Narrowband Powerline Communication-Applications and Challenges—Part I

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Transmitting data between remote devices has a long history and is becoming sine qua non in the modern world. Thanks to technological evolution and new emerging markets, powerline communication (PLC) is today a viable technology for both low speed and high speed networking. Broadband PLC represents an interesting alternative to cable, DSL or Wi-Fi as a last-mile solution for Internet distribution and home multimedia networking. For narrowband PLC, there is today a potentially vast market of command and control applications.

This article intends to give an overview of the state of the art and trends in narrowband PLC. The topics include basic modulation principles, characteristics of power lines, applicable regulations, typical applications and implementation challenges. Also, market perspectives and promising opportunities are discussed to assess the viability of the narrowband PLC in the Smart Energy world.

No new wires

The key advantage of PLC is the use of existing electrical lines as communication medium, which provides the major benefit of eliminating considerable costs of installing networking infrastructure, like dedicated cables or antennas.

Data is sent on the power lines by superposing a modulated high-frequency carrier signal on the line voltage, being high, medium or low, AC or DC. The carrier signal is then decoupled and demodulated at the receiving end to recover the information.

Once upon a time

Powerline communications have a long history; actually, it is almost as old as the power grid itself. The first research and developments date from end of the 19th century. In the beginning of the 20th century, carrier frequency systems began to operate over high-voltage lines, then over medium and low voltage distribution systems for telemetry purposes.

The term Power Line Carriers emerged in the 1940s. In the 1970s and 1980s home-control PLC devices became commercially available, and at the same time the first standards were developed. The interest increased during the 1990s, with popular technologies like X-10, CEBus and LonWorks. The drive was to produce a reliable system which is cheap enough to be widely installed and able to compete cost effectively with wireless solutions. Over the last 20 years, research in PLC has intensified; new modulation and error control coding techniques were proposed, as well as new standards from industry alliances and professional associations. The emerging PLC technologies became promising for both consumers and energy providers.
**Broad vs. Narrow**

We distinguish today between two classes of PLC systems: narrowband and broadband. Usually, narrowband PLC (NB-PLC) refers to low bandwidth communication, utilizing the frequency band below 500kHz and providing data rates of tens of kbps. Broadband PLC (BPL) utilizes a much wider frequency band, typically between 2MHz and 30MHz, and allows for data rates of hundreds of Mbps.

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<th>Narrowband PLC</th>
<th>Broadband PLC</th>
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<td><strong>Data rate</strong></td>
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<td><strong>Frequency</strong></td>
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<td><strong>Modulation</strong></td>
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BPL technologies are used today for high-speed data transfer applications like Internet, HDTV, and audio. The optimism in this market is reflected by a number of solutions from companies like Atheros, Maxim, Sigma, all in the Home Area Networking. The NB-PLC finds many applications in the command, control and monitoring markets, like smart building automation, renewable energy generation, advanced metering, street lighting, plug-in electric vehicles, etc. Consequently, the narrowband PLC market is seeing healthy competition, with a large number of suppliers, including Echelon, Maxim, ST Microelectronics, Texas Instruments and Ariane Controls.

**Modulation schemes**

Different modulation schemes are used by the two categories of PLC technologies. Narrowband systems are mostly based on single-carrier modulation, while broadband technologies use multi-carrier techniques. Let’s look at the features of the main types of modulation used in narrowband PLC systems.

**Single-carrier modulation**

Single-carrier modulations, like Amplitude-Shift Keying (ASK), Frequency-Shift Keying (FSK) and Phase-Shift Keying (PSK), use a number of distinct signals to represent digital data. With these schemes, data is transmitted by changing, or modulating, a characteristic of a reference signal, for example the amplitude, the frequency or the phase. In the simplest form of these modulations, two discrete values of these parameters are used to represent binary data. For example, Binary
Frequency-Shift Keying (BFSK) uses a pair of discrete frequencies to transmit the "1" (called the mark frequency) and the "0" (called the space frequency).

The performance of single-carrier PLC technologies has been proven in many implementations. X-10 is based on On-Off Keying modulation, the simplest form of ASK that represents data as the presence or absence of a carrier wave, synchronized with the zero-crossing of the power line voltage. Echelon’s transceivers use BPSK, ST’s ST7537 to ST7540 transceivers are based on BFSK, as well as Ariane’s PLM-1 modem. These solutions have the advantage of providing reliable communication at reduced power consumption and low cost. The low data rate, typically limited to 10kbps, makes these solutions appropriate for command and control, metering and monitoring applications.

The main drawback of single-carrier PLC systems is their sensitivity to narrowband noise and signal distortion. The robustness can be increased by error detection and correction mechanisms, which combined with message repetition can be very efficient. Narrowband Powerline Communications--Part I, Page 2.

Spread-spectrum modulation

Another modulation scheme used in NB-PLC systems is spread-spectrum (SS). This technique operates by spreading the original narrowband information over a wider band of frequencies. Consequently, the transmitted signal occupies a bandwidth much greater than the minimum necessary to send the information. In this way, SS modulation allows overcoming frequency-selective perturbations and burst noises from the power lines. However, the redundancy in data transmission also makes the spectral efficiency low.

There are few implementations of SS techniques in PLC systems, the most successful being Yitran’s DCSK (Differential Code Shift Keying) modems.

Multi-carrier modulation

While mainly used in broadband PLC systems, multi-carrier modulation schemes have been recently applied in narrowband PLC. One of the most popular multi-carrier modulation techniques is OFDM (Orthogonal Frequency-Division Multiplexing). Several OFDM-based NB-PLC solutions that address mainly the smart grid market have been proposed by industrial alliances like PRIME and G3-PLC.

With OFDM, data is split into sub-carriers of different frequencies, modulated in parallel with conventional techniques, like BPSK, QPSK or QAM. Hence, a low bit rate transmission is converted into a high bit rate transmission by transmitting different parts of the data on many different sub-carriers.

The main advantage of multi-carrier modulation over single-carrier schemes is its robustness to narrowband interference and frequency-selective perturbations. Also, multi-carrier systems allow higher data rates than single-carrier and SS modulation schemes. An important feature of OFDM is its adaptability to the channel conditions; sub-carriers within the OFDM waveform can be selected in order to avoid transmitting at frequencies where the signal-to-noise ratio is too low.

However, these features come at a price. OFDM-based systems are more complex, meaning higher cost and increased power consumption compared to single-carrier solutions. Also, because of their large frequency bandwidth, the maximum effective data rate is considerably limited by the restrictions in narrowband frequency bands - to about 30kbps in European CENELEC bands (frequencies up to 148.5kHz) and about 128kbps at frequencies up to 500kHz.
The power grid

Let’s take a look at the power grid and its characteristics as communication channel. Electrical power lines are usually classified into high, medium and low voltage lines. High voltage lines form the transmission network that transports energy at over 100kV from generating power plants to electrical substations located near demand centers. Medium voltage lines (typically below 50kV) and low voltage lines (less than 1kV) form the distribution network, which carries electricity from the transmission system and delivers it to consumers.

Various wiring topologies exist and differ from country to country, and also within each country, for example radial and interconnected distribution networks, delta and wye three-phase services, single-phase and split-phase low-voltage services, different earthing systems.

Powerline communications have been used at all levels of the power grid; on high voltage lines for telemetry, protection and control by utility companies; on medium voltage for advanced metering and grid optimization by electricity providers, but also for high-speed Internet distribution; finally, the vast majority of PLC applications are on low voltage lines, both indoor and outdoor (between transformers and buildings), for both low-speed command and control applications and high-speed networking.

PLC challenges

The power lines were not designed for data transmission and they constitute a challenging environment for communication. The transmission grid and even more the distribution grid have the characteristics of a very complicated wired network, which vary with time, location and are frequency-dependent. High signal attenuation and considerable noise are the main factors that affect the communication performance. Also, severe electromagnetic compatibility restrictions impose non-negligible challenges to PLC systems.

Signal attenuation

There are many sources of attenuation and distortion of PLC signals on the power lines. Here is a summary of the most common factors:
- **Impedance of loads connected to low voltage power line** - In most frequency ranges, the load impedance shows inductive or capacitive behavior, but resistive loads (like heating elements, for example) can also cause extremely low impedance values. The impedance is highly varying with frequency, but also changing in time, as devices are continuously plugged in or out, and switched on or off.

- **Multiple phases** - In residential split-phase power lines and commercial or industrial three-phase systems, PLC transceivers can be connected on different phases. The PLC signals that are typically transmitted between one phase and neutral have to travel from one phase to the other through the distribution transformer or some phase-to-phase loads, and are generally highly attenuated.

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- **Transformers** - Power distribution transformers cause high signal attenuation when PLC devices are located on primary and secondary sides, for example in communication between meters on the low voltage line and a concentrator connected on medium voltage side.

- **Line losses** - The characteristic impedance of the wiring between transmit and receive locations can also add significant signal attenuation, particularly in outdoor long power lines (for example in street lighting networks or metering systems).

- **Multipath propagation** - Signal propagation on multiple paths and signal reflection due to impedance mismatches in branching points can generate attenuation distortion of PLC signals. This phenomenon is less observed at low communication frequencies (below 150kHz), since the signal wavelength is quite long (over 1km).

Measurements carried out in indoor and outdoor environments reported in the literature have shown that the signal attenuation can range from 15dBs to 60dB or more. While the attenuation depends on the network topology, location of PLC transceivers and connected loads, it is also time- and frequency-dependent. Attenuation variations of 20dBs over time are not unusual. Also, it has been observed that signal attenuation tends to increase with frequency, although the increase is not always monotonic.

**Noise**

When the PLC signals are severely attenuated, the noise becomes a significant concern for data reception. Generally, channel noise is generated by electrical loads and varies with time of day, location and frequency. The noise power level at a certain location is the sum of noise waveforms from different sources and depends on the distance to noise sources. Also, noise has greater power in the lower frequency range and decreases at higher frequency, which is particularly challenging for narrowband PLC operating below 150kHz.

As one would expect, there are many sources of noise on the power lines. They can be roughly classified in several classes:

- **Narrowband noise**, that is mainly due to amplitude modulated signals (for example from broadcast stations).
- **Continuous background noise**, which can be:
- **Time-invariant**, having constant envelope for a long period (for example, thermal noise generated
by internal circuitry).

- Time-variant, whose envelope changes with line voltage (for example, noise from inverter-drive fluorescent lamps).
- Impulsive noise, consisting of abrupt impulses with short duration and high amplitude. There are at least three categories of impulsive noise:
  - Impulses synchronous with AC line voltage, at the same frequency or double (for example, noise generated by light dimmers or brush motors).
  - Impulses asynchronous to AC line voltage, whose frequency is much higher than that of mains voltage (for example, noise from switching regulators).
  - Single-event impulses, that occur at random times, less frequently, and that are typically caused by switching operations (for example, wall switches or capacitor banks for power factor correction).

While noise is mostly generated by the devices connected to the power line, one possible source of noise that can disturb the reception of low communication signals is PLC transceiver’s circuitry, mainly its power supply. Switching-mode power supplies (SMPS) and regulators can be particularly problematic and their switching frequency should be carefully considered. SMPS may couple significant noise at the switching frequency or its harmonics back onto the mains power line. Also, a SMPS or a DC/DC switching regulator with improperly filtered output can produce noise and ripple on the transceiver DC supply voltages.

**EMC regulations**

Besides the harsh channel conditions, another challenge for PLC is the compliance with the standards and regulations for electromagnetic compatibility. These standards do not define particular modulation methods, but typically specifies:

- Frequency bands allocated for different applications
- Limits for the transmitted signals in the operating bands
- Limits for electromagnetic emissions (conducted and radiated).

These normative specifications are generally produced by regulatory agencies, independent or governmental, and apply for specific geographical areas. For example, Federal Communications Commission (FCC) in US, Industry Canada, European Committee for Electrotechnical Standardization (CENELEC) in the European Union, Association of Radio Industries and Businesses (ARIB) in Japan.
The above diagram summarizes the allocation of frequency bands for narrowband PLC by the main international standards. We can observe that while US FCC Part 15, Industry Canada ICES-006 and Japan ARIB provide larger frequency range, the European CENELEC standard is more restrictive, with a frequency band from 3kHz to 95kHz reserved for utility applications and only from 95kHz to 148.5kHz for consumer applications. Also, the maximum signal levels and electromagnetic emissions accepted by CENELEC are tighter.

**About the Author**

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**Next:** PLC transceivers