

# Ecological Home Network: An Overview

*This paper discusses the current state of relating technologies and various aspects necessary for a better home network implementation from an ecological point of view.*

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**ABSTRACT** | A home network is one of the next-generation information and communication technology (ICT)-centered applications, and this paper discusses the current state of relating technologies and various aspects necessary for better home network realization. It is necessary to discuss the technologies for a good home network, but it is also important to consider this from the different aspects other than technologies. Cost, power consumption, maintainability, and relevant data volume are such view points, and they support better ecological home network. This paper first discusses the technology components which support realization of a home network. They are network technologies, varieties of devices, software-based systems and standards, and home gateway, the key component of a better home network. Then, the author shows several considerations from the ecological viewpoints such as cost saving, energy saving, human load saving, and data volume saving. The real technology and business for a home network is still in an evolving stage, and it is necessary to discuss the implementation issues for a home network. Home gateway is an important component for managing a home network, and the author proposes a home gateway architecture suitable for better implementation of a home network as a whole.

**KEYWORDS** | Ecology; home gateway; home network; network standards; smart home

## I. INTRODUCTION

A smart home is a good target for information and communication technology (ICT)-integrated applications for human beings. It brings about a better life and an intelligent living environment in addition to economic

growth and daily convenience. Many human activities in modern age are now based on usage of the Internet, which interconnects many people and things around the globe. A smart home is a home equipped with its own network system which connects all the devices and things in the home. This network is called a home network. A home network is typically connected to the Internet, and it is desirable to design this home network elaborately, and to account for various aspects of networks and the surrounding conditions.

One of the aspects is technology. A home network should deal with various devices and equipments, and handle many kinds of network devices. The size of some of the target objects may be very small and fragile, and the power they need may also be small. They can be quite different from usual internet equipments which are well designed and implemented. There are many communication schemes used within a home network, and it is necessary to deal with these delicate devices carefully. There are many interfaces for these network devices and other facility devices, and it is necessary to take into consideration the interface matching and harmonization for these devices.

Another important aspect of a home network is related to the necessity to manage different quality and quantity like power consumption, trouble shooting, total cost saving, reliability, manageability, and so on. While good solutions for these concerns may be strongly related to technology used by a home network, some other solutions may be achieved through appropriate design philosophy, management strategy, and smart considerations for total solutions.

There are many issues and solutions, both for the technology aspects and for other concerns. It is necessary to list these issues and to carefully consider solutions for these issues. Though we are accustomed to these activities, we have limited experience in finding solutions for these other concerns. Some of these concerns may fall into different professional domains like social science, biology, environmental science, geology, and so on.

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A smart home is a very important and influential system and application in our life and society because all people are more or less related to their own home. A smart home is strongly related to Earth, and it is necessary to harmonize a smart home and the global problems on Earth. Ecology is a concept where human beings' activity and the environmental issues of Earth itself should be harmonized and coworked. The next-generation smart home should consider these directions and issues, and we should pursue the "ecological" smart home and the "ecological" home network.

Ecology relates to these various domains and is concerned with long-range studies and solutions. While ecology is related to technologies from various fields, real ecological thinking examines the overall and unified mixture of technological facts and human wisdom.

In this paper, in order to clarify the problems and their solutions for an ecological home network, Section II discusses the characteristics of a home network. Section III discusses the technological aspects of a home network, as there are various technologies which construct a home network in general. As these technologies are widely developed and utilized, the key issue is the standardization of technologies, and this section shows several examples of the standardized technologies. Section IV discusses the ecological aspects of a home network, and, in fact, they are not only natural resource aspects but social aspects as well.

A smart home is a very important application, but its current status is not matured.

Section V shows the design philosophy and implementation issues of an ecological home network. An architecture of its main system component, home gateway, or a home network management system is shown and discussed in detail. Section VI discusses remaining issues as a conclusion.

## II. HOME NETWORK CHARACTERISTICS

A smart home is first supported by a good home network, and then supported by the Internet, as shown in Fig. 1. Usually, there are many kinds of objects or devices which

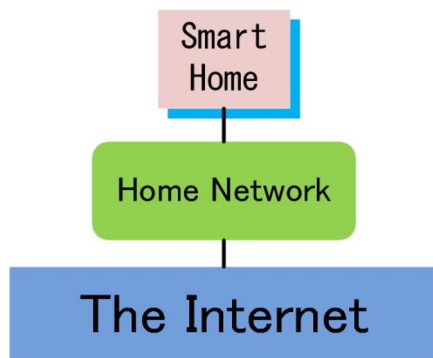


Fig. 1. Network environment for a home network.

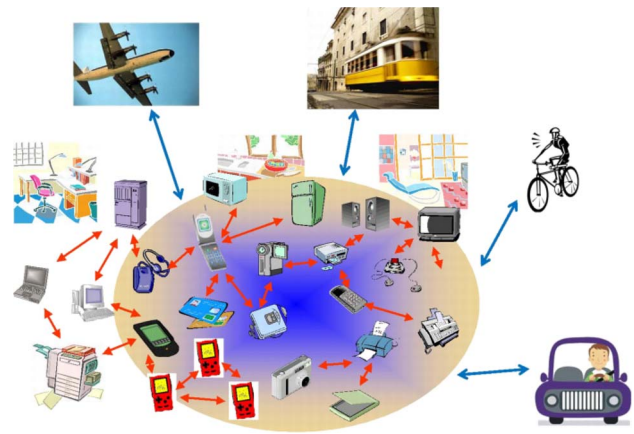


Fig. 2. Things around a smart home.

are utilized by human beings in daily lives, as shown in Fig. 2. It is necessary to have some connectivity among these things, and this has recently been called the Internet of Things. A home network is a part of the Internet of Things. Network mechanism in a home network needs not necessarily observe the same technologies used on the Internet, such as protocols, addressing scheme, networking functions, and so on. A home network's role is limited within each home, and its network connectivity should cover only a home.

It is necessary to design and implement a home network elaborately because there are varieties of relevant network technologies, both in hardware and software, and the selection and combination of these technologies should be carefully taken under consideration. Network technology has a long history in the ICT area, and there have been many standardized network technologies so far, and it is rather safe to introduce standardized technologies for real implementation of a home network.

Implementing and utilizing a home network is still in an early stage of development. It may involve high cost, and the operation and management can be rather time consuming and difficult. There needs to be an additional power and energy to operate and maintain a home network smoothly. Therefore, it is important to evaluate the implementation cost and the operation cost with care. Total cost, maintainability, power consumption, user friendliness, and so on are more important for a home network than for a usual Internet-based system.

## III. RELEVANT TECHNOLOGIES IN A HOME NETWORK

### A. Network Schemes and Devices

In a home network, it is possible to use several different kinds of networks for appropriate user applications. The network hierarchy is shown in Fig. 3. The

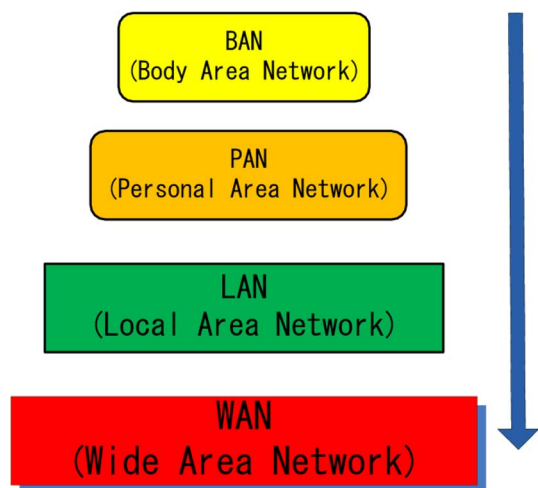


Fig. 3. Network hierarchy for a home network.

Internet is usually based on a local area network/wide area network (LAN/WAN) scheme, while a home network consists of body area network/personal area network/local area network (BAN/PAN/LAN).

BAN is a short-range wireless communication scheme with low power consumption, and it usually connects small healthcare devices attached to a human body. Recently, the first standard (IEEE 802.15.6) [1] for BAN has been issued by the IEEE 802 Committee. This standard technology has been developed mainly by the National Institute of Information and Communication Technology (NICT) in Japan. In the future, other standards for the BAN scheme are expected. In a home network, as various kinds of healthcare services for family members become ever more important, BAN will become more popular.

PAN is a wireless communication network scheme with a little bit larger communication range than that of BAN. One of the examples of PAN is Bluetooth (IEEE 802.15.1) [2], and its communication range is more than 10 m at the longest. It needs a small size transceiver, and the power consumption is small. Another popular PAN is ZigBee (IEEE 802.15.4) [3] with very little power consumption. Bluetooth needs a pairing operation to connect to a device, and it is reliable and steady. Therefore, it has been used to connect a keyboard, a mouse, a printer, some kinds of media devices, mobile phones, and so on in a home network. On the other hand, ZigBee is easy to find target device, and it can connect multiple devices simultaneously to build an *ad hoc* network. It is suitable to construct sensor networks in a home, connecting several sensors distributed throughout a house.

Another short-range wireless communication is near-field communication (NFC). It is usually used in the form of the integrated circuit (IC) card, and its communication range is less than 10 cm. The standard for this network scheme is developed by the International Organization for Standardization (ISO), and the typical NFC standard is ISO14443 [4].

The original ISO14443 includes three types: A, B, and C. Type C developed by Sony Corporation (Tokyo, Japan) is called FeliCa (ISO18092) [5]. FeliCa is widely used as an IC card, especially in the public transportation, including an electric tram car and a bus in Japan. In a home network, it can be used to connect a printer, a projector, a sound device, a digital camera, a mobile phone, and so on.

A home network is a LAN, and is typically connected to the Internet through a home gateway (HGW). A typical LAN scheme includes a carrier sense multiple access with collision detection (CSMA/CD) Ethernet (IEEE 802.3 series) [6], WiFi or wireless LAN (IEEE 802.11g/b/n) [7], a home network based on a coax cable Multimedia over Coax Alliance (MoCA) [8], mobile phone (tethering), and so on.

Due to the important role played by the HGW, several industrial consortia like the Home Gateway Initiative (HGI) [9] have been created to develop and standardize HGW technologies. Several products have been designed and manufactured, and have become commercially available.

## B. Devices

There are all kinds of devices in a home network. They play different roles, but all of them are indispensable to support human beings' daily life.

- 1) Network devices: In order to connect various devices, it is necessary to use some network devices like router, adapter, bridge, connecting hub, etc.
- 2) Computing devices: In a home network, a family member may use a desktop personal computer (PC), a notebook, a tablet computer, a mobile phone, and a smartphone for various purposes through using their computing power.
- 3) Sensor devices: It is useful to deploy multiple kinds of sensor devices to obtain various information. Human-body-related sensors are indispensable to collect data for healthcare services. A geographical sensor is used to identify the location of various places. A radiation sensor is important to measure certain kinds of radioactivity.
- 4) Home appliances: There are many kinds of home appliances in a modern smart home, and it is very desirable to connect these appliances to a home network for operation, maintenance, and other purposes. Historically, each home network was developed for home appliance management. It is becoming popular to control air conditioners from outside a house using mobile phones.
- 5) Media service devices: There are multiple media devices to handle audio/video recording and playing. The screen has become high definition, and sound has become multidimensional. People can enjoy a home theater through these high-quality media devices. It is necessary to implement high-bandwidth communication channel for these purposes.
- 6) TV/radio devices: TV and radio broadcasting is very popular and is inevitable in our modern life,

and so it is necessary to connect TV equipment to a home network. Recently, TV broadcasting plans based on 4-K and 8-K high definition have been announced, and TV is a main equipment in our home theater. Usually, the TV set top box (STB) is used to control channel selection and other TV services, and it is desirable to connect STB to the home network, allowing TV broadcasting communication connection. Of course, it is necessary to have a high-bandwidth communication channel.

- 7) Security devices/disaster prevention devices: A home network can be used to make a smart home safe. Multiple cameras for security and multiple motion sensors located at windows and entrances can be connected together through a home network, and an alarm control security system can detect automatically any invasion. It is also possible to use natural disaster detection devices for major earthquake detection. Early detection of a big disaster may help human beings take action and move to safer areas.
- 8) Power-related devices: There has been a strong concern to control the power consumption of a smart home, and home power management systems, such as the home energy management system (HEMS), have appeared recently [10]. Such a system can be connected to the home network of a smart home, and an efficient ecological operation can be achieved. It is possible to install a battery and a solar panel in a smart home, and its management system can be connected to a home network to enable a total energy management.

### C. Software: Protocols, Systems, and Service Applications

It is necessary to have various software functions and packages to operate a home network in a systematic way. Well-designed protocols are essential. In the initial stages of a home network development, network systems have been naturally Internet oriented, and there have been several standardized protocol systems developed as follows.

- 1) Universal Plug and Play (UPnP) Forum [11]: UPnP defines the protocol system to connect devices to the network instantly.
- 2) Ubiquitous Open Platform Forum (UOPF) [12]: This is supported by the Japanese Forum for Internet Service Provider and home appliance companies, and its purpose is to connect digital home appliances to the Internet easily.
- 3) Digital Living Network Alliance (DLNA) [13]: This is supported by many digital home entertainment makers and mobile PC or phone makers, and its purpose is to construct the common guidelines for easy networking between these devices in a home network. It is based on the UPnP and the Hyper Text

Transfer Protocol (HTTP). There are many digital home devices which are certified for these guidelines.

- 4) Open Service Gateway Initiative (OSGi) [14]: OSGi Alliance defines a Java-based service platform, which is controlled remotely through a network. Based on this platform, service software has been developed, and service registry has service programs that are controlled remotely.
- 5) ECHONET [15]: ECHONET is a standard developing consortium in Japan, and defines a smart house concept based on energy saving, energy accumulation, and energy generation. It has developed standards for a smart home, which enable mutual connection for equipments and systems developed by multivendors.
- 6) P2P Universal Computing Consortium (PUCC) [16]: PUCC developed standards which enable connection among devices in different kinds of networks. It defines overlay protocols to connect devices in different kinds of networks.

It is possible to develop real service applications using the above protocol systems and platforms. Home theater entertainment, healthcare service, security service, elder people support service, energy management service, natural disaster prevention service, and so on are possible examples of a smart home. With the devices and home networks having more and more elaborated functions, it is now possible to support at-home business development or children studying in a smart home.

### D. Home Gateway

A special dedicated network node in a home network, called HGW, is shown in Fig. 4. It connects a broadband

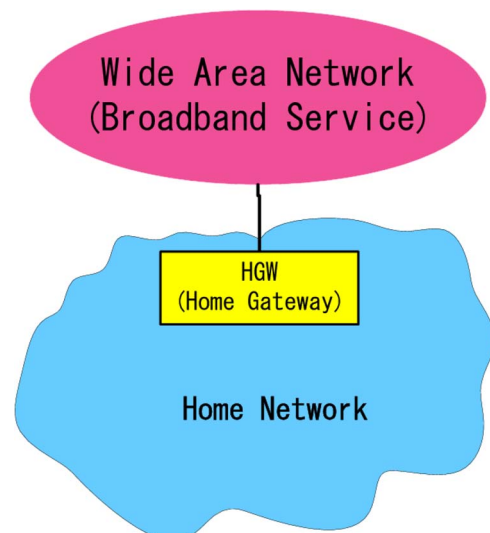


Fig. 4. Home gateway.

public service network and the home network in a smart home. HGI has been developing specifications for HGW standard architecture.

As is shown in Fig. 3, a home network includes a hierarchical network scheme to connect various kinds of devices, and HGW connects this home network to the Internet service through a broadband public provider. PAN/BAN network schemes such as Bluetooth or ZigBee need a corresponding network adapter, and HGW may be equipped with these adapters.

There are some specific services provided by service providers outside a smart home, and HGW is a good relay point to support these kinds of communication services. These services include TV broadcasting, IP telephone, network gaming, and so on, and need a high-bandwidth communication channel.

Service application systems are provided through the Internet, and a user in a smart home uses these application systems through HGW. Some of them need data from several devices in the home network, and these application systems require smooth cooperation with HGW.

Recent computing environment has greatly changed, and a low-cost cloud-computing service has become available to ordinary people. It is still in the developing stage, and there are no steady standard technologies yet. It is expected that cloud service interfacing and coordinating will be included in HGW to support easy and high-quality cloud-computing services provided to users of a home network.

#### IV. ECOLOGICAL CONSIDERATION

It is interesting and important to consider a home network from viewpoints other than technologies [17], [18]. These viewpoints are the ecological characteristics of a home network.

Four different points of view are discussed as follows.

- 1) Cost saving: A home network typically comprises multiple network devices, various digital devices, and software modules. A well-designed home network will support comfortable and efficient daily life, and it may seem that high-quality and expensive hardware and software are indispensable. It is, however, necessary to save cost for a home network construction in order to realize its sustainable cycle of reconstruction. Power line communication (PLC) [19] is one of the methods which supports the cost reduction for a home network construction. This idea corresponds to the ecological cycle for natural resource consumption. The requirement for a home network in terms of service functions, system soundness, and efficiency should be well considered to avoid high cost.
- 2) Energy saving and control: Energy consumption of a house is an important concern. HEMS is a device

dedicated to manage home energy consumption, and there are several kinds of systems currently commercially available. HEMS provides functions such as visualization of home energy consumption, automatic switch on/off control for some home appliances, and management of solar panel power generation. Current HEMS is still evolving, and it is expected that more elaborated HEMS will be designed and implemented at an appropriate cost level. It is expected that total management for home energy consumption will be available. In the near future, electric power supply will become more sophisticated. For example, electric power supply to the home by an automobile battery will become very popular, and it will be necessary to manage and utilize this power to save a large amount of electric energy supplied by an electric power company. Power generation plants using natural resources such as wind, geothermal resources, or sunshine are already in use in various areas, and harmonization of power consumption for various power sources is becoming an important issue for a smart home energy management. A home networks should be designed carefully to optimize total energy consumption of the home. EnOcean (San Ramon, CA, USA) [20] developed a new technology called "energy harvesting." It utilizes several kinds of energies such as mechanical energy, solar photo-voltaics, and thermal energy to get electric power. This technology is used, for example, to activate wireless switches without battery in a house, and it is possible to greatly reduce the electric power consumption in a home network. It will contribute to the ecological strategy for the global natural environment issue.

- 3) Maintainability and easiness of an operation: It is expected that a home network becomes very important for ICT and its components and related technologies become complicated gradually. It is, however, natural that users of a home network are ordinary citizens. Sometimes, they are old people and young children, and it is not expected that all users of a home network have good skills for ICT operation and knowledge. Even for users with much experience in ICT applications, it is sometimes realized that initial settings, error recovery, and software downloading and installing are rather complex and difficult to successfully finish. It may give an impression to home network users that these kinds of systems and services are not important and not useful. User manuals and interactive online guides might be helpful, but this is not a final goal. It is very important to design a home network as easy as possible for any levels of user skills. For example, OSGi tries to establish a

standard for simple and easy software development and installation based on Java virtual machine and environment. It can support to develop a good home network rather easily. A home network ecocycle, or the succession of a home network through different generations is realized by participation of end users, as well as by manufacturers and engineers.

- 4) Data volume management: A home network with various kinds of sensors and digital devices generates a lot of data that can be used for various purposes. This new technology is called “big data.” This area becomes feasible with the availability of low-cost cloud-computing services, and end users need not worry about the availability of their own disk storage space. Using big data of user activities and other services, it is possible to make better decisions for a lot of purposes. Statistical handling for big data will bring about new business and technological challenges, and many people are exploring this new area. There are scenarios where services running in a home network accumulate a lot of data in this network. These services may be healthcare, net shopping, home security, geographical data for human mobility, natural disaster protection, and so on. Considering data usability, it is not desirable to accumulate huge amount of data in a home network. Even though cloud-computing service is cheap and convenient, huge volume disk storage still costs money, and big data processing is not free either. Intelligent data processing is more useful than huge volume data accumulation. Management of reasonable data volume in a home network is preferred, and it contributes to support the ecocycle operation or the sustainability of a home network.

## V. TOWARD A TOTAL HOME NETWORK SYSTEM DESIGN

A home network becomes more and more important in our daily life, and it is necessary to design and implement a home network system with great design consideration. In a home network, there should be one control system which is equipped with various network devices and general purpose computing power. Some other interfaces for additional communication devices are required.

HGW is a key component to connect a home network to the Internet in general, and it should be carefully and elaborately designed and implemented. It should play as the “total” home network management system. In fact, it is a specially designed hardware with many software modules, and it is really an operating system in distributed manner for the overall home network system. Fig. 5 proposes the ideal architecture of HGW or the total home network management system.

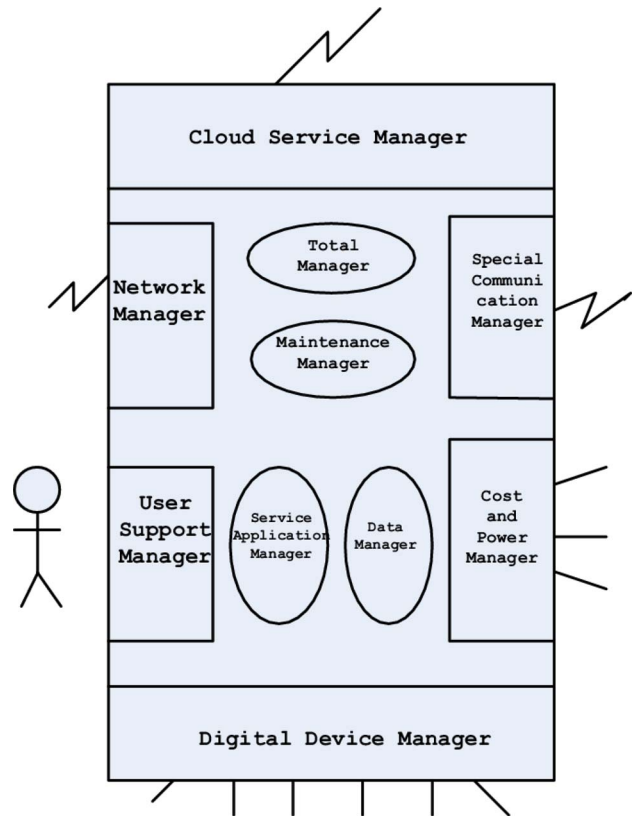


Fig. 5. Architecture of a home gateway.

There are the following components in HGW.

- 1) Total management module: This is the main control part of the whole system. A home network management system is, in fact, a distributed operating system, and this part controls all the components in a distributed manner.
- 2) Network manager for a WAN/LAN/PAN/BAN hierarchy: A home network should manage a network hierarchy with varieties of network devices, i.e., Bluetooth devices, ZigBee devices, BAN related devices, cable LAN, WiFi, high-speed routers, and intelligent WAN devices. It needs to implement smooth communication among these hierarchical networks.
- 3) Specific communication service manager: A home network may need to support TV broadcasting service, cable TV service, low-cost telephone service, mobile phone service, and so on. It may be served through the Internet, or it may need specific communication lines and services.
- 4) Digital device manager: There are many digital devices in a home network, i.e., varieties of sensor devices, digital media devices, many kinds of home appliances, electric power management devices, home security devices, and so on. It is

necessary to control all of these devices so that any application can handle these devices smoothly. Easy installation of device drivers and automatic management module installation are essential.

- 5) Service application manager: Users of a home network typically have many service applications. These software systems usually work within the Internet services. Sometimes they may be located and work inside a home network. In any case, all applications must be easily searched and accessed by users through this management system.
- 6) Cloud-computing service manager: Users in a home network need to access the cloud-computing service provided by service providers outside a home network, and it is necessary to smoothly connect to this service without complicated user and program interfaces.
- 7) User support manager: Users in a home network desire to be able to control this home network and execute service applications at any time. They want to manage the home network status as well as check logs of ecology related status. A well-designed user interface and an easily understandable operation guide are essential.
- 8) Cost and power manager: It is necessary that the cost and power consumption status is visible to users at any time. It is desirable for home network users to control these figures at any time.
- 9) Data manager: It is important that users can keep track of data generated in a home network. Volume management for these data will be indispensable.
- 10) Maintenance manager: It is important to ensure that a home network is easy to operate and maintain. A home network should be operational at any time, and easy recovery from the system failure is indispensable. Automatic error detection and recovery is one solution. It is helpful

that remote maintenance be available. It is envisaged that a maintenance center for home networks performs remote maintenance as well as emergency service.

The aforementioned management service is integrated in one management software system. With this management system, the ecological home network can be implemented in any smart home, leading to a more convenient daily life and customers' satisfaction.

## VI. CONCLUSION

A home network will be providing the next-generation large-scale service enabled by ICT, and the key point is to develop elaborated systems to support overall functions. These include not only technological functions such as network connections, digital device management, etc., but also functions relating to different aspects such as ecological requirements.

A smart home and its underlying management platform, an ecological home network, consists of various technological components as well as several management functions for resource saving, energy saving, cost saving, human responsibility saving, and so on. The standardization of these technologies greatly contributes to the realization of an elaborated home network. Our home is a base for human life and activities, and its sustainability should be observed by best management enabled by ICT with great considerations for various aspects of ecological viewpoints.

A home network is still in an evolving stage, and it is necessary to pursue an elaborated design philosophy and its implementations. This paper shows the architecture of HGW as one of the implementation methods. The total management system is crucial for realizing a better ecological home network, and the proposed HGW will be helpful for this purpose. ■

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In 1966, he began working at the Electrotechnical Laboratory, Japanese Government. He became a Lecturer at the Institute of Informatics and Electronics, Tsukuba University, Tsukuba, Ibaraki, Japan, in 1974, and then became an Associate Professor in the School of Engineering, Keio University, Yokohama, Kanagawa, Japan, in 1978. He was the Dean of Faculty of Environmental Information at the Shonan Fujisawa Campus, Keio University, in 1995-2001, and he was also a Vice President of Keio University in 2001-2005. In 2006-2010, he was with



the Faculty of Global Media Studies, Komazawa University, Tokyo, Japan. He was the Dean of this faculty, which was newly established in 2006, and it aims to pursue the next-generation digital media and its impact on social activities. His specialty is computer and information systems, e.g., operating system, network system, web technology, and so on. He is interested in the standardization of computer technologies.

Prof. Saito has been the Associate Chair of the World Wide Web Consortium (W3C) since 1996, which is engaged in the industrial standardization of a basic web system. He also has been the Chairperson of the P2P Universal Computing Consortium (PUCC) since 2004, which works for the standardization of P2P networks, including the overlay network protocol. This protocol is widely accepted in various application fields such as healthcare, home appliances, and so on.