

The Impact of Broadband PLC Over VDSL2 Inside The Home Environment

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Abstract- The availability of in-home broadband services is not monopolized by a specific technology, but different technologies are currently available and used to deliver high speed data to the customers. This is plausible because the market did not favor a specific broadband technology over others, although wireless routers have been deployed most the last years. Nevertheless, powerline communications in house lately gained in importance, since this technology is easy to set-up and performs reasonably well under certain conditions, which will be treated in this paper. Hence, it would be common to find two or more broadband technologies operating in proximity of each other or at the same place. A concern has been raised lately by some service providers about the co-existence of different technologies, and the possible opposing effects of one technology over others and vice-versa. In this paper, we discuss the co-existence between in-home broadband technologies focusing on Broadband Power Line (BPL) and x-Digital Subscriber Line (xDSL), mainly on VDSL2.

I Introduction

Now-a-days a majority of broadband services is delivered by the ordinary telephone lines using xDSL technology. With the increasing penetration of powerline communications (PLC) and Broadband Power Line (BPL), which is a technology that uses the ordinary power lines to deliver high data rates, the possibility of using the two different technologies in the same place is questionable. Especially in the in-home environment where potential customers are present, the two networks (the power and telephone) can exist in proximity and sometimes are in the same duct. At the beginning, it has been perceived that the interference between the two networks is of the same order as the crosstalk between two close telephone lines (the capacitive and inductive cross-talk), and can be avoided by separating the two lines by few centimeters. But, recent studies showed that this interference is much stronger than it has been perceived and can't be avoided easily [1]. The power distribution network is designed to transport electrical power at low frequency (50 Hz in many countries or at 60 Hz in other parts of the world), and not designed to carry high speed data. Hence, in using the power network to transport high speed data, it will produce unintentional radio frequency emissions that may adversely cause high interferences in a wider frequency range than their own bandwidth (due to frequency harmonics and the statistical properties of noise like interference). Furthermore, even though the xDSL technology uses dedicated transmission lines that have a low and predictable level of radiated emission, these lines were designed to transport voice utilizing the lower-frequency band (4 kHz and below), and not designed to transport high data rates. Thus, unintentional radio frequency emissions are expected also to be generated by xDSL. However, the telephone network, from communication point of view, is much better than the power distribution network, and the influence of BPL on xDSL is much stronger than the influence of xDSL on BPL, since the radio emission generated by BPL is much stronger than the one generated by xDSL [1]. In this paper, the focus will be on the interference generated by BPL systems and its possible impact on the existing xDSL systems.

II Interference between BPL-systems and telephone lines

The radio emission generated by BPL and measured on the neighboring telephone lines is higher than the normal cross-talk between two conductors due to the common-mode currents that can be easily generated in BPL systems, which makes that the power cables act as antennas when used to carry high frequency signals. Especially, this will be the case for frequencies and cable lengths that can meet the quarter of the wavelength. Common-mode

Table 1: The effect of the dielectric properties of the insulation on the effective length of the antenna

The used cable length [m]	The resonance frequency [MHz]	The effective length of the antenna [m]	The ratio between the actual cable length and the effective length of the antenna
5	22.4	3.4	1.4706
8	13.1	5.7	1.4035
9	11.41	6.57	1.3699
22	4.755	15.75	1.3968

currents originate from cable unbalance and from the small capacitances that can be formed between the electrical promises and the earth. Common-mode current’s magnitude is difficult to predict, but it has been shown in the previous section that very small currents can produce considerable emissions. To estimate the amount of coupling between BPL and telephone line, the coupling factor a_k has been calculated between the interference source U_S generated by the BPL system and the interfering signal U_I measured on the telephone line using the basic laws of field theory as stated in equation 1.

$$a_k = 20 \times \log_{10}\left(\frac{U_I}{U_S}\right) \quad (1)$$

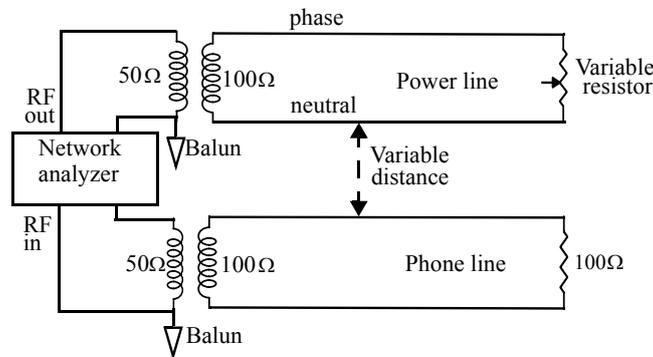


Figure 1: The physical measurement setup used to measure the crosstalk between the power and telephone lines

The interfering signal U_I was measured using the measurement setup shown in figure 1. The measurements were conducted using balanced connections to inject the signals into the power cable and to measure the signals picked up by the telephone line. The connections were balanced using impedance-matching baluns. The telephone line end is matched to 100 Ohm. In real life, the impedance attached to the power line is time variant and depends on the connected equipments. In the measurement set-up the load on the power line was varied using a range of values.

A. Measurements and results

The measurement setup shown in figure 1 was used to measure the interference picked up by a telephone line which resides in the proximity of a power line used to transport BPL signals. The obtained results show a significant increase when the frequency increases towards the frequency corresponding to the quarter wavelength. This result supports the theoretical assumptions that in the MHz-region the dominant interference is caused by the electromagnetic radiation. Although in realistic installations the length of cables is not likely to meet the quarter wave length, since the power lines are all connected inside the home in addition to their connection with the public electricity network, sub-sections of the cabling may meet the resonance requirement. Such a sub-section of the power line network may be caused by branches, impedance discontinuities, bends, transformers or other devices. For a velocity of propagation of approximately $2 \times 10^8 m/s$, the resonance frequency yields 22.24 MHz for a 3.4 m cable. The measurements showed that this resonance frequency corresponds a cable length of 5 m. Thus, the effective length of the antenna is reduced due to the dielectric properties of the insulation of the power line. Table 1 shows the used cable lengths in the measurements, the measured resonance frequency, the effective length of the antenna that correspond to the resonance frequency and the ratio between the actual cable length and the effective length of the antenna. The resonance frequencies correspond reasonably well with the regions where a steep increase in interference is observed (Figure 2).

To simulate realistic scenarios and to avoid having quarter wave antennas, long cables (longer than 10m) were used with a separation distance of about 1.5 m, and a new measurement campaign was conducted. The interference is depicted in figure 3. At frequencies up to about 2 MHz, the interference was almost of the same level as the

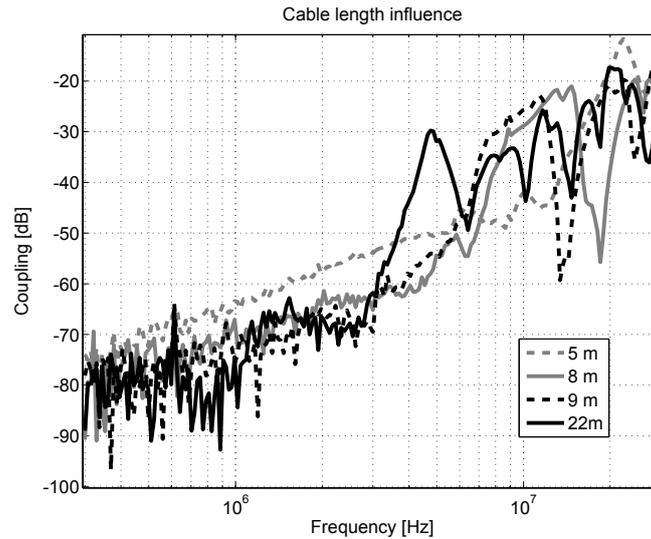


Figure 2: The influence of power line length

background noise. At this frequency range, the dominating field is the conducting one and almost no radiation can be noticed. At higher frequencies (more than 2 MHz) the interference starts to increase with a slope of about 80 dB/decade up to a certain cut-off frequency (about 10 MHz in figure 3), and then it stays almost constant; i.e, the radiated field starts to increase linearly with the frequency up to a certain value (saturation value) and then the envelop stays constant. At this frequency value, the radiation efficiency of the wires reaches its optimum. The cut-off frequency value depends on the radiating cables length and dielectric properties of the insulation used materials. In this saturation region, peaks and valleys can be seen due to the constructive or destructive effect of the standing waves.

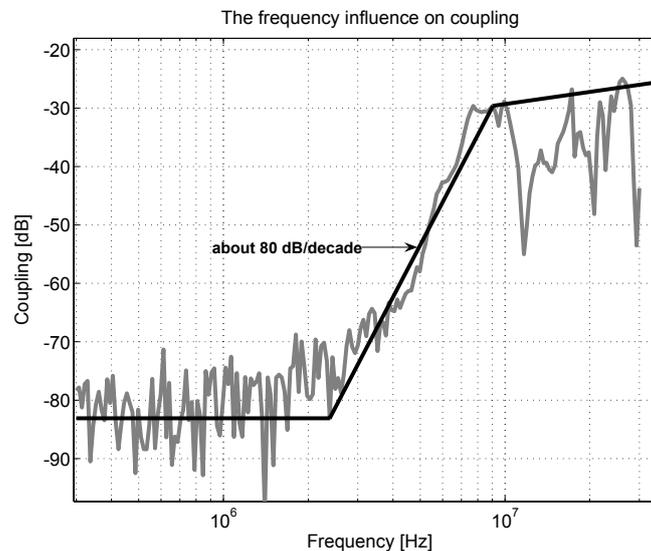


Figure 3: The influence of the frequency

B. Reducing the interference between BPL and telephone lines

The results of the electrical measurements show that high interference levels are present for the considered scenarios. Because the analog front end of the BPL and DSL modems may have different characteristics regarding the common-mode rejection, these results cannot be straightforwardly translated in effects on modem operations and performance. Nevertheless, it has to be taken into account that in the considered scenarios BPL devices may degrade the performance of DSL lines.

To reduce the interference between BPL and the telephone line, the effects of radiated fields have to be minimized. This can be done by suppressing or reducing the levels of the common-mode currents, either on the

power line or on the DSL line or both. Suppressing common-mode currents is a viable option as these currents are not necessary for proper device operations. For DSL, such filters are readily available at low cost in the form of radio frequent interference filters that can be placed in series with the telephone loop. The use of suppression elements also called *common-mode choke* proves to be an effective and rather simple solution. Using such a device on the telephone line reduces significantly the interference by 20 to 30 dB as shown in figure 4. This figure shows the worst case scenario in which the power line and telephone line are located in the nearest vicinity (0 cm distance). Placing a common-mode choke on the power line as well reduces the interference levels further by 10-15 dB as shown in figure 4.

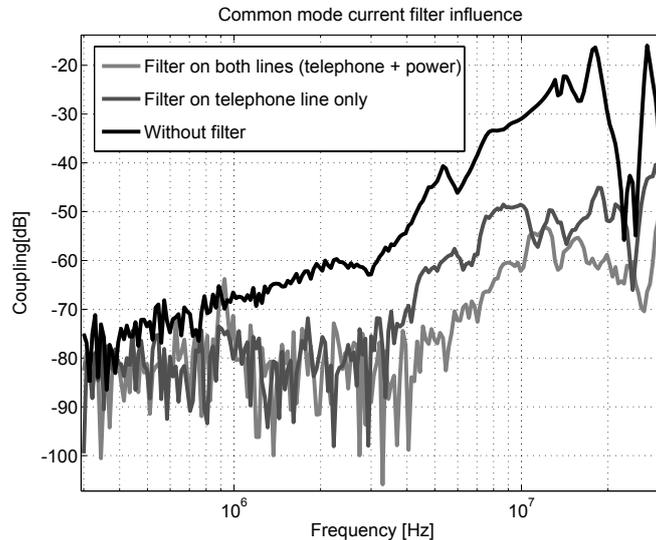


Figure 4: A common-mode choke filter effectively reduces the interference between power lines and telephone lines

III BPL influence on VDSL2 performance

The use of BPL is expected to affect mostly the VDSL because the two technologies share the same frequency range. For the sake of efficiency (VDSL efficient), the power spectral density (PSD) is enhanced by choosing one of two operation modes:

1. V-ON: The option of V-ON corresponds to operation of VDSL in mode for maximum reach and speed, with consequent maximum (and presumed acceptable when V-ON is selected) emissions. Table 2 summarizes the important frequencies and PSD levels of the mask.
2. V-OFF: V-OFF corresponds to no PSD enhancement and is applicable to situations where emissions are of prime concern. V-OFF can only be used with the ADSL-compatible option A-ON. In this case, the PSD limit is -60 dBm/Hz from 1.104 MHz to 20 MHz and decays linearly on a logarithmic scale in dB reaching -120 dBm/Hz at 30 MHz.

The typical BPL transmit PSD is assumed to be flat with a value of -60 dBm/Hz, with notches in the excluded frequency bands. However, BPL transmit PSD levels up to -50 dBm/Hz were reported by the National Association for Amateur Radio (ARRL)[2].

To measure the influence of BPL emissions on VDSL, the V-ON mode was considered (because it performs better than V-OFF mode), and three PSD values were chosen for the BPL system. The performance of VDSL system is measured by counting the number of error frames and calculating its ratio to the total number of frames. The results are depicted in table 3. The results show that using flat BPL transmit levels of -80 dBm/Hz or lower appears to be sufficient to avoid impacting VDSL up to 20 MHz. Using -60 dBm/Hz does not affect VDSL up to 14 MHz, and -50 dBm/Hz up to 3.5 MHz. However, using the *common-mode choke* filter described in section II which is a viable solution as it is commercially available, will improve potentially the VDSL performance since the impact of BPL on VDSL can be avoided completely in all frequency ranges (up to 30 MHz) if -80 dBm/Hz PSD is used for BPL. For the rest of the PSD values (-60 dBm/Hz and -50 dBm/Hz) the impact can be avoided up to 20 MHz.

The VDSL performance was measured using the PSD values provided in table 2. These values could be slightly changed depending on the used VDSL profile. In some profiles the PSD value for the range 20 to 30 MHz was

Table 2: Stepped PSD mask for V-ON

Low Freq.[MHz]	High Freq.[MHz]	PSD limit (dBm/Hz)
0.0	0.3	-90
0.3	1.104	-51
1.104	3.5	-51
3.5	7.0	-54
7.0	14.0	-57
14.0	20.0	-60
20.0	30.0	-90
30.0	-	-120

Table 3: The influence of BPL emissions on VDSL. The percentage of error frames to the total number of frames is provided for each frequency interval and BPL PSD value

Frequency [MHz]		Error Frames Percentage [%]. Measured for three different values of the BPL PSD mask		
Low freq.	High freq.	-50 dBm/Hz	-60 dBm/Hz	-80 dBm/Hz
0.0	0.3	0	0	0
0.3	1.104	0	0	0
1.104	3.5	0	0	0
3.5	7.0	85.3	0	0
7.0	14.0	99.6	2.86	0
14.0	20.0	99.6	99.6	0
20.0	30.0	99.6	99.6	99.6

defined as -56.5 dBm/Hz. For values in this range (-60 dBm/Hz), the impact on VDSL can be completely avoided using the mentioned filter and with a BPL PSD of up to -50 dBm/Hz.

IV Conclusions

This paper has addressed BPL emissions and their influence on telephone lines used as digital subscribers to access networks. The obtained results show that in MHz-region, the dominating interference is generated by the radiated field of the common-mode current. Historically, the radiation region is considered to be above 30 MHz, but this assumption seemed not valid in our case where the contribution of radiation, obviously, started at about 2 MHz and reached its maximum at a saturation frequency of about 10 MHz. This saturation frequency can be affected by line lengths, coupling geometry, load impedance, the position of the transmitter and the receiver, etc. The fact of having strong radiated fields has raised concerns about the performance of xDSL services (mainly VDSL2) in presence of BPL in their proximity. However, the measurements showed that the impact of BPL on VDSL can be avoided by using a common-mode current filter. The overall results can be summarized as follows:

1. The conducting field interference between BPL and VDSL is not that strong as would generally be perceived, but the radiated field has pushed the interference to higher values than expected.
2. This interference has a strong impact on the neighboring VDSL systems.
3. This impact can be avoided by using PSD values not larger than -80 dBm/Hz for BPL transmission.

We have demonstrated that the commercial *common-mode choke* filters significantly reduce the interference between power lines and telephone lines. In case of using high PSDs (up to -50 dBm/Hz), connecting a common-mode choke filter to the line with the VDSL modem will do the job and the impact of BPL will be avoided.

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