INTERFERENCE ON MULTICARRIER–BASED POWER LINE COMMUNICATION SYSTEMS

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ABSTRACT

An indoor Powerline telecommunication is considered to emphasize the influence of noise on system performances. Indeed, one of the main difficulties in such a transmission is the great variability of noise and that the channel are frequency dependent. Taking the path loss into account, an upper frequency limit of 30 MHz is usually assumed. Extensive measurements have been performed to get an idea of the various features of the channel and to deduce a channel model, which is introduced in a simulation tool to compare the efficiency of channel coding and to optimize the parameters for the transmission scheme.

INTRODUCTION

One of the main characteristics of the radio channel using the low voltage power line network as physical link between the transmitter and the receiver, is its important variability in time domain due to the great number of electrical appliances which are switched randomly either in the on or off mode and the impulsive noise. In this paper, we will first present Indoor Power line channel characteristics and the way of modeling the channel. A comparison of the performances of the OFDM and DMT transmission schemes in a stationary noise is then given. Lastly, the influence of the impulsive noise on a OFDM transmission is pointed out to draw conclusions on the optimization of the transmission scheme depending on the noise characteristics.

INDOOR POWER LINE CHANNEL MODEL

Both the channel (impulse response and attenuation) and the noise characteristics are deduced from measurements. It results that the power line network can be modeled in a frequency range extending up to 30 MHz by a transfer function in addition with three types of noise: background noise, narrow band noise and impulsive noise.

The time-varying transfer function characteristics

The power line network, even in a residential indoor environment, is a complicated one due to the geometrical configuration of the line on the one hand and, on the other hand, to the presence of appliances, plugged or not, and behaving as unknown loads for the network. To be able to make a statistical channel modeling, numerous experiments must be made in typical environments. As an example, let us consider the simple network structure made by only a two-wire line, 23 m long, interconnecting a fuse box at one end, to a distant plug at the other end. This network contains 5 plugs randomly distributed and the channel transfer function is measured between the third and the fifth ones. Between these two plugs, to simulate an appliance, a spectrum analyzer is connected or not to the power line, the more distant plug being always open. The complex channel transfer variation, measured in the 1 MHz – 30 MHz frequency band, is given in Fig. 1 by successively considering the spectrum analyzer unplugged or plugged in either ON or OFF mode. At low frequency, the three curves have nearly the same shape while, above 13 MHz, both an additional attenuation and fading appear when the device is plugged OFF.

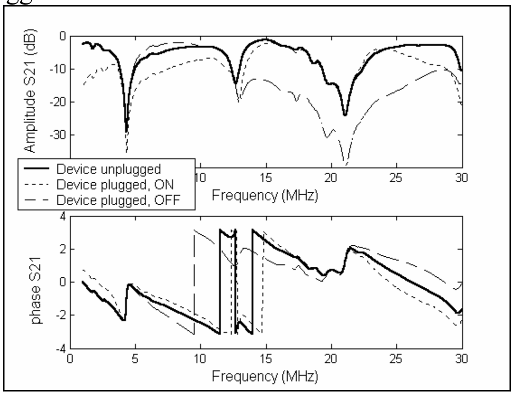

Fig. 1 : Example of channel measurement

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The channel impulse response is calculated through an IFFT in the frequency band which is a priori chosen for the OFDM transmission. The several taps deduced from the discrete impulse response feed a tapped-delay-line filter to model the channel.

Noise characteristics

Stationary noise

A typical background noise in the 0-30 MHz frequency band is presented in Fig. 2. It appears that the stationary noise can be considered as the superposition of a colored and of a narrow band noise. The first one has a power spectral density (PSD), which first decays exponentially with frequency, up to 3 MHz. Above that frequency, it remains nearly a constant and can be considered as an AWGN. It also appears various peaks corresponding to a narrow band noise, due to broadcast transmitters. Therefore, in the transmission scheme, a filtered gaussian noise is used to simulate the background noise, the narrow band noise being modeled by sine waves, their amplitudes and phases being randomly distributed.

Impulsive noise

The impulsive noise characteristics are deduced from a statistical study based on measurements made in a house. It appears that the impulsive noise, modeled by a damped sinusoid, can be divided into two types, which occur on different time scales. The first type is a single transient, its average total duration being on the order of 100µs and its pseudo frequency being smaller than 500kHz. On the contrary, bursts are made of a succession of elementary pulses with a pseudo frequency greater than 1 MHz, and their mean duration are about 50 µs.

The most energetic part of the signal is situated, in the frequency domain, around the pseudo-frequency f_o. Consequently, a single damped sinusoid would mainly contribute to a degradation of the signal to noise ratio only for frequencies smaller than 500 kHz. Since in the following, the frequency band of the OFDM transmission extends up to 6 MHz, the effect of single transients is negligible compared to the disturbance caused by bursts having frequency content within the transmission bandwidth. Furthermore, it is expected that the bandwidth of a PLT modem will extend from few MHz to 20 MHz and thus, they will not be disturbed by single transients.

The general shape of a burst and its main parameters are given in Fig. 3. Td is the estimated duration of each elementary pulse and T_{IA} the interarrival time.

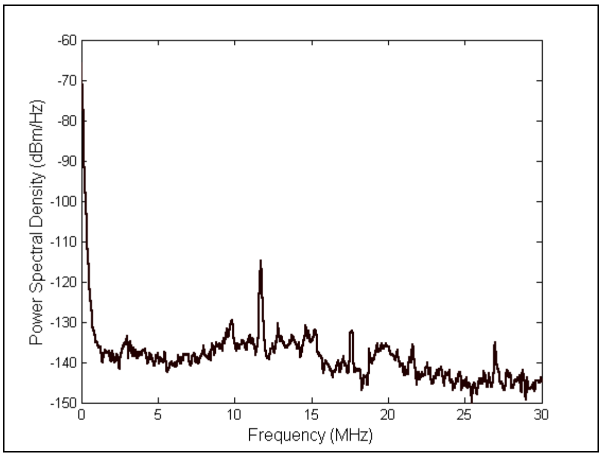

Fig. 2 : Power Spectral Density of stationary Noise

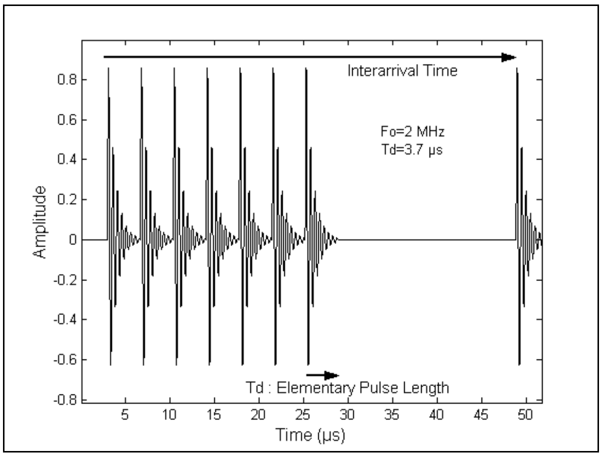

Fig. 3 : Impulsive noise model

Instead of introducing the maximum pulse amplitude A, it is more convenient to define a time varying Signal to Impulsive Noise Ratio SINR [1]defined by $SINR=P_{signal}/P_{impulse,}$ where $P_{impulse}$ is the average power of the elementary impulse and P_{signal} is the signal power, both quantities being averaged on the duration of an OFDM symbol.

THE TRANSMISSION LINK IN A STATIONARY CHANNEL

The OFDM transmission link

The principle of an OFDM transmission scheme, presented in Fig. 4, is to transmit the information in parallel with N subcarriers modulated in QPSK, through an IFFT. The major advantage is to cope with the frequency selectivity of the channel by dividing the available bandwidth into N equal sub bands, in which a flat channel is assumed, and allowing the use of a simple equalization algorithm, the estimation of the channel response being obtained during a preamble time slot. Lastly, the equalizer coefficients are deduced from the zero forcing criteria and the synchronization is assumed to be ideal. Furthermore we have added a Reed-Solomon encoder and an interleaving to quantify the contribution of channel coding. The Reed-Solomon code, noted RS(N,K) is a nonbinary block code: the code consists in

K information symbols of m bits and (N-K) parity check symbols. This code is guaranteed to correct up to t = (N-K)/2 symbols of m bits [2]. And even if an optimization of the code parameters is conceivable, a more realistic approach is to apply the ADSL standards. The information is coded in bytes, a code word is 255 bytes long, an information word contains K = 239 bytes and the code can correct up to 8 bytes per code word. But in order to simplify the interpretation of the results, it is more convenient that the lengths of the code word and of the OFDM symbol are multiple. That is why the length of the code word is increased by a byte by the way of zero padding. In all simulations, the performances of OFDM transmission scheme is performed by considering N_s subcarriers with a QPSK modulation, a bit rate of 10 Mbit/s, and a prefix cyclic of about $N_s/10$ samples.

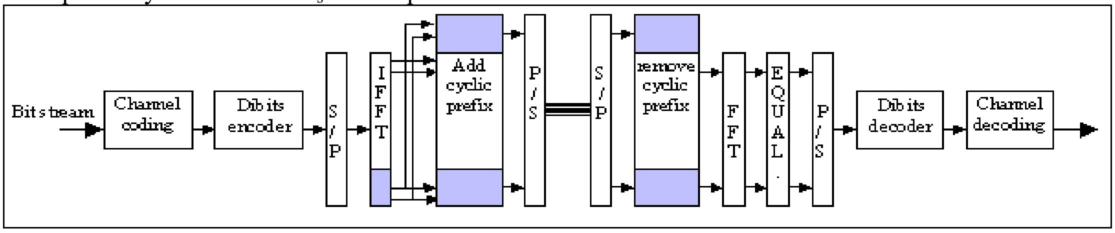

Fig. 4 : OFDM transmission process

The Discrete Multitone (DMT) link

The DMT process is based on the OFDM scheme, in which the constellation size and the subcarrier power depend on the signal to noise in each subcarrier, in using algorithm based on the water filling. But as the Powerline transmission shall have a power limit to fulfill constraints of electromagnetic compatibility, no power allocation is performed and the bit allocation is deduced from the algorithm proposed by Fischer and Huber [3], which objective is to transmit at fixed data rate in minimizing the error probability. The power is equidistributed on the subcarriers. In fact some researches [4,5] are conducted to measure the impact of Powerline systems and networks on the others services using the same [0-30 MHz] frequency range, to give the radiated and the conducted emission limits and the measuring procedure.

Performances comparison

The aim of this first step is to compare OFDM and DMT schemes in a frequency selective channel and in presence of stationary noise. To compare various configurations, in the same way, the bit rate is fixed to 10 Mbit/s, the subcarriers number is equal to 256 and the number of bit per frame is fixed to 512. The cyclic prefix is equal to 28 samples, greater than the delay spread of the channel. The power spectral density can vary between –130 dBm/Hz to – 90 dBm/Hz. The carrier frequency, defined as the first carrier of the OFDM spectrum is equal to 9 MHz, and the spectrum is extended up to about 15 MHz, corresponding to the narrow band noise part of the stationary noise described in Fig. 2. The channel state is shown in Fig. 1, when the appliance is plugged ON. During the initialization phase, 20 frames are sent to estimate the channel state and 20 other frames to estimate the noise. The results in terms of Bit Error Rate (BER) versus Power Spectral Density (PSD), are presented in Fig. 5.

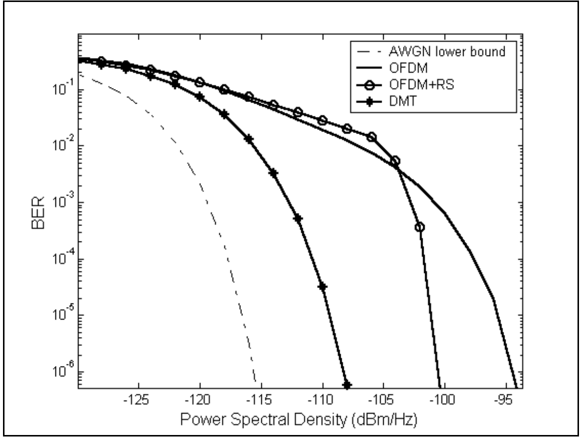

Fig. 5 : BER in presence of narrow band noise and in a selective channel

The first curve, noted ‘AWGN lower bound’ presents the analytic BER in the selective channel and in the presence of a gaussian noise of PSD equal to –135 dBm/Hz. The curve, noted ‘OFDM+RS’ shows the BER of the OFDM link with the Reed-Solomon code RS(255,239). In this figure, the contribution of the RS code clearly appears for a PSD greater than –104 dBm/Hz, but the improvement obtained with the bit allocation (curve noted ‘DMT’) is better than in the case of an OFDM link with RS

TRANSMISSION LINK IN PRESENCE OF IMPULSIVE NOISE

In this second part, we evaluate the influence of the impulsive noise on the performance of an OFDM link and the contribution of channel coding. We emphasize its effect on the BER by assuming, in this section, a flat fading channel.

The first study deals with the impact of a burst of 50 µs duration on the performances of the OFDM link and in particulary a parametric study is achieved on the OFDM symbol duration which is related to the number of subcarriers. The performances, shown in Fig. 6, are given in term of the number of erroneous bytes versus SINR. It appears that the number of erroneous bytes increases with the number of subcarriers. In fact, bursts energy is concentrated in the frequency range around its pseudo-frequency, and as the increasing data symbol is realized in spite of a decreasing subband, the number of noisy subcarriers increased, whatever the SINR. In that configuration and for a bit rate of 10 Mbit/s, 256 subcarriers, with Reed-Solomon code RS(255,239), are well adapted.

In a second step, the number of subcarrier is set to 256 and we analyse the contribution of the channel coding versus the duration of the burst. A block interleaving is introduced by writing row-by-row the elements into a matrix and by reading them column-by-column. The interleaving matrix is a 256 x D matrix, D varying between 2 and 64. The role of the interleaving is to spread burst of symbol errors over a number of different RS blocks, in which the number of byte errors is hopefully smaller than the correction capacity of each RS block. The performances are presented in Fig. 7 when the duration of the burst varies from few µs to 4 OFDM symbols and the SINR is fixed to –20 dB. The simulation is realized for different value of D. From this figure, we can notice that there is no error for D greater or equal to 8 and when the burst duration is lower than one OFDM symbol because the 64 erroneous bytes are spread on 8 RS code words and consequently, the resulting 8 erroneous bytes per code word are corrected by the RS channel coding. An optimized value D=32 , not shown in Fig. 7, because there is no error, is required to improve the performances when the burst covers 4 data symbols. Nevertheless, this conclusion is only valid if the interarrival time of bursts is greater than the duration of 4*D OFDM symbols used for the interleaving.

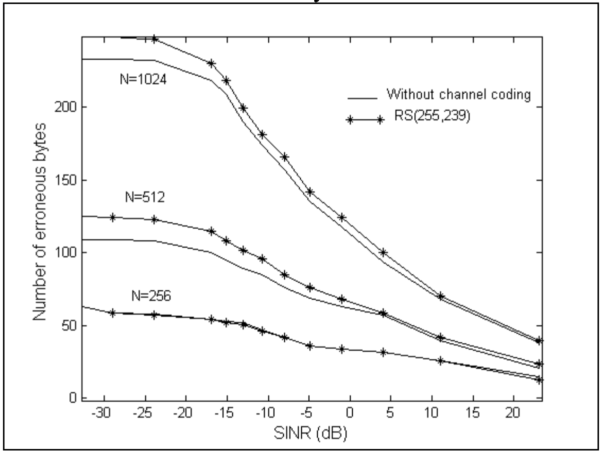

Fig. 6 : Erroneous bytes versus SINR and N

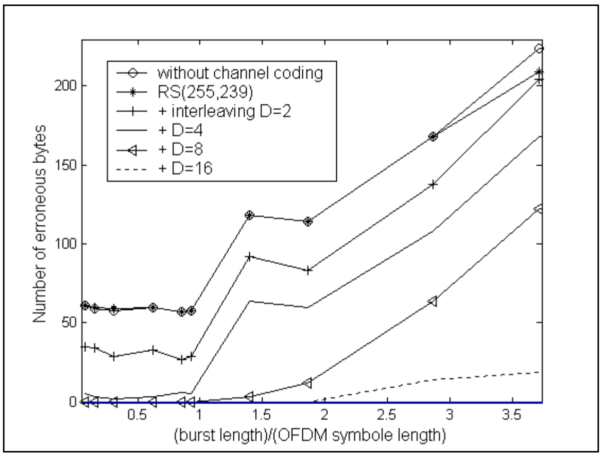

Fig. 7 : Influence of channel coding, SINR=-20dB

CONCLUSION

An OFDM and DMT transmission on power lines are simulated to emphasize the impact of the different noise on the transmission performances. Extensive noise measurements have been performed to deduce a model. The result shows that the OFDM transmission link, added with a bit allocation, is required to cope with the channel fading and the narrow band noise. Concerning the impulsive noise, the burst is modeled by a succession of damped sinusoids which fits quite well the experimental result. It has been shown that both interleaving and Reed Solomon coding are needed to improve the performance of an OFDM transmission of 256 subcarriers. An RS(255,239) code and an interleaving with a factor D greater or equal to 32 is required to correct the effect of a burst duration lower than 4 OFDM symbol.

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