Development of IP Network System for Electric Power Using Cable Modems

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ABSTRACT We developed an IP network system for power line customers to operate in the year 2000. The main objects of developing this IP system are an amazing system price reduction compared to the growingly popular 1:1 transmission system, and also a variety of applications for individual customers with customer security assurance.

The main scheme of this optical system adopts branches of the 8x4 passive double star optical system. To develop speed and cost efficiency, we selected a mass produced cable modem, which accepts IP and ATM controlling protocols that can be used for PDS optical networks.

Another important aim is to assure a channel capacity with high Quality of Service (QoS) to transport customer data with sufficient reliability.

Since this system started operation customer numbers have gradually increased, and the system has demonstrated its design efficiency and cost performance. The skeleton and the structure of the system and the equipment are described below.

1. INTRODUCTION

The current power line information transmission method for meter-reading is 1:1 information transmission, and the upstream gathering scheme uses a hierarchical structure of equipment based on HDLC tansmission in which information is restructured to each frame length at each node. This conventional system confronts the difficulties of extending newly added bits in frames, which meant flexible insertion of new customer information was impossible. IP network systems are flexible and generally used in communication network systems, among which the cable modem-equipped LAN system is well-known and is easily expandable to cover a large area. This system has a flat structure compared to the current hierarchy step-up structure, so a network arrangement can be adopted for any area and time, and a variety of QoS is applicable to customers for newly developed services or Internet services. We carefully examined the problems of current power network communication and developed a practical optical IP network system for power line information. An outline is given below.

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2. OUTLINE OF THE SYSTEM

2.1 Structure of System

1) Outline of the system is shown in Figure 1.
2) Equipment and connecting scale numbers (Table 1) are shown below.
   - IP managing equipment
   - Headend (HE) modem equipment
   - Headend (HE) controlling equipment
   - Optical branching couplers
   - Power line customer terminal (Terminal II)

2.2 Structure of Network

(1) Upper network

Current system hosts are accommodated in the current packet network. Among them is the electric power meter-reading host. Our newly developed IP network system runs in an Ethernet system. So, connecting each network requires protocol conversion. Also developed is IP managing equipment (IP Manager), which converts upper network protocols into IP network protocols and vice versa.

(2) IP network developed

The newly developed IP network includes HE equipment which runs the current ATM system, and has Terminal Equipment including a cable modem board corresponding with HE. The Ethernet packet is modulated into cells and is transported between HE and Terminals, so the number of cells is controlled under the design speed for the assured transportation bit rate under ATM. Use of cells is

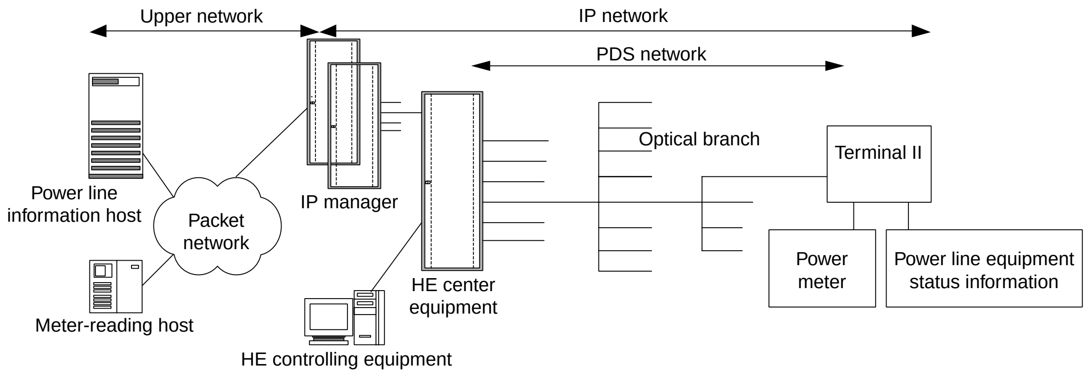

Figure 1 System diagram.

Table 1 Capacity of the system.

No	Equipment	Maximum connecting numbers of equipment	
1	IP manager	4 channels x 600 (2400)	Power meter
2	HE center equipment	6 channels x 32 (192)	Terminal II
3	Terminal II	2	Power meter

classified into fixed bit rate use (CBR: Constant Bit Rate) and cooperative bit rate use (VBR: Variable Bit Rate). The downstream transmission is modulated in 64 Quadrature Amplitude Modulation (QAM) and has 1 channel with a maximum speed of 30.34 Mbps. The upstream transmission is modulated in Quadrature Phase Shift Keying (QPSK) and has free use of six channels, each with a maximum speed of 2.56 Mbps. We selected the CBR method because it provides the most reliable transmission of information for electric power equipment, even in a crowded state.

(3) PDS network

The transmission medium is optical fiber, which is connected to a Passive Double Star (PDS) network. The final stage of the optical network has optical branching couplers of 1x8 and 1x4, and a maximum branching of 32 customers in one optical network block, and has a standard length of ca 20 km.

3. OPTICAL NETWORK

3.1 Outline of Optical Network

The information summarizing stage of the optical network has IP-M equipment distributed in main branch offices connected to the current packet network, and each IP-M has several HE systems.

1) Each HE system has dual ports for upper information transmission routes.
2) Each HE system has a single port for a lower information transmission route, due to recycling of information contents, required information time, summing of information bits at every cycle, and current information accuracy.

3.2 Design Conditions of Optical Network

In accordance with practical grouping numbers, the system design conditions are selected as follows:

1) Maximum optical path dynamic range: ca 20 dB-37 dB.
2) Maximum optical path length: up to ca 50 km.
3) Maximum optical branching number: 32.

A 32 branch means 8x4, double stage branches of 8-branch and 4-branch in accordance with time and district for customer's needs.

Selection of a practical optical dynamic range considers real optical cable loss and joints, and optical branch losses. Standard length is selected to cover maximum numbers under the location distribution condition of local centers and customers. Optical attenuator or detour center is adopted.

3.3 Calculating Dynamic Loss of Optical Path Length

A calculating model pattern is introduced in the optical dynamic loss calculation between HE and terminals. The model is divided into two sections:

1) Optical equipment and connecting devices with typical loss sections

e.g., optical equipment installed in buildings, repeating stations, and terminal stations

2) Optical transmission media of a long span with typical loss sections

e.g., cable sections, branching cable sections including junction boxes

Modeling a typical structure element into equivalent loss figures, and its corresponding section by the calculating series method, the system dynamic loss is summarized as total loss amount, and these figures are identified as typical standard values. If figures are out of range, remodeling is done by calculating the standard range with the arrangement of attenuators. A flow-chart of convenient calculations is supplied, and a personal computing program is developed. A typical design model is shown in Figure 2.

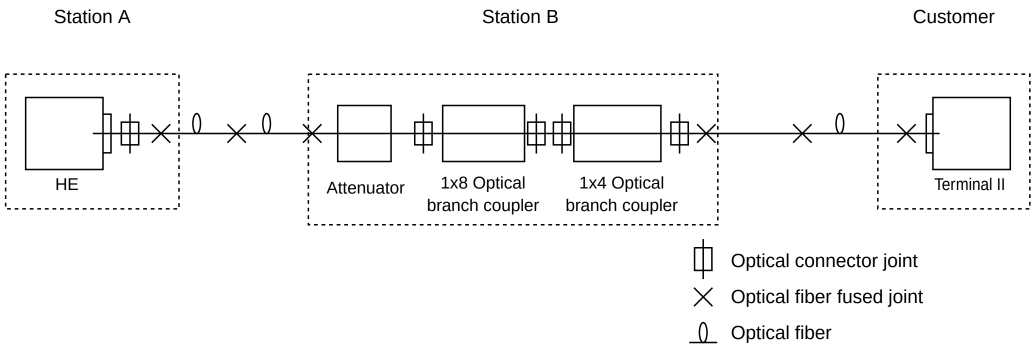

Figure2 Optical path design.

	Power meter	Power line	Terminal II	IP manager	Meter-reading host	Power equipment host
Power equipment information (Standard condition)			Gathering	Polling		
			Packeting	Format arrangement		
			Gathering			
			Packeting	Format arrangement		
Power equipment information (Changed condition)			Gathering	Format arrangement		
Meter-reading information			Gathering	Protocol conversion	Polling	
			Packeting	Protocol conversion		

Figure 3 Information flow diagram.

4. OUTLINE OF SYSTEM PROCEDURE

4.1 Basic Operation

The system operation is classified into three types. The flow of data is shown in Figure 3.

1) Normal data gathered of customer's electric power usage
2) Changing status of the customer's electric power apparatus
3) Reading electric power meter

4.2 Communication between IP-M and Terminal II

IP-M is a repeating center with protocol conversion originating from the current upper network host. Terminal II is a newly developed multi-function terminal with meter-reading and Ethernet transmission.

(1) Communication protocol

Communication between IP-M and Terminal II is User Datagram Protocol/Internet Protocol (UDP/IP) method. The UDP method requires no retry call, so to ensure security an upper level application protocol operates.

(2) Polling sequence

IP-M communication requires duplex transmission, and it has a single downstream transmission medium, so a duplicate polling method is adopted. Its polling sequence is discussed below. Figure 4 is the communication diagram.

IP-M gives successive duplicate polling frames starting from system 1 and system 2 to the specified Terminal II. Terminal II receives duplicate polling information and allows first access and rejects second access to prevent transmission channel congestion. The answer from Terminal II is returned to IP-M in duplicate frames, each into system 1 and system 2. With the response, IP-M judges that its polling request was received by Terminal II. With no response by time-out from Terminal II, IP-M makes retry polling access to Terminal II.

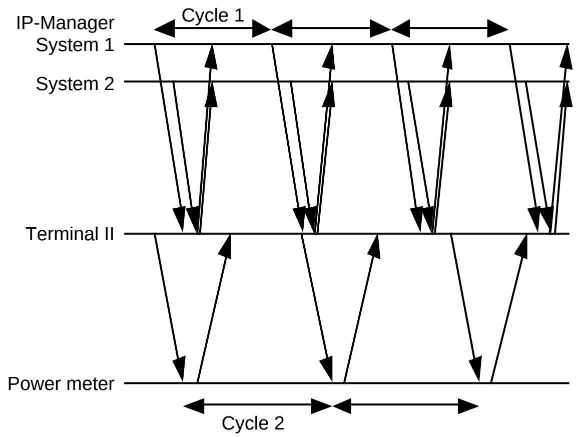

Figure 4 Polling flow diagram.

(3) Meter-reading access

When Terminal II decodes meter-reading information repeated through IP-M from the meter-reading host, the terminal accesses the electric power meter requested for the consumed electric power digits. The terminal receives

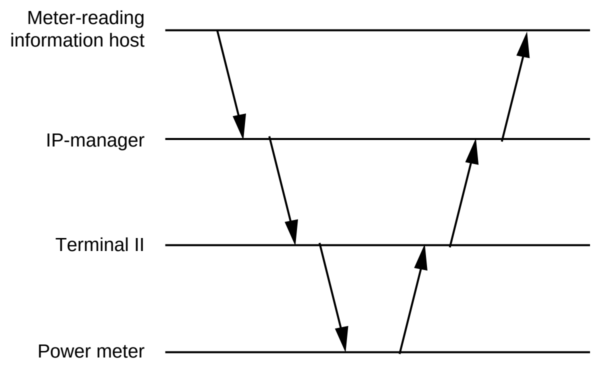

Figure 5 Meter-reading flow diagram.

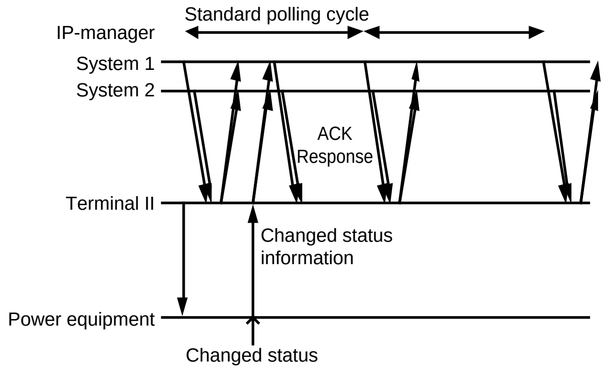

Figure 6 Status information flow diagram.

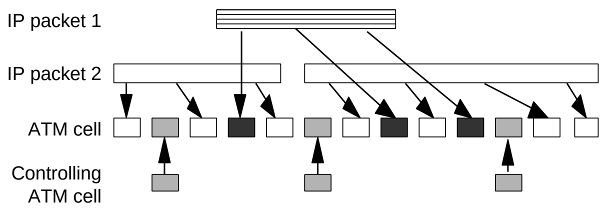

Figure shows that IP packet 2 has higher priority, ensuring a higher level of transmission speed by utilizing ATM cells. Controlling ATM cell is used for communication between HE and terminal II.

Figure 7 Collision controlling packet assembly.

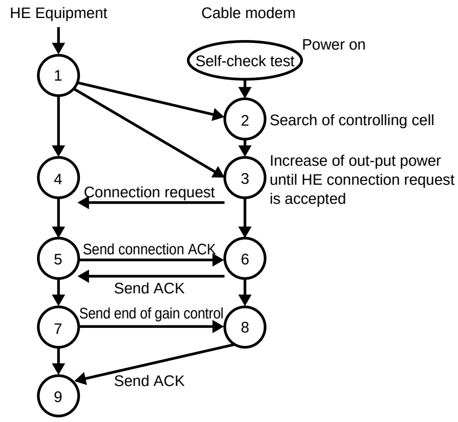

Figure 8 Optical power level controlling sequence flow.

the requested consumed power information data from the power meter and sends it to the host through IP-M. Figure 5 shows the meter-reading diagram.

(4) Changed status gathering

Normal communication between IP-M and Terminal II has the starting information at IP-M, but this section of changed status gathering has the starting point at Terminal II. To have a short response in the emergent change of electric power status, the terminal starts to take pollings to IP-M, and IP-M returns the responding acks to the terminal. Terminal II acknowledges the admittance of IP-M with respect to the changed electric statuses. In the actual response task, faster information out of either system 1 or system 2 is sufficient, and a duplicate system runs in an apparently normal status. Figure 6 shows flow diagrams of changed status gathering for the electric power apparatus.

The important point is that this system has the assurance of QoS from CBR transmission and collisions of simultaneous change statuses of terminals are clearly avoided to inform IP-M without any delay time.

4.3 Outline of Equipment Operation

4.3.1 Operation of IP-M

IP-M is located in the interface of the upper current packeting network and the lower IP network. Then the IP-M controls the polling system to Terminal IIs, and it converts upper host request protocols to lower IP requests with data assembling and vice versa. Another task of IP-M is as a DHCP (Dynamic Host Configuration Protocol) server for automatic address delivering to Terminal IIs.

4.3.2 Operation of HE Modem System

(1) HE communication method

The HE of LAN center has an optical tree topological connection to Terminal IIs. Every HE and Terminal II has the same type of modem, and all Terminal IIs within a block have the same transmission media and physically cooperative use. The IP network has a transmission variable packet of 64 bytes to 1518 bytes, so direct transmission of the packet from one terminal stops communication to others. We selected practical ATM modems of high-speed networking devices to solve this congestion problem. The fact is that a real IP packet is split into 53 byte ATM headed cells and its cell transmission equally uses every terminal coming into equal terminal communication.

(2) Collision restriction

A Passive Double Star (PDS) network inevitably involves the possibility of transmission collision. So, to prevent collisions, a control center is introduced to distribute controlling ATM cells for transmissions of each terminal and its QoS control. Figure 7 shows the packet and cell arrangement of collision control.

(3) Automatic optical power level control

This cable modem system has an Automatic Gain Control (AGC) function for equalizing imbalances at local distances, so a certain constant power input can be attained, notwithstanding the area distances of Terminal IIs. So this merit is used in the optical design of transmission equipment in an optical PDS network. Figure 8 shows the AGC sequence in an optical network. The live cable modem of the Terminal II starts to give a connect request in the minimum status level, and boosts up the power level until the HE response returns. Then we get a constant HE input signal level.

4.3.3 HE Controlling Equipment

Using special HE controlling software, we set communication parameters, maintenance of Terminal IIs for registering and deleting, communication status observing, recording status, and user status.

4.3.4 Operation of Terminal II

Terminal II operates to let an electric consumer access the value of consumed power under a host request, and also counts pulses of power consumed. When the consumer has the electricity statuses of power equipment, Terminal II also accumulates on-off signal bits for their statuses. Terminal II also gets access every four minutes from the host, and gathers consumed power values and power apparatus statuses at every corresponding time. When electric power apparatus experiences a change of status, the terminal II starts to operate to give information on the changed status spontaneously to IP-M, even without access from IP-M. Table 2 shows the specification of a cable modem. Table 3 shows the specification of optical PDS network transmission equipment.

Table 2 Outline of cable modem specification.

Term	Downstream	Upstream
Transmission speed	30.336 Mbps	2.56 Mbps
Modulation type	64-QAM	QPSK
Frequency band	300-MHz Band	30-MHz Band
Bandwidth	6 MHz	1.8 MHz
Error correction Integrated	Viterbi / Reed-Solomon	Reed-Solomon
Encryption	DES, 40-bit key	DES, 40-bit key
RF level	45 - 75 dB μV	78 - 118 dB μV
Required CN	23 dB (10^{-9} BER)	16 dB (10^{-9} BER)

Table 3 Outline of optical transmission equipment.

Term	Downstream	Upstream
Center frequency	300 MHz	30 MHz
Modulation type	64-QAM	QPSK
Transmission medium	Single mode optical fiber of 1.3 μm zero-dispersion shift	
Optical channel	1.31-μm band	
Optical output level	+8 dBm (max)	Modulated optical amplitude (rms) less than 21 μW, greater than 1.38 mW
Optical input level	-8.2~-30.1 dBm	-
RF level	45~75 dB μV	78~118 dB μV
Optical connector	SC-PC	

Photo 1 HE center equipment.

Photo 2 Terminal equipment.

Photo 3 HE control equipment.

5. CONSTRUCTION AND SETTINGS OF TERMINAL II

Construction and settings of Terminal II has the following two design merits.

(1) Compact size

Smaller size with upgraded functions are achieved with the same size of current box. We use a new function communication board and currently use existing connecting terminals installed outside.

(2) Simplified terminal communication settings

We simplified address setting and parameter setting for counting electricity consumption from the power meter, which is normally done with a personal computer carried in the field. We simplified field settings, so setting time is reduced to a few hours instead of several days. The main checking work is done by IP-M and HE controller located at the center.

6. SUMMARY

Having developed an IP network system for the first time in Japan for electric power communication using a cable modem, we reduced total system cost and improved customer IP information system security and QoS without transmission collision problems. We have also achieved the expected system functions and actual effects.

7. FURTHER STUDY

A power line customer IP information system requires a variety of flexible network responses for constantly varying customer information requests. Transmission speed improvements and network flexible access applications are coming on line.

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Manuscript received on January 11, 2002.