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High-Speed Optical Home Network Using Graded Index Plastic Optical Fibers for a Smart House

Tetsuya Toma[1,2], Hideo Asada[3], Tetsuro Ogi[2], Yasuhiro Koike[1]

[1] **Keio Photonics Research Institute, Keio University**
Kawasaki, Kanagawa 212-0032, Japan
t.toma@kpri.keio.ac.jp, koike@appi.keio.ac.jp

[2] **Graduate School of System Design and Management, Keio University**
Yokohama, Kanagawa 223-8526, Japan
t.toma@sdm.keio.ac.jp, ogi@sdm.keio.ac.jp

[3] **Architech Consulting Co. Ltd.**
Tokyo, 110-0016, Japan
h_asada@archi-tec.jp

Abstract

In this paper, we propose a home monitoring, management, and communication system (HMMCS) with high-seed optical home network for a smart house in a smart city to optimize the energy usage and to create a comfortable environment. The HMMCS monitors the interior environment and the electricity consumption of all electric appliances. It also records log data, shares information and movies/images, and cross-connects with web services. We assembled small-scale prototype HMMCS and developed application software with an original user interface. The results of a test run reveal that the HMMCS can monitor electricity consumption and interior environments in real time and can control different types of electric appliances including servers that play movies. The maximum data traffic load in a smart house has been calculated using the measured traffic data. Moreover, we found that a smart house with HMMCS inevitably requires a high-speed optical network for real-time, high-quality responses.

Keywords: *Smart house, high-speed optical network, user interface, plastic optical fiber, ultra high definition video transmission*

1. Introduction

In a smart city, electricity supply facilities and buildings communicate information to each other in real time to optimize the electricity supply and consumption in a city. Making cross-references among various types of information such as information related to energy and environment, life log of people, movies and pictures, and any of the web-based social services, leads us to the next stage of communication and generate a new sense of value. In a residential house in a smart city, many types of sensors are installed everywhere in the house, and monitors the interior environment, human behavior, and electricity consumption for all home facilities and appliances in real time. At the same time, home facilities and appliances, which are connected through an IP home network, are adequately controlled according to the monitored data to make the interior environment comfortable with minimum electricity consumption. In addition to these, the residents benefit by its increased security using the high quality video interphone, and enjoy entertainment with high definition large size displays. We call such a house a "smart house."

To build a smart city with smart houses, it is important to install high-speed network infrastructure with a system that monitors the energy and the environment and controls the facilities and the appliances in real time, both for a city and for houses (see Fig. 1). Home energy management systems (HEMSs) are currently used for monitoring and visualizing the electricity consumption and the interior environment of a residential house. There are some studies about HEMSs [1, 2], but these HEMSs are unable to control home facilities and appliances and are unable to communicate information with other

Table 1 Comparison of HMMCS with regular HEMS

	HEMS	HMMCS
Monitor electricity consumption	✓	✓
Show history of electricity consumption	✓	✓
Control appliances	(✓)	✓
Monitor room environment	(✓)	✓
Store & broadcast movies		✓
Record life log		✓
Interconnect with web services		✓

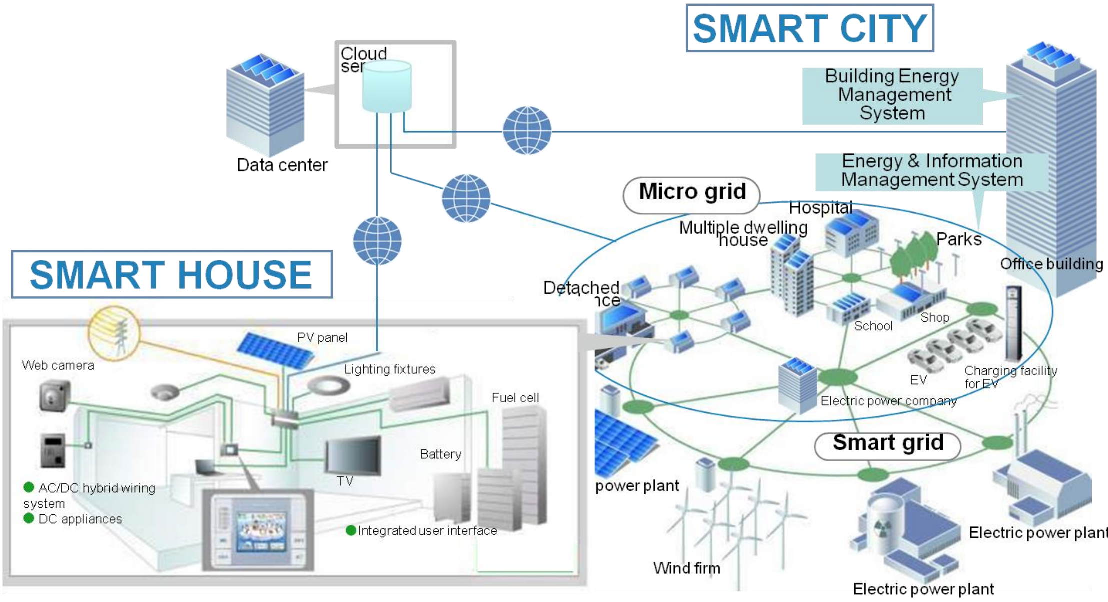


Fig. 1 Image of "Smart City" including Smart Grid and Smart Houses

systems or web servers. Therefore, the current HEMSs are not sufficient to use in a smart house in a smart city (Table 1).

The purpose of this study is to propose a home monitoring, management, and communication system (called the system "HMMCS") for a smart house in a smart city and discuss the functions required for this system and the problems to be solved.

2. Design Concept of HMMCS

The proposed HMMCS monitors and manages the electricity consumption and the interior environment of a smart house in real time. It also monitors and records human behavior as a life log and learns human habits. The recorded life log data are used for controlling appliances and making the interior environment comfortable with minimum electricity consumption. The HMMCS interconnects with commercial or non-commercial web services and provides a way to communicate with people and any other information. First, we determined the functions necessary for the HMMCS and designed the components of the system. Then, we assembled a small-scale prototype HMMCS and developed the application software for the system and for a remote terminal device, tablet, or smartphone, including the original user interface to monitor the data and control the appliances. Finally, we executed a test run of the HMMCS and determined the data traffic load of the home network for monitoring/controlling and communicating information in real time.

As an optical cable, a graded index plastic optical fiber (GI POF) is suitable for such a house, because it is flexible and can be bended, twisted or bundled. It has similar bandwidth to silica multimode optical fiber (MMF), but is safer than MMF which may hurt a person handing the cable when the glass fiber is broken. Installation is easy in a residential building [3, 4, 5].

The HMMCS monitors the energy consumption and the interior environment of a smart house, records the corresponding data in a home server, and controls the home appliances in real time according to the recorded environmental data. The system also works as a digital hub to provide face-to-face communication with distant people and as a media server to share digital movies and photos.

A scenario of life in the near future in a smart house was assumed by our team at the beginning of this study; this scenario involved an installed high-speed IP home network. The image of the proposed home network is shown in Fig. 2. Further, we determined the functions of the HMMCS and the hierarchy of these functions. Then, we assembled a small-scale prototype HMMCS, built a hardware system, and developed the application software of the HMMCS. The hardware system consists of a PC,

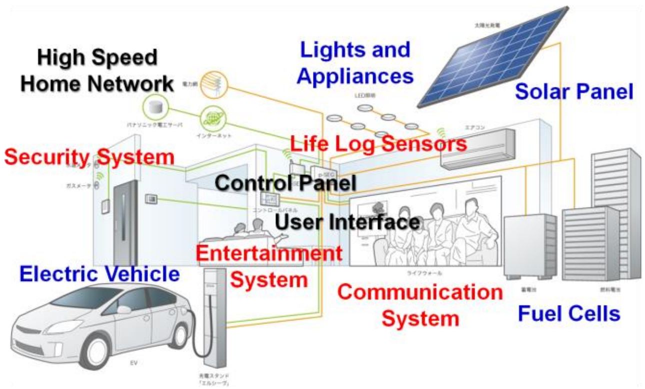


Fig. 2 Image of proposed home network with high-speed optical network

digital data logger, thermo sensors, and electricity distribution board with electric power meters. A table device was used for the remote control terminal of the system. A PC also worked as a home media server to share stored movies and photos and as a communication server to communicate with distant people via high-quality images and sound. Moreover, we developed the application software for both the home server and the remote control terminal. Then, we executed a weeklong trial run of the HMMCS to know the potential of the system, points to be improved with respect to the user interface, and the traffic load of the IP network.

2.1 Scenario Writing and Function Design

To design the functions to be installed in the HMMCS, we, first, examined the day-today activities carried out in a smart house. We assumed that a home server and high-speed IP network cables were installed, and residents have their own handheld network device, such as a smartphone or a tablet device. We then derived the following four main functions for the HMMCS: (1) monitoring and visualizing energy and environment; (2) controlling and monitoring home appliances; (3) storing and managing life log data, movies, and pictures; (4) utilizing life log data for ensuring a comfortable life with less energy use.

The first function “monitoring and visualizing energy and environment” monitors not only the parameters of the interior and the exterior environments, such as temperature, humidity, and illuminance, but also the energy generation (by photovoltaic power generation, etc.), energy consumption, and the stored electric power in the storage batteries. It also shows the energy generation and usage history of the house.

The second function “controlling and monitoring home appliances” controls the different types of home appliances in the same manner and on the same screen of a handheld tablet device.

The third function “storing and managing life log data” stores all life log data, such as the behavior of the occupants when using a heater/cooler and lighting fixtures, and the daily schedule of the occupants.

As the fourth function, the HMMCS learns the patterns and habits of the residents, and automatically generates an appropriate control program for realizing a comfortable environment with less energy consumption. Programs watched on television are also recorded in the life log data, and these data are used for suggesting programs that a resident would like to watch. These life log data are tagged by keywords and interconnected.

2.2. Software Design

We had two major considerations in this study with respect to the development of the application software of the proposed HMMCS. The first one was the “load balancing decentralized data storage.” As the HMMCS records many types of physical data and life log data, it was important to design a data storage structure to visualize and to analyze patterns in real time using the recorded and stored data. To do this, we used the load balancing decentralized data storage system.

The second consideration was the “application design pattern.” The virtual decentralize technology exhibits optimal performance even in an environment with multiple home servers and cloud systems with processing speeds. Many home appliances in a house, such as television sets, air conditioners, and lighting fixtures, have their own remote controllers. These remote

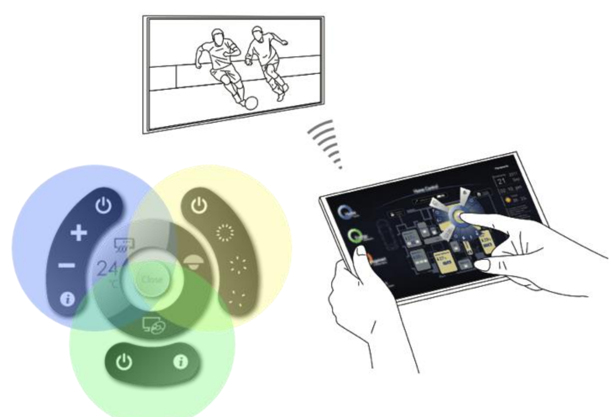


Fig. 3 Application design pattern. A television set, an air conditioner, and a lighting fixture could be controlled on the same screen by using the integrated user interface.

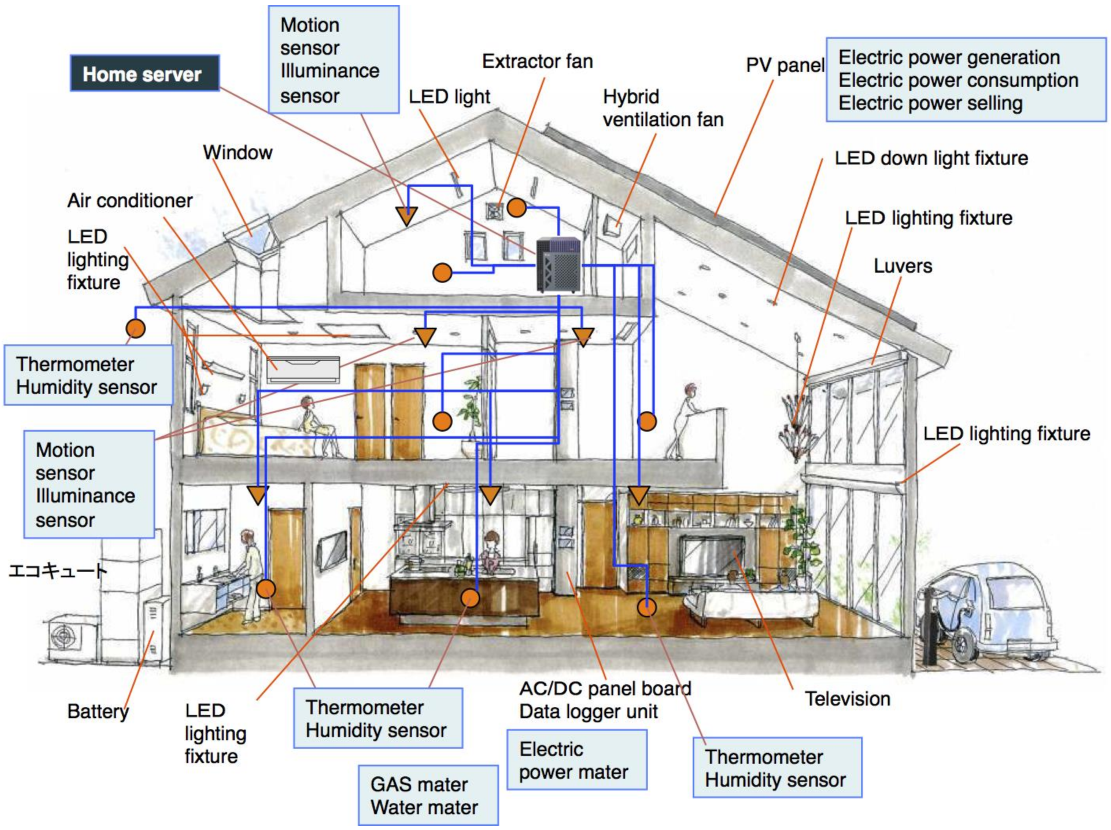


Fig. 4 A home server and sensors installed in a smart house. A home server records all types of data and controls the facilities and appliances.

controllers have a number of push buttons, and it is not easy for a consumer to remember all these functions. The HMMCS provides an integrated user interface (UI) that sophisticatedly controls appliances on the same screen of the handheld tablet device that we developed. Fig. 3 illustrates the developed handheld tablet device and the integrated controller UI. A home server receives a user operation from the handheld device and then sends the operation to the target facilities/appliances as an abbreviated infrared (IR) command.

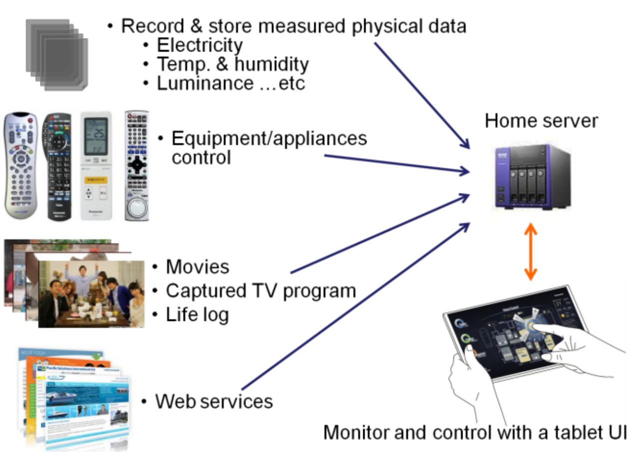


Fig. 5 All appliances and electronics are monitored and controlled

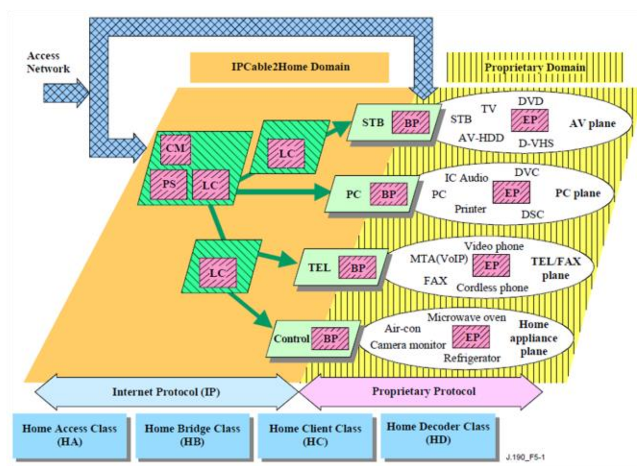


Fig. 6 Architecture of Home Network in ITU-T J.190 Standard

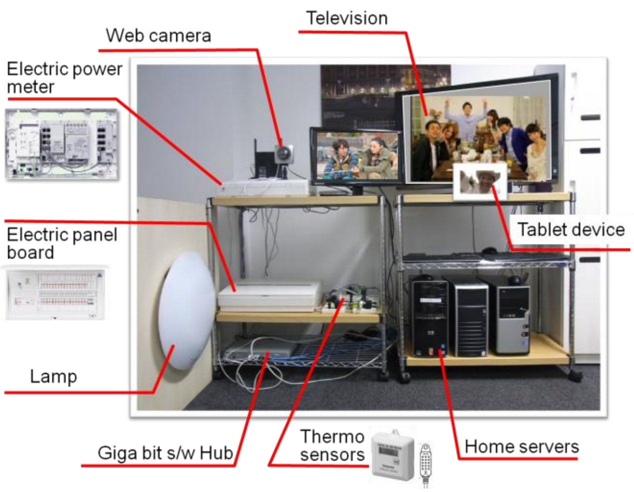


Fig. 7 Small scale prototype HMMCS used for the verification

2.3. Monitoring and Control System of Home Appliances

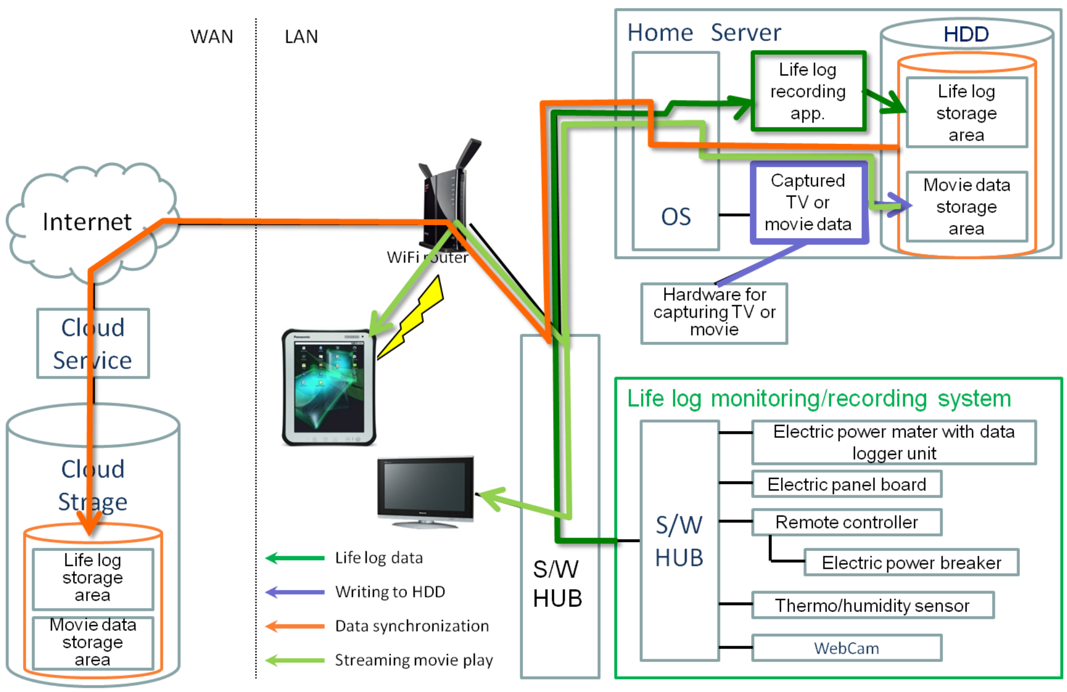
The home server of the HMMCS records many types of physical data and life log data. At the same time, it controls several home facilities and appliances. Fig. 4 shows a home server and the sensors installed in a smart house. The home server records the physical data measured by the sensors and controls the facilities and appliances through a high-speed optical network cable installed in the house. These appliances are connected the home server and the residents can monitor and control them with a tablet user interface we developed as shown in Fig. 5. Power lines connect each appliance to an electric panel board. Further, a Watt-hour meter is used for measuring the electricity consumption. Then, a data-logger unit collects these data and sends the data to the home server through a high-speed optical network using GI POF. Figure 6 shows home network architecture standardized as ITU-T J.190 that illustrates the network includes various planes such as AV, PC, telephone, appliances, and so on, bundled with IP protocol [6].

3. Verification Method of HMMCS

We assembled a small-scale prototype HMMCS and developed an application software running on a home server with an original user interface for a handheld tablet device. A small-scale prototype HMMCS consists of a PC as the home server, a data logger unit, an electric panel board having the watt-hour meter, web camera units, and thermo and humidity sensors.

3.1. Prototype Assembly of HMMCS

Fig. 7 shows the components of the small-scale prototype HMMCS. The PC on the right-hand side denotes the home server, and the white box at the bottom represents the electric panel board mentioned earlier. The other white box in the middle is the data logger unit. The data



[6]

Fig. 8 Connections between each component and data flow diagram of the prototype HMMCS

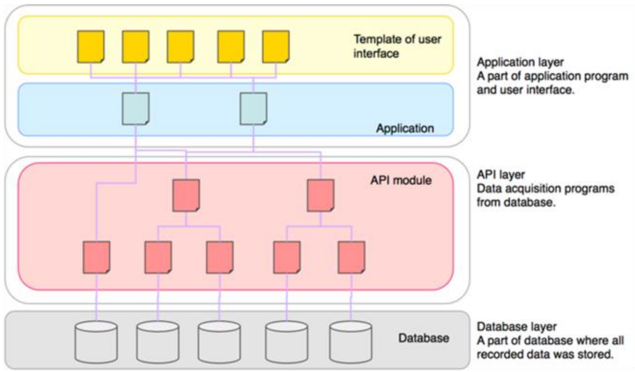


Fig. 9 The structure of the application program installed in the home server. It has three layers: the bottom one is the database layer, the middle one is the API layer, and the top layer is the application layer.

logger unit recorded the electricity consumption data using the watt-hour meter and the temperature and humidity using the thermo and humidity sensors in real time. The recorded data were sent to the home server and stored in an internal hard-disk drive storage. The home server recorded eight different TV programs broadcasted at the same time for a week and stored them. In this small-scale prototype, the real-time recording system was not packaged, and the movie data for a week were preinstalled in the home server.

A gigabit Ethernet metal cable and GI POF were combined to form the home network in the prototype. We modified the design of an off-the-shelf tablet device and a commercially available smartphone to build the remote control terminal of the home server. Fig. 8 shows the data flow diagram with the system components of the small-scale prototype HMMCS.

3.2. Development of Prototype Application Software

An application program installed in the home server was designed for adding functions. Figure 9 shows the construction of the application program. The program has three layers. The bottom layer is the database layer, which stores all the recorded physical data and the life log data. The middle layer is the application programming interface (API) layer and contains small program modules to manage the data from the database layer. The top layer is the application layer, which contains the application programs and the user interface modules for them. The database was a set of small databases.

The construction of databases, which stores different types

Fig. 10 The screens of the proposed handheld device: (a) Top left: The main screen with current conditions, “command circle,” and icons on the bottom bar. (b) Top right: The screen showing the detailed setting of a room air conditioner. (c) Bottom left: The screen for controlling the television set; the TV programs currently being aired are displayed on this screen. (d) Bottom right: The screen showing the overall energy input/output, storage and consumption.

of physical data and life log data, is also carefully designed in order to refer to each other without any delay in the response time. Some data are copied to a cloud server in order to access the life log and movie data when the occupants are outside the house. The cloud sever connects to commercial/non-commercial databases and forms a relation with them.

3.3. User Interface on Proposed Handheld Device

A handheld network device or a tablet PC as shown in Fig. 3 was developed as the remote terminal of the home server application. It provided a user interface for viewing the current situation and the history of the environment and energy generation and usage of the smart house. It also provides a user interface to control the home facilities and appliances on the same screen in an integrated manner. Any other device that can access the IP network via a web browser, such as a tablet or a smartphone, may be able to serve the same purpose.

Fig. 10 shows the screenshots of the handheld device. Fig. 10(a) shows the main screen of the remote terminal. The main menu is shown as an icon at the bottom. The right-hand side image at the top of Fig. 10 shows the hourly energy condition by a bar chart. The left-hand side shows other information such as weather, today's TV programs, and the suggested cooking recipes. The house layout shown in the middle image shows the present condition of appliances, such as lighting fixtures, an air conditioner, and a television set, and shows whether the rooms are occupied or not.

For example, to turn on the television set in the living room, we need to tap the television icon in the living room section; a "command circle" will then appear in the center of the screen. The "command circle" operation was originally developed here and was an integrated user interface to control different types of appliances in the same manner. The icons shown on the right-hand side of the circle are buttons to turn the lighting fixtures in the living room on/off. The icons shown on the left-hand side are buttons to turn the air conditioner on/off and to change the set temperature of the air conditioner. The icons shown at the bottom of the circle are buttons to turn the television set on/off and to perform any other operation on the television set, such as choosing/watching the recorded programs and retrieving the detailed information about a program on air.

Fig. 10(b) shows a screenshot of the detailed setting for a room air conditioner. The temperature shown by the largest character is the set temperature, and the outside air temperature and the room air temperature are shown on its left. The icons shown at the top are the buttons for changing the appliances to be controlled.

Fig. 10(c) shows a screenshot of the television controller and the list of the recorded TV programs. The images that appeared on the screen are those of TV programs currently being aired, and all of them are recorded and kept for a week. Further, if someone tags a TV program as "like!," the program is not removed from the home server. Fig. 10(d) shows the overall energy information of the house. The circle and the numbers on it show the amount of electricity consumed, stored, bought, and generated. The chart on the top shows the time history of the electricity consumption; it is updated in real time and shows the hourly, daily, monthly, and yearly data.

4. Results and Discussion

Real-time monitoring and management/control are important for the HMMCS to optimize the electricity consumption in a smart house. Therefore, we performed a trial run of the small-scale prototype HMMCS and checked the network data traffic load to avoid the delay of real-time monitoring/management and degradation of the movies being played. The functions of the home server application and the user experience of the remote control terminal device have also been discussed.

Table 2 shows the data traffic load of the small-scale prototype HMMCS. Here, we assumed that four people lived in the smart house and that each of them had a television set and a tablet device. The data traffic for an individual action or for an appliance was measured using the small-scale prototype HMMCS. The values shown in Table 2 are the data traffic load for four people or the total load of the house.

They were calculated by multiplying the data traffic for one action by the quantities shown in the table. The maximum data traffic load was 287.9 Mbps; it was smaller than the maximum data traffic load of a metallic gigabit Ethernet, which was approximately 600–700 Mbps. Assuming that the screen quality is enhanced by the digital broadcasting commonly used today, the data traffic load will increase considerably. The values shown within the parentheses are the data traffic load in the case of ultra-high-resolution 4K movies, assuming their data size was eight times more than that of HD movies. The maximum data traffic load in the case of 4K movies was approximately 1.2 Gbps and was larger than the maximum data transfer rate of the metallic gigabit

Ethernet. This fact suggests that a 10-Gb Ethernet is required for transferring all the movie data without any delay or noises. For such a high-speed network infrastructure in a smart house, optical fiber network cables are recommended, and the most suitable cable for a residential house is a graded index plastic optical fiber (GI POF) because it is flexible, less fragile, safe, and easy to connect.

Table 2 Data traffic of the HMMCS for each action in a smart house

Category	Action (Frequency)	Qty.	Data traffic [Mbps]
Home movie sharing	Capturing TV programs (All time)	8 channels	12.8 (102)*
	Playing on TV	4	55.36 (443)*
	Playing on tablet device	4	55.36 (443)*
Following the fashion	Getting program information	4	7.31
	Getting contents	4	14.71
	Getting hot keywords	4	1.56
Web camera movies/pictures sharing	Watch web camera movies (All time)	4	55.36
	Watching recorded movies	4	6.24
Energy & environment monitoring	Electric power (All time)	30	0.01
	Thermo/humidity sensor (All time)	4	0.03
	Watching recorded data	4	11.37
Food management	Stocked foods management	4	33.89
State of appliances	Monitoring	4	33.89
Maximum data traffic			287.9 (1153)*

* Values shown in parentheses show the estimated data traffic load when the ultra-high-resolution 4K movies were used.

5. Conclusions

We proposed a home monitoring, management, and communication system (HMMCS) for a smart house in order to optimize the energy use in a smart city and realize a comfortable environment. We assembled a small-scale prototype HMMCS consisting of a home server, metal and optical fiber network, thermo/humidity sensors, power meter, an electric panel board, and remote terminals. We also developed application software with an integrated user interface for controlling the different types of appliances in the smart house in the same manner via a terminal device. Our trial run showed that more than 1-Gbps data traffic might flow in the near future with high-resolution 4K movies and that a high-speed optical network is required to avoid a data response delay and noises with respect to movies. Thus, we concluded that a flexible and easy-to-connect GI POF cable was suitable for smart houses.

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Tetsuya Toma obtained a master’s degree in Applied Chemistry from Keio University in 1988, joined Sumitomo 3M. Moved to 3M Company in USA in 2001 and worked as an advanced product development specialist until 2007. Developed various new products for global electronics markets. After serving for 20 years in 3M, he joined Keio University in 2008 and is researching on communication systems. Also joined Keio Photonics Research Institute in 2010. Contributed as a team leader of this project and wrote this paper.

Hideo Asada received his Master degree in 1993 at Graduate School of Musashi Institute of Technology in Tokyo, Japan and joined Obayashi Corporation. He returned to the university and earned Doctor of Engineering (Architecture and Building Technology) in 2001. After serving for several research institutes as a researcher, he joined Architech Consulting Co., Ltd. in Tokyo, Japan in 2005. His research fields are energy and environment analysis of building technology, and "exergy" analysis of built environment system and human body. He published 11 peer-reviewed papers and gave 42 oral presentations. He wrote about 10 joint-author books including "Exergy –Theory and Applications in the Built Environment, Green Energy and Technology" from Springer in 2013.

Tetsuro Ogi obtained a master's degree in Mechanical Engineering from the University of Tokyo, and joined Mitsubishi Research Institute in 1986. Earned a Ph.D. in Mechanical Engineering from the University of Tokyo in 1994 and was named associate professor in 1996. In 2004, he moved to the Graduate School of Systems and Information Engineering, University of Tsukuba as an associate professor. In 2008, he moved to the Graduate School of System Design and Management, Keio University. His research field includes systems engineering, virtual reality, human interface, etc. Served as an advisor of this project from the network technology stand point.

Yasuhiro Koike earned his B.S. at Keio University in 1977, M.S., in 1979 and Ph.D. in 1982 in applied chemistry at the Graduate School of Engineering of Keio University. Has been Professor at Keio University since 1997. Specializes in "photonics polymer" such as graded-index polymer optical fiber (GI POF), highly scattered optical transmission (HSOT) polymer, zero birefringence polymer, etc. He has been pursuing an R&D project of Face-to-Face Communication system on the FIRST Program of the Cabinet Office of Japan since 2010. He is a recipient of International Engineering and Technology Award of the Society of Plastics Engineers, the Fujiwara Award, and Medal with Purple Ribbon in Palace, etc. Councilor, Keio University. The GI POF used in this study was his original invention.