MEASUREMENTS AND MODELING OF IN-HOUSE POWER LINES INSTALLATION FOR BROADBAND COMMUNICATIONS

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Keywords

Power line communication, Transfer function, Impulse response, Noise, OFDM performance

Abstract

The Power lines when used for communications purposes present [1,3] varying impedance, attenuation of the signal and phase shift. In this paper an attempt is made to study attenuation and noise characteristics for a "typical Greek residence" loaded with widely used electric devices. Our measurement results are found in good agreement with those already reported in the literature. On these results a channel capacity estimation is made for the worst noise scenario and an OFDM transmission scheme is proposed. The performance of the system is evaluated in terms of BER and SNR.

INTRODUCTION

The Power lines when used for communications purposes present [1,3] varying impedance, attenuation of the signal and phase shift. This happens because loads are continuously connected and disconnected randomly resulting to changes of the circuit topology. Stationary channel models can be conceived and apllied for a given topology. But a statistical channel model would be closer to the real channel behavior. But this of course entails extensive measurements, statistical analysis of the results and trials for definition exact of the depth and frequency zones of the notches of transfer function. Generally there is no systematic way to predetermine the position or the depth of the transfer function's fadings. Empirically we can claim that the more loads are connected to the line the deeper and numerous the notches are. Another conclusion from the measurements campaign is that the bigger the distance between transmitter and receiver the greater the attenuation of the transmitting signal is.

In our investigation, in order to design a communication system whose properties could match to the majority of the electrical house grids we studied the topology of several house installations trying to characterize them in a systematic way. So we concluded in two basic configurations, the star and the tree configuration (figure 1 and 2). All power lines circuits fall into one or the other category or a combination of them. We have chosen also to work with an ordinary configuration of the electric grid loaded with widely used devices with known consumption. Thus a "typical Greek House" is constructed step by step. Its configuration, dimensions and loads are shown in figure 3.

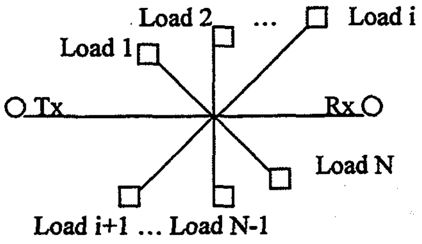

Figure 1. Star Structure

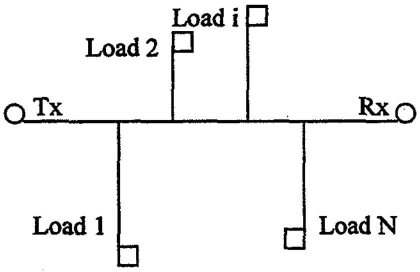

Figure 2. Tree Structure

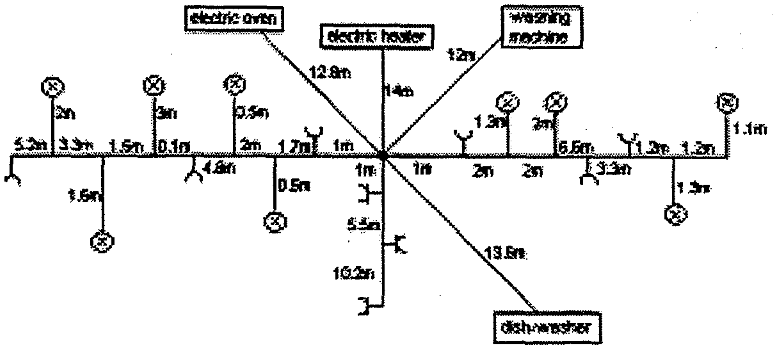

Figure 3. Typical Greek Apartment

For this "standard house" noise and attenuation measurements for different Tx-Rx positions were made and the results were used to define the transmission parameters of the grid for broadband communications.

MEASUREMENTS AND MODELING

Transfer Function

The transfer function describes the properties of the channel in the frequency domain. The **magnitude** of the transfer function expresses the attenuation of a signal traveling across the line, while the phase gives the delay that signal is experiencing. The frequency range examined in our study comes up to 30MHz. For the magnitude campaign a tracking generator was used with a *spectrum analyzer*. Isolation transformers and high pass filters were constructed to support the precision of our experiments. We are mainly interested in determining mean values and the standard deviation of the attenuation of the communication signal injected in the line. Measurements for typical distances between outlets were carried out. That is for 19, 36 and 190m. The mean attenuation throughout the frequency zones was increased with a factor between 2 and 6 dB with an exception in the frequency range 10-15MHz where the mean attenuation increased about 11dB comparing measurements at 19 and 36 m. For the 190m case the mean attenuation increased with a factor around 20dB ± 4dB. Standard deviation also increases with the Tx-Rx distance and provides a measure for the average attenuation over the frequency zones. Plots of measurements are shown in the figure 4 and the extracted mean values and standard deviations are shown in the following table 1.

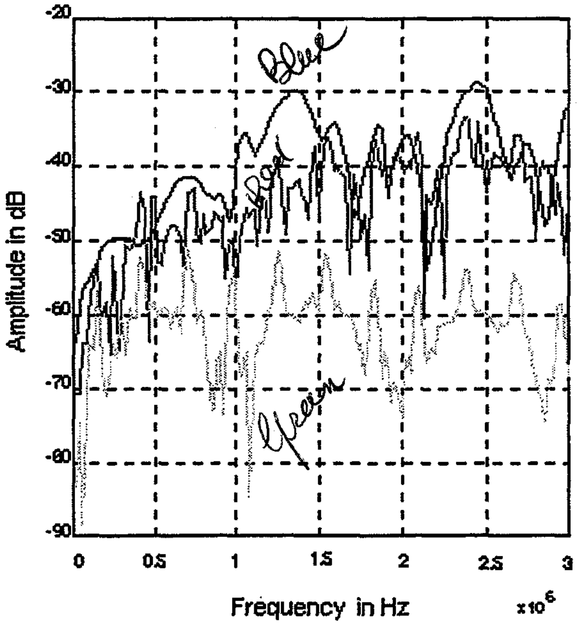

Figure 4. Transfer Function Amplitude for three different Tx-Rx distances

Table 1.

Freq. Range	1-5 MHz	5-10MHz	10-15MHz	15-20MHz	20-25MHz	25-30MHz
BLUE :T-R=19m						
mean value	-51,8030	-43,4866	-33,5098	-38,4700	-36,8354	-38,4608
stand devia	6,0762	1,6736	3,8268	7,0874	26,9072	10,5014
RED:T-R=36m						
mean value	-55,9382	-48,8926	-44,5046	-41,8284	-40,7212	-41,2696
stand devia	33,0364	5,6278	6,8628	12,0492	20,2236	7,4368
GREEN:T-R=190m						
mean value	-64,2032	-60,9650	-61,5386	-62,0004	-60,8646	-63,3358
stand devia	36,2778	17,3628	21,0442	18,2202	7,2614	7,2166

The **phase response** for the three examined configurations are shown below. Measurement were done by using a *network analyzer*. As distance between transmitter - receiver increases phase response changes rapidly with the increase of frequency.

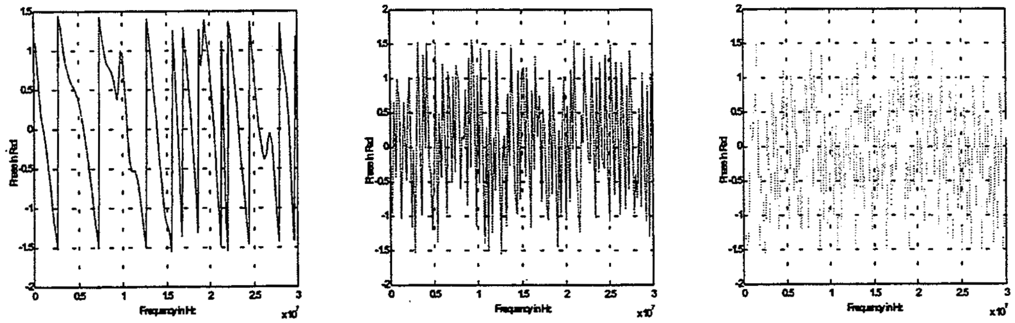

Figure 5. Phase response of the transfer function for the three Tx-Rx distances

In Greek installations wiring of two thickness size is found, that is intersections are 1.5 mm^2 and 2.5 mm^2. For the same configurations but different wire thickness the attenuation is measured. The root mean square deviation between them is shown below. One square millimeter gives an improvement of 15% to 66%. Obviously the difference in thickness becomes more significant as frequency increases.

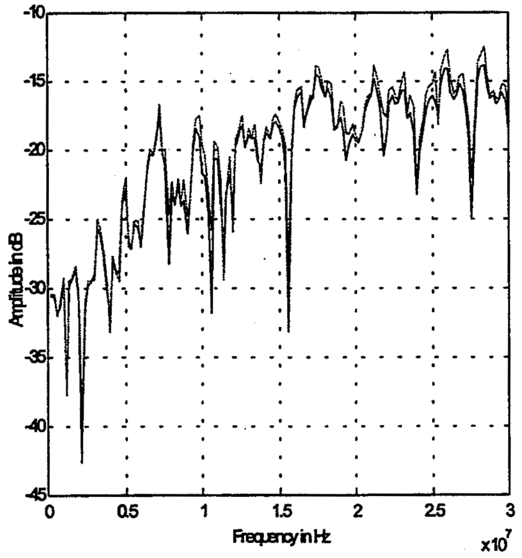

Figure 6. Study the same configuration having cables with different thickness 1,5mm^ 2 and 2,5mm^2

The examination of the channel in time domain can be done by implementing an inverse discrete fourier transform of the transfer function in the frequency domain. This way the impulse response is extracted and important channel properties are obtained. Furthermore, the significant signal paths (great edges in the plot) are investigated and the delay spread is estimated calculating the percentage of the energy reaching the receiver. At figure 7 the impulse response is given for the 36 meters distance Tx-Rx. 50 % of the energy reaches the receiver in 233 nanoseconds whereas 75% reaches Rx in 366nsec and 99% in 1.66μsec.

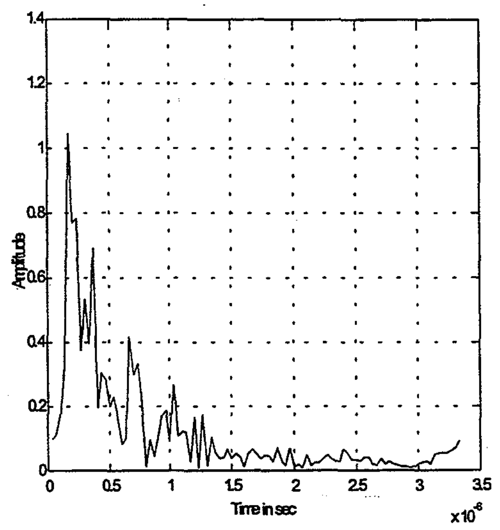

Figure 7. Impulse Response

Noise

As noise sources on the power grid we can consider all the electronic or electrical equipment connected to the power lines. Some of them generate broadband noise (electrical motors) while others (light dimmers) inject impulses of noise. Some noise is harmonically related to the A.C. 50 Hz supply. Finally there are portions of noise that are induced from the environment onto power lines because these act as antennas due to their length. For example radio stations transmitting at medium and short wave bands inject deterministic noise into the lines. Noise can be studied both in the frequency and time domain. In time domain inter-arrival time of impulse noise and the duration of impulses, are interesting factors. Whereas in frequency domain plot of noise, gives a clear view of its power distribution. Using a *spectrum analyzer and a GPIB card*, the noise power level was measured for the chosen "typical Greek apartment". The noise measurement set up is shown below.

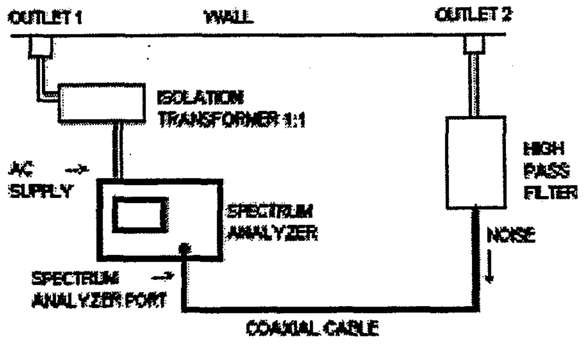

Figure 8. Noise measurements set up.

Splitting the day in three time zones, (morning, afternoon and evening), three different noise procedures took place. Then the samples were statistically processed and a noise level was determined with 95% of samples being below this level. Also the worst measured case indicating the greatest noise level measured was extracted. This worst noise scenario is then used to determine frequency regions where transmission is preferable or not.

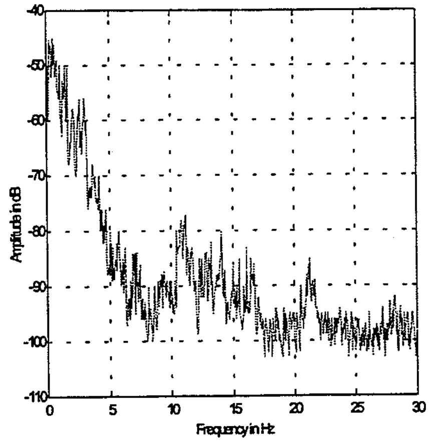

Figure 9. Background noise 95% of the samples are below the level of ordinate

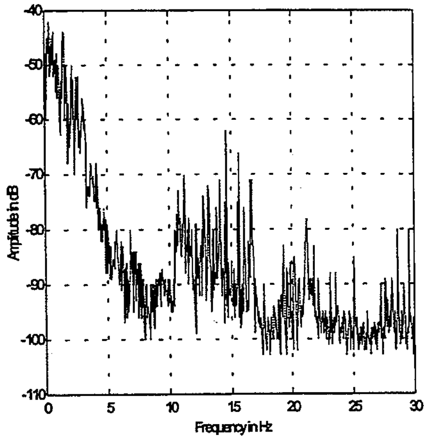

Figure 10. Harmonic Analysis Worst measured case

CHANNEL CAPACITY-OFDM PERFORMANCE

The investigation of the line capacity was the next step of our research. The study has two basic objectives. First, to determine the frequency ranges where tranceivers are expected to communicate effectively. Second, to select a proper loading algorithm for the transmission. The worst noise scenario and the highest signal attenuation channel for the Tx-Rx 36m distance case is examined. That distance was chosen as the worst representative found in a residence or office. Theoretically we are interested in the determination of the error rate at a given Bit Rate and Signal to Noise Ratio for different combinations of modulation, coding, error correction etc. From communication point of view and in order to fulfill certain applications the error rate is predefined and the SNR is imposed from the communications medium. Thus the attainable bit rate for the proposed channel is needed. The problem is a typical optimization problem of the function

$$R = 1/(2\cdot N)\cdot\sum_{i=1}^{N}\log_2(1+|H(f_i)|^2\cdot s_i/(\Gamma\cdot\sigma_i^2))$$

with the restriction the total transmitting power to be constant. $s_{tot}=\sum_{i=1}^{N}s_i$.

The solution is the well known water filling theory and gives

$$s_i+\Gamma\cdot\sigma_i^2/|H(f_i)|^2 = K = 1/N(s_{tot}+\sum_{i=1}^{N}\Gamma\cdot\sigma_i^2/|H(f_i)|^2) \qquad (1)$$

where K is a constant, index *i* denotes the sub-channel. s_i and s_{tot} refer to the subchannel energy and the total energy respectively, $H(f_i)$ is the channel attenuation, σ_i^2 the noise variance at that subchannel and finally Γ is the SNR gap for our system from achieving capacity [8].

It is well known also that subcarriers having high bit error probability dominate to the whole error probability of the system. These channels must not be used for carry information. Under these considerations a loading algorithm is applied for an optimal distribution of the energy and the bit rates.

Mainly four loading algorithms are of practical interest. The Hughes-Hartogs algorithm [4] calculates a matrix whose elements are the incremental power needed to transmit one more bit from m-1 to m at subchannel n. That is $\Delta P_{m,n}=P_{m,n}-P_{m-1,n}$. Then one more bit is allocated at subchannel n that has the lower $\Delta P_{m,n}$. Intensive shorting and iterations make this algorithm having great computational cost. Chows algorithm [5] distributes energy equally to subchannels $s_i = s_{tot}/N$ and bit rates b_i according to $b_i=\log_2(1+SNR_i/(\Gamma\gamma_m))$ where i denotes the subchannel, Γ is the SNR gap and γ_m is the systems noise margin that is determined iteratively so that the total bit rate is equal to the desired one. The basic idea of Fischer's algorithm [6] is to transmit at a bit rate, determined by the application, with a BER as low as possible. It distributes energy in a flat way ($s_i = s_{tot}/N$) and data rates according to $b_i = b_{tot}/N + 1/N\cdot\log_2(\prod_{i=1}^{N}\sigma_i/\sigma_i^N)$

where σ_i denotes the noise variance at channel i and N the available channels at a specific iteration. Iterations are continued until all b_i are positive, so in every iteration channels with $b_i<0$ are rejected and new N and b_i are calculated. Obviously all described algorithms are sub-optimal compared to the water filling distribution. As it was mentioned above, subcarriers having high bit error probability dominate on the total error probability calculation. These must be turned off. Then the energy is distributed to the remaining channels. In [7] the steps of an optimal algorithm are described in detail.

For our power line channel Leke algorithm gives the results of Figures 11 and 12.

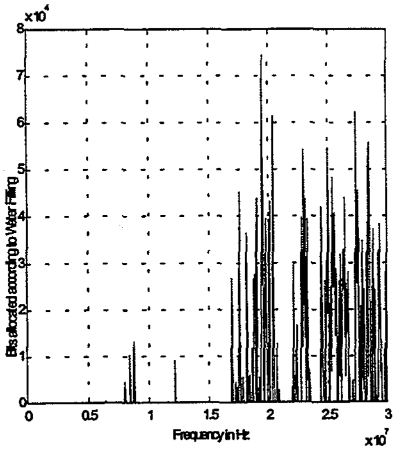

Figure 11. Bit allocation for high channel Attenuation and worst noise scenario.

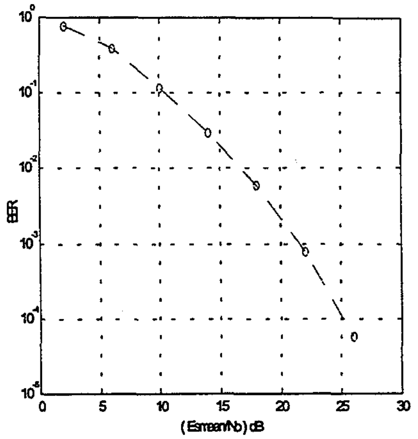

Figure 12 . Performance of an OFDM system adaptive to channel SNR.

Figure 11 gives the allocation of bits to the frequency bands based on the SNR of the band. Regions on the band We notice that frequencies over 16MHz are loaded but the lower band is almost not used. That was in a way expected since noise weakens with frequency increase. These are the worst channels measured. Although channel characteristics are not good the obtained channel capacity is 3.142 Mbps in a frequency range equal to 6.46 MHz.

Figure 12 displays BER versus SNR for an OFDM simulation system implementing an adaptive strategy. The target rate was 8Mbps. Since our research did not cover the statistical examination of how often channel characteristics change, the time distribution of channel variations was based using a random time function.

CONCLUSIONS

Our measurements confirmed that there is no important difference for the characterization of power lines for indoor and outdoor communications, although in-house power grids have different standardization. For the worst measured case the results are very promising. The bottom down performance allows the transmission of 3 Mbps. Further research is needed to examine an average noise scenario for the typical residence configuration.

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