Telecomunicaciones y Electrónica

Diseño de Constelaciones No-Uniformes a través del algoritmo PSO para el estándar DTMB.

Non-Uniform Constellations design through PSO algorithm for DTMB standard.

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Resumen:

El objetivo del artículo es diseñar nuevos esquemas de mapeo de símbolos para el estándar DTMB haciendo uso de las Constelaciones No-Uniformes (NUC) y mostrar las mejoras del sistema resultante. Dichas constelaciones proporcionan una mejora potencial para recepción a bajos niveles de Relaciones Señal a Ruido y por lo tanto, una reducción en la separación con respecto al Límite de Shannon. Las NUC en Una y Dos Dimensiones son diseñadas basados en la optimización de la capacidad del BICM (Bit-Interleaved Code Modulation). El algoritmo metaheurístico "Particle Swarm Optimization" (PSO) se implementa con el fin de maximizar la ecuación de capacidad BICM para el diseño NUC en Dos Dimensiones. Todas las simulaciones se llevan a cabo para modelos de canal AWGN y Rician y para todas las especificaciones de la cadena de codificación del estándar DTMB con 6 MHz de ancho de banda. La propuesta incluye el diseño de NUC para 256-QAM, aumentando la razón bits máxima posible de DTMB a 32.486 Mbps.

Palabras claves: Constelaciones No Uniformes, PSO, DTMB, Límite de Shannon, capacidad de BICM, QAM.

Abstract:

The aim of this paper is to design new mapping schemes for DTMB standard taking advantage of the Non-Uniform Constellations (NUC) and to show the improvements of the resulting system. Such constellations, provide a potential improvement regarding the reception at lower Signal to Noise Ratio, and hence, a reduction in the gap from the Shannon Limit. One and Two Dimensional NUC are designed based on the optimization of the BICM (Bit-Interleaved Code Modulation) capacity. The metaheuristic algorithm Particle Swarm Optimization is implemented in order to maximize the BICM capacity equation for Two Dimensional NUC design. All simulations are carried out for AWGN and Rician channel and for all DTMB coding chain specifications with 6 MHz of channel Bandwidth. The proposal includes NUC for 256-QAM, increasing the maximum possible bit rate of DTMB to 32.486 Mbps.

Key words: *Non-Uniform Constellations, PSO, DTMB, Shannon Limit, BICM capacity, QAM.*

1. Introduction

The evolution of Digital Terrestrial Television Broadcasting (DTTB) Systems since the first generation up to recent next-generation ATSC 3.0 system has progressively reduced the gap from the Shannon Limit. Technologies such as Low Density Parity Check (LDPC) codes, Layer Division Multiplexing (LDM), Multiple-input-multiple-output (MIMO), Bit-Interleaved Code Modulation (BICM) and Non-Uniform Constellations (NUC) allow a more efficient use of the spectrum capacity, i.e., lower Signal to Noise Ratio (SNR) receptions, higher data rates and hence, more robust systems. [1]

The DTMB Standard belongs to the first generation DTTB systems [2]. Its performance regarding the Shannon Limit, [3], and the use of the Spectrum Capacity is far from the state of art systems. The aim of this paper is to propose new mapping schemes for DTMB standard taking advantage of the Non-Uniform Constellations and to show the improvements of the resulting system.

The Non-Uniform Constellations belong to the longtime studied constellation shaping techniques, specifically geometrical shaping. In 1974, Foschini and his colleagues proposed NUC, which minimizes symbol error rates over an Additive White Gaussian Noise (AWGN) channel in [4]. Subsequently, Forney in [5] mathematically proved an ultimate limit for the SNR Gain of the constellation shaping techniques for the Signal Set Capacity. Later, in the year 1996 in [6], a more realistic Capacity limit is presented: the BICM Capacity. In [7] were presented for the first time the one dimension (1D) NUC potentials, based on the BICM Capacity maximization. In [8] two-dimension (2D) NUC up to 32-QAM were designed, based on an iterative gradient-search method for the BICM Capacity maximization. In [9] optimized 1D and 2D NUC with high order up to 1048576 constellations points were presented.

During the last ten years, several papers have reinforced this technology, proving its advantage over the widely used and studied Uniform Constellations (UC). Therefore, this is one of the key technologies of the new generations of broadcasting standards. In [10] a 2D NUC proposal is made for DVB-T2 standard based on the optimization of the BICM capacity. This proposal shows how the NUC reduce the gap from Shannon Limit of the system. For 256-QAM they achieve a reduction that goes from 0.4 bps to 0.2 bps and an SNR gain of up to 1.05 dB. The system with 2D NUC is within 1.3 dB of difference with respect to the Shannon Limit, almost half that with the traditional uniform constellations (UC). In 2012 the 1D NUC were proposed and adopted in DVB-NGH (Next Generation Handheld) [11]. In [12] 1D and 2D NUC were proposed and adopted for the ATCS 3.0 standard with SNR gains up to 1.8 dB for 1D 4K-QAM and up to 1.3 dB for 2D 256-QAM.

Recently, in [13] and [14] new constellations design methodologies were presented. The first one is based on a two-steps algorithm, which consists of an initial constellations design plus an iterative optimization. The second one consists in the maximization of the BICM capacity by mean of the Particle Swarm Optimization (PSO) algorithm and the definition of the initial set of constellations for the PSO. In [15] a set of high order NUC was presented that achieve higher gains than those presented by ATSC 3.0 and then in [16] new condensation methodologies were presented for 2D NUCs with a reduction in the complexity of the design process and de-mapping between 13% and 94% with a reduction in SNR gain of less than 0.1 dB.

In this paper, optimized new constellations in 1D are designed, based on the BICM capacity numerical optimization criterion as described in [7]. For BICM capacity maximization in 2D NUC, the PSO algorithm is implemented, and a different set of initial constellations is used in comparison with [14]. The proposal includes the design of the high order NUC 256-QAM. The major contribution of this paper is the comparison of the DTMB standard´s performance using the Uniform Constellations (UC) and the proposed 1D and 2D NUC (including 256-QAM) with regard to the gap from the Shannon Limit, Spectral Efficiency, BICM capacity and BER (Bit Error Rate) vs. SNR.

The rest of the paper is structured as follows: Section 2 provides the Introduction and theoretical fundamentals of Channel Capacity limits and Non-Uniform Constellations. Section 3 describes the NUC design criterions and the proposed NUC for DTMB. In Section 4, simulation results are discussed and finally, in Section 5, the paper conclusions are presented.

2. Channel Capacity and NUC Concepts

2.1 Channel Capacity

From 1948, Claude E. Shannon in his groundbreaking paper "A mathematical theory of communication" defined the maximum possible throughput over any given channel as the channel capacity (C_C) [3]. The information throughput is the difference between the entropy of the transmitted symbols $H(s_k)$ and the conditional entropy $H(s_k|r_k)$, being s_k and r_k the channel input and channel output respectively [8]. This difference is also known as the mutual information (*MI*) between s_k and r_k, $I(s_k,r_k) = H(s_k) - H(s_k|r_k)$ [8]. In [8] these entropy concepts are clearly described.

In [3], Shannon redefines C_C as the maximum *MI* $I(s_k,r_k)$ among all possible distributions $p(x_l)$, of an arbitrary symbol alphabet X, (1).

$$C_C = \max_{p(xl)} I(s_k,r_k). \tag{1}$$

A real communication system is only possible if the amount of information bit per symbol, η

= RcM (Rc: code rate, M: bits per symbol), does not exceed the channel capacity, $\eta \leq C_C$ [8]. For AWGN channels the C_C is given by (2). This is the well known Shannon limit (C_C), which assumes an infinite symbol alphabet X, resulting in the upper theoretical limit of communications systems.

$$C_C = log_2(1 + SNR). \tag{2}$$

2.2 BICM Capacity Optimization

In practical systems, the number of symbols is not infinite. For example, the traditionally used UC QAM has a symbol alphabet |X| = L, which goes from 4-QAM up to maybe 4k-QAM nowadays. Breaking the idealization of infinite symbols, another capacity limit is considered, which is the signal set capacity C_S. The inconvenience with C_S is that the bit labeling function μ of the symbols is not taken into account in its definition and assumes ideal reception of the symbols. Multilevel codes (MLC) and the use of iterative de-mapping and decoding (BICM-ID) are some of the ways to reduce the gap from C_S, increasing considerably the receiver complexity. [1]

A more realistic approach to communications systems is to consider a non-ideal reception as well as the influence of μ in the capacity definition. Breaking these idealizations of C_S, it is defined the BICM capacity C_B [17]. These latter capacity concepts offer a new method to reduce the gap from C_C and C_S at a reasonably low receiver complexity. This method comprehends the application of bit-interleaved coded modulation chain in the system design [9]. As C_B depends on μ, the way to maximize this capacity is through the geometrical shaping of the symbols in the constellation. Therefore, the way to reduce the gap to the Shannon limit by optimizing C_B is the use of the NUC. C_B can be calculated from (3) [8].

$$C_B = \sum_{m=0}^{M-1} E_{b,r_k}\left[\log_2 \frac{\sum_{x_l \in \mathrm{X}_b^m} p(r_k|s_k = x_l)}{p(r_k)}\right] \tag{3}$$

Where M is the number of constellation bits, $p(s_k|r_k)$ is the transition probability density function (p.d.f) and $p(r_k)$ is the p.d.f of the received symbols. In [8] all the details about the calculations and constraints of this equation are described.

In AWGN channel, the SNR, constellation symbol positions and bit labeling are the only parameters that affect the transition probabilities and hence the C_B.

Usually, Gray labeling [18] is deployed, where adjacent symbols differ in one bit only. There exists different Gray labeling, however, the binary reflected maximizes C_B for both AWGN and Rayleigh fading channel [19] [20].

The UC, such as QAM, are the basic case of the constellations arrangements. The imposed constraints by the UC do not allow to reduce these gaps for the specifics SNR of operation of systems as DTMB. Therefore, the BICM capacity optimization and the resulting NUC are the way to improve this.

The operation SNR is the required threshold to receive successfully the DTMB signal in a specific mode. This concept will be referred to as target SNR from now on.

2.3 1D NUC QAM

The 1D NUC are designed by relaxing the UC constraints of equal minimum distance (d_{min}) between contiguous constellation points while keeping the rectangular structure [10]. Different L-QAM constellations have different Degrees of Freedom (DOF) for optimization that are the L complex symbols, $x_l \in$ X. In these constellations, the DOFs are limited to just one dimension [15]. This restriction reduces the possible gain of this technique. The equation to find the DOF for 1D NUC is (4), [9].

$$DOF_{1D\ NUC} = \frac{\sqrt{L}}{2} - 1 \qquad (4)$$

where L is the number of symbols in the constellation.

With these NUC, the receiver can de-map the real and the imaginary parts of a QAM constellation independently, such as in UC, thus reducing the complexity of the de-mapper at the receiver.

2.4 2D NUC QAM

For 2D NUC the constraint of keeping rectangular shape is relaxed, allowing to utilize all the possible DOFs. Therefore, the gain of this technique should be bigger than in 1D NUC, but at the expense of increased complexity in the optimization process as well as in the receiver implementation. Now, the constellation values can take any shape inside one quadrant. The other three quadrants are derived from the first quadrant by symmetry. The equation to find the DOF for 2D NUC is (5), as in [9].

$$DOF_{2D\,NUC} = 2\left(\frac{L}{4} - 1\right) \tag{5}$$

For both cases, 1D NUC and 2D NUC, the BICM capacity gain increases with the number of symbols in the constellations L, because the number of DOFs is increased, see Table 1. In following sections this characteristic will be shown up. The zero DOFs for 4-QAM are because any change in this constellation shaping is just linear transformations or different power normalizations, which does not imply any BICM capacity optimization.

Table 1. DOFs for 1D and 2D NUCs for one quadrant

Dimensions		Constellations			
		4-QAM	16-QAM	64-QAM	256-QAM
DOFs	1D	0	1	3	7
	2D	0	6	30	126

3. Proposal of 1D and 2D NUCs

3.1 Optimization Criterions

In previous sections, it was shown that C_B is a function of the SNR and the constellation symbols positions. Therefore, a different optimum NUC may result for an AWGN channel for each SNR value in the optimization process. In [21], by means of BER vs. SNR curves, it is selected the target SNR of the NUC, according to the SNR of the code's waterfall region. It results in a different NUC for each FEC code rate.

In order to select the DTMB target SNR, it is implemented a simulation model of the coding (and decoding) chain as described in the DTMB standard for 6 MHz channel bandwidth, [22]. Table 2 shows the obtained target SNR for each DTMB modulation mode. It is also implemented the UC for 256-QAM, which is not included in the DTMB standard.

Table 2. Target SNR for NUCs design

mapping	16-QAM			64-QAM			256-QAM		
R_c	0.4	0.6	0.8	0.4	0.6	0.8	0.4	0.6	0.8
SNR (dB)	7.75	9.95	12.45	11.85	14.70	17.68	16.50	20.20	23.55

Viewing Table 2, and the DTMB coding chain characteristics in [22], it can be seen that DTMB has an LDPC code length of 7493 bits, with three possible code rates. In comparison with ATSC 3.0 in [12], it is evident the simplicity and resulting inflexibility of DTMB, regarding code rates options and LDPC length. These are the reason for the high SNR requirements, limiting the possible improvements of the resulting DTMB system with NUCs.

3.2 1D NUC / Numerical Optimization

For 1D NUC design, it is followed the Numerical Optimization procedure of [7], for the target SNRs of Table 2. The initial constellations are the UC with binary reflected Gray labeling. The initial constellations are labeled assuming constellation points on the axis as follows, [7]:

$$16QAM = \{-a, -1, +1, +a\}. \tag{6}$$

$$64QAM = \{-c, -b, -a, -1, +1, +a, +b, +c\}. \tag{7}$$

$$256QAM = \begin{Bmatrix} -g, -f, -e, -d, -c, -b, -a, -1, \\ +1, +a, +b, +c, +d, +e, +f, +g \end{Bmatrix}. \tag{8}$$

As can be seen, the number of parameters defined for each constellation in (6), (7), (8), coincides with the DOFs of Table 1 for 1D NUCs.

For 16-QAM it is possible to use plots to find a maximal, plotting C_B as a function of a, for the target *SNR*, [7]. For 64 and 256-QAM, it is not possible to use plots to find a maximal, therefore, numerical optimization was used.

The 1D NUC with the biggest BICM capacity gain are those designed for $R_c = 0.4$. The opposite case, are those designed for $R_c = 0.8$. To have a better idea about these capacity gains and the resulting reduction of the gap from the Shannon limit we can see the Figure 1. It shows the shortfall of 1D NUC and UC from the Shannon limit for the cases of bigger Capacity gains ($R_c = 0.4$). For 16-QAM the gain is 0.0169 bit/s/Hz, 0.0838 bit/s/Hz for 64-QAM and 0.2566 bit/s/Hz for 256-QAM. It can be observed that for 16-QAM the UC and the NUC have almost the same curve, the capacity gain is minimal and it is only appreciable around the target SNR (7.75 dB). This happens because the target *SNRs* in DTMB standard are high for a 16-QAM constellation, which only has 1 DOF. Hence, the NUC optimization to achieve maxim BICM results in almost the same UC.

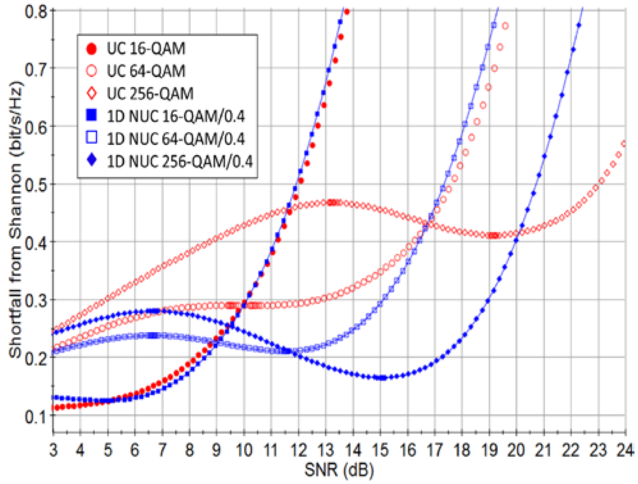


Figure 1. The shortfall from Shannon of UC and 1D NUCs for 16, 64 and 256-QAM.

As it is shown in Figure 1, the BICM capacity gain for 64-QAM of the NUC over the UC, is bigger than in 16-QAM. In the same way, for 256-QAM is bigger than in 64-QAM. This is because the number of DOFs increases with the order of the constellations, see Table 2.

3.3 2D NUC / Particle Swarm Optimization (PSO)

For 2D NUC design, the C_B maximization was achieved through the Particle Swarm Optimization, as in [14].

The PSO is an evolutionary computation technique developed in 1995 [23]. This algorithm is similar to a genetic algorithm (GA), where the system is initialized with a population of random solutions, which are called particles. These particles in the algorithm emulate the behavior of animal’s societies that do not have any leader in their group or swarm [24].

As it is described in [23], the main concept of this algorithm is that each particle keeps track of its coordinates in the problem space defined by the cost function to optimize, which are associated with the best personal solution (*pbest*). This is the cognitive component of the algorithm. The global best (*gbest*) and its location in the problem space of the whole swarm is also tracked and shared to the whole swarm. This is the social component of the algorithm. The particles at each time step change their velocity and position toward its *pbest* and *gbest* location. [23]

The PSO equations used to calculate the velocity ($v_{ij}(t+1)$) and the position ($x_{ij}(t+1)$) are (9) and (10), respectively. [23]

$$v_{ij}(t+1) = wv_{ij}(t) + r_1c_1\left(p_{ij}(t) - x_{ij}(t)\right) \tag{9}$$

$$+r_2c_2\left(g_j(t) - x_{ij}(t)\right)$$

$$x_{ij}(t+1) = x_{ij}(t) + v_{ij}(t+1) \tag{10}$$

$p_{ij}(t)$ and $g_j(t)$ are the pbest and the gbest respectively. The sub-index i specifies a particle in the whole swarm and j the different variables that define the particles. $x_{ij}(t)$ and $v_{ij}(t)$ are the position and the velocity in the time step t. c_1 and c_2 are the acceleration constants, we use these constants as 1.49618. The inertia factor is w, we use this constant as 0.72984. r_1 and r_2 are random numbers between 0 and 1. For a better understanding of these values and their constraints, you can see [23].

In this specific case of PSO utilization, the cost function is the C_b equation presented in (3), which after some transformations is ready to use as equation (11). M is the number of bits per symbols, X is the alphabet of symbols and X_b^M is the subset of all the symbols x ($x \in X$), that has the value $b \in \{0,1\}$ in the bit m. Noise variance is σ^2. C_b is maximized for the target SNRs defined in Table 2.

The PSO algorithm has as inputs the cost function (C_b) and the population of random solutions. The population, in this case, is a set of random constellations defined by the dispersion of an initial constellation. The selection of this initial constellation is a key aspect in the NUC design.

$$C_B = M - \frac{1}{2^{M+1}\pi\sigma^2}\iint_{-\infty}^{\infty}\sum_{m=0}^{M-1}\sum_{b=0}^{1}\sum_{x_l\in X_b^m}[\, e^{\frac{-1}{2\sigma^2}\left[(x-Re[x_l])^2+(y-Im[x_l])^2\right]} \times$$
$$log_2\frac{\sum_{x_l'\in X} e^{\frac{-1}{2\sigma^2}\left[(x-Re[x_l'])^2+(y-Im[x_l'])^2\right]}}{\sum_{x_l''\in X_b^m} e^{\frac{-1}{2\sigma^2}\left[(x-Re[x_l''])^2+(y-Im[x_l''])^2\right]}}]dxdy \tag{11}$$

In order to select the initial constellation, some of the ATSC 3.0 NUC defined in [25] are implemented for 16, 64, and 256-QAM, and the optimal ones are selected, according to the criterions hereinbefore mentioned. The ATSC 3.0 NUC that offers the biggest C_b for the different target SNRs (Table 2) are selected as the initial constellation for each case. Then, these initial constellations are dispersed and it is generated the initial population for the algorithm.

The 2D NUC with the biggest BICM capacity gains are those designed for R_c = 0.4. The opposite case, are those designed for R_c = 0.8. The designed NUCs for 16, 64 and 256-QAM with Rc = 0.4 are shown in Figure 2.

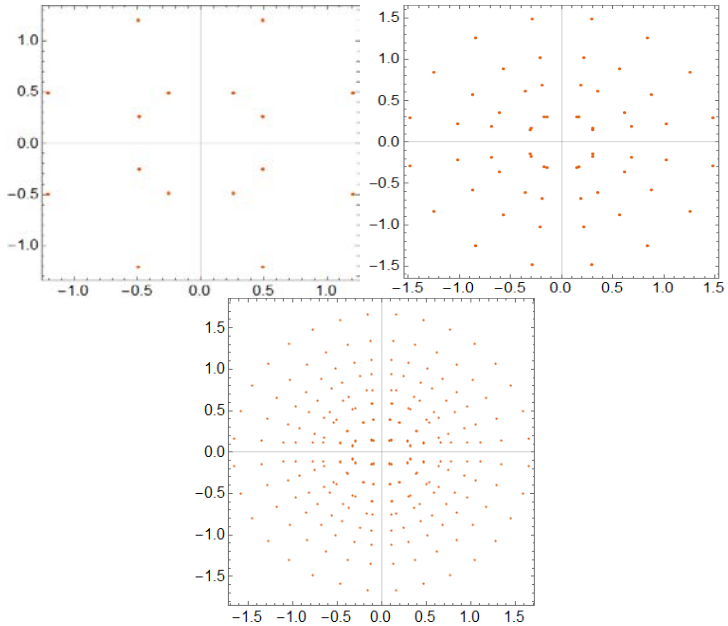
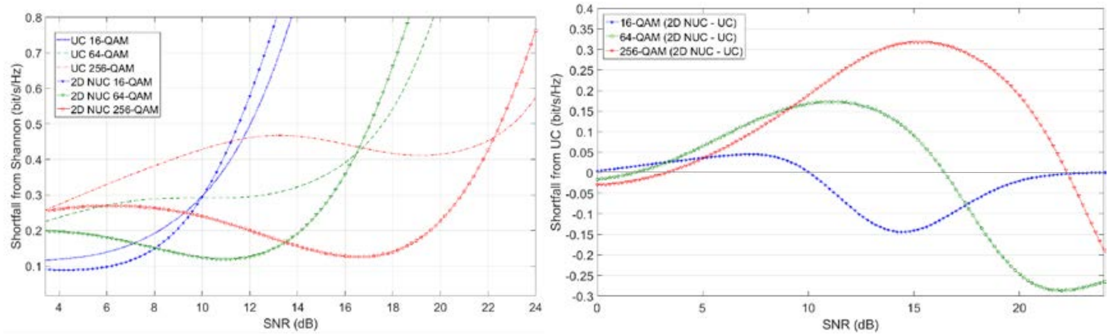


Figure 2. Designed NUCs for 16, 64, 256-QAM, for Rc = 0.4.

Figure 3 (a) gives us a better idea about these capacity gains and reduction of the gap from the Shannon limit. It shows the shortfall of 2D NUC and UC from Shannon limit for the cases of bigger Capacity gains (R_c = 0.4). For 16-QAM the gain over UC is 0.0438 bit/s/Hz, 0.1704 bit/s/Hz for 64-QAM and 0.3111 bit/s/Hz for 256-QAM. Comparing these results with the achieved for 1D NUC (Figure 1), we can see the improvements of 2D NUC over 1D NUCs. For 2D NUC the gain also increases with the order of the constellation. The reason is the same as for 1D, the DOFs increase with the order of the constellation, see Table 1. The Figure 3 (b) shows in a better way this increment of the gain in proportion with the increment of the constellation order. Moreover, it is another way to see the gain of the 2D NUC over the UC. From Figure 4 and Figure 6, it can be seen how the NUC gain over the UC is not only for the specific target SNR. The same NUC can be used for several dBs around its specific target SNR, with gain over the UC. For example, for the 256-NUC in Figure 3 (b), the NUC has around 3 dB of gain over the UC, for 22 dB of SNR. This means that this specific NUC can be used instead of the UC for all this range of SNR, with gain over the UC. In [7] the authors arrive at the conclusion that a per-SNR optimization would be better.



(a) (b)

Figure 3. (a) The shortfall from Shannon of UC and 2D NUCs for 16, 64 and 256-QAM, (b) The shortfall from UC of 2D NUCs for 16, 64 and 256-QAM.

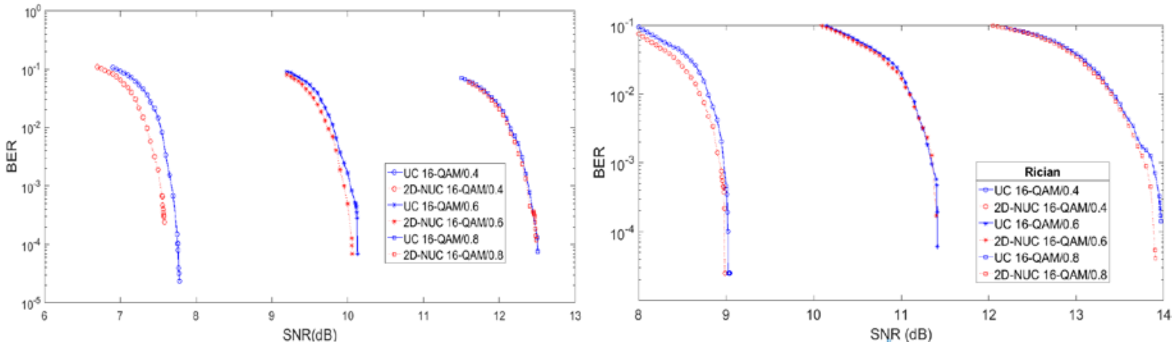
4. Simulation Results

The proposed NUC are inserted in the DTMB simulation model in order to evaluate their performance, keeping exactly the other parts of the coding chain. For all simulation results, an AWGN channel is considered. Then, the BER curves are redrawn as a function of the SNR including the proposed NUC for 16, 64 and 256-QAM. In the simulations are also include simulations for 16 and 64-QAM in Rician channel model.

The results for 16-QAM are shown in Figure 4 (a) whereas the results for the same setting in Rician channel are shown in Figure 4 (b). The figures only show the results for the NUC with the biggest SNR gain and the UC. In the whole simulations, the 2D NUC have the best performance. The difference in DOFs is the main reason for this outperforming of 2D NUC over 1D as seen previously. For 16-QAM in AWGN channel the SNR gains go from 0.2 dB for Rc = 0.4 to 0.02 dB for Rc = 0.8. The results presented in [10] and [26] for ATSC 3.0, for 16-QAM, are similar to those presented in this paper. In [10], the authors declare that for 16-QAM, only 0.2 dB gain can be expected for 2D NUCs. For Rc = 0.8 the 2D NUC have almost the same threshold SNR of UC and the SNR gain is minimal. This is because the proposed NUC for this code rate has almost the same geometrical shape as the UC. In the Rician channel, the gains range from 0.07 dB to 0.01 dB.

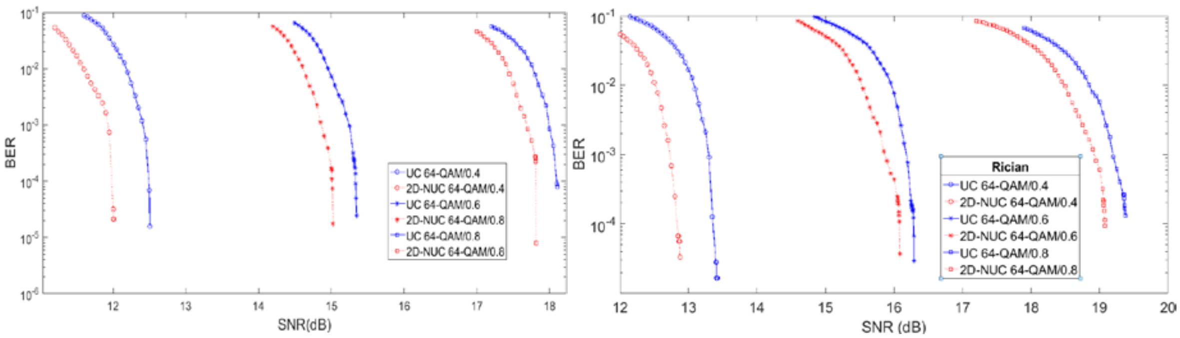
The results for 64-QAM are shown in Figure 5 (a) whereas the results for the same setting in Rician channel are shown in Figure 5 (b). The SNR gains go from 0.5 dB for Rc = 0.4 to 0.29 dB for Rc = 0.8. The results presented in [10] and [26] for DVB-T2 and ATSC 3.0 respectively, for 64-QAM, are similar to those presented in this paper. The main difference is for Rc = 0.8 where the SNR gain is 0.06 dB lower than the minimal SNR gain archived in

DVB-T2. In the Rician channel, the gains range from 0.53 dB to 0.21 dB.



(a) (b)

Figure 4. NUCs for 16-QAM vs UC: (a) in AWGN channel, (b) in Rician channel.



(a) (b)

Figure 5. NUCs for 64-QAM vs UC: (a) in AWGN channel, (b) in Rician channel.

The results for 256-QAM are shown in Figure 6. The SNR gains for 256-QAM go from 1.12 dB for Rc = 0.4 to 0.53 dB for Rc = 0.8. The results presented in [10] and [26] for DVB-T2 and ATSC 3.0 respectively, for 256-QAM, are similar to the results presented in this work. The main differences are for Rc = 0.4, where the SNR gain is 0.07 dB higher than the minimal SNR gain archived in DVB-T2, and for Rc = 0.8 where the SNR gain is 0.02 dB lower than the minimal SNR gain archived in DVB-T2.

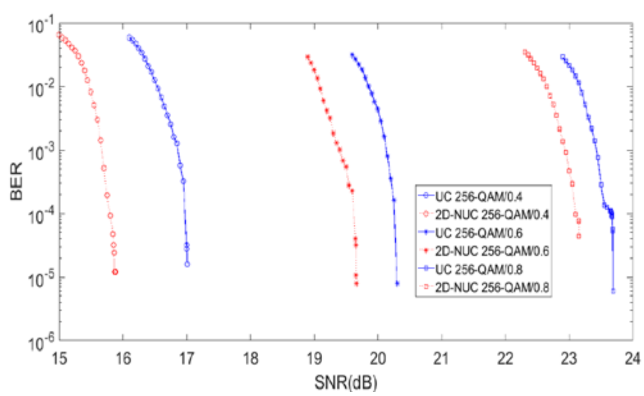


Figure 6. NUCs for 256-QAM vs UC in AWGN channel.

The Figure 7, summarizes the SNR gains of 1D and 2D NUC over UC. Comparing these results with a similar figure presented in [26], it can be seen that the gains achieved in this paper are in concordance with the expected results. Evidently, the conditions are very different with regard to the coding chain, but the significance of the comparison is that the SNR gains for both are in the same orders of magnitude.

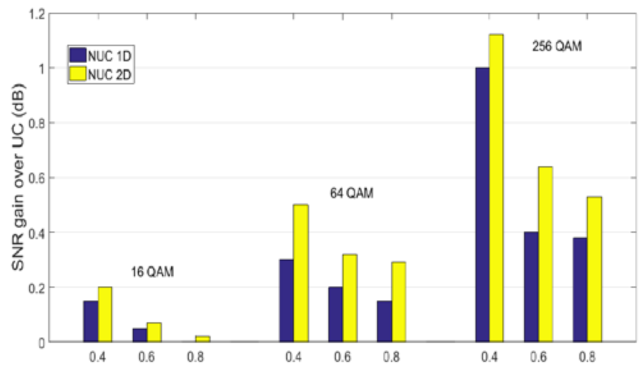


Figure 7. SNR gain of 1D and 2D NUCs over UC in AWGN.

It is important to remark that the achieved SNR gains for the proposed NUC are not as good as possible because the DTMB coding chain is not BICM and does not have a bit interleaver to decouple the LDPC code block and the mapping block.

In order to have a major clarity about the performance of the proposed DTMB with NUC and the conventional DTMB, their capacities on AWGN channels and the Shannon Limit are plotted in Figure 8. The figure shows how the reduction of the gap from Shannon Limit is exactly in the values of SNR gain presented.

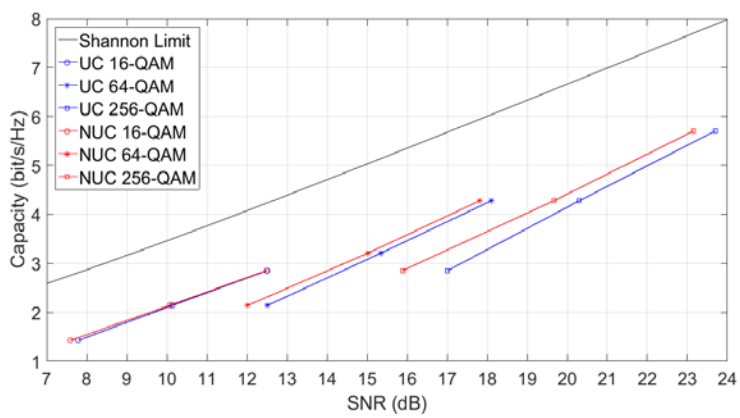


Figure 8. SNR gain of 1D and 2D NUCs over UC in AWGN.

Comparing DTMB with the state of the art DTTB systems, it is evident that these improvements are not enough. Other optimizations in the coding and decoding chain are necessary in order to further reduce the gap from Shannon Limit. For this, in forthcoming papers, it will be discussed topics like the design of high-order constellations, larger LDPC code length and the implementation of a BICM chain.

The DTMB standard for 6 MHz channel bandwidth allows a bit rate that ranges from 4.0605 Mbps to 24.3654 Mbps. Now, with the proposed 2D NUC for 256-QAM, the maximum bitrate reaches the 32.486 Mbps. Besides, in the resulting DTMB system, the necessary SNR value for correct reception of the different DTMB modes is smaller. The SNR gain and the reduction of the gap from Shannon Limit achieved with the proposed NUC mean that now the system is more robust. In terms of practical DTMB deployments, it means that the signal can reach a larger coverage area for the same transmission power.

5. Conclusions

This paper proposes optimized Non-Uniform Constellations for DTMB coding chain. Besides, it describes the design methodologies and selection criterions for the proposed NUCs. The proposed methodology for NUC design is based on the BICM Capacity optimization, and PSO algorithm and Numerical Optimization for 2D and 1D respectively. In order to validate the outperformance of the proposed 1D and 2D NUC over the typical UC of DTMB, extensive simulation results are presented for AWGN and Rician channels. Moreover, it is shown that the NUC in 2D outperforms the NUC in 1D for each target SNR. The maximum SNR gain achieved by the proposed NUC ranges from 1.12 dB to 0.02 dB for 256-QAM with Rc = 0.4 and 16-QAM with 0.8 respectively. The maximum bit rate for DTMB with 6 MHz of channel bandwidth was increased up to 32.486 Mbps due to 256-QAM inclusion.

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