XDSL TECHNIQUES FOR POWER LINE COMMUNICATIONS

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Abstract

In this paper we consider the power line grid from the secondary (low voltage) transformer coil to the subscriber (input of a building). We study the line characteristics and compare them with the known line characteristics of its competitor ADSL scheme as it is a wired alternative for the local loop access. We have also simulated an ADSL modem and run the simulation for the two different media. The comparison includes data rate, BER and transmitting power and proves that power lines need much more energy per transmitting bit under similar circumstances in order to transmit more than 1 Mbps. This increased energy could probably lead to EMC problems and it is towards this direction that study should continue.

1. Introduction

The power line distribution network used for communication purposes has been under study for several years. It can be divided into parts according to the voltage magnitude that it holds. So we have the high voltage, the medium voltage and the low voltage distribution network. The low voltage power line grid has been known as the "last mile access" medium that connects the subscribers of a PLC network with the medium/low voltage transformer where probably the first level nodes of such a communication network will be placed. Because of the fact that telecommunication signals suffer large attenuation when passing through this transformer [1], the latter can be regarded as a physical boundary. The in-house grid has been thoroughly examined [2-4]. The idea of using it for building up local area networks is mature and several modems already exist. There are competitors of these PLC LANs like mobile, ad-hoc, HiperLAN and Bluetooth. However, the studies on the last mile access grid of power lines are not as frequent as the in-house research. A good reason for that seems to be the absence or the low demand for the key application.

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ADSL is a wide spread technique used for communication purposes over wired media. It has been used for the copper lines of the subscribers' network and its parameters could be adapted to the simple last mile grid. From the early ADSL studies the idea of introducing it to the power line grid was examined but not thoroughly. Specifically in [5] it is proposed among other things that ADSL DMT modems can interoperate on the common channels as shown in figure 1. The central office modem can talk to several remote modems simultaneously. In this fashion no in-house rewiring is needed, which makes power lines one of the best candidates to promote this idea.

In this paper we initially try to investigate the power line grid that connects the buildings to the secondary coil of the low voltage transformer. We describe the topology and its characteristics as far as signal attenuation and noise level are concerned. These characteristics are compared with the respective characteristics of a typical last mile grid of the telephone network. Then the idea of using ADSL for PLC is modified and we examine whether an ADSL modem can be used for communication purposes over the PL last mile grid. Communication factors like data rate, mean transmitting power and error rate are compared between the two networks. Finally, some aspects about further work on the subject are presented.

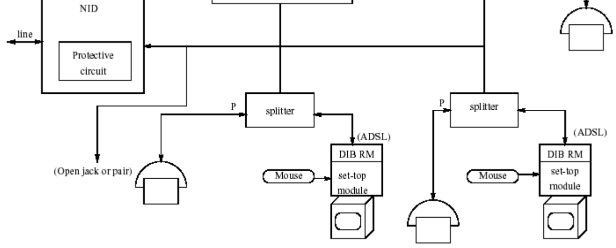

Figure 1. ADSL modems over power lines.

2. Characteristics of ADSL

Asynchronous Digital Subscriber Line is a version of the xDSL family that aims to use copper cables in a more efficient way. Using DMT modulation and increasing the frequency range up to around 1MHz a significant data rate improvement is achieved at the expense of reducing the distance that the telecommunication signal can travel. ADSL can already provide 2 Mbps to distances that range from 4.6 to 5.5 kilometers and 6 or more Mbps to a distance of 2.7-3.7 km. The occupied frequency region runs from 25.875KHz up to 1.104MHz [6]. This region is divided into 256 subcarriers having a 4KHz spacing. The resulting symbol period is 250 μsec and a guard of 32 samples is added. A BER of 10^{-9} can be achieved when typical BER for the xDSL family is 10^{-7}. The carriers are loaded with bits according to the channel behaviour through the frequency range of transmission. So weak carriers carry less bits and strong carriers are loaded with more. In order to ensure these low BERs a margin fluctuating from 6 to 14 dB is left to sustain analogous noise level fluctuations. ADSL cables are vulnerable to impulsive noise so interleaving of several depths (16/32/64) and forward error coding - usually Reed-Solomon coding which specialised on impulsive noise cancellation - is used. Impulsive noise is a main source for errors as it affects bursts of symbols.

A topology of the ADSL local loop is shown in figure 2. This seems to be a point to point connection with good impedance matching at each end. A splitter is vital for upconverting the data to the upper frequency region. The topology of this local loop does not create multiple paths so the transfer function of our channel is expected to be free of notches (fig. 3 and 4). Technically we can find 2 different cable types regarding the dielectric material used. The cable that uses paper for insulation and the one using plastic insulator (usually polyethilenium). The type of insulator greatly affects the level of the signal attenuation which is introduced to the channel. We have plotted the channel attenuation using different cable lengths in the frequency region of interest in figures 3 and 4, for plastic and paper insulator respectively. The attenuation increases exponentially, reaching –90dB at a distance of 6Km.We can easily conclude that the cable type affects the level of attenuation by comparing the two figures.

We can distinguish two different noise scenarios based on whether the copper cable used for ADSL transmission is underground or indoor. The indoor cables present a higher noise level in comparison with the underground ones. The in-house cables within the measured frequency range(1,104 MHz) seem to suffer from background noise which is almost 20dB stronger. Despite this significant difference we have used the noise level defined in [9] to ensure a good test interoperability between the two systems in our study. Figure 5 is indicative.

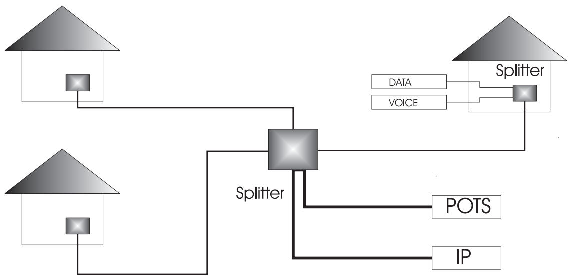

Figure 2. ADSL network

3. Local loop measurements over PLC

Extensive measurements of the in-house power line installation for broadband communications have been presented. In this paper we investigate the last mile and integrate the measurements campaign by measuring outside a building. We focus on the part of the distribution grid that connects buildings to the coil of the low voltage transformer. Figure 6 presents the typical topology of such a network. Measurements took place inside the University campus, specifically on the line which connects the medium/low voltage transformer to the input of the power distribution network of the Faculty of Engineering.

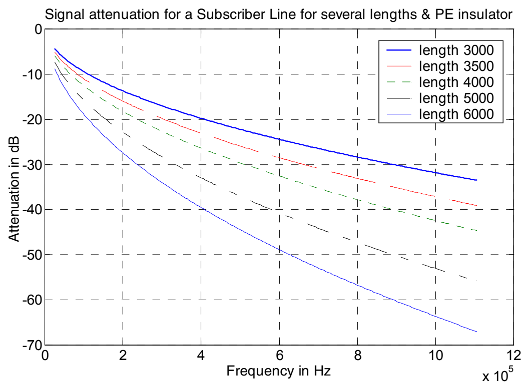

Figure 3. Attenuation level for a subscriber line with PE insulator and several lengths.

The parallel connection of loads of different impedances leads to impedance mismatching at the connection points. These are points of signal reflection. It appears that this topology has many things in common with the in-house grid. The differences arise due the size of the network and the cable types used. The powerline last mile cable

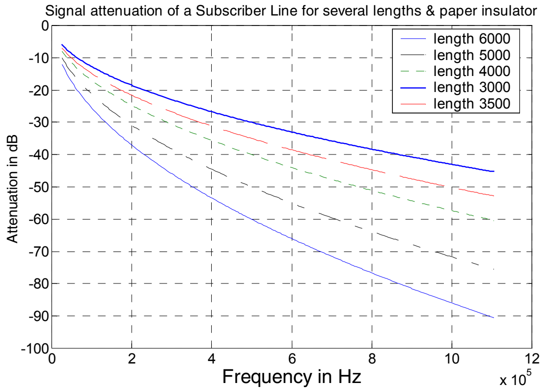

Figure 4. Attenuation level for a subscriber line with paper insulator and several lengths.

section is larger compared to the one inside the house (reducing attenuation) while the cable is longer in size (increasing attenuation). We have to state explicitly that

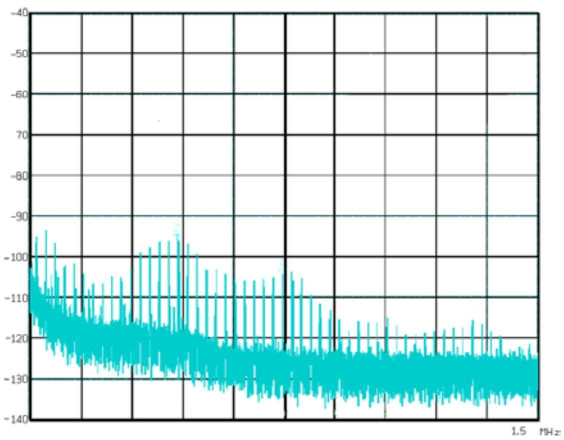

Figure 5. Noise level over ADSL cables in dBm.

the downstream transmission under study refers to data flow from the transformer to the entrance of the building. The noise level is measured near the receiver as it is that noise level which affects our communication scheme. Figure 7 presents the mean noise power level measured near the subscriber. These mean values come from measurements at the same point but at different intervals during the day. It is profound that the noise level depends on time, as in-home noise measurements have already proved.

Please note that the general characteristics of the plot are the same compared to those found from the noise measurements in an apartment [2] or in buildings [3]. For instance, we observe a clear decay as high as 30dB in the first 5 MHz region. This is quite normal since measurements take place near the subscriber where the noise sources are the same with those inside the house. Figure 8 presents the worst and best noise scenario measured, regardless of location and time. The worst level measured seems to be statically rare. This is why we chose two alternative noise scenarios in our simulations, namely the best and mean noise level as shown in figure 8. Finally, figure 9 shows the transfer function amplitude that was measured on power lines. Its general shape seems to be in good agreement with the transfer function usually measured inside a house.

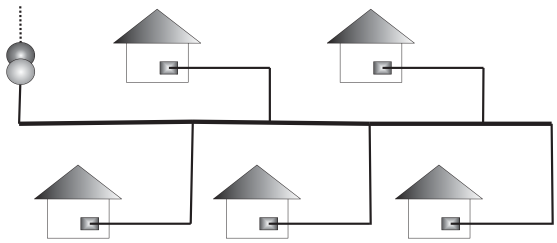

Figure 6. Power Line Local Loop

4. Comparison between the characteristics of the two local loops

The two media seem to have extremely different line characteristics which is primarily explained due to differences between the two topologies. First of all, attenuation of the DSL line increases gradually following an increase of the frequency without showing any sudden drop or rise.

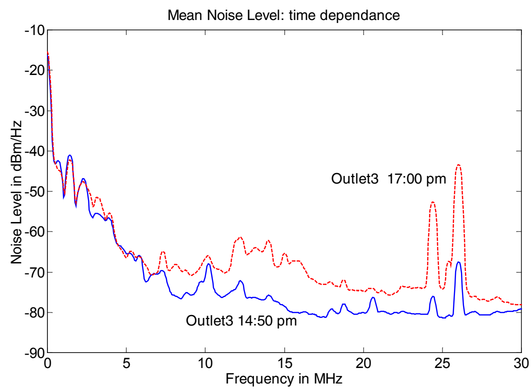

Figure 7. Power Line Noise Measurements: mean noise power at different hours a day.

On the other hand, the PLC local loop presents high level attenuation at unpredictable frequency regions. Deep notches are present due to connected loads leading to multipath propagation. However, note that the noise level between PL and DSL presents so much difference that we can say that this is the main issue which determines the quality of any communication attempt along the two channels. The noise measured in the ADSL loop fluctuates between –135dB up to –110dB whereas the respective noise on the power line loop was found to range between –60 up to –50dB in the frequency band of 5-30MHz. The main reason for that is that noise sources

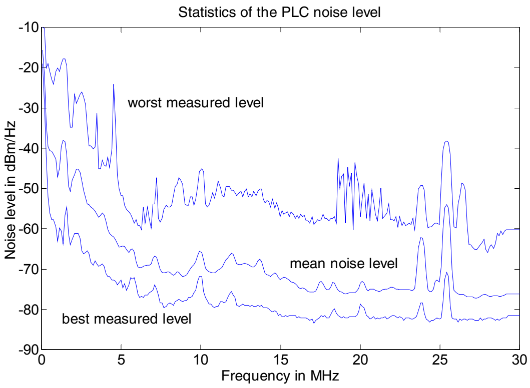

Figure 8. Power Line Noise Measurements: worst and best noise scenario.

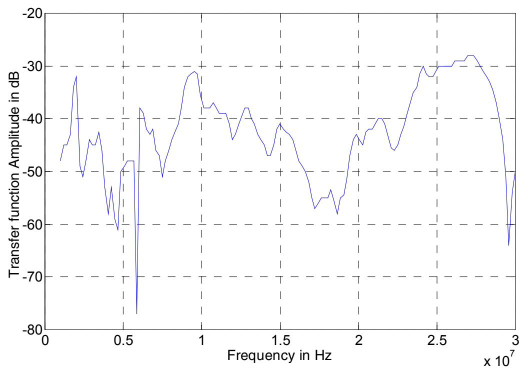

Figure 9. Transfer function amplitude

are connected to the power line grid and their harmonics are directly induced to the line. On the other hand, the noise of the DSL loop is coupled to the circuit as the latter functions like an antenna receiver. In the next paragraph we compare the performance of the two circuits when used for data transmission.

5. ADSL and PL communication performances

We have simulated the features of an ADSL modem and run the simulation using a subscriber line and a power line as the physical medium. The general characteristics of such a modem have been described in a previous paragraph. In [7-8] we can find the regulations that govern such a transmission. For the DSL case we have considered two structures. The first one, which leads to better channel characteristics, uses a cable with a polyethilenium insulator while the other one uses paper for insulation. The loop lengths are 3500m and 6000m respectively. The power line channel was simulated by adding the noise presented in [9]. We imposed a BER less than 10^{-7} and data rates ranging from 2.8Mbps up to 8Mbps. Figure 10 depicts the normalized energy consumption per bit transmission for several transmission data rates for a DSL medium while fig. 11 shows PL local loop results. Both of them present the same general attitude when the data load increases. Apart from that, however, it is obvious that several orders of magnitude extra energy is required in order to preserve the same BER (10^{-7}). Table 1 presents the difference in energy per transmitted bit between the two best and worst cases. The difference is enormous; 43dB and 34dB more energy is needed, respectively, if a DSL modem were to operate over a PL last mile access loop. This tradeoff is required to deal with the extra noise power encountered on a power line.

So if ADSL techniques are going to be used for data transmission over power line local loops we need

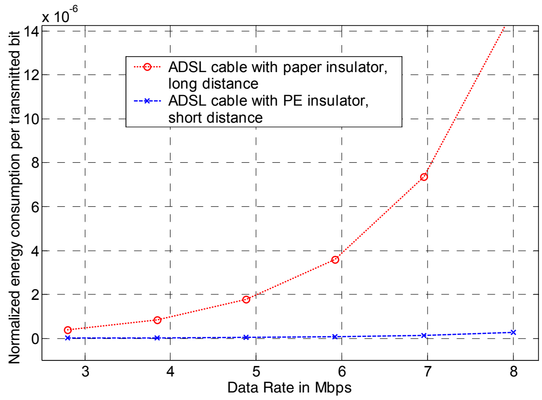

Figure 10. Normalized energy consumption per bit transmission for several transmission data rates ADSL environment.

Table 1.

DATA RATE	700	960	1220	1480	1740	2000
$\Delta E_{b,best-vs-best\ channel}$	42.6	43.4	43.8	44.1	44.2	44.3
$\Delta E_{b,worst-vs-worst\ channel\ \Delta}$	32.6	33.5	34.8	35.3	35.5	35.8

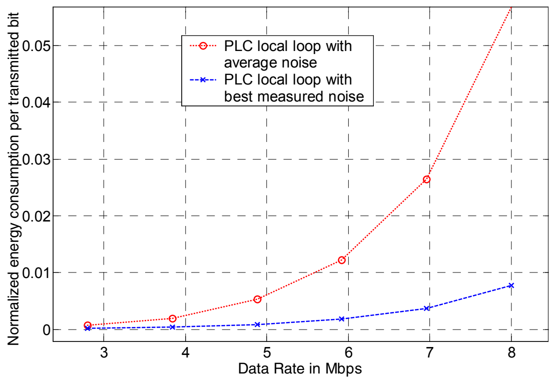

Figure 11. Normalized energy consumption per bit transmission for several transmission data rates over PLC environment.

to make a compromise between the data rates and the quality of our communication scheme (BER). The question is what level of transmitting power is acceptable in such a scheme.

Another important characteristic that has to be examined is the transmitting power of our scheme over the aforementioned frequency zones. The ADSL recommendations suggest a frequency range occupation up to 1.104MHz. Power lines occupy a larger region up to 30MHz. Figures 12 and 13 illustrate the transmitted energy per carrier over ADSL and PLC respectively. In order to bring both schemes close as far as the order of magnitude is concerned we have used different communication qualities. The high frequency emission in conjunction with the high levels of energy will probably cause electromagnetic compatibility problems to radio stations operating in the SW region.

6. Further work

This study considers the power line grid from the low voltage coil of the transformer to the subscriber for the first time and examines the telecommunication performance that an ADSL modem would have.

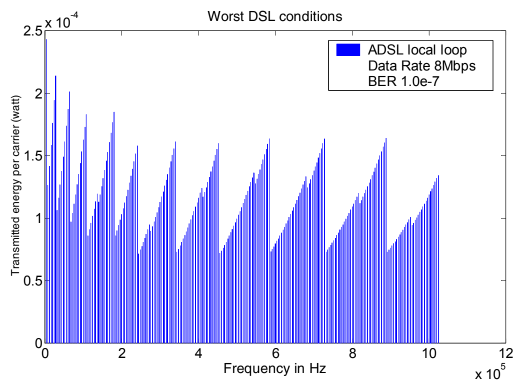

Figure 12. Transmitted energy per carrier over ADSL.

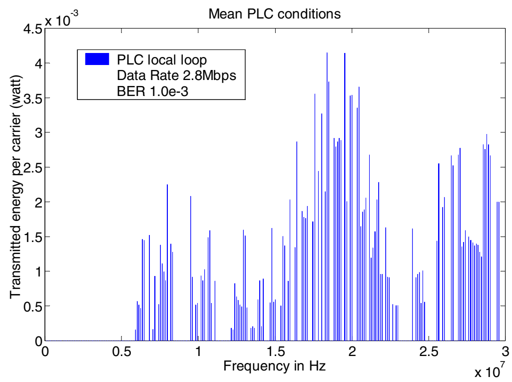

Figure 13. Transmitted energy per carrier over PLC.

The results reveal two main issues. The first one is that the power line local loop cannot compete with already existing local loops (ADSL) by using similar features in our investigation. Moreover, EMC problems seem to arise. Further work on EMC will determine whether power lines can be used as a competitive medium for broadband data transmission. Simultaneously, coding and modulation schemes specifically designed for powerline communications need to be researched. Features like QAM constellation size, noise margin, impulsive noise cancellers, guard time, and convolutional coding constraint length have to be examined and adapted in order to produce better results. Also, bit error rate and bit rate requirements have to be reconsidered.

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