television switch-off in Europe and the new opportunities in digital terrestrial television markets based on new multichannel HDTV (High Definition Television) services have generated an impetus to update the mature and well-established standard DVB-T (Digital Video Broadcasting Terrestrial). Consequently, the DVB (Digital Video Broadcasting) consortium has developed a new digital terrestrial television system, known as DVB-T2 (Second Generation Digital Video Broadcasting Terrestrial) [1] to introduce HDTV services or new datacasting services. The DVB-T2 technology will not replace its predecessor DVB-T, but rather both systems will coexist in the market for many years. The DVB Steering Board approved the DVB-T2 specification at the end of June 2008. It was released as a DVB Bluebook [1] and sent to the ETSI (European Telecommunications Standard Institute) for standardization.

The framework for the development of the DVB-T2 specification has been the fulfillment of a set of Commercial Requirements defined in [2] where the key requirements were:

1. The DVB-T2 standard should provide a minimum capacity increase of a thirty per cent over the existing DVB-T specification.
2. A flexible and configurable robustness for each transmitted service.

These requirements were fulfilled by using state of the art technology like the rotated constellations. This technique provides additional robustness in multipath propagation scenarios. Although this technique is not new and many studies and analysis can be found in the literature [3]-[8], this paper is the first one that shows the performance results of the rotated constellations in a fully compliant DVB-T2 system.

The rest of the paper is organized as follows. Section II presents an overview of the forthcoming DVB-T2 standard. In section III, the principles of the rotated constellation technique are explained. In section IV, simulation results are shown and analyzed. Finally, the conclusions are summarized in section VI.

II. Second Generation DVB-T

The DVB-T2 specification developed by the DVB Project describes a digital terrestrial transmission system for delivering audio, video and data services, and specifically, HDTV services or new datacasting services. This standard uses the same frequency spectrum than DVB-T, the UHF band, allowing for compatibility with Geneva 2006 Agreement [9]. This new standard has been fundamentally designed for fixed reception (receiver devices with roof-top and set-top antennas). However, the DVB-T2 reception is also feasible in portable and mobile devices (PCs, laptops or in-car receivers).

A. *Physical-layer Architecture*

In Fig. 1, a block diagram of a DVB-T2 transmitter is depicted. The DVB-T2 standard offers a physical-layer that introduces new modulation and coding techniques in comparison with DVB-T. Besides, the range of standard COFDM (Coded Orthogonal Frequency Division Multiplexing) parameters has been extended respect to DVB-T in order to provide a greater flexibility, and consequently, a greater set of configuration options is possible. Table I briefly presents possible values of the main COFDM parameters for the DVB-T2 standard.

The fundamental aim of the inclusion of the transmission modes 16k and 32k is the guard interval overhead reduction. This implies a considerable increase of the system throughput for larger FFT (Fast Fourier Transform) sizes. These new transmission modes are not appropriate for mobile reception since the reduced carrier spacing limits the Doppler frequency that can be tolerated due to ICI (Inter Carrier Interference). It is also possible to choose between normal or extended carrier modes. The extended carrier mode allows the use of more carriers per symbol and consequently, it presents the benefit of increasing the data capacity.

In terms of error correction, LDPC (Low Density Parity Check) [10]-[11] are used combined with a BCH (Bose-

Chaudhuri-Hocquengham) encoder, as in DVB-S2 (Second Generation Digital Video Broadcasting Satellite) [12]. Since this coding scheme greatly outperform the performances of the convolutional and Reed Solomon codes used in DVB-T, DVB-T2 introduces a higher order constellation, a 256-QAM which increases the spectral efficiency and bit rate.

In addition, two new bandwidths are included: 10MHz, useful for professional applications, and 1.712 MHz, to allow DVB-T2 to be used in narrower RF channel, for instance, in band III or L-band. With respect to pilots, DVB-T2 presents eight patterns of scattered pilots in comparison with the static pattern defined in DVB-T. These patterns are chosen depending on the selected FFT size and guard interval. This configurability allows a significant reduction of the scattered pilot overhead. With respect to the continual pilots, its number is reduced for high transmission modes, so the overhead is also reduced without any performance loss.

TABLE I
COFDM PARAMETERS IN DVB-T2

Parameters	Values	
	Also available in DVB-T	**Only available in DVB-T2**
Transmission Modes	2k, 8k	1k, 4k, 16k, 32k
Guard intervals	1/4, 1/8, 1/16, 1/32	19/256, 19/128, 1/128
Order Constellation	QPSK, 16-QAM, 64-QAM	256-QAM
Bandwidth	5, 6, 7, 8 MHz	1.712 , 10 MHz

Optionally, the DVB-T2 standard can supports MISO (Multiple Input Single Output) which can improve the overall performances in SFNs (Single Frequency Networks) using a transmitter diversity technique based on Alamouti encoding [13].

DVB-T2 proposes also two complementary techniques for PAPR (Peak to Average Power Ratio) reduction. The first one is Active Constellation Extension (ACE) [14] that provides greater benefits in lower order constellations, whereas the second one, the Tone Reservation method [15], provides greater benefits in higher order constellations. Both can be applied simultaneously.

In the Bit Interleaved Coded Modulation (BICM) block [16]-[17], four interleaving stages are included in the DVB-T2 specification: bit, cell and time interleaver, carried out in the BICM block, and frequency interleaver, run in Frame Builder block. Finally, the rotated constellations technique is included in this new specification to achieve a better performance in difficult propagation scenarios.

In terms of framing structure, the DVB-T2 system input is one or more logical data streams, which are carried in individual Physical Layer Pipes (PLPs). Each PLP can have different physical parameters, like coding rate or constellation, according to the services' particular needs. These PLPs are carried in data symbols that are part of the T2-frames. Each T2-frame begins with a preamble made of special symbols: the P1 and P2 symbols. Those symbols are used for time and frequency synchronization and carry layer 1 signaling allowing the receiver to know where the PLPs within the T2-frames are located.

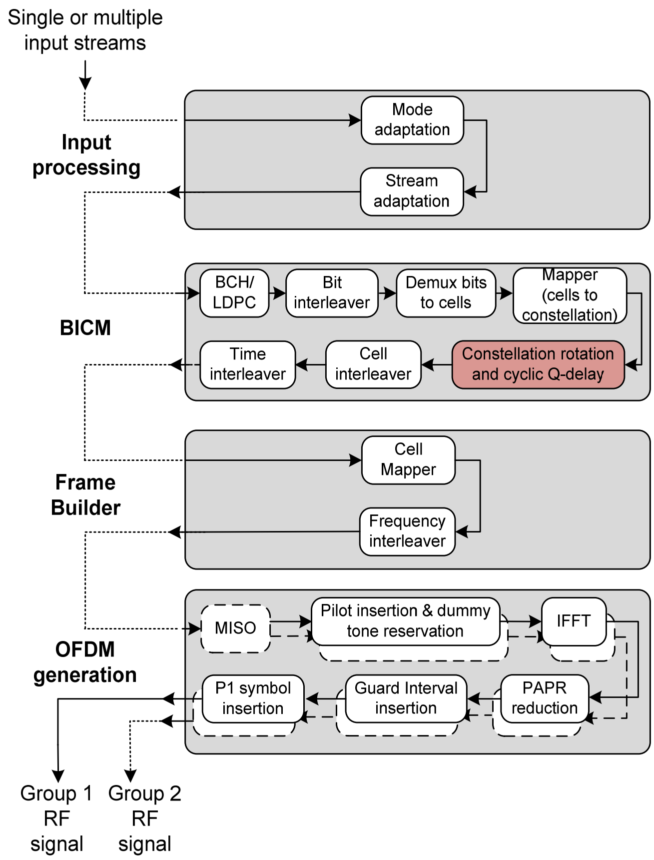

Fig. 1 Physical-layer architecture of a DVB-T2 transmitter.

III. ROTATED CONSTELLATIONS

The rotated constellations, originally suggested in [3], have been introduced in the upcoming DVB-T2 standard. This technique was studied in [4], [5] as a technique to improve the diversity order of BICM scheme over fading channels. In [6] a study about the application of this technique to advanced Forward Error Correcting (FEC) code solutions such as turbo or LDPC codes is presented. On the other hand, this technology has been previously applied in different systems as MC-CDMA (Multi-Carrier Code-Division Multiple Access) [7]. This method is also known as Signal Space Diversity (SSP), since the final purpose is to increase the diversity order, that is, to achieve a redundancy in information bits of the coded modulation, to improve the receiver performance in severe propagation scenarios. In this section, the principles of this technique are presented. Then, a study in detail is carried out in the context of DVB-T2.

A. *Principles*

In a non-rotated constellation, the receiver needs both in-phase (I) and quadrature (Q) components of one constellation point to identify what information was transmitted, because the estimation of I does not give information about Q component. Besides, both components suffer the same fading when the signal is propagated over the channel.

In the case of a rotated constellation, a certain rotation angle is applied in the complex plane to a classical signal constellation, such that each component, I or Q, has enough information by its own to guess which was the transmitted symbol. The appearance of a rotated constellation is depicted in Fig. 2, where the corresponding conventional constellation is also plotted. Two examples are shown, a QPSK (Fig. 2a) and 16-QAM (Fig. 2b) constellation.

After the rotation, an interleaving process is performed only over the Q components. This is done in order to transmit separately the I and Q of a constellation point in different carriers and even in different time slots. Thus, if one of the components is destroyed or affected by a deep selective fading of the channel, the other component can be used to recover the information. Additionally, due to this interleaving process, the in-phase and quadrature components of a transmitted symbol are affected by independent fadings. The result of this technique is to increase the robustness of the receiver in propagation scenarios with deep fades and/or erasure events.

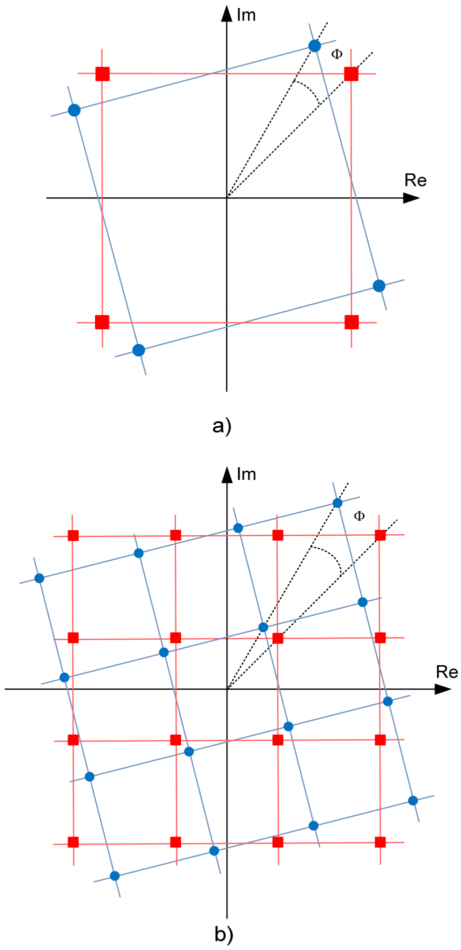

Fig. 2 a) Rotated and classic QPSK constellations. b) Rotated and classic 16-QAM constellations. The red square points represent the conventional constellation; the blue circles show the constellation after rotating.

B. Implementation in DVB-T2

In a DVB-T2 system, the block that carries out the constellation rotation is included in the BICM scheme (see Fig. 1), after the bit interleaver and before the cell and time interleavers.

The resulting constellation is similar to sending a higher-order constellation. For example, in a rotated M-QAM constellation, the number of projections on each axis is M. However, if a non-rotated M-QAM constellation is applied, the number of projections is $\sqrt{M}$. Furthermore, as DVB-T2 specifies the use of Gray symbol mapping, the I and Q channels of a conventional constellation can be mapped separately as two independent $\sqrt{M}-\mathrm{PAM}$. In the case of a rotated M-QAM constellation, the result is equivalent to map two related M-PAM. An example for a 16-QAM constellation is represented in Fig. 3.

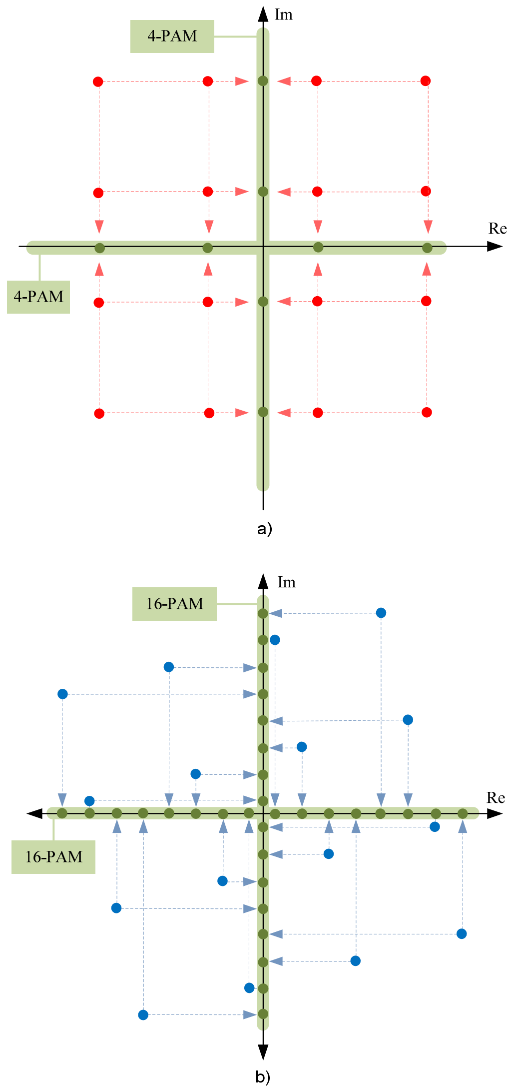

Fig. 3 a) Classic 16-QAM constellations with projections in axis (2x 4-PAM). b) Rotated 16-QAM constellations with projections in axis (2x16-PAM). The green points represent the projections on axis; the red circles represent points of the classic 16-QAM constellation; the blue circles show points of the rotated 16-QAM constellation.

In the DVB-T2 specification the interleaving process is implemented within a FEC block through a cyclic delay of one cell over the Q components. This idea was initially suggested in [8]. This cyclic Q delay must be removed at the receiver, this can be done easily delaying the I component by one OFDM cell.

In the receiver side, the LDPC decoding requires the use of soft decisions or metrics, known as Log Likelihood Ratios (LLRs). If rotated constellations are not used, a conventional one-dimensional demapper is applied. However, in the case of rotated constellations, the classical demapper is replaced with a two-dimensional LLR demapper. The Implementation Guideline of DVB-T2 [2] describes the main concepts of this demapper and proposes different implementation methods, as the 2D LLR demapper applying the Max-Log approximation, or the 2D LLR demapper with iterative demapping. The impact of computational complexity is increased due to the implementation of 2D demapper.

The constellation rotation technique improves the performance of a DVB-T2 receiver in all the fading channels. However it is not compatible with the ACE PAPR reduction technique.

C. Rotation angle in DVB-T2

The performance gain obtained when using rotated constellations depends on the choice of the rotation angle. The optimum rotation angle depends on the chosen modulation and channel type. However, in DVB-T2, a single rotation angle has been chosen for each constellation size independently of the channel type. Theses angle values are presented in Table II. Although those angles are only optimum for a particular channel type, they always present a performance improvement respect to non-rotated constellations in fading channels with or without erasures. The angle values given in Table II are a good compromise for all feasible channels in DVB-T2.

TABLE II
ROTATION ANGLES IN DVB-T2

Modulation	Rotation Angle (ϕ) [degrees]
QPSK	29.0
16-QAM	16.8
64-QAM	8.6
256-QAM	atan(1/16)

IV. SIMULATIONS RESULTS

The performance of the DVB-T2 receiver with rotated constellations has been tested by computer simulations in different propagation scenarios. The obtained results have been compared with the performance of a DVB-T2 receiver without rotated constellations to analyze the achieved gain with this technique.

All the results presented in this paper are obtained for a DVB-T2 system configured in 2k mode with a 1/8 guard interval and 8 MHz channel bandwidth. Simulations have been run for two types of constellation: the lower order, QPSK, and the higher order, 256-QAM, and different code rates.

Simulation results are analyzed over two different channel types. First, a Rayleigh-fading channel (P channel) defined in the DVB-T specification, and second, the specific channel defined in DVB-T2 called Rayleigh Memoryless with Erasures (RME) channel. The P1 channel describes portable indoor reception conditions. On the other hand, the RME channel, defined in [2], models the behaviour of the BICM block of DVB-T2 system over a terrestrial multipath channel providing arbitrary probability of carrier erasures. In the studied case, the RME channel presents an erasure ratio of 20%.

The obtained results are presented in Table III and Table IV, where the required carrier to noise ratio (C/N) to achieve a bit error rate (BER) of 10^{-5} is shown. The achievable performance gain when using rotated constellations is also shown for different code rates.

Simulation results show that in some scenarios the only way to properly decode the received signal is to use rotated constellations; if non-rotated constellations are used, the BER of 10^{-5} cannot be reached after the LDPC decoder. This is represented by the infinity symbols in table IV.

It should be noted that the maximum gain is obtained when high code rates are used. This can be easily explained since these code rates have a lower error correcting capability and the system performances rely more on the diversity introduced by the rotated constellations. On the other hand, the gain is higher for low order constellations: the maximum gain for the P1 channel is almost 3dB for the QPSK and only 0.11dB for a 256QAM.

TABLE III
REQUIRED C/N FOR A BER=10^{-5} IN RAYLEIGH CHANNEL (P1 CHANNEL)

Configuration		Required C/N (dB) for a BER=10^{-5}		Gain (dB)
Constellation	Code Rate	Without Rotated constellations	Rotated constellations	
QPSK	1/2	2.70	1.99	0.70
	3/4	7.96	6.09	1.87
	5/6	10.69	7.80	2.90
256-QAM	1/2	15.57	15.48	0.08
	3/4	22.76	22.66	0.01
	5/6	25.60	25.49	0.11

TABLE IV
REQUIRED C/N FOR A BER=10^{-5} IN RME CHANNEL WITH 20% OF ERASURES

Configuration		Required C/N (dB) for a BER=10^{-5}		Gain (dB)
Constellation	Code Rate	Without Rotated constellations	Rotated constellations	
QPSK	1/2	4.37	2.85	1.52
	3/4	17.65	4.37	9.72
	5/6	∞	10.56	∞
256-QAM	1/2	18.79	18.39	0.40
	3/4	34.67	28.30	6.37
	5/6	∞	35.37	∞

V. CONCLUSIONS

In this paper, the rotated constellation technique of the forthcoming DVB-T2 standard has been analyzed in terms of BER performance. It has been shown that for frequency selective fading channels a very good performance can be obtained with rotated constellations. Moreover, in the case of RME channels it is sometimes the only way to correctly decode the received signal. The simulations results show that the performance gain between rotated and non-rotated constellations is higher for low order constellations, and also for high coding rates where the system performances rely more on the diversity introduced by the constellation rotation.

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