The proposal of a phased expansion plan for smart meters and home network

Kunihiro Yamada[†], Takashi Furumura[‡], Koji Ishio[‡],Handa Chen[‡],
Toru Shimizu[*], Masanori Kojima, and Tadanori Mizuno[**]

[†]Professional Graduate School of Embedded Technology, Tokai University, Tokyo, Japan,
[‡]Megachips Corporation, [*]Renesas Electronics Corporation, [**]Aichi Institute of Technology
{yamada@kunighiroi.com}

Abstract - In this paper we have carried out research and development for the implementation of a home network and to cut consumption during electric power peak periods. As a result, we propose technological innovations for a home network and a gradual expansion plan for a smart meter and home network. More specifically, the proposal describes #1 a system to create a home network which includes a smart meter in a two-layer configuration with existing networks, #2 implementation of an electric power peak cut system which considers safety, and #3 the installation of a high performance communication system with a "mutual complementary wireless and wired network" into the home network.

Keywords: smart meter, home network, energy saving, energy management, regional safety, DSM, Mutually complementary network, wireless and wired ;

1 NEED FOR A HOME NETWORK

Since the Great Tohoku Earthquake ended operations of a nuclear power plant, the need for a home network to reduce electric power consumption during maximum power demand, in other words, implement an electric power peak cut in a home has been increasingly discussed. Along this line, and based on the smart grid initiative, researchers have been extensively working on regional energy management technology, building control energy systems and home energy management systems (or HEMS) [1]. Prompted by the Great Hanshin Earthquake on January 17, 1994 and the tsunami which struck Indonesian Sumatra on December 26, 2004, a home network is considered essential for safety and energy saving of a home. Believing that a home network should not be impossible given the current technological level, we have been studying its implementation [2]. Functioning as a sensor for the region, each individual home collects information on nature and man-made disasters. This eventually leads to home and regional safety, energy saving and convenience [3].

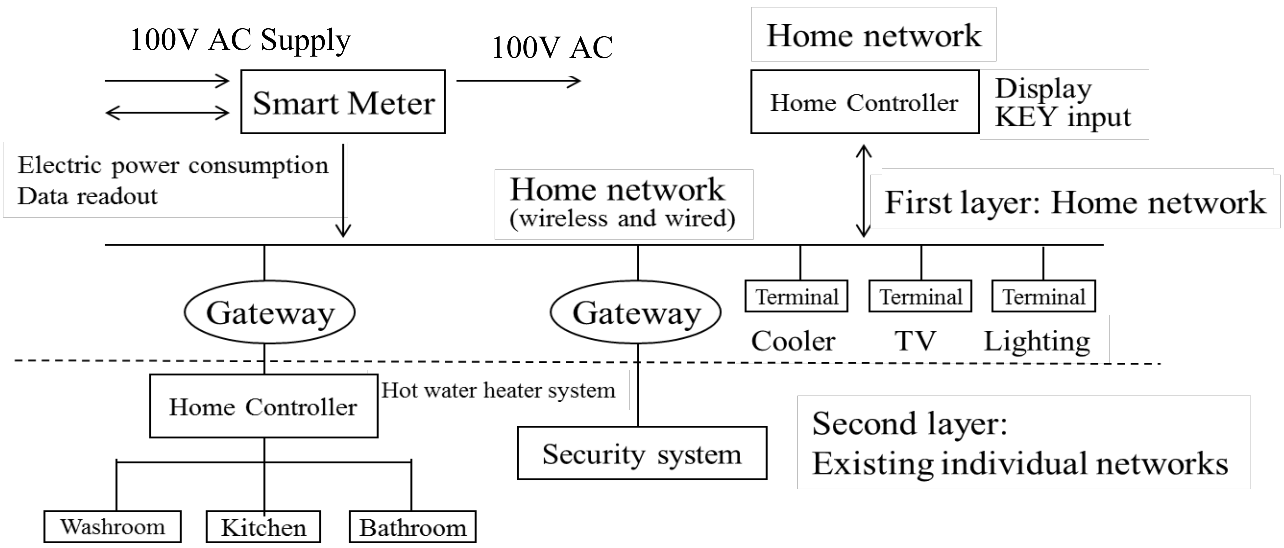
Although researchers have been proclaiming the necessity for a home network since the 1980's under the banner of home automation, this has not been achieved due to three issues. The first issue is the concern regarding integration of a home network for the entire home although there are already existing individual networks. Integration of two different network systems is extremely difficult. The second is the lack of research on the convenience that could be obtained by connecting home appliances, computer peripheral devices and sensors to the network because the home network terminals (nodes) are expensive and have not been standardized. And last is that installation of a home network and adjustment requires work by an engineer, which translates into high prices.

To address the first issue regarding integration of a home network and existing individual network systems, one solution is to configure a two-layer network which can combine both systems. To resolve the second issue of home network terminals being very expensive, a mutual complementary communications system using wireless and wired applications can be realized by a single chip using present semiconductor technologies to reduce costs [4].

By establishing high communications performance which eliminates installation and adjustment, the third issue regarding the high costs of engineering work can be handled [5]. This is the mutual complementary communications system mentioned above, which can provide stable, consistent communication performance at ordinary homes [6]. This communications system is called a "mutual complementary network by wireless and wired communication."

2 STRUCTURE OF TWO-LAYER HOME NETWORK

A typical home today has several individual networks, including a hot water heater, an interphone system, a home security system, Internet and a telephone line. Since it is difficult to create a home network that covers the entire home by combining all these existing individual network systems, one solution is to form a two-layer network structure. In this particular structure, as shown in Fig.1, a gateway connects the home network covering the entire home with the existing individual network systems. Various electric and electronic devices, such as home appliances including air conditioners and refrigerators, and computer peripherals including printers, hard disc drives, and lightings, are all hooked up to the home network covering the entire home.



;

Figure 1: Structure of a two-layer home network (Patent; similar gateway)

Viewed from either one of the layers, the gateway is a terminal within the network. This gateway chooses the path of least load to the network. In other words, it is an arrangement where the interior conditions are presented, and the information can be used by the other side (or specifications) when helpful. And of course there are no restrictions regarding development and growth between the two layers of network. This particular system of a home network works smoothly with the existing network systems to provide information to avoid various dangerous conditions and contributes to improved convenience. The authors refer to the connection (gating) of these two network systems as “light gating”.

3 PROPOSAL FOR ELECTRIC POWER PEAK CUT WHICH CONSIDERS SAFETY

One measure to address concerns regarding an insufficient electric power supply is the “electric power peak cut” concept. In the future, the electric power company may directly control home devices such as an air conditioner through a smart meter [7]. However, such a system still requires careful attention as such control may involve risk to human life or cause accidents. In Japan, 30% of the total electric power generated is consumed by households [8]. Attempts have been made to make energy usage “visible” in order to promote an individual sense of economy, thus reducing electric power consumption. Such attempts, however, have limitations. Hence a more advanced idea of “demand side management (DSM)” is proposed at this time.

Our proposal to reduce home electric power demand utilizes demand side management as its core structure, where the appliances in the home are reset with a control mode in the home network controller, based on a “peak cut control table,” prepared in advance. Table 1 shows “peak cut control table”. The table defines the values which dictate the control mode of each home appliance starting with the level at the time of peak cut. Compared with the normal consumption conditions, the home owner sets up the controller so that Level 1 peak cut reduces consumption to 67%, Level 2 to 50% and Level 3 to 33%. The authors plan to incorporate two features into this control. One readily shows the amount of energy cutback and associated electric power fee by simulation, and another introduces a game which takes advantage of edutainment (educational entertainment) [9].

In the two-layer home network structure shown in Fig.1, electric power of 100vAC is supplied through the smart meter. The smart meter measures, and reports electric power consumption to the electric company while receiving and maintaining electric power during peak cut. The electricity rates in Table 2 are simulation examples to explain this system. The table shows three levels of electricity rates and when they are to be applied. The application time is arbitrarily set at 10:00-16:00.

As shown in Case 1 in Table 2, the electric power consumption is cut back to maintain a constant electricity bill for a home. Within this peak cut time frame, since the electricity fee rate is 300% at Level 3, the usage rate is reduced to 33%, which translates to an 83% overall reduction. If peak cut is implemented for three months for all six hours, the annual total electric power consumption rate becomes 96%. While this is only a 4% reduction, 83% of the total demand, as discussed above, may be sufficient in reducing peak demand supply.

Case 2 in Table 2 is a simulated electric power bill where the electric power consumption remains unchanged at a home even during the peak cut time. At Level 3, the fee rate during the peak cut time period is 300% and the average for one day is 150%. The electricity bill for one month of peak cut time is 104% and 113% for three months. Assuming that half the homes adhere to this cost increase, there is a 92% load reduction. This suggests that simply increasing the electricity bill may not be sufficient. It is necessary that the home controller simulates the electricity bill based on the individual peak cut control table while accumulating the data of actual consumption.

Table 1: Peak Cut Control Table (Patent; Similar).

	Normal time			Peak cut time	
Home appliances	Level 1	Level 2	Level 1	Level 2	Level3
Air conditioner (inverter)1	F	low	off	off	off
Air conditioner (inverter)2	F	low	low	off	off
Air conditioner (inverter)3	F	F	low	off	off
Air conditioner (inverter)4	F	F	F	low	off
Air conditioner (inverter)5	F	F	F	F	low
Floor heating 1	F	low	off	off	off
Floor heating 2	F	F	low	off	off
Floor heating 3	F	F	F	F	low
Refrigerator	F	F	low	off	off
Washing machine	F	F	low	off	off
Rice cooker	F	F	low	off	off
Hot water system(Gas)	F	F	F	F	low
Hot water system (electric/ Heat storage)	F	F	low	off	off
Lighting 1	F	F	off	off	off
Lighting 2	F	F	off	off	off
Lighting 3	F	F	low	off	off
Lighting 4	F	F	low	low	off
Lighting 5	F	F	F	F	low
Desktop PC	F	F	F	off	off
Display	F	F	F	off	off
HDD	F	F	F	off	off
Printer	F	F	F	off	off
Existing network					
Hot water system(Gas)	F	F	F	F	F
Hot water system (electric)	F	F	off	off	off
Hot water system (electric/Heat storage)	F	F	F	off	off
Door intercom system	F	F	F	F	F
Security system	F	F	F	F	F

F : Free setting by resident (assumed to be 100% in load calculation)

Low , off : Selected setting by resident

Table 2: Peak Cut Time Electric Power Rates (Unit%).
Peak cut June - August, 10:00 to 16:00 (4 electricity rate settings: Normal, Level 1, Level 2, Level 3)

Electricity rate setting	Normal	Level 1	Level 2	Level 3
Electric power rate ratio (yen/KWt)	100	150	200	300
Case 1: Electric power consumption ratio (#1)	100	67	50	33
Case 1: Electric power consumption ratio (#2)	100	92	88	83
Case 1: Electric power consumption ratio (#3)	100	98	97	96
Case 2: Electric power rate ratio (one day)	100	113	125	150
Case 2: Electric power rate ratio (one month out of 12 months)	100	101	102	104
Case 2: Electric power rate ratio (three months out of 12 months)	100	103	106	113

In case 1, electric power consumption is regulated to maintain the same electric power fee.
In case 2, electric power consumption is not regulated.
#1: Percentage of electricity within the time frame when peak cut is implemented(%)
#2: Percentage of total electric power consumption within the time frame when peak cut is implemented(%)
#3: Percentage of total electric power consumption for one year when peak cut is implemented(%)

4 PROPOSAL OF A MUTUAL COMPLEMENTRY NETWORK BY WIRELESS AND WIRED COMMUNICATIONS

Propose a “mutual complementary network by wireless and wired communications”, which leads to high performance, be applied to the home network. The mutual complementary network is a communication system that simultaneously employs two or more different methods to improve the communication performance [5]. As “two or more different methods”, this study uses wired and wireless communications. Specifically, the PLC (Power Line Communication) [10] is used for wired communication and Zigbee [11] for wireless.

As shown in Fig.2, when transmitting data from point A to point B, the data is simultaneously sent by wired and wireless methods. In this case, communication is successful if the data communication can be completed by either method. In a three story, 200 square-meter reinforced concrete houses, communication performance by wireless alone is 82% as shown in Fig.3, while wired is 70%. Considering theoretical communication inability for both wireless and wired to be 5.4%, this translates to 94.6% of the communication performance. In fact, however, an even better communication performance of 100% was achieved [6].

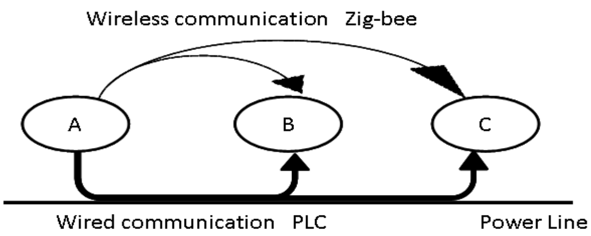


Figure 2: Mutual complementary network by wireless and wired communication

In practical application, using a simpler routing three times reduces the rate of unsuccessful communication to as low as 0.02%. Evaluation of an actual system to determine whether this is sufficient or not, is desired. In a “simpler routing” system, if communication is unable to go through one route, another route is used.

This routing system is completely independent from the previous communication performance while minimizing the software load [12].

		Wireless Communication	
		Able 82%	Unable 18%
Wired communication	Able 70%	Able 57.4%	Able/Unable → Able 12.6%
	Unable 30%	Unable/Able → Able 24.6%	Unable 5.4%

Figure 3: Communication performance of a mutual complementary network (by wireless and wired communications)

5 STEP-BY-STEP ACHIEVEMENT OF HOME NETWORK EQUATIONS

A smart meter and home network cannot be constructed overnight. As mentioned above, the home network has not been realized even though researchers have advocated its necessity and effectiveness since the 1980's. Looking back, one reason was that necessity was not as high as expected, and there were technological problems, such as cost. Today, this is no longer the case. The necessity is supported by a more urgent call for energy saving and home safety, while a “mutual complementary network by wireless and wired communications” solves technological and cost issues. One remaining obstacle is the lack of enthusiasm and action to create a home network under one set of standards by concerned parties. The home network definitely needs a common set of standards to connect home appliances.

Figure 4 shows a proposed plan to reduce home electric power consumption based on a step-by-step plan to expand the smart meter and home network. The first step is regarding an electric power supply and electric power consumption meter at a current general home

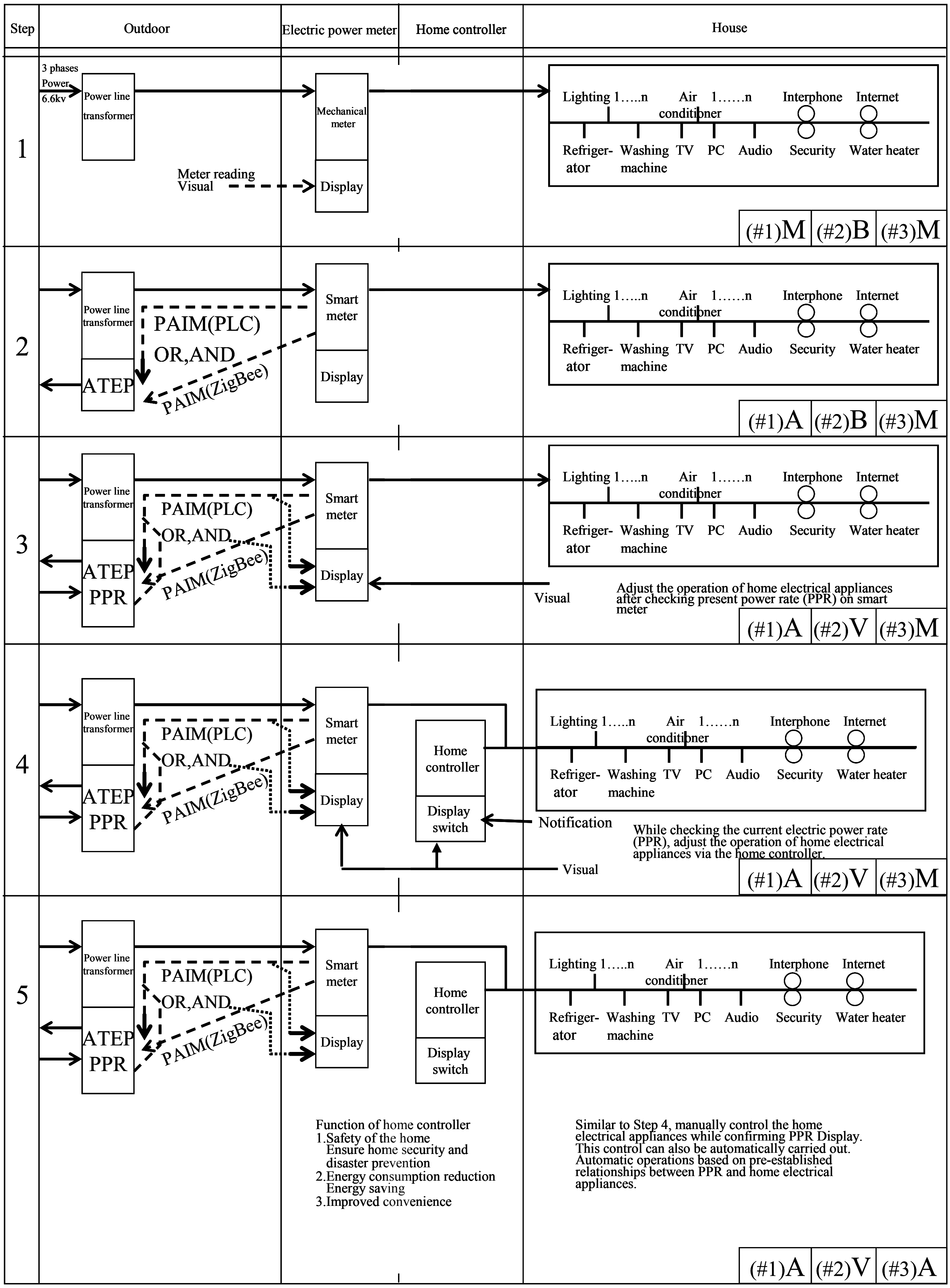


Figure 4: Steps to reduce home energy consumption using a smart meter and home controller,

Definition: PAIM : electric Power Automatic Inspection of a Meter, ATEP: the Amount Total of used Electric Power, PPR: the Present Power Rates

#1: Meter Reading-A-Automatic,-M-Manual, #2: Visualize of Electric Power-B-Blind, -V-Visual, #3: Reduction Easiness of Electric Power-A-Automatic,-M-Manual

The electric power consumption is visually measured to generate the electricity bill. In the second step, the electric power company uses an electronically operated electric power meter to collect and calculate the electric power consumption from each home through wired and/or wireless communication. Such an electronic meter is called a smart meter. In the third step, the smart meter indicates the consumption status of electricity for the month so the resident can directly control the home electric appliances. The fourth step connects the smart meter to the home controller via the network. In turn, the home controller is connected to various home appliances through the network. To implement peak cut, the home resident uses the home controller to read the peak cut level from the smart meter and implements energy saving measures according to the level.

The fifth step requires setting a "peak cut control table" to control the energy saving measures to a specified level during peak cut. The smart meter posts the electric bill level at the time of peak cut so the home controller can regulate the home appliances. At times other than peak cut, simulation and control functions of the home controller can be used to identify other energy saving opportunities and further improve disaster mitigation, security and convenience in each individual home.

6 CONCLUSION

This paper proposes a step by step plan to introduce a smart meter and home network in order to reduce electric power consumption. Three major technologies are discussed: " a two-layer home network", "a system to implement electric power peak cut while considering safety" and "a mutual complementary network by wireless and wired communications" which support the proposed plan. The proposed plan can only be implemented when people at various homes are mutually and socially influenced. Specifically, the following four ways were discussed above.

1) Influence home economics by increasing the electric power rate during peak cut time.
2) Promote the control of the electric power demand by introducing edutainment.
3) The home network is also effective in areas other than energy and energy saving.
   Ensure security and disaster prevention and improve convenience.
4) Raise social issues regarding carbon dioxide emissions and nuclear power plants so that individuals can consider their responsibility as a member of society.

It is also important that electrical appliance manufactures equip their products with terminals so they can be connected to the home network. Once the effectiveness of the home network is recognized, information gained by institutes and organizations regarding the electric power crisis will become a driving force to promote proposed implementations.

The home network is essential in times of electric power crisis. In other words, technology can save mankind. If we are really advanced persons who no longer need nuclear power generation, cutting back on electricity to this degree is only natural. To reduce home electric power consumption more is required than just targeting peak cut. It does not mean to only use electric power when you need it, it means cutting back even outside the peak cut time. It does not simply mean not wasting it. It is that you cut back on the energy or don't use it all. The author et al., will continue to study the subject in order to realize a home network which contributes to home safety, security and energy saving and convenience.

REFERENCES

[1] T. Matsuzaki, H. Matsuda, Y. Saito, and H. Kaneko, ``Business Approach of Smart Grid and Smart Community,'' Mitsubishi Corp. Monthly technical report, Vol.86,No.2, pp.100-128 (2012)

[2] S. Kawaguchi, M. Kojima, and K. Yamada, ``Mutually Complementary Network System Between Wired and Wireless Communication for Home Appliances,'' Proc of the 13th IEEE International Symposium on Consumer Electronics (ISCE2009) pp.455-459 (2009).

[3] K. Yamada, The mutual complement network by Wireless and Wired Fair 2005 of industry-university cooperation Guide book p.26 (2005).

[4] J. Watanabe, ``Digital Hard and Course dissection; Megachips Corp. develops the product of an energy-saving semiconductor and theme of visible of electric power that is an offensive,'' Japan Industry Newspaper 2012.1.24.

[5] K. Yamada, Y. Hirata, Y. Naoe, T. Furumura, Y. Inoue, T. Shimizu, K. Yoshida, M. Kojima, and T. Mizuno, ``Dual Communication System Using Wired and Wireless Correspondence in Small Space,'' M.Gh.Negoita et al. (Eds.): KES 2004, LNAI 3214, pp. 898-904 (2004) © Springer-Verlag.

[6] K. Yamada, K. Kitazawa, H. Takase, T. Tamura, Y. Naoe, T. Furumura, T. Shimizu, K. Yoshida, M. Kojima, and T. Mizuno, ``Dual communication System Using Wired and Wireless Correspondence in Home Network,'' R. Khosla et al. (Eds.): KES 2005, LNAI 3681, pp. 438-444, (2005)© Springer-Verlag.

[7] The day when electric power meter becomes smart, NIKKEI LECTRNICS, pp.105-112, 2008.11.3

[8] The power consumption ratio classified by trend investigation-field of the present condition about the amount of used electricity of electric power use apparatus, and the near future, Fuji Keizai Management Co.LTD. p.47, 2009.3.23.

[9] X. Zhou, S. Hata, and K. Yamada, ``Project-based Learning for Edutainment using Locomotion Robots,'' Proc. of International Workshop on Advanced Computational Intelligence and Intelligent Informatics (2011).

[10] M16C/6S http://www.renesas.com

[11] URL http://www.zigbee.org

[12] N. Yusa, F. Henmi, H. Banba, H. Mineno, and K. Yamada, ``Adaptation a School Building of the Mutual Complementary Network by Wireless and Wired,'' A. König et al. (Eds.): KES 2011, Part III, LNAI 6883, pp. 227-236 (2011).© Springer-Verlag.

(Received September 27, 2012)
(Revised August 31, 2013)

Kunihiro Yamada received the M.E. .degree in electric engineering from the Ritsumeikan University in 1973 and received the Ph.D. degree in industrial science and engineering from Sizuoka University, Japan, in 2002. In 1973, he joined Mitsubishi Electric Corp. From 2005 to 2013, he had been a Professor of Tokai University. Japan. Since 2009, he is the director (outside) of Megachips Corp., Japan. His research interests include architecture of microprocessors and the mutual complement networks by wired and the wireless. He is a members of IPSJ of Japan.

Takashi Furumura received the M.E.degree in electric engineering from the Waseda University in 1978, and he joined Mitsubishi Electric Corp. from 1978 to 2007. He had been a Renesas Solution Corp., Japan. His major interests include KBC, SMB and Zigbee micro controller. In 2007, he joined Megachips Corp. His major interests include Smart Grid system using wired and wireless solution.

Koji Ishio received the B.E.degree in electric engineering from the Doshisha University in 1985, and he joined Oki Electric Industry Corp. from 1985 to 1995.His major interests include Image process and document control ASIC of Facsimile system. In 1995, he joined Megachips Corp. His major interests include Wireless and Wired ASIC, and Hybrid Communications Technology system using wired and wireless solution.

Handa Chen received the B.E. and M.E degrees in electric engineering from Shanghai Jiaotong University, China in 1982 and 1987, received the Ph.D. degree in communication engineering from Osaka University, Japan, in 1997. From 1982 to 1984, he joined The Third Engineering Institute of Transportation Ministry, China. From 1987 to 1992, he was an Assistant Lecturer of Shanghai Tiedao University , China. Since 1997, he joined MegaChips Corp., Japan. His research interests include communication theory and digital signal processing.

Toru Shimizu received B.S., M.S., and Ph.D. degrees of Information Science from The University of Tokyo, Japan. Since 1986, he has been involved in microprocessor, microcontroller and SoC design R&D in Mitsubishi Electric, Renesas Technology, and Renesas Electronics. His R&D activities cover LSI architecture and design as well as embedded software and application technology. He is a senior member of the IEICE and the IEEE. He is a steering committee member of the A-SSCC and a director of the Embedded Technology Conference Executive Committee.

Masanori Kojima received the B.E. degree in electric engineering from Osaka University in 1967 and received the D.E. degree in electric engineering from Osaka City University, Japan, in 1995. In 1967, he joined Mitsubishi Electric Corp. From 2002 to 2011, he had been a Professor of Osaka Institute of Technology, Japan. His research interests include electric engineering and information science. He is a member of IEICE of Japan.

Tadanori Mizuno received the B.E. degree in Industrial Engineering from the Nagoya Institute of Technology in 1968 and received the Ph.D. degree in Computer Science from Kyushu University, Japan, in 1987. In 1968, he joined Mitsubishi Electric Corp. From 1993 to 2011, he had been a Professor of Shizuoka University, Japan. Since 2011, he is a Professor of the Institute of Technology, Japan. His research interests include mobile computing, distributed computing, computer networks, broadcast communication and computing, and protocol engineering. He is a member of Information Processing Society of Japan, the Institute of Electronics, Information and Communication Engineers, the IEEE Computer Society, ACM and Informatics Society.