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Novel Concept "HEMS E Project" Challenge

Takashi Yoshikawa
Kindai University Technical College
Kasugaoka, Nabari, Mie 518-0459, JAPAN
e-mail: yoshikawa@ktc.ac.jp

***Abstract*—HEMS (Home Energy Management System) is widely recognized as the useful technology for saving energy. On the other hand HEMS is never influenced around common people. The reason is supposed coming from following three points. 1. High initial cost, 2. Location dependence (The present HEMS is mounted into the wall), 3. Personal unconcern for energy saving. Then I introduce the novel concept for HEMS. We have named the concept, "HEMS E Project". The concept is composed with "sensor network technology" taking place of the conventional wired system, "energy harvesting technology" as the power source of sensor network nodes which can continue to work without battery or AC power supply cable and "Wireless Power Transmission method in the case of no energy resource in the room. So we explained above, "HEMS E" Project consists of three elements corresponding to horizontal line of the letter "E". Now we have come to clarify the potential of "HEMS E Project" through various experiments. I summarize the results in this paper.**

Keywords-HEMS; sensor network; energy harvesting; wireless power transmission

I. INTRODUCTION

In recent days, the saving energy consumption is very important key word in the modern society. The major trend of the saving energy is focused in the industrial, factory, transport, electrical appliances and so on. On the other hand the almost all of the people in the developed country do not care the saving energy in their individual life. In such situation HEMS (Home Energy Management System) is very important technology. HEMS is the technology that the person monitor the amount of his energy consumption in a house, and tries to reduce the energy consumption The people recognize HEMS is the built in system (wall mounted system) on the house. Then HEMS is regarded as expensive and lower flexibility for customize. This is because HEMS dose not spread to all the people. Then we have introduced novel concept for HEMS. The concept is composed with three technologies. One is the sensor network technology, one is energy harvesting technology, and the other is wireless power transmission technology. We call it "HEMS E Project". The letter "E" express the symbol of energy saving, showing core technology HEMS with vertical line, and three fundamental technology supporting HEMS with three horizontal lines (Figure 1).

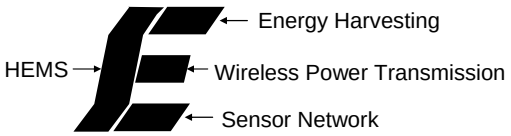

Figure 1. HEMS "E" Project expression

We have examined the way for satisfying "HEMS E Project" specification. At the beginning of the study of novel HMES, we have to decide HEMS specification. In the next section 2, I will show the modeling of HEMS. Next, the energy harvesting is shown in section 3, sensor network is shown in section 4, and wireless power transmission is shown in section 5. Finally, the current state of "HEMS E Project" is summarized.

II. HEMS SPECIFICATION [1]

A. HEMS Modeling

There are many kinds of HEMS. The concept of our HEMS is to use the sensor network nodes driven with the harvesting energy. The harvesting energy is very low, so we have to estimate the consumption energy by sensor network node. The consumption energy is corresponding to the kinds of HEMS. At first, we have categorized HEMS into 6 models according to the function of the HEMS in table 1.

TABLE I. HEMS MODELING

Monitoring HEMS		Control HEMS	
1	Surroundings Monitoring Pre-HEMS (pHEMS)	4	+Controlling Electric apparatus (cHEMS)
2	+Energy Consumption Monitoring (mHEMS)	5	+Controlling with Fixed and Vital status (cvHEMS)
3	+Human Vital Monitoring (vHEMS)	6	+High Duty Customize control (ccHEMS)

HEMS is largely separated into two categories, one is monitoring HEMS and the other is control HEMS. Each HEMS is separated into three models according to the

variation of application. There are two kinds of HMES terminal which are fixed and movable (with human body). The higher model number HEMS can cover the richer application and will need higher power to work.

B. Consumption Power of Sensor Node for HEMS

We have estimated the average consumption power for each HEMS by making prototype of sensor network node and measured the average consumption power for each module (sensor, MCU, RF-IC and so on). Figure 2 shows the sequence of sensor network HEMS and Figure 3 shows the block diagram for sensor network HEMS node. Based on the Figure 2 and Figure 3, we have measured the average consumption power for each HEMS model (1~6) regarding energy conversion loss. The results are shown in table 2.

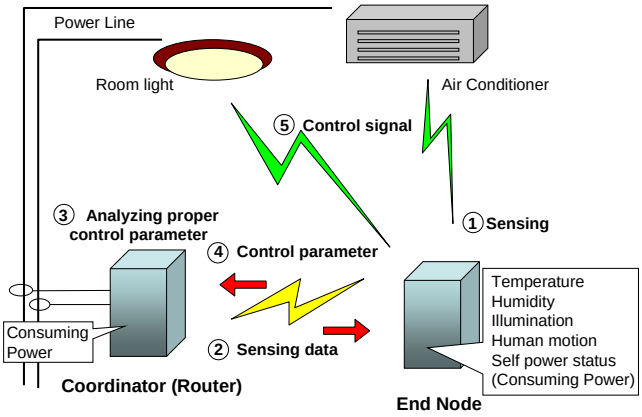

Figure 2. Sequence of sensor network HEMS

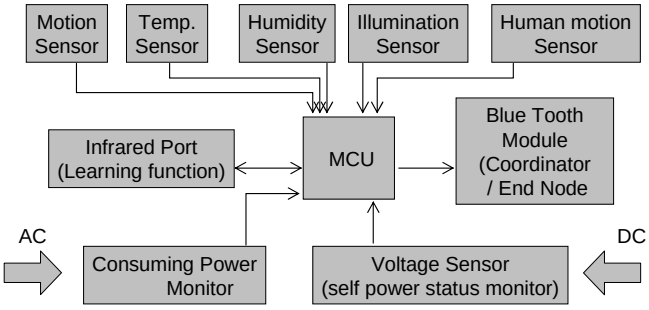

Figure 3. Block diagram for sensor network HEMS node

TABLE II. AVERAGE CONSUMPTION POWER FOR EACH HEMS

Model 1 Fixed	31uW	Model 2 Fixed	37uW	Model 3 Fixed	37uW
Model 4 Fixed	52uW	Model 5 Fixed	52uW	Model 6 Fixed	100uW
		Movable	58uW	Movable	78uW

The consumption power is estimated less than 100uW. It is because the duration of data transmission is set to too long as 10 min. while it works under very low power (sleep mode) in other time. On the other hand, it is clarified that the average power provided by energy harvesting needs more than 100uW if we perform model 6 HEMS.

III. ENERGY HARVESTING AT HOME [2]

We will many sensor network nodes to get more detailed information. In such situation it is very hard to change the battery which halls into the out of battery occasionally. Then we have tried to introduce the energy harvesting as the as the power source of sensor network nodes. Watching around the house at the view points of the existence of energy, setting the energy harvesters (power generation devices), we have experimented the ability of power generation in our life. There are two types of energy harvesting, one is the harvester can generate power over wide area in the house for long time but the generated average power is less than 100uW(~200uW) (group I), and the other is the harvester can generate higher power but the place to be set are restricted (group II). At first we have experimented account for group I energy harvesting. In this group, there are following represent energy harvestings,

* The illumination power generation by the room light equipment
* The thermal gradient power generation between human body and room temperature in a house.

As the 2nd step, we have experimented account for group II energy harvestings. In this group, there are following represent energy harvestings,

* Wind power generation by an ventilation fan at kitchen
* Human step power generation on the floor at kitchen [3]
* Micro hydroelectric power generation at kitchen or bath tab.
* Magnetic flux leakage energy from the light bulb

The conceptual view for each energy harvesting is shown in Figure 4.

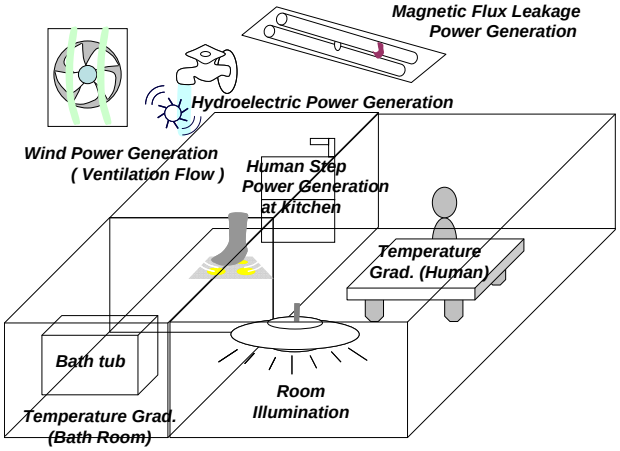

Figure 4. Energy harvesting everywhere at home

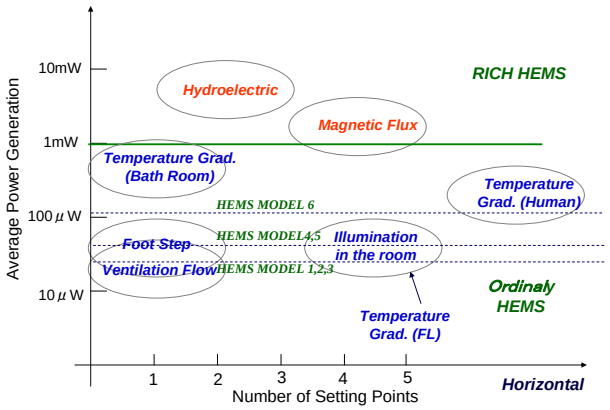

Figure 5. Average generated Power for many kinds of energy harvesting

Figure 5 show the results hydroelectric energy harvesting and magnetic flux energy harvesting can generate higher power over 1mW. We call such power region "RICH HEMS". If we can use this harvester, transmitting duration can shorten, and we can get rich information. But hydroelectric and magnetic flux energy harvesting can be located from 2~4 points in a house. We have to consider proper application at this point. The temperature gradient energy harvesting can generate more than 100uW so it can be used for model 6 HEMS. The foot step vibrating and illumination energy harvesting can be used in HEMS model 1~5. The foot step energy harvesting can generate higher power at once but the power generating frequency is very little. Above results show the generated power by energy harvesting at home can be useful enough for various HEMS.

IV. SENSOR NETWORK HEMS [1]

A. *Feasibility Study of Sensor Network*

In our previous consideration, we have clarified HEMS specification and the generated power by energy harvesting at home. Then we have experimented to examine the validity of our power budget design. We have sensor network node equipped with solar panel as its power supplier (Figure 6). The generated power by a-Si solar panel is charged into EDLC (Electric double-layer capacitor) and consumed through the regulator.

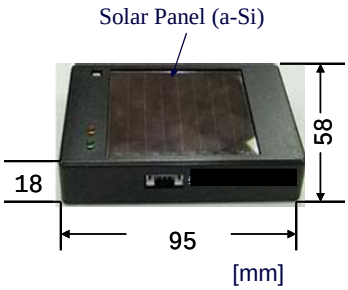

Figure 6. Sensor network node with solar panel

We have planned the illumination schedule in a week (Figure 7). This schedule is based on the life of a single person who goes out two days a week and 4 hours illuminated at morning and evening a day. And node is left in the room for a week monitoring the voltage at EDLC (Figure 8).

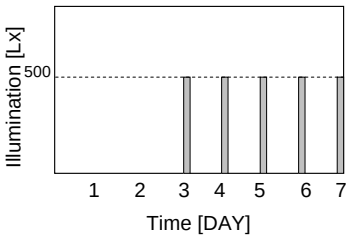

Figure 7. Illumination schedule in a week

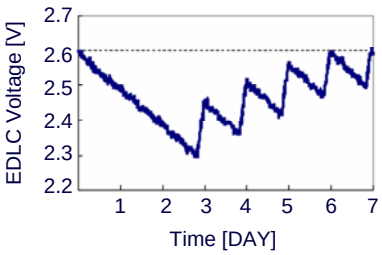

Figure 8. Power budget experiment

B. *HEMS Routing with Energy Harvesting*

The network topology we have considered before is just star topology. The consumption energy of the sensor network node is very low because the node only gets up and sends the data periodically and sleeps in other time but listens under the star topology. But there is one problem that the data transmission is restricted within outlook distance. Then we introduce the router between the networks (Figure 9). In the practical case, there are some routing nodes which location are unfixed, so we want to introduce energy harvesting into routing nodes like as the end nodes explained before. We have calculated under condition in order to estimate the ability to construct the routing node with energy harvesting.

(1) Less than 20uW Average Power Consumption.
(Considering energy conversion loss)
(2) 2~5 Area Data Hopping.
(3) More than 5 End Nodes in One Area.
(4) Less than 10minutes interval time.

We have adopted the protocol such that the data transmitting route between two routers is serial along for one direction with single hopping. The routing node stacks the other routing node's one packet datas temporaly and sends the stacked datas to upper router (near the cordinator) at once. In such sequence the cordicater can get the datas from all router nodes every time. And using this protocol, the energy consumption can be reduced by using RDA(Rotated Data Acquisision) method. RDA is the way that data transmission direction between routing nodes is changed alternately.

As the result, we can get following calculated results.

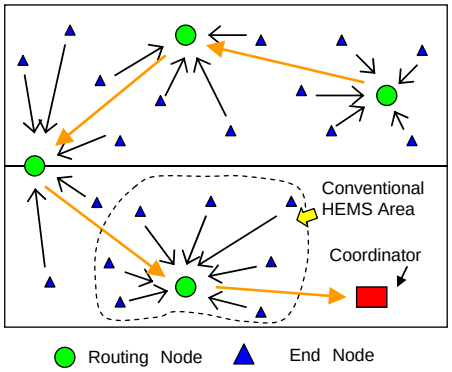

Figure 9. Introduce the routing nodes

TABLE III. NETWORK SCALE ESTIMATION WITH ROUTER NODES

Number of Router	2	3	4	5
End nodes (1 direction)	9	6	4	3
R End nodes (RDA)	12	9	7	6

The calculated results show the hopeful numerical value because 4 router and 4~7 end nodes under each router is suitable network scale for HEMS on ordinary household.

V. WIRELESS POWER TRANSMISSION APPLYING FOR HEMS [4]

The energy harvesting is clarified to be useful as the power source of sensor network HEMS node. But in the situation of lacking power source in the room for example bed room or toilet and so on, we have to supply the power to the sensor network nodes in other way. In other case, if there was any trouble and the battery of sensor node was empty, we have to supply the energy to wake up the sensor nodes. The wireless power transmission is useful technology, especially magnetic resonance type wireless power transmitting is so useful because it can transmit gradually higher energy toward the broad direction. By using such wireless power transmission, we can transmit the energy to the unspecified nodes we can not know where they are simultaneously. We have tried to make many kinds of transmitting coil and measure the transmitting characteristics to transmit more efficiently aiming at the further and higher power transmission and minimize the coil scale. We have tried to make various coils (single loop coil (circular and rectangle), spiral coil [5], and L-S coil [6] and thin film coil and so on) and tested. The shapes of the cols are shown in Fig.10 and experimental results are shown in Figure 11. The size of the receiving coil is fixed less than 0.1m, which is the practical size to set in a house.

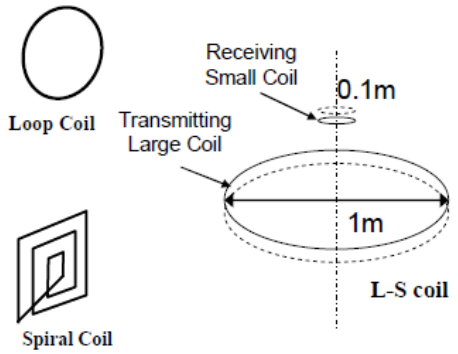

Figure 10. Various Coil Shapes

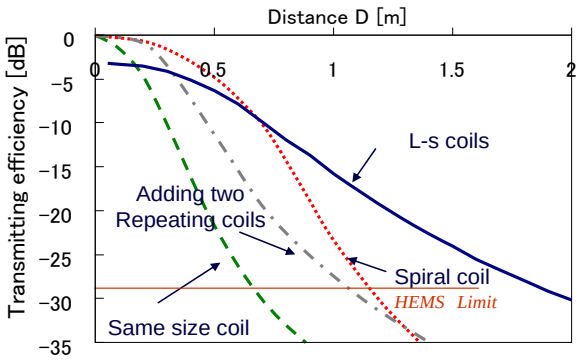

Figure 11. Wireless power transmission efficiency

Transmitting efficiency as 0.13% line (-29.8db) in Figure 11 corresponds to 100uW receiving power line referring to the electro-magnetic protection index. Considering the HEMS application, it is desirable that transmitting distance is more than 1m. Then every coils except same size coil (single loop coil) satisfy that condition.

VI. CONCLUSION

We have studied HEMS "E" Project for about 10 years. Account for energy harvesting, many kinds of energy harvesting was examined. Some of energy harvestings in a house can generate more than 1mW averagely and almost all of energy harvesting can generate more than 100uW that satisfies the sensor network HEMS specification.

Next we have examined the validity of the sensor network HEMS using energy harvesting. One week feasibility experiment using the prototype sensor network node with solar panels has the good agreement with our design of the energy budget. Moreover we have tried to examine the routing node that works with the harvesting energy. The calculated results satisfy HEMS condition of network scale. Finally, we have studied the ability of wireless power transmission introducing for HEMS. The experimental data shows the results that can transmit more than 100uW power to a receiver at the distance of more than 1m. Any way, I believe HEMS E project arrived at the 1st step of feasibility stage. Now the time has come we should go to next stage combining element technologies.

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