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Wavelet modulation: An alternative modulation with low energy consumption

La modulation en ondelettes : une modulation alternative à faible consommation d'énergie

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ABSTRACT

This paper presents wavelet modulation, based on the discrete wavelet transform, as an alternative modulation with low energy consumption. The transmitted signal has low envelope variations, which induces a good efficiency for the power amplifier. Wavelet modulation is analyzed and compared for different wavelet families with orthogonal frequency division multiplexing (OFDM) in terms of peak-to-average power ratio (PAPR), power spectral density (PSD) properties, and the impact of the power amplifier on the spectral regrowth. The performance in terms of bit error rate and complexity of implementation are also evaluated, and several trade-offs are characterized.

RÉSUMÉ

Dans cet article, nous présentons la modulation en ondelettes, basée sur la transformée discrète en ondelettes, comme une modulation à faible consommation d'énergie. Le signal généré par cette modulation a, en effet, de faibles variations de puissance par construction. Nous analysons la modulation en ondelettes pour plusieurs familles d'ondelettes et nous comparons ses performances avec celles de l'OFDM, en termes de facteur de crête (PAPR), de propriétés de la densité spectrale de puissance ainsi que de l'impact de l'amplificateur de puissance sur la remontée des lobes secondaires. Les performances en termes de taux d'erreur binaire et de complexité d'implémentation sont également évaluées, et plusieurs compromis sont caractérisés.

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This work is an extended version of our study on the Meyer wavelet modulation, published in the conference papers [1,2]. Compared to [1,2], we present here a more complete study covering other wavelet families and analyzing the power amplifier effect on the spectral regrowth.

1. Introduction

In communications, an important effect of the large amplitude variations of the transmitted multicarrier signal is the weak power efficiency of the power amplifier. This causes intensive energy consumption and growing need for cooling. Our objective is to propose an alternative to the classical multicarrier modulations in order to reduce energy consumption.

Orthogonal frequency division multiplexing (OFDM) is a modulation scheme adopted by various wireline and wireless communication standards as a modulation technique for data transmission. However, the OFDM signal suffers from high power fluctuations. The variations of its envelope generate non-linear distortions when we introduce the OFDM signal into a power amplifier (PA). In order to avoid the compression range of the PA and amplify the signal in the linear domain of the PA characteristic, an input back-off (IBO) is performed at the input of the PA. However, when the input back-off gets larger, power efficiency gets poorer, which induces high energy consumption.

PA energy consumption may represent more than 60% of the energy consumption of the LTE macro base-station transmitter [3]. Reducing the envelope variations, and then improving the amplifier's efficiency, contributes to reducing energy consumption at the level of mobile equipments (batteries that last longer), and at the level of the base stations (energy savings and reduced electricity bill for telecom operators). Therefore, this could help the reduction of CO2 emissions and prevent environmental pollution.

The peak-to-average power (PAPR) is a random variable that has been introduced to measure the power variations of the OFDM signal. Much research has been conducted in order to reduce the PAPR and analyze its probability distribution. In our previous work [4], we have studied the complementary cumulative distribution function (CCDF) of the PAPR, and we have shown that it depends on the waveform used in the modulation. The PAPR reduction problem can therefore be formulated as an optimization problem. In [5], we have shown that having a temporal support strictly less than a symbol period is a necessary condition on the waveforms for a better PAPR than OFDM. Since the wavelet basis satisfies this condition, we are interested in exploring wavelet modulation and energy consumption through the evaluation of its PAPR.

In this paper, wavelet modulation is proposed as an alternative modulation with low energy consumption. Power consumption is evaluated through the study of PAPR performance, and compared with that of OFDM. The simulation results show that the proposed scheme for wavelet modulation achieves significant gains in terms of PAPR compared with OFDM, at the cost of affordable increased complexity. A comparison in terms of bit error rate and power spectral density between the OFDM system and the wavelet modulation system is also investigated in this work.

2. Wavelet modulation

Wavelets have been applied in several wireless communication applications such as data compression, source and channel coding, signal denoising and channel modeling. Moreover, wavelets have been proposed as a modulation basis for multicarrier modulation systems. The resulting system based on wavelet modulation is often named in the literature as Wavelet-OFDM [6] or also known as orthogonal wavelet division multiplexing (OWDM) [7].

The most common scheme in the literature is wavelet packet modulation (WPM), which is a generalized form of wavelet modulation. WPM has been introduced in the literature by Lindsey [8], who studied the application of the wavelet packet basis in orthogonal multiplexing of data. In this paper, we have chosen to focus on wavelet modulation for its significant PAPR performance gains, as will be studied in Section 3.

2.1. Wavelet basis

Let ψ and ϕ be two functions $\in L^2(\mathbb{R})$,[1] of a finite support[2] $[0, T_0]$, such that:

$$\|\psi\|^2 = \|\phi\|^2 = 1 \tag{1}$$

$$\text{and} \quad \int_{-\infty}^{+\infty} \psi(t) = 0 \tag{2}$$

The norm $\|.\|$ of a function $g \in L^2(\mathbb{R})$ is defined as: $\|g\|^2 = \int_{-\infty}^{+\infty} |g(t)|^2 \, dt$. ψ and ϕ can be named the mother wavelet function and the mother scaling function respectively.

Let L be the effective number of scales selected; we define contracted versions ψ_j and ϕ_j of the functions ψ and ϕ, for $j \geq J - L$,

[1] The space of square integrable functions.

[2] The support of a function means here the interval outside which the function is equal to zero.