Performance Measurements on Power Line Carrier Data Transmissions in Indoor Office Environments

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14th December 2005

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Abstract

Communications over power lines where initially developed to provide voice and data transmissions for electric utilities. At that time a speed of several hundreds of bits per seconds was sufficient. Technology improvements made possible speeds of tens of megabits per seconds or more over the low voltage residential power lines. Despite the large debate over the regulation issues on the electromagnetic emissions of PLC devices, many electric utility companies continue to make field tests in order to offer their clients more services on the same network and to penetrate the market of high-speed data communications. The performances of PLC transmissions are affected by many factors, such as electric network topology, consumer distribution and the nature of the consumers. In this article we make an in-depth analysis of the problems related to data communications using the low voltage residential power lines and present a series of performance measurements made in real filed topologies using commercial equipments.
Keywords: *communications, power, line, coupling, speed, data, transmission.*

1 Introduction

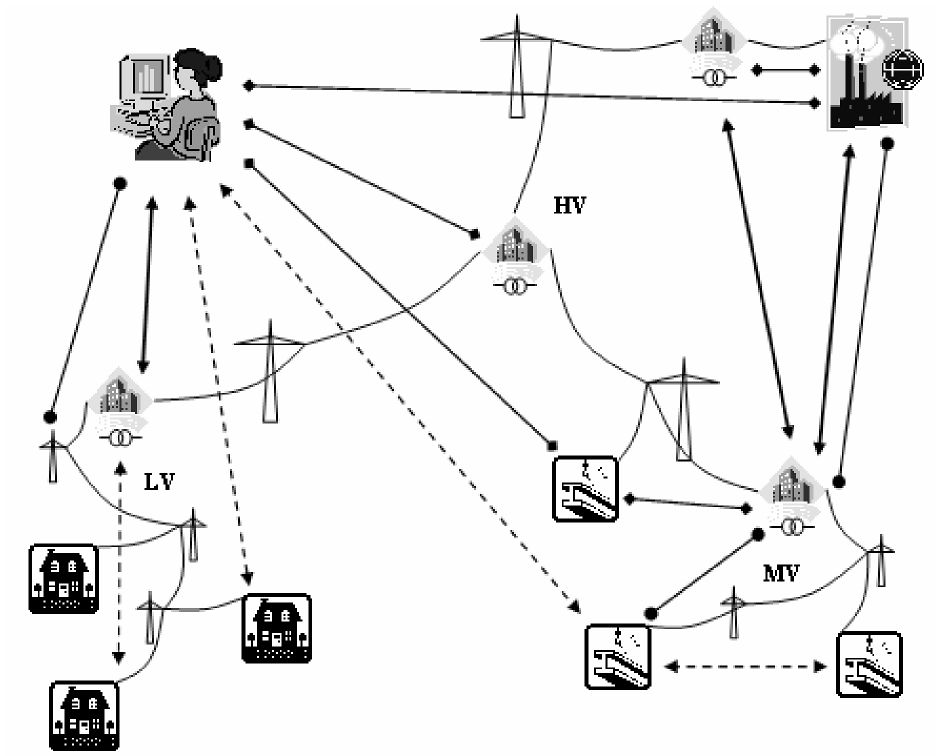
Power line communications is an old transmission technology, developed to assure voice and low speed data communications for energy transport and distribution companies. The deregulation of the energy market forced the power utilities to explore new markets to find business opportunities. The research has initially been focused on providing services related to power distribution such as load control, meter reading, tariff control, real-time billing, remote control and smart home appliances. These services would open up new markets for the power utilities. The moderate demands in terms of data volume per time unit of these applications make it easier to obtain reliable communication. Firstly, the information bit rate is low; secondly, they do not require real-time performance. On the contrary to power related applications, computer network communications require high bit rates and, in many cases, real-time responses are mandatory (such as video on demand and pay-TV). During the last decade the use of Internet has increased and also the timing restrictions of web applications. This complicates the design of the communication system but has been the focus of many researchers during the last years. If it would be possible to supply this kind of network communication over the low voltage power-line, the utilities could also become communication providers, on a rapidly developing market. Systems under trial exist today under tests in many countries and claim a bit rate of more than 40 Mbps, but most commercially available systems use a low bit rates, about 100-768 kbps, and provides low-speed demanding services such as automatic meter reading. Due to the lack of regulation in this field a standard in this field is not broadly accepted [1].

2 Data transmission over power lines

Data communications over power lines are widely used in electric energy companies. A diagram showing today communication paths used by a large power distribution company is shown in Figure 1. Most of the links are over leased line and low speed PLC. Communications links between the dispatcher and the medium voltage automation are only in part satisfied by an old radio low speed 9600 bps communication network. Leased lines in this field are not an alternative due to highly cost of the solution. Long distance high-speed communications are assured by leased radio links on 3.5GHz. There are no links and no information transfer between the dispatcher and the residential customers.

Voice transmissions are assured by public or private phone companies via fixed or mobile terminals. Due to tariff policies, the long distance costs associated to voice call are much lower on mobile networks than on fixed ones.

Applications like Automatic Meter Reading are assured by GSM modems integrated in a national network closed user group. Again, the associated costs of this type of transmission are prohibitive. Fiber optic cables are to be installed on the high voltage transmission power network, will assure the communications needs for power system regulatory center, voice and data transmission for power stations. In this architecture the customer is not part of the project [1,2].



	Power plant	(H, M, L)V	**H**igh, **M**edium, **L**ow **V**oltage Power Distribution Network
	Dispatcher		Leased Line
	Substation		Radio link
	Industrial consumer		Low Speed PLC
	Residential consumer		Without Communication

Figure 1: Power distribution network topology from producers to end users and the associated data transmission network, without low-voltage PLC

Despite the progresses in implementing power line communications there are some difficulties associated to this type of transmission: attenuation varies with time, place and frequency; network configuration often changes because of switching loads; ordinary modulation cannot be used due to multiple propagation paths; lack of shielding as wires acts as antennas; due to EMC, the transmission level cannot be increased.

Country	**Region**	**Technology**	**Speed (Mbps)**	**Users**	**Services**
Spain	Saragossa	Ascom DS2	2 ... 12	3000	Internet VoIP
	Barcelona	Ascom	2 ... 3	25	Internet VoIP
	Seville	DS2	6 ... 12	25	Internet VoIP
Germany	Mannheim	Ascom	2 ... 3	2800	Internet VoIP
Austria	Innsbruck	n/a	1 ... 2	10 ... 25	Internet
	Vienna	n/a	1 ... 2	n/a	Internet VoIP
	Axams	n/a	2 ... 3	50 ... 100	Internet

Table 1: Electric energy utilities providing PLC access to customers

Power line communications have some advantages over other transmission medium: it is the most pervasive medium with multiple outlets in every room in the house; it is available worldwide and easy to adopt by customers, with the minimum cost; very easy to install; offer high-speed connectivity at Ethernet-class data rates.
Implementing such a system, the electricity companies may assure to the end customers many services, like: broadband Internet, internet telephony, automatic meter reading, video on demand, alarm monitoring, smart appliances.

Supplementary services are assured for the utility company too: intelligent demand side management, load switching and balancing, fault location, peak saving, power quality monitoring, real-time pricing. Many utility companies where interested by this new technology, some of them have implemented test networks in 2001 - Table [1].

Important developments where made by semiconductor companies from all continents [3]. The most significant technical data of these networks that utilizes the PLC system to transmit data over power lines are presented in Table [2].

PLC Semiconductor producers	Speed (Mbps)	Physical Layer	Frequency Band (MHz)
Ascom	3.0	OFDM/GMSK	15.0 ... 25.0
Cogency	14	OFDM/DQPSK	4.5 ... 21.0
DS2	45	OFDM/DQPSK	1.0 ... 38.0
Inari	12	OFDM	2.5 ... 18.0
Intellon	14	OFDM/DQPSK	4.3 ... 20.9
ITRAN	24	DS/SS	4.0 ... 20.0
nSine	10	OOK/GFSK	8.0 ... 32.0
Primenet	24	DS/SS	4.0 ... 20.0
Siemens	1.2	OFDM	1.0 ... 5.0

Table 2: The main producers of PLC integrated circuits

3 Field measurement results

We made some tests using two commercial PLC to Ethernet Bridge adapters - Allnet ALL1682. These devices are able to communicate over low voltage residential network at a speed of 14Mbits per seconds at a maximum distance of 200 meters. The modulation used is OFDM and the security of the transmission is assured by using a 56-bit DES encryption algorithm. The low voltage network topology used is shown below:

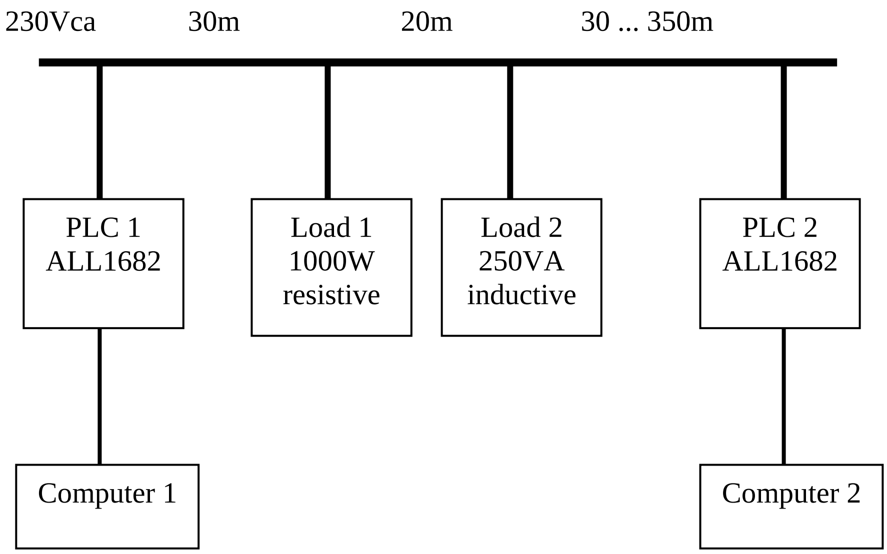


Figure 2: Low voltage power distribution network used for testing

As shown in Figure 2 we used a low voltage energy distribution network situated in a real working environment. There where two controllable loads on this network, one with resistive impedance and a power of 1000 W, placed on 10 meters from the first device and an other, with a highly inductive impedance and a power of 250VA, placed at 20 meters form Load 1. As we may see, the second PLC devices could be placed at a distance of 30 to almost 300 meters from Load 2.
We made all measurement using a network traffic monitor to display the communication speed between the two computers and we made a series of tests using the ping command line utility for Windows 2000.

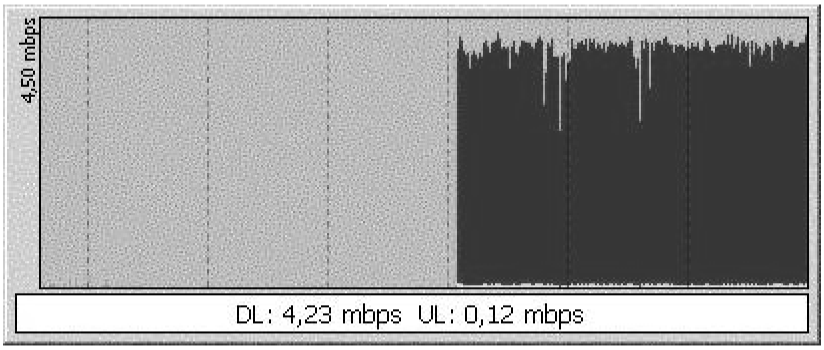


Figure 3: Data speed measured for a distance of 50m between the two PLC devices

In the first case we use a distance of 50 meters between PLC1 and PLC2 with no other load connected (all consumers in the building where disconnected during the holiday). We made some large file transfers (more than 1Gbyte per file). As we may see in Figure [3] the maximum speed obtained was around 4 Mbps (despite the 14 Mbps in the specifications - the link quality was excellent but some data packets are used to continually test the link status and for error detection algorithms). There where a small number of lost packets, only a packet from about 400 packets sent:

Reply from 192.168.100.103 : bytes=32 time=16ms TTL=62
Reply from 192.168.100.103 : bytes=32 time<10ms TTL=62
Reply from 192.168.100.103 : bytes=32 time=15ms TTL=62
Reply from 192.168.100.103 : bytes=32 time<10ms TTL=62

Ping statistics for 192.168.100.103 :
Packets: Sent = 393, Received = 392, Lost = 1 (0% loss),
Approximate round trip times in milli-seconds:
Minimum = 0ms, Maximum = 23ms, Average = 6ms

In the seconds case we measured the link speed by using both loads connected to the power supply network and a distance of 350 meters (more than the 200 meters from the specifications). The same tests where performed, using the same programs and the same files. The speed of the transfer is shown in Figure [4]:

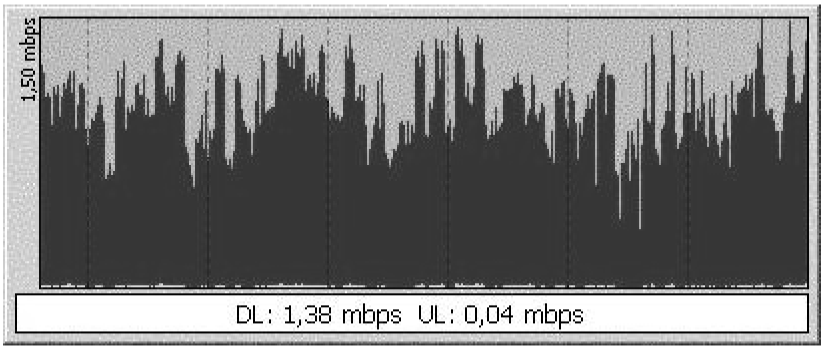


Figure 4: Data speed measured for a distance of 350m between the two PLC devices

The maximum transfer speed obtained was 1.38Mbps and there where periods of time when the link between the PLC devices was lost. The mean Round Trip Time was 124 milliseconds and there where 4 percent of lost packets.
The results from the ping command are:

Reply from 192.168.100.103 : bytes=32 time=126ms TTL=62
Reply from 192.168.100.103 : bytes=32 time=18ms TTL=62
Reply from 192.168.100.103 : bytes=32 time=156ms TTL=62
Reply from 192.168.100.103 : bytes=32 time=118ms TTL=62

Ping statistics for 192.168.100.103 :
Packets: Sent = 1567, Received = 1504, Lost = 63 (4% loss),
Approximate round trip times in milli-seconds:
Minimum = 0ms, Maximum = 328ms, Average = 124ms

We made some tests by disconnecting and connecting Load 1 and Load 2 from the supply during the file transfer. The effects for the transfer where catastrophic, as the network link was lost, even in the short distance test.

4 Conclusions

Tests with Power line Communication have been carried out in around 25 countries, where the system has been installed in approximately 30000 residences.

The mapping of results has been extremely positive, and forecasts a great demand for the system. The market for communication devices integrating home networking technologies is estimated at more than $ 3 billion in 2005.

Digital Power line technology is definitely an exciting alternative to connecting to the Internet via phone and modem. An investment in power line technology will make the power utility companies a high bandwidth carrier, providing data, voice, and video transmission. The electrical utility companies will be able to provide a direct route for high-speed broadband communications directly to the home or office of their customers. Their lines are already entering every house and office building.

These same companies have plenty of expertise in running and maintaining distribution cables and systems. Long distance service can be provided over the existing power transmission lines, by integrating and the optical fiber cables that many communications companies already have in place, with the power grid. It is sure that by integration of power line and fiber optic line technologies the electrical companies could challenge the local telephone companies in a few years and win.

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