Power Line Communications

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Power line communications (PLC) are not new. The idea of sending signals along the power lines has long been used for switching off peak loads on and off – a very low speed application. But the technology has improved dramatically in the last few years to the point where owners of power infrastructure, i.e. utilities, can now offer local loop services competitive with and superior to those of Incumbent Local Exchange Carriers (ILECs), i.e. Telco's.

This white paper gives an overview of the technology of PLC and InovaTech, and the application of that technology in helping deregulating utilities to diversify, improve margins, and grow.

An overview of power line communications

Power lines normally carry a 50 Hz (60 Hz in the USA) current-bearing, electrical signal into houses and businesses. Appliances and machinery use this signal to produce mechanical and thermal energy as they perform the tasks for which they were designed.

The prime goal of the entire infrastructure – generators, transmission grids, substations, and distribution networks – is to deliver energy to consumers with safety, efficiency, and at a low cost. In order to carry the large currents necessary for heavy work, power line conductors are heavy copper wires. In contrast, the conductors used to provide telecommunications are usually rather light copper wires, because their purpose is not to carry current, but signals.

This difference is important. The electrical characteristics of neither conductor is well suited to broadband communications, but much of the development effort of the last few years has been directed at providing higher speeds using conventional telecommunications local loop wiring ("twisted pair"), and in overcoming the shortcomings of the entire local loop system when it comes to increasing speeds. Given that backbone telecommunications are usually carried on optical fibre, with bit rates measured in Gigabits per second (Gbps), there is a serious mismatch between the trunking and local loop capabilities available to deliver high-speed broadband services to customers.

One solution to this problem is to provide optical fibre directly to the customer. The costs of doing this have been variously estimated at around USD1500 per connection, plus the required network provisioning costs, i.e. routers and switches necessary for managing the services. This cost has generally inhibited wide-scale availability of fibre connections.

The current state of the art in driving the legacy local loop faster is so-called DSL (Digital Subscriber Line) technology, which uses carefully chosen modulation and line conditioning to achieve bit rates in the range of a few hundred to a few thousand kilobits per second.

However, control of the resulting services is still largely in the hands of ILECs, who have used their ownership of the local loop to keep prices high. In addition, DSL suffers from at least two technical disadvantages:

- The attainable speed is dependent on the particular exchange and subscriber wiring used to provide it. Indeed, some exchanges may be unable to support DSL at all
- There is increasing evidence that, once the number of DSL-enabled twisted pairs leaving an exchange in one bundle exceeds 15, there is an unacceptable level of cross talk between pairs. This phenomenon severely degrades achievable throughput.

Even if DSL ultimately achieves limited success, the fact remains that the ILEC monopoly of the local loop is an incentive to provide a competing service. Despite the fact that mandated unbundling of the local loop has been applied in the U.S.A. for over 10 years, less than 2% is so unbundled. PLC provides the option for a competing service.

Competing Broadband Access Technologies

Technology	Carrier (MHz)	Max Downstream Data Rate	Max Upstream Data Rate	Access	Max Distance (km)	Connection
PLC	1 to 10 MHz	30 Mbps	20 Mbps	LV Power Lines	2	Shared Bandwidth
ADSL	20 kHz – 1.1 MHz	7 Mbps	640 kbps	Dedicated PSTN	6	Point to Point
VDSL	300 kHz – 30 MHz	52 Mbps	1.6 Mbps	Dedicated PSTN	1	Point to Point
Cable	5–42 MHz, 450-750 MHz	43 Mbps (shared)	2 Mbps (shared)	CaTV	25	Shared Bandwidth
LMDS	27-29 GHz	300 Mbps (shared)	300 Mbps (shared)	Fixed Wireless	5	Shared Bandwidth
MMDS	2.5-2.7 GHz	10 Mbps (shared)	512 kbps (shared)	Fixed Wireless	50	Shared Bandwidth
Dial-up	300-3400 Hz	56 kbps	33.6 kbps	PSTN	6	Point to Point

PLC has suffered from many technical problems akin to those of DSL, but has had a fraction of the resources applied to the problem. Fortunately, the availability of lower cost ASIC fabrication (Application Specific Integrated Circuits), more effective modulation algorithms, and a better understanding of the causes behind some earlier failures have led to solutions. Coupled with the technical success, European governments, particularly, have moved on the regulatory issues. There are now European standards for radio frequency emissions, with legislation already enacted in Germany, the world leader in PLC, for implementation of large-scale PLC networks.

An array of technology suppliers have announced the development of broadband powerline technology and some are now offering dedicated PLC chips capable of gross link speeds ranging from 2 to 50 Mbps, with performance being demonstrated in realistic overhead and underground distribution systems in several European countries. The technology that underpins the most effective of these chips has been built around OFDM (Orthogonal Frequency Division Multiplexing) modulation – a highly efficient modulation scheme that closely stacks individually modulated carriers across the available transmission frequencies responding in real time to the varying line conditions.

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Orthogonal Frequency Division Multiplexing (OFDM)

The OFDM modulation technique employs methods that allow high-speed data transmission over noisy and unpredictable mediums, such as wireless or powerline, while maintaining low Bit Error Rates (BER) at relatively low Signal to Noise Ratios (SNR).

OFDM allows a transmitter to “pack” a relatively high data transmission rate into a relatively low frequency band. The table below provides an example of possible raw bit rates achievable with various modulation methods (given a 10MHz frequency band between 1MHz and 11MHz).

Modulation Method	Raw Bandwidth (Approximate)
BPSK	10 MBPS
QPSK	20 MBPS
16-QAM	40 MBPS
64-QAM	60 MBPS
256-QAM	80 MBPS

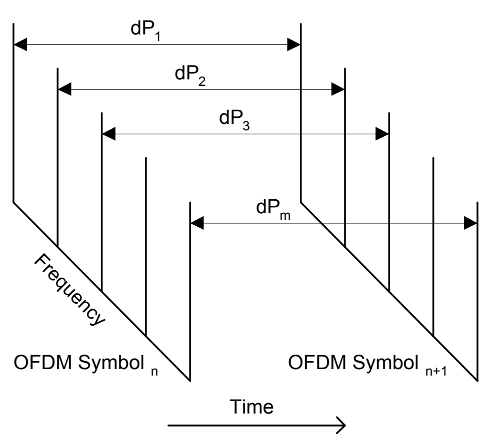
OFDM transmits a high-speed bit stream by “demultiplexing” it into multiple parallel lower-rate streams, each of which modulates separate but closely spaced carriers. When the carrier spacing is set equal to the inverse of the bit rate on each carrier, the signals on each carrier are orthogonal.

In practical terms, if a receiver performs an FFT (Fast Fourier Transform) of the received waveform over a time span equal to the bit rate on an individual carrier, the value of each point in the FFT output is a function only of the bit (or bits) that modulated the corresponding carrier, and is not impacted at all by the data modulating any other carrier.

The motivation for using multiple carriers comes from the frequency-selective nature of the communication channel. While single-carrier modulations can be used for such channels, they require complicated adaptive equalizers to correct the channel, and, in an environment where the source of a given transmission is not immediately known, training the equalizer can be challenging.

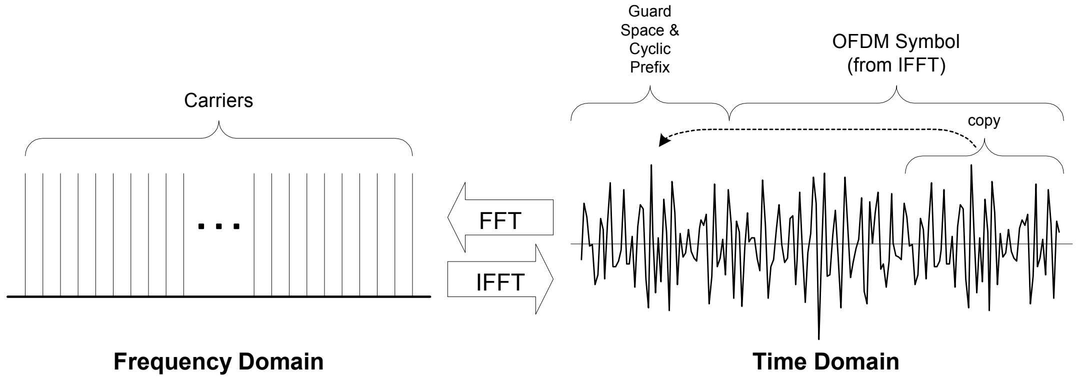
In the general case, OFDM has the advantage that when carrier spacing is small, the channel equalization problem becomes a simple scaling.

Differential phase encoding across symbols



Most OFDM implementations use an inverse FFT (IFFT) to generate the waveform samples. The frequency domain points input to the IFFT consist of the set of complex symbols that modulate each carrier. The output of the IFFT is a set of time domain samples that span an interval of time equal to the inverse of the carrier spacing. The diagram below shows the process of conversion between the frequency domain and the time domain.

Transform from the frequency to the time domain and adding the cyclic prefix



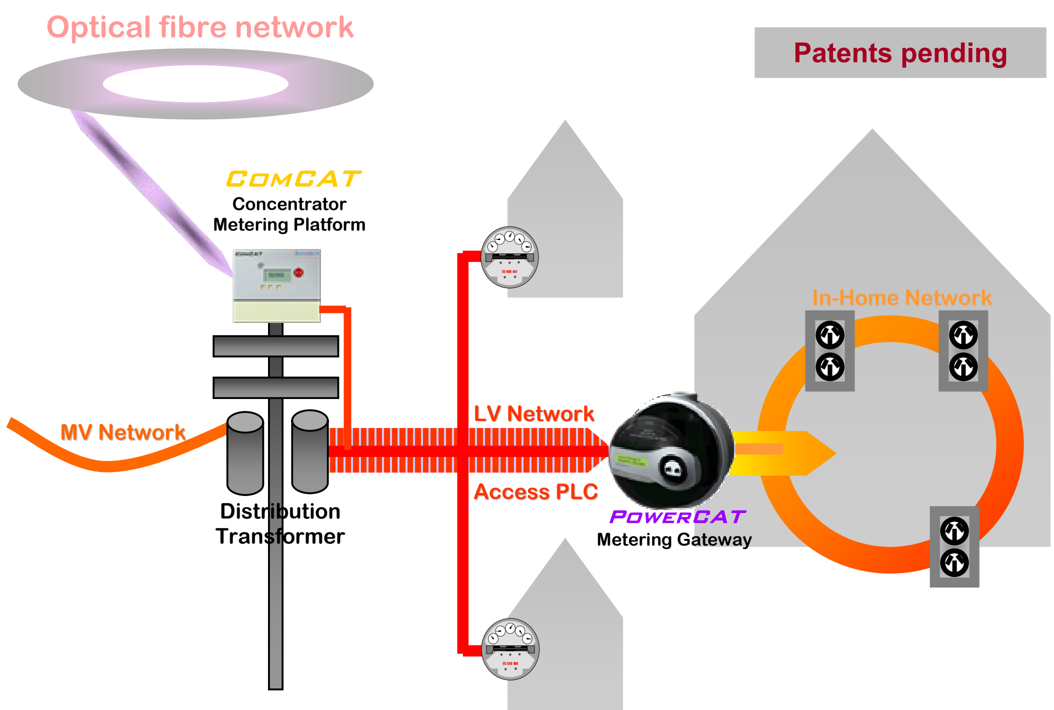
In many cases, the channel introduces group delay distortion. This means that signals at some frequencies encounter more delay than signals at other frequencies.

In the absence of any measures to mitigate against group delay variation, the interval used by the receiver to form its FFT would be unable to avoid containing energy from symbols other than the desired symbol. The “cyclic prefix” shown in the diagram above is part of a technique that solves this problem, although at the expense of some throughput.

The transmitter copies a section of the end of the sample’s output by the IFFT, and places them at the beginning of the time domain sample set prior to transmission. If the duration of this prefix exceeds the variation in delay across the frequency band of interest, then it will be possible to form an FFT over samples that are not influenced by the previous or following OFDM symbols.

Convergent Automation Technology System (CATS)
(Patents pending)

InovaTech has incorporated this PLC technology into a complete metering, energy management, and telecommunications solution referred to as CATS (Convergent Automation Technology System).



A few features of this system are:

- CATS provides the local loop at speeds up to 50 Mbps between the distribution transformer, where a ComCAT is located, and the utility customer's premises.
- The premises device (PowerCAT or PolyCAT) provides a gateway to the internal network, where In-House Power Line Communications-enabled devices and standards apply.
- The IPCAT provides the gateway between the carrier protocol used in the access network, and the TCP/IP used on the internal network.
- The backbone chosen is whatever is available – optical fibre, hybrid fibre coaxial, LMDS, free space optics, etc
- InovaTech's CATS PLC solution is neutral to many of the network choices made by the customer – Internet gateway, PSTN gateway, internal network choices, etc

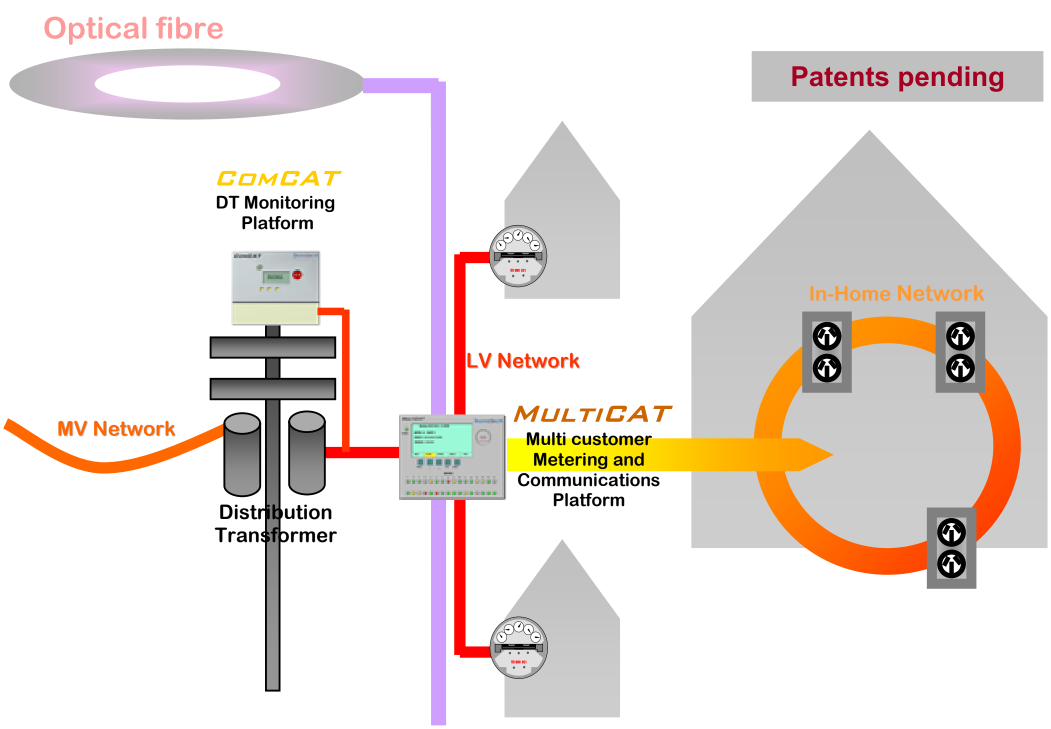
- The proposed frequencies to be allocated to Access PLC are in the range 1.5-10 MHz. With measured bits per Hz in excess of 7, InovaTech's PLC solution easily achieves the nominated bit rates. Provisions are under discussion to allow the full range of frequencies unless other signals are detected on the network, in which case the PLC system would restrict itself to non-interfering frequencies.

The number of customer premises per distribution transformer varies significantly amongst network operators. If we choose a figure of, say, 100, with all houses adopting the service, then the average maximum bandwidth seen by a customer in a fully loaded area would be around 0.5 Mbps. However, given the normal "bursty" nature of IP traffic, this figure would vary between much higher and lower figures, with the range being larger in lightly loaded areas.

InovaTech's CATS solution can be deployed in a number of ways with two distinct deployment methodologies in response to the intended capabilities proposed by the system operator.

Where system operators propose offering valued added services which are exceedingly demanding of available bandwidth, InovaTech has developed a variation of the conventional CATS architecture whereby optical fibre is deployed along the path of either the overhead or underground energy cabling and directly interfaced through a specialised InovaTech product called MultiCAT. This unique topology in known as **Kerb Translation Architecture (KTA)**

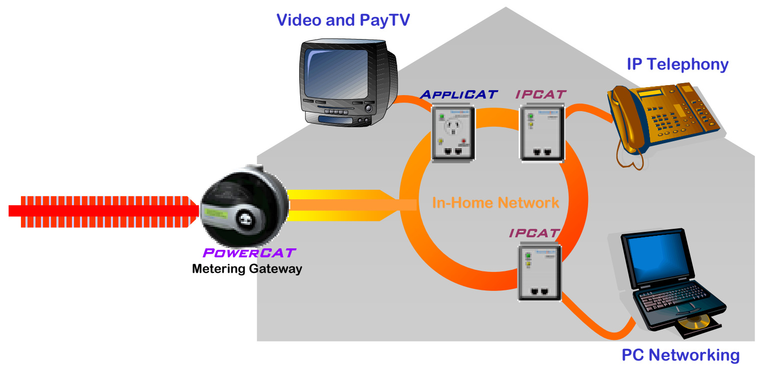
The unique MultiCAT product accepts an optical fibre feed in an FTTK (Fibre-To-The-Kerb) architecture provides HS-PLC (High-Speed Power Line Communications) to and through the customer's premises. The MultiCAT also incorporates revenue metering, power quality monitoring, tamper detection and remotely-actuated disconnect contactors.



This unique architecture effectively merges the Access and In-House transition and has the potential to deliver ultra high-speed communications capability to each house. Depending on the number of customers who connect to the energy network at each point, this implementation of CATS may deliver from 10 to 100 Mbps to each customer depending on the number of co-located terminations at the translation point (kerb).

Powerline technology for the internal network

In a conventional powerline communications architecture, where the Access powerline communications is implemented at the DT (Distribution Transformer), the transition from Access powerline communications to In-House occurs at the customer gateway. The CATS solution integrates the customer gateway function with the metering, power quality and revenue assurance functions as well as tamper detection and energy reconciliation.



In the customer premises the powerline communications is reticulated through the existing power distribution wiring using the In-House powerline communications frequencies (10 to 30 MHz). InovaTech has developed a termination device called the IPCAT, which connects to the In-House powerline communications through a conventional GPO (General Power Outlet) Using an IPCAT, a wide variety of industry standard interfaces for in-home devices become available, including standard Ethernet interfaces, USB and RS232. It will also be possible to deliver the functionality of industry standard STBs (Set Top Box) such as video output, infrared keyboard support through a variation of the InovaTech IPCAT technology.

Business applications and revenue opportunities

As with any form of Internet access, PLC offers opportunities utilities to partner in the provision of a wide range of business and consumer applications, or even to provide them directly, through diversification to obtain the requisite resources.

Specific property management applications, such as security, fire alarm, convergent metering, and CCTV monitoring services can be provided more cost effectively. Power wiring is usually ubiquitous in business premises, whereas telephone wiring is placed selectively, so it is probable that PLC solutions can be installed without rewiring.

For industrial sites, PLC offers low-cost, flexible condition monitoring for a wide range of processing equipment and machinery. “Lights off” factories can use PLC to provide a rich numerical and visual picture of unattended operations, with savings in staffing, security services, down time, and product quality costs.

Consumers will shortly be able to buy internet-enabled appliances, whose attraction will not so much lie in home automation, but in the peak-shaving opportunities for retailers trying to manage their demand/supply equation in periods of high demand. A retailer might even find it attractive to subsidise consumer purchases while spot prices in Australia can vary as high as $10,000 per MWhr.

There are also opportunities in reduced broadband access charges, particularly when it comes to the wiring and provisioning costs of dedicated internal networks.

A comprehensive display of InovaTech's CATS solution with integrated powerline communications technology will be available in Hong Kong from November 2001, at an exhibition of future technologies called Project INTEGER (http://www.integer.com.hk). The technology participants include Avaya Communications, Cisco, CLP Power, Echelon, Electrolux, Honeywell, PCCW-HKT, Samsung Electronics, Schneider, and Siemens.

One of the most attractive business and consumer applications will be IP telephony. The emerging SIP (Session Initiation Protocol) standard will enable low cost, multifunctional handsets that provide a vast array of features, under end-user control such as:

- Teleconferencing
- Option setting eg forwarding, voice/email messaging, security
- Videoconferencing

The important point about this standard is that it is purely IP based, and requires no intervention or servicing from traditional carriers – all end-user features are configured between the end points of the session - see

http://www.cisco.com/univercd/cc/td/doc/product/voice/c_ipphon/sip7960/sipadmin/overview.htm

These handsets are now commercially available, and they offer utilities with PLC capabilities the opportunity to enter the communications market directly. One option, for example, is to offer free local telephony to the SME/consumer sector as an alternative to ILEC services. The complementary national and IDD services can be contracted very cost effectively from the competitive market of service providers, and the entire offering provides diversification and growth opportunities not available in traditional energy services.

In addition, a PLC provider may be able to offer Pay TV services, re-broadcast FTA TV, video on demand, e-commerce services, online bill management and payment, and other common online services for consumers.

The important feature of the InovaTech solution is that any connection to the PLC-enabled network is a standard TCP/IP connection, thus exploiting the wide availability and low cost of network devices built for this purpose.

The implementation issues

It is clear from the above summary that the InovaTech PLC offering is a system solution, not a point solution. To be entirely effective and to secure all the energy and network management benefits provided by such a convergent approach, the entire distribution transformer and its downstream customers are re-metered with PLC-enabled technology. Although this can be done on a DT-by-DT basis, obviously it is best to choose a suburb, region or housing estate for wholesale re-metering.

Entire new subdivisions or high-rise buildings are obviously attractive, because there is no legacy metering system in place.

The commercial approach to this depends on the strategy and goals of the utility. One approach would work as follows:

- A business case for re-metering is drawn up, with attendant benefits in obsolete meter replacement, power quality monitoring, improvements to DT condition monitoring, and peak shaving through the combination of real time metering and remote appliance disconnects.

- Value-added telecommunications services are offered progressively following re-metering, as each business case and gateway service is implemented.

The advantage of this approach is that it is built on the measurable benefits of real time metering in wholesale energy costs – a business well understood by retail energy operators.

InovaTech meter costs are generally at or below comparable competitive product prices. Installation costs can also be reduced by the use of plug-in meters and shorting bars, to remove the need for customer disconnection. InovaTech can assist with implementation in other ways – with build-own-operate financing, project management, and even outsourced provisioning and operation.

Summary

PLC technology has now matured and is available. Standards are either in an advanced stage of development or are released and embodied in statute.

Customer premises equipment, e.g. SIP phones, are also commercially available, as are the power line devices needed to implement a working TCP/IP network with gateways to public networks. In-home standards, networking devices, and appliances are being produced and delivered to consumer markets.

Business cases supporting the commercial deployment of PLC-based networks are strong, with both energy-related and telecommunications arguments being available, dependent on the commercial environment of the utility. The competitive environment in the local loop is changing only slowly, providing a lucrative window for utilities to diversify into communications and value added services.

The time has arrived for utilities everywhere to plan and install PLC networks.

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