Multi Binary Turbo-Coded Wavelet OFDM in Flat Fading Channels

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Wavelets represent a successful story of the last decade in signal processing applications. Thus, these signals, with some highly desirable properties, are widely used in domains as compression, denoising, segmentation, in-painting or classification. By the other hand, in data communications, the same successful story can be assigned to multi-carrier modulation techniques. The principle of the Orthogonal Frequency Division Multiplexing (OFDM) is employed in a large number of transmission standards, over wired and wireless channels: WiFi, WiMAX, DAVB or ADSL.

The wavelet based OFDM (WOFDM), sometimes referred to as wavelet modulation is the point where the above concepts meet with each-other. Although they are widely used in signal processing, few wavelets applications are known in data transmission. The idea that gathers the two concepts is to use wavelet signals as carriers in a multi-carrier data transmission.

Despite its excellent behavior in unfriendly channel environments, OFDM raises some practical problems which are difficult to overcome. Thus, the bandwidth is increased by the use of a cyclic prefix and the transmission is highly sensitive to the Doppler spread introduced by the time variant channels. Next, the OFDM systems are very sensitive to the narrow band interferences. Furthermore, the synchronization in time and frequency is critical for the system performance and the peak-to-average ratio of the signal is very large due to the non-constant nature of the envelope. Finally, the out-of-band rejection of such a signal is not satisfactory, since the OFDM spectrum is made of sinc functions, whom sidelobes contain an important amount of energy.

Recent research has shown that some of these drawbacks may be counteracted using wavelet subcarriers instead of the OFDM's complex exponentials. The idea is based on the orthogonality of the wavelets composing a wavelet family:

$$\left\langle \Psi_{j,k}, \Psi_{m,n} \right\rangle = \begin{cases} 1, & \text{if } j = m \text{ and } k = n \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

This property validates the association between the multi-carrier concept and the wavelet signals. Previous research made on wavelets showed that they provide a more flexible basis than the complex exponentials. These exponentials have a perfect frequency resolution, but they span over the whole time axis. Wavelets offer a better time-frequency resolution compromise: good frequency resolution at high frequencies and improved time resolution at low frequencies. Next, in OFDM, every carrier is gated by the symbol duration, generating the sinc spectra, with the associated issues related to the energy of the sidelobes. This problem is alleviated in Wavelet OFDM (WOFDM), because wavelets, by their nature, have finite time duration and they localize the symbols on the time axis. Thus, they can be simultaneously seen as carriers and pulse shaping waveforms. Furthermore, these signals meet Nyquist criterion for zero ISI and consequently, the pulse-shaping may be considered as "already done" in WOFDM [1,2]. Exactly as for OFDM, the wavelet modulation may be simply implemented using the Inverse Discrete Wavelet Transform (IDWT) in the modulator and the direct transform (DWT) in the demodulator. Both transforms are implemented using Mallat's filter banks algorithm.

The BER performance of WOFDM was extensively studied in previous papers, in AWGN and flat fading channels. Briefly, our investigations showed that, while there is no difference between OFDM and its wavelet-based version for AWGN channels, it may be worthwhile to carry a deeper research on the fading channels case. Thus, WOFDM provided significantly better results than OFDM, no meter what was the wavelet use as carrier. Furthermore, the choice of the wavelets mother is meaningful for the BER performance of WOFDM: Haar wavelet provided, by far, the best results. In general, our empirical research led us to the conclusion that, better the time localization of the carrier, higher the resilience to the time-variant character of the fading and lower the BER of the system.

All the above investigations were conducted in a simple scenario, without considering any additional issues as synchronization or channel coding. This time, our goal is to associate the WOFDM transmission with a very powerful channel coding technique, namely the turbo-codes. The transmission chain used for simulation is shown in fig. 1.

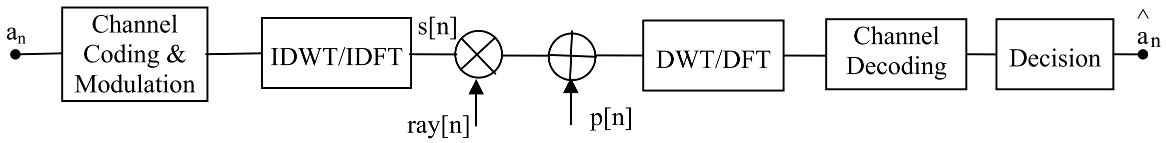

Fig.1: Transmission chain used for simulation.

In fig.1, the bit sequence is denoted by a_n. The data is encoded using a multi binary turbo-code. Multi Binary Turbo Codes (MTBC). MBTCs, are a new family of Turbo Codes (TC), with multiple inputs [3, 4]. Particularly, it was shown by means of simulations that parallel concatenation of *r*-input binary RSC codes provides better overall performance than TCs with single input over AWGN channel. The main advantage of the multi-binary turbo-codes versus Turbo Codes (TCs) [4] is their minimum distance, which is in general larger than classical TC. The constituent encoders for MBTCs are the rate-1/2 Recursive Systematic Convolutional RSCs encoders, with memory equal with 3, proposed in [3]. Its generator polynomial is equal to $G=[13\ 15\ 11]_8$. The redundant bits are interleaved by an S-interleaver [4]. The length of the coded sequence is equal to 2·256 bits. The FEC blocks are processed either by IDWT or by IDFT modulator to obtain the WOFDM and the OFDM symbols respectively. A Rayleigh distributed sequence, ray[n] multiplies the useful sequence s[n]. The Rayleigh sequence is intended to simulate the flat fading effect and encompasses the Doppler spread of the signal. The normalized value of this parameter is taken into account: $f_m = f_d T_S$, where T_S is the sampling time. We consider the value $f_m = 0.05$ for this parameter. The additive noise perturbing the useful signal is taken into account by means of p[n], which is a Gaussian distributed sequence, with flat power spectral density. In both cases, the demodulator is based on the direct transform, and a decision is made based on a threshold comparison after the decoding is applied. One of the decoding algorithms used in this paper is the MaxLogMAP algorithm. The extrinsic information is less reliable, especially at the beginning of the iterative process. A more robust approach consists in scaling the extrinsic information with a scaling factor smaller than 1.0. The best observed performance is obtained for a scaling factor of 0.75 [4]. 15 iterations are assumed at the decoder. In the case of WOFDM, simulations were made for different wavelets mother, from Daubechies, Symmlet and Coiflet families. Some results are shown in figures 2 and 3. The results illustrated in fig. 2 confirm our conclusion from the un-coded case, namely that all techniques perform the same in AWGN and with results which are similar to BPSK modulation. For the Rayleigh fading case, it is obvious that all wavelet modulations perform better than OFDM. This is a confirmation of our previous results too. In the case of the flat Rayleigh fading, there is no ISI introduced by the channel, which is not frequency selective (is flat). Instead, it is the Doppler spread of the signal which damages the transmission performance. An explanation for the superior performance of wavelet based methods is that, no meter what is the wavelet used as carrier, its duration is smaller than the duration of carriers used in OFDM. In this last case, all subcarriers span over the whole symbol duration, and the transmission is strongly affected by the variance in time of the channel.

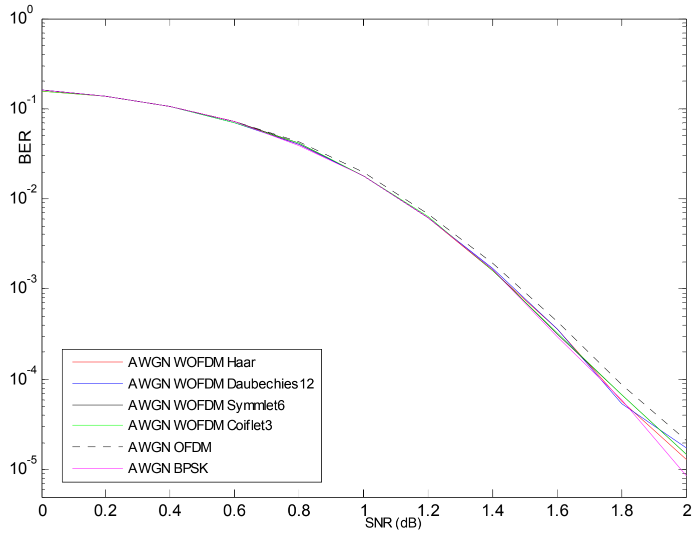

Fig.2: WOFDM versus OFDM in AWGN channels.

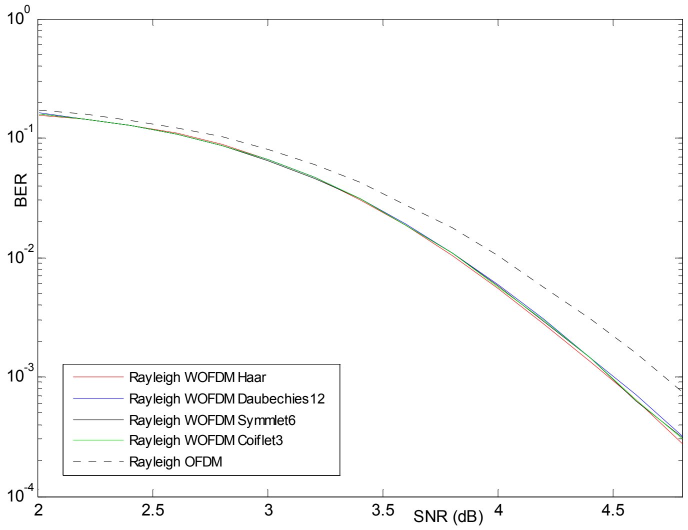

Fig.3: WOFDM versus OFDM in flat fading channels.

Reference:

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