Development of High Speed Power Line Communication Modem

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Along with the wide spread of the Internet, many people are eager for the development of high-speed and low-cost "last mile" access which offers the users the large capacity communication services. The power line communication (PLC) technology, which provides high-speed communication services to the electricity users over existing electricity networks, is attracting worldwide attention. Sumitomo Electric started the study about PLC in 1998, and had developed 45-Mbps PLC modem. The 45 Mbps modems are being supplied to ENDESA, which is the biggest power utility company in Spain. Sumitomo Electric is also developing the next generation PLC modem which data rate is 200 Mbps.

1. Introduction

Power line communication (PLC) technology at the low speed of a few hundred bits per second (bps) using carrier waves of 450 kHz or less has been used for many years to control devices such as distribution line switches. With the rapid dissemination of the Internet in recent years, optical fibers owned by power utility companies have been laid near distribution transformers in metropolitan areas; before these can be fully utilized, however, there is a need to develop an inexpensive, high-speed (a few Mbps) means of communication access for covering a few ten meters to a few hundred meters of the "last mile" to the home. For reasons of economy and convenience, one attractive candidate is power line communication technology, which employs existing power distribution lines that run into homes. This method does not require additional wiring and makes it possible to retrieve information from the power outlets in each room of the home. However, signal transmission characteristics of power lines are poor compared to ordinary communication lines, and high level of noise exists in power lines. Promising methods for improving these types of inferior characteristics are the modulation/demodulation technologies, such as orthogonal frequency division multiplex (OFDM), spread spectrum (SS), and forward error correction (FEC). These methods, however, involve complex signal processing, making it difficult to implement the processing functionality into a single chip.

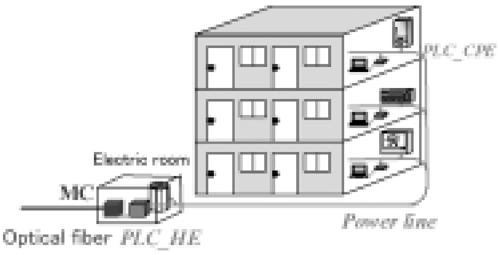
Due to the technology and cost issues, it was difficult to apply these effective technologies and easily achieve high-speed/long-distance communication using power lines. However, thanks to the recent progress of ASIC technology, low-cost, high-performance silicon chips are being developed, and the environment is changing to enable high-speed communication at 10 Mbps or more using power lines. This approach is rapidly attracting attention in Japan and overseas as a communications means of providing Internet access and in-home networks. Some practical applications of PLC already started in countries outside Japan.

Sumitomo Electric started the development of this technology in 1998, and in March 2003 successfully commercialized the world's fastest PLC modem, which achieves a transmission speed of 45 Mbps. In October 2003, Empresa Nacional de Electricidad SA (ENDESA), the largest power utility company in Spain, started commercialization of PLC-based Internet access and Voice over IP (VoIP) service with modems manufactured by Sumitomo Electric. Although it is not possible to use PLC equipment in Japan due to legal regulations, Sumitomo Electric is receiving requests for PLC from countries throughout the world. For the time being, Sumitomo Electric is actively working to expand this business overseas and has started the development of next-generation 200-Mbps PLC modem, the successor to 45-Mbps modem. The related topics will also be discussed in this paper.

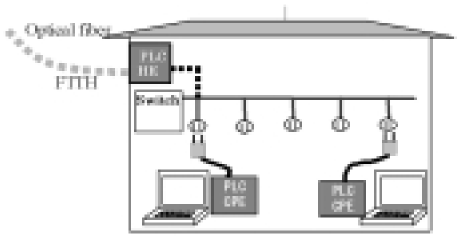
2. Development of 45-Mbps PLC

2-1 Overview of high-speed PLC systems

High-speed PLC is a technique for achieving high-speed Internet access by communicating over existing power distribution lines to cover the distance of a few tens to a few hundreds of meters to the home from a high-speed communication media, such as optical fiber laid to distribution transformer equipment. Figure 1(a) shows an example of transmission via PLC to each customer's home from optical fiber laid to the underground (or indoor) transformer of the underground distribution line. Using the power outlets in the home, as shown in **Fig. 1(b)**, communication can be achieved easily without the need for additional wiring. The approach is therefore promising for applications in an in-home LAN in combination with FTTH and xDSL.



(a) Application in access system



(b) Application in in-home LAN

Fig. 1. Overview of PLC technology

PLC has the advantage that systems can be configured without new wiring. However, there are technical issues that arise when using the lines originally designed for power transmission as the communication lines by superimposing a high-frequency signal on the line. That is, although the distribution lines themselves have not much transmission loss, they have many branches, and impedance matching is not possible at the terminal points (outlets, etc.). The transmission path loss due to branching loss is therefore large, and there is significant attenuation at specific frequency bands due to wave reflection at the terminal points.

Furthermore, various types of electrical devices and appliances are connected to the distribution lines, making the noise level in the line path extremely high. It is necessary to develop communication equipment that can handle this adverse environment.

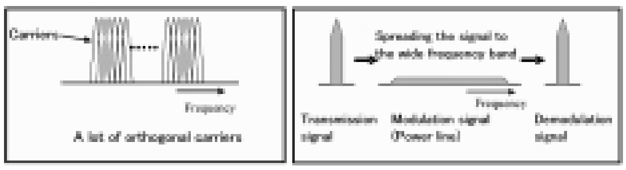
2-1 Modem prototyping

(1) System studies

In the efforts to make PLC practical, the authors felt that it is necessary to achieve not only the convenience of being able to use power outlets in each room for communication, but also high speeds as good as or better than other broadband communication technologies. When the authors started development, broadband communication systems exceeding 1 Mbps, such as ADSL, had already been put into practical use. Under these circumstances, the authors began joint studies with the Tokyo Electric Power Company, Inc., assuming use of the MHz frequency band (2 to 30 MHz). This is despite the fact that in Japan, the Radio Law restricts the frequency band usable for PLC to 450 kHz or less.

As described above, as the result of branching of the distribution line path, transmission characteristics are affected by frequency selective phasing due to the multi-path configuration. In the MHz band, branch length of distribution line path causes significant effects. An environment where frequency selective phasing occurs is very similar to that found in wireless communications. Hence the authors considered using the OFDM and SS systems that are used in wireless communications. As shown in **Fig. 2**, in the OFDM system, numerous carrier waves (a few tens to a few thousands) are densely superimposed. The method requires complex calculations such as Fourier transforms and inverse Fourier transforms, and this tends to make the cost high. In the SS system, the carrier wave is transmitted by spreading it over a wide frequency band and restoring it to the original single carrier wave when it is received. Compared with the OFDM system, it requires only simple calculation processing and the cost is lower, but at present the transmission speed is not so fast.

Another point to be considered is that the high-frequency current flowing in power lines during PLC turns power lines into antennas, which radiate weak radio waves called radiated emission. The MHz band is used for applications such as shortwave broadcasting and amateur radio, and it is necessary to avoid interference to equipment used for those purposes. For this reason, the authors adopted the OFDM system which allows control of output for each carrier. Furthermore, higher speeds can be expected in the future due to the high efficiency of frequency utilization.



(a) OFDM system (b) SS system

Fig. 2. Modulation systems

(2) OFDM prototype modem

The authors prototyped a modem to evaluate the applicability of the OFDM system to PLC. Specifications of the prototype modem are given in **Table 1**, and an external view of the modem is shown in **Photo 1**.

Table 1. Specifications of prototype modem

Item	Specification
Modulation	OFDM
Number of carriers	Approx. 70
Frequency band	Several to 40 MHz (variable)
Bandwidth	4 MHz (Upstream: 2 MHz, Downstream: 2 MHz)
Data rate	8 Mbps (Upstream: 4 Mbps, Downstream: 4 Mbps)
Multi-access method	TDMA/FDD
LAN interface	10BASE-T
Size	Approx. W520×H500×D400 mm

Photo 1. Prototype modem

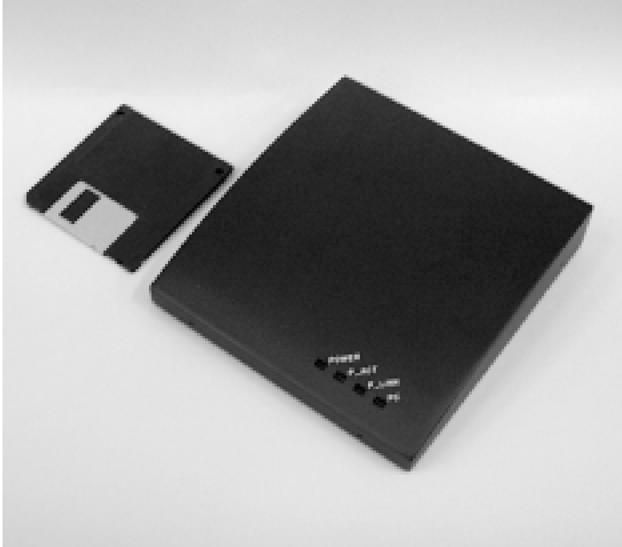


Photo 2. 45-Mbps prototype modem

This modem was designed based on OFDM technology developed by Sumitomo Electric's Wireless Communication Department, with improvements made for use in PLC. The modem has various features, such as a variable signal frequency band and guard interval time. The authors evaluated the utility of the OFDM technology in an experimental environment simulating distribution line's characteristics.

Because the prototype modem was based on a field programmable gate array (FPGA), and making the modem practical would require special-purpose ICs to reduce size and cost, the investigations of the technologies of chip vendors were also conducted at the same time. Already in 2000, there were chip vendors who had perfected dedicated ICs to support OFDM and SS systems. However, the technology of Design of Systems on Silicon (hereafter abbreviated as "DS2") shared many common points with Sumitomo Electric's prototype modem, including the modulation and access systems, despite only having modems at the FPGA level. Sumitomo Electric therefore decided to use chips from DS2 to develop a practical modem.

(3) Development of 45-Mbps modem

The prototype modem the authors had developed using the DS2 chips is shown in **Photo 2**.

The transmission speed of this modem is a maximum of 45 Mbps (upstream: 18 Mbps, downstream: 27 Mbps). High-speed communication of 10 Mbps or more in the downstream can be achieved in an experimental environment simulating a distribution line's characteristics. However, due to the reasons given above, it had been impossible to evaluate the system in an actual environment in Japan and had to conduct field testing overseas. The largest power utility company in Spain, ENDESA, is a leader in the efforts to make PLC practical. ENDESA have a trial site in Zaragoza City, so the authors took equipment there to conduct tests.

As shown in **Fig. 3**, the authors conducted communication testing between the underground transformer room and the watt-hour meter room in an apartment house, and between the meter room and user apartments. In both cases, the authors were able to achieve a downstream speed of 10 Mbps, and thereby confirmed performance in an actual environment.

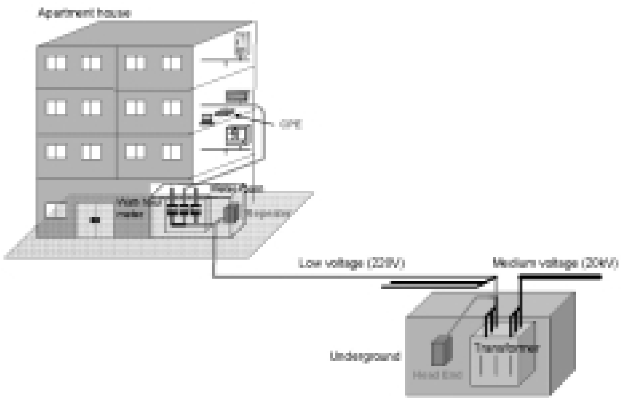


Fig. 3. Experiment configuration at ENDESA

3. Specifications of 45-Mbps PLC modem

The 45-Mbps PLC modem Sumitomo Electric commercialized based on the above prototype is designed to enable, in particular, the maintenance of head end (HE) and repeater (RE) from their front sides. The HE is designed to enable installation of a gigabit Ethernet switch (2-port, Sx or Lx) so that an optical ring or cascade type network can be configured as a backbone. It also has a power supply back-up system, which can provide power for two hours during a power outage when a battery unit is added. Basic specifications are given in **Table 2**.

Table 2. Specifications of the head end and repeater

Item	Specification
Modulation	OFDM
Number of carriers	Max. 1280 (programmable)
Frequency band	2.5 MHz to 11.8 MHz (Link1) 13.8 MHz to 22.8 MHz (Link2)
Bandwidth	6.3 MHz (Upstream: 2.5 MHz, downstream: 3.8 MHz)
Data rate	Max.45 Mbps (Upstream: 18 Mbps, Downstream: 27 Mbps)
Multi-access method	TDMA/FDD
Transmission power	Max. -40 dBm/Hz
LAN interface	100BASE-Tx/10BASE-T (HE: Gigabit-Ethernet is available (as option))
Console port	1 port (for maintenance)
Switch feature	Available (supporting L2 switch and spanning tree)
Operating temperature	0 to 55℃
Allowable humidity	90% without condensation
AC input	AC 100-240 V 50/60 Hz
Power backup	Two hours (only HE, as option)
Remote management	Available with SNMPv2
Size	HE: W430×H400×D300 mm Battery box: W223×H301×D250 mm (as option)
	RE: W270×H386×D232 mm
Standard	CE mark (EN60950, EN55022, EN55024)

Table 3. Specifications of the customer premises equipment

Item	Specification
Modulation	OFDM
Number of carriers	Max. 1280 (programmable)
Frequency band	13.8 MHz to 22.8 MHz (Link2)
Bandwidth	6.3 MHz (Upstream: 2.5 MHz, Downstream: 3.8 MHz)
Data rate	Max. 45 Mbps (Upstream: 18 Mbps, Downstream: 27 Mbps)
Multi-access method	TDMA/FDD
Transmission power	Max. -50 dBm/Hz
Interface	100BASE-Tx/10BASE-T 1port USB (1.0) 1port Telephone (RJ11) 1port
Operation temperature	0 to 45℃
Allowable humidity	90% without condensation
AC input	AC 100-240 V 50/60 Hz (for coupling unit)
VoIP protocol	H.323 v2 (RAS, H.225, H.245)
Size	W42×H185×D217 mm (coupling unit: W75×H45×D120 mm)
Standard	CE mark (EN60950, EN55022, EN55024)

Photo 3. Customer premises equipment

4. Regulations in Japan

Because the Radio Law in Japan only allows the superposition of the signals of 450 kHz or less on power lines, the law needs to be amended in order to use the 2-MHz to 30-MHz band. However, in Japan, voices have been raised against the amendment of the law due to worries about generating noises in such equipment used for shortwave broadcasts and amateur radio.

In April 2002, a Research Group on Power Line Communication Equipment was established within the Ministry of Public Management, Home Affairs, Posts and Telecommunications, and the feasibility of opening this band to PLC was debated to achieve PLC commercialization. However, it was decided that there is still a possibility of interference between the radiated emission from PLC and these types of wireless equipment. In July, a conclusion was reached that it is premature to open the 2-MHz to 30-MHz band to PLC. Although Sumitomo Electric is continuing its efforts to amend the Radio Law and achieve practical use of PLC in Japan, it has decided to first deploy its PLC system overseas where the practical systems can be implemented without the need for amending the law.

5. Overseas Expansion

The power utility company that is making the most active efforts toward PLC is the aforementioned ENDESA (Spain). The metropolitan areas of Spain and other European countries have a high percentage of underground power lines, and high levels of funding are required to lay optical fiber. Therefore, these areas present an excellent opportunity for disseminating PLC as a means of high-speed communication. Starting in 2002, Sumitomo Electric conducted field evaluation of the prototype modem and measurement of radiated emission in ENDESA's area, and thereby developed a good relationship with this company. Upon hearing ENDESA would select a modem manufacturer for the commercialization of PLC services in autumn 2002, Sumitomo Electric immediately brought its modem into the trial site.

Performance evaluation was conducted over a few months at ENDESA. The high-speed communication performance and long-term reliability of Sumitomo Electric modem in the field were highly evaluated, and ENDESA decided to use the modem. Sumitomo Electric subsequently started delivery of commercial modems in 2003. As shown in **Fig. 4**, the PLC system for ENDESA is large scale, with PLC applied not only to low-voltage (LV) distribution lines but also to medium-voltage (MV) distribution lines. In addition to a broadband Internet connection service, the system also provides an IP telephone service, attracting attention from around the world. When the PLC service in Zaragoza became commercialized in October 2003, more than 1000 households subscribed for the commercial service and the number of subscribers is still increasing. ENDESA has plans to start a service in Barcelona from January 2004.

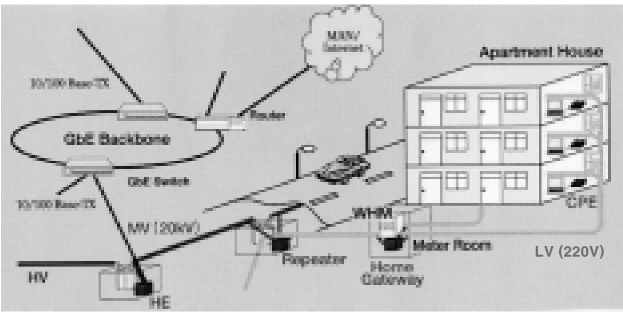


Fig. 4. Example of the power line communication system of ENDESA

Sumitomo Electric began delivering modems in June 2003 and have already delivered the units to about 900 households for commercial service in Zaragoza. Sumitomo Electric plans to continue deliveries in response to additional future demand in Zaragoza and the new service in Barcelona.

The modems Sumitomo Electric has recently delivered provide commercial high-speed access communication service (Internet and IP telephone) to apartment houses. Communication signals are injected into high-voltage (20 kV) underground power cables in a transformer room located inside a manhole. The system is comprised of head ends (HE) that function as connection point with the backbone optical network, repeaters (RP) that amplify and repeat signals en route, home gateways (HG) that are provided in the meter rooms of apartment houses, and customer premises equipment (CPE).

6. Conclusions

In this paper the development of high-speed modems has been described. The utility of this PLC technology is currently being verified in Spain, and is attracting attention throughout the world.

Sumitomo Electric is working to develop the PLC modems with even higher speed. It is expected that these high-speed modems will achieve a communication speed of 200 Mbps, which is on a par with that of optical communications. The main specifications and features of this high-speed modem are as follows.

<Main specifications>
- Modulation: OFDM
- Frequency band: 3 to 34 MHz (Bandwidth: Max. 30 MHz (programmable))
- Data rate: Max. 200 Mbps (@BW= 30 Mz)

<Features>
- High speed: 200 Mbps
- Small size and low cost: Very highly integrated ASIC. No host CPU.
- High performance: Gigabit Ethernet available. Wide dynamic range and flexible frequency configuration.

Sumitomo Electric plans to achieve early completion of the development of the 200-Mbps modem, in which not only higher speed but also lower cost, greater compactness, and higher functionality can be achieved. After the modem shifts into mass production, Sumitomo Electric will conduct sales promotions to power utility companies and communications companies throughout the world, and make a strong effort to cultivate the overseas markets.

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