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A Study of Power Line Communication-based Smart Outlet System Expandable at Home

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ABSTRACT

Unprecedented attention is being given to Smart Grid, Micro Grid and Internet of Things (IoT) in the Republic of Korea recently but such systems' effect is not well experienced by the market since they require additional and costly reforms for the existing household electrical system where adaptive communication platforms are needed. As such platforms, both wireless and wire communication technologies are being considered at the moment. Usually, they include WiFi, Zigbee technologies and the latter, LAN technology. However, communication speed decline due to signal attenuation and interference during wireless communications are considered to be the major problem and the extra works involving time and costs for the LAN system construction can be another demerit. Therefore, in this paper, we have introduced a Power Line Communication-based Smart Outlet System Expandable at Home to complement these disadvantages. Proposed IoT system involves Power Line Communication (PLC) technology which is essential to constructing a Smart Grid.

Key words: PLC, IoT, Smart Outlet System, Smart Grid, 220V, Artificial Intelligence, AI.

1. INTRODUCTION

Recently, in the Republic of Korea, there is a rising interest on Smart Grid, Micro Grid and Internet of Things (IoT). According to various companies such as Samsung, LG and KT are attempting to build the Smart Homes which is the basis of the IoT technology.

However, despite of many products being introduced to the market, not many are feeling an effect of them. The main reason is some form of new structure must be added to existing household to provide a basic platform that enables communications between 'Things' in order to achieve IoT [1-4].

The current trend is to use wireless communication technologies like WiFi, Zigbee or cable communication technology often exemplified by Lan as such platform.

WiFi and Zigbee-based communications have an advantage of avoiding additional cabling works but their demerits are the system reliability and communication speed can be declined the signal interferences at the final stage of implementing a Smart Home where all the appliances will be connected and start to communicate each other. One can consider using a wire communication like Lan to complement such demerits but extra construction works are inevitable. Thus, in this paper, we have Smart Outlet System Expandable at Home,

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to build a Smart Grid in the future by using Power Line Communication (PLC) technology. This alternative system transmits data through existing 220V household power lines so that no extra construction works will be required.

2. RELATED RESEARCH

The question of PLC's actual role in a Smart Grid has not been definitively answered yet. That is, some argues that PLC can be an excellent measure for many applications whereas others are somewhat critical and support wireless technology as a better and proven choice [5-14]. Although majority of critiques agree that the Smart Grid can use various communication methods (e.g., fiber optics, wireless or wireline), they still express their concern over PLC's undefined standardization protocols and its low data rates. Another demerits of PLC system presented were the expensive PLC modems and Electro Magnetic Compatibility (EMC) problems, which have been dealt with recent years.

Meanwhile, the cost PLC system establishment is comparable to setting up a wireless system as the power lines are already available for use. Another current advantages are that the PLC technology has gone through many test bed experiments and gained credibility [15-21]. It's been judged that the technology has matured enough for extensive and wider applications, especially for the Smart Grids for transmission and distribution functions. By supporting AMR and AMI applications, PLC started to penetrate market successfully.

On the other hand, there are two major aspects can restrict the growth of PLC in the market. First one is use of inadequate and incomplete PLC system just to take initiative in the market for commercial reason. Some examples can be found in the PLC vendors who promote PLC-based Smart Grid applications with Broand Band (BB)-PLC modems that are not technically appropriate for the applications. These modems have been developed for the Home and Building Area networks (HAN/BAN) or internet access purpose to begin with so that their operation ranges are too limited for Smart Grids.

The other obstacle for the Smart Grids is 'standardization'. The PLC industry shifted its position from having none of BB-PLC standards at all to adopting multiple non-interoperable technologies certified by some of Standards Developing Organizations (SDOs), which included TIA-1113, ITU-T G.hn, IEEE 1901 FFT-OFDM, and IEEE 1901 Wavelet-OFDM [22].

For this reason, using the BB-PLC modems exclusively for the Smart Grid applications raises the question of which standard to use and of incompatibility. These problems also affect the use of multiple non-interoperable technologies that adopt multi carrier HDR NB-PLC standardized in IEEE P1901.2 and ITU-T G.hnem. It is evident that such situation brings about much confusion for both the market and users, as well as delaying of deployment. These might have been the unforeseeable obstacles but it is fact that the industry has overlooked the problems and was optimistic that they can fully manage such situations.

One of hopeful situation can be found in the PHY/MAC-agnostic coexistence scheme defined in CENELEC EN 50065 [23], which certified some of NB-PLC standards after their publication and allowed NB-PLC solutions to be used in the market for the last two decades. However, at the same time, there are other skeptics who point out that such a coexistence would lead to a delay in establishing a single global PLC standard as non-standardized solutions could become pervasive in the market. Such pro and con debates further delayed the global PLC deployment but the confusion was larger in US, such that US National Institute of Standards and Technology (NIST) came forward to deal with the situation addressing it the problem in the Priority Action Plan (PAP), removing the obstacles and guiding the PLC-based Smart Grid applications in the right direction [24-25]. It is hoped that their recommendation will bring more clarity in the market and industry.

3. DESIGN AND IMPLEMENTATION OF PLC-BASED SMART OUTLET SYSTEM EXPANDABLE AT HOME

3.1 A Design of functional diagram of Smart Outlet System expandable at home using PLC

Fig. 1 and Fig. 2 are the functional diagrams of Smart Outlet systems expandable at home using PLC and the home servers in each diagram aggregate, analyzes and store power consumption amounts in the database after they receive the information from the Smart Outlet. Additionally, power they deliver power information to the user and control appliances connected the Smart Outlet through respective home servers. Home server aggregates power consumption amounts every three minutes and then stores the information in Mysql DB. In this design, the user can check the power use information on a PC or smart phone by connecting to the DB through PHP (Android).

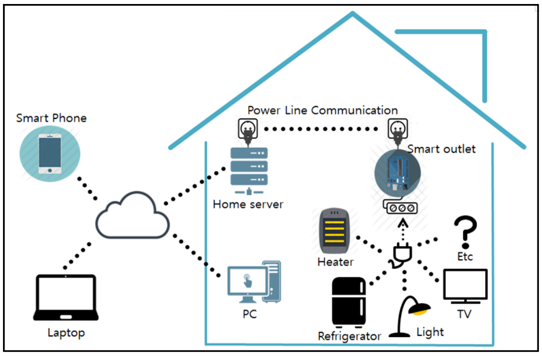

Fig. 1. A Functional Diagram of Smart Outlet System Expandable at Home Using PLC (1).

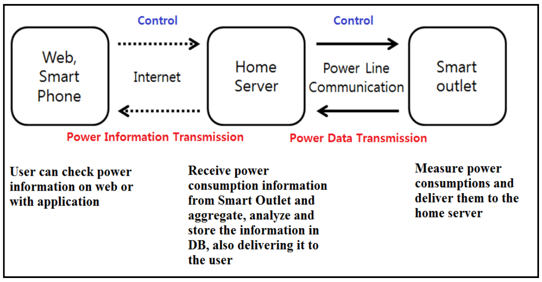

Fig. 2. A functional Diagram of Smart Outlet System Expandable at Home Using PLC (2).

Fig. 1 shows a functional diagram of Smart Outlet system expandable at home using PLC (1), which is the main aim of the proposed system in this paper, has been implemented by using 220V to allow system expansion at home.

In the functional diagram of the expandable Smart Outlet System using PLC (2) Fig. 2 shows that the appliances connected to the Smart outlet can be controlled through home server.

In this design, a total amount of power used by the household appliances is monitored by an electric outlet (220V) in which a PLC modem and a module that calculates and controls household power use are embedded. The data obtained from this outlet will be then put together, analyzed through Home Server and used by the Artificial Intelligence (AI) to optimize the power use pattern.

Additionally, daily and monthly power use amounts will be provided to the user in real-time in addition to the data obtained from comparative analysis between user's current and past power use amounts, and between the user and another person who uses similar appliances. The other notable function is that the system provides both AI-based and manual remote control functions in accordance with user's power use patterns.

3.2 A Implementation of functional diagram of Smart Outlet System expandable at home

Fig. 3 shows overall implemented system where Home Server receives data from terminal Arduino for the control. Home Server communicates with Arduino through PLC by serial communication. Power use amounts will be aggregated every 3 minutes and then stored at the MySQL DB of Home Server. Home Server and Arduino is interlocked with PHP, as web and DB.

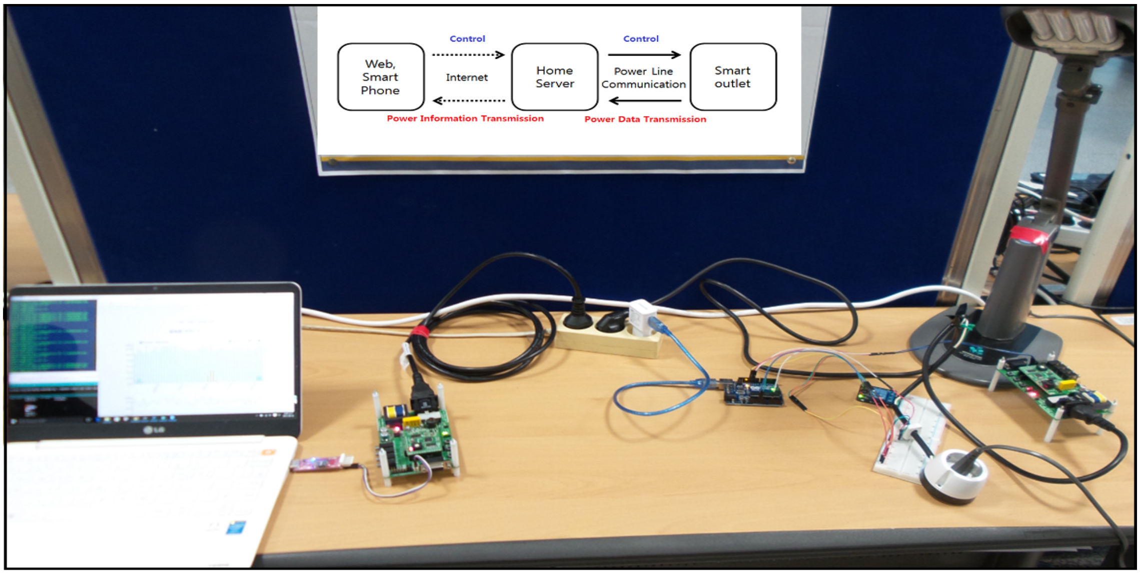

Fig. 3. Overall Implemented System.

The Smart Outlet consists of a relay module and a current measuring sensor to control power together with an Arduino Uno R3 circuit board acting as the MCU to control this module and sensor [5, 26, 27]. The circuit board is connected to the PLC modem (NC-EPLC) and perform serial communications by interlinking IN/OUT pin (Arduino) with TTL port (NC-EPLC).

3.3 Implementation of Home Server

Fig. 4 is the fabrication design of Home Server to perform data transmission/reception. The main function of Home Server is to carry out the serial communications with the Smart Outlet for data delivery and reception.

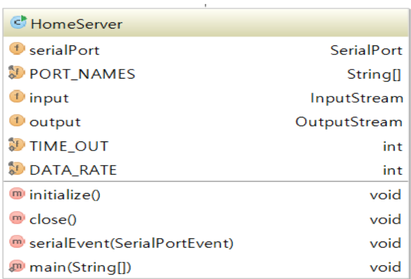

Fig. 4. Home Server Main Class.

Subsequently, delivered data will be processed and stored at the DB as in Fig. 5. The power use data is transmitted every 5 seconds and stored separately following individual index of each Smart Outlet. This power use data will be indicated with Wh unit every 3 minutes for each appliance once the thread CalculateThread has been initiated.

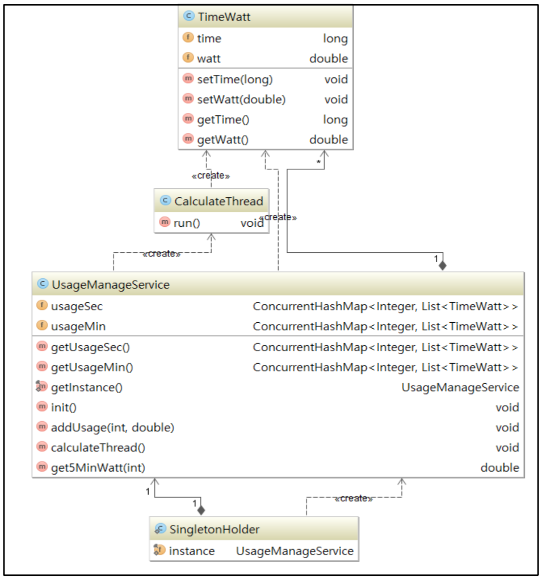

Fig. 5. ManageService UML Diagram.

The database used to interlink Smart Outlets with appliances is consisted of objectID which is the primary key of the Smart Outlet, and the appliance name relevant to this objectID.

Fig. 6 is the composition of the DB table which stores appliance names and this table will be managed with NameManageService class and Name DAO Data Acess Objects as below. These loads HashMap that stores objectID and objectName when Home Server starts its operation and lets the user to conveniently check and change the name of the appliance being connected to the Smart Outlet by interlinking with relevant HashMap when he/she checks the amount of power used.

Column ID	Name	Type
0	**objectId**	**INTEGER**
1	objectName	VARCHAR

Fig. 6. Composition of DB Table.

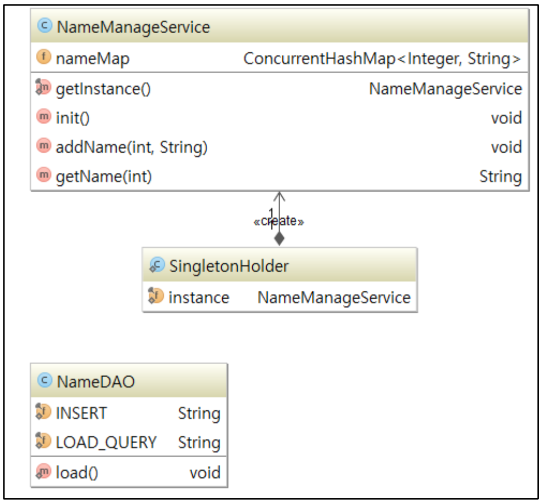

Fig. 7. Composition of NameManageService Class that Interlinks Smart Outlet with Relevant Appliance Name.

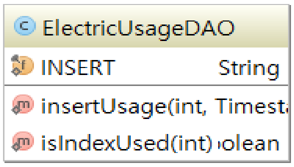

Fig. 8. Electrical Power Use DAO.

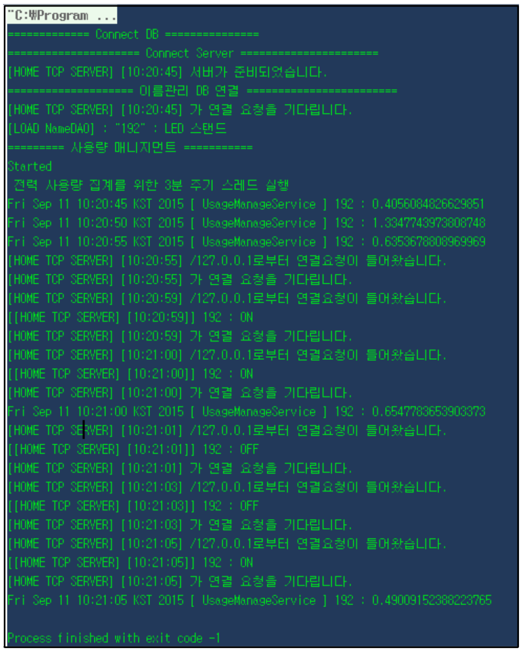

Fig. 9. Home Server Console.

The power use data processed with Calculate Thread every 3 minutes in each Smart Outlet will be stored at electric_usage table through Electric UsageDAO as shown in Fig. 7.

The electric_usage table includes objectID, time period (3 minute base), appliance name and power use amount Fig. 8.

As shown in Fig. 9, Home Server receives aggregated power use data from Smart Outlet every 5 seconds and stores it at database after processing it to convert as unit Wh.

4. PERFORMANCE EVALUATION FOR THE FABRICATION OUTPUT

i7-4770k CPU and 12Gb Ram were used for the testing environment to conduct the test and the outcomes of the IN/OUT processes. Fig. 10. shows the results of delays while loading the database with 30,000 data. The test was carried out for both mobile and PC environments. For these environments, the time to load the web that has the function of checking the power consumption rate was measured. The results showed that the delays were 0.8 to 1.2sec for PC and 0.3 to 0.4sec for mobile device.

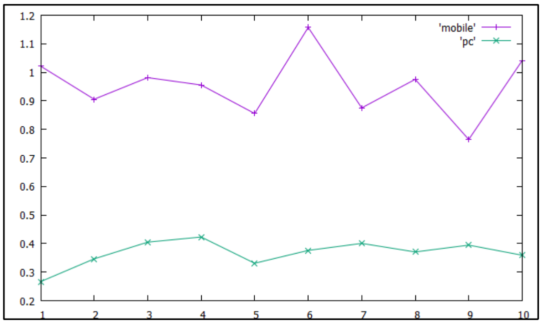

Fig. 10. Loading Delays in Mobile and PC Environment.

Additionally, Fig. 11. shows the delays occurring between Smart Outlet and Home Server connected with a 2m-length power line. The results shows that the delays are within the limits of 0.01 to 0.08 seconds, both of which are negligibly small when compared with the delays generated between Home Server and the web server.

With performance evaluation test in Fig. 11, it will be safe to say that the product, Smart Outlet, has reached the adequate level of commercialization in terms of reliability and performance under the household PLC environment.

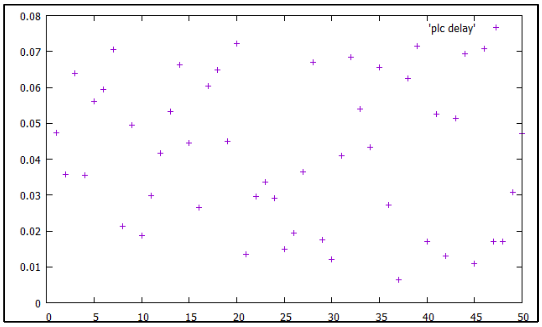

Fig. 11. Delays between Smart Outlet and Home Server.

5. CONCLUSION AND FUTURE WORK

With the proposed Power Line Communication-based Smart Outlet System Expandable at Home, users will be able to establish Smart Grids through existing 220V power lines without installing separate additional power lines to carry out data communications. Moreover, users can check power consumptions of their household appliances instantly on an hourly basis and control them remotely in real-time.

Also, since this system can control and adjust the home alliances' power consumption patterns without any additional manual operations, user's convenience can be maximized. With such merits, we plan to commercialize the system after completing patent registration and pursuing Industry-University collaborations.

We expect that our proposed system will contribute in solving the problems derived from current environmental pollution and future energy exhaustion by optimizing household electrical power use. Also, We expect that the proposed system in this paper will aid in optimizing the power consumption patterns and amounts at homes. The standby electricity equivalent to approximately 520 billion won is being wasted each year in the Republic of Korea and it will be great significance if such a waste can be reduced even in partial amount. Additional merit of the system is that it can maximize user convenience since the system aids in controlling the power levels through IoT connections between the appliances without special operations by the user.

By using the expandable 220V PLC technology, which is the base technology of the system, and connecting the appliances to the home server, point-to-point communications between the household appliances will be possible so that the system can have an advantage in future extended functions. Meanwhile, the problems regarding the noises and attenuations during communications, and security will be discussed as future tasks while preparing for the extended paper and commercialization.

Appendix

SUNCOM, established by one of the Industry-University collaboration projects, is proceeding with a business that utilizes PLC technology in the Republic of Korea and has already developed 200-500Mbps level PLC-based products. Additionally, in the preceding research [28-30] and business project, they have carried out the PLC-based internet constructions more than 40 occasions for the existing ships. We'd like to thank Taehoon Koh (President of SUNCOM Co., Republic of Korea) for his valuable in deducing PLC technology. And We'd like to thank Dr. course Sugarbayar Otgonchimeg for his check English Grammar.

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