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► To cite this version:

S. Mallier, F. Nouvel, Jean-Yves Baudais, D. Gardan, A. Zeddami. Multicarrier CDMA over lines — Comparison of performances with the ADSL system. IEEE International Workshop on Electronic Design, Test and Applications, Jan 2002, New Zealand. pp.450-452. hal-00283640

HAL Id: hal-00283640

<https://hal.science/hal-00283640>

Submitted on 18 Sep 2014

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Multi-Carrier CDMA over copper lines

- Comparison of performances with the ADSL system -

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Abstract

This paper deals with the comparison of two multi carrier modulation techniques over existing copper twisted pairs: the Discrete Multi Tone (DMT) modulation and the Multi Carrier Code Division Multiple Access (MC-CDMA) modulation. The first form has been proposed for Asymmetrical Digital Subscriber Line (ADSL) [3]. However in ADSL, the wire pairs suffer from disturbances such as transients, radio-frequency noise. Among them, impulse noise is considered to be one of the most damaging impairments. Then, our proposal intends to limit the effects of such a noise thanks to the use of the latter form of modulation which combines multi carrier technique with spread spectrum. In order to improve the performances of the system proposed still further, various detection techniques are studied. In this context, we show that the MC-CDMA technique presents better performances than the normalised ADSL technique under identical simulation parameters (data rate, bandwidth, transmitted power, coding, interleaver).

1 Introduction

The wish of France Telecom to make best use of the existing copper network between the telephonic central and the customer results in the survey and the development of high rate xDSLs systems, and in particular the ADSL system. However, the transmission quality is affected by many factors as the cables attenuation, the coupling by crosstalk, the electromagnetic environment... In this survey, we are more especially interested in the impulse noise (fast electric transient) present on the copper twisted pair in the subscriber's home.

In a first part, the impulse noise model used is presented. It will be applied in the performance evaluation of the high data rate transmission system under consideration.

In a second part, we briefly present the principle of the DMT modulation normalized for ADSL transmission. In this paper, the results of simulation obtained with the ADSL system will serve as elements of comparison and reference.

In the third part, we introduce the MC-CDMA system. This promising multiple access scheme with high bandwidth efficiency is based on a serial concatenation of Direct Sequence (DS) spreading with Multi-Carrier modulation. This combination provides the advantages of frequency diversity and enables multiple access, by allocating a different code to each user. This combination can also be applied over a copper line by, allocating different codes to the same user. Our purpose is to benefit from the spreading code properties to protect oneself from the impulse noise because of its high immunity against interference and jamming [6].

In the last part, various detection techniques combined with the MC-CDMA modulation are proposed in order to limit the effects of the impulse noise. On the one hand, single detections are easy to implement but they don't take into account Multiple Access Interferences (MAI). On the other hand, multi-code detection technique is based on the important assumption that the codes are known to the receiver a priori.

2 Impulse noise

Impulse noise is dependent on the electromagnetic environment typology (neon, electrodomestic appliances) and is injected by coupling on the transmission cables. From measurement, made by France Telecom, in a wide range of sites (building, industries), a statistical analysis of inter-arrival allows to identify two main models of impulse noise: burst impulse and isolated impulse [5]. Moreover, a statistical analysis on parameters reflecting at best the impact of impulse noise on ADSL modems has been realised: temporal parameters are the length, the peak to peak amplitude; frequency parameter is the Power Spectral Density PSD).

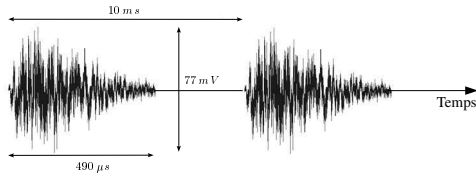


Figure 1. Isolated impulse model

Figure 1 represents the isolated impulse model with its average parameters. Because of its strongest impact on the quality of transmission, this model will be used to characterize the impact of impulse noise on systems.

3 DMT modulation

DMT modulation was chosen by ITU-T for standardization of ADSL [3]. Ideally, DMT modulation partitions a channel into N independent memoryless subchannels, each of which supports a given Quadrature Amplitude Modulation (QAM). After Forward Error Correction (FEC) and interleaving for coded systems, the input bitstream is separated into blocks of b bits with each block forming one DMT symbol. Based on a bit allocation scheme, these b bits are then distributed so that subchannels with higher SNR's (Signal-to-Noise Ratios) receive more bits, and subchannels with lower SNR's receive fewer bits, while subchannels for which the SNR is below a certain threshold are completely turned off [7].

4 MC-CDMA

The MC-CDMA modulation is based on a serial concatenation of DS spreading with Multi-Carrier modulation [2]. The MC-CDMA transmitter spreads the original data stream over different subcarriers in the frequency domain using a given spreading code. The effect of spreading is that different data can be transmitted on the same carriers in a CDMA manner. Figure 2 shows the MC-CDMA transmitter of j^{th} spreading code. The data symbol $x_j(t)$ is transmitted in parallel over N_c subcarriers, each multiplied by one chip $c_{k,j}$ of its specific Walsh-Hadamard spreading code $C_j = [c_{1,j} \ c_{2,j} \ \dots \ c_{L,j}]$.

In this figure, the length L_c of the spreading code is equal to the number N_c of subcarriers but this is not mandatory. Practically, the Multi-Carrier (MC) modulation and demodulation is easily carried out in the digital domain by performing IFFT and FFT operations. Furthermore, the insertion between adjacent MC symbols of a guard interval Δ longer than the delay spread of the impulse response of the channel, guarantees the absence of Inter Symbol Interference (ISI). In the receiver, after direct FFT, the received sequence is equalized in the frequency domain (cf figure 2).

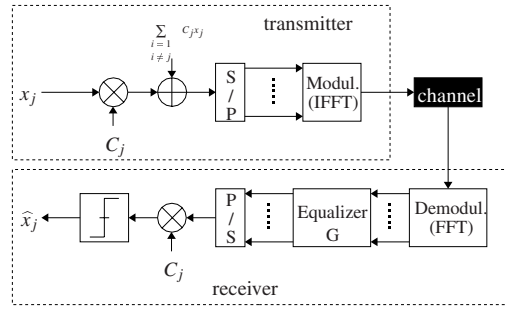


Figure 2. Studied MC-CDMA transmitter and receiver

5 Detection techniques

To combat the channel impairments and thus the MAI, a multitude of detection techniques was proposed [2]. They can be classified as either single-code detection or multi-code detection.

5.1 Single-code detection

Single code detection is performed by one tap equalization to compensate for the phase and amplitude distortions h_k caused by the wire pairs channel. The one tap equalizer is simply one complex-valued multiplication per subcarrier. Various detection techniques can be carried out [4]. For those well known basic techniques, the assigned equalization coefficient is equal to:

$$\begin{aligned} g_k &= h_k^* && \text{Maximum ratio combining (MRC)} \\ g_k &= h_k^* / |h_k| && \text{Equal Gain Combining (EGC)} \\ g_k &= 1/h_k && \text{Orthogonality Restoring Combining (ORC)} \end{aligned}$$

5.2 Multi-code detection

In order to improve the performance of the receiver still further, multi-code detection can be processed, in which knowing about the interfering spreading codes is exploited in the detection process. Among multi-code detections, the Parallel Interference Cancellation (PIC) detector estimates the interferences due to the other simultaneous signals so as to remove this multiple code interference component from the received signal [1]. Interference cancellation can be carried out iteratively in multiple detection stages. To cope with the MAI, various combinations of single detection techniques can be studied. Indeed, in the initial detection stage, the data symbols of all active codes are detected in parallel by a first single code detection. After the despreading and the demapping, the decisions of this initial stage are used to reconstruct the interfering contribution.

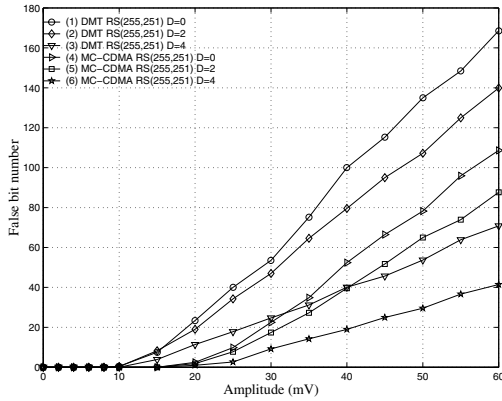


Figure 3. Comparison of performances between the MC-CDMA and DMT modulations (ORC detection)

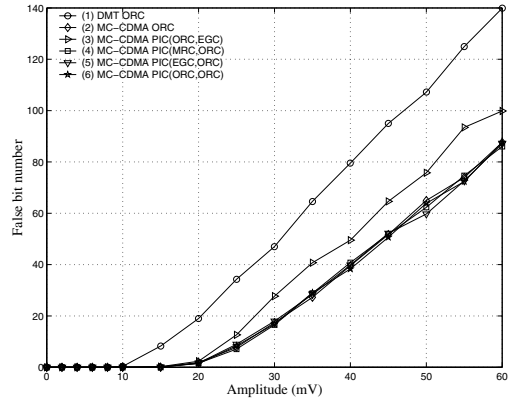


Figure 4. Optimization of the detection technique for the MC-CDMA system [RS(255,251), D=2]

The resulting interferences are then subtracted from the received signal and the data detection is performed again on the signal with reduced MAI.

6 Simulation

6.1 Parameters

In order to compare the DMT and MC-CDMA modulations, transmission parameters respect the ADSL standardization (bandwidth, carriers number, PSD mask...).

The characteristics of the simulated MC-CDMA system are the following ones : the length L_c of the Walsh-Hadamard spreading code is equal to 128, the number of codes is equal to 128 (the system is full loaded), the sub-carriers are MAQ-16 modulated, all codes have the same power.

6.2 Results

The simulation results are presented with Reed Solomon (RS) coding channel (255,251) and various interleaver depth (D) for the two systems. Figure 3 illustrates the strongest resistance of the MC-CDMA modulation compared with the DMT modulation in presence of impulse noise. Under identical interleaver depth, the false bits appear for higher impulse noise amplitudes.

In order to optimize the MC-CDMA system, the detection techniques are modified. Figure 4 shows that the single-code detection (curve 2) and the multi-code detection PIC (curves 4,5,6) present equivalent performances. However, practically, single-code detection is easier to implement.

7 Conclusion

In this paper, we demonstrate under identical simulation parameters, that the MC-CDMA modulation is more resistant than the DMT modulation in an impulse noise environment. Furthermore, a set of techniques of detection have been applied to a MC-CDMA signal. Results show that the single-code ORC detection is optimal and increases the amplitude threshold from which false bits appear. Thus, MC-CDMA could be a good candidate for future DSL systems.

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