Power line communication

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Power line communication or **power line carrier** (**PLC**), also known as **Power line Digital Subscriber Line** (**PDSL**), **mains communication**, **power line telecom** (**PLT**), or **power line networking** (**PLN**), is a system for carrying data on a conductor also used for electric power transmission. **Broadband over Power Lines** (**BPL**) uses PLC by sending and receiving information bearing signals over power lines to provide access to the Internet.

Electrical power is transmitted over high voltage transmission lines, distributed over medium voltage, and used inside buildings at lower voltages. Powerline communications can be applied at each stage. Most PLC technologies limit themselves to one set of wires (for example, premises wiring), but some can cross between two levels (for example, both the distribution network and premises wiring).

All power line communications systems operate by impressing a modulated carrier signal on the wiring system. Different types of powerline communications use different frequency bands, depending on the signal transmission characteristics of the power wiring used. Since the power wiring system was originally intended for transmission of AC power, the power wire circuits have only a limited ability to carry higher frequencies. The propagation problem is a limiting factor for each type of power line communications.

Data rates over a power line communication system vary widely. Low-frequency (about 100-200 kHz) carriers impressed on high-voltage transmission lines may carry one or two analog voice circuits, or telemetry and control circuits with an equivalent data rate of a few hundred bits per second; however, these circuits may be many miles long. Higher data rates generally imply shorter ranges; a local area network operating at millions of bits per second may only cover one floor of an office building, but eliminates installation of dedicated network cabling.

Contents

High-frequency communication (≥MHz)

High frequency communication may (re)use large portions of the radio spectrum for communication, or may use select (narrow) band(s), depending on the technology.

Home networking (broadband)

Power line communications can also be used to interconnect home computers, peripherals or other networked consumer peripherals. Proprietary specifications for power line home networking have been developed by a number of different companies within the framework of the HomePlug Powerline Alliance, the Universal Powerline Association and the HD-PLC Alliance.

On December 12 2008, the ITU-T adopted Recommendation G.hn/G.9960 as the first worldwide standard for high-speed powerline communications[1]. G.hn also specifies communications over phonelines and coaxial wiring.

A few days later, on December 19 2008, IEEE P1901 confirmed[2] the baseline text for another standard for high-speed powerline communications, which includes both in-home and access applications. Although IEEE P1901 specifies multiple non-interoperable PHY and MAC options[3], it provides mechanisms for coexistence between them[4].

Internet access (broadband over powerlines)

Broadband over power lines (BPL), also known as power-line Internet or powerband, is the use of PLC technology to provide broadband Internet access through ordinary power lines. A computer (or any other device) would need only to plug a BPL "modem" into any outlet in an equipped building to have high-speed Internet access. International Broadband Electric Communications or IBEC and other companies currently offer BPL service to several electric cooperatives.

BPL may offer benefits over regular cable or DSL connections: the extensive infrastructure already available appears to allow people in remote locations to access the Internet with relatively little equipment investment by the utility. Also, such ubiquitous availability would make it much easier for other electronics, such as televisions or sound systems, to hook up.

But variations in the physical characteristics of the electricity network and the current lack of IEEE standards mean that provisioning of the service is far from being a standard, repeatable process. And, the amount of bandwidth a BPL system can provide compared to cable and wireless is in question. The prospect of BPL could motivate DSL and cable operators to more quickly serve rural communities. [5]

PLC modems transmit in medium and high frequency (1.6 to 80 MHz electric carrier). The asymmetric speed in the modem is generally from 256 kbit/s to 2.7 Mbit/s. In the repeater situated in the meter room the speed is up to 45 Mbit/s and can be connected to 256 PLC modems. In the medium voltage stations, the speed from the head ends to the Internet is up to 135 Mbit/s. To connect to the Internet, utilities can use optical fiber backbone or wireless link.

The system has a number of issues. The primary one is that power lines are inherently a very noisy environment. Every time a device turns on or off, it introduces a pop or click into the line. Energy-saving devices often introduce noisy harmonics into the line. The system must be designed to deal with these natural signaling disruptions and work around them.

Broadband over power lines has developed faster in Europe than in the United States due to a historical difference in power system design philosophies. Power distribution uses step-down transformers to reduce the voltage for use by customers. But BPL signals cannot readily pass through transformers, as their high inductance makes them act as low-pass filters, blocking high-frequency signals. So, repeaters must be attached to the transformers. In the U.S., it is common for a small transformer hung from a utility pole to service a single house or a small number of houses. In Europe, it is more common for a somewhat larger transformer to service 10 or 100 houses. For delivering power to customers, this difference in design makes little difference for power distribution. But for delivering BPL over the power grid in a typical U.S. city requires an order of magnitude more repeaters than in a comparable European city. On the other hand, since bandwidth to the transformer is limited, this can increase the speed at which each household can connect, due to fewer people sharing the same line. One possible solution is to use BPL as the backhaul for wireless communications, for instance by hanging Wi-Fi access points or cellphone base stations on utility poles, thus allowing end-users within a certain range to connect with equipment they already have. In the near future, BPL may also be used as a backhaul for WiMAX networks.

The second major issue is signal strength and operating frequency. The system is expected to use frequencies of 10 to 30 MHz, which has been used for many decades by amateur radio operators, as well as international shortwave broadcasters and a variety of communications systems (military, aeronautical, etc.). Power lines are unshielded and will act as antennas for the signals they carry, and have the potential to interfere with shortwave radio communications. Modern BPL systems use OFDM modulation, which allows them to mitigate interference with radio services by removing specific frequencies used. A 2001 joint study by the ARRL and HomePlug Powerline Alliance showed that for modems using this technique "in general that with moderate separation of the antenna from the structure containing the HomePlug signal that interference was barely perceptible at the notched frequencies" and interference only happened when the "antenna was physically close to the power lines" (however other frequencies still suffer from interference).

Much faster transmissions using RF through microwave frequencies transmitted via a newly discovered[3] transverse-magnetic(TM) surface wave propagation mechanism [4] can operate using only a single power line conductor. An implementations of this technology called E-Line has been demonstrated using only a single power line conductor[5]. These systems have shown the potential for symmetric and full duplex communication well in excess of 1 Gbit/s in each direction. Multiple WiFi channels with simultaneous analog television in the 2.4 and 5.3 GHz unlicensed bands have been demonstrated operating over a single medium voltage line conductor. Because the underlying propagation mode is extremely broadband, it can operate anywhere in the 50 MHz - 20 GHz region. Because it is not restricted to <80 MHz, as is the case for conventional BPL, these systems can avoid the need to share spectrum with other licensed or unlicensed services and can completely avoid the interference issues associated with use of shared spectrum while offering complete flexibility for modulation and protocols of a microwave system.

Medium frequency (kHz)

Home control (narrowband)

Power line communications technology can use the household electrical power wiring as a transmission medium. INSTEON and X10 are the two most popular, *de facto* standards using power line communications for home control. This is a technique used in home automation for remote control of lighting and appliances without installation of additional control wiring.

Typically home-control power line communication devices operate by modulating in a carrier wave of between 20 and 200 kHz into the household wiring at the transmitter. The carrier is modulated by digital signals. Each receiver in the system has an address and can be individually commanded by the signals transmitted over the household wiring and decoded at the receiver. These devices may be either plugged into regular power outlets, or permanently wired in place. Since the carrier signal may propagate to nearby homes (or apartments) on the same distribution system, these control schemes have a "house address" that designates the owner.

Since 1999, a new power-line communication technology "universal powerline bus" has been developed, using pulse-position modulation (PPM). The physical layer method is a very different scheme than the modulated/demodulated RF techniques used by X-10. The promoters claim advantages in cost per node, and reliability.

Low-speed narrow-band communication

Narrowband power line communications began soon after electrical power supply became widespread. Around the year 1922 the first carrier frequency systems began to operate over high-tension lines with frequencies of 15 to 500 kHz for telemetry purposes, and this continues.[6] Consumer products such as baby alarms have been available at least since 1940.[7]

In the 1930s, ripple carrier signalling was introduced on the medium (10-20 kV) and low voltage (240/415V) distribution systems. For many years the search continued for a cheap bi-directional technology suitable for applications such as remote meter reading. For example, the Tokyo Electric Power Co ran experiments in the 1970s which reported successful bi-directional operation with several hundred units.[8] Since the mid-1980s, there has been a surge of interest in using the potential of digital communications techniques and digital signal processing. The drive is to produce a reliable system which is cheap enough to be widely installed and able to compete cost effectively with wireless solutions. But the narrowband powerline communications channel presents many technical challenges. A mathematical channel model and a survey of work can be found in reference no. 5[9].

Applications of mains communications vary enormously, as would be expected of such a widely available medium. One natural application of narrow band power line communication is the control and telemetry of electrical equipment such as meters, switches, heaters and domestic appliances. A number of active developments are considering such applications from a systems point of view, such as 'Demand Side Management'.[10] In this, domestic appliances would intelligently co-ordinate their use of resources, for example limiting peak loads.

Control and telemetry applications include both 'utility side' applications, which involves equipment belonging to the utility company (i.e. between the supply transformer substation up to the domestic meter), and 'consumer-side' applications which involves equipment in the consumer's premises. Possible utility-side applications include automatic meter reading(AMR), dynamic tariff control, load management, load profile recording, credit control, pre-payment, remote connection, fraud detection and network management, [11] and could be extended to include gas and water.

A project of EDF, France includes demand side management, street lighting control, remote metering and billing, customer specific tariff optimisation, contract management, expense estimation and gas applications safety [12].

There are also many specialised niche applications which use the mains supply within the home as a convenient data link for telemetry. For example, in the UK and Europe a TV audience monitoring system uses powerline communications as a convenient data path between devices that monitor TV viewing activity in different rooms in a home and a data concentrator which is connected to a telephone modem.

The most robust low-speed powerline technology uses DCSK technology available from Yitran Communications. Renesas Technology licenses this know-how from Yitran and incorporates it in the single chip MCU + PLC family of devices known as M16C/6S. Renesas also licenses a state of the art network layer for AMR/AMM applications which can run on these devices.

High-speed narrow-band powerline communication — distribution line carrier

DLC uses existing electrical distribution network in the medium voltage (MV) — i.e., 11 kV, Low Voltage (LV) as well as building voltages. It is very similar to the powerline carrier. DLC uses narrowband powerline communication frequency range of 9 to 500 kHz with data rate up to 576 kbit/s. DLC is suitable (even in very large networks) for multiple realtime energy management applications. It can be implemented under REMPLI System as well as SCADA, AMR and Power Quality Monitoring System. DLC complies with the following standards: EN 50065 (CENELEC), IEC 61000-3 and FCC Part 15 Subpart B.

There are no interference issues with radio users or electromagnetic radiation. With external inductive or capacitive coupling, a distance more than 15 km can be achieved over a medium voltage network. On low voltage networks, a direct connection can be made since the DLC has a built-in capacitive coupler. This allows end-end communications from substation to the customer premises without repeaters.

The latest DLC systems significantly improve upon and differ from other powerline communication segments. DLC is mainly useful for last-mile and backhaul instrastucture that can be integrated with corporate wide area networks (WANs) via TCP/IP, serial communication or leased-line modem to cater for multi-services realtime energy management systems.

Transmitting radio programs

Sometimes PLC was used for transmitting radio programs over powerlines. When operated in the AM radio band, it is known as a carrier current system. Such devices were in use in Germany, where it was called *Drahtfunk*, and in Switzerland, where it was called *Telefonrundspruch*, and used telephone lines. In the USSR PLC was very common for broadcasting since the 1930s because of its low cost and accessibility. In Norway the radiation of PLC systems from powerlines was sometimes used for radio supply. These facilities were called *Linjesender*. In all cases the radio programme was fed by special transformers into the lines. To prevent uncontrolled propagation, filters for the carrier frequencies of the PLC systems were installed in substations and at line branches.

An example of the programs carried by "wire broadcasting" in Switzerland:

- 175 kHz Swiss Radio International
- 208 kHz RSR1 "la première" (French)
- 241 kHz "classical music"
- 274 kHz RSI1 "rete UNO" (Italian)
- 307 kHz DRS1 (German)
- 340 kHz "easy music"

Utility applications

Utility companies use special coupling capacitors to connect medium-frequency radio transmitters to the power-frequency AC conductors. Frequencies used are in the range of 24 to 500 kHz, with transmitter power levels up to hundreds of watts. These signals may be impressed on one conductor, on two conductors or on all three conductors of a high-voltage AC transmission line. Several PLC channels may be coupled onto one HV line. Filtering devices are applied at substations to prevent the carrier frequency current from being bypassed through the station apparatus and to ensure that distant faults do not affect the isolated segments of the PLC system. These circuits are used for control of switchgear, and for protection of transmission lines. For example, a protection relay can use a PLC channel to trip a line if a fault is detected between its two terminals, but to leave the line in operation if the fault is elsewhere on the system.

While utility companies use microwave and now, increasingly, fiber optic cables for their primary system communication needs, the power-line carrier apparatus may still be useful as a backup channel or for very simple low-cost installations that do not warrant installing fiber optic lines.

Low frequency (<kHz)

Utility

Power line carrier systems have long been a favorite at many utilities because it allows them to reliably move data over an infrastructure that they control. Many technologies are capable of performing multiple applications. For example, a communication system bought initially for automatic meter reading can sometimes also be used for load control or for demand response applications.

PLC is one of the technologies used in the automatic meter reading industry. Both one-way and two-way systems have been successfully used for decades. Interest in this application has grown substantially in recent history—not so much because there is an interest in automating a manual process, but because there is an interest in obtaining fresh data from all metered points in order to better control and operate the system. PLC is one of the technologies being used in Advanced Metering Infrastructure (AMI) systems.

In a one-way (inbound only) system, readings "bubble up" from end devices (i.e. meters), through the communication infrastructure, to a "master station" which publishes the readings. A one-way system might be lower-cost than a two-way system, but also is difficult to reconfigure should the operating environment change.

In a two-way system (supporting both outbound and inbound), commands can be broadcast out from the master station to end devices (meters) -- allowing for reconfiguration of the network, or to obtain readings, or to convey messages, etc. The device at the end of the network may then respond (inbound) with a message that carries the desired value. Outbound messages injected at a utility substation will propagate to all points downstream. This type of broadcast allows the communication system to simultaneously reach many thousands of devices—all of which are known to have power, and have been previously identified as candidates for load shed. PLC also may be a component of a smart power grid.

Broadband over power line (BPL)

US FCC

On 14 October 2004, the U.S. Federal Communications Commission adopted rules to facilitate the deployment of "Access BPL" -- i.e., use of BPL to deliver broadband service to homes and businesses. The technical rules are more liberal than those advanced by ARRL and other spectrum users, but include provisions that require BPL providers to investigate and correct any interference they cause. These rules may be subject to future litigation.

On 8 August 2006 FCC adopted a memorandum opinion and an order on broadband over power lines, giving the go-ahead to promote broadband service to all Americans.[13][14] The order rejects calls from aviation, business, commercial, amateur radio and other sectors of spectrum users to limit or prohibit deployment until further study is completed. FCC chief Kevin Martin said that BPL "holds great promise as a ubiquitous broadband solution that would offer a viable alternative to cable, digital subscriber line, fiber, and wireless broadband solutions", and that BPL was one of the agency's "top priorities".[15]

New FCC rules require BPL systems to be capable of remotely notching out frequencies on which interference occurs, and of shutting down remotely if necessary to resolve the interference. BPL systems operating within FCC Part 15 emissions limits may still interfere with wireless radio communications and are required to resolve interference problems. A few early trials have been shut down [6][7], though whether it was in response to complaints is debatable.

The ARRL sued the FCC, claiming that the FCC violated the Administrative Procedure Act in creating its rules. On 25 April 2008, a US Court of Appeals agreed with the ARRL that the FCC violated the APA, especially by redacting data from the public that could have shed doubt on the FCC's decision.

"It is one thing for the Commission to give notice and make available for comment the studies on which it relied in formulating the rule while explaining its non-reliance on certain parts", D.C. Circuit Judge Judith Rogers wrote. "It is quite another thing to provide notice and an opportunity for comment on only those parts of the studies that the Commission likes best."[16]

Potential for interference

Power and telecommunications companies have started tests of the BPL technology, over the protests of the radio groups. After claims of interference by these groups, many of the trials were ended early and proclaimed successes, though the ARRL and other groups claimed otherwise. Some of the providers conducting those trials have now begun commercial roll-outs in limited neighborhoods in selected cities, with some level of user acceptance. There have been many documented cases of interference reported to the FCC by Amateur Radio users. Because of these continued problems, Amateur Radio operators and others filed a petition for reconsideration with the FCC in February 2005. Austria, Australia, New Zealand and other locations have also experienced BPL's spectrum pollution and raised concerns within their governing bodies. In the UK, the BBC has published the results of a number of tests (The effects of PLT on broadcast reception,PLT and Broadcasting, Co-existence of PLT and Radio Services) to detect interference from BPL installations. It has also made a video (Real Media format), showing broadcast of data and interference from in-home BPL devices.

In June 2007, NATO Research and Technology Organisation released a report titled HF Interference, Procedures and Tools (RTO-TR-IST-050) which concluded that widespread deployment of BPL may have a "possible detrimental effect upon military HF radio communications and COMINT systems."

New powerline modems are able to detect the existence of SW-Radio services at the location and time of operation by monitoring the ground noise at the socket where the modem is connected. The frequencies allocated by radio broadcast will be omitted from powerline communication. Such new technologies remove interferences from powerline modems to SW-Radio broadcast. Tests to verify this technique were organized by ETSI. There is a technical report ETSI TR 102616 on the plugtest of the Coexistence between powerline communication and SW-Radio broadcast. Finally the concept was standardized in ETSI TS 102578.

In April 2009 the Wireless Institute of Australia reported that radio amateurs in Australia appear to be safe from the rollout of a nationwide Broadband over Powerline or BPL system. Australia's government announced that it will be building a system based on fibre optic technology. This decision would appear to remove the possibility of widespread interference to radio communications from any network-wide adoption of BPL technology, but still leaves as a concern the possibility of interference from in-home use of BPL as an internal distribution technology. The decision by Australia to opt away from BPL could be a major blow to the worldwide implementation of this technology.

Automotive uses

Power-line technology enables in-vehicle network communication of data, voice, music and video signals by digital means over direct current (DC) battery power-line. Advanced digital communication techniques tailored to overcome hostile and noisy environment are implemented in a small size silicon device. One power line can be used for multiple independent networks. The benefits would be lower cost and weight (compared to separate power and control wiring), flexible modification, and ease of installation. Potential problems in vehicle applications would include the higher cost of end devices, which must be equipped with active controls and communication, and the possibility of intereference with other radio frequency devices in the vehicle or other places.

Prototypes are successfully operational in vehicles, using automotive compatible protocols such as CAN-bus, LIN-bus over power line (DC-LIN) and [DC-bus][8]. [17] [18]

LonWorks power line based control has been used for an HVAC system in a production model bus [9].

Failure Scenarios

There are many ways in which the communication signal may have error introduced into it. Interference, cross chatter, some active devices, and some passive devices all introduce noise or attenuation into the signal. When error becomes significant the devices controlled by the unreliable signal may fail, become inoperative, or operate in an undesirable fashion.

1. **Interference:** Interference from nearby systems can cause signal degradation as the modem may not be able to determine a specific frequency among many signals in the same bandwidth.
2. **Signal Attenuation by Active Devices**: Devices such as relays, transistors, and rectifiers create noise in their respective systems, increasing the likelihood of signal degradation.
3. **Signal Attenuation by Passive Devices**: Transformers and DC-DC converters attenuate the input frequency signal almost completely. "Bypass" devices become necessary for the signal to be passed on to the receiving node. A bypass device may consist of three stages, a filter in series with a protection stage and coupler, placed in parallel with the passive device.

Standards organizations

During the early days of Powerline Communications, several competing organization developed proprietary specifications, including the HomePlug Powerline Alliance, Universal Powerline Association and HD-PLC Alliance. On December 2008, the ITU-T adopted Recommendation G.hn/G.9960 as the first worldwide standard for high-speed powerline communications [19]. X10 is a de facto standard also used by RadioShack's Plug'n'Power system.

ITU-T Home networking Recommendations

Common Name	Recommendations
HomePNA 2.0	G.9951, G.9952, G.9953
HomePNA 3.0	G.9954 (02/05)
HomePNA 3.1	G.9954 (01/07)
G.hn/HomeGrid	G.9960
G.hnta	G.9970

- Consumer Electronics Powerline Communications Alliance (CEPCA) (Sony, Mitsubishi and Panasonic) is developing a standard to realize coexistence between various Powerline technologies, available today. [10]

- IEEE produces standards for several types of power line communications systems.
  - IEEE 643-2004 "Guide for Power-Line Carrier Applications" is a standard for communication over the transmission line network (above 69kV).
  - IEEE 1675-2008 "Standard for Broadband over Power Line Hardware" is a standard for hardware installation and safety issues.
  - IEEE P1775 "Powerline Communication Equipment — Electromagnetic Compatibility (EMC) Requirements — Testing and Measurement Methods" is a working group focused on PLC equipment, electromagnetic compatibility requirements, and testing and measurement methods.
  - IEEE P1901 "IEEE P1901 Draft Standard for Broadband over Power Line Networks: Medium Access Control and Physical Layer Specifications" is a working group for delivering broadband over power lines. The aim is to define medium access control and physical layer specifications for all classes of BPL devices — from long distance connections to those within subscriber premises. Many companies and standard bodies are participating in the developing IEEE P1901 standard including HomePlug Powerline Alliance, UPA, CEPCA and OPERA. On December 2008, P1901 adopted a baseline text that includes three incompatible PHY/MAC specifications (one based on OFDM, another based on Wavelet modulation, and a third one that is compatible with the G.hn standard).
  - IEEE BPL Study Group — "Standardization of Broadband Over Power Line

Technologies" drove the creation of the BPL related P1901 working groups. It still meets time-to-time looking to create new working groups if needed. website

- LonWorks powerline communication is used worldwide, for example for Home Automation, Street Lighting, Energy Management and Utility Metering. The protocol can also use other media, such as IP-based networks, and it is standardized through ISO/IEC. Powerline communication can use CENELEC A-band (for utilities) or C-band (for general use, e.g. by consumers). Related standards can be found on [11]
- OPERA (Open PLC European Research Alliance) is a R&D Project with funding from the European Commission. It aims to improve the existing systems, develop PLC service, and standardise systems.
- POWERNET is a R&D Project with funding from the European Commission. It aims to develop and validate a 'plug and play' Cognitive Broadband over Power Lines (CBPL) communications equipment that meet the regulatory requirements concerning electro-magnetic radiations and can deliver high data rates while using with low transmit power spectral density and working at low signal to noise ratio.

See also

- Digital subscriber line
- Electric power transmission
- HomePlug Powerline Alliance
- HomePNA
- KNX (standard)
- List of broadband over power line deployments
- List of PLC manufacturers
- LonWorks
- Multimedia over Coax Alliance
- Power line carrier communication
- Power over ethernet
- Residential gateway
- Smart Grid
- Universal Powerline Association
- IEEE P1901
- ITU-T G.hn

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Internet access								
Network type	**Wired**					**Wireless**		
	Optical	**Coaxial cable**	**Ethernet cable**	**Phone line**	**Power line**	**Unlicensed terrestrial bands**	**Licensed terrestrial bands**	**Satellite**
LAN	1000BASE-X	G.hn	Ethernet	HomePNA · G.hn	G.hn	Wi-Fi · Bluetooth · DECT · Wireless USB		
WAN	PON	DOCSIS		Dial-up · ISDN · DSL	BPL	Muni Wi-Fi	GPRS · iBurst · WiBro/WiMAX · UMTS-TDD, HSPA · EVDO · LTE	Satellite

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