COMPARATIVE STUDY OF LOADING ALGORITHMS FOR PLC APPLICATIONS

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ABSTRACT

In this study a trial is made for an in depth investigation of the criteria and mechanisms of loading algorithms proposed so far in the literature. There are three basic categories of them based on the type of the optimization problem they solve. As optimization problems we can consider: to minimize or maximize a specific parameter and thus result to an equation to be used for bits and power assignment on the OFDM carriers. There are three categories of practical interest. In this paper one algorithm of each category was chosen and compared to the others in a real PLC environment.

I INTRODUCTION

OFDM modulation has been proved to be effective for power line communications because of its efficiency in deteriorating intersymbol interference inserted by multipath phenomenon. The guard time suffix used is longer than the channel delay so interference is eliminated. The guard time has also a cyclic format in order to preserve orthogonality of subcarriers. Another channel problem that has to be faced is the frequency selectivity of the power lines. Adaptive modulation schemes are the key means to overcome it, that is the carriers used for transmission and the power and bit assignment on the carriers must follow channel properties.

Theoretically, the problem for optimal data transmission in parallel over neighboring frequency zones is confronted by the waterfilling approach [1]. The channel is broken into N subbands and water filling optimizes the function

$$C = \sum_{i=1}^{N} c_i \qquad (1)$$

which gives the overall capacity of the system by determining the transmission power in every band. The condition of this optimization problem is that the total transmission energy must be constant. In practice the water filling's demand for infinite number of subcarriers and the very low level of error probability is out of question. The number of subcarriers can become large but is always finite and the coding protection can support a small but non zero number of bit errors. Thus a parameter, Γ is introduced to describe how far is our system from achieving the highest capacity. This constraint optimization problem is solved using the Lagrange Multirliers method and gives:

$$P_n = K \cdot \Gamma \cdot {\sigma_n}^2 / g_n \qquad (2)$$

where P_n is the power allocated at the n_{th} subcarrier, ${\sigma_n}^2$ is the noise variance at the n_{th} subcarrier, g_n is the channel's attenuation of the n_{th} subchannel and K is a constant independent of the frequency region.

In the literature several algorithms have been proposed for an optimal power allocation. All of them try to solve an optimization problem, maximizing or minimizing a system parameter, satisfying one or two restrictions. The result is the same for all of them, that is power and bit allocation to the OFDM carriers.

In this study a trial for an in depth comparison of these techniques is made. The algorithms are compared on a "common channel performance" although the starting point is not the same. The paper is structured as follows: In section II the system description is presented, that is the channel attenuation and a noise scenario obtained by measurements. In section III the main loading algorithms are described. The principles and targets of each one are analyzed. The comparative performance evaluation is presented in section IV. Finally some concluding remarks are presented in section V.

II SYSTEM DESCRIPTION

The Power line channel properties are thoroughly examined in several papers in the literature [2] [3] [4]. The transfer function presents deep notches in unpredictable frequency regions. These notches are varying with time because of the topology variations of the channel. Figure 1 is a sample transfer function of a typical Indoor PLC channel. The channel can be by no means considered as a flat one. Carriers at 4 MHz and

12 MHz confront a hostile environment and probably they contribute many errors. Since the channel is dynamic these comments are valid only for a specific time interval. Noise properties are presented in figure 2, where the noise power level for 95% of the noise samples measured in the Laboratory [2] are given. For simplicity in this study the noise is considered to be Gaussian having in every frequency band variance proportional to the power level of the figure.

The applied modulation was of QAM type and with 512 subcarriers. That means a respective number of different AWGN sources were needed, each one dedicated to an OFDM subcarrier. For this specific channel the delay was calculated and found 1.733 μsec. Thus a 30 KHz subcarrier spacing was used.

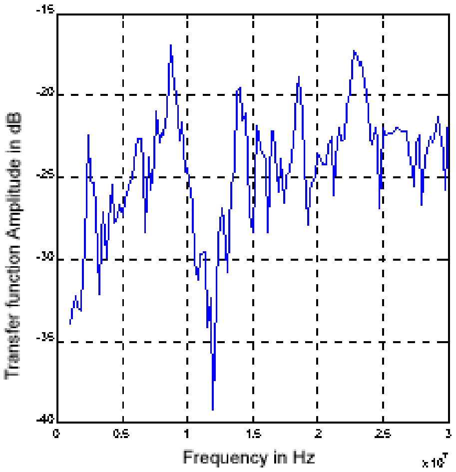

Figure 1. Power line Channel Transfer Function

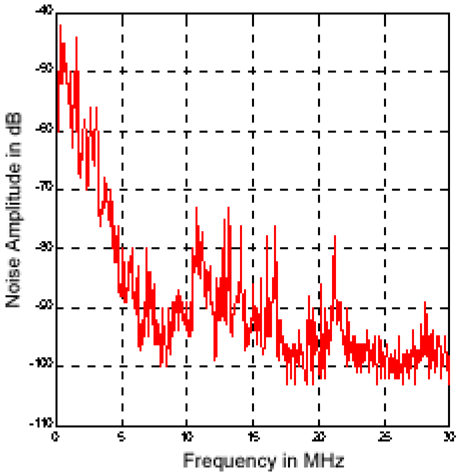

Figure 2. Average Noise Level

III DESCRIPTION OF THE ALGORITHMS

There are three loading algorithms of practical interest. All of them aim to assign power and bits on the OFDM subcarriers for optimizing a function under some constraints. The Hughes-Hartogs algorithm [5] minimizes the total energy transmission under the restriction of a predetermined error probability and total bit rate. It works on a table whose elements are the incremental energies required to transmit one more bit on each subchannel. The columns of the table are the subchannels and the rows are the increasing number of bits. Beginning from the first row of the table (where 0 bits are allocated in each subcarrier) in every algorithm's iteration the next row is searched in order to find the subcarrier that needs the minimum energy to transmit one more bit. This way gradually, bits are allocated, using the lowest possible total energy. The drawback of this algorithm is the high computational effort that is imposed by the extensive sorting of energies. On the other hand when the algorithm converges an integer number of bits are allocated to the different frequency zones. This result does not need to be processed any more and this is very important. If the algorithm resulted in a decimal (that is continues) number of bits in every frequency zone then a second process of bit rounding and moreover energy distribution should be done. Bit round off results in a new power allocation introducing the so called quantization error. This error which is small in general can be sometimes important. This is a strong advantage that Hughes-Hartogs Algorithm presents and some how compansates the extensive sorting disadvantage described above.

Piazzo's algorithm [6] minimizes energy at a predetermined bit error rate (BER) but it needs computational effort. It is an optimized version of Hughes - Hartogs algorithm. Both these algorithms are sharing the same basic idea so they constitute one category of the loading techniques.

Another loading approach introduced in [8] maximizes the total transmitting bit rate for a given probability of error and total transmission energy. This algorithm distributes energy either in a flat manner or using the water filling approach. It uses the noise variance σ_n^2 and channel attenuation $|H_n|^2$ for $n=1,2\ldots,N$ number of subcarriers and compare the product

$$g_n = \Gamma \cdot \sigma_n^2 / |H_n|^2 \qquad (3)$$

with the constant:

$$K = 1/N_{on} \cdot (\varepsilon_{tot} + \Gamma \cdot \sum_{n=1}^{N} \sigma_n^2 / |H_n|^2) \qquad (4)$$

The n's that satisfy the inequality $g_n > K$ are turned off. Finally the $N_{on'}$ remaining subchannels share the total energy either flatly

$$\varepsilon_n = \varepsilon_{tot} / N_{on'} \qquad (5)$$

or according to the waterfilling approach

$$\varepsilon_n = K - \Gamma \cdot g_n \qquad (6)$$

As waterfilling aims to transmit a maximum number of bits per second it can be considered as a maximum rate algorithm. It encounters the issue of bit and energy reallocation as it assigns a non integer number of bits to a frequency subchannel.

Finally Fischer and Huber proposed in [9] a new loading algorithm. Its objective is not to transmit as many bits as possible according to channel capacity but to transmit a predetermined number of bits per second minimizing the probability of bit error. Thus a minimization problem of error probability is solved for QAM constellations with the restrictions that the total energy is constant and the total bit rate is also constant. The optimization problem has as solution the equation:

$$R_i = R_{tot}/M + 1/M \cdot \log\left(\prod_{k=1}^{M} \frac{N_k}{N_i^{\,N}}\right) \qquad (7)$$

where M is the total number of subchannels, R_{total} is the bit rate target and N_i is the noise variance at i_{th} subchannel. For negative R_i we turn off the respective channels. Finally energy is distributed flatly among the remaining subchannels. This algorithm need to perform bit round off as well, because it does not allocate integer number of bits on every carrier. All the above described algorithms are presented in table 1.

IV RESULTS

Since algorithms begin with different assumptions we tried to define a methodology of comparison. In figure 3 there is a comparison of Piazzo's Algorithm and Fischer-Huber's. First we obtained the total minimized energy that Piazzo's algorithm gives for predetermined total bit rate, R_{tot} and bit error probability. Then the minimized total system energy was used as input data into Fischer's Algorithm for the same total bit rate target R_{tot}. The output was the probability of bit error. This output was compared to the probability of error used for Piazzo's algorithm.

Table1

Algorithm	**Hughes-Hartogs & Piazzo**	**Leke-Cioffi**	**Fischer-Huber**
Optimized Function	Minimize Total Energy	Maximize total bit rate	Minimize Prob. of error.
Restrictions	1. Error Prob. stable. 2. Total bit rate stable.	1. Error Prob. stable. 2. Total energy stable	1. Total energy stable 2. Total bit rate stable
Energy Distr.	Not flat	Either Flat or not.	Flat

It was found that Piazzo's performance is better than all the others. Specifically it presents 1 dB and 2 dB better performance compared to Ficher-Huber (F-H) and Leke-Cioffi (L-C) respectively for the higher part of SNR. This occurs because of the bit and power round off analyzed in section III that the F-H and L-C have to do. The round off is necessary because the F-H and L-C results in a non integer number of bits for every OFDM carrier. This round off is equivalent to a small scale reallocation of the bits and the latter introduces a "quantization error" that leads the system to slightly less optimal performance.

Among F-H and L-C, as was expected, there is a clear dominance of F-H since the latter is oriented to minimize the bit error probability.

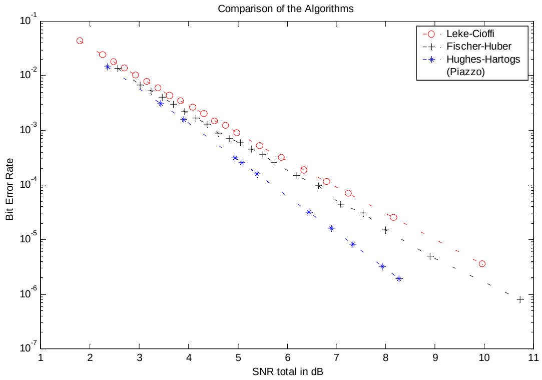

Fig. 3 Pergormance comparison (BER versus SNR) between the Algorithms

Working in a same way, the maximized total bit rate of L-C algorithm for a predetermined bit error probability and total energy S_{tot}, was used as input to the F-H and H-H algorithm for the same total system energy S_{tot},. As shown in figure 4, Leke-Cioffi algorithm presents the same or even better results compared to Fischer's algorithm. Piazzo's (H-H) has the worse behavior of all. The results are sensible since L-C optimizes Bit Rate. On the other hand for Piazzo's (H-H), we can say that this is the cost of being better in the bit error rate comparison diagram. Generally we can observe that increase in the data rate results in increase of the error rate. The question is if

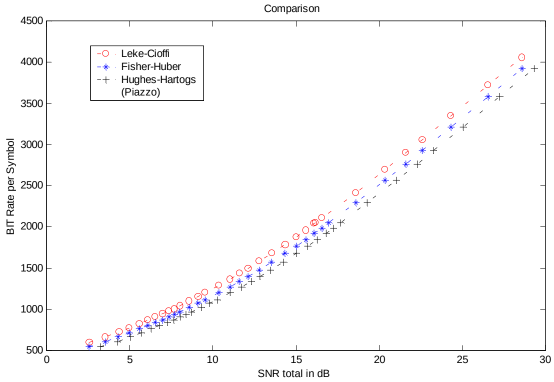

Fig. 4 Performance comparison between Cioffi's and Fischer-Huber's Algorithm

the profit in the data rate figure that L-C algorithm presents is big enough to compensate for the loss in the error rate. Indicatively the 5 dB SNR is chosen and a zoom in it for a detail investigation is made with MATLAB. The bit rate increase is given in table 2 and the bit error rate increase is presented in table 3. These tables give us a measure to evaluate how much improvement is gained by the algorithms. We see that the F-H algorithm transmits 7.5% more bits from H-H at the expense of double error rate and 8.4% less bits than L-C keeping bit error rate 33% lower from the respective error rate that L-C introduces.

Table 2

ALGO	H-H	F-H	L-C
Bits Transm. On Average	665 bits	715 bits	775 bits
Percentage of Increase	7.5% ➔ 8.4%		

Table 3

ALGO	H-H	F-H	L-C
Bit Error Rate	$3\cdot10^{-4}$	$6\cdot10^{-4}$	$9\cdot10^{-4}$
Percentage of Increase	100% ➔ 50%		

V CONCLUSIONS

In this paper a comparative study of the most important loading algorithms is performed. The channel that was chosen was an In house Power Line channel. The channel transfer function and noise power level were obtained from measurements. The algorithms were put on a common platform and compared on the bit and error rate criteria. Concerning the first criterion L-C algorithm has a clear first performance. On the other hand H-H algorithm has better error rate performance.

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