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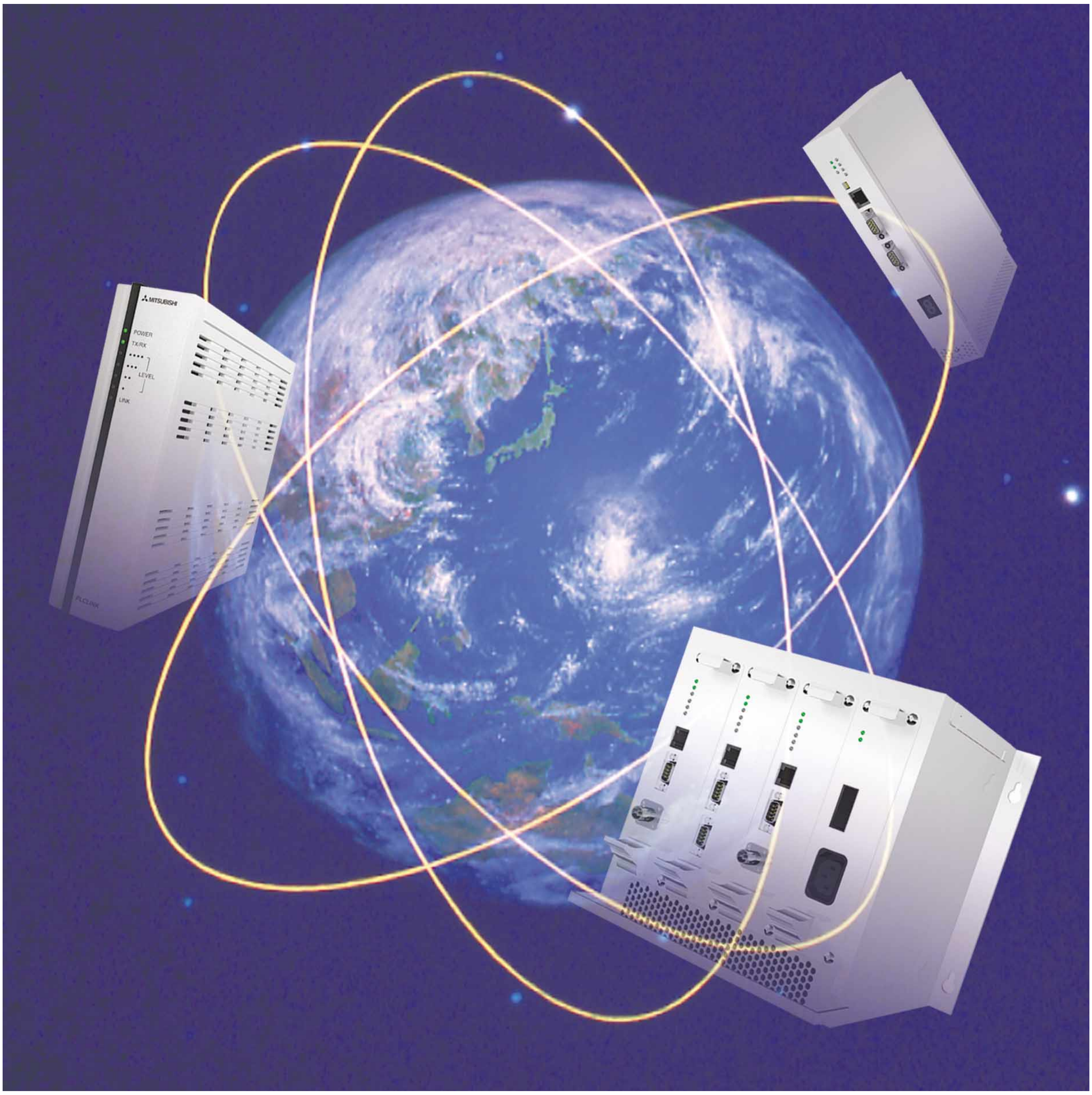
High Speed Power Line Communication Technology



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Changes for the Better

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High Speed Power Line Communication Technology

Cover Story

The access-type PLC network system is designed to form an access network by using already-existing MV and LV power lines, and provides end-users with Internet-access and VoIP services. The PLC access-type network system consists of MV (medium-voltage) nodes that are equipped with an interface with a backbone optical network, CPE (Customer Premises Equipment), and REPs (repeaters) that relay signals between MV nodes and CPE.

The figure shows MV (medium-voltage) nodes、REP, and CPE. The user can have high-speed Internet access or use high-speed digital services such as image downloading and video streaming by connecting a personal computer to an Ethernet or a USB interface of the CPE, and thus accessing his/her ISP (Internet service provider). At the same time, VoIP service can be subscribed to by connecting an analog telephone set to the CPE's telephone interface.

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CONTENTS

Technical Reports

R&D P. Report

Technical Highlight

Overview

Author: *Akira Horiguchi**

The widespread use of broadband communication, has been encaged worldwide as a basic infrastructure of information communication for society. Several communication means are available e. g. cable television (CATV), ADSL or high-speed PLC. Some countries have few fixed telephone lines, while in others CATV is rare. Therefore, ADSL or CATV alone cannot support the proliferation of broadband access.

In contrast, high-speed PLC technology uses existing power lines for communication and so obviates the need for stringing new communication cables and is a viable means of increasing broadband access.

Communication using power lines has a long history; indeed, the idea has been around since the beginning of the twentieth century. In the 1980s, very low-speed PLC systems were used for controlling electronic equipment such as light dimmers. However, since the characteristics for power lines to serve as a communications means have not been defined and because the characteristics of power lines will change when power equipment and household electrical appliances are connected to them, PLC systems are still not widely used.

In spite of such problems, high-speed PLC is becoming economically viable due to advances in analog circuit technology, digital signal-processing technology, and large-scale integration (LSI) technology. In recent years, PLC systems operating at up to 200 Mbps have been announced, and R&D is currently underway to increase the speed further.

In the future IT society, network access will be available anywhere and to everyone. It is firmly believed that high-speed PLC will contribute toward achieving such objective.

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Perspective on Power Line Communication

Authors: *Tadashi Matsuzaki*[*] and *Shinji Tanabe*[**]

Power Line Communication (PLC) is a type of communication using power line in which modulated radio-frequency signals are transmitted. Thanks to recent advances in digital communications technology, it is becoming possible to achieve communications speeds in excess of 100Mbps. The potential implementation of PLC, with the main focus on Internet access, is being studied in various European and Asian countries as well as in the United States, and huge markets have begun forming.

1. Power Line Network

Power lines assume a wide variety of network topologies because their length, number of branches, power line equipment such as connected capacitor bank are vary from area to area, country to country. They were not originally intended for use of data networking as broadband media, thus no particular requirements were not considered. As for materials of electric wire there are differences between those used for distribution lines and in home line respectively, as well as differences among countries. Compounding the problems, in many cases, noise is produced by equipment connected to power line, meaning the signal-transmission characteristics of power lines for radio-frequency vary according to location, as well as time. When the characteristics of power lines are seen from the perspective of communications on a frequency-band basis, Bands below 2 MHz present adverse conditions due to reasons of high noise and low impedance and difficult to achieve high speed communication. On the other hand, the 2-to-30-MHz range is, with a relatively low level of noise, and possible to use as a broadband media, even though signal transmissions suffer losses in this range.

2. PLC Communications Technology

Generally speaking, communications functionality is defined using a layered model. PLC-specific communications technology centers on the lowermost physical and MAC (Media Access Control) layers. The physical layer consists of modulation methods and synchronization that can be applied to the communications characteristics of power lines. Among modulation methods applicable for PLC modems, the following three methods are typical: a single carrier method that relies on phase-shift-keying (PSK) or frequency-shift-keying (FSK) modulation, spread-spectrum communication which is also adopted by cellular phones and similar equipment for CDMA (Code Division Multiple Access), and OFDM (Orthogonal Frequency Division Multiplexing) which is also used by ADSL and digital broadcasting. In the case of high speed PLC, many chipmakers are adopting OFDM. OFDM is a method whereby each carrier is placed in such a manner that its bandwidth overlaps those of adjacent carriers by exploiting orthogonality. Since this method permits the use of a few hundred to a few thousand carriers simultaneously within a limited bandwidth, its frequency utilization efficiency is very high and transfer rates ranging from several tens to several hundreds of Mbps are possible. Furthermore, flexible bandwidth utilization is also possible, for example, through changing the number of bits to be allotted to each individual carrier, depending on the condition of transmission paths and avoiding particular carriers on a selective basis to ensure peaceful coexistence with pre-existing communications bands. An overview of OFDM technology is shown in Fig. 1.

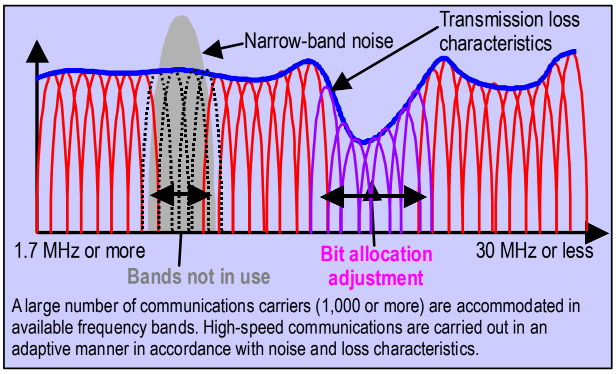

Fig. 1 OFDM technology

In addition, as an important technology for use on the physical layer, there is coupling circuitry with which to inject/extract signals to/from power lines. In the case of power distribution and branch lines, technology exists enabling the installation of PLC modems without having to interrupt power transmission.

In the case of PLC, multiple modems are connected in a bus or star topology. In order to perform communication through shared bandwidth on power lines, it is necessary to implement media-access control. Since power line-based communication cannot take the form of simple bus type communication as seen Ethernet bus topology, it is not possible to use collision detection like CSMA/CD (Carrier Sense Multiple Access

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with Collision Detection). When it comes to simple data transmissions alone, CSMA/CD is quite often employed. However, when offering a bandwidth guarantee to transmit information such as video streams, more sophisticated polling and token-passing techniques are also used.

Since modulation schemes alone often cannot ensure adequate communication quality, powerful error correction codes along with error detection codes are employed. For data that requires further-enhanced reliability, re-transmissions are used additionally. This functionality are realized on the MAC layer. Moreover, since power lines are shared by multiple modems for communication, anti-wiretapping measures are implemented using encryption.

When designing a communications network with PLC, there are power line-specific issues to be addressed such as power-line topology and the necessity to do routing to another power system in the event of power distribution fault such as short circuit. However, by virtue of advances in automated setup technology performed by routers and layer-2 switches, resilient routing technology and network management technology, it is becoming possible to use PLC as a large-scale broadband network economically through the use of equipment incorporating these technologies.

In order to design PLC network, it is important to estimate the power line characteristics for radio band frequency by the information of power line topology such as line length, number of branches, equipment such as capacitor bank which is connected to power line.

Thanks to many experiences of field trials having been conducted in recent years and recent advances in theoretical analysis of power line characteristics for radio band frequency, PLC technology has been progressing when using power lines as broadband media. Provisioning tool which estimate broadband speed by the topology information, is being developed.

By following the steps shown in Fig. 2, Mitsubishi Electric Corporation has been developing high-speed PLC systems by taking the characteristics of power lines into consideration.

3. High-speed PLC-based Service

For PLC-enabled business models, access-network and in home LANs are considered to be the most promising.

The expression "access-network" refers to a form of service allowing Internet connectivity through power lines and can prove a potent tool for areas where telephone lines are long and ADSL cannot provide adequate speed or for areas where optical fibers cannot be installed. With distribution substations and the like serving as base points, Internet access is achieved by means of PLC, using distribution lines. An example of access-type PLC is shown in Fig. 3. In the case of an access-network, a range of services conceivable for implementation as well as Internet-access service include automatic meter-reading (AMR), energy management, and leakage current and power theft detection, etc.

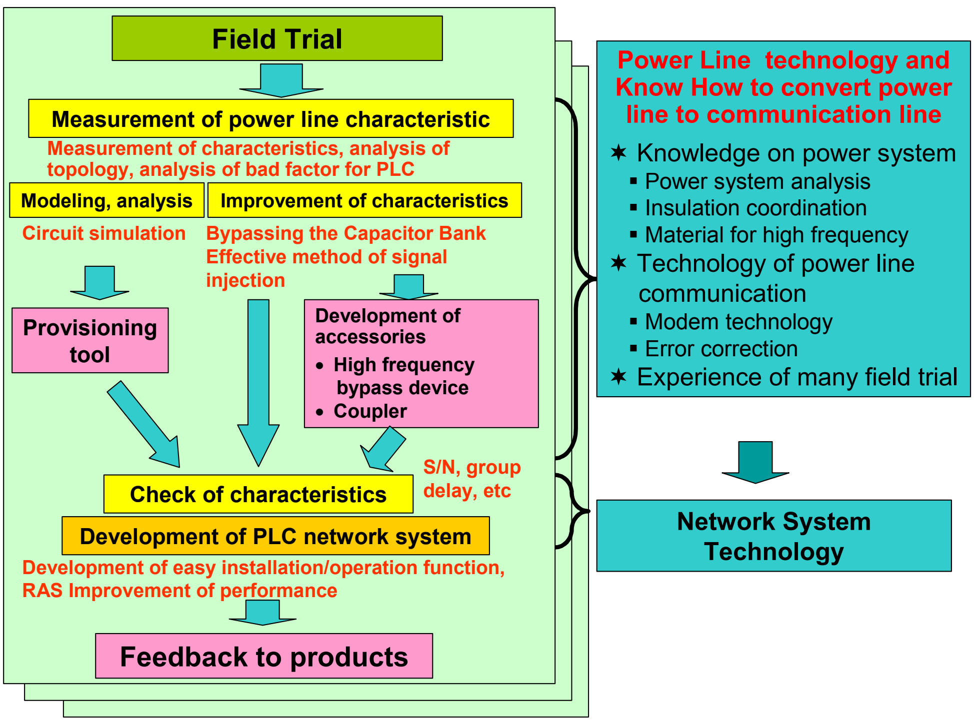

Fig. 2 PLC system development process

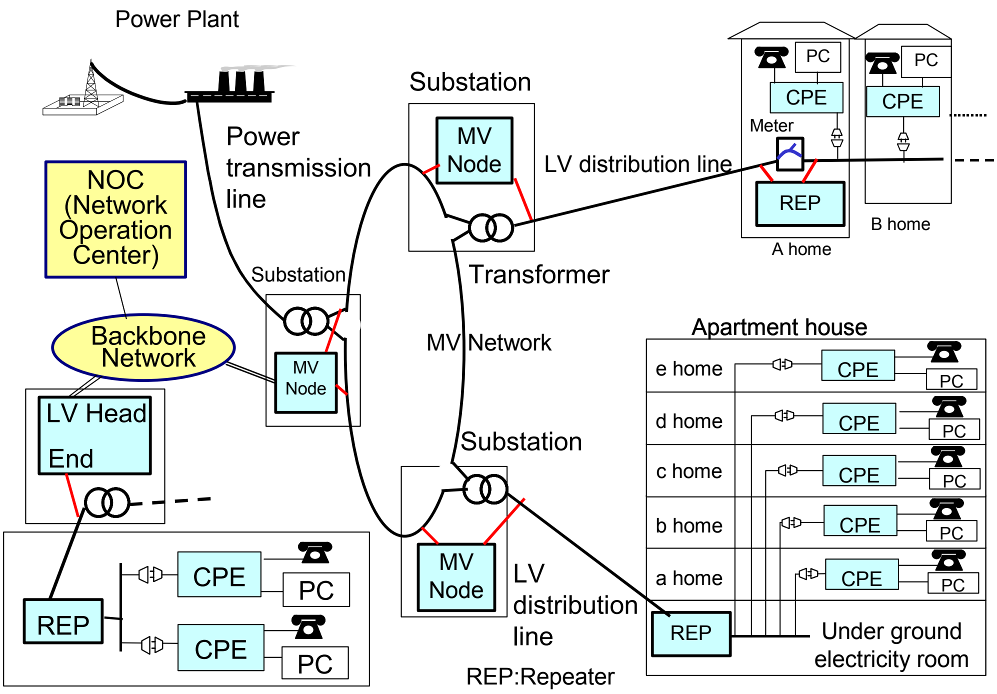

Fig. 3 Internet access using existing power line

On the other hand, in home LAN is intended to allow communications to take place using indoor power lines. Promising uses of home network applications which would enable Internet, printer, set top box, digital video recorder and digital audio system to be shared among multiple personal computers, and images, movies and music to be enjoyed in any room of the home. Moreover, if inexpensive PLC chips are realized and become available, they will be able to be embedded in sensors, refrigerators, air conditioners and similar equipment, so that simply plugging in such units would configure a network easily and inexpensively, allowing them to work interactively for home security and automation.

PLC technology has application not only for access-network in home networks but also for applications to be carried by using wire not originally intended for communicative purposes. By expanding the scope of application through the use of non-communications infrastructures for such as roads, railroads, gas and waterworks as well as metal wiring installed in automobiles, railway cars and vessels, PLC holds out the possibility of broadening its application to new forms of service.

Great expectations are being pinned on PLC, which makes possible to access high-speed Internet and in home LANs through existing power lines. Given this situation, it is important to continue striving to develop high-quality products that enable easy network installation and working toward the realization of mass production to enable low cost. Also called for is deregulation, concerning the efficient use of frequency bands and the standardization of application technology. Mitsubishi Electric Corporation has been comprehensively involved in wide-ranging areas of technology and providing total solutions to high-speed PLC.

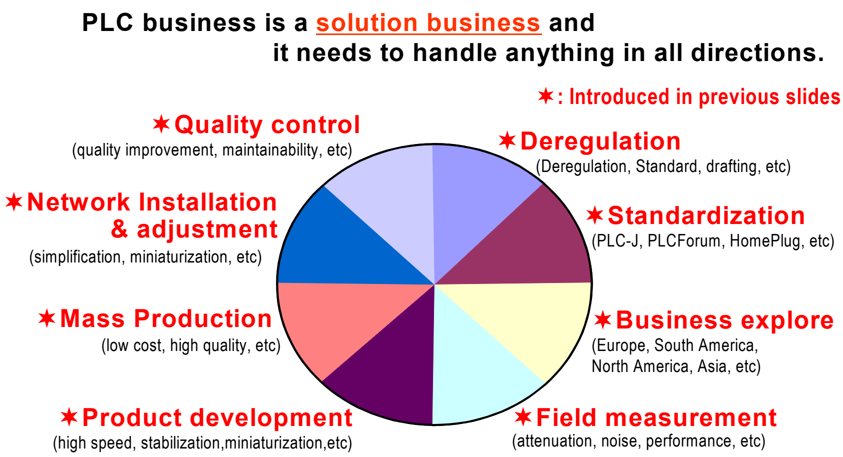

Fig. 4 Technology chart for total PLC system

World Trends in Power Line Communication

Authors: *Yoshinori Mizugai** and *Masahiro Oya***

High-speed PLC technology using power lines is expected to serve as a highly potential means of popularizing broadband access and, thereby, bridging the digital divide. Field trials are being carried out in a number of countries and some have reached commercial fruition. This paper discusses market trends in the PLC business in various countries, along with business models.

1. Trends in High-speed PLC Systems in Different Countries

At present, many countries are moving toward the commercialization of PLC for the primary purpose of providing Internet access. As shown in Fig. 1, a PLC system consists of MV node repeaters, CPE (Customer Premises Equipment) installed on the premises of customers, PLC signal coupling units, and a network management system which is responsible for the operation management of equipment.

In European countries, high-speed PLC experiments have been conducted and have reached the commercialization stage in Spain, Germany, Switzerland, the United Kingdom as well as other countries. Table 1 shows the status of the implementation of PLC service in representative countries. In Spain, ENDESA began service in Saragossa and Barcelona in 2003 while Iberdrola went into service in Madrid and Valencia the same year. PPC (Power Plus Communications) AG in Germany, SSE (Scottish Southern Electric) in the United Kingdom, and others have also launched commercialization. As the demand for high-speed service grows due to video streaming, Video on Demand (VoD), virtual conferencing applications and so forth, the need for high-speed access is expected to grow.

In the United States, PLC is referred to as BPL (Broadband over Powerlines) and promoting the availability of broadband Internet access in suburban areas, alongside access for cable and XDSL, is one of the PLC objectives in this country.

PLC-based Internet access experiments are being planned or implemented in various nationwide locations in the United States.

Table 1 Worldwide PLC trial and commercial initiatives

Country (Area)		State of power distribution lines	State of PLC penetration
Europe	Spain	Each MV/LV transformer supplies power to about 300 homes. The percentage of underground distribution lines is high.	Electrical power companies ENDESA and Iberdrola began commercial service in 2003.
	France		Electrical power company EDF is conducting testing.
	United Kingdom		Electrical power company SSE began access-type service.
	Germany		Electrical power company PPC is providing a commercial access-type service.
North America		Each MV/LV transformer services 5 to 10 households.	Now that the FCC has declared the policy for promoting Internet access by power lines, PLC penetration is expected to accelerate down the road.
South America		Power is supplied from overhead LV distribution lines.	In Chile and Mexico, trials are underway.
Asia	Singapore and Malaysia	Mainly Underground distribution lines. There are many high rises and office buildings.	Trials are in progress.
	China	Underground power lines in big cities, but overhead distribution lines are used in all other areas.	A demonstration trial is being conducted in Beijing, involving some 2,000 households.
	Hong Kong	Underground distribution lines. There are many high rises and office buildings.	Practical service is being provided to high rises, hotels, etc.
	South Korea	More of the same situation as Japan	The Radio Law, similar to the corresponding one in Japan, was relaxed.
Japan		Both high-voltage (medium-voltage by international standards) and low-voltage distribution lines are predominantly of the overhead type. In urban areas, underground cables are used.	By the Radio Law and its work-execution regulations (ministerial ordinance), use is only permitted of equipment designed to use frequency bands from 10 to 450 kHz. With effect from January 26 of 2004, the ministerial ordinance was revised to permit the performance of experiments with technology to reduce the leakage of electrical fields in the 2-to-30-MHz range.

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In addition, studies are being actively conducted at the United Power Line Council (UPLC), the Power Line Communications Association (PLCA) and others to pave the way for practical use. Among others, the city of Manassas, a member of the American Public Power Association (APPA), has commercialized BPL ahead of all others in the United States as a city-operated electric utility.

In Asia, South America and others, there are many countries where the telephone service is not highly available. In such countries, the use of power lines has already achieved high rates of penetration as it is highly beneficial. Therefore, the feasibility studies on PLC introduction are being actively carried out.

2. Status of PLC Implementation in Different Countries

In Europe, sponsored by the European Commission, the Open PLC European Research Alliance (OPERA), a high-speed PLC project, commenced its activity in January of 2004. Consisting of a total of 36 members such as electrical power companies, manufacturers, research institutions and consultants, OPERA has plans to develop unified European PLC standards. The European Commission's long-range objective is to develop broadband markets in Europe to implement PLC as a technology to complement DSL and cable access. By taking part in this Project, Mitsubishi Electric Corporation, has been playing an active role in developing and standardizing high-speed PLC technology.

Furthermore, participating in the PLC-Forum and the HomePlug Powerline Alliance, both of which are international PCL-promotion organizations, and Japan's PLC-J, Mitsubishi Electric has been contributing to the development and standardization of high-speed PLC technology.

3. System Design With Consideration of Electrical power System Characteristics

Electrical power systems vary in configuration from country to country depending on the state of the respective power sources and loads. The practice of using medium-voltage (11-to-33kV) and low-voltage (100-to-400V) power distribution lines as high-speed PLC communication means and optical networks as backbone networks is commonplace.

Each medium-voltage power system is in a loop configuration as shown in Fig. 1. Under normal service conditions, they can be broadly divided into open-loop systems, each with a single opening, and tree systems with radial arranged lines. In the case of tree systems, connection points for adjacent systems are provided in order that paths/loads may be switched when necessary for operation.

Since the distribution power network connections change due to switching associated with the activation of protection relays or operation, thus prompting communication-path changes, it is necessary to construct a network system suitably equipped to deal with such changes.

Additionally, in terms of distribution line types, there are underground cables and overhead power distribution lines. Where transformers are concerned, they can be divided into pole-mounted transformers, pad-mounted transformers and indoor transformers.

The number of customers hooked up to MV/LV transformers varies according to country and location and has an impact on the communications characteristics and economic viability of systems. Therefore, it is important to implement technology to determine the characteristics of power distribution lines and use those lines for communications purposes. Drawing on our experience based on participation in global field trials, we at Mitsubishi Electric Corporation have been involved in the design of PLC equipment placements and network management systems by taking into consideration a combination of conditions, such as network configuration, characteristics, operational conditions and the characteristics of network equipment.

4. Efforts to Pave the Way for Deregulation

Since the 2-to-30-MHz band, which is to be used for PLC applications, is assigned to shortwave radio broadcasting, amateur ham radio stations and others, the application of high-speed PLC should be implemented with appropriate consideration given to possible EMC (electromagnetic compatibility) problems -- such as to ensure that high-speed PLC has virtually no impact on such shortwave traffic. In order to suppress electromagnetic fields leaking from power lines, it is also necessary to develop PLC modems that generate a minimal amount of common-mode current. At the same time, measures should be taken on the power-line side as well. We, Mitsubishi Electric engineers, have been working to develop measures to reduce leakage in the shape of electric fields by performing various kinds of experiments to determine the leakage characteristics of power lines.

5. Future Models

High-speed PLC applications of the future include Automatic Meter Reading (AMR), power system fault detection, power theft detection, leakage current detection, and the measurement/control/energy-management of electrical power equipment for electrical power companies, as well as home security, the remote-monitoring/control of electrical household appliances, online games, home networks, and billing services for consumers in general.

Figure 2 shows an example of a remote-metering

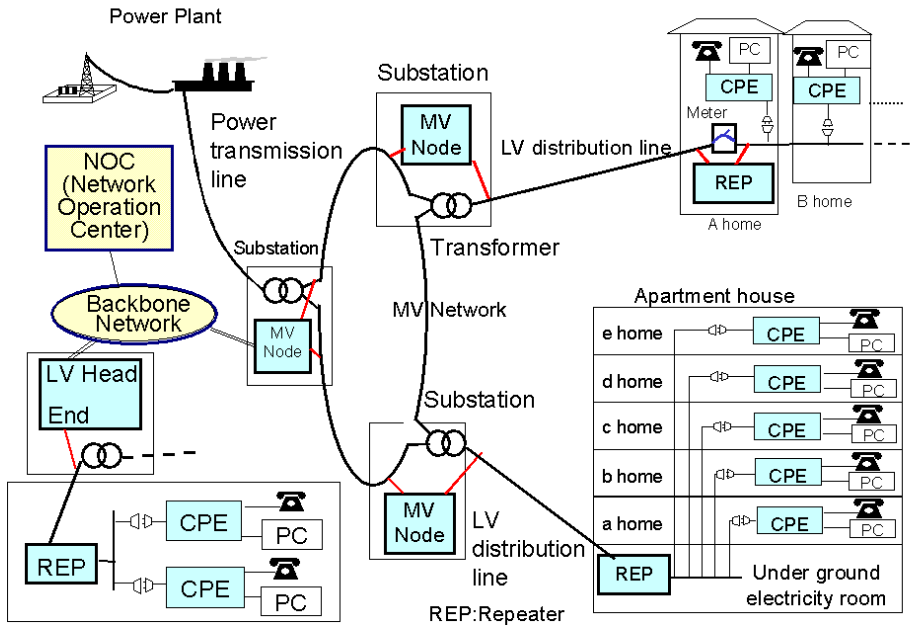

Fig. 1 PLC Access and Distribution Network

application whereby each household's charges are determined on a time slot-by-slot basis and switch ON/OFF actuation is remotely performed.

Figure 3 shows an example of a network that enables high-speed, high-capacity communications among home AV equipment, personal computers and similar equipment.

PLC technology has application not just for power lines but also cables and similar originally not intended for communicative applications. Expanding the scope of application of PLC through the use of non-communicative infrastructural networks such as roads, railroad rails, gas pipelines and waterworks as well as pre-existing metallic wiring installed within automobiles, rolling stock and vessels will open up new applicatory possibilities for an increasing range of new service forms. We are convinced that in future, PLC's application areas will continue to increase and become a key technology to support the broadband society.

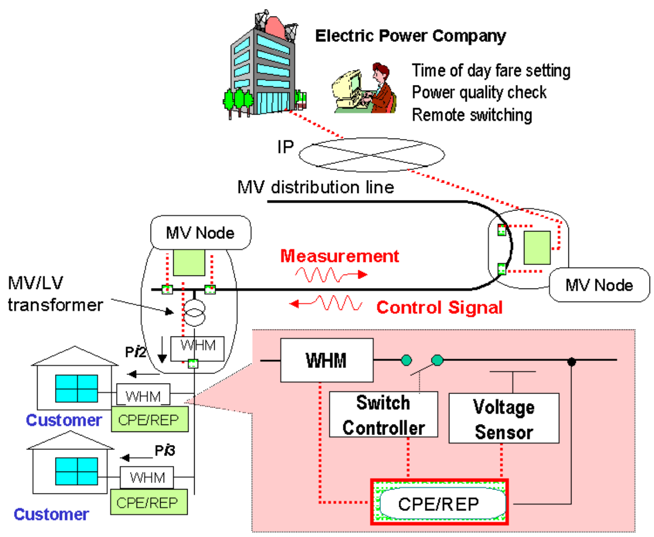

Fig. 2 Service model for utility company

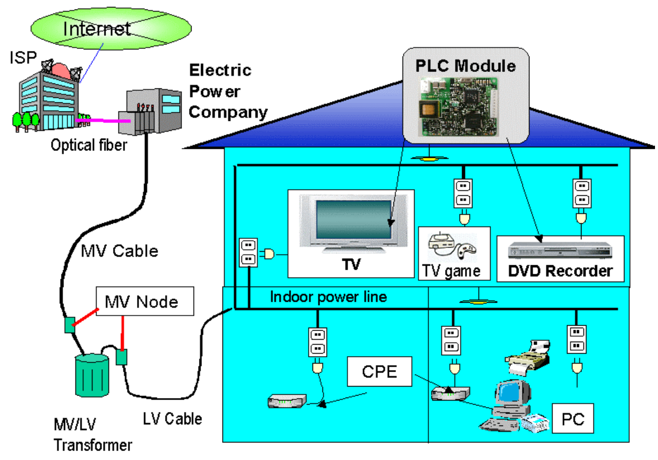

Fig. 3 Broadband home network

High Speed PLC for Access Network System

Authors: *Sawako Ojima** and *Yasuaki Hori**

We have newly developed a high-speed 200Mbps power-line communication (PLC) system, "PLC-AW Series," which makes it possible to configure access-type communications systems by using medium-voltage (12kV to 21kV) and low-voltage (120/240V). This article introduces this PLC-AW Series.

1. System Overview

Figure 1 shows a configuration of an access-type high-speed PLC network system. The access-type high-speed PLC network system is designed to form an access network by using already-existing MV and LV power lines, and provides end-users with Internet-access and VoIP services.

The PLC access-type network system consists of MV (middle-voltage) node that is equipped with an interface with a backbone optical network, CPE (Customer Premises Equipment), REPs (repeaters) that relay signals between MV nodes and CPE, and signal coupling units that are responsible for coupling high-frequency signals to power lines. The user can have high-speed Internet access or use high-speed digital services such as image downloading and video streaming by connecting personal computer to an Ethernet (RJ45) or a USB interface of CPE and thus accessing his/her ISP (Internet service provider). At the same time, VoIP service can be subscribed by connecting an analog telephone set to the CPE's telephone interface (RJ11).

2. Features of PLC Technology

High-speed power line communication is a technology with which uses already installed power lines as a high-speed communications infrastructure. When it comes to conventional communication lines such as optical fibers and coaxial cables, their transmission characteristics are standardized, and problems like attenuation and impedance mismatches have been solved beforehand. On the other hand, when power lines that were originally strung to supply electric power are to be used as communications paths, a high degree of engineering expertise is required in order to transfer high-frequency signals at high speeds over those power lines because their individual transmission loss characteristics (See Fig. 2), impedance, etc vary greatly.

Factors that contribute to the deterioration of the signal-transmission characteristics of power lines include the power lines' own losses, impacts from power-distribution devices that are connected to the power lines, noise emanated from those power-distribution devices, home electric appliances and the like, and multi-path caused by reflections which occur on account of the presence of branch lines installed for the purpose of supplying power. Coping with these adverse characteristics that are peculiar to power lines and thereby providing various kinds of services such as data, voice, image and video at high transmission rates and with high stability are technical challenges involved in the development of a high-speed access-type PLC system.

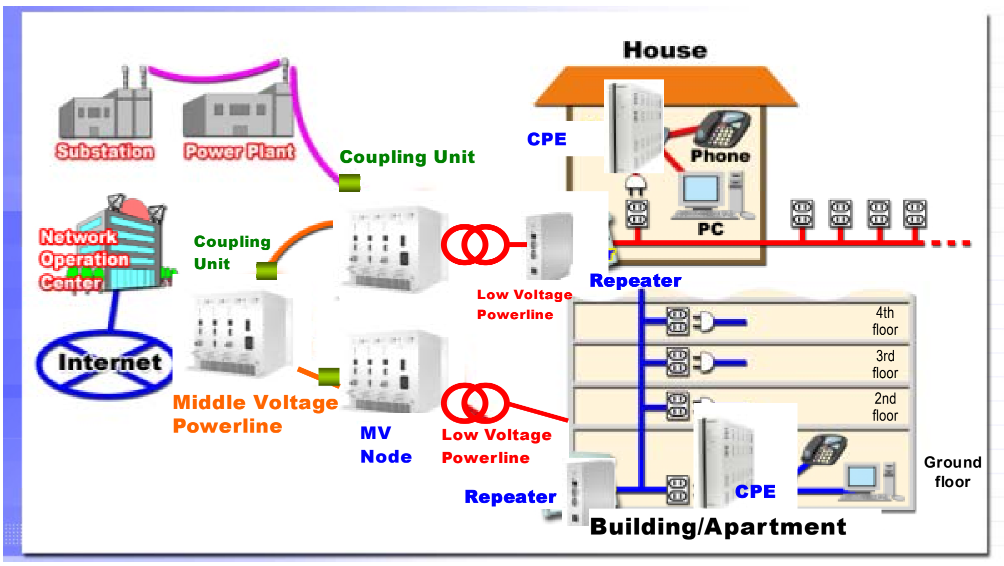

Fig. 1 High speed PLC access network system

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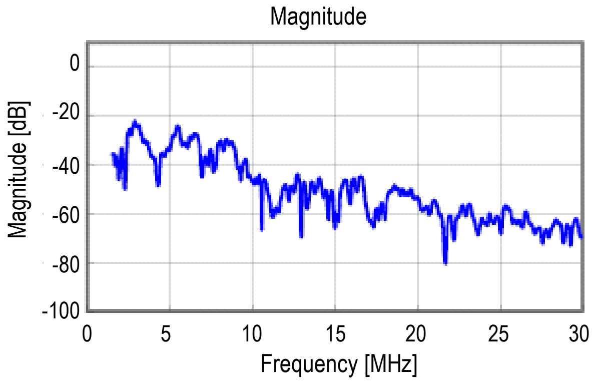

Fig. 2 Powerline Attenuation Characteristics

In addition, equipment installation conditions to be met include the securing of safety from high voltage, specifications to be applied under high-temperature outdoor conditions, and ease of installation.

The "PLC-AW Series" introduced this time has overcome the above-mentioned engineering challenges and embodies excellent equipment specifications, including a physical communications speed of a high 200 Mbps, environmental resistance and excellent stability.

3. Features of the 200-Mbps "PLC-AW Series"

The major features of the PLC-AW Series are as follows:

a. Achievement of a physical speed of 200 Mbps (with the OFDM scheme)
b. Enhancement of Quality-of-Service (QoS) functionality
c. Environmental resistance
d. Enhancement of ease of installation
e. Reduction of physical size
f. Enhancement of RAS functionality

Common system specifications are shown in Table 1.

As for communications performance, a speedup to a maximum physical speed of 200 Mbps has been achieved as opposed to 45 Mbps, which is the top speed registered by Mitsubishi Electric's current unit "PLC-AM Series". The modulation method adopted is OFDM (Orthogonal Frequency Division Multiplexing). Under OFDM, the enhancement of frequency utilization efficiency is achieved through the use of a large number of carriers that are orthogonally allocated to one another. This, in turn, enhanced transmission efficiency in the face of power line attenuation characteristics that are subject to wild fluctuations.

Table 1 PLC-AW series modem specification

Item	Specification
Frequency range	2~30 MHz
Physical speed	200 Mbps
Secondary modulation method	OFDM (Orthogonal Frequency Division Multiplexing)
Primary modulation method	QAM (Quadrature Amplitude Modulation)
Output power	-50 dBm/Hz
Access protocol method	Original TDM (Time Division Multiplexing)
Management protocol	TCP/IP, Telnet, SNMP, NTP,..
Standards	CE Marking FCC, UL

The attenuation characteristics of power lines are not linear as shown in Fig. 2 and undergo fluctuations as a function of frequency because of factors such as the inductive (L) and capacitive (C) components of distribution lines. By adopting OFDM (Orthogonal Frequency Division Multiplexing), carriers are assigned across a wide frequency spectrum going up to a ceiling of 30 MHz. As shown in Fig. 3, the transmission efficiency is enhanced by adaptively capturing the SNR (Signal to Noise Ratio) of each individual carrier in response to fluctuating attenuation characteristics and adaptively performing QAM (Quadrature Amplitude Modulation) on each of those carriers in relation to its SNR value.

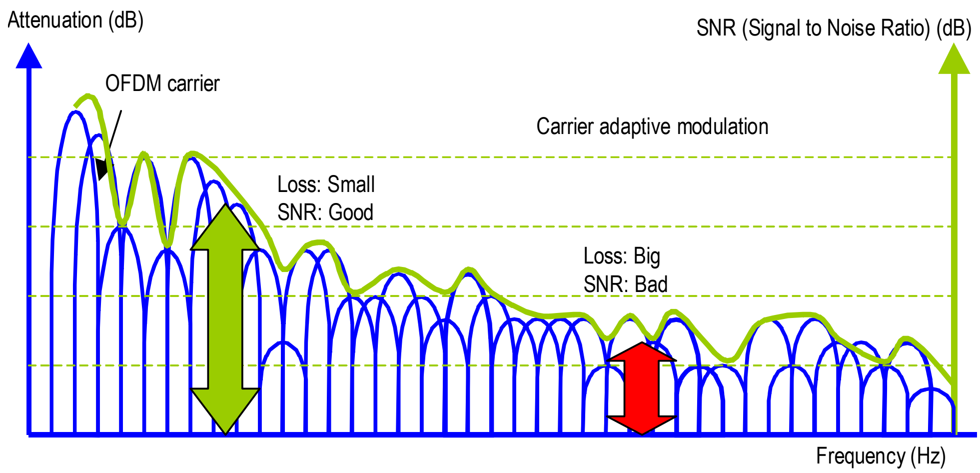

Fig. 3 OFDM carrier allocation and SNR (Signal to Noise Ratio)

3.1 Specifications of Equipment

3.1.1 MV Node Specifications

Each MV node is equipped with an Ethernet backbone interface with a maximum transfer rate of 1 Gbps as a communications interface and PLC interfaces through which to connect to MV lines by way of signal coupling units.

As for environmental conditions, since MV nodes are installed on underground transformers and on outdoor utility poles, environmental condition has been realized in keeping with high-temperature outdoor specifications (ambient temperatures of -10°C to 60°C and dust-proofing).

As installation conditions, wall mounting is used for ease of installation. Through the adoption of front-access insertion and removal of boards and front placement of cables, maintainability and operability has been enhanced. Figure 4 shows a photo and Table 2 shows major specifications.

Fig. 4 MV node (PLC-AW series)

Table 2 MV Node specification

Item	Specification
Installation point	MV (12~21 kV) LV (120~240 V)
Environmental condition	-10~50°C 0~95 %RH
Size	W: 265 × D: 234 × H: 295 (mm)
Communication Interface	PLC Interface 10/100 Mbps Ethernet Interface

3.1.2 Repeater (REP) Specifications

REP is a signal-relaying equipment that is responsible for relaying PLC signals between MV node and CPE. Being installed in places where there is large attenuation, repeaters perform signal relaying.

As for environmental conditions, a temperature resistance of -10°C to 60°C has been achieved to permit installation in enclosed limited spaces like electrical meter rooms.

As to ease-of-installation conditions, a 2-way wall-mount design permitting selection between side mounting and backplane mounting has been adopted. In addition, thickness and size reductions have been achieved. Figure 5 shows a photo and Table 3 shows major specifications.

Fig. 5 REP (Repeater) (PLC-AW series)

Table 3 REP (Repeater specification)

Item	Specification
Installation point	Meter Room
Environmental condition	-10~50°C 0~95 %RH
Size	W: 43 × D: 176 × H: 290 (mm)
Communication Interface	PLC Interface 10/100 Mbps Ethernet Interface

3.1.3 CPE Specifications

Installed inside the home of the user, the CPE serves as an interface between his/her personal computer and analog telephone line and, thereby, provides him/her with Internet-access and VoIP services. Figure 6 shows a photo and Table 4 shows major specifications.

Fig. 6 CPE (Customer Premises Equipment)

Table 4 CPE Specification

Items	Specification
Installation point	User's House
Environmental condition	0~45°C 0~95 %RH
Size	W: 43 × D: 194 × H: 154 (mm)
Communication Interface	PLC Interface 10/100 Mbps Ethernet Interface USB Interface TEL(RJ11) Interface

As a salient feature, the simple and slim design has been achieved. Furthermore, the styling of the housing has been implemented in such a manner that it is compatible with the total image of the MV node, REP and CPE.

4. Functionality

4.1 Enhancement of QoS functionality

At a time when the deployment of broadband networks and the use of multimedia communications services such as IP telephony and streaming have been expanding sharply, the enhancement of QoS functionality has been growing in importance.

IEEE802.1p-based QoS control in 8 traffic classes (priorities) has been made possible. Table 5 shows an example of settings to be made for such services as VoIP and online game applications, with bandwidth and jitter being specified as control parameters.

Table 5 Sample of QoS setting according to the priorities)

Priority	Application	QoS parameters	
		Bandwidth	Jitter
P7 (High)	VoIP	Small	High
P6	Gaming	Small	Middle
P5	Streaming	Middle	High
P4	FTP	Big	Middle
P3	Internet	Small	Low
P2			
P1			
P0 (Low)	Others		

4.2 Enhancement of RAS (Reliability Availability Serviceability) functionality

As access-type communications equipment, high reliability is required of the PLC system. RAS functionality has been implemented with the following items as its features. In addition, since the PLC equipment is intended to be installed on transformers and/or utility poles, provisions to be remotely controlled have been made.

a. Temperature monitoring, and temperature-alarm issuance in the event of a temperature anomaly
b. Fan control, and fan alarm
c. Power-supply control, and power-supply alarm

5. Summary

By virtue of the realization of high-speed communications performance against of the poor transmission-path characteristics of power lines, a design that places importance on stability and reliability, the PLC-AW Series, as an access-type network system has been made possible.

We are determined to forge ahead with new development efforts over the coming years in order to propel our PLC products into global and widespread adoption.

PLC Network Management System

Authors: *Toshinobu Akitomi** and *Takeo Kikuchi**

Concerning access-type Power Line Communication (PLC) that uses power lines as communications means, this article introduces a network management system "NEOpS," which is designed to perform maintenance and operation in connection with the newly introduced "PLC-AW series" PLC equipment.

1. System Overview

Figure 1 shows how a high-speed PLC network is configured. An access-type high-speed PLC network provides an access network by using existing low-voltage (LV) and medium-voltage (MV) power lines, and provides service for connecting end-user PCs and analog telephones to Internet service providers (ISPs) and public switched telephone networks (PSTN) through backbone networks. PLC equipment is installed in substations and meter boxes. Since it is troublesome to set individual pieces of PLC equipment one by one in the field, remote setting via a NOC (network operation center) is required. Furthermore, as the number of units increases with the growth of the number of units on the market, it becomes important to cut down on cost through the enhancement of efficiency of setting operation. In addition, functionality to allows monitor and control PLC-specific information, including monitoring of varying physical propagation characteristics. In order to meet these demands, the NEOpS network management system has been developed that supports both "PLC-AM series" PLC equipment already in place in the market and new-type "PLC-AW series" PLC equipment.

2. NEOpS Features

The NEOpS server is designed to manage PLC equipment only, for such purpose as customer field trials or small-scale operations. The number of client devices it can manage is of the order of 1000, which means it is suited especially for large-scale commercial deployments. For communication with PLC equipment, the SNMP (Simple Network Management Protocol) is used. Table 1 shows a summary of features.

- Configuration management

  This feature performs registration, deletion, and settings change of MV Node, REP (repeater), and CPE (Customer Premise Equipment) information. At the time of registration, PLC-specific information of the entry such as MAC address, frequency, card configuration, and end user information is stored into a database. Once entered, the PLC equipment becomes included in the topology view and tree view displayed on the screen for monitoring. In addition, the configuration file of the registered equipment can be edited from the NEOpS server.

- Fault management

  This feature monitors possible failures by periodically polling PLC equipment other than CPE units installed in houses. In order not to interfere with commercial communication bands, polling intervals can be set in units of seconds. The feature also has the capabilities to receive SNMP traps and display their information in the form of fault history, as well as to indicate any fault condition in topology view. Detected events are

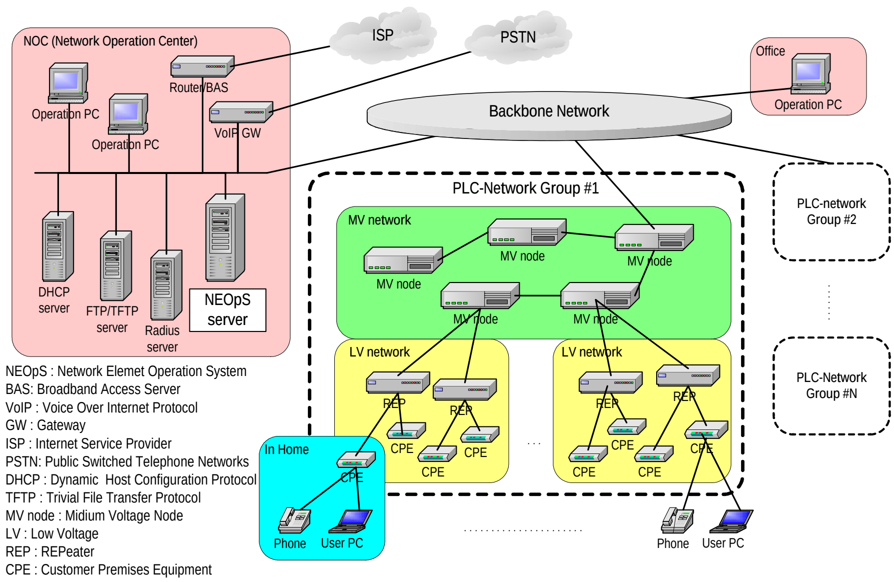

Fig. 1 PLC Network system overview

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Table 1 PLC NEOpS features

Functionality		Brief description
Configuration management	Register/remove	Registers/deletes a piece of PLC equipment to/from the server.
	Link with DHCP	Working in conjunction with the DHCP server, it manages the mapping between MAC address and IP address.
	Link with Radius	Working in conjunction with the Radius server, it registers authentication information for PLC equipment.
	Display status	Collects information on the current status of PLC equipment using the SNMP protocol and displays it.
	Equipment settings	Remotely references and sets communication parameters of PLC equipment using the SNMP protocol.
	Edit config. file	Allows the direct editing of a configuration file and registers the file with the server.
Fault management	Polling monitor	Periodically checks the current statuses of PLC equipment and displays the statuses.
	Traps monitor	Receives and displays SNMP traps from PLC equipment.
	Fault history	Logs occurrences and recoveries of faults and allows the user to search for a fault of interest that has occurred for display.
Performance management	Comm. monitor	Periodically collects PLC communication information including physical speeds and SNRs for display in graph form.
	Traffic statistics	Periodically collects statistical data such as octets transmitted/received for display in graph form.
Equipment management	Version info	Displays versions of card and firmware in PLC equipment.
	Upgrade	Remotely upgrades firmware.
	Config. file	Uploads/downloads a PLC equipment configuration file to/from a file server.
	Telnet	Makes direct telnet access to a piece of PLC equipment.
System functionalities	Tree view	Displays PLC equipment connection relationships in a tree view.
	Topology view	Displays network configuration graphically to show the current statuses of PLC equipment in a dynamic manner.
	Topology drawing	Allows the user to create a topology views as he/she likes.
	Operator management	Manages login and password information of operators and sets restrictions on the kinds of operations individual operators are authorized to perform.

logged so that events of interest will be able to be searched for and displayed.

- Performance management
  This feature can collect PLC network-specific physical characteristics such as PLC's physical speed, transmission/reception levels (TXGain/RxGain), SNR (Signal to Noise Ratio) and BPC (Bit Per Carrier), as well as data communications traffic, and render such collected data into graphs. Fig. 2 shows an example of such a graph being displayed.

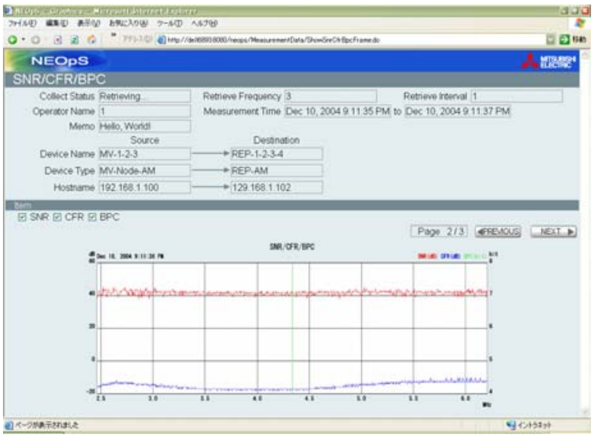

Fig. 2 Graph view

- Equipment management
  This feature displays card information and firmware version information. The downloading of firmware or a configuration file can be directed from NEOpS. In addition, direct telnet access is possible to PLC equipment.
- Screen display and operator management
  The screen consists of a tree view area and individual information display area. The individual information display area shows the topology view, properties, graph view, fault history and the like for each piece of PLC equipment. Access to NEOpS is managed by the operator management function, so that unauthorized manipulations can be blocked. General users can only reference the states. To perform registration and/or make settings on PLC equipment, the operator must have an administrator privilege. Using a PC with an Internet browser installed, an operator can monitor and operate from anywhere on the window that the NEOpS server provides.

3. NEOpS's Challenges and Measures

Figure 3 shows an overview of software structure.

- Ease of installation and address settings
  It is necessary for each PLC equipment to have its own IP address for remote management. Since a method of assigning a fixed IP address at the time of installation involves a complicated procedure, PLC equipment shall be configured in a way that its IP address will be dynamically assigned by the DHCP server. However, generally speaking, equipment whose IP address has been dynamically assigned cannot be monitored. Therefore, NEOpS is equipped with a functionality that is implemented by installing a script on the DHCP server and that can reference the IP address of equipment using the MAC address as a key.
- Device authentication and plug-and-play
  PLC equipment automatically detects any newly connected equipment and controls whether to allow access from this equipment to the network with the help of the Radius authentication mechanism. Further, by setting up a profile, the PnP (plug and play) of

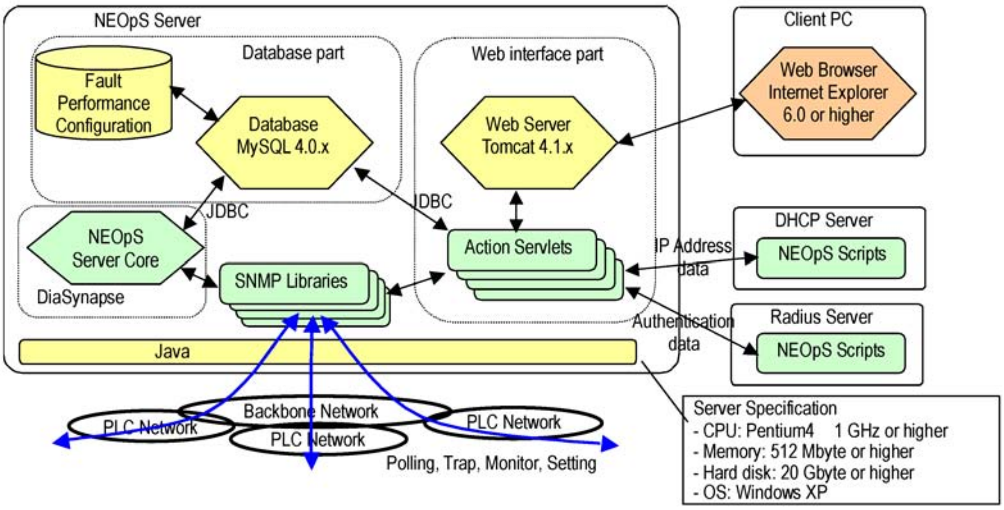

Fig. 3 NEOpS software architecture

PLC equipment is enabled. The setting up of the Radius server is a very complicated task. For this reason, in the case of NEOpS, in order to relieve the burden of the operator to set up the Radius server, we have developed a function that is designed to perform automatic registration by having a script installed on the Radius server.

- Tree view and topology view

Forms of connection of PLC equipment are of the open ring type, the radial type, the tree type, and so on, where MV nodes, REPs, and CPE are hierarchically connected with each layer of level formed by respective types of equipment. If we try to display these connection relationships graphically at a time (or in a single view), the relationships between upper-level equipment and lower-level equipment are difficult to interpret, and thus operation on the screen becomes difficult to perform as well. To solve this problem, NEOpS presents PLC equipment connection relationships in a combination of a tree view and a topology view. Fig. 4 shows an example screen shot displaying the tree view and the topology view. The tree view can offer the user ease of operation and represent the hierarchical relationships among individual pieces of equipment in an intuitively obvious manner. The topology view can represent the topology of PLC equipment precisely.

- Support for both PLC-AM and PLC-AW series

As Internet access service subscribers increase in number, it is assumed that newer and older models of PLC equipment are connected to a network all together. Our company, Mitsubishi Electric Corporation, is now offering two series of PLC equipment: the PLC-AM and PLC-AW series. The two series differ in setting items and collection data items, as well as the meanings of individual items. Therefore, NEOpS has been designed to support the Private MIB (Management Information Base) of both series individually, being capable of automatically recognizing the model/series of the equipment of interest at the times of setting up and data collection, to offer the user ease of operation.

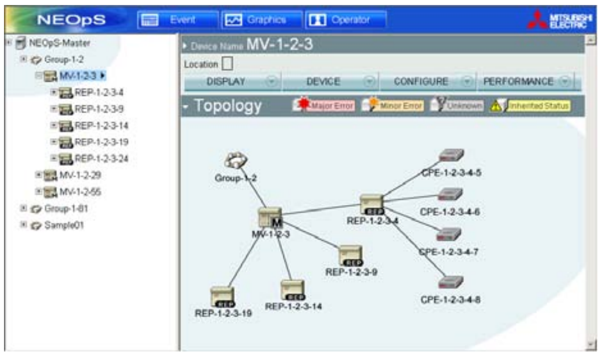

Fig. 4 Tree view and topology view

- Expandability

To enhance the expandability of NEOpS, DiaSynapse from Mitsubishi Electric Corporation has been adopted as a Java-base development framework. In addition, a general-purpose database has been introduced for use with JDBC (Java Database Connectivity). By making software in the form of modules with such Java technologies as its basis, a robust and scalable system can be constructed.

Having developed not only high-speed PLC equipment but also the NEOpS system, we have plans to offer total network system solutions that include the designing of a high-speed PLC network to the maintenance and operation of such a network on customer premises.

Power System Technology for Power Line Communication System

Authors: *Tetsuro Shimomura** and *Hiromu Okamoto**

Power Line Communications (PLC) system uses power distribution network already deployed as telecommunication media. So it is important to develop technologies which allows to know the communication characteristics of distribution lines originally intended to transmit electricity and foresee the behavior of the signal between injection point and extraction point.

This paper outlines the features of power distribution networks and the technologies used to evaluate the performance of distribution lines for communications purposes, as well as technology concerned with the power network required for PLC system.

1. Power System Features and Technical Requirement for PLC system

The configuration of the power distribution network depends on the deployment of electrical load of consumer, geography of the service area, concepts concerning the power-system operation, and those concerning protection in the event of a system fault.

The power distribution network is designed for the efficient transfer of power at fifty or sixty hertz. While this type of system works well for the distribution of power at power line frequencies, it presents severe problems when used as a communication system.

PLC is primarily applied to medium- and low-voltage systems. For medium-voltage system configurations, systems typically employed are open loop, including loop topologies, which are typically opened in one place by an automatic switch or manual, and tree-like topology systems, which include radial distribution line. Depending on the way the electrical loads are distributed, distribution line types and lengths vary from power system to system.

For low-voltage systems, the methods of wiring vary from one service area to another, such as single-phase three-wire wiring, tri-phase three-wire wiring, and tri-phase four-wire wiring.

To use distribution systems as communications paths, signal coupling units with which to inject and extract PLC signals on those lines are necessary, with a choice of Capacitive Coupling Unit (CCU) and Inductive Coupling Unit (ICU) options.

The installation of a signal-coupling unit may involve high-voltage work for overhead power line. For coupling units directly exposed to live parts therefore, effective insulation is important.

By distribution line type, there are underground cables and overhead distribution lines. Transformers can also be divided into pole-mounted, pad mounted and indoor-mounted varieties while the locations of user meters also vary widely. A PLC system design giving consideration to line length, power-transmission capacity and load makeup is required.

2. Technologies to Determine Distribution-Line Characteristics and Make Models of Distribution Lines

Since pre-existing distribution lines are used for communications purposes, PLC is influenced by the signal-transmission characteristics of those distribution lines in the frequency range 2-30MHz. To design a PLC system, the steps shown in Fig. 1 are followed. To grasp the characteristics of distribution lines and evaluate those characteristics as communications lines, technology to work out the configuration of the relevant power system, to model it and then analyze this model is essential in all cases. Since the modeling of distribution-line characteristics must include prior verification of the adequacy of models based on the results of measured characteristics, our company, Mitsubishi Electric Corporation, has been conducting field trials globally and thereby measuring the characteristics (especially in terms of signal attenuation) of distribution lines.

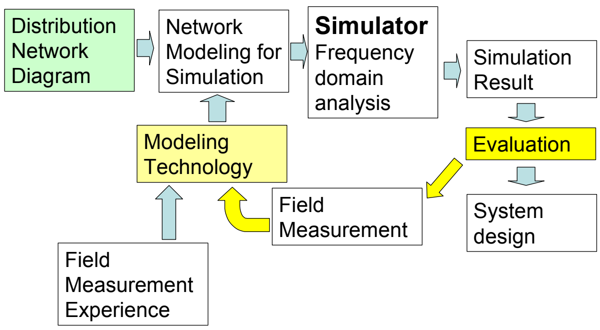

Fig. 1 Evaluation steps for power distribution line characteristics

Furthermore, while PLC Internet access remains in the early stages of its commercial introduction, there may be a need to develop tools, for example, to perform predictions concerning communications performance in given locations. This would then facilitate an-

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swering inquiries from prospective subscribers concerning things such as communication speed in their particular locations. The development of technologies for such tools will become a major challenge.

3. Measurement of Distribution Line Characteristics and Development of Analytical Technology

PLC uses frequencies in the range of 2-30 Mhz, while the degree of attenuation varies from frequency to frequency. Factors that contribute to attenuation are the characteristic impedance and loss characteristics of power lines, the presence/absence of branch lines, the number of branches, the lengths of the branch lines, and the presence/absence of load: in other words, the topology of the power network configuration and the characteristics of the components of which it consists.

In order to perform an assessment of the communicative performance of relevant distribution lines of interest, we have developed a tool connected to the Broadband Power-line Channel Analyzer (BPCA), as shown in Fig. 2. This analyzer is capable of measuring signal attenuation, group delay, phase characteristics and impulse response as signal transmission characteristics of power lines. Since it requires no stringing of a control cable between two geometric points, it can be easily installed or carried from one place to another and, thereby, facilitates measurement between two distant points. Moreover, since the analyzer is equipped with a processing capability to produce graphical output on the spot, it contributes to enhanced work efficiency.

An example of the results of measurements performed on a number of cable sections of a 22-kV cable system is shown in Fig. 3. The horizontal axis represents the cable length while the vertical axis represents the signal attenuation. The two lines were plotted based on the results of frequency-characteristics measurements conducted at frequencies of 5 and 10 MHz respectively. They show the relationships between cable length and signal attenuation and as can be seen, attenuation is distance-dependent. Moreover, attenuation characteristics vary with frequency such that the higher the frequency, the greater the attenuation. A cable-type power network includes attenuation characteristics that are dependent on distance and frequency.

On the other hand, the results of measurements performed on overhead distribution lines reveal a degree of frequency dependence not so pronounced as that found in the results of measurements performed on comparable distribution power cables.

Factors contributing to attenuation are electrical resistance causing conductor loss, the dielectric loss through the insulating-material layers surrounding conductors, and reflective loss occurring due to mismatches of characteristic impedance at the time of propagation from one type of distribution line to another.

We at Mitsubishi Electric Corporation have established analytical technology through the modeling of dielectric loss alongside with the skin effect, which is a type of conductor loss caused by electrical resistance. As shown in Fig. 4, the results of measurements conducted on <u>*our simulated power distribution network*</u> correlate positively with the results of computer analyses performed using a digital simulation model. Through application of this technology, we carry out studies on PLC systems.

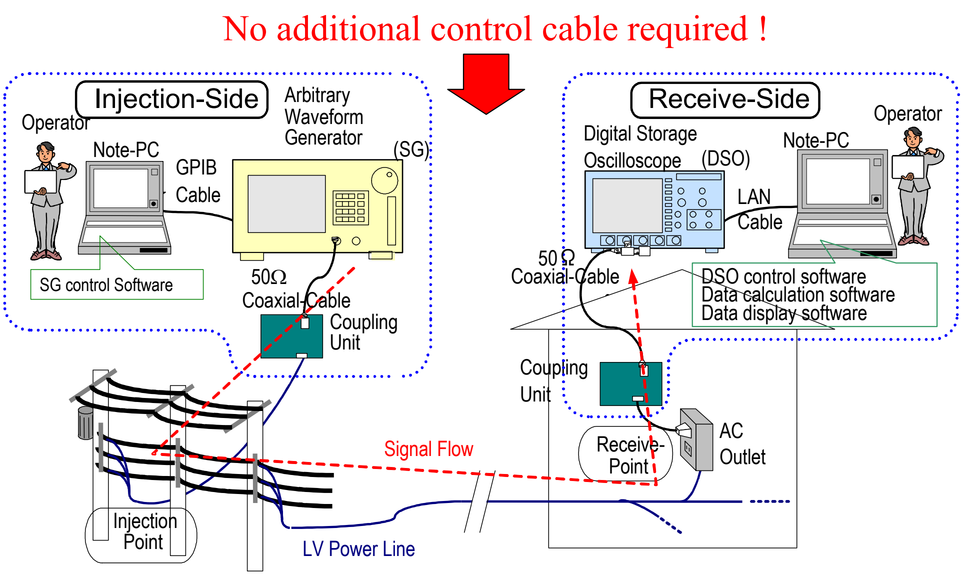

Fig. 2 Broadband Power-line Channel Analyzer (BPCA)

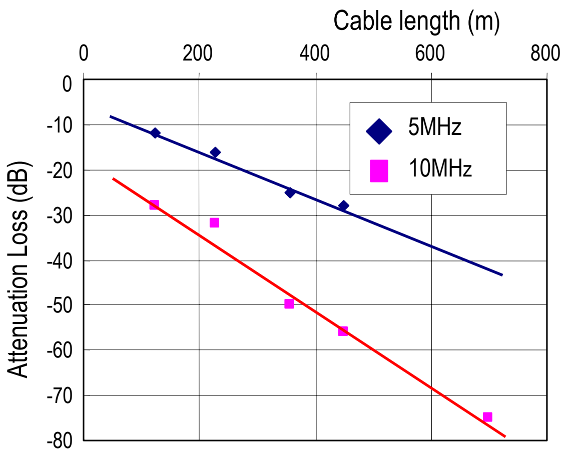

Fig. 3 Frequency dependent characteristics of signal attenuation on cable

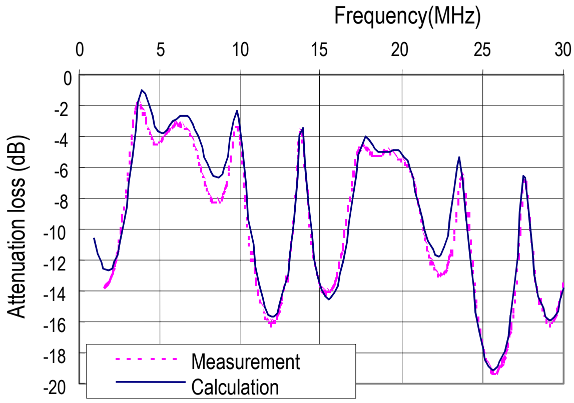

Fig. 4 Comparison of results between measurement and analysis

4. Technology to Improve the Characteristics of Power Lines

The results of the measured characteristics performed on distribution lines and in-house wiring may reveal the presence of sections where signals are exposed to significant attenuation, rendering impossible communication.

Factors that cause significant attenuation include impedance discontinuity caused by branch lines as well as at busbars within switchboards, the impacts of the stub effect caused by branch lines, and so forth. One measure to take involves bypassing sections of transmission paths prone to attenuation by diverting signals around those sections. We, at Mitsubishi Electric Corporation, have created simulated circuitry of busbars, then designed performance using our analytical technology, from which we have developed signal-bypass equipment.

5. Service Provision System

When PLC reaches a stage of proliferation, a service must be set up to answer inquiries from prospective subscribers concerning PLC service availability. Although this availability is determined by the characteristics of the power-distribution networks concerned, it is impracticable to measure the characteristics (attenuation characteristics in particular) of all the relevant distribution lines out in the field. Accordingly, technology able to estimate the communication characteristics of the distribution lines between prospective subscribers and nearby modems through simulation is required. This is where the distribution network analytical technology described in the previous section serves as the basic requirement.

This time, we have developed a component-based simulation technique with which to render individual elements comprising distribution systems into components, and estimate characteristics by combining those components all the way from the point of signal injection to that of extraction in model form.

We have provided a brief explanation of our (newly developed) technology to transform distribution lines into communications lines as part of PLC system development through the application of power-system technology.

In future, as the use of PLC proliferates, system design technology paying consideration to the communications characteristics of power distribution systems will become ever more important.

Inductive Coupling Unit and Bypass Tool for Power Line Communications

Authors: *Yuichiro Murata** and *Toru Kimura***

In an access-type PLC (Power Line Communications) system, medium- and low-voltage power distribution systems are used as part of a communications network. For radio frequency PLC using such distribution systems as communications paths, signal coupling and conditioning equipment are important items of hardware. The former equipment connects communications signals of a PLC modem to a distribution line, while the latter improves the communications characteristics of such distribution lines. There are bypass tools and blocking filters for conditioning tool. The function of bypass tools is to bypass communications signals around power distribution equipment, a major source of signal attenuation. The function of blocking filters is to prevent the signals from being conveyed to unnecessary power distribution systems. Signal coupling and conditioning equipment are key device for PLC business. It is necessary for us to develop considering the equipment installation and performance.

This article describes the R&D works we have conducted to develop signal coupling equipment and a bypass tool.

1. Signal Coupling Equipment

An ICU (Inductive Coupling Unit) is a piece of equipment to place communication signals in the 2 MHz- to 40-MHz range onto a distribution line and a key device in the PLC system. A current of several hundred amperes is being applied to a medium-voltage distribution line at a voltage of 6.6 to 35 kV. Since the ICU is capable of achieving signal coupling with the distribution line without contact required, it is characterized by high reliability and ease of installation on existing distribution lines.

Figure 1 shows the ICU construction. Structurally, it consists of a magnetic core with gaps plus a distribution line and modem output coil, both of which are wound around the latter core. Using the mutual inductance between the distribution and modem output lines, radio-frequency signals are coupled to the distribution line. The ratio of the magnetic core's mutual inductance to the self-inductance is known as the core's coupling coefficient, k. Figure 2 shows an example of the relationships between the calculated coupling coefficients and the ICU's coupling efficiency, with self-inductance chosen at 1,500nH. The greater the coupling coefficient, the better the coupling efficiency becomes. Furthermore, the coupling coefficient has an effect on the ICU's coupling efficiency in radio frequency regions of 10 MHz or over.

The gaps provided are to prevent the magnetic core from being saturated by the power current traversing the distribution line. The larger the length of the gaps, the less the effect of the magnetic saturation, but since the core's coupling coefficient k also becomes smaller, the ICU's coupling efficiency is reduced. To cope with this, we have successfully optimized the core geometries using magnetic analysis.

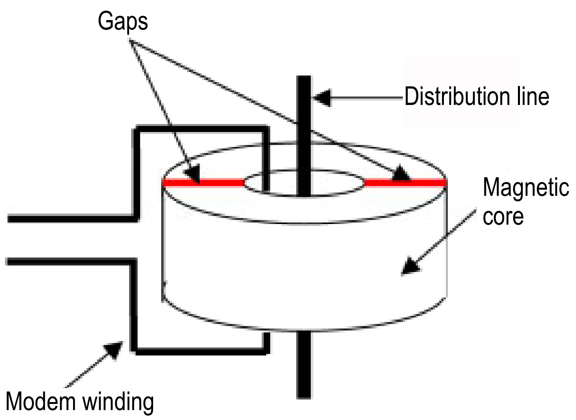

Fig. 1 ICU structure

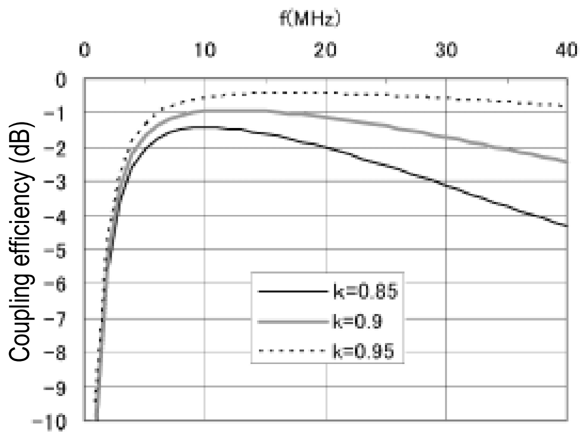

Fig. 2 Calculated attention with changing coupling coefficient

The coupling efficiency of the ICU varies according to factors such as the shape and magnetic characteristics of the magnetic core, the length of the gaps, and

*Advanced Technology R&D Center **Information Technology R&D Center the characteristic impedance of the distribution line. This means that we start requiring ICUs that are matched to the characteristics of the distribution lines upon which they are to be installed. Consequently, we have been implementing ICU design through the use of magnetic field and circuit analyses.

Figure 3 shows an ICU we have developed. Figure 4 shows the characteristics of the ICU with a current of 300A. The coupling efficiency measured a maximum of -6 dB at 9 MHz in this case.

We are now downsizing and increasing efficiency of ICU by conducting the core geometries and material characteristics.

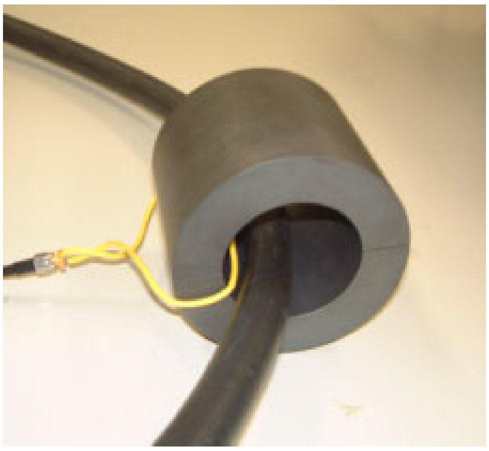

Fig. 3 Fabricated ICU

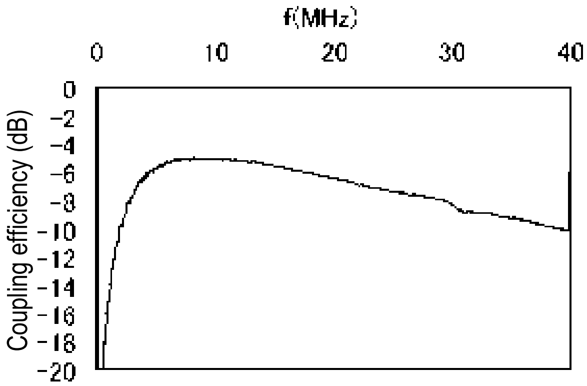

Fig. 4 Coupling efficiency for fabricated ICU

2. Bypass Tools

On power distribution systems that serve as transmission paths for access-type PLC systems, distribution devices such as transformers, distribution panelboards, voltage regulators and similar are installed. When these devices exist in communications paths, the characteristics of such paths may be adversely affected by the latter, giving rise to such phenomena as decreased communication rate or even failure. To resolve this problem, it was customary practice to install PLC repeater equipment in the vicinities of distribution devices to relay communications signals while circumventing the distribution devices. However, this strategy is costly, due to the cost of purchasing such PLC repeater equipment itself as well as the outlay for its installation and maintenance. Given these circumstances, equipment that is capable of improving the characteristics of transmission paths adversely affected by distribution equipment without the use of PLC repeater equipment, economical and easily installable has been sought after. This demand has given us impetus to start developing our own bypass tool, capable of improving the communications characteristics of distribution lines and reducing installation costs.

Figure 5 shows the installation configuration of the bypass tool. Referring to Fig. 5, a variety of distribution devices such as transformers, panelboards and voltage regulators are present. The bypass tool is installed in such a manner as to straddle this aggregate of distribution devices, consisting of high-frequency separation circuits and a cable. PLC modem derived high-frequency communications signals carried over a single distribution line are separated from commercial frequency power and coupled to the other distribution line through the cable. Thanks to this arrangement, the PLC modem's high-frequency communications signals are bypassed by the bypass tool without traversing the distribution devices.

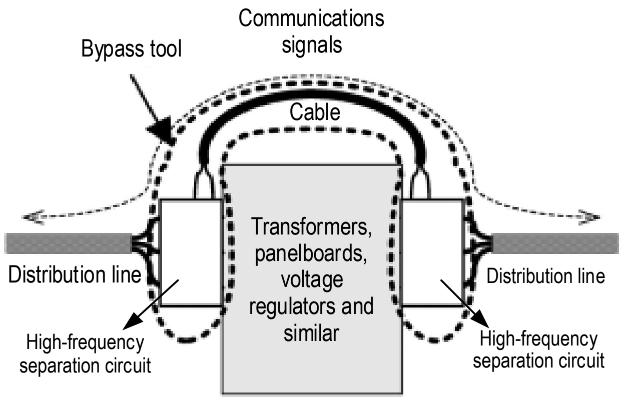

Fig. 5 Bypass tool structure

In order to confirm the principle effect of the bypass tool, we conducted a proof-of-principle demonstration experiment at our intracompany laboratory. This experiment was conducted on a transmission path using a device that simulated a BusBar, a type of panelboard, for use as a distribution device. We performed comparative measurements of the attenuation characteristics by using and then not using the bypass tool respectively to verify the differences.

Figure 6 shows the transmission path we employed for the experiment, with the results of the attenuation characteristics recorded based on the transmission path shown in Fig. 7. Referring to the attenuation characteristics curve plotted for the case without

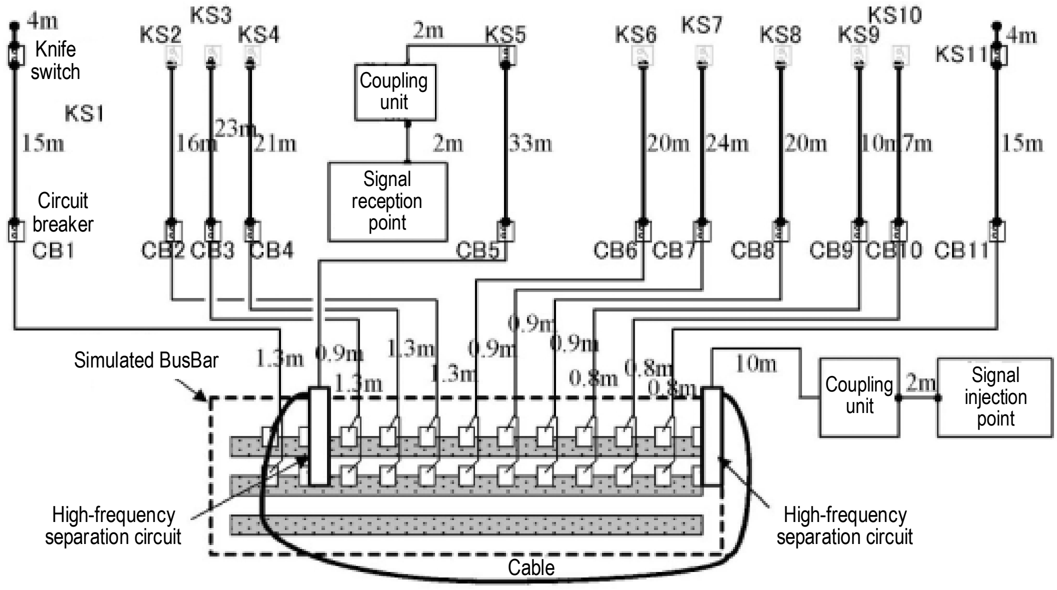

Fig. 6 Transmission power line structure

using the bypass tool, notches centering at around –35 dB and bottoming out at -30 dB to -50 dB are observed throughout the entire frequency spectrum. The use of the bypass tool eliminated such notches, with the overall average remaining at about -20 dB. From these findings, we were able to confirm the effect of the bypass tool in improving attenuation characteristics. We are now designing the bypass tool for real power distribution systems.

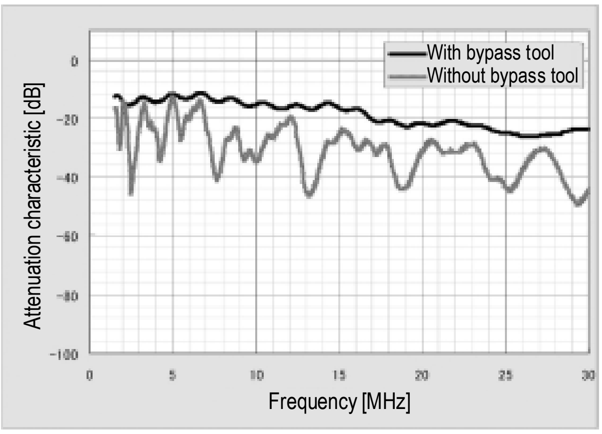

Fig. 7 Effect of bypass tool

3. Conclusion

This article concerned signal coupling equipment and bypass tools, both of which are key device for a PLC business, and discussed the results of the development work conducted within our company. Our task ahead is to create a component model of the newly developed PLC equipment while, at the same time, conducting commercialization studies with particular emphasis on the ease of installation on pre-existing distribution lines. Using this model, we will build a system which would facilitate us improving the communications characteristics of power distribution systems on a computer with the help of a communications type support tool for service provision that would make pass/fail judgments.

An Introduction to the Low-Density Parity-Check

Author: *Wataru Matsumoto**

1. Article Introduction

With respect to low-density parity-check codes (hereafter LDPC), which have recently been attracting attention as a type of error-correction code offering capacities virtually equivalent to communication channels, this article includes an overview of an LDPC means of code construction, a coding and decoding method respectively and discusses certain problems and the respective solutions.

2. Overview of LDPC codes

An LDPC code is a linear code defined by a very sparse checking matrix. A sparse matrix refers to one containing very few nonzero elements. In the case of a two-element finite field {0, 1} $\in F_2$, namely that concerned in this article, a sparse matrix means one with very few "1"s in it.

Figure 1 shows a rough block diagram of a communication system using LDPC codes. Since Fig. 1 is a simplified diagram, the assumption of various fading communication channels present as communication channels within actual cable and wireless communication systems must be made. In addition, it should be noted that in order to implement stable communications over fading communication channels, a modulator-decoder pair would typically be expected to incorporate synchronization, equalizing and reflected-wave canceling circuitries and similar.

In the following discussion, with particular emphasis on coding and decoding among LDPC codes, a summarized procedure whereby AWGN (Additive White Gaussian Noise) communication channels are assumed to exist alongside communication paths is provided below for purposes of simplification.

<Coding and Decoding Procedure>

(1) Prepare a parity check matrix H with a small number of "1" elements in it.

(2) Obtain a generated matrix G which satisfies $GH^T = 0$.

(3) Using the equation mG = C, generate a codeword C from message m, and then modulate and transmit it.

(4) Perform demodulation on the receiving side, and then perform sum-product decoding.

(5) Output an estimate value m'.

Where, $m: = (m_1, m_2, \ldots, m_k) \in \mathbf{F}_2^k$

$C: = (c_1, c_2, \ldots, c_n) \in \mathbf{F}_2^n$

$H \in M((n-k) \times n, \mathbf{F}_2)$

$G \in M((n \times k), \mathbf{F}_2)$

$m': = (m'_1, m'_2, \ldots, m'_k) \in \mathbf{F}_2^k$

Further, $\mathbf{F}_2$ represents a two-dimensional finite field, while M (n×k, $\mathbf{F}_2$) represents a two-dimensional n by k matrix.

The above summarizes the procedure for the coding and decoding of LDPC codes.

Since the H construction method proposed by Gallager, who is the inventor of LDPC code, involved some random operation, the construction process was not deterministic (such that an identical matrix can be constructed at all times with a few pieces of data and simple rules). This method is undesirable for use with real-world communication systems.

Another problem is that the amount of Gauss-elimination calculation with which to obtain G that satisfies equation $GH^T = 0$ for coding purposes, as well as the amount of memory in which to store the data required for representing G are relatively large.

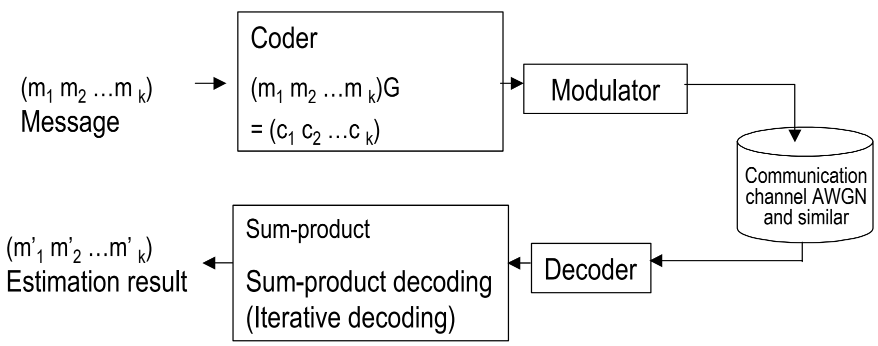

Fig. 1 A communication system with LDPC codes

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Further, the majority of the calculation required in terms of throughput is the sum-product decoding algorithm which is based on a method called iterative decoding. In terms of straightforward generalization, the processing power of this method when adopted may impose limitations on the overall communication speed of a communications system as a whole.

With the aforementioned in mind, the following important technical issues are required:

(1) Method of constructing an H with a high error correction capability in a deterministic manner.
(2) Simple coding method
(3) Simple and high-performance decoding method

This article introduces H-construction and coding methods being developed and studied by the author as solutions to (1) and (2), as well as the recent trend in decoding studies as solutions to (3).

3. Parity-Check-Matrix Construction and Coding Methods

Firstly, a regular LDPC code should be defined. Suppose the number of "1" in every column (also known as the column weight) is *j*, and the number of "1" in every row (also known as the row weight) is *l*. Such an LDPC code is denoted as a (*j, l*) - regular LDPC code. On the other hand, an LDPC code including columns or rows of non-uniform weights is known as an irregular LDPC code. It has been established that an irregular LDPC code with a positive weight distribution in terms of both columns and rows (called a degree distribution) offers superior decoding bit-error-rate characteristics when compared to a regular LDPC code. Moreover, Richardson et al have promoted a method of obtaining optimum degree distribution through density evolution [1].

As for regular LDPC codes, certain deterministic code construction methods have been suggested [2] [3]. On the other hand, as for irregular LDPC codes, only a few such methods have been suggested, of which none can truly be regarded as practical [4]. However, each of the papers [2] [3] [4], that the authors have referred to also suggests a simple method to implement coding. Of these, [2] and [3] are methods in which codewords are generated based on certain generated polynomials and using a cyclical code structure. On the other hand, [4] proposes a method of generating a redundant part through convolution, using a feedback polynomial.

Furthermore, in general, if H is constructed in a manner such that the area of its upper-right triangle is 0 (Fig. 2), coding is possible with the use of H alone by repeating back substitution (simultaneous linear equations).

The author is developing a method of designing parity check matrices of deterministic irregular LDPC codes while imposing the constraint that the top-right triangle must be 0. In particular, as a differentiation feature, the method includes a function that works in the form of RC-LDPC codes (Rate-Compatible LDPC: an LDPC code allowing variable coding rates without changing message lengths). In this method, for example as shown in Fig. 3, parity check matrices of coding rates $r_1 = (n_1 * m_1)/n_1$, $r_2 = (n_2 * m_2)/n_2$, and $r_3 = (n_3 * m_3)/n_3$ can be included in a single check matrix, with each of the check matrices $m_1 \times n_1$, $m_2 \times n_2$, and $m_3 \times n_3$ for performing the respective coding rates optimized by density evolution. Using this method, an RC-LDPC code able to display a favorable performance with different coding rates can be achieved. Due to limited space here, I would like to confine further detailed explanation to separate written material [5].

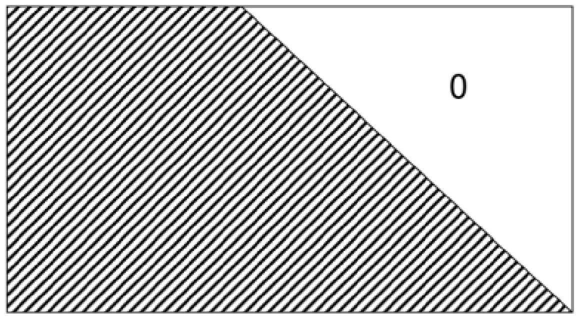

Fig. 2 A parity check matrix in lower triangular form

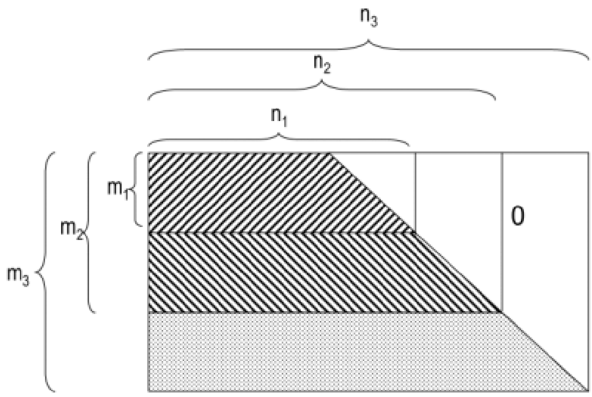

Fig. 3 A parity check matrix for RC-LDPC codes

4. Trend in Studies on Decoding Methods

In decoding an LDPC code, a method known as sum-product decoding or another method known as BP (belief propagation) is used. These are fundamentally the same, even though they differ in terms of whether the algorism is based on a calculation procedure or expressed from the viewpoint of on-graph probabilistic inference problems.

In general, the calculation of the tanh function becomes necessary for sum-product decoding, and based on the fact that the amount of calculation required for this function alone is massive. Another scheme that uses a simple comparative operation instead of the tanh function, thus requiring far less calculation, is normalized BP decoding [6].

In recent years, certain other decoding schemes requiring comparable amounts of calculation in the form of normalized BP decoding have been promoted. With these simplified decoding schemes combined with parallel processing, it has become possible to achieve throughputs ten to a hundred times greater than those used in the decoding scheme for turbo codes.

Given the current situation as described above, although the use of LDPC codes can justifiably be expected to improve performance, they are also associated with many ongoing problems when implemented in actual systems, which must be solved in a step by step manner. However, as LDPC codes are drawing more attention in recent years, relevant studies are being actively conducted in various quarters, representing steady progress toward the practical implementation of "a communications system approaching communication channel capacities".

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Distribution Network Analysis and Service Provisioning Support Tool

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In Power Line Communication (PLC) system, medium- and low-voltage power distribution lines are used as a communication network. However, since no consideration is given to signal transmission characteristics in the frequency spectrum used by PLC systems, deterioration in transmission characteristics, such as reflections caused by impedance mismatches, occurs.

If PLC signals on power lines can be estimated on paper to some extent, it will be efficient for the design and operation of PLC networks through the extraction of places where propagation is considered degraded and the formulation of solutions such as the use of signal repeaters and bypass tools. Furthermore, it also becomes possible to provide prospective service subscribers with service level information. With this in mind, the authors have been working on the development of our Service Provisioning Support Tool, that makes decisions concerning the possibility of communication.

The key function of the Service Provisioning Support Tool is in estimating the transmission characteristics of power distribution networks. Since the set of equipment used in a power distribution system is designed to operated at a normal power frequency of 50 or 60 Hz, their behavior must be determined at radio frequencies ranging from a few to a few tens of MHz.

This article describes a technology essential for facilitating their use as distribution lines for signal transmission or PLC infrastructure facilities. To further clarify, the article provides explanations concerning the development of a signal transmission line model working alongside distribution lines in order to operate at the frequencies used by PLC, component modeling employing such distribution line analysis technology, a simulation method, and the functions of the Service Provisioning Support Tool.

1. Analysis of Distribution Line Characteristics

The parameters required to develop a distribution line model for use in the analysis of distribution line characteristics include the effective relative permissibility and dielectric dissipation factor of the conductor insulating sheath as well as the length and characteristic impedance of the distribution line. Using these parameters, we discuss a technique with which to calculate the transmission loss occurring when signals are transmitted the distribution line.

The causes of the transmission loss include conductor loss due to electrical resistance, dielectric loss from the insulation sheaths encasing the conductors, and reflection loss occurring due to differences in characteristic impedance when signals traverse the boundaries of dissimilar distribution lines.

Of the aforementioned types, the conductor loss is determined by the dimensions and characteristics of a given conductor while the dielectric loss is determined by the dielectric dissipation factor and the construction of the insulating sheaths of distribution lines.

Generally, the conductor and dielectric losses can be calculated on an approximate basis using figures for the distribution line length and the attenuation constant. The attenuation constant can be expressed as an aggregate of characteristic impedance, resistance and conductance while the distribution line is expressed in the form of a distributed constant circuit. Distribution line resistance, meanwhile, can be expressed in terms of the surface area and electrical conductivity of the conductor. At radio frequencies such as those used for PLC, current flows only through the surface of the conductor due to the skin effect, and it is necessary to take the depth from the conductor surface that contributes to the current flow into consideration when we consider the current carrying conductor surface. On the other hand, the figure for the distribution line conductance can be expressed in terms of the capacitance between distribution lines and their dielectric dissipation factor.

The reflection loss arises from differences in the characteristic impedance values between adjacent distribution lines and determined by the characteristic impedance values themselves. The characteristic impedance of distribution lines is determined by such things as the construction of the distribution lines and the effective relative permissibility of the insulation sheaths encasing the conductors. It ranges from dozens to hundreds of ohms, depending on the type of electrical wire used.

By calculating the above losses, it is possible to compute transmission losses attributable to distribution lines, to which signals are exposed as they travel from the point of injection to the user side.

In order to verify distribution line model, we con-

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ducted an actual measurement of transmission loss on a test distribution system consisting of distribution lines only, and then made a model of the distribution lines used in the distribution system subject to measurement and calculated its transmission loss, to compare the transmission loss actually recorded with the figure obtained through calculation.

Figure 1 is an external view of the test distribution system after undergoing measurement. This test distribution system is one containing both VVF (PVC (Polyvinyl Chloride)-insulated PVC-sheathed cable, Flat-type) and OW (Outdoor Weather-proof PVC-insulated wires).

The result of the actual transmission loss measurement and the result of the transmission loss calculation using the distribution line model are shown in Fig. 2. As can be seen from this figure, the actual results of the transmission loss measurement and the computational results are virtually identical.

2. Service Provisioning Support Tool

The Service Provisioning Support Tool is an application software designed to enable an Internet Service Provider to perform various studies from their desktop computer – such as selecting PLC modem operating frequencies (and modes), spotting locations that are impervious to modem signals, and selecting locations for the installation of signal repeaters and bypass tools to deal with such areas without reception. The tool is expected to enhance the efficiency and operation of the PLC network design. Furthermore, since the tool can be used to furnish prospective PLC subscribers inquiring to call centers with information about the potential of providing Internet service or information concerning the estimated communications speed, it is considered to be beneficial in encouraging new subscribers.

An overview of the Service Provisioning Support Tool in operation is shown in Fig. 3. As shown, with the distribution line model, the noise model, and the accessory model obtained through the analysis of distribution line characteristics as inputs, the transmission characteristics in the PLC-specific frequency spectrum are determined by the performance of a transmission characteristics simulation. Subsequently, by factoring in the operating characteristics of the PLC modem, an estimated communications speed can be calculated.

Among these sections, the key is that concerning the transmission characteristics simulation as well as how to build a distribution line model in the PLC-specific frequency spectrum.

As for the transmission characteristics simulations used in the Service Provisioning Support Tool, an infrastructural facility constituting a transmission line is modeled into a component, and the individual components present from the point of signal injection to that of signal extraction are integrated in order to facilitate the transmission characteristics. Since facility components are used, we call this simulation method Component-Based Simulation (CBS).

When compared with SPICE (Simulation Program with Integrated Circuit Emphasis), which is being widely used for circuit simulation, the use of CBS has the following advantages in terms of the simulation of transmission characteristics:

(1) As opposed to SPICE simulations, where equivalent circuitry itself must be managed in the form of data, only parameters must be managed on a component-by-component basis in the case of CBS.
(2) Since data management is implemented on a component-by-component basis in CBS, it is easier to link with a database storing component models than equivalent circuit models in the case of SPICE simulations and similar occasions.
(3) In the case of CBS, component parameters prepared from actual measurement data (transmission

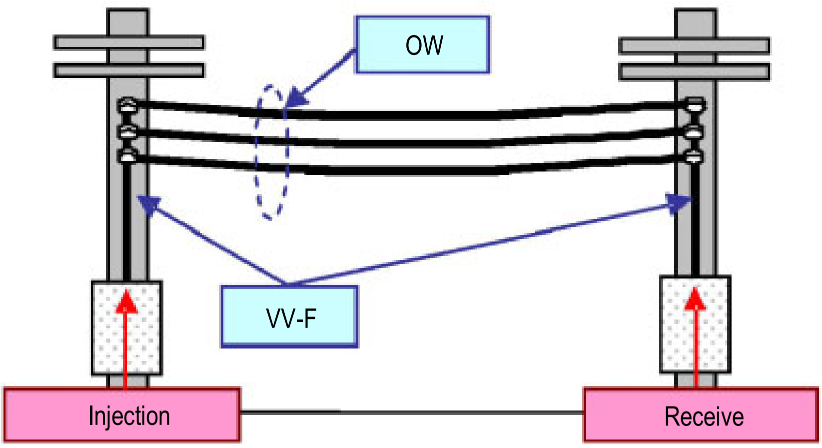


Fig. 1 Configuration of test distribution network

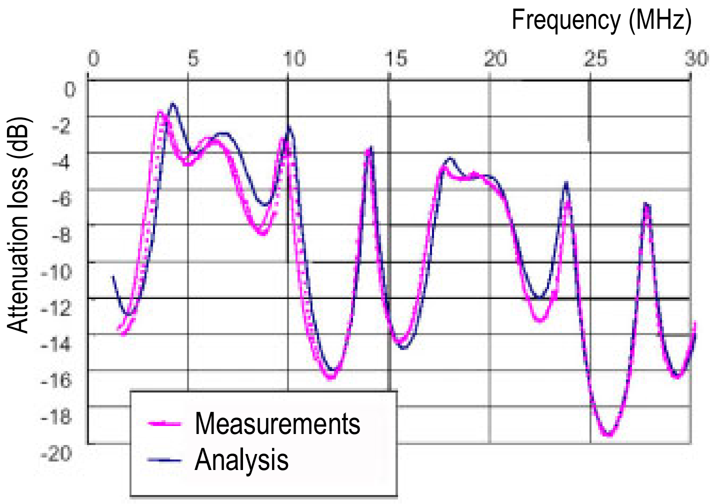
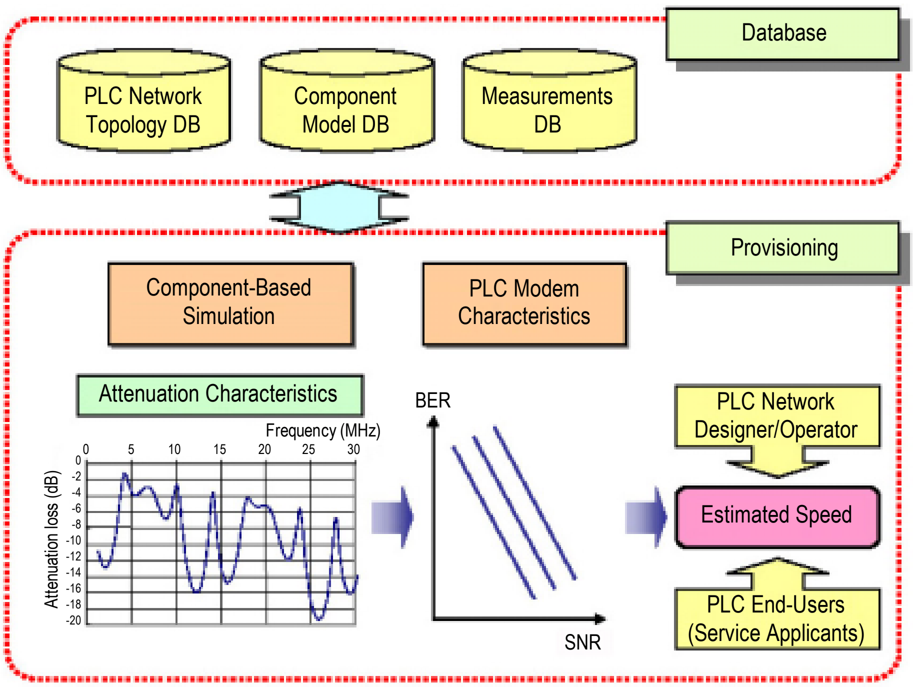


Fig. 2 Comparison of results between measurements and analysis



SNR: signal-to-noise ratio BER: bit error rate

Fig. 3 Function diagram of service provisioning support system

characteristics) of component models can be used for simulations.

(4) Unlike SPICE circuit simulations that involve solving circuit equations through the use of such methods as nodal analysis, the amount of performable calculations may be relatively few in CBS, since the simulation can run based on calculations performed on combinations of components alone.

A component model is one representing the electrical characteristics of equipment or a group of equipment. When two-port networks are used for representative purposes, the voltage-current relationships for each port can be represented through a two-port matrix. Since such a two-port matrix can be obtained uniquely from an equivalent circuit model, it proves well-suited as a model to represent electrical characteristics.

By combining component models, the transmission speeds from the location of the injection to that of extraction are determined using the following procedure:

(1) To combine component models, calculate the input impedance, starting from the load side, in order, and then calculate impedance from the location of extraction to the load side.

(2) From the location of extraction, trace the transmis-

sion characteristics back to the power supply side by combining the component models via a matrix operation and, thereby, determine the characteristics of the components from the location of injection to that of extraction. If components are cascade-connected, the transmission characteristics can be obtained by multiplying their respective two-port matrixes. If a parallel connection is made, such as a branching connection, the transmission characteristics can be obtained considering paralleling impedance.

(3) Calculate the transmission characteristics from the injection to the extraction location.

(4) Once the transmission characteristics from the injection to the extraction location have been obtained, determine the number of bits per carrier at carrier frequency intervals based on the frequency characteristics of the frequency range used by the PLC modem and then determine the transmission speed by multiplying with this figure with the number of symbols transmitted per carrier.

3. Conclusion

This article has discussed the Service Provisioning Support Tool; intended for the estimation of transmission speeds through the analysis of distribution lines and conducted to determine their transmission characteristics when they are seen as transmission paths, along with other findings gleaned. The Service Provisioning Support Tool is currently still in a developmental stage. We have plans to evaluate the tool in actual field implementation following appropriate verification and evaluation.

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