Simplified Metrics Calculation for Soft Bit Detection in DVB-T2

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Abstract. *The constellation rotation and cyclic quadrature component delay (RQD) technique has been adopted in the second generation terrestrial digital video broadcasting (DVB-T2) standard. It improves the system performance under severe propagation conditions, but introduces serious complexity problems in the hardware implementation of the detection process. In this paper, we present a simplified scheme that greatly reduces the complexity of the demapper by simplifying the soft bit metrics computation having a negligible overall system performance loss.*

Keywords

Demapper, DVB-T2, OFDM, rotated constellation.

1. Introduction

The rotated and cyclic quadrature delayed constellation (RQD) technique improves the performance of the DVB-T2 receiver under fading channels by means of the rotation in the complex plane of a classical QAM constellation [1]. After the rotation, a cyclic delay is applied to the quadrature (Q) component of the constellation symbol, performing an interleaving process. Therefore, the in-phase (I) and quadrature components of the transmitted symbol are sent in different carriers and even in different time slots, and thus, affected by independent fadings.

Although the RQD technique improves the reception in fading channels [2], [3], the hardware complexity of the detection process is notably increased compared with non-rotated constellations, even when the max-log approximation is employed. In the case of rotated constellations, each Log Likelihood Ratio (LLR), needed by the Low Density Parity Check (LDPC) decoder used in standards as DVB-T2, is a function of both I and Q components of the received data. This requires the calculation of two-dimensional (2D) distances from the received point to all the ideal constellation points [4]. As an illustrative case, if we consider the highest order constellation in DVB-T2 (256-QAM), 256 Euclidean distances must be calculated for each LLR metric.

2. Detection Process for Rotated Constellation

Mathematically, the expression for the LLR metrics for the i^{th} bit (b_i) of the received symbol ($I+jQ$) when the max-log approximation is used is [4]:

$$\begin{aligned} LLR(b_i) \approx \frac{1}{2\sigma^2}\Big\{ &\min_{x\in C_i^0}\left((I-\rho_I I_x)^2+(Q-\rho_Q Q_x)^2\right) \\ &-\min_{x\in C_i^1}\left((I-\rho_I I_x)^2+(Q-\rho_Q Q_x)^2\right)\Big\} \end{aligned} \tag{1}$$

where σ^2 represents the noise variance, C_i^k is the subset of symbols of the ideal constellation whose i^{th} bit's value is k ("0" or "1"), ρ_I and ρ_Q are the channel coefficients for the real and imaginary component respectively, and I_x and Q_x are the real and imaginary component of the ideal constellation symbols.

As it can be followed from (1), 2^m terms like:

$$D^2=(I-\rho_I I_x)^2+(Q-\rho_Q Q_x)^2 \tag{2}$$

must be calculated in the case of a 2^m-QAM constellation. Note that D represents the Euclidean distance between the received complex value $I+jQ$ and the ideal constellation point propagated through the channel ($\rho_I I_x+j\rho_Q Q_x$).

In the DVB-T2 standard, m can take values up to 8 (in the case of a 256-QAM constellation). This means that for each received constellation point, 256 terms as the one in (2) must be calculated, which makes the detection process very complex in terms of hardware implementation.

3. Simplified Demapper

In order to reduce the complexity introduced by the use of the RQD technique, four different approaches have been proposed in the literature.

In [5], the authors propose to decorrelate the received signal in order to be able to detect it as two independent PAM modulations, obtaining a great complexity reduction. However, this method already shows a performance loss of

0.3 dB in the carrier-to-noise ratio (C/N) in some configurations for a bit error rate (BER) level of only 10^{-3}.

The second approach is the one suggested in [6]-[10]. In them the authors show that, using different subsets of the original constellation, the number of distances to be calculated can be considerably reduced. Depending on the accuracy of the chosen subset the performance will be more or less affected by the reduction of the number of distances to be computed.

The third approach, which is compatible with the previous one, is exposed in [7]. The authors propose to use:

$$D \approx \begin{cases} \max(a,b), & \min(a,b) \le \dfrac{\max(a,b)}{4} \\ \max(a,b) + \dfrac{\min(a,b) - \dfrac{\max(a,b)}{4}}{2}, & \text{otherwise} \end{cases} \tag{3}$$

as a simplification when calculating (2), where a and b are:

$$a = abs(I - \rho_I I_x)\,, \tag{4}$$

$$b = abs(Q - \rho_Q Q_x)\,. \tag{5}$$

This approximation leads to the scheme shown in Fig. 1, which avoids the use of multipliers for the square terms in (2), and leads to a negligible performance loss.

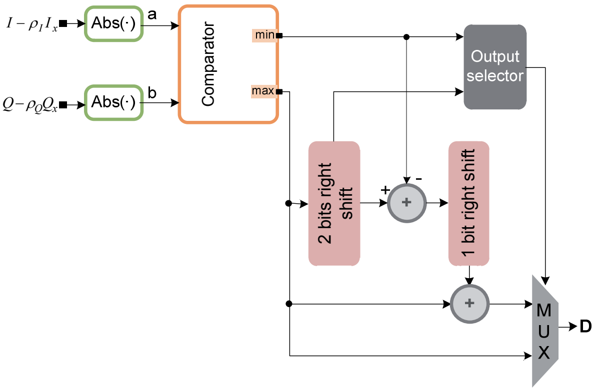

Fig. 1. Scheme of the method proposed in [7].

Finally as the fourth approach, authors in [11] present four computationally efficient demodulation schemes with hybrid soft-hard outputs used in hard demapping of data. From [11], the methods that show less performance losses still require the computation of LLR distances, so it is compatible with both previous approaches (subsets and metrics simplification).

In this paper we will propose a method that focuses on this third approach, reducing the complexity of obtaining the metrics needed by the LDPC decoder.

4. Proposed Method

When max-log approximation is used as shown in (1), it is needed to find the point of the constellation that minimizes the distance between the received signal and the subset of constellation points in which the i^{th} bit value is "0" or "1". Many distance metrics can be found in the literature different from the traditional Euclidean distance; however all of them need to accomplish some conditions. Being D the distance between the points i and j these restrictions are:

$$D(i,j) \ge 0\,, \tag{6}$$

$$D(i,i) = 0\,, \tag{7}$$

$$D(i,j) = D(j,i)\,, \tag{8}$$

$$D(i,j) \le D(i,h) + D(j,h)\,. \tag{9}$$

In (9) it is expressed the restriction known as triangle inequality.

The main target of this work is to obtain a method that can reduce the hardware implementation complexity of the soft bit decision detection as the used in standards as DVB-T2. So the proposed used distance metric needs to be as simple as possible keeping a good performance. Manhattan distance [12] for an n-dimensional space can be formulated as indicated:

$$D(i,j) \approx \left|x_{i1} - x_{j1}\right| + \left|x_{i2} - x_{j2}\right| + \ldots + \left|x_{in} - x_{jn}\right|\,. \tag{10}$$

This approximation has a much simpler implementation than the traditional Euclidean one, and one of the most simple among the distance metrics that meet (6)-(9).

To reduce the complexity of the RQD demapper, the simplicity of (10) leads us to propose using the 2 dimensions expression of the Manhattan distance:

$$D \approx a + b\,. \tag{11}$$

This approximation will be used instead of (3) when looking for the minima of the distances needed in (1).

Focusing in the case of QAM constellations used in the DVB-T2 standard, it can be found that with traditional non rotated constellations the decision area for every constellation takes the shape of a square mesh when the Euclidean distance is used.

When non rotated constellations are used the aforementioned grid represents also the decision regions for the Manhattan distance approximation. This means that either using the Euclidean distance or Manhattan approximation leads to the same result when looking for the constellation point that minimizes the distance with a received signal, so the performance loss is null. Note that the value of this minimum is not the same for both but the constellation point that produces it is.

However in DVB-T2, the use of the rotated constellation technique changes the decision regions as shown in Fig. 2. In this case, the decision regions for the Euclidean distance are bounded with dashed lines and the decision regions for the Manhattan approximation are limited by continuous lines. For the sake of simplicity the same channel gain has been assumed for I and Q components, if not the shape of the regions would be not square but rectangular (depending on the power gain ratio between ρ_I and ρ_Q). As can be easily noticed, the regions for the two distance metrics are different, but they are coincident in the majority of the area. The grey marked zones in Fig. 2 represent the non-coincident areas, thus the points where the Euclidean distance and the Manhattan approximation would give a different result when looking for the constellation point that minimizes the distance.

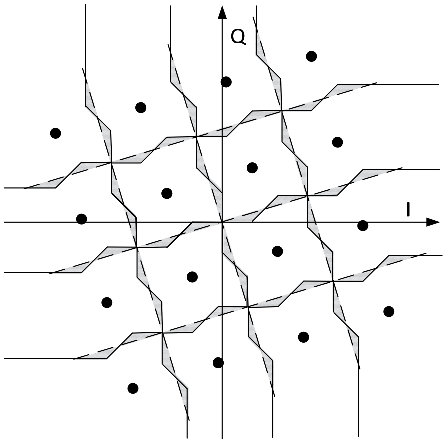

Fig. 2. Decision areas for a rotated 16-QAM constellation.

In Fig. 3, the mismatch rate is shown when comparing the minimum obtained with the exact Euclidian distance and the Manhattan approximation for all the available constellations in the DVB-T2 standard in presence of AWGN. Depending on the code rate and the constellation, the C/N needed to correctly perform the detection process varies and so the BER level at the output of the demapper (BER_{DEM}) that the LDPC needs to correct the errors.

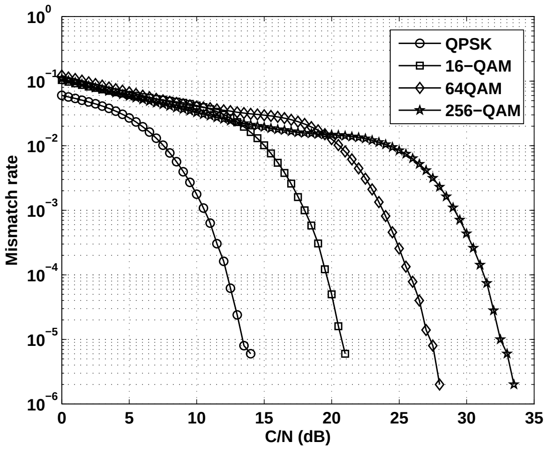

Fig. 3. Mismatch rate between the exact Euclidean calculation and the proposed approximation in AWGN conditions after the demapper.

However, the mismatch rate shown in Fig. 3 always remains under the required BER_{DEM} level, so that this mismatch will lead to a very slight performance loss as it will be shown in Section 5.

To clarify this, Tab. 1 shows a comparison of the BER_{DEM} and the mismatch rate presented by the proposed approximation at the same C/N level, for a 16-QAM constellation and a P1 Rayleigh channel [13]. This C/N level has been chosen to have a BER level after the LDPC (BER_{LDPC}) under 10^{-6}.

Code rate	C/N@BER_{LDPC}=10^{-6} (dB)	BER_{DEM}	Mismatch rate
1/2	8.45	0.157	0.048
3/5	10.20	0.118	0.040
2/3	11.65	0.093	0.033
3/4	13.30	0.068	0.020
4/5	14.45	0.053	0.013
5/6	15.35	0.043	0.008

Tab. 1. Mismatch and BER after the demapper comparison. 16-QAM constellation and P1.

Focusing on the complexity reduction, in the case of a 256-QAM, the proposed simplification requires only the calculation of additions per each received point instead of multiplications when compared to (2) and it avoids the use of comparators when compared to (3).

From a digital implementation point of view, the absolute values can be computed by using one's complement arithmetic instead of two's complement, obtaining even a higher complexity reduction.

In order to avoid performance loss, once the minimum distances have been found, we still use (2) to compute the LLRs. Note that (2) is only used two times per LLR instead of 2^m.

The scheme of the hardware implementation of this approximation is shown in Fig. 4. The proposed method is compared with the exact Euclidean calculation by using the number of additions and multiplications needed in Tab. 2. In the case of DVB-T2 m can take values up to 8 (256-QAM), that means that the number of multiplications needed by the proposed scheme represents the 0.8 % of the ones needed for the exact Euclidean calculation of the distance maintaining almost the same amount of additions.

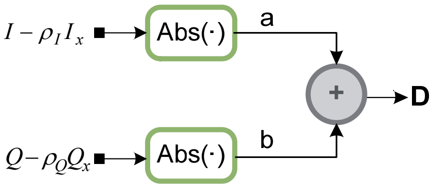

Fig. 4. Proposed method scheme.

	Exact calculation	Proposed method
Additions	2^m	2^m+2
Multiplications	2^{m+1}	4

Tab. 2. Complexity comparison.

5. Simulation Results

Simulations have been run to determine the impact of the proposed detection technique on the system performance. For that purpose, BER curves at the output of the LDPC decoder of a DVB-T2 system have been obtained by using the DVB-T2 Common Simulation Platform [14], a simulation model verified by the DVB-T2 technical module.

Simulations have been run for a LDPC block size of 64 800 bits and all the code rates (CR) included in the DVB-T2 standard: 1/2, 3/5, 2/3, 3/4, 4/5, and 5/6, a maximum of 50 LDPC iterations, and three propagation scenarios: a P1 Rayleigh channel [13], a 0dB Echo channel with an echo delay set to 95% of the guard interval, and the worst case defined in [2], the Rayleigh Memoryless channel with Erasures (RME), in this case with a 15% erasure event rate [15], [16]. Ideal channel estimation has been used. For the sake of brevity only some of the results obtained will be explicitly shown in this paper. However, for all the possible CR and constellations (QPSK, 16-QAM, 64-QAM, and 256-QAM), the simulation results show a performance loss for the proposed method always under 0.1 dB measured at a BER level of 10^{-6}. To illustrate this, Figs. 5, 6, and 7 show the BER curves against the C/N for a CR of 3/4 (an intermediate CR) in the three aforementioned propagation scenarios. In each figure, three different approximations have been represented: the max-log approximation, the method presented in [7], and the proposed method in this paper. From these figures it can be followed that the performance loss is negligible in all the simulated propagation scenarios.

In Tab. 3, a summary of the performance loss obtained when using the proposed method in this paper is shown. The table contains the simulation results of all the constellations and code rates available in DVB-T2 for a RME (15% erasure events) propagation scenario (as stated before the worst case proposed in the implementation guidelines). It can be seen that the performance loss is negligible for all the possible cases.

Code rate	QPSK	16-QAM	64-QAM	256-QAM
1/2	<0.05	<0.1	<0.05	<0.05
3/5	<0.05	<0.1	<0.05	<0.05
2/3	<0.05	<0.1	<0.1	<0.1
3/4	<0.05	<0.1	<0.05	<0.05
4/5	<0.05	<0.05	<0.05	<0.05
5/6	<0.05	<0.1	<0.05	<0.05

Tab. 3. RME (15% erasure events) channel performance loss (dB).

Code rate	0dB Echo	P1 Rayleigh	RME (15%)
1/2	<0.1	<0.1	<0.1
3/5	<0.05	<0.1	<0.1
2/3	<0.1	<0.1	<0.1
3/4	<0.05	<0.1	<0.1
4/5	<0.1	<0.1	<0.05
5/6	<0.05	<0.1	<0.1

Tab. 4. 16-QAM performance loss (dB) in different channels.

From Tab. 3 it can be also followed that the proposed approximation finds its worst work case for a 16-QAM constellation. The performance of the proposed method for a 16-QAM constellation in every studied propagation scenario can be seen in Tab. 4. In both tables <0.05 indicates that the performance loss when compared with max-log is under 0.05 dB and <0.1 indicates that this loss is between 0.1 and 0.05 dB.

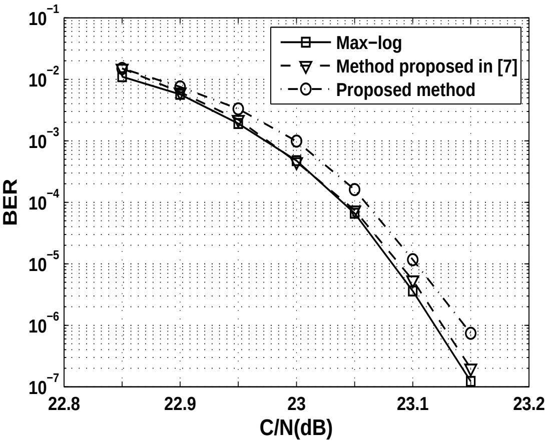

Fig. 5. BER against C/N for 256-QAM, CR=3/4, in P1 Rayleigh channel.

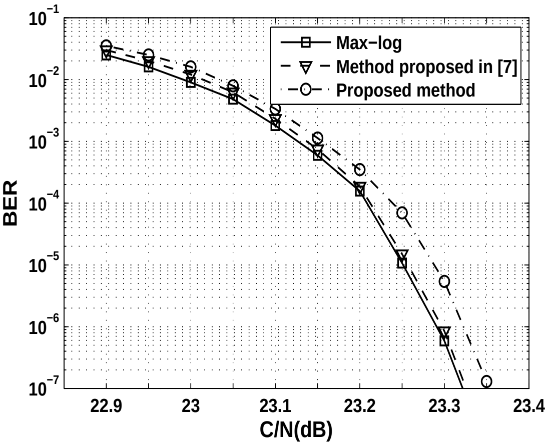

Fig. 6. BER against C/N for 256-QAM, CR=3/4, in 0dB Echo channel.

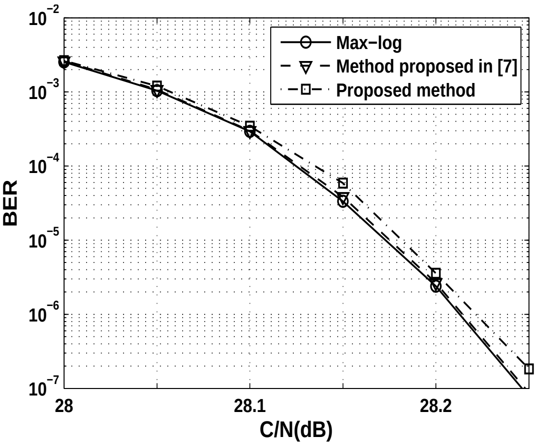

Fig. 7. BER against C/N for 256-QAM, CR=3/4, in RME channel.

Regarding the number of LDPC iterations, the performed simulations showed no noticeable differences. The average number of iterations for a BER level of 10^{-5} differs in less than 5 iterations when comparing our proposed method with the ideal max-log LLRs. This difference is even less for lower BER levels.

In conclusion, the main benefit of the proposed method is that it has a negligible impact on the system performance having a much simpler hardware implementation than the one presented in [7].

6. Conclusion

In this paper, a method to reduce the hardware complexity of the demapper for rotated constellation with application to DVB-T2 has been presented. It decreases the number of multipliers needed in the hardware implementation by reducing the number of multiplications needed to a 0.8%. This reduction is obtained by using an approximation in the calculus of the Euclidian distance. The performance of the method has been validated by means of computer simulations in three different propagation scenarios, including the most severe one defined in [4], the RME scenario with a 15% of erasures. The performance loss obtained is always under 0.1 dB measured at a BER of 10^{-6}.

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