Special Issue on Smart Cities, Optimization and Modeling of Complex Systems – iJIST, ISSN : 2550-5114
Vol. 6 - No. 1 - February 2022

Low complexity demapping algorithms survey in DVB-T2: Rotated constellation case study.

A-C. Honfoga, M. Dossou, and V. Moeyaert

***Abstract*—Signal Space Diversity (SSD) technique was adopted in Digital Video Broadcasting-Terrestrial, second generation (DVB-T2) standard ten years ago to increase system performance over fading channels. This technique consists of rotated and cyclic Q-delayed M-Quadrature Amplitude Modulation (QAM) and has been proposed without considering the complexity induced by the demapper. "Genie Aided" demapping algorithm based on iterative demapping has been presented in DVB-T2 and lets this system approach the Shannon limit. Furthermore, this algorithm is not suitable for hardware implementation. Due to the complexity of the hardware implementation algorithms, the advantages of this rotated constellation have not been effectively exploited for network deployment. Moreover, receivers provided by manufacturers do not include suitable demappers when this technique is applied. Therefore, several low complexity algorithms have been proposed during the last decade in the scientific literature to reduce the number of metrics and operators used in the demapping process. This paper presents an exhaustive review of demappers proposed for DVB-T2 and all the low complexity demapping algorithms existing up to now in the literature that is suitable for hardware implementation. Details about these algorithms are given in terms of reduction, parameters, performance and percentage of reduction obtained. Furthermore, performance of the joint usage of rotated constellation and iterative demapping in DVB-T2 Single Frequency Network (SFN) environment has been highlighted using the Common Simulator Platform (CSP) DVB-T2.**

***Index Terms*—DVB-T2, rotated constellation, cyclic Q delay, fading channel, Signal Space Diversity (SSD).**

I. INTRODUCTION

The demand for high data transmissions over fading channels has been the driver of many wireless communications systems improvement during the last two decades. To overcome these challenges, several signal processing techniques like Forward Error Correction (FEC) codes, geometrical and probabilistic constellations, diversity and interleaving techniques have been recently proposed in modern communications systems such as DVB-T2 [1] and Advanced Television Systems Committee, third generation (ATSC 3.0) [2]. Indeed, DVB-T2 provides a minimum capacity increase of thirty percent when compared to DVB-T and flexible robustness for transmitted service. DVB-T2 is the European terrestrial digital broadcasting system second generation standard published by European Telecommunications Standards Institute (ETSI) in 2009 [1]. Due to the Bit Interleaved Coding Modulation (BICM) [3] scheme and new techniques like FEC coding or Signal Space Diversity (SSD) [4] included in this system, its performance is much more excellent than DVB-T performance [3].

BICM is the coded and modulation scheme whose principle and performance have been described by Zehavi [4] over fading channel. It presents better understanding than the Coded Modulation (CM) scheme [5]. SSD technique has been first introduced in [6], [7] and proposed for DVB-T2 transmissions to increase the diversity order of BICM scheme and the signal robustness against fading channel impairments while maintaining the system spectral efficiency. The SSD technique gives maximum gain when used with low constellation sizes (4-QAM) and high Code Rates (CR) (CR=$4/5$ and CR=$5/6$). Conversely, the gain is more reduced for high constellation sizes (256-QAM) and low code rates [3]. The SSD performance gains obtained using (4-QAM, CR=$1/2$) and (16-QAM, CR=$1/2$) are respectively $3.4\,\mathrm{dB}$ and $2.8\,\mathrm{dB}$ in SFN environment channel (0dB echo) [8]. Furthermore, this gain increases when iterative demapping method is applied in the BICM chain. This method, called "Genie Aided" demapping, lets DVB-T2 BICM chain capacity to be closer to the Shannon limit [3]. Its performance is more highlighted when SSD technique based rotated constellation is chosen.

Indeed, SSD technique is an optional block of DVB-T2 which consists of rectangular QAM constellation rotation (counterclockwise rotation of the rectangular shape) and the cyclic Q delay. The constellation rotation induces a correlation between I and Q components of each QAM symbol, and the cyclic Q delay insertion introduces the independence between I and Q channel coefficients. Although the SSD technique effectively increases the robustness of the transmitted signal, the demapper complexity increases. To recover the data, equalizers based on uncorrelation methods such as Zero Forcing (ZF) and Minimum Mean Square Error (MMSE) can not be applied. Indeed, during the demapping process, euclidean distance computed between constellation symbols and received symbols must include I and Q channel coefficients. This requires the computation of two-dimensional euclidean distance (2D-demapper) and induces the increase of the hardware complexity detection process when compared to

Paper submitted on April 25, 2021. This work was supported by ARES ("Académie de Recherche et d'Enseignement Supérieur")

A-C. Honfoga is with the Electromagnetism and Telecommunication Department, Faculty of Engineering (FPMs), University of Mons (UMONS), Boulevard Dolez 31, 7000, Mons, Belgium (e-mail: anne-carole.honfoga@umons.ac.be) and the LETIA, Polytechnic School of Abomey-Calavi, University of Abomey-Calavi, Abomey-Calavi, Benin.

M. Dossou is with the LETIA, Polytechnic School of Abomey-Calavi, University of Abomey-Calavi, Abomey-Calavi, Benin. (e-mail: michel.dossou@epac.ac.bj).

V. Moeyaert is with the Electromagnetism and Telecommunication Department, Faculty of Engineering (FPMs), University of Mons (UMONS), Boulevard Dolez 31, 7000, Mons, Belgium (e-mail: veronique.moeyaert@umons.ac.be).

the detection process with classical QAM constellation (1D-demapper). Also, the higher the constellation size, the higher the complexity. Even though iterative demapping has been the proposed one in DVB-T2 [3] standard as the alternative to the common Max-Log demapper to increase the rotated constellation transmission performance, this algorithm is more complex for hardware implementation [9] but is helpful for software implementation [10].

However, following this observation, many detections process algorithms have been proposed in several works to deal with the hardware implementation complexity induced by the common used method Max-Log detection. These algorithms are based on two kinds of complexity reduction. While some algorithms are based on the reduction of the number of euclidean distance (number of candidates points of the constellation) computed in the Logarithm Likelyhood Ratio (LLR) bit computation [11], [12], [13], other algorithms focused on complexity of euclidean distance (kind of operators used in the calculation) [15]. Moreover, some others are focused on both complexity reduction of the euclidean distance computation and the number of euclidean distance to compute [14], [16], [17], [18], [19]. Indeed, we presented it for the first time comparison of all algorithms.

To the best of our knowledge, any work has not yet been presented on comparing all of these algorithms. This paper gives a technical comparison of these algorithms according to their reduction method. It additionally fills the gap in the literature about DVB-T2 system performance simulation using the CSP DVB-T2 when rotated constellation and iterative demapping are used or not in SFN environment. The low complexity demappers proposed for DVB-T2 are compared in detail in terms of the number of metrics and operators used and the percentage of reduction obtained. Therefore, the DVB-T2 system and parameters are explained in section II. This is followed by SSD techniques presentation, rotated constellation performance evaluation and the 2D-demapper relevance in section III. Low complexity demapper algorithms are compared in section IV. This is followed by the discussion and analysis in section V. The paper is finalized by the conclusion in section VI.

II. DVB-T2 SYSTEM DESCRIPTION

A. *DVB-T2 blocks diagram*

DVB-T2 system is based on many blocks such as: Physical Layer Pipe (PLP) multiplexing, FEC (Bose-Chaudhuri-Hocquenghem (BCH) and Low Density Parity Check (LDPC) codings), QAM, SSD technique (rotated constellation and cyclic Q delay), interleaving techniques (bit interleaving, symbol interleaving, frequency interleaving, time interleaving), Cyclic Prefix - Orthogonal Frequency Division Multiplexing (CP-OFDM) modulation and Multiple Input Single Output (MISO). Fig. 1 presents the transmitter blocks diagram.

The mapper block consists in a set of three blocks: QAM, constellation rotation and cyclic Q delay blocks. The reverse operations are done in the receiver. Among DVB-T2 system blocks, three of them are optional blocks: rotated constellation, cyclic Q delay insertion and MISO.

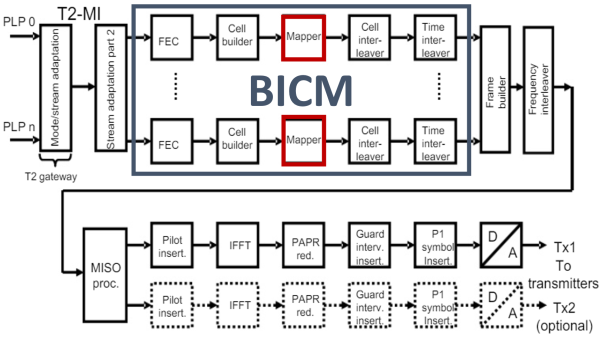


Fig. 1. DVB-T2 system blocks diagram (adapted from [1])

Performance are evaluated after QAM demapping, LDPC decoder and BCH decoder using Bit Error Rate (BER), which computes the number of binary errors transmitted to the total number of transmitted bits. Also, the Modulation Error Ratio (MER) which indicates the modulation quality of the received signal, can be computed before the QAM demapper [20].

PLP multiplexing consists of transmitting multiple layers of broadcasting service signals. Different layers of PLP data are encoded and modulated according to each code rate and modulation format. Then, it is multiplexed into a single T2 frame for transmission (cf Fig. 2(a) for 8K mode). Since all PLPs are multiplexed into one T2 frame, the same FFT operation mode is applied for all of them (PLPs) as presented in Fig. 1. Besides the PLP multiplexing used in DVB-T2, Future Extension Frame (FEF) multiplexing is proposed as a mean to transmit each data differently encoded and modulated with different Fast Fourier Transform (FFT) modes in the same super-frame. It consists in the use of the future extension of DVB-T2 in the same system. This is the case of DVB-T2-Lite profile (a lite version of DVB-T2 system), which is based on the same T2 system and can be transmitted in the FEF part of the super-frame (cf Fig. 2(b)). The main parameters of this system are presented in table I. In this table, the numbers of subcarriers defined for OFDM modulation are represented by FFT mode. K is equal to 1024. This means that the number of subcarriers varies from 1024 to 32768. The constellation sizes used are 4, 16, 64 and 256. In DVB-T2, two FEC frames such as short and long FEC. While the short FEC frame is used for low-capacity receivers adapted to portable and mobile receptions, the long FEC frame is adapted for rooftop antenna reception. Various code rates used in DVB-T2 allow one to choose the CR suitable for a specific application. The higher the CR, the lower the signal robustness. The lower the CR, the higher the signal robustness. As Cyclic Prefix (CP) is needed to deal with Intersymbol Interference (ISI) in OFDM, various CP is proposed in DVB-T2 to have a flexibility of choice on the CP and FFT mode suitable for a specific application. Therefore, the CP is chosen according to the FFT mode. The maximum bit rate achieved in DVB-T2 is 50.32 Mbit/s. All of these parameters allow DVB-T2 system to be flexible.

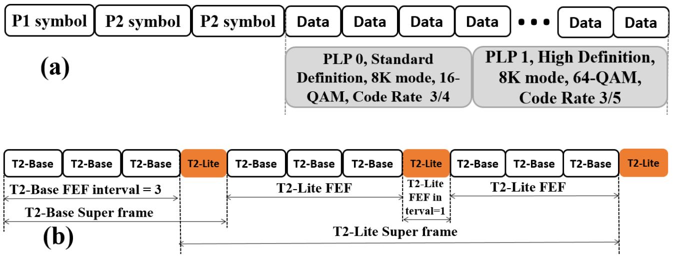


Fig. 2. DVB-T2 frame and super-frame structures employing respectively M-PLP and FEF techniques.

TABLE I
DVB-T2 SYSTEM PARAMETERS

FFT mode	1K, 2K, 4K, ((8, 16, 32)K and ext)
Modulation	4, 16, 64, 256-QAM
FEC frame	long (64800 bits), short (16200 bits)
CR LDPC	1/2, 3/5, 2/3, 3/4, 4/5, 5/6
Bandwidth	1.7, 5, 6, 7, 8, 10 MHz
CP	1/128, 1/32, 1/16, 19/256, 1/8, 19/128, 1/4
Capacity	50.32 Mbit/s

B. *Channel models presented in the DVB-T2 standard*

DVB-T2 standard defines many generic simulation fading channel models such as Rician, Rayleigh, Rayleigh with erasure, Typical Urban 6 and 0dB echo channels [3]. These channels are characterized by their Power Delay Profile (PDP).

- Rician channel is used to emulate fixed (rooftop antenna) reception environment and includes Line Of Sight (LOS) and Non Line Of Sight (NLOS) paths.
- Rayleigh channel is used to emulate portable reception environment and includes only NLOS paths.
- Rayleigh channel model with erasure is the modified version of the classical Rayleigh fading channel which is used to model a channel with deep fades. Erasure events are modeled by a discrete random process e_t which is multiplied by the channel coefficient in time domain and take 0 value with a probability of P_e and 1 value with a probability of 1-P_e.
- Typical Urban 6 channel is the channel which emulates DVB-T2 urban environment and includes only NLOS paths.
- 0dB echo channel is a high frequency selective channel typically used to model Single Frequency Network (SFN). SFN is a network of emitters transmitting the same signal with the same frequency.

Among all of these channels listed above, Rayleigh channels with and without erasure and 0dB echo channel are usually used to evaluate rotated constellations performance. 0dB echo channel has been used for simulation using a DVB-T2 simulator called CSP-DVB-T2.

In this section, DVB-T2 system blocks diagram and channel models have been briefly presented. In the following section, the SSD technique is presented in details.

III. SSD TECHNIQUE DESCRIPTION

A. *Rotated constellation concept*

The constellation rotation concept has been introduced in the DVB-T2 standard to improve the system's performance by exploiting the frequency diversity that the latter offers. Before the adoption of this concept in DVB-T2, some works have been done and prove the performance of the joint use of constellation rotation and FEC techniques (Turbo and LDPC codes) [21]. Moreover, the performance of the joint use of SSD technique and BICM modulation in broadcasting systems has been proven while showing the advantage of SSD technique as being a repeating code and defining the criteria for the choice of rotation angle [22].

Indeed, QAM symbols are constructed using Gray mapping. After that, a rotation technique is applied to the classical constellation and creates a correlation between I and Q components. When, a cyclic Q delay addition follows this operation, channel coefficients applied to transmitted symbols become independent. Fig. 3 presents the constellation points after constellation rotation.

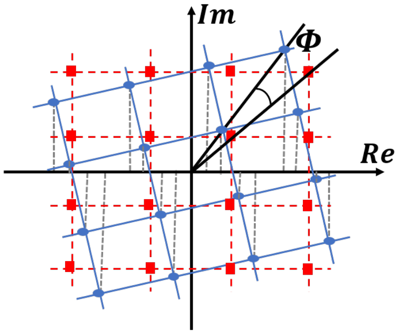


Fig. 3. Classical QAM and rotated constellation (adapted from [13])

As noticed on this figure, a rotation angle Φ is applied to the classical symbols (red color), and each rotated constellation symbol (blue color) includes a unique I and Q components.

If S represents a complex symbol from a classical QAM,

$$S = I_s + j.Q_s \tag{1}$$

I_s and Q_s denote respectively the In-phase and Quadrature symbols components. Due to the constellation rotation, S is multiplied by $e^{j\Phi}$ and becomes Z.

$$Z = I_z + j.Q_z = (I_s + j.Q_s).e^{j\Phi} \tag{2}$$

$$Z = (I_s + j.Q_s)(sin\Phi + j.cos\Phi) \tag{3}$$

$$I_z = I_s.sin\Phi - Q_s.cos\Phi \tag{4}$$

$$Q_z = I_s.cos\Phi + Q_s.sin\Phi \tag{5}$$

The addition of a cyclic Q delay consists of performing a time delay of Q_z components of all transmitted symbols. This operation is carried out on the scale of one LDPC frame and consists of inserting a delay of a QAM symbol duration on Q components of all the symbols. For example, if Z_1, Z_2, Z_3,

Z_4 denote the symbols after constellation rotation and if it is supposed that the LDPC frame length is 4.

$$Z_1 = I_{z_1} + j.Q_{z_1} \tag{6}$$

$$Z_2 = I_{z_2} + j.Q_{z_2} \tag{7}$$

$$Z_3 = I_{z_3} + j.Q_{z_3} \tag{8}$$

$$Z_4 = I_{z_4} + j.Q_{z_4} \tag{9}$$

After cyclic delay insertion, Z_1, Z_2, Z_3, Z_4 become X_1, X_2, X_3, X_4.

$$X_1 = I_{z_1} + j.Q_{z_4} \tag{10}$$

$$X_2 = I_{z_2} + j.Q_{z_1} \tag{11}$$

$$X_3 = I_{z_3} + j.Q_{z_2} \tag{12}$$

$$X_4 = I_{z_4} + j.Q_{z_3} \tag{13}$$

By this way, complex symbols which undergo OFDM modulation do not contain their own Q components. This technique is also called frequency diversity technique. Indeed, I and Q components go through different subcarriers. Therefore, the fact that these two subcarriers carry the same information on the channel leads to consider the SSD technique as a repeating code. When one of the subcarriers is attenuated or erased due to the channel effects, the information contained in this subcarrier can be recovered because this same information is found on the second subcarrier. On the receiver side, the channel coefficients of components I and Q of each transmitted symbol are independent. Furthermore, before the demapping process, the cyclic Q-delay is removed. This is done simply by delaying the I components by one QAM symbol duration to reunite it with the corresponding Q value. The Q component of the first symbol of the FEC block is stored until the end of the FEC block to reunite it with its corresponding I component.

B. Two-dimensional demapper relevance

SSD technique advantages and principles have been presented in the previous section. It is shown that I and Q components of each symbol are not affected on the same way by fading channel. The use of the channel coefficients becomes mandatory when computing euclidean distance in the LLR expression as ZF or MMSE equalizers can not be done before the demapping process. Then, a 2D-demapper is needeed when constellation rotation is used. In this section, the 1D and 2D demappers available in the scientific literature are presented.

1) Complexity analysis of 1D and 2D demapper

Let us consider a 16-QAM including the constellation diagram and binary data ($b_0b_1b_2b_3$) presented in Fig. 4(a). As noticed on this figure, the I and Q components (blue color) projected on the real and imaginary axis follow the Gray mapping. The bits with even index contain the I component and the bits with odd index contain the Q component. The Hamming distance between adjacent I or Q components is equal to 1. To compute the LLR for each bit, euclidean distance is computed between I components or Q components. Indeed, LDPC decoding should be performed using LLR values for each bit as soft decisions or metrics. When constellation rotation is not applied, the LLR computation takes into account only the component (I or Q) on which the half of the symbols bits is represented [3]. This means that the euclidean distance is a 1D distance.

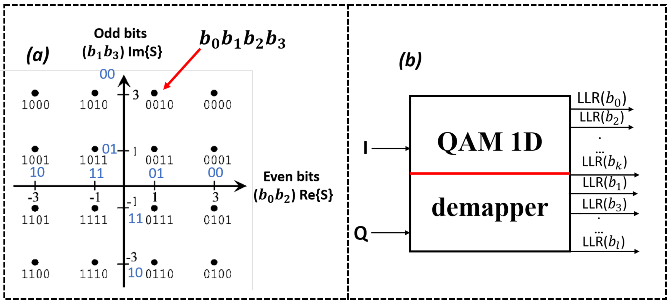


Fig. 4. Classical QAM symbols and 1D-demapper

Fig. 4(b) presents the 1D-demapper where k and l represent respectively the even and odd indexes. The number of metrics (euclidean distances or candidate points needed for euclidean distance computation) is $2^{(\frac{m}{2}+1)}$ with m the number of bits per symbol.

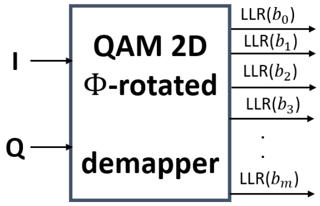


Fig. 5. 2D-demapper (adapted from [3])

When rotated constellation is used, both I, Q components are required in the LLR bit computation instead of the use of only one component in the LLR bit computation for a classical QAM constellation. Their respective channel coefficients are needed for LLR bit computation and then the euclidean distance computation. This leads to the use of 2D-demapper (Fig. 5). The number of euclidean distance to be computed is 2^m. When compared to the number needed for 1D-demapper, the complexity increases by $2^{\frac{m}{2}}$ [13] when using a 2D-demapper.

2) Computation of perfect LLR and simplified LLR suitable for hardware implementation (Max-Log approximation)

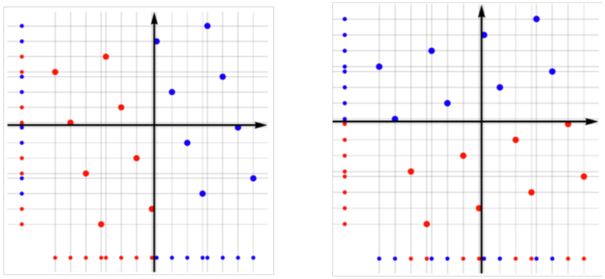
As previously presented, rotated constellations require the receiver to form metrics LLR as a function of two dimensions, rather than the conventional variables-separables one dimensional approach suitable for a sole constellation.

Let us consider:

- X, the transmitted symbol with components I_x and Q_x.
- R, the received symbol with components I_r and Q_r and without channel equalization.
- ρ_I and ρ_Q, fading channel coefficients respectively for I and Q components.
- b_i, the bit on which the LLR is computed.
- C_i^0 and C_i^1, the set of constellation points for which the i^{th} bit can take 0 or 1 values.

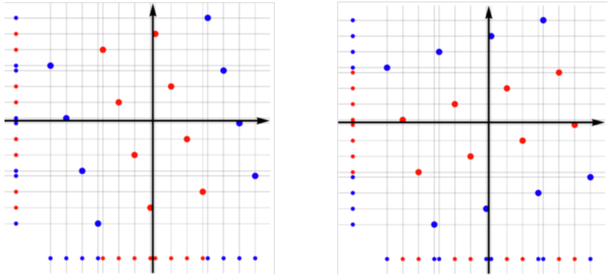
- σ^2 the power of Additive White Gaussian Noise (AWGN).
- 2^m possible states of the QAM constellation which conveys m coded bits.

C_i^0 and C_i^1 are presented on Fig. 6 for a constellation size equal to 16.



C_0^0 is the subset for which b_0 takes value 0 (red color) C_0^1 is the subset for which b_0 takes value 1 (blue color)

C_1^0 is the subset for which b_1 takes value 0 (red color) C_1^1 is the subset for which b_1 takes value 1 (blue color)



C_2^0 is the subset for which b_2 takes value 0 (red color) C_2^1 is the subset for which b_2 takes value 1 (blue color)

C_3^0 is the subset for which b_3 takes value 0 (red color) C_3^1 is the subset for which b_3 takes value 1 (blue color)

Fig. 6. Subsets of 16-QAM rotated constellation

One can compute 2D euclidean distance using eq. (14).

$$Dist^2 = (I_r - \rho_I I_x)^2 + (Q_r - \rho_Q Q_x)^2 \tag{14}$$

The LLR used in the demapper presented on Fig. 5 is defined in eq. (15).

$$LLR(b_i) = \ln(\frac{Pr(b_i = 1|I_r, Q_r)}{Pr(b_i = 0|I_r, Q_r)}) \tag{15}$$

A positive LLR value means that b_i was more probably transmitted as a 1. A negative LLR value means that b_i was more probably transmitted as a 0. These probabilities are computed following this description. Indeed, a particular symbol called X is transmitted (with I_x and Q_x components). The received constellation (I_r and Q_r) would be ideally identical. However, in real transmission conditions, I_x and Q_x which have been transmitted, have been subjected respectively to fading channel factors ρ_I and ρ_Q and noise. Therefore, the conditional probability distribution function (pdf) of receiving particular I_r and Q_r given that point X was transmitted is shown in eq. (16).

$$p(I_r, Q_r|X) = \frac{1}{2\pi\sigma^2} e^{\frac{Dist^2}{2\sigma^2}} \tag{16}$$

Now, if the reception of a particular bit b_i is considered which is transmitted as 1, then any of 2^{m-1} possible states of the subset C_i^1 was transmitted, if b_i is transmitted as a 0, then one of the possible states of the subset C_i^0 is transmitted. The conditional pdf for the received symbols values I_r, Q_r, given that b_i was transmitted as a 1 is thus given by the expression 17. This expression is given with the assumption that all of the 2^{m-1} possible transmitted states for which $b_i = 1$ are transmitted with equal probability. This means that each of the other (m-1) bits takes the values 0 and 1 with equal frequency. The same expression in eq. (18) is obtained when supposed that b_i was transmitted as a 0. However, the summation is taken over points $X \in C_i^0$.

$$p(I_r, Q_r|b_i = 1) = \frac{1}{2^m\pi\sigma^2} \sum_{X \in C_i^1} e^{-\frac{Dist^2}{2\sigma^2}} \tag{17}$$

$$p(I_r, Q_r|b_i = 0) = \frac{1}{2^m\pi\sigma^2} \sum_{X \in C_i^0} e^{-\frac{Dist^2}{2\sigma^2}} \tag{18}$$

$LLR(b_i)$, given that I_r and Q_r are received, is deducted using Bayes' theorem. Using this theorem, the expression presented in eq. (15) is also equal to expression presented in eq. (19).

$$LLR(b_i) = \ln(\frac{p(I_r, Q_r|b_i = 1)}{p(I_r, Q_r|b_i = 0)}) \tag{19}$$

Using the assumption that the transmitted bit b_i is equally likely to be 0 or 1, the LLR is obtained by eq. (20). This equation invokes the exact computation of the LLR bit.

$$LLR(b_i) = \ln \frac{\sum_{X \in C_i^1} e^{-\frac{Dist^2}{2\sigma^2}}}{\sum_{X \in C_i^0} e^{-\frac{Dist^2}{2\sigma^2}}} \tag{20}$$

As noticed on this equation, exponential operation is used and is complex to realize in hardware implementation. Also, the calculation of the LLR uses all the points of the constellation since C_i^0 and C_i^1 are subsets of dimension $2^{\frac{m}{2}}$. To deal with exponential operator, the Max-Log approximation presented in eq. (21) is used.

$$\ln(e^{a_1} + ... + e^{a_k}) \approx= \max_{j=1...k} a_j \tag{21}$$

$$a_j = \frac{Dist^2}{2\sigma^2}$$

By inserting this equation in expression (20), the LLR formula becomes eq. (22).

$$LLR(b_i) = \frac{1}{2\sigma^2}[min_{X \in C_i^0} Dist^2 - min_{X \in C_i^1} Dist^2] \tag{22}$$

This expression allows to avoid an exponential operator. However, the number of candidate points used is still the same. The more the size of the constellation increases, the more the complexity increases. For example, when 256 constellation size is used, the number of euclidean distances to compute is also 256.

C. 2D LLR demapper with iterative demapping and decoding

As previously presented, the max-log approximation is the reduced version of the demapper used by many research to further reduce its complexity. Moreover, 2D LLR computation with iterative demapping and decoding has been proposed in DVB-T2 standard to reduce the demapping complexity and increase DVB-T2 system performance behaviour when SSD technique is applied. In this subsection, this demapping method is presented and its performance is compared with the max-log demaping algorithm.

3) Perfect LLR with iterative demapping and Genie Aided demapper

The iterative demapping algorithm method consists in the usage of extrinsinc bit information coming from the LDPC decoder in the demapping process (Fig. 7).

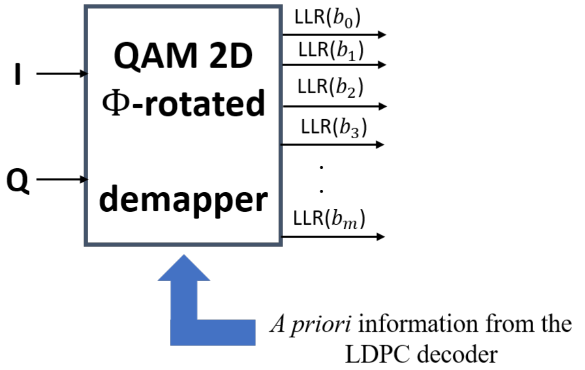


Fig. 7. 2D- LLR demapper for iterative demapping (adapted from [3])

When iterative demapping is used, the LLR for bit b_i should be computed using *a priori* information of the likely state of the m-1 other bits, obtained from the LDPC decoder in the previous iteration. Due to this knowledge, the assumption of equiprobability of all states X is not possible. Therefore, a more robust expression for the pdf of the received values I_r, Q_r given that b_i was transmitted as a 1 is obtained eq. (23).

$$p(I_r, Q_r|b_i = 1) = \frac{1}{2^m\pi\sigma^2}\sum_{X\in C_i^1}(e^{-\frac{Dist^2}{2\sigma^2}}Pr_{apriori}(X|b_i = 1)) \tag{23}$$

In this equation, there is the sum of the contribution from each of the 2^{m-1} possible transmitted points X in the half constellation representing the subset C_i^1. As known, C_i^1 is distinguished by the choice of $b_i = 1$. Each symbol (constellation point) has his unique probability to be transmitted. This probability can be expressed as a function of the probabilities that the (m-1) bits other than b_i take the value 0 or 1 as required to correspond to the mapping state X. These probabilities are in fact estimated by the previous iteration of LDPC decoding. Let $x_{m-1}x_{m-2}...x_2x_1x_0$ represent the values of the bits $b_{m-1}b_{m-2}...b_2b_1b_0$ which match the point X in the half-constellation C_i^1. The probabilities that the $(m-1)$ other bits take the value 0 or 1 required to match the mapping state X are described in eq. (24).

$$Pr_{apriori}(X|b_i = 1) = \prod_{k\neq i} Pr_{LDPC}(b_k = x_k) \tag{24}$$

Using the same method, eq. (25) and eq. (26) are obtained in the case of $b_i = 0$.

$$p(I_r, Q_r|b_i = 0) = \frac{1}{2^m\pi\sigma^2}\sum_{X\in C_i^0}(e^{-\frac{Dist^2}{2\sigma^2}}Pr_{apriori}(X|b_i = 0)) \tag{25}$$

$$Pr_{apriori}(X|b_i = 0) = \prod_{k\neq i} Pr_{LDPC}(b_k = x_k) \tag{26}$$

Instead of performing the hard decision in the decoding process for a max-log demapping, LDPC decoder performs the soft decision decoding. The extrinsic bit LLR related to bit b called $LLR_{EXT}(b)$, is related to the LDPC decoder's input and output soft-decision values $LLR_{IN}(b)$ and $LLR_{OUT}(b)$ by eq. (27).

$$LLR_{EXT}(b) = LLR_{OUT}(b) - LLR_{IN}(b) \tag{27}$$

The extrinsic bit probabilities are obtained from the extrinsic bit LLR by the following eq. (28) and (29).

$$Pr_{LDPC}(b = 0) = \frac{1}{1 + e^{LLR_{EXT}(b)}} \tag{28}$$

$$Pr_{LDPC}(b = 1) = 1 - \frac{1}{1 + e^{LLR_{EXT}(b)}} \tag{29}$$

When collecting information from eq. (23), (24), (25), (26), (27), (28) and (29), and applying Bayes' theorem, the LLR for bit b_i at the output of the demapper is computed using eq. (30).

$$LLR(b_i) = \ln\frac{\sum_{X\in C_i^1} e^{-\frac{Dist^2}{2\sigma^2}}\prod_{k\neq i} Pr_{LDPC}(b_k = x_k)}{\sum_{X\in C_i^0} e^{-\frac{Dist^2}{2\sigma^2}}\prod_{k\neq i} Pr_{LDPC}(b_k = x_k)} \tag{30}$$

One can notice that despite the performance allowed by iterative demapping, its complexity is higher than exact LLR complexity computation.

However, a light version of this method called genie aided demapping is proposed to reduce the complexity. This method assumes that the LDPC decoding of all bits except b_i is error free and known to be so. Therefore, only two constellation points are supposed to be transmitted. These points depend on the values of the bits except b_i. Among these two points, one point matches $b_i = 1$ and the other matches $b_i = 0$ (cf fig .8). Then the numerator of eq. (30) contains only one state X relative to the point for which $b_i = 1$ and the probability product is equal to 1. As the decoding is known to be error free. The denominator contains one state X relative to the point for which $b_i = 0$ and the probability product is equal to 1. Let's consider I_1, Q_1 and I_0, Q_0 respectively the components of the states previously presented. Instead of computing the euclidean distance on 2^m points, this distance is computed on only two points. The LLR becomes a simple function of I and Q in eq. (31).

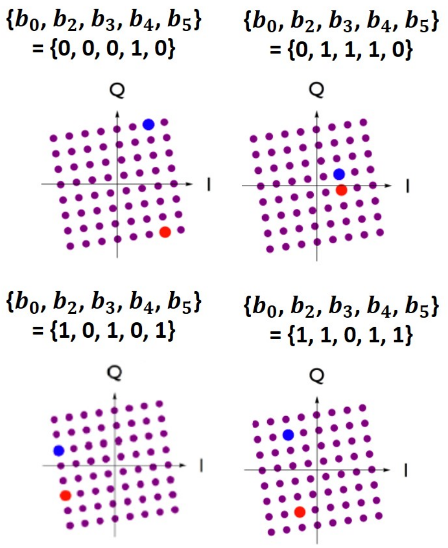


Fig. 8. Examples of rotated-64-QAM constellation states, when $b_i = b_1$ is unknown, and the other 5 known bits b_0, b_2, b_3, b_4, b_5 take 4 out of the possible 32 combinations for example.

$$LLR(b_i) = \ln \frac{\sum_{X \in C_i^1} e^{-\frac{(I_r - \rho_I I_1)^2 + (Q - \rho_Q Q_1)^2}{2\sigma^2}}}{\sum_{X \in C_i^0} e^{-\frac{(I_r - \rho_I I_0)^2 + (Q - \rho_Q Q_0)^2}{2\sigma^2}}} \tag{31}$$

When analysing this equation, one can notice that the exponential operator has been used only twice instead of 2^m in the perfect LLR computation. Also, the product term which appeared in eq. (30) disappeared. This method called "Genie Aided" demapping is light and increases the BICM system capacity. The following part presents its performance when compared to the classical demapping without rotated constellation.

4) Genie Aided demapper performance using the CSP DVB-T2

As previously presented, Genie Aided Demapper is an algorithm with a reduced complexity. Also, it allowed to increase DVB-T2 system capacity. In this part, Genie Aided demapper system performance is highlighted when compared to the 1D demapper system performance. The simulation result is obtained using CSP DVB-T2 simulator (with the update 2017-08-04 version) [23], [24]. This simulator emulates the whole version of DVB-T2 system and is proposed in the guidelines implementation of DVB-T2 as an additional source of assistance for implementers [3]. The simulator model was implemented in Matrix Laboratory (MATLAB) software. The BICM with iterative demapping is the chain which allowed DVB-T2 system to approach the Shannon limit as its performance is more highlighted when SSD technique is applied [25]. The simulation parameters are summarized as following: the subcarrier number used is 8192 (8K mode), the CP is $1/32$, the CR used is 1/2 and the modulations are Quadrature Phase Shift Keying (QPSK), 16-QAM, 64-QAM and 256-QAM. The normal mode is used. BER simulation results are presented in Fig. 9.

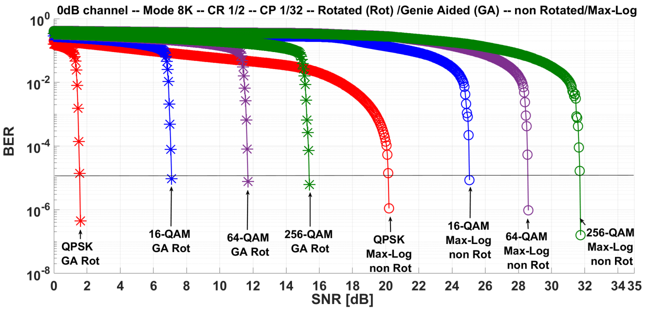


Fig. 9. (Rotated constellation + Genie Aided demapper) compared to (Non rotation constellation+ 1D demapper) in DVB-T2 using 0dB echo channel

Table II presents the gain obtained for each constellation size due to the Genie Aided demapper usage and rotated constellation. As noticed on Fig. 9 and table II, a noticeable gain is obtained when SSD technique is jointly used with Iterative Demapping. These gains are more noticeable for low order constellation. R_{GA} means that rotated constellation is applied and Genie Aided (GA) demapper is used. nR means that rotated constellation is not applied (nR) and 1D demapper (1D Max_log) is applied. Furthermore, the results obtained with Genie Aided demapper is comparable to those presented in the standard [3]. Despite the performance provided by Genie Aided demapper, it is only suitable for software implementation. For hardware implementation in DVB-T2 receiver, Max-Log demapper algorithm complexity need to be reduced. To reduce this complexity, many low complexity demappers are proposed in the several works. All of them reduce the Max-Log demapper algorithm by reducing the number of metrics or the complexity of the euclidean distance expression. Details about these algorithms are presented in the following section.

TABLE II
SNR VALUES AND GAIN OBTAINED USING 0 dB ECHO CHANNEL

BER=10^{-5}							
QPSK		**16-QAM**		**64-QAM**		**256-QAM**	
$Gain_{GA}$		$Gain_{GA}$		$Gain_{GA}$		$Gain_{GA}$	
18.6 dB		17.9 dB		17 dB		16.4 dB	
SNR[dB]							
R_{GA}	nR	R_{GA}	nR	R_{GA}	nR	R_{GA}	nR
1.6	20.2	7.1	25	11.7	28.5	15.4	31.8

IV. LOW COMPLEXITY DEMAPPER ALGORITHMS

As presented in the previous section, the Max-Log demapper algorithm is proposed in DVB-T2 standard for hardware implementation. The constellation sizes usually chosen by broadcasters for DVB-T2 network deployment are 64 and 256 [26]. Algorithms proposed in the literature focus on the demapper complexity reduction often use these constellation sizes. While some algorithms reduce only the QAM demapper complexity, the last algorithm presented in this paper (cf IV.C.5) reduces the demapping complexity and increases the signal robustness and then the system performance. This section presents firstly those algorithms that reduce the number of euclidean distance, secondly those which reduce the complexity of computation of euclidean distance and lastly the algorithms for both the complexity of computation of euclidean distance and the number of euclidean distance reduction.

Nevertheless, it is useful to first compute the Max-Log complexity as a basis.

Indeed, the complexity of euclidean distance presented in eq. (14) is computed in term of number of real multiplications (RM) and real sums (RS). As noticed in this equation, 4 RM and 3 RS are needed. For the sake of simplicity, we denote the number of candidate points which represent the number of euclidean distances or metrics. The LLR bit computation for symbol of constellation size 256 using eq. (22) induces $(4X256+8) = 1032$ RM, $(3X256+8) = 776$ RS and $(256X8) = 2048$ real comparisons (RC). Indeed, the real comparison operator is used due to the presence of the min operator in the equation. This operator induces the comparison between all the euclidean distances computed between the received symbol and the symbols of the individual subset C_i^0 and C_i^1 to choose the smallest distance for the two subsets.

A. Algorithms based on number of candidate points reduction

1) Demapper proposed by Perez Calderon et al, 2011 [11]

These authors proposed the choice of constellation quadrants which are taken into account depending on the quadrant on which the received symbols belong to. Indeed, there are four quadrants on QAM constellation. Depending on the quadrant in which the received symbol is located, the 2D euclidean distance can be computed on a reduced subset of constellation points instead of all the constellation points. These subsets of constellation points are carefully determined by computing the histogram of minimum 2D distance and then identifying the received symbols which are more likely to be at the minimum distance for a specific quadrant. The constellation points with the greatest occurrence probability are grouped into a subset for this particular quadrant. By using histogram of minimum distance, authors conclude that in the case where the received symbol belongs to quadrant 2 (Q2), the candidate points must belong to Q2 and the neighboring quadrants Q1 and Q3. This means that the number of candidate points decreases by 25%. Furthermore, some points of Q1 and Q3 could be removed. This induces also the decrease of the number of candidates points by 6.25%, 12.5%, 18.75% and 25%. These values depends on the subset used for the reduction. The first subset which reduced the number of candidates points by 25% + 25% indicates that the first 25% correspond to the Q4 candidates points and the second 25% correspond to the half of Q1 and Q3 candidates points. The second subset which reduced the number of candidates points by 25% + 18.75% indicates that the first 25% correspond to the Q4 candidates points and the second 18.75% correspond to the half of Q1 and Q3 candidates points, each of them reduced by the quarter of the candidates points. The two last subsets reduced the number of candidates points by respectively 25% + 12.5% and 25% + 6.25%. However, the more the number candidate points decreases, the more the system performance decreases. For all the foregoing, the subset of candidate points which reduced the points by $25\% + 6.25\% = 31.25\%$ is the selected subset with negligible impact (loss < $0.2\,\mathrm{dB}$) on system performance for constellation size of 256. This performance loss is obtained by comparing the BER curves of the proposed demapper to the ideal Max-Log demapper performance and by measuring the difference in terms of Signal to Noise Ratio (SNR) at a BER of 10^{-4} after LDPC decoder using parameters such as a 256-QAM, a LDPC block size of 64800 bits, different code rates (CR) and Rayleigh channel with 15% of erasure event [11].

2) Demapper proposed by Stefano Tomasin et al, 2012 [12]

These authors proposed an algorithm which consists in identifying the constellation points whose euclidean distance is very close to the received symbol. Indeed, it consists in the separation of the constellation diagram into different sectors of size $(2.2^{\frac{m}{2}})$ delimited by real values M_c. After this separation, it will be necessary to identify the real value M_c close to the real part of the received symbol. Once this value is identified, the constellation points on which euclidean distance will be computed is between the two values of M_c close to the M_c value previously identified. This region includes $2^{(\frac{m}{2})}$ constellation points. This algorithm reduces the number of candidate points by 93.75% with negligible performance loss for constellation size of 256. This performance loss is obtained by comparing the BER curves to the ideal Max-log demapper performance and measuring the difference in terms of carrier-to-noise ratio (C/N) at a BER of 10^{-7} after LDPC decoder using parameters such as a 16-QAM, a LDPC block size of 16200 bits, different code rates (CR) and rayleigh channels without and with 20% of erasure event. Using these parameters, the proposed algorithm gives the same performance when compared to the Max-Log demapper. When compared to the algorithm proposed by Perez Calderon in 2011, this algorithm reduces the complexity more than the IV.A.1 algorithm.

3) Demapper proposed by Perez Calderon et al, 2013 [13]

These authors proposed a complexity reduction algorithm based on sub-quadrants identification instead of quadrants in [11]. It is based on the selection of the sub-quadrants among the four quadrants of the constellation. Instead of computing the distance between the symbol received and all the other constellation points, they first compute the probability of appearance of the received symbols of a sub-quadrant in the other sub-quadrants. Then, the constellation points with a high probability of occurrence is maintained. The choice of the subset of candidate points has a significant impact on the system performance. These candidate points are likely to be at a minimum distance from the received symbol. This algorithm reduces the number of candidate points by 78% with a negligible performance loss for constellation size of 256. This performance loss is obtained by comparing the BER curves to the ideal Max-Log demapper performance and measuring the difference in terms of carrier-to-noise ratio (C/N) at a BER of 10^{-7} using parameters such as a 256-QAM, a LDPC block size of 64800 bits, different code rates (CR), rayleigh channels without (P1 channel for portable reception) and with 15% of erasure event and 0dB echo channel. When compared to the quadrant demapping algorithm firstly presented (cf IV.A.1), this algorithm further reduces the number of candidate points lying on the subset which induces a better percentage of complexity reduction and real channel estimation.

B. Algorithm based on the euclidean distance complexity reduction

The research group of Perez Calderon authors proposed in 2014 the Manhattan approximation as an alternative to the euclidean distance in the LLR expression [16] to reduce the hardware implementation complexity. As noticed on the 2D euclidean distance formula, the real multiplication operator is more complex to realize than the real addition. By reducing the number of real multiplication, the demapper complexity is further reduced. This algorithm focuses on the number of real multiplication reduction and then presents better performance algorithms than previously presented. Indeed, Manhattan distance means eq. (32) instead of eq. (33).

$$Dist_{Manhattan} = (I_r - \rho_I I_x) + (Q_r - \rho_Q Q_x) \tag{32}$$

$$Dist_{euclidean} = \sqrt{(I_r - \rho_I I_x)^2 + (Q_r - \rho_Q Q_x)^2} \tag{33}$$

The use of Manhattan distance allows to reduce the number of RM by 99.2% with a negligible performance loss. Instead of 2^{m+1} real multiplications, only 4 real multiplications are used. This performance loss is obtained by comparing the BER curves to the ideal Max-Log demapper performance and measuring the difference in terms of carrier-to-noise ratio (C/N) at a BER of 10^{-6} using parameters such as a 256-QAM, a LDPC block size of 64800 bits, different code rates (CR), Rayleigh channels without (P1 channel for portable reception) and with 15% of erasure event and 0dB echo channel.

C. Algorithms based on the number of candidate points and euclidean distance complexity reductions

In the 2 previous subsection, algorithms based on only euclidean distance number have been presented. In this part, algorithms reducing both the number of candidate points and euclidean distance computation are presented.

1) Demapper proposed by Meng Li et al, 2009 [15]

These authors proposed a sub-region demapping algorithm and presented the Field-Programmable Gate Array (FPGA) design and prototyping. This algorithm reduces the number of Euclidean distances by breaking down the constellation into two-dimensional sub-regions and simplifies the algorithm of euclidean distance computation. This reduces the complexity of euclidean distance by decreasing the number of real multiplication.

Indeed, depending on the signs of I_r and Q_r, four sub-regions have been identified. Each sub-region includes a quadrant and the constellation points which are closer to the quadrant (Fig. 10). This method reduces the number euclidean distances by 60% and 69% respectively for constellation sizes of 64 and 256. Instead of 64 and 256 candidate points used to compute euclidean distances, respectively 25 and 81 are used. Moreover, a linear approximation of euclidean distance presented in eq. (34), (35) and (36) are used is order to exploit real comparisons instead of real multiplications in eq. (14) which decreases again the complexity with a negligible performance loss. Let us consider

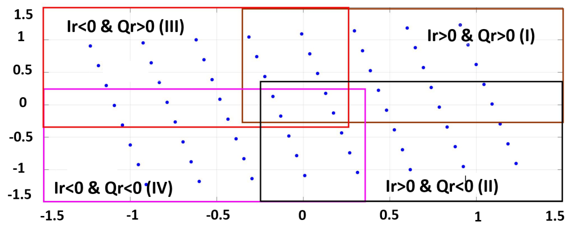


Fig. 10. Sub-regions used for 64-QAM constellation demapping

$$a = I_r - \rho_I I_x ; b = Q_r - \rho_Q Q_x$$

and suppose that a and b are positive. The euclidean distance between two points is defined as $\sqrt{a^2+b^2} = a\sqrt{1+(b/a)^2}$. By supposing that a is the maximum of the two values, the ratio b/a is smaller than one. A linear approximation of the Euclidean distance can be performed following these equations.

$$Dist = \sqrt{a^2+b^2} \tag{34}$$

if $(min(a,b) \leq \frac{max(a,b)}{4})$

$$Dist = max(a,b) \tag{35}$$

else

$$dist = max(a,b) + ((min(a,b) - max(a,b)/4)/2) \tag{36}$$

This performance loss is obtained by comparing the BER curves to the ideal Max-Log demapper performance and measuring the difference in term of the ratio of Energy per Bit (E_b) to the Spectral Noise Density (N_o) at a BER of 10^{-6} after LDPC decoding using parameters such as a 64-QAM, Rayleigh channels without and with 15% of erasure event.

2) Demapper proposed by Kitaek et al, 2012 [13]

These authors proposed a complexity reduction algorithm which computes the LLR by using a key observation for 2D LLR contours of bits as a function of channel coefficients ρ_I and ρ_Q under AWGN and Rayleigh channels. When compared to the algorithm previously presented, this algorithm reduces the demapper complexity without performance loss. When only AWGN channel is used, it is supposed that $\rho_I = \rho_Q$ and the LLR contours appear as rotated, like the rotated constellation. The demapping process is done in two steps. In the first stage, when Rayleigh channel is used, according to the channel coefficients values ($\rho_I < \rho_Q$ or $\rho_I > \rho_Q$), the LLR of bits from the high channel coefficient between I and Q is determined firstly using a LLR lookup table whose values are obtained using a shift. The other LLRs are computed in the second stage using the sub-region of $2^{\frac{m}{2}}$ candidates points. This algorithm reduces the complexity by 87.5% for constellation size of 64 without performance loss. Indeed, this performance loss is equal to 0 when the performance of the proposed algorithm is compared to the Max-Log demapper performance.

3) First demapper proposed by Jianxiao Yang et al, 2015 [17]
These authors proposed a soft demapping algorithm derived and implemented over a FPGA platform. It reduces the number of candidate points from 2^m to $2^{(\frac{m}{2}+1)}$. This induces 75% and 87.5% of complexity reduction respectively for constellation sizes of 64 and 256. Also, euclidean distance complexity has been reduced by using a low complexity approximation eq. (37).

$$Dist = max(|a|,|b|) + (\frac{1}{2} + \frac{1}{16} + \frac{1}{32}).min(|a|,|b|) \quad (37)$$
$$a = I_r - \rho_I I_x ; b = Q_r - \rho_Q Q_x$$

Using this equation, the 2 main real multiplications and 1 real sum in eq. (33) are replaced by 1 real multiplication and 3 real sums. This allows to further reduce the complexity.

4) Second demapper proposed by Jianxiao Yang et al, 2015 [18]
These authors proposed a sphere demapping algorithm which induces the computation of $2^{\frac{m}{2}}$ euclidean distances instead of 2^m for the Max-Log demapper. Moreover, they proposed new optimum rotation angles Φ different from angles proposed in DVB-T2 standard. These angles are $\alpha = arctan(\frac{1}{2^{\frac{m}{2}}})$ with $m = 2, 4, 6, 8$. These angles have some properties which allow to reduce the complexity of euclidean distance computation and then to increase DVB-T2 system performance. Indeed, based on the structural properties of the rotated QAM constellations, a dedicated low complexity Max-Log called "sphere-demapper" is designed and its radius implies the exact amount of involved constellation points. This algorithm achieves a complexity reduction by more than 60%.

5) Demapper proposed by Tarak Arbi et al, 2018 [19]
These authors complete the work previously done in [18] (IV.C.4) by studying properties of these angles when Rayleigh channel with erasure is used. Furthermore, they proposed a reduced version of the sphere decoding algorithm well suited to the channel with erasure event (when one of the received symbol component (I or Q) has been completely lost). Using this algorithm the hardware implementation complexity is reduced and a performance gain is obtained. Indeed, using the rotation angles proposed, the constellation points are uniformly projected on I and Q axis. This confers some properties to the constellation. This demapping algorithm is proposed using the angle properties and allows to increase the signal robustness. Using this algorithm, the complexity is reduced by 60%. Moreover, using Rayleigh channel with erasure event of 15%, a performance gain (Carrier to Noise ratio) obtained at a BER of 10^{-6} respectively 0.1 dB, 0.5 dB and 0.75 dB for 4-QAM, 16-QAM and 64-QAM.

V. DISCUSSION AND ANALYSIS

For all the foregoing, we can notice that many low complexity demapper algorithms have been proposed for the hardware implementation of rotated QAM demapping to have a low cost receiver and a high autonomy. Nevertheless, these algorithms proposed different reduction methods. Moreover, the last algorithm of all of the presented algorithms in this paper (cf IV.C.5) reduces the complexity and increases the signal robustness allowing to get a gain of $0.75\,\mathrm{dB}$ at a BER of 10^{-6} for 64-QAM and in the worst reception conditions (Rayleigh with erasure event). This algorithm could be best as the other algorithms do not increase the signal robustness but only decrease the demapping complexity. Due to the performance of the last algorithm proposed in 2018, it could be applied like a low complexity demapping algorithm for DVB-T2 based 2D-Non Uniform Constellations (NUCs) as these constellations have been proposed in DVB-T2 systems and highlighted a better performance using Rayleigh channel (P1) [27] and TU6 channel [28]. Furthermore, the hardware resources required to implement this algorithm have been evaluated and compared to those needed for the Max-Log algorithm using an Application Specific Instruction-Set Processors (ASIP) model [29]. One of the advantages of all of these algorithms is that some of them are exploited in the designing of low complexity demappers for advanced constellation technique Non Uniform Constellations (NUCs) [30], [31]. Researches are still in progress on rotated constellation technique up to this date and its performance have been recently evaluated in the presence of Gaussian, Ricean, Rayleigh and 0dB echo channel for of the purpose of identification of the channel that presents the higher gain [32].

TABLE III
COMPARATIVE TABLE OF DEMAPPING ALGORITHMS

Authors	Channels	Const	Percent
Algorithms based on number of candidate points reduction			
Perez-Calderon et al, 2011 [11]	Rayleigh with erasure of 15%	256	31.25%
		–	–
Stefano Tomasin et al, 2012 [12]	Rayleigh without and with erasure of 20%	64	87.5%
		256	93.75%
Perez-Calderon [13] et al, 2013	P1, 0dB echo, Rayleigh with erasure of 15%	256	78%
		–	–
Algorithm based on the euclidean distance complexity reduction			
Perez-Calderon [16] et al, 2014	AWGN, P1, 0dB echo	256	99.2%
	Ray with erasure of 15%	64	99.2%
Algorithms Based on the number of candidate points and the computation of the euclidean distance			
Meng Li et al, 2009 [15]	Rayleigh without and with erasure of 15%	64	$\geq 60\%$
		256	$\geq 69\%$
Kitaek Bae [14] et al, 2012	AWGN and Rayleigh with erasure of 5%	64	87.5%
		–	–
Jianxiao Yang [17] et al, 2015	Rayleigh	256	$\geq 87.5\%$
		64	75%
Jianxiao Yang [18] et al, 2015	Rayleigh without and with erasure of 15%	256	$\geq 60\%$
		64	$\geq 60\%$
Tarak Arbi [19] et al, 2018	Rayleigh without, with	256	$\geq 60\%$
	erasure of 5 % and 15%	256	$\geq 96\%$

Table III gives a summary of all of these algorithms. In this table, the algorithms are classified according to their specific reduction criterion, the type of channel on which their performance were evaluated, the constellation sizes used and the percentage of reduction arising from their application. It is observed that all of these algorithms are focused on the high order constellations as the complexity increases with the constellation order. While some algorithms performance are evaluated on Rayleigh channel with erasure, the others are focused on the impact of erasure events on the channel by evaluating their performance when erasure event are present or not. The reduction percentages have been computed according to the number of candidate points excluded from the constellation points used to perform the bit demapping and the number of multiplication operator used in the euclidean distance computation. The symbol $\geq$ means that the percentage of reduction is more than that presented for algorithms which reduce both the number of candidate points and the complexity of computation of the euclidean distance.

VI. CONCLUSION

In this paper, we presented the SSD technique used in DVB-T2 and compared low complexity algorithms proposed for the demapper hardware implementation. These algorithms have been characterized by the type of applied complexity reduction. We can conclude that recently proposed algorithms present better performance in terms of percentage of reduction and gain when Rayleigh channel with erasure is used. Moreover, the algorithm recently proposed in 2018 by the last authors increases DVB-T2 performance and reduce the complexity.

This paper gives a deep comparison of algorithms allowing the manufacturer to have a large and complete view and to make a good choice for the demapper hardware implementation. Moreover, it gives a compliant detail about rotated constellation and the kind of demapper needed when it is used. As this technique provides the increasing of the frequency diversity and the signal robustness, its use in DVB-T2 could optimize broadcasters network using receivers which include a reduced complexity demapping algorithm. Despite the higher performance of rotated constellation, a low complexity hardware implementation algorithm has not yet been implemented in the commercial receivers to benefit from the performance of this technique. This work constitutes a basis for manufacturers and researchers who would like to implement or propose a low complexity demapping algorithm for rotated constellation or other constellation shaping techniques.

ACKNOWLEDGMENT

This work has been carried out under support from the ARES-CCD within the framework of the PHORAN PFS project.

REFERENCES

[1] European Broadcasting Union, “Digital Video Broadcasting (DVB); Frame structure channel coding and modulation for a second generation digital terrestrial television broadcasting systems (DVB-T2),” ETSI EN 302 755 V1.4.1, 2015.

[2] Advanced Television Systems Committee, ATSC Physical Layer Protocol, "Next generation broadcasting system to handheld," Document A/322, Washington, January 2020.

[3] European Broadcasting Union, “Digital Video Broadcasting (DVB); implementation guidelines for a second generation digital terrestrial television broadcasting system (DVB-T2),” ETSI TS 102 831 V1.2.1, 2012.

[4] E. Zehavi, "8-PSK trellis codes for a Rayleigh channels," IEEE Transaction on Communication., vol. 40, No. 5, pp. 873-884, May 1992.

[5] B. Joseph and V. Emanuele, "Signal space diversity: a power-and bandwidth-efficient diversity technique for the Rayleigh fading channel,", Vol. 44, No. 4, pp. 1453-1467, July 1998.

[6] J. Stott, “CM and BICM limits for rectangular constellations”, DVB document server, TM-MIMO0007, 2012.

[7] X. Giraud, E. Boutillon, and J C. Belfiore, "Algebraic tools to build modulation schemes for fading channels", IEEE Transaction on Information Theory, Vol. 43 , No.3 , pp. 938-952, May 1997.

[8] L. Polak and T. Kratochvil, “Performance of the rotated constellation in DVB-T2,” In proceedings of the 7th International Conference on Digital Telecommunications, p84 - 87, 2012.

[9] M. Slimani, J. Robert, and P. Schlegel, U. H. Reimers, R. Burow, F. Kattanek, R. Pfeffer, and L. Stadelmeier, “Results of the DVB-T2 Field Trial in Germany,” IEEE Transaction on Broadcasting, Vol. 61, No. 2, June 2015.

[10] O. Haffenden, “The common simulation platform,” BBC Research White Paper 196, May 2011.

[11] D. Pérez-Calderon, V. Baena-Lecuyer, A. C. Oria, P. Lopez, and J. G. Doblado, “Rotated constellation demapper for DVB-T2,” Electron. Lett., vol. 47, pp. 31–32, Jan. 2011.

[12] M. Butussi, and S. Tomasin, “Low Complexity Demapping of Rotated and Cyclic Q Delayed Constellations for DVB-T2,” IEEE Wireless Commun. Lett., vol.1, pp.81-84, Apr. 2012.

[13] D. Pérez-Calderon, V. Baena-Lecuyer, A. C. Oria, P. Lopez, and J. G. Doblado, "Simplified rotated constellation demapper for second generation terrestrial digital video broadcasting," IEEE Transactions on Broadcasting, vol. 59, pp. 160-167, 2013.

[14] B. Kitaek, K. Kyeongyeon and Y. Ho, "Low complexity two-stage soft demapper for rotated constellation in DVB-T2,", IEEE International Conference on Consumer Electronics (ICCE), pp. 618-619, 2012.

[15] M. Li, C. Abdel Nour, C. Jégo, and C. Douillard, “Design of rotated QAM mapper/demapper for the DVB-T2 standard,” in Proc. of IEEE SIPS 2009, pp. 18-23, Oct. 2009

[16] D. Pérez-Calderon, V. Baena-Lecuyer, A. C. Oria, P. Lopez, and J. G. Doblado, "Simplified Metrics Calculation for Soft Bit Detection in DVB-T2," Radioengineering, vol. 23, No. 1 p. 399-404, 2014.

[17] J. Yang, M. Li, C.A. Nour, C. Douillard, B. Geller, “Max Log Demapper Architecture Design for DVB T2 Rotated QAM Constellations,” Proceedings of IEEE SIPS, Hangzhou, October 2015.

[18] J. Yang, K. Wan, B. Geller, C. Abdel Nour, O. Rioul, and C. Douillard, “A low-complexity 2D signal space diversity solution for future broadcasting systems”, in Proc. IEEE Inter. Conf. on Comm., ICC 2015, pp. 2762-2767, June 2015.

[19] T. Arbi, B. Geller, J. Yang, K. Wan, C. Abdel Nour, O. Rioul, and C. Douillard, “Uniformly Projected RCQD QAM: A Low-Complexity Signal Space Diversity Solution over Fading Channels With or Without Erasures ”, IEEE Transactions on Broadcasting, vol. 64, No. 4, pp. 803-815, 2018.

[20] N. Suwansukho and S. Promwong, Evaluation of Rotated Constellation in DVB-T2 Based on Measurement Data, 5th International Conference on Engineering, Applied Sciences and Technology (ICEAST), 2019.

[21] C. Abdel Nour and C. Douillard, “On lowering the error floor of high order turbo BICM schemes over fading channels,” in IEEE Global Commun. Conf., GLOBECOM’06, San Francisco, USA, pp. 1–5, Nov. 2006.

[22] C. Abdel Nour and C. Douillard , "Improving BICM performance of QAM constellations for broadcasting applications," 50^th Int. Symp. on Turbo Codes and Related Topics, Lausanne, Switzerland, pp. 55-60, Sep.2008.

[23] DVB-T2: The Common Simulation Platform, BBC R&D White Paper 196, available at http://downloads.bbc.co.uk/rd/pubs/whp/whp-pdf-files/WHP196.pdf

[24] DVB-T2 Common Simulation Platform, available at: https://sourceforge.net/projects/dvb-t2-csp/files/releases, and http://dvb-t2-csp.svn.sourceforge.net/

[25] T. Cheng, K. Peng, Z. Liu, and Z. Yang, “Efficient receiver architecture for LDPC coded BICM-ID system,” IEEE Commun. Lett., vol. 19, no. 7, pp. 1089–1092, Jul. 2015.

[26] European Broadcasting Union, "Frequency and network planning aspects of DVB-T2," TECH 3348 REPORT, VERSION 4.1.2, 2020.

[27] J. Morgade, D. Ansorregui, B. Mouhouche, H. Jeong and H. Lee, "Improving the DVB-T2 BICM Performance by Newly Optimized Two-Dimensional Non-Uniform Constellations," IEEE Fourth International Conference on Consumer Electronics Berlin (ICCE-Berlin), 2014.

[28] A-C. Honfoga, M. Dossou, P. Dassi and V. Moeyaert, "Joint use of 5G waveform UFMC and Non Uniform Constellations in DVB-T2", 6th IEEE Congress on Information Science and Technology (CiSt), 2020.

[29] A. R. Jafri, A. Baghdadi, M. Waqas and M. Najam-Ul-Islam, "High-Throughput and Area-Efficient Rotated and Cyclic Q Delayed Constellations Demapper for Future Wireless Standards", IEEE access, 2017.

[30] C. Barjau, M. Fuentes, T. Shitomi and D. Gomez-Barquero, "MIMO Sphere Decoder with Successive Interference Cancellation for Two-Dimensional Non-Uniform Constellations", IEEE communications letters, vol. 21, no 5, pp. 1015-1018, 2017.

[31] Liu, Yu-Sun and Chien, Chih-Hao and You, Shingchern D, "Low-complexity demapping algorithm for two-dimensional non-uniform constellations in ATSC 3.0", IET Communications, vol. 15, no 6, pp. 815-823, 2021.

[32] H. S. Ghayyib and S. J. Mohammed, "Performance Enhancement of FEC Code For DVB-T2 System by Using Rotated Constellations", 1st Babylon International Conference on Information Technology and Science, 2021.

A-C Honfoga was born in Cotonou, Benin on March 17, 1994. She received the M.S. degree in network and telecommunications engineering from the Polytechnic School of Abomey-Calavi, Abomey-Calavi, Benin in 2015.

From 2016-2017, she was network and telecommunications engineer at ASSI ("Agence des services et systèmes d'information de l'Etat"). From 2017-2021, she is a researcher in Electromagnetism and Telecommunication Department, Faculty of Engineering (FPMs), University of Mons (UMONS), Belgium and Electrical Engineering Department at University of Abomey-Calavi, BENIN. She is preparing the PhD degree in applied sciences (Wireless transmission).

M. Dossou was born in Cotonou, Benin on June 12, 1982. He received the B.S. and M.S. degrees in electrical engineering from the Polytechnic faculty of Royal Military Academy (RMA), Brussels, BELGIUM in 2003 and 2006, and the Ph.D. degree in non-linear optics from the University of Lille, FRANCE in 2011 with a scholarship from the Centre National de la Recherche Scientifique (CNRS).

From 2011 to 2012, he was a Research Assistant with the PhLAM (Physique des Lasers, Atomes et Molécules) laboratory of the University of Lille, FRANCE. In 2012, he joined the Polytechnic School of Abomey-Calavi, becoming Assistant Professor in 2015. Since 2019, he has been appointed Associate Professor with the Electrical Engineering Department from the University of Abomey-Calavi, BENIN. He is the author of more than 30 articles. His research interests include optical fibre technology, wireless communications and broadcasting.

Dr Dossou was awarded the 2006 Best M.S. dissertation Award of the Association of Engineers from RMA.

V. Moeyaert was born in Mons, Belgium on March 19, 1970. She received the M.S. degree in Electrical Engineering and the Ph.D. degree in Applied Sciences from the Polytechnic Faculty of Mons (FPMs), Mons, Belgium, in 1993 and 2002.

From 2002 to 2005, she was a research and teaching associate at the Polytechnic Faculty of Mons (FPMs), Belgium. From 2005 to 2009, she was associate professor at the Polytechnic Faculty of Mons (FPMs), Belgium and from 2009 to 2013 at the University of Mons (UMONS), Belgium. Since 2013, She is Professor in Telecommunications at the University of Mons, Belgium. She has her main research interests in the physical layer performance estimation and optimisation of optical, electrical and wireless transmission systems, either analogue or digital. Particularly, she is working on HFC networks, RoF systems, LPWAN IoT systems, VLC communications in the frame of smart cities, and PLC systems for both the power grid and railway signalling.