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

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***Abstract*-Hierarchical modulation, used in DVB-{T, H} (Digital Video Broadcasting – Terrestrial and Handheld), allows two separate bit streams to be modulated on one single stream according to their relative priority (high priority and low priority stream). We investigate the robustness of coupled OFDM (Orthogonal Frequency Division Multiplex) and hierarchical modulation systems under impulse noise as it appears in DVB (Digital Video Broadcasting) technologies. Analytically and confirmed by simulation, we estimate the penalty induced by the presence of impulse noise.**

I. INTRODUCTION

Impulse noise combined with Gaussian noise is one of the major causes of errors in digital communications systems and thus in DVB-{T, H} (Digital Video Broadcasting-Terrestrial and Handheld) networks [1]. These two kinds of noises behave in a different way to corrupt digital communications. Gaussian noise, also known as background noise, is permanently present through the network with moderate power. Contrary, impulse noise randomly appears as bursts of relative short duration and very large instantaneous power. Moreover, the impulse noise is particularly time-varying as it originates from electromagnetic effects in the environment of the network [2].

Hierarchical modulation used in these networks, allows two separate bit streams to be modulated on one single stream according to their relative priority (High Priority-HP and Low Priority-LP streams) [3].

In practice, hierarchical modulation is coupled with OFDM (Orthogonal Frequency Division Multiplexing). And for that reason the study of the impact of impulse noise in OFDM hierarchical modulation is of practical importance.

On one hand there have already been numerous studies of classical OFDM systems in presence of impulse noise [4], [5], [6], [7], [8]. Generally, classical OFDM systems are proved to be more robust against impulse noise than classical single carriers QAM (Quadrature Amplitude Modulation) systems. This advantage appears because the impulse noise energy is spread among OFDM sub-carriers. However, this spreading effect turns into disadvantage if the impulse noise energy becomes too strong.

On the other hand, performance of hierarchical modulation have only been analysed in presence of Gaussian noise [9].

Henceforth, in this paper, we investigate the behaviour of coupled OFDM and hierarchical modulation systems under impulse noise environment as it appears in DVB-{T, H} specifications. The penalty induced by the presence of impulse noise in each stream is analytically estimated and confirmed by computer simulations.

II. SYSTEM MODEL

A. Introduction of OFDM hierarchical modulation

OFDM hierarchical modulation is the combination of an OFDM system and some hierarchical QAM modulation as illustrated in fig. 1. It is constituted by a concatenation of a hierarchical QAM modulator and an OFDM modulator.

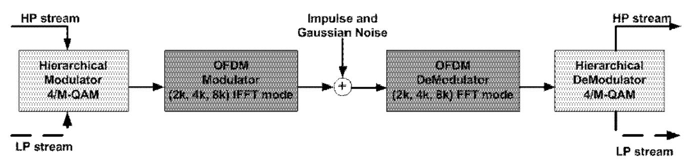

Figure 1. Simulated block diagram of OFDM hierarchical QAM system

In DVB-{T, H} systems, Hierarchical Modulation (HM) is defined on QAM (Quadrature Amplitude Modulation) and it is denoted 4/M-QAM. The 4/M-QAM is simply defined by its constellation diagram (see fig. 2 for 4/16-QAM case). The HP stream is modulated with QPSK (Quadrature Phase Shift Keying), equivalent to 4-QAM, 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 style.

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 two first bits, i_1q_1, are assigned the HP stream, and the next $log_2(M)-2$, i_2q_2, bits are allocated to LP stream. Hence, hierarchical modulation can be view as HP stream transmitted with the fictitious symbol of QPSK defined by the two first 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 characterise hierarchical constellation:

- d_1, which represents the minimum distance between two fictitious symbols;

- d_2, which represents the minimum distance between two neighbouring symbols within one quadrant;
- d'_1, which represents the minimum distance between two symbols in adjacent quadrants;
- $\alpha = d'_1/d_2$, the constellation ratio which determines the QAM constellation for hierarchical modulation;
    - α=1, uniform constellation,
    - $\alpha \neq 1$, non-uniform constellation.

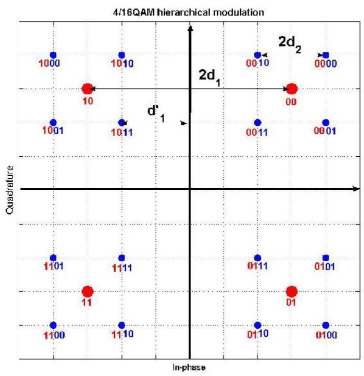

Figure 2. Constellation diagram of 4/16-QAM modulation

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) and FFT (Fast Fourier Transform). Basically, the information bits are mapped into N complex baseband complex symbols d_k using 4/M-QAM scheme. The block of N complex baseband symbols, considered in the frequency domain, is changed by means of an IFFT that brings signal in time domain. The sequence of complex received symbols r_i, after sampling and assuming ideal channel, is given by:

$$r_i = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} d_k e^{j\frac{2\pi ki}{N}} + n_i \qquad 0 \le i \le N-1 \tag{1}$$

where d_k is the 4/M-QAM complex symbol of the nth sub-carrier, n_i is the channel noise (jointly impulsive and Gaussian noise in this case), and N is the number of sub-carriers.

The estimated baseband complex 4/M-QAM symbol is recovered by performing a FFT that transforms the received signal in frequency domain, and it is given by:

$$\hat{d}_k = \frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} r_i e^{-j\frac{2\pi ki}{N}} = d_k + \frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} n_i e^{-j\frac{2\pi ki}{N}} = d_k + z_k \tag{2}$$

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

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

B. The Middleton class-A model

Impulse noise is basically defined with tree 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. For this model, the in-phase and quadrature Probability Density Function (PDF) of voltage f_n(x,y) is given by [10], [11]:

$$f_n(x,y) = e^{-A_A} \sum_{q=0}^{\infty} \frac{A_A{}^q}{q!} \cdot \frac{1}{2\pi\sigma_q^2} \exp\left(-\frac{x^2+y^2}{2\sigma_q^2} \right) \tag{3}$$

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, σ^2_g and σ^2_i are respectively the variance of Gaussian and impulse noises.

Specifically, A_A parameter 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.

III. Bit Error Probability of OFDM hierarchical QAM calculation

A. PDF of noise corrupting hierarchical 4/M-QAM symbol

The PDF of z_k can be derived by analysing physically the Middleton class-A parameters. By this way, we observe that: - the duration of impulses becomes equal to the OFDM symbol duration, - the power of impulses is spread out over OFDM symbol and becomes partly Gaussian.

Notice that the Gaussian part of noise lasts for all the N samples of OFDM symbol, while the impulsive part of noise appears on average only during N_i samples. N_i indicates the total duration of impulse within the OFDM symbol, and it is expressed by:

$$N_i = X_{imp} D_{imp} \tag{4}$$

Where X_{imp} is the average number of impulse per OFDM symbol and D_{imp} is the mean duration of typical impulse expressed in number of sub-carriers.

X_{imp} is given by:

$$X_{imp} = \left\lceil \frac{N A_A}{D_{imp}} \right\rceil \quad (5)$$

Therefore, f_z, the PDF of impulse noise z_k, disturbing the hierarchical QAM symbol, is always given by a Middleton class-A model. But their parameters become:

$$A_{Az} = \frac{N}{N + D_{imp}/A_A} \quad (6)$$

$$\sigma_{gz}^2 = \sigma_g^2 + \frac{(X_{imp} - 1) A_A \sigma_i^2}{X_{imp}} \quad (7)$$

$$\Gamma_z = X_{imp}\Gamma + (X_{imp} - 1) \quad (8)$$

where: - A_{AZ} is the impulse index of f_z, - σ^2_{gz} is the Gaussian component variance of f_z, - Γ_z is the ratio of Gaussian and impulsive component of noise, D_{imp} is the mean duration of impulse event, - and X_{imp} is the mean number of impulse event during one OFDM symbol.

B. Bit error probability of hierarchical 4/M-QAM calculation

For square 4/M-QAM, i.e. $M=2^{2n}$ which is the case of interest, the Bit Error Probability (BEP) of HP bits is given by [9]:

$$P_{hp}(M) = \frac{1}{2}\left[P(i_1, M) + P(q_1, M)\right] = P(i_1, M) = P(q_1, M) \quad (9)$$

where $P(i_k, M)$ et $P(q_k, M)$ represent respectively the bit error probability of the k^{th} in-phase and quadrature bits for 4/M-QAM hierarchical modulation.

On the other hand, the BER of the LP bits is obtained by [9]:

$$P_{lp}(M) = \frac{2\sum_{k=2}^{n} P(i_k, M)}{2n - 2} \quad (10)$$

where $P(i_k, M)$ represents the BEP of k^{th} in-phase LP bit of 4/M-QAM hierarchical modulation.

We define the impulse noise penalty, P_{imp}, as the asymptotic penalty induced in each communication stream by the joint presence Gaussian and of impulsive noise compared to the case where only the Gaussian noise is present. We can show that the magnitude of the penalty induced by the impulsive noise in an OFDM hierarchical QAM modulation is given by:

$$P_{imp} = 10 \cdot \log_{10}\left(\frac{\sigma_{gz}^2 \left(1 + 1/(A_{Az}\Gamma_z)\right)}{\sigma_g^2}\right) \quad (11)$$

We note that the impulse noise penalty does not depend on the order M of QAM modulation, the uniformity parameter α, but it depends on the number of sub-carriers N and the noise properties through A_{Az}, σ_{gz} and Γ_z.

IV. SIMULATION RESULTS AND CONCLUSIONS

We depict in fig. 3 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 [12]. 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.

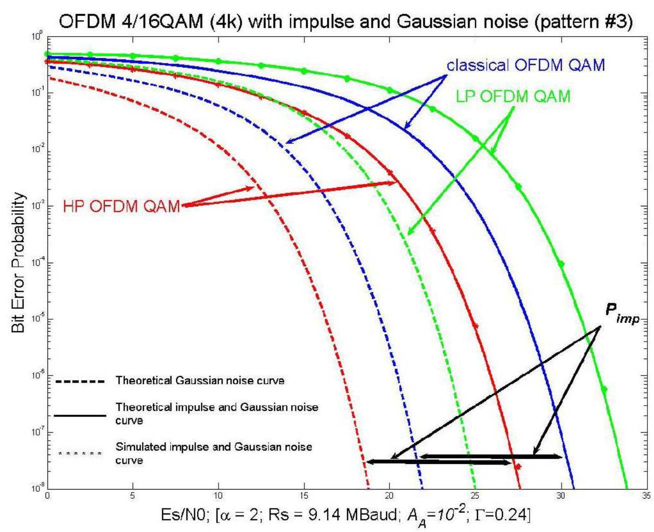

Figure 3. Simulation of HP and LP bit error probability of OFDM 4/16QAM in presence of both impulse and Gaussian noise given by pattern #3

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REFERENCES

[1] José Lago-Fernández, John Salter, "Modeling impulsive interference in DVB-T", EBU technical review 2004

[2] E. Biglieri, "Coding and modulation for a horrible channel," IEEE Commun. Mag., vol. 41, no. 5, pp. 92-98, May 2003

[3] ETSI, EN 300 744, V1.5.1, Digital Video Broadcasting (DVB): framing structure, channel coding and modulation for digital terrestrial television, Nov. 2004

[4] Suraweera, H.A. Armstrong, J., "Noise bucket effect for impulse noise in OFDM", Electronics Letters, vol. 40-10, pp. 1156- 1157, Sept. 2004

[5] M. Ghosh, "Analysis of the effect of impulse noise on Multicarrier and Single carrier QAM systems", IEEE Trans. Commun. Vol.44, pp. 145-147, Feb. 1996

[6] F. Abdelkefi, P. Duhamel, F. Alberge, " Impulsive noise cancellation in multicarrier transmission", IEEE Trans. Commun., vol. 53, No. 1, pp. 94-106, Jan.2005

[7] H. T. Huynh, P. Fortier, G. Delisle, "Influence of a class of man-made noise on QAM Multicarrier systems", Seventh Communication Theory Mini-conference (Globecom '98), Sydney, Australie, pp. 231-236, 8-12 Nov 1998

[8] S. V. Zhidkov, " Performance analysis and optimization of OFDM receiver with blanking nonlinearity in impulsive noise environment", IEEE Transactions on Vehicular Technology, Vol. 55, No. 1, pp. 234-242, Jan. 2006

[9] P. K. Vitthaladevuni, M-S. Alouini, "BER Computation of 4/M-QAM Hierarchical Constellations", IEEE Transactions on Broadcasting, Vol. 47, No. 3 (2001), pp. 228-239

[10] Middleton, "Canonical Non-Gaussian Noise Models: Their Implications for Measurement and for Prediction of Receiver Performance", IEEE Trans. EMC, vol. EMC-21, No. 3, Aug. 1979, pp. 209-220.

[11] L. Berry, "Understanding Middleton's Canonical Formula for Class A Noise", IEEE Trans. EMC, vol. EMC-23, No. 4, Nov. 1981, pp. 337-344

[12] ETSI TR 102 401 v1.1.1, Digital Video Broadcasting (DVB); Transmission to Handheld Terminals (DVB-H); Validation Task Force Report, May 2005

[13] S. Miyamoto, M. Katayama, "Performance analysis of QAM system under Class A impulsive noise environment", IEEE Trans. EMC, vol. 37, No.2, May 1995

[14] JG Proakis, Digital Communications, 4th ed., McGraw-Hill, New York, 2001