8

Performance Analysis of DVB-T/H OFDM Hierarchical Modulation in Impulse Noise Environment

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1. Introduction

DVB-T\H (Digital Video Broadcasting – Terrestrial \ Handheld) are standards of the DVB consortium for digital terrestrial handheld broadcasting and are based on Coded Orthogonal Frequency Division Multiplex (COFDM) signals as described in the documents ETSI 300 744 and ETSI EN 302 304 in 2004. Orthogonal Frequency Division Multiplex (OFDM) modulation is based on a multi-carriers scheme, instead of the single carrier modulation scheme used classically in DVB-Cable. In OFDM, the bit stream to be transmitted is serially separated and modulated in parallel over several subcarriers which increases the robustness to multipath in wireless environment.

In the DVB standard, the recommended modulation scheme is multi-carriers QAM modulation but hierarchical modulation is also proposed as an optional transmission mode where two separate bit streams are modulated into a single bit stream. The first stream, called the “High Priority” (HP), is embedded within the second stream called the “Low Priority” (LP) stream. At the receiver side, equipments with good receiving conditions demodulate both streams, while those with bad receiving conditions only demodulate HP stream. Hierarchical modulation, therefore, gives more service opportunities for receivers in good operating conditions compared to receivers in bad receiving conditions that only decode basic services.

Hierarchical modulation has been included in many digital broadcasting standards such as MediaFLO, UMB (Ultra Mobile Broadband), T-DMB (Terrestrial Digital Multimedia Broadcasting), DVB-SH (Digital Video Broadcasting - Satellite Handheld). Nevertheless, in the new version of video broadcasting, DVB-T2 (Digital Video Broadcasting- Terrestrial second version), the hierarchical modulation has been replaced by Physical Layer Pipes (PLP). Notice that, in order to provide dedicated robustness, the PLP technologies allow different levels of modulation, coding and power transmitted per service. Thus, PLP differentiates the quality in service by service basis, while the hierarchical modulation works based on receivers conditions independently of the services (DVB Document A122, 2008).

Impulse noises combined with Gaussian noises are one of the major causes of errors in digital communications systems and thus in DVB-T\H networks (Biglieri, 2003). These two kinds of noises behave in a different way to corrupt digital communications. Gaussian noise,

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also known as background noise, is permanently present through the network with a moderate power. On the contrary, impulse noise randomly appears as bursts of relative short duration and very large instantaneous power.

The primary purpose of this chapter is to investigate the behaviour of coupled OFDM/QAM and hierarchical modulation systems under impulse noise environment as it appears in DVB-T/H specifications. This impact is evaluated firstly by expressing Bit Error Rate (BER), when it is simulated, or Bit Error Probability (BEP) when it is calculated, of both HP bit stream and LP bit stream with impulsive impairment, and secondly by validating these expressions through simulation. The Signal to Noise Ratio (SNR) penalty induced by the presence of impulse noise in each stream is also analytically estimated and confirmed by computer simulations.

This chapter will first introduce the insights of OFDM and hierarchical modulation in DVB-T/H and will also give some examples of possible implementations. After, it will give a brief overview of impulsive noise characteristics. Then, it will describe the method to theoretically analyze the BER at the bit level in presence of impulse noise. At this level, an original method to obtain the SNR penalty on HP stream due to the introduction of LP stream is reported. And finally, the conclusion will bring some comments in next DVB-T/H technologies.

2. System model

DVB-T/H are technical standards that specify the framing structure, channel coding and modulation for terrestrial handheld television. These standards define the transmission of encoded audio and video signals using the COFDM modulation.

Many parameters, which are listed here, are settled to characterize DVB-T/H transmission stream:

- The code rate: it is the ratio of data rate of the useful bits to overall data rate (typical values are: ½, 2/3, ¾, 5/6, 7/8).
- The modulation order: non-hierarchical (4-QAM, 16-QAM, 64-QAM), hierarchical (4/16-QAM, 4/64-QAM).
- The guard interval: it is defined to guarantee the safety interval for the subsequent symbol (typical length of guard interval: ¼, 1/8, 1/16, 1/32).
- The number of sub-carriers: 2k (2048), 4k (4096, only for DVB-H) and 8k (8192).
- The hierarchical uniformity parameter: 1 for uniform constellation and 2 or 4 for non-uniform constellation.

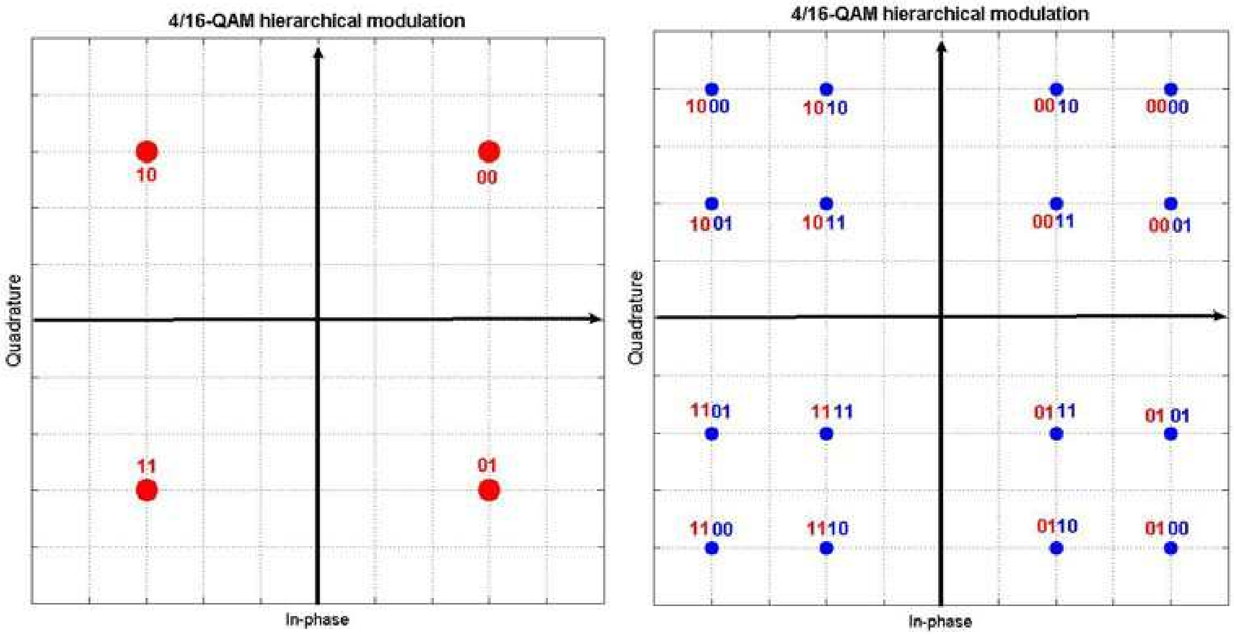
2.1 Introduction of hierarchical modulation

Hierarchical Modulation (HM) is defined to be used on quadrature modulations (QAM) and mainly consists of two separate bit streams that are modulated onto a single bit stream. The first stream, called the “High Priority” (HP), is modulated with basic quadrature modulation order (4-QAM) and the second stream, “Low Priority” (LP), is embedded on HP stream to define high order QAM modulation (M-QAM, where M is greater that 4).

The Hierarchical Modulation is designed such that HP stream is more robust against disturbances than LP stream. Therefore, only receiver with good channel condition (imposed by distance, fading, interferences, and impulse noise) can decode HP and LP streams while others can only use HP stream. This leads to differentiate service content depending of receiving conditions.

In DVB-T/H systems, Hierarchical Modulation (HM) is only defined on QAM (Quadrature Amplitude Modulation) and is denoted 4/M-QAM. Generally, square QAM is used in which M is 2^{2n}, and 2n is the number of bits per symbol. The 4/M-QAM is simply defined by its constellation diagram as depicted in fig. 1 for a 4/16-QAM. In this diagram, the HP stream is modulated with QPSK, equivalent to 4QAM, and thus specifies the quadrant in the entire constellation. The LP stream is modulated with (M÷4)-QAM, and is embedded on primary QPSK. The entire constellation is mapped with Gray coding to allow only one bit variation between adjacent symbols.

For example, in fig. 1 for 4/16-QAM, on the entire $\log_2(16)=4$ bits ($i_1q_1i_2q_2$) of the 4/M-QAM symbol, the first two bits, i_1q_1, are assigned the HP stream (fig.1a), and the next $\log_2$(M)-2, i_2q_2, bits are allocated to LP stream (fig. 1b).



(a) HP stream (i_1q_1) modulated in QPSK

(b) Embedded LP (i_2q_2) stream into QPSK to give ($i_1q_1i_2q_2$)

Fig. 1. Illustration of construction of constellation diagram of 4/16-QAM modulation

Hence, hierarchical modulation can be view as HP stream transmitted with the fictitious symbol of QPSK defined by the first two bits (each fictitious symbol defining a quadrant), whereas the LP stream used the (M/4)-QAM modulation around these fictitious symbols.

Many parameters are used to characterize hierarchical constellation and are defined in fig. 2:

- $2d_1$ which represents the minimum distance between two fictitious symbols,
- $2d_2$ which represents the minimum distance between two neighboring symbols within one quadrant,
- $2d'_1$ which represents the minimum distance between two symbols in adjacent quadrants.

The ratio, α, of d'_1 and d_2 is the uniformity parameter and it defines the balance of power between HP stream and LP stream. As illustrated in fig. 3, the hierarchical QAM constellation is called:

- uniform constellation when $\alpha = 1$,
- non-uniform constellation when $\alpha \neq 1$,.

Uniform constellation leads to equal power distribution between HP and LP while for non-uniform constellation, the power is unbalanced and is more in HP stream for growing α.

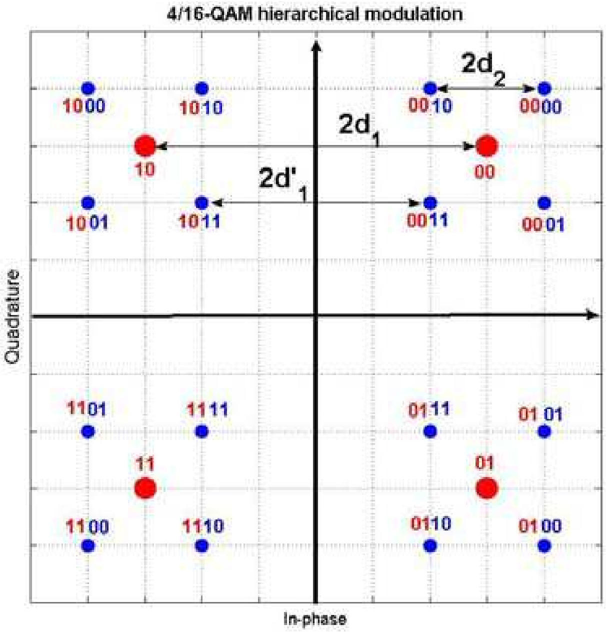
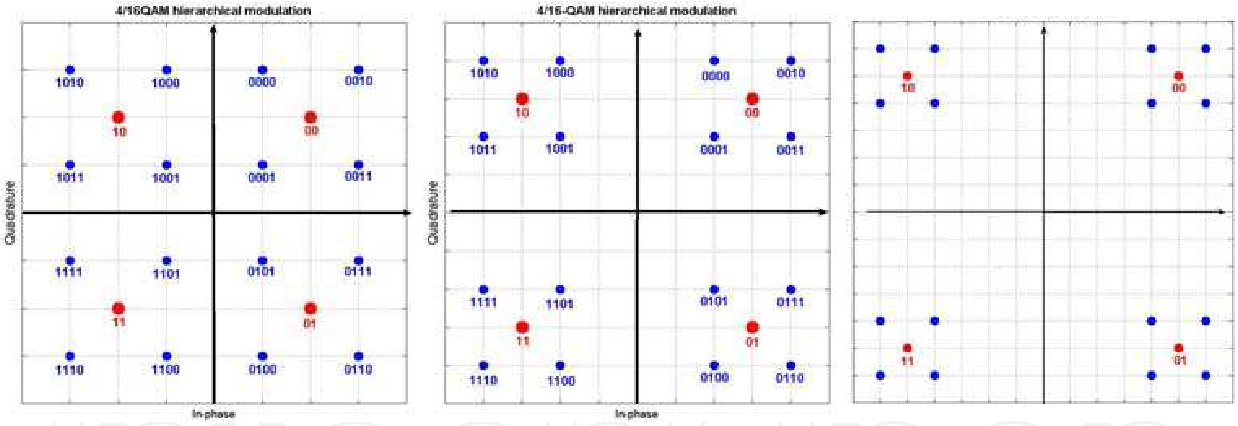


Fig. 2. Presentation of HM parameters in constellation diagram of 4/16-QAM modulation.



(a) α = 1 (b) α = 2 (c) α = 4

Fig. 3. Illustration of constellation diagram of 4/16-QAM modulation with various uniformity parameter (α = 1,2,4).

In the square 4/M-QAM, i.e. where the constellation order is $M=2^{2n}$ which is the case of interest, the distances parameters are linked by this expression (Vitthaladevuni, 2001):

$$d_1 = d_1^{'} + \left(\frac{\sqrt{M}}{2} - 1 \right) d_2 \tag{1}$$

where M is the constellation order.

Concerning the energy distribution, it has been shown in (Vitthaladevuni, 2001) that, for square 4/M-QAM, the total average energy per symbol, E_s, is given by:

$$E_s = 2d_1^2 + \frac{2}{3}\left(\frac{M}{4} - 1\right)d_2^2 \tag{2}$$

On this expression, the average energy per symbol of HP and LP streams, E_{hp} and E_{lp}, can be written as:

$$E_{hp} = 2d_1^2 \tag{3}$$

$$E_{lp} = \frac{2}{3}\left(\frac{M}{4} - 1\right)d_2^2 \tag{4}$$

where E_{hp} represents the average energy of 4-QAM with constellation points separated by distance $2d_1$ (fictitious symbol in 4/M-QAM). Likewise, E_{lp} represents the average energy of M/4-QAM with constellation points separated by distance $2d_2$.

One important property that characterizes the hierarchical modulation is the penalty of modulation, also called modulation efficiency (Jiang, 2005, Wang, 2008) which is defined as the excess power that is needed in the HP stream to achieve the same Bit Error Probability (BEP) than in classical QPSK. In other words, it therefore quantifies the excess of power needed for receivers which are designed to deal with HP stream compared to the case where only classical QPSK is send.

2.2 Possible implementations of hierarchical modulation

Hierarchical modulation allows different kind of resources (bandwidth and bit rate) exploitation for receivers in various conditions. Therefore, it can be used to smoothly introduced new kind of services without needing new and expensive spectrum allocation. By this way, mobile reception or High Definition (HD) can complete and enhance the offer of the broadcaster (Schertz, 2003, Faria, 2006).

In the case of mobile reception scenario, the HP stream can be dedicated to broadcasting mobile programmes, while the LP stream can be devoted to broadcast traditional fixe or portable programmes. The HP stream will present sufficient robustness to achieve mobile channel communication. However, LP stream, weaker, will use less disturbed fixe or portable channel. Trade-off between mobile and fixe or portable channel will be assured by sizing uniformity parameters and error coding properties.

In the case of High Definition scenario, HP stream can be used for Standard Definition (SD) programmes, while LP stream can transmit HD programmes. Users with HD receivers will access broadcasted enhanced HD programmes and others, with no HD capabilities, will continue to enjoy traditional broadcasted SD programmes.

2.3 Introduction of OFDM modulation

OFDM is a parallel transmission scheme where the bit stream to be transmitted is serially separated and modulated with several sub-carriers. In practice, OFDM systems are implemented using the combination IFFT (Inverse Fast Fourier Transform) at the emitter side and FFT (Fast Fourier Transform) at receiver part (Proakis, 2001). Basically, the information bits are mapped into N baseband complex symbols c_k using quadrature modulation scheme as shown in fig. 4. The block of N complex baseband symbols, considered in the frequency domain, is changed by means of an IFFT that brings signal into the time domain. The sequence of complex received symbols r_l, after sampling and assuming ideal channel, is given by:

$$r_l = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} c_k e^{j\frac{2\pi kl}{N}} + n_l \qquad 0 \le l \le N-1 \tag{5}$$

where c_k is the M-QAM complex symbol of the n^{th} sub-carrier, n_l is the channel noise (jointly impulsive and Gaussian noises in this case), and N is the number of sub-carriers.

The estimated baseband complex M-QAM symbol is recovered by performing a FFT that transforms the received signal in frequency domain, and it is given by:

$$\hat{c}_k = \frac{1}{\sqrt{N}} \sum_{l=0}^{N-1} r_l e^{-j\frac{2\pi kl}{N}} = c_k + \frac{1}{\sqrt{N}} \sum_{l=0}^{N-1} n_l e^{-j\frac{2\pi kl}{N}} = c_k + z_k \qquad 0 \le k \le N-1 \tag{6}$$

where z_k denotes an additive noise term which is in fact the frequency conversion of n_l.

From relation (2), it can be seen that the noise in the k^{th} QAM symbol depends on all noise samples present during the OFDM symbol. In fact, the noise, and particularly the impulse noise, is spread over the N QAM symbols due to the FFT operation.

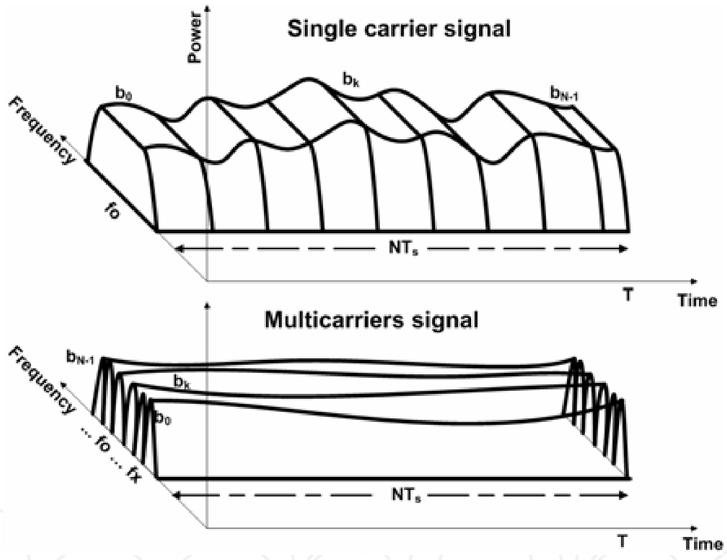


Fig. 4. Representation of OFDM modulation

2.4 Introduction of OFDM hierarchical modulation

OFDM hierarchical modulation is the combination of an OFDM system and some hierarchical QAM modulation as illustrated in fig. 5. It is constituted by a concatenation of a hierarchical QAM modulator and an OFDM modulator.

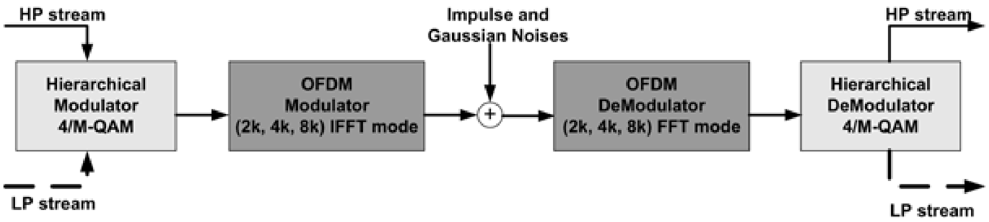


Fig. 5. Simulated block diagram of OFDM hierarchical QAM system

In DVB-{T, H} systems, OFDM modulation uses 2k (2048), 4k (4096), 8k (8192) subcarriers. Further, Hierarchical Modulation (HM) is defined based on QAM (Quadrature Amplitude Modulation) and it is denoted 4/M-QAM.

2.5 The Middleton class-A model

Impulse noise is basically defined with three statistical properties: the duration, the inter-arrival and the voltage amplitude. Middleton class-A is a complete canonical statistical model of joint impulse and Gaussian noise where the properties are defined by a compound Poisson process (Middleton, 1979, Berry, 1981). For this model, the in-phase and quadrature Probability Density Function (PDF) of voltage $f_n(x,y)$ is given by:

$$f_n(x,y) = e^{-A_A} \sum_{q=0}^{\infty} \frac{A_A{}^q}{q!} \cdot \frac{1}{2\pi\sigma_q^2} \exp\left(-\frac{x^2+y^2}{2\sigma_q^2} \right) \tag{7}$$

where $\sigma_q^2 = \frac{(q/A_A + \Gamma)}{1+\Gamma}$, $\Gamma = \frac{\sigma_g^2}{A_A \sigma_i^2}$, A_A is the impulsive index, Γ is the mean power ratio of the Gaussian component and the impulsive component, σ_g^2 and σ_i^2 are respectively the variances of Gaussian and impulse noises.

Specifically, A_A corresponds to the product of the average rate of impulse generation and the mean duration of typical impulses. Small values of A_A and Γ give predominance to impulse type of noise while large values of A_A and Γ lead to a Gaussian type of noise.

3. Bit error probability of OFDM hierarchical QAM calculation

3.1 Bit error probability of hierarchical 4/M-QAM calculation

In hierarchical modulation, the bit error probability must be determined at the bit level. In fact, a noise can lead to error in the LP bits and not disturb the HP bits. Bit error probability of hierarchical QAM HP and LP streams has been presented in scientific literature (Vitthaladevuni, 2001, 2004), and here the principles will be described.

For square 4/M-QAM ($M=2^{2n}$), the entire bit stream is ($i_1q_1i_2q_2...i_nq_n$) in which the HP stream is (i_1q_1) and the LP stream is ($i_2q_2...i_nq_n$). The BEP of HP bits is given by (Vitthaladevuni, 2001, 2004):

$$P_{hp}(M) = \frac{1}{2}\left[P(i_1,M) + P(q_1,M)\right] \tag{8}$$

where $P(i_1,M)$ and $P(q_1,M)$ represent respectively the bit error probability of the first in-phase and quadrature bits of 4/M-QAM hierarchical modulation.

The symmetry of the constellation diagram reduces equation (8) to:

$$P_{hp}(M) = P(q_1,M) = P(i_1,M) \tag{9}$$

On the other hand, the BEP of the LP bits is obtained by (Vitthaladevuni, 2001, 2004):

$$P_{lp}(M) = \frac{\sum_{k=2}^{(1/2)\log_2 M} P(i_k, M) + P(q_k, M)}{\log_2(M) - 2} \tag{10}$$

where $P(i_k,M)$ and $P(q_k,M)$ represents the BEP of k^{th} in-phase and quadrature LP bits of 4/M-QAM hierarchical modulation.
Using again the symmetry of the constellation diagram, this equation is rewritten as:

$$P_{lp}(M) = \frac{2\sum_{k=2}^{(1/2)\log_2 M} P(q_k, M)}{\log_2(M) - 2} = \frac{2\sum_{k=2}^{(1/2)\log_2 M} P(i_k, M)}{\log_2(M) - 2} \tag{11}$$

Equations (9) and (11) show that, due to the symmetry, the bit error probability of HP and LP streams only depends on only in-phase bits, or on only quadrature bits. Therefore, in-phase bits were chosen to make error probability calculation. The in-phase bits constellation diagram which corresponds to the reduced diagram is constructed and depicted in fig. 5 for 4/16-QAM. There, a symbol is defined by i_1-i_2-i_3-..., where the dashes represent the positions in quadrature axis.
In the next part, the development of error probability for the 4/16-QAM, which can be generalized to 4/64-QAM and widely to 4/M-QAM, will be described.

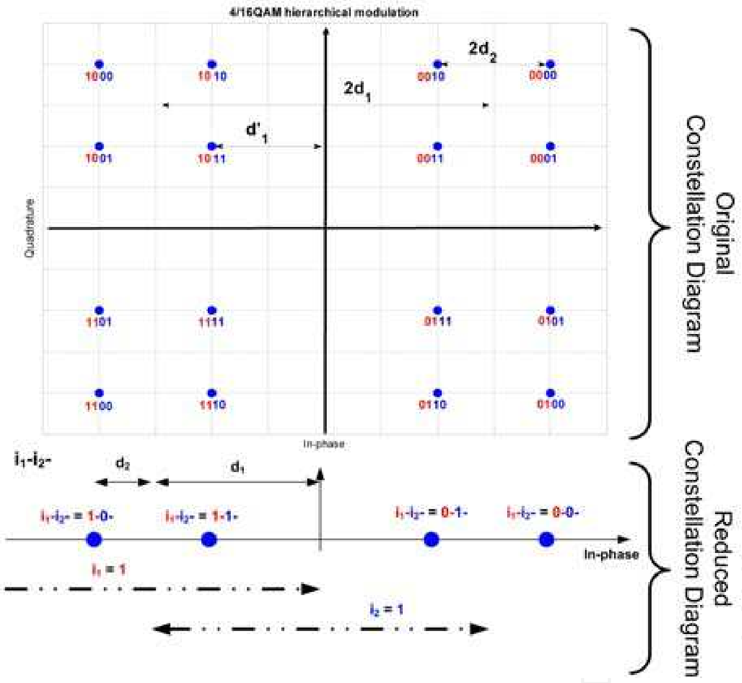


Fig. 6. Construction of in-phase reduced constellation diagram of 4/16-QAM

3.2 Case of 4/16-QAM hierarchical modulation

Before calculating the bit error probability of HP stream, we express here $P(i_1,16)$:

$$P(i_1, 16) = P(i_1 = 1)P(error / i_1 = 1) + P(i_1 = 0)P(error / i_1 = 0) \tag{12}$$

where $P(i_1{=}x)$ is the probability that bit i_1 is equal to x, and $P(error/i_1{=}x)$ is the conditional probability to have an error if bit i_1 is equal to x.

Fig. 6 shows the reduced diagram of 4/16-QAM and two kinds of symbols with probability ½ can be transmitted when i_1=1: 1-0- and 1-1-. Similarly, when i_1=0, the two kinds of symbols with probability ½ can be transmitted: 0-0- and 0-1-. Derived from (12), the expression of $P(i_1,16)$ is thus given by:

$$\begin{aligned} P(i_1,16) &= P(i_1=1)\left[1/2\,P(error/1-0-)+1/2\,P(error/1-1-)\right] \\ &\quad + P(i_1=0)\left[1/2\,P(error/0-0-)+1/2\,P(error/0-1-)\right] \end{aligned} \tag{13}$$

where $P(error/x\text{-}y\text{-})$ is the conditional probability to have an error if the transmitted symbol is equal to x-y-.

Fig. 7a shows that when the bit i_1 is 1 and the emitted symbol is 1-0-, error appears when displacement on the reduced constellation diagram is greater than d_1+d_2 on the right. Likewise, fig. 7a shows that when the bit i_1 is 1 and the emitted symbols is 1-1-, error appears if the displacement is greater than d_1-d_2 on the right. Similar analysis when i_1=0 leads to express $P_{hp}(16)$ as:

$$\begin{aligned} P_{hp}(16) = P(i_1,16) &= \frac{1}{2}\left[1/2\int_{d_1^{'}+d_2}^{+\infty} f(x)dx + 1/2\int_{d_1-d_2}^{+\infty} f(x)dx\right] \\ &\quad + \frac{1}{2}\left[1/2\int_{-\infty}^{-d_1-d_2} f(x)dx + 1/2\int_{-\infty}^{-d_1+d_2} f(x)dx\right] \end{aligned} \tag{14}$$

where $f(x)$ is the PDF of voltage amplitude of noise.

Thus, by using equation (7) to express the PDF of voltage amplitude noise $f_n(x)$, the bit error probability of HP stream can be written as:

$$P_{hp}(M) = \frac{1}{2}\left(\frac{1}{2}\Upsilon\left(d_1^{'}+2d_2\right) + \frac{1}{2}\Upsilon\left(d_1^{'}+2d_2\right)\right) \tag{15}$$

where $\Upsilon(\mathrm{d}) = \int_{-\infty}^{d} f_n(x)dx$, and expressed by:

$$\Upsilon(\mathrm{d}) = e^{-A_A}\sum_{k=0}^{+\infty}\frac{A_A^k}{k!}\cdot\frac{1}{2}\cdot erfc\left(\frac{d}{\sigma_k}\right)$$

In the other hand, the bit error probability of LP in-phase bits is obtained by calculating $P(i_2,16)$. It is given by:

$$P(i_2,16) = P(i_2=1)P(error/i_2=1) + P(i_2=0)P(error/i_2=0) \tag{16}$$

Based on reduced constellation diagram, it becomes:

$$\begin{aligned} P(i_2,16) &= P(i_2=1)\left[1/2\,P(error/1-1-)+1/2\,P(error/0-1-)\right] \\ &\quad + P(i_2=0)\left[1/2\,P(error/1-0-)+1/2\,P(error/0-0-)\right] \end{aligned} \tag{17}$$

The fig. 7.b shows that when the bit i_2 is 1 and the emitted symbol is 1-1-, error appears when displacement on the reduced constellation diagram is greater than $2d_1$-d_2 on the right and d_2 on the left. Equally, fig. 7.b shows that when the bit i_2 is 1 and the emitted symbols is 0-1-, error appears if the displacement is greater than d_2 on the right and $2d_1$-d_2 on the left. Similar analysis when i_2=0 leads to express $P_{lp}(16)$ as:

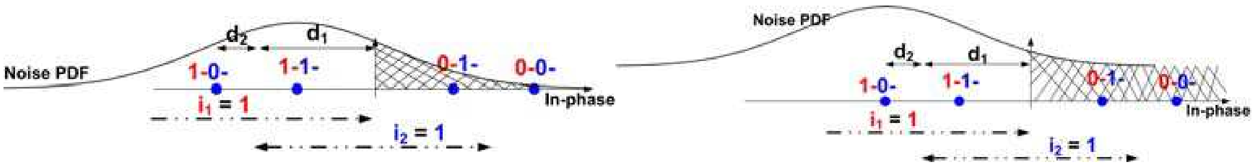
$$P(i_2,M)=\frac{1}{2}\left[1/2\left(\int_{-\infty}^{-d_2} f(x)dx+\int_{2d_1-d_2}^{+\infty} f(x)dx\right)+1/2\left(\int_{-\infty}^{-2d_1+d_2} f(x)dx+\int_{d_2}^{+\infty} f(x)dx\right)\right]$$
$$+\frac{1}{2}\left[1/2\int_{d_2}^{2d_1-d2} f(x)dx+1/2\int_{-2d_1+d2}^{-d_2} f(x)dx\right] \quad (18)$$

where *f(x)* is the PDF of voltage amplitude of noise.
Thus, by using equation (7) to express the PDF of voltage amplitude noise $f_n(x)$, the bit error probability of LP stream can be written as:

$$P_{lp}(16)=\frac{1}{2}\left(Y(d_2)+\frac{1}{2}Y(2d_1^{'}+d_2)-\frac{1}{2}Y(2d_1^{'}+3d_2)\right) \quad (19)$$

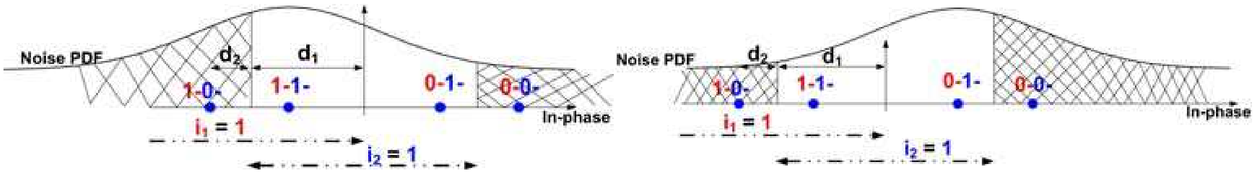
where $\mathrm{Y(d)}=\int_{-\infty}^{d} f_n(x)dx$, and expressed by:

$$\mathrm{Y(d)}=e^{-A_A}\sum_{k=0}^{+\infty}\frac{A_A^k}{k!}\cdot\frac{1}{2}\cdot erfc\left(\frac{d}{\sigma_k}\right)$$



P(error/1-1-) P(error/1-0-)

when i$_1$=1



P(error/1-1-) P(error/0-1-)

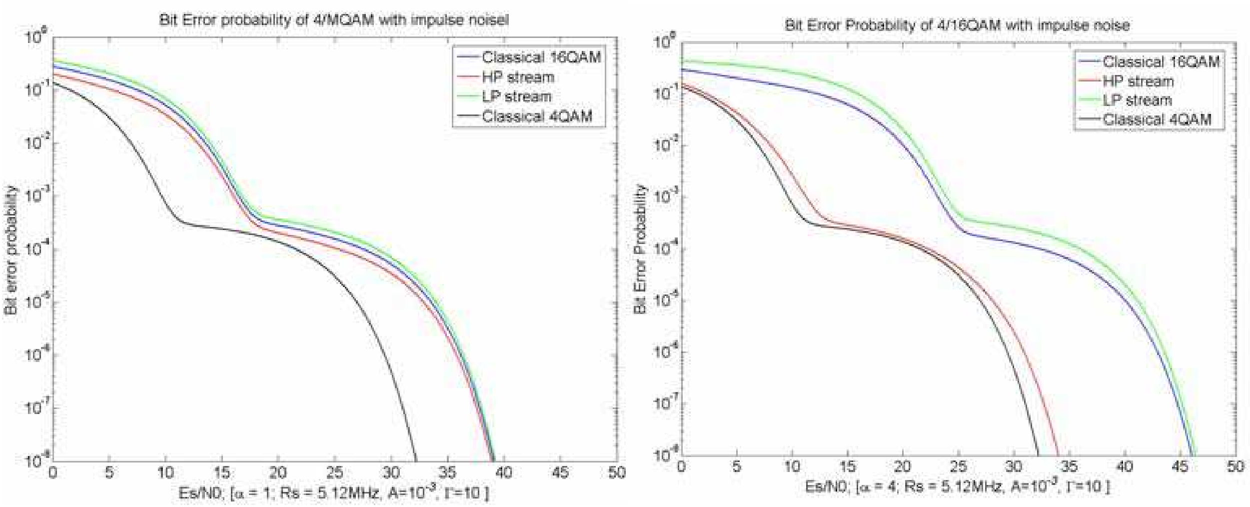
when i$_2$=1

Fig. 7. Illustration of P(error/x-y-) computation

Fig. 8a and 8b depict the error probability of HP and LP stream of hierarchical 4/16-QAM with α is equal to 1 and 4 and when the noise is given by Middleton class-A noise. Globally, the HP stream is less protected than the classical QPSK while the LP stream is less protected than the M-QAM with same constellation diagram.

When α is equal to 1, the HP and LP curves of error probability (red and green) are almost the same. They are around the curve of pure 16-QAM (blue), and far from the curve of pure 4-QAM (black). However, when α is equal to 4, the HP and LP curves are different. HP curve of error probability (blue) is close to the curve of pure 4-QAM (black).

This seems logic because when α grows, the energy of the constellation is more concentrated on HP stream and on base 4-QAM in the entire constellation. In fact, when α is increased, the energy of fictitious symbols grows (d_1 increases), expression (3). In contrary, the energy of refinement symbols diminishes (d_2 decreases), expression (4). Moreover, impulse noise induced a plateau in the error probability curve as it is the case of classical QAM (derived from Miyamoto, 1995).



a) α=1 b) α=4

Fig. 8. Analytical curves of error probability of 4/16QAM with impulse noise ($A=10^{-3}$, $\Gamma=10$)

3.3 Analysis of modulation penalty

Hierarchical modulation allows transmission of two different streams on the same transmission channel: one hp stream based on 4-QAM, and one LP stream build above the 4-QAM. Therefore, HP 4-QAM stream differs from pure 4-QAM by a quantity called the penalty modulation.

One calculation method exists in the scientific literature (Jiang, 2005), but does not lead to exact value at high Signal to Noise Ratio (SNR) which is the case in practice.

A new calculation method has been suggested to compute penalty of modulation (Tamgnoue, 2007). For that, we define:

- SNR as the signal to noise ratio of the hierarchical modulation;
- MNR (Modulation Noise Ratio) as the signal to noise ratio of the HP stream considering the introduction of LP stream.

To estimate the MNR, the worst case symbols are selected in the constellation diagram. These symbols correspond to the nearest symbols to the middle of the constellation diagram as illustrated in fig. 9. Thus, SNR and MMR are respectively obtained as:

$$SNR = \frac{2d_1^2 + \frac{2}{3}\left(\frac{M}{4} - 1\right)d_2^2}{2\sigma_N^2} \tag{20}$$

and

$$MNR = \frac{2\alpha^2 d_2^2}{2\sigma_N^2} \tag{21}$$

Therefore, the penalty denoted P_{mnr} is given by (Tamgnoue, 2007):

$$P_{mnr} = \frac{SNR}{MNR} = \left(1 + \frac{\left(\sqrt{M}/2\right) - 1}{\alpha}\right)^2 + \frac{\frac{1}{3}\left(\frac{M}{4} - 1\right)}{\alpha^2} \tag{22}$$

This penalty is function of M and α, whereas it does not depend on SNR. It grows with M and it is in inverse proportion to α.

The fig. 10.a and fig. 10.b depict the calculated penalty in term of error probability. In these figures, the calculated penalty is in green, and the modulation penalty estimated from curves of error probability is depicted in red. Globally, the penalty does not changes significantly and is constant when probability error varies.

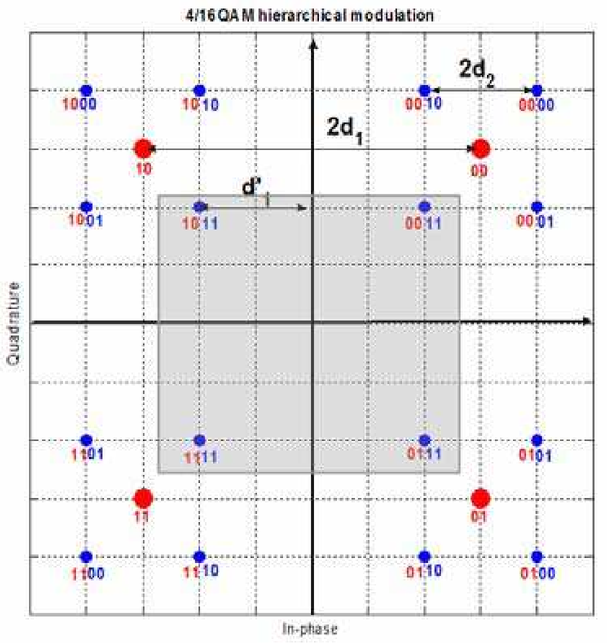
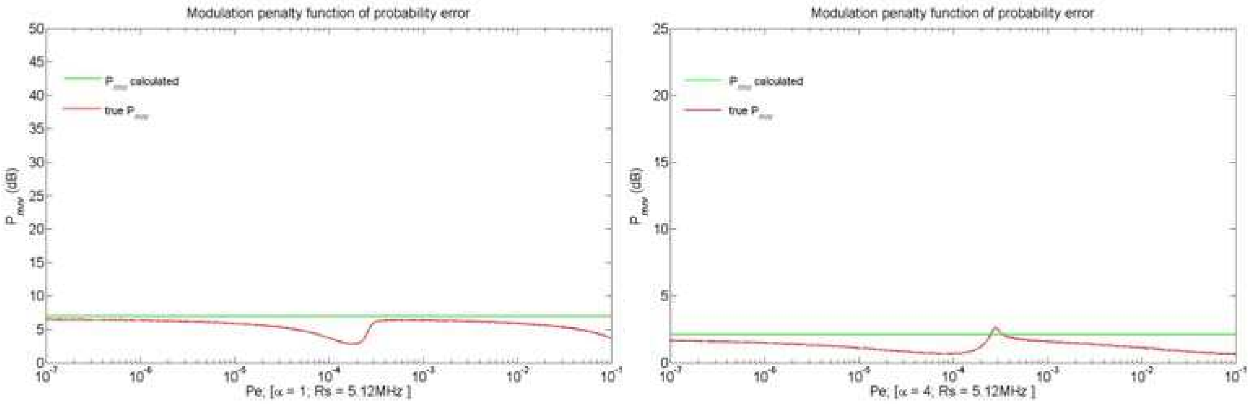


Fig. 9. Penalty analysis in constellation diagram



a) α=1 b) α=4

Fig. 10. Analytical curves of modulation penalty of 4/16QAM with impulse noise ($A=10^{-3}$, $\Gamma=10$)

3.4 Bit error probability of OFDM hierarchical 4/M-QAM calculation

At the receiver side, the noise in hierarchical symbol is given by:

$$z_k = \frac{1}{\sqrt{N}} \sum_{l=0}^{N-1} n_l e^{-j\frac{2\pi k l}{N}} \qquad 0 \le k \le N-1 \tag{23}$$

where n_l is the noise in the transmission channel.

Therefore, error probability OFDM hierarchical 4/M-QAM is the same as 4/M-QAM where the noise in presence is given by z_k. PDF of z_k is thus needed.

Like presented by Huynh (Huynh, 1998), lets define:

$$u_k = \frac{1}{\sqrt{N}} n_l e^{-j\frac{2\pi kl}{N}} \tag{24}$$

Given the circular symmetry of the PDF of n_l, the PDF of u_k is given by:

$$f_u(x,y) = e^{-A_A} \sum_{q=0}^{\infty} \frac{{A_A}^q N}{q!} \cdot \frac{1}{2\pi\sigma_q^2} \exp\left(-\frac{\left(x^2+y^2\right)N}{2\sigma_q^2} \right) \tag{25}$$

Following the approach discussed by Ghosh (Ghosh, 1996), it is supposed that u_k are independent random variables. Using the characteristic function method, the PDF of z_k is thus given by:

$$f_{z'}(x,y) = e^{-A_A N} \sum_{q=0}^{\infty} \frac{(A_A N)^q}{q!} \cdot \frac{1}{2\pi\sigma_{z'q}^2} \exp\left(-\frac{x^2+y^2}{2\sigma_{z'q}^2} \right) \tag{26}$$

where $\sigma_{z'q}^2 = \dfrac{q/(A_A N)+\Gamma}{1+\Gamma}$ and $\Gamma = \dfrac{\sigma_g^2}{(A_A N)\dfrac{\sigma_i^2}{N}}$.

It is thus similar to general Middleton class-A equation when A_A becomes $A_A N$ and σ^2_i becomes σ^2_i/N.

However, the hidden hypothesis surrounding this expression is that only when one pulse of duration equal to one QAM symbol impedes the entire OFDM symbol. It means that this pulse has been spread in all the N subcarriers, so duration grows N time and power decreases by a factor N.

In the general case, pulse will have duration of N_i in term on number of QAM symbols and an OFDM symbol will contain X_{imp} pulses. Therefore, PDF of z_k, $f_z(x,y)$, will become (Tamgnoue, 2007):

$$f_z(x,y) = e^{-A_A} \sum_{q=0}^{\infty} \frac{{A_z}^q}{q!} \cdot \frac{1}{2\pi\sigma_{zq}^2} \exp\left(-\frac{x^2+y^2}{2\sigma_{zq}^2} \right) \tag{27}$$

$$A_z = \frac{N}{N + D_{imp}/A_A} \tag{28}$$

$$\sigma_{zq}^2 = \frac{\left(q/A_z + \Gamma_z\right)}{1+\Gamma_z} \tag{29}$$

$$\sigma_{zg}^2 = \sigma_g^2 + \frac{\left(X_{imp}-1\right)A_A\sigma_i^2}{X_{imp}} \tag{30}$$

$$\Gamma_z = X_{imp}\Gamma + \left(X_{imp} - 1\right) \tag{31}$$

In the case of OFDM 4/16-QAM, the expression of error probability of HP and LP stream, by using equation (27) to express the PDF of voltage amplitude noise $f_z(x,y)$, are given by:

$$P_{z/hp}(M) = \frac{1}{2}\left(\frac{1}{2}\Upsilon_z\left(d_1^{'} + 2d_2\right) + \frac{1}{2}\Upsilon_z\left(d_1^{'} + 2d_2\right)\right) \tag{32}$$

and,

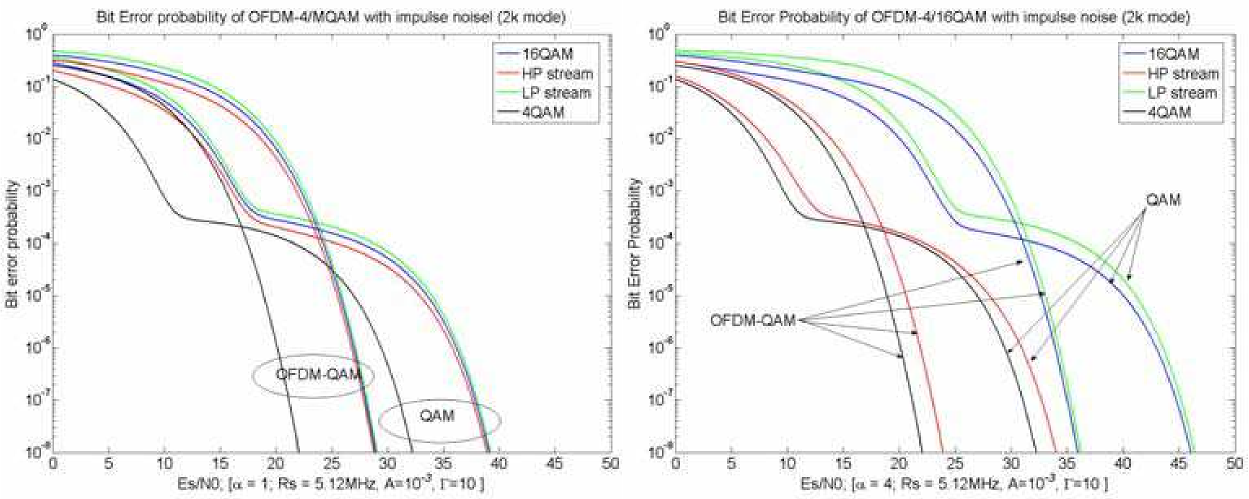
$$P_{z/lp}(16) = \frac{1}{2}\left(\Upsilon_z(d_2) + \frac{1}{2}\Upsilon_z\left(2d_1^{'} + d_2\right) - \frac{1}{2}\Upsilon_z\left(2d_1^{'} + 3d_2\right)\right) \tag{33}$$

where $\Upsilon(\mathrm{d}) = \int_{-\infty}^{d} f_z(x)dx$, and expressed by:

$$\Upsilon(\mathrm{d}) = e^{-A_z}\sum_{q=0}^{+\infty}\frac{A_z^k}{q!}\cdot\frac{1}{2}\cdot erfc\left(\frac{d}{\sigma_{zq}}\right).$$

The fig. 11.a and fig. 11.b depict the error probability of HP and LP stream of OFDM hierarchical 4/16-QAM with α is equal to 1 and 4 when the noise is given by Middleton class-A noise. For comparison purpose, the curves of simple hierarchical QAM are added on the figures.

It appears directly that the plateau has vanished due to the introduction of OFDM. It is a general observation which has already been studied in classical OFDM/QAM systems in presence of impulse noise (Zhidkov, 2006, Abdelkefi, 2005, Suraweera, 2004, Huynh, 1998, Ghosh, 1996). OFDM/QAM is proved to be more robust against impulse noise than classical single carrier QAM systems. This advantage appears because the impulse noise energy is spread among OFDM subcarriers. However, this spreading effect turns into disadvantage if the impulse noise energy becomes too strong.



(a) α=1

(b) α=4

Fig. 11. Analytical curves of error probability of OFDM hierarchical 4/16QAM with impulse noise (A_A=10^{-3}, Γ=10).

In the same figures, when α is equal to 1, the HP and LP curves of error probability of OFDM 4/16-QAM are almost the same. However, when α is equal to 4, the HP and LP curves are different. HP curve of error probability (blue) is close to the curve of pure OFDM with 4-QAM (black).

4. Simulation results

4.1 Impulse noise simulation

For analysis purpose, DVB has defined impulse noise model which is based on gated Gaussian noise (ETSI TR 102 401, 2005). In this model of impulse noise, an impulsive event comprises a train of bursts and each burst contains many impulses. The impulsive events are defined by their patterns which are therefore characterized by: burst duration, burst inter-arrival time, pulse duration, impulse inter-arrival time. This pattern is used as a gate and applied to Additive White Gaussian Noise (AWGN) to obtain gated Gaussian noise. By this way, 6 patterns have been defined an used to resilience evaluation of impulse noise.
But this model does not fit directly to Middleton class-A model which is a statistical analytical model. Nevertheless, to transform this model according to analytical Middleton model, the pattern parameters have been taken as statistical parameters and some links have been defined between them. As illustrated in fig. 12, the pattern has been built in such a way that the mean values of the duration and inter-arrival time are linked with the constraint that their ratio equals the Middleton impulsive index A_A. The duration has been given by a Rayleigh distribution while the inter-arrival has been given by the Poisson distribution. The amplitude has been statistically obtained with Rayleigh distribution. On the top obtained impulse noise, AWGN has been added to simulate the Gaussian contribution with the constraint that the ratio of mean Gaussian noise power and impulse noise power is equal to the mean power ratio Γ.

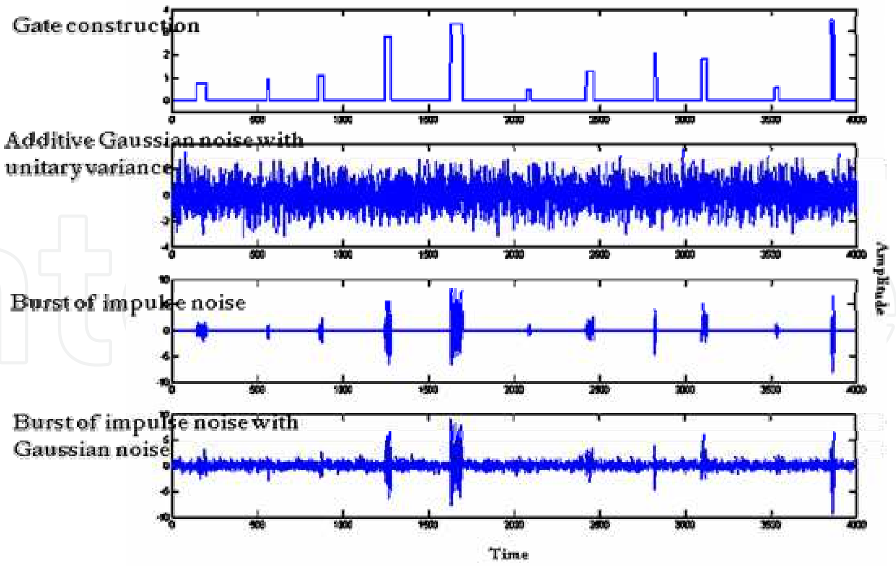


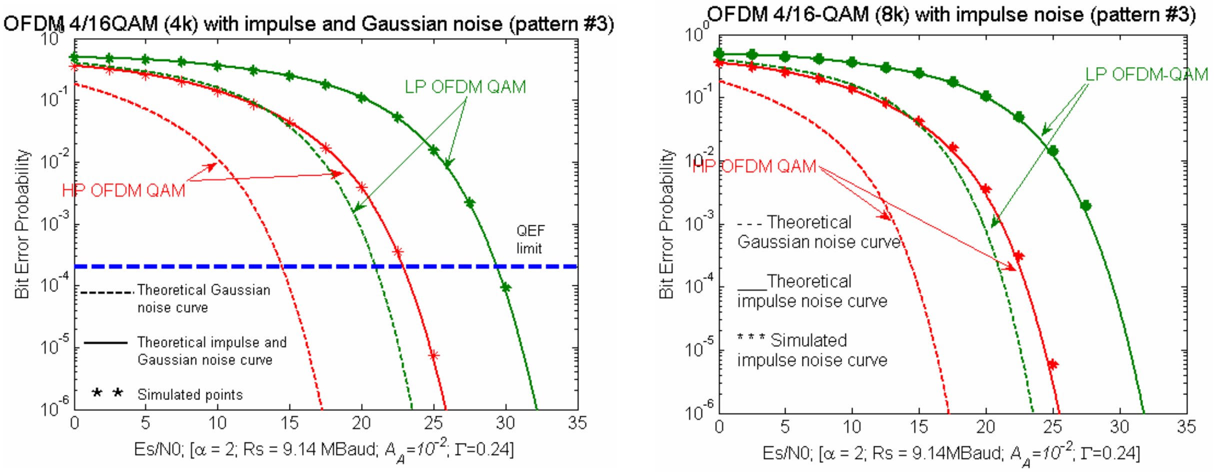
Fig. 12. Simulation of joint Gaussian and impulse noise.

4.2 Results analysis

The fig. 13.a and fig. 13.b depict some analytical and simulated bit error probability of HP and LP stream of OFDM hierarchical 4/16-QAM in presence of impulse noise. The values of the parameters of impulse noise are given by the impulse noise test pattern #3 specified in validation Task Force Report (ETSI TR 102 401, 2005, Lago-Fernández, 2004). In this figure, we illustrate simulation points by markers, analytical curves of BEP with both impulse and Gaussian noise by solid lines and analytical curves of BEP with Gaussian noise by dashed lines.

We observe that the simulated results are very close to analytical curves. Generally, HP stream is more robust than classical OFDM QAM which is also more robust than LP stream. The parameter α =2 leads to a good compromise between the strength of HP stream and the weakness of LP stream.

Compared to the case where the noise is purely Gaussian, we observe a right shift in the BEP curve. This shift corresponds to the penalty induced by impulse noise. For the case of impulse noise test pattern #3, in 4k OFDM mode, the impulse noise penalty is the same for the two streams and is equal to 8.3 dB.



(a) α = 2, mode 8k

(b) α = 2, mode 8k

Fig. 13. Simulation of HP and LP bit error probability of 2k OFDM 4/16-QAM in presence of both impulse and Gaussian noise given by pattern #3

5. Conclusions

Hierarchical modulation is a modulation technique allowing to transmit two completely separate streams modulated in the same transmitter and on the same channel. On this, a High Priority (HP) streams are embedded within a Low Priority (LP) streams. Hierarchical modulation has been defined in many standards.

In the frame of DVT-T\H, this paper have analyzed the bit error probability of hierarchical OFDM QAM modulation in presence of both Gaussian and impulse noises. It has proved that the curve of error probability depends on the parameters of hierarchical QAM, on the number of subcarriers, and on all the noise properties (not only on the PDF of voltage). Furthermore, the power penalty induced by hierarchical modulation has been defined and analytical formula to tackle this penalty has been provided. The formulas we have derived can be used when installing a new OFDM hierarchical QAM communications. Indeed, according to the desired BEP and the impulse noise properties, transmission parameters, like the number of subcarriers, the modulation order and the signal power, can be obtained efficiently to make right use of system resources.

Analysis of bit error probability performance has show that mix of OFDM and hierarchical modulation used in DVB-T\H systems present real differentiate performance for HP streams and LP streams. It improves the spectrum and the resources utilisation and it gives features to deal with impulse noise. It offers many opportunities for operators to delivering enhanced services. For instance, operators can launch different services for different kind of receiver (fixe or mobile). Many trials are been taken around the world demonstrating the capabilities of hierarchical modulation.

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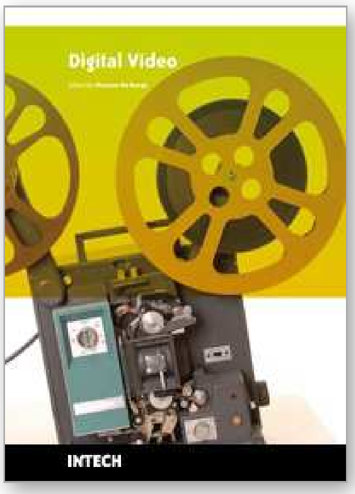

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This book tries to address different aspects and issues related to video and multimedia distribution over the heterogeneous environment considering broadband satellite networks and general wireless systems where wireless communications and conditions can pose serious problems to the efficient and reliable delivery of content. Specific chapters of the book relate to different research topics covering the architectural aspects of the most famous DVB standard (DVB-T, DVB-S/S2, DVB-H etc.), the protocol aspects and the transmission techniques making use of MIMO, hierarchical modulation and lossy compression. In addition, research issues related to the application layer and to the content semantic, organization and research on the web have also been addressed in order to give a complete view of the problems. The network technologies used in the book are mainly broadband wireless and satellite networks. The book can be read by intermediate students, researchers, engineers or people with some knowledge or specialization in network topics.

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