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A Power Measuring and Controlling Sensor Network for Home Services

Jaewook Jung[1, 2] Tatsuya Yamazaki[2] Tetsuo Toyomura[2] YoungJae Kim[1]
Minsoo Hahn[1] and Takashi Matsuyama[2, 3]

[1]Digital Media Laboratory, Information and Communications University
517-10 Dogok-dong, Gangnam-gu, Seoul, 135-854, South Korea

[2]National Institute of Information and Communications Technology
3-5 Hikaridai, Seika-cho, Soraku-gun, Kyoto, 619-0289, Japan

[3]Kyoto University
Yoshida-Honmachi, Sakyo-ku, Kyoto, 606-8501, Japan

E-mail: clownjjw@icu.ac.kr, yamazaki@nict.go.jp, toyomura@nict.go.jp, smart@icu.ac.kr, mshahn@icu.ac.kr, tm@nict.go.jp

Abstract There were many researches for measuring and controlling the power to provide services in home, but all previous researches used On/Off breaker to control the power. Therefore, the provided services were also restrictive. We propose PowerNet, advanced power management sensor network. PowerNet consists of PowerNet Module and PowerNet Manager. PowerNet Module has three functions; measuring the power consumption rate, continuously controlling the supplying power and communicating with other modules by ZigBee. PowerNet Manager gathers the power consumption data, extracts context and provides the service for safety and saving energy. We show experimental results of PowerNet in a real environment.

Keyword Power Management, Sensor Network, User Behavior, Context-Aware, Continuous Power Control, ZigBee

1. Introduction

Energy has been a problem one should not ignored in most of the research field, not only Information and Communication Technology (ICT) field but also Chemistry, Mechanics, and so on. Except ICT field, most of the filed have concentrated on economical issue, for example, a developing new type of energy cell or a hybrid car. The research topic of ICT filed is a little different with other fields.

There are two streams related with energy at ICT area. One is a power monitoring and signature analysis to distinguish the appliance type and know the status of appliance [3], [4], [5], [8]. As a result, that system detects the event of appliance. Another one is using the power consumption data as raw information with time, location, and the number of user to extract context and provides services to the user [1], [2], [6], [7], [11]. Most of research, however, use the On/Off breaker circuit to control the supplying power [1], [6], therefore the provided services also are restricted.

In this paper, we present PowerNet system with the advanced control method, not On/Off control method. PowerNet system consists of PowerNet Module and PowerNet Manager. PowerNet Module has three functions. First function is the measuring the power consumption rate of appliance and second one is communicating with PowerNet Manager by wireless communication. Finally, PowerNet Module continuously controls the supplying power to appliance. PowerNet Manager gathers the measured power consumption data from PowerNet Module, analyzes that data, and sends the control command to PowerNet Module to change the supplying power rate.

PowerNet has two applications, energy saving service scenario and notifying emergency service scenario. The suggested system has been verified by demonstration in Ubiquitous Home of National Institute of Information and Communications Technology (NICT).

2. PowerNet System Overview

PowerNet system consists of two parts, PowerNet Module and PowerNet Manager in Figure 1. One PowerNet Module is connected with one home appliance and there are multiple PowerNet modules. PowerNet manager communicates with PowerNet modules to gather the power consumption data of appliances and send the control commands by ZigBee. Only one PowerNet Manager is existed at one home.

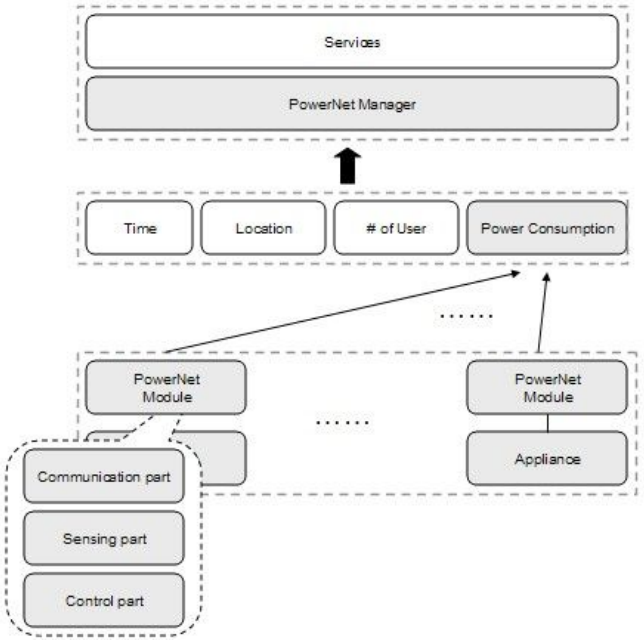


Figure 1 PowerNet System Overview

2.1. PowerNet Module

PowerNet Module has three parts, sensor part, control part and communication part. Figure 2 shows PowerNet Module. Sensor part measures the power consumption rate of the connected appliance. Control part manages the supplying power rate to the connected appliance. Communication part communicates with PowerNet Manager by ZigBee.

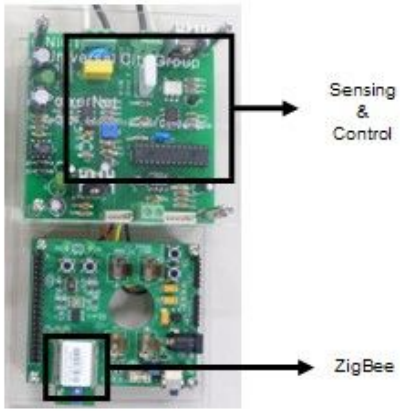
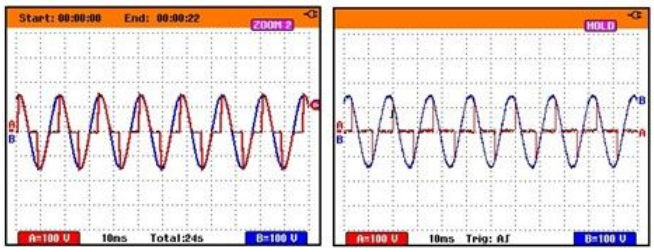


Figure 2 PowerNet Module

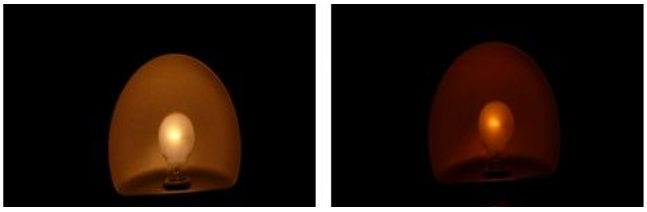
PowerNet Module uses PIC16LF73, which has 8bits Analog-to-Digital Converter (ADC), and measures the power consumption rate of the connected home appliance by using a shunt resistor and ADC.

PowerNet Module sends the measured data to PowerNet Manager and receives the control command from PowerNet Manager. JENNIC 5139 chip is used for wireless communication and baud rate is 19200 [9].

PowerNet module has two kinds of control methods which are the continuous phase control and the continuous on/off phase control. According to the type of a connected load, PowerNet module changes the control method. Usually, there are two kinds of loads at home, resistor load and coil load. For example, a bulb is a resistor load and a vacuum machine is a coil load.



(a) 50% **(b) 25%**



(c) 50% **(d) 25%**

Figure 3 Continuous Phase Control

Red Wave: The controlled supplying power

Blue Wave: The non-controlled supplying power

The continuous phase control method is used at a resistor load in Figure 3. PowerNet Module controls the supplying power within one wave, 8.3ms at 60Hz. Figure 3(a) shows that PowerNet module supplies the 50% power to the 60W bulb and Figure 3(b) shows the supplying 25% power to the bulb. According to the quantity of the supplying power, the brightness of bulb is also changed in Figure 3(c) and 3(d) which show that Figure 3(c) is brighter than Figure 3(d).

The difference between a resistor load and a coil load is the effect of inverse voltage. Actually, both of them generate the inverse voltage but the duration time of the inverse voltage is different. The time of a resistor load is

very short, therefore that's not matter to control the supplying power. On the other hand, the time of coil load is long and that's the matter. To solve the inverse voltage problem, two solutions are existed. One is the removing the inverse voltage by using a RLC circuit but the size grows bigger because of a coil. Another one is the controlling the supplying power at the point of the minimizing the inverse voltage. PowerNet Module uses the latter solution, because a module size is important to be installed at a real environment like a home or an office.

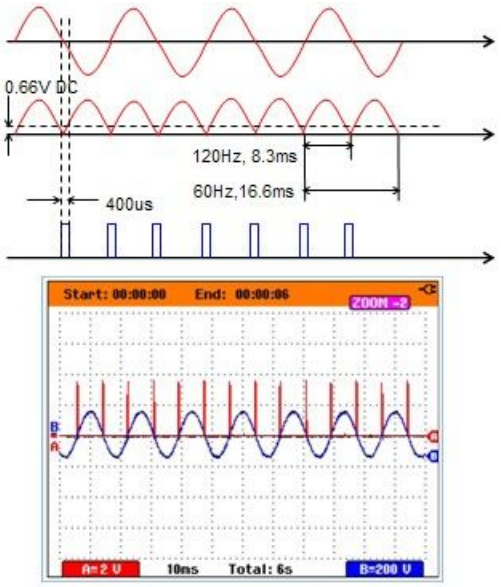


Figure 4 Zero-crossing

At the zero-crossing point, the inverse voltage is minimized in Figure 4. PowerNet module stably controls the supplying power to a coil load appliance by using the continuous on/off phase control method. This method controls the supplying power by one wave unit in Figure 5.

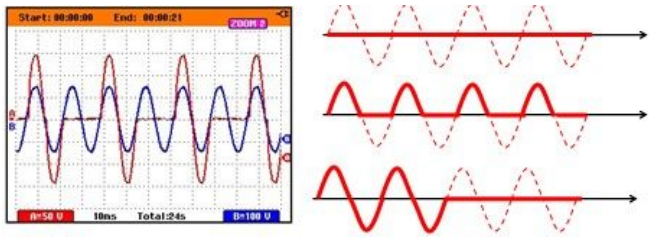


Figure 5 Continuous On/Off Phase Control

2.2. PowerNet Manager

PowerNet Manger gathers the power consumption data of home appliances from multiple PowerNet Modules by wireless communication and analyzes the measured data to provide proper service according to context. According to the result of analysis, PowerNet Manager sends the control command to each PowerNet Module and provides services to user.

Figure 6 shows PowerNet Manager graphical user interface. It consists of three parts which are graph, map, and control part. Graph part shows the power consumption data as a graph. Map part expresses the status of appliances on the map of Ubiquitous-Home which is the test bed of NICT Keihanna Center. At control part, user can set up the properties of PowerNet Manager.

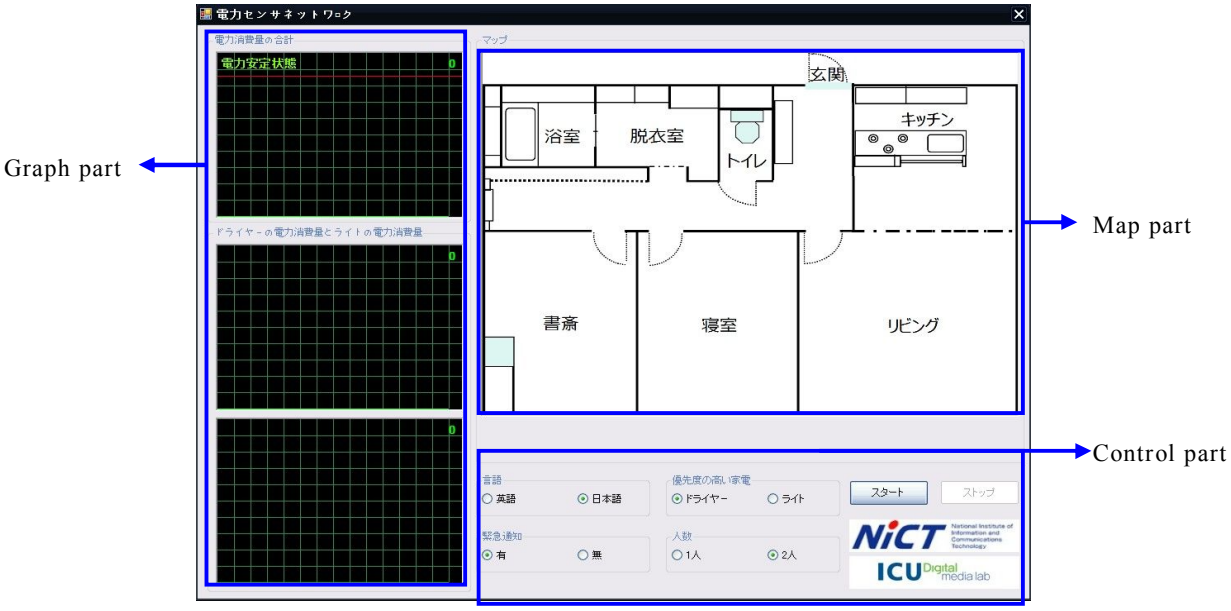


Figure 6 PowerNet Manager Application

3. Application

Two applications are installed at Ubiquitous-Home of NICT. One is Energy saving application and another is emergency application. For demonstration, two appliances are used, one bulb lamp and one hair drier. The lamp is set on the dinning room and the hair drier is set on the bath room.

3.1. Energy saving scenario

PowerNet Manger receives the power consumption data from PowerNet Modules. If the total power consumption rate is over the permissible power, PowerNet Manger starts the energy saving mode. PowerNet Manager has two service modes for energy saving according to the number of users, one user or more than two users in the home. Figure 7 shows the service logic.

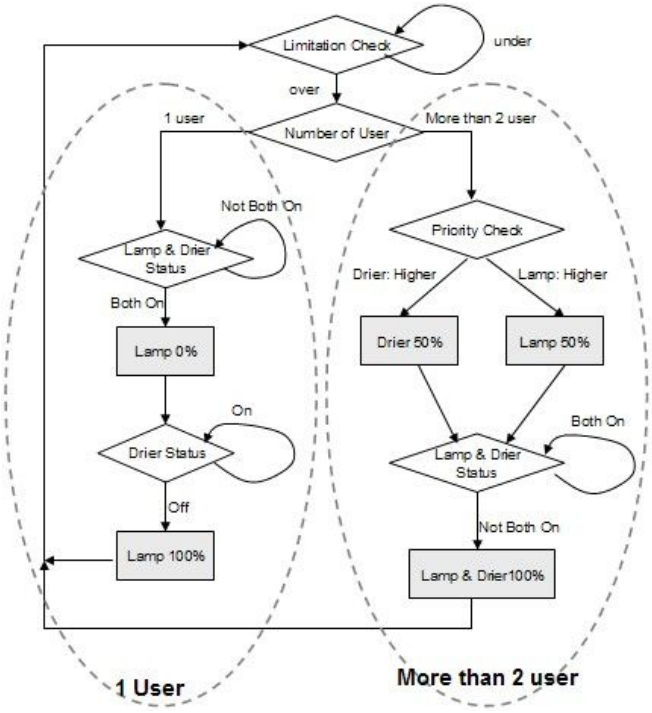


Figure 7 Energy Saving Scenario

At the case of one user, when the user turns on the hair drier in the bath room, PowerNet Manager sends the supplying power 0% command to the PowerNet module connected with the lamp in the dinning room. Then, PowerNet module controls the supplying power to 0% and the lamp of dinning room is turned off. Reversely, when user turns off the hair drier, PowerNet system turns on the lamp by changing the supplying power to 100%. In this mode, when user uses the hair drier in the bath room, there is no person in the dinning room. Therefore, turning off lamp doesn't any effect to the user and PowerNet system saves energy.

At the case of more than two users, PowerNet system doesn't control the supplying power rate to 0%, because there are users in the different places at the same time. At the day time, when two appliances are turned on at same time, PowerNet system supplies 50% power to the lamp in the dinning room and 100% power to the drier in the bath room. Conversely, at the night time, PowerNet system supplies 50% power to the drier and 100% power to the lamp. As a result, PowerNet system saves the energy by using basic context information which is the number of users, location, time, and power consumption pattern. Beside the energy saving at usual situation, this application will be useful at some emergency situation of the power plant. For example, the power consumption rate of entire town is increased at summer night, because most of the home turns on the air conditioner. In this situation, PowerNet will protect the overload of the power plant by starting energy saving mode.

3.2. Emergency notifying scenario

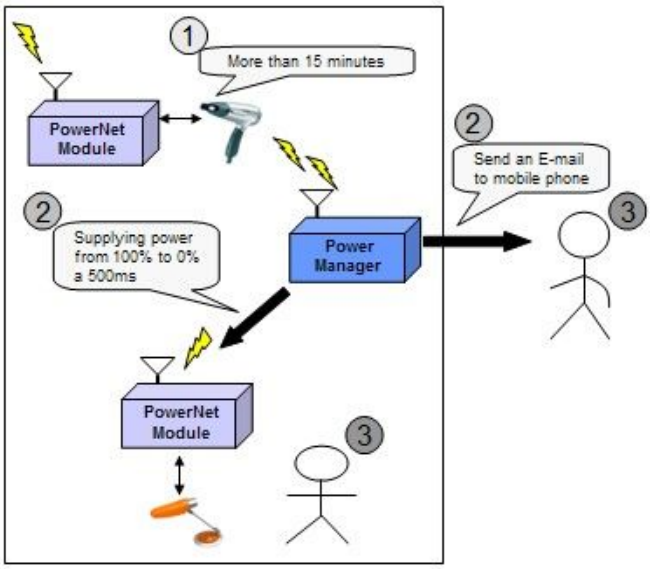


Figure 8 The process of emergency application

PowerNet system uses the continued usage time of hair drier to detect the emergency situation. At the typical home, user doesn't continuously turn on the hair drier more than 15 minutes. If the on state of hair drier maintains more than 15 minutes, PowerNet system judges as that some emergency situation is occurred at the home. PowerNet system informs the emergency situation by using two methods in Figure 8. For outdoor people, PowerNet Manager sends an E-mail to the mobile phone of other family members. For indoor people, PowerNet

Module blinks the lamp by controlling the supplying power from 100% to 0% per 500ms. At an aging society, this application will detect the emergency status of elder people without the feeling of watch.

4. Experiment

Energy saving scenario and emergency scenario were tested at Ubiquitous Home of NICT, 100V and 60Hz. One laptop for PowerNet Manager, two PowerNet Modules, one hair drier (1200W), one lamp (120W), and one mobile phone of NTT DoCoMo are used.

4.1. Energy-Saving Scenario Experiment

Figure 9 shows the result of energy saving mode at the case of one user. When the hair drier is turned on, PowerNet Module connected to the lamp decreases the supplying power to 0%. At the energy saving mode of the lamp, the energy usage rate is 90.91% with respect to not-saving mode.

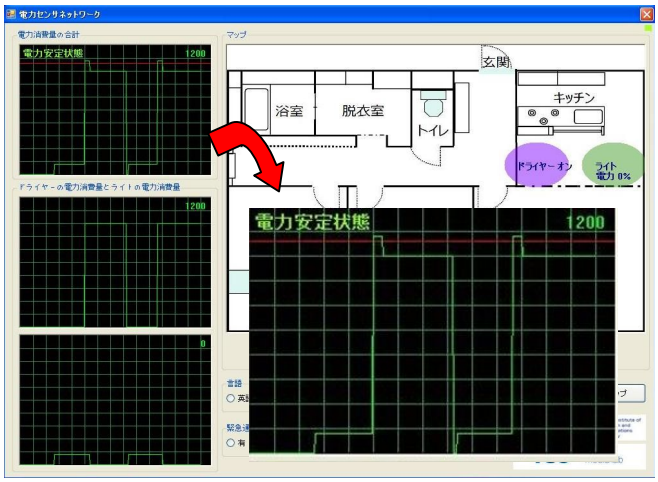
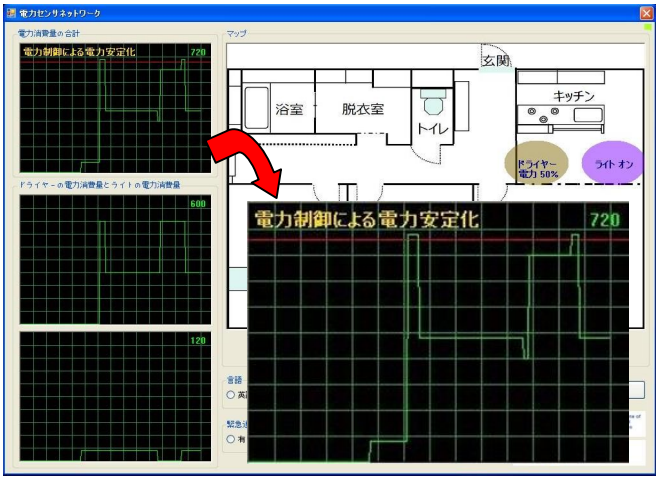


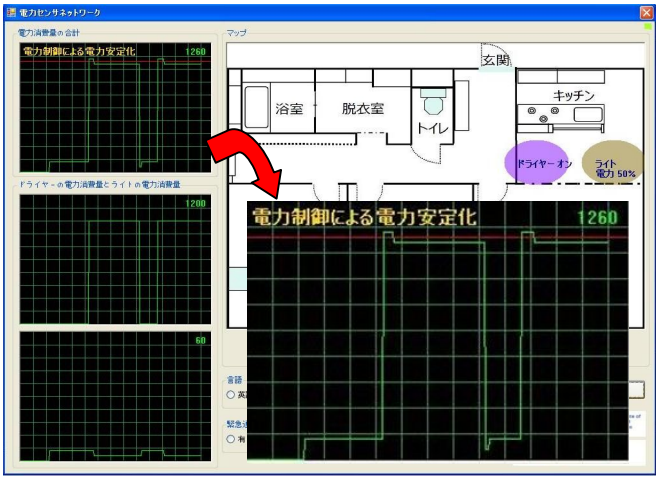
Figure 9 Energy Saving Mode (1 user)

For the case of more than two users, we optionally set the permissible power, 1300W, a red line. At the normal state which is not over the permissible power, both of PowerNet Modules supply 100% power to the hair drier and the lamp.

Figure 10 (a) shows the result of energy saving mode at hair drier having higher priority. When the total power consumption rate is over 1300W, PowerNet Module connected to the lamp decreases the supplying power to 50%. Reversely, Figure 10(b) shows the result of energy saving mode at the lamp having higher priority. When the total power consumption rate is over 1300W, PowerNet Module connected to the hair drier decreases the supplying power to 50%.



(a) Higher priority: Lamp



(a) Higher priority: Drier

Figure 10 Energy Saving Mode (more than 2 users)

This experiment shows that PowerNet can save energy by measuring the power consumption rate and continuously controlling the supplying power of the resistor load and the coil load. At the energy saving mode of the lamp, the energy usage rate is 95.46% with respect to not-saving mode. At the energy saving mode of the hair drier, the energy usage rate is 54.55% with respect to non-saving mode.

4.2. Emergency Scenario Experiment

Figure 11 shows the blinked wave form by controlling the supplying power and the received message from PowerNet Manager. The Soft Bank's mobile phone is used. This experiment shows that PowerNet detects the usage time of appliance and notifies some information by controlling the status of other appliances.

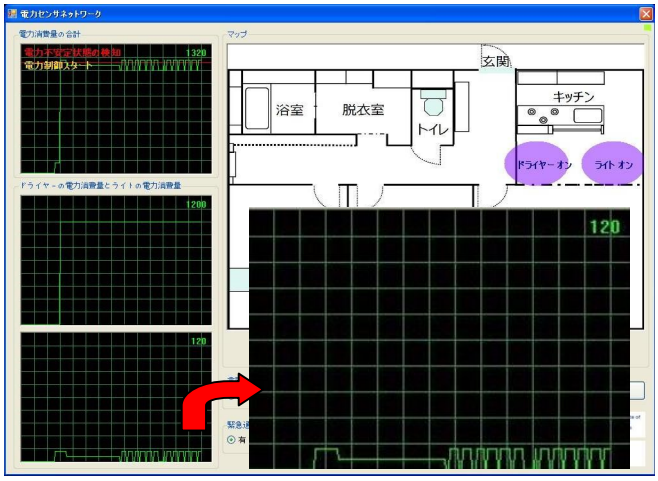


Figure 11 Emergency Mode

5. Conclusion and future works

In this paper, we suggested PowerNet consisting of PowerNet Manager and PowerNet Module. PowerNet measured the power consumption rate of each appliance, analyzes the measured data, and provides two home services, energy saving and emergency, by controlling the supplying power rate of each appliance. To control the supplying power rate, PowerNet module uses the continuous phase control method for a resistor load and the continuous phase control method for a coil load at the zero-crossing point. PowerNet is installed at Ubiquitous Home of NICT and verified.

Future work of this research is summarized as follows: 1) Make a smaller size, under 100mm x 100mm x 30mm, PowerNet Module. 2) Verify PowerNet at Active Home [10] which is the smart home test bed of Information and Communications University Digital Media Laboratory in Korea. 3) Add to the number of PowerNet Modules.

Acknowledgements

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