Smart Energy Meter (SEM) with Adaptive Communication Data Transfer Method

Haizum Hanim Ab Halim, Nashiren Farzilah Mailah, Mohammad Lutfi Othman, Noor Izzri Abdul Wahab and Norhisam Misron

August 1, 2024

電気学会論文誌●（●●●●●●●部門誌）
IEEJ Transactions on ●●●●●●●●●●●●●●●
Vol.●● No.● pp.●-●● DOI: ●.●●/ieejeiss.●●.●

Paper

Smart Energy Meter (SEM) with Adaptive Communication Data Transfer Method

Haizum Hanim Ab Halim[a)] Non-member, Nashiren Farzilah Mailah[b)] Non-member, Mohammad Lutfi Othman[c)] Non-member, Noor Izzri Abdul Wahab[d)] Non-member, Norhisam Misron[e)] Non-member

(Manuscript received Feb. 28, 2022, revised May 00, 20XX)

Smart Meter (SM) is an intelligent device with additional functions which include the ability to measure and record energy consumptions, and allows two-way communication with the utility for automated monitoring, and accurate billing management. The obvious problems in SM is it is uses a single communication system as there was no contingency plan in transferring the data when the signal strength was weak. Thus, a new Smart Energy Meter (SEM) with an adaptive data transfer algorithm is been designed with control devices and sensors that can measure and record the data using three types of communication system in one device; Wi-Fi, GSM and RF. The idea of combining three types of wireless communication is to ensure the data fully transferred to the data center accurately and promptly. The selection of communication to transfer the SEM data is arranged by comparing the received signal strength indicator (RSSI) of Wi-Fi and GSM value with the priority given to Wi-Fi, followed by GSM and RF. The prototype has been tested in laboratory scale to check its performance and the data was successfully transferred fully without failed and received by the data interface system (DIS).

Keywords: Smart Meter, Smart Energy Meter, Wi-Fi, GSM, RF

1. Introduction

Smart Meter (SM) is a modern trend in energy delivery systems to drive efficiency and transmit the consumption energy data directly to the electricity provider via Information and Communications Technologies (ICT). This unique device is able to increase energy efficiency and integrated renewable energy sources, supporting a new generation of intelligent appliances and plug-in electric vehicles and also the utility is able to manage the electricity demand during peak load crisis and decreasing the outage events through SM (1-2). The emergence of SM has minimized the usage of manpower in manual meter data collection activity, thus saving the cost of implementing such activities.

In light of this evolution in SM technologies, numerous studies have been conducted worldwide investigating the integration of communication systems with SM. Most of the SM invention are designated with single communication, where it is led to a slew of issues in energy data delivery process. Poor networking during data transmission of SM data has caused delays and backlog in data stored in the meter where the single communication in SM could malfunction at some time and it was entirely dependent on the strength and the limitation of the communication (3). Most of the communication technologies available have drawbacks such as distance limitations, signal failures in poor conditions and distant location noise (4-5). SM with a single communication also has a limitation on the location and atmospheric condition, since every communication has their own characteristics. Even though there have been numerous communication technologies had been proposed, communication is still the most critical issue in smart metering (6). The lack in stability in communication system has caused the SM to fail in sending the data adequately and in real-time to the utility where such data was important for billing and monitoring purposes. Communication failure and incompetency in monitoring have affected energy management including energy forecasting, fraud in electricity, demand management and power outage (7).

[a] Correspondence to: Nashiren Farzilah Mailah.
E-mail: nashiren@upm.edu.my
UPM Serdang, 43300, Selangor, Malaysia

2. The Proposed System

The motivation of this work is to propose a solution in providing a reliable and efficient Smart Energy Meter (SEM) that is able to operate in more than one type of communication system. These communication system is managed to switch among them effortlessly whenever there is an interruption on the communication signals. A single phase SEM is consisted with three types of communication, and the SEM development is containing hardware development, software programming and data interface system (DIS) as data center. This prototype is accommodated with MCU, energy metering IC, Liquid Crystal Display (LCD), and three types of communication (Wi-Fi, GSM and RF). An adaptive communication data transfer algorithm is written by using Arduino Integrated Development Environment (IDE) that is able to evaluate the strength of the communication signals and determine the best communication system for it to transfer the energy data measured by the proposed SEM and switched among the communication system if in any instance interruption occurs during data transfer.

A simple data center is developed to collect and store all the data from the SEMs for monitoring purpose. DIS is built by using PC, RF transceiver and GSM gateway. Data from SEM that received via Wi-Fi communication is displayed through localhost website, while data that received via GSM and RF communication is displayed through Hercules Setup utility. All data from both localhost website and Hercules can be converted into Microsoft Excel file for monitoring and storage purpose. Several tasks have been written in the program for SEM prototype, there are energy calculation, communication and data transfer task. Fig. 1 and Fig. 2 shows a flow chart of SEM prototype and a diagram of overall architecture of the SEM prototype and DIS respectively.

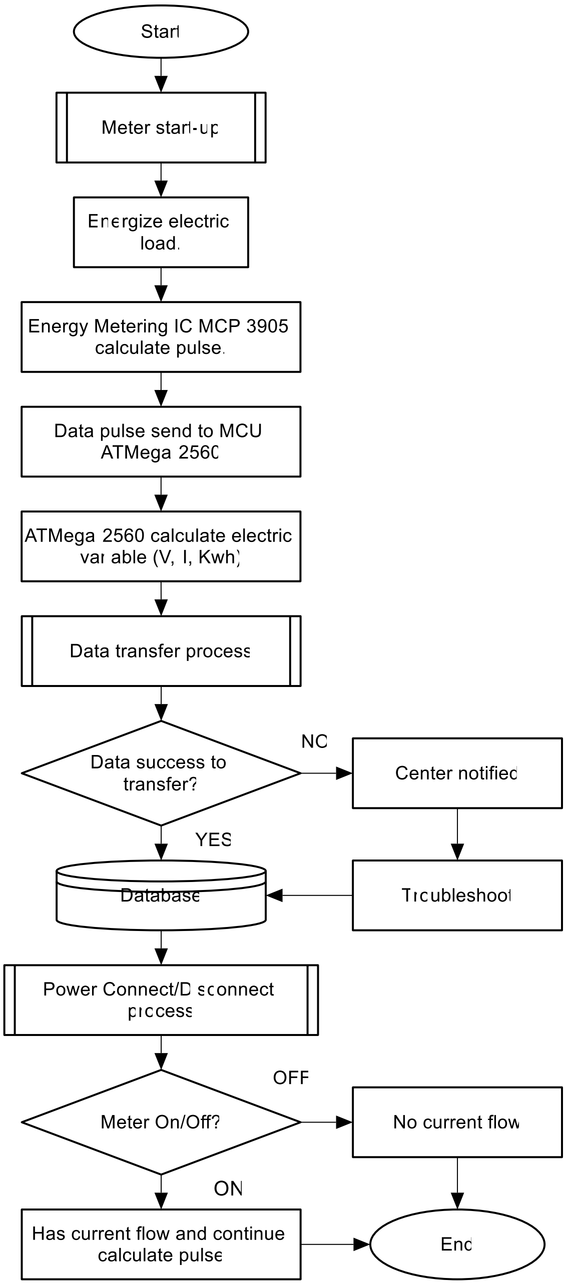

Fig. 1. Flow chart of SEM prototype

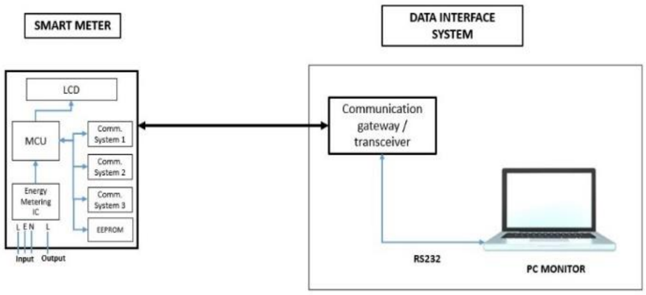

Fig. 2. Diagram of overall architecture of the SEM prototype and DIS

2.1 Energy Metering IC MCP 3905 Energy metering IC MCP 3905 with shunt as current sensing is used for SEM application is able to measure real power by counting electrical pulse produced in the IC when current flows through the IC. MCP 3905 IC is selected because it is lower cost and less accuracy issues included saturation and phase response at high-power factors (8). In addition, MCP 3905 is familiar and had been used in TNB research work to develop remote accessible power measuring system for domestic users (4). Energy measuring circuit is in charged in measuring electrical parameters that are voltage, V (V), current, I (A) and energy consumption, E (kWh). Fig. 3 shows the image energy metering IC MCP 3905 surface mount technology (SMT) package (8).

Fig. 3. Image of energy metering IC MCP 3905 SMT package (8)

2.2 ATmega 2560 ATmega 2560 is chosen as master controller of SEM because it is capable to handle maximum 4 UART in one system, low power and high performance. ATmega 2560 is responsible to perform all SEM tasks for example arranges the SEM tasks accordingly and simultaneously, allowed communication between other devices in the circuit, do calculation and processed of the data received, allowed communication with other communication devices, and many other function that related to SEM program. In addition, ATmega 2560 is run in Windows and using C++ language where it is suitable with Arduino IDE program. Fig. 4 shows the image of ATmega 2560 in SMT package.

Fig. 4. ATmega 2560 in SMT package

2.3 Communication Types ESP 8266 Wi-Fi module, GSM SIM 900 and RF Zigbee Xbee IC chips are selected as communication devices for SEM because of their low cost deployment, advantageous on their portability and accessibility and compatible to Arduino programming. ESP 8266 Wi-Fi module is widely used in SM research for data transmission due to low cost (9-10).

3. An Adaptive Data Transfer Algorithm

An adaptive data transfer algorithm is designed and developed using Arduino programming that is responsible in evaluating the strength of the communication system based on the RSSI value and then the algorithm will select which communication system will be given the priority to transfer the energy data from the SEM to the data center. It will give priority to Wi-Fi, GSM and RF communication of this order.

In telecommunication, notably in radio frequency, the transmitting power output that received by a reference antenna at a certain distance from the transmitting antenna is known as signal strength, where it is measured in decibel-miliwatts (dBm). A signal strength is determined by RSSI through signal strength measurement scale (11). Signal strength measurement scale between Wi-Fi and GSM is difference. The highest RSSI value indicates that the communication system exhibits strong signal to get a good wireless connection and able to transmit the data from the SEM to DIS. For example, in the beginning Wi-Fi is set as the main communication on the SEM and during data transfer event, if the communication selection task detected RSSI of Wi-Fi falls lower than the accepted level, it will switch to GSM to continue transmit the data. The communication algorithm has been designed to always give priority to the strongest communication system based on the RSSI value in the order of Wi-Fi, GSM and RF communication and switched to the next communication system if interruption occurs during data transfer event.

Through the algorithm, Wi-Fi is selected to perform the data transfer task if the RSSI level is greater than -67 dBm. When the RSSI level of Wi-Fi lower than -66 dBm, GSM will proceed for data transfer task when the GSM value are greater than 10. Otherwise, if the RSSI level of Wi-Fi below -66 dBm and the GSM value below -93, then the data transfer task will be taken by RF. Table 1 shows the communication selection condition between Wi-Fi and GSM.

Table 1. Communication selection condition between RSSI Wi-Fi and GSM

Wi-Fi (dBm) \ GSM (dBm)	>-81	-93 – -81	<-93
> -55	Wi-Fi	Wi-Fi	Wi-Fi
-66 to -55	Wi-Fi	Wi-Fi	Wi-Fi
< -66	GSM	GSM	RF

4. Results and Validation

Several tests have been conducted to check the capability and the reliability of SEM, there are:

a. Functionality Test 1: To measure energy consumption and electrical on heating element (example: electric kettle)

b. Functionality Test 2: To transfer SEM data via designated algorithm

4.1 Functionality Test 1 SEM prototype is being tested to measure electrical parameters of electric kettle and then compared with readings from a digital Wattmeter. Electrical parameters that were recorded are voltage (V), Current (I) and energy (kWh). Readings for each measurement are taken for every 30 seconds. Table 2 shows reading of voltage, current and energy consumption data for electric kettle.

Table 2. Reading of voltage, current and energy consumption data for electric kettle

Time (s)	30	60	90	120	150	180
Energy (kWh)	2.338	2.346	2.350	2.355	2.361	2.366
Voltage (V)	239	240	240	241	240	241
Current (A)	9.774	9.780	9.783	9.789	9.795	9.800

From Table 1, it is shows that the voltage and current recorded by the SEM is almost constant that is at 240V and 9.7A respectively. The energy consumed is increased with time. Table 2 shows the result of current measurement of SEM prototype and digital Wattmeter and Table 3 shows result comparing of voltage measurement of SEM prototype and digital Wattmeter respectively. Error calculation of voltage and current for both SEM and Digital Wattmeter is determined in percentage through Equation (1)

$$Error\ (\%) = \frac{Digital\ Wattmeter\ (reading) - SEM\ (reading)}{Digital\ Wattmeter\ (reading)} x\ 100 \ldots\ldots\ldots\ldots\ldots (1)$$

Table 3. Result comparing of current measurement of SEM prototype and digital Wattmeter

Time (s)	30	60	90	120	150	180
SEM	9.774 A	9.780 A	9.783 A	9.789 A	9.795 A	9.800 A
Digital Wattmeter	9.774 A	9.778 A	9.779 A	9.783 A	9.785 A	9.799 A
Error (%)	0.00%	0.02%	0.04%	0.06%	0.10%	0.01%

Table 4. Result comparing of voltage measurement of SEM prototype and digital Wattmeter

Time (s)	30	60	90	120	150	180
SEM	239 V	240 V	240 V	241 V	240 V	241 V
Digital Wattmeter	242 V	242 V	241 V	241 V	242 V	242 V
Error (%)	1.24%	0.83%	0.41%	0.00%	0.83%	0.41%

4.2 The Result of Functionality Test 2 The second part of Functionality Test is to test function of the communication change task. The data is successes to transfer to the DIS without failed through the three communication that arranged accordingly. Table. 5 shows result of data transferring through designated communication algorithm.

Table. 5. Result of data transferring through designated communication algorithm

Date	Time	Voltage (V)	Current (A)	Energy (kWh)	RSSI Wi-Fi	GSM value	Comm. system
18/2/2020	9:22:44 AM	230	0	0.03	-77	-64	WI-FI
18/2/2020	9:23:15 AM	230	0	0.03	-77	-64	WI-FI
18/2/2020	9:23:48 AM	230	0	0.03	-77	-64	WI-FI
18/2/2020	9:24:21 AM	230	0	0.03	-77	-64	WI-FI
18/2/2020	9:24:52 AM	230	0	0.03	-77	-63	WI-FI
18/2/2020	9:25:25 AM	230	0	0.03	-99	-94	RF
18/2/2020	9:25:57 AM	230	0	0.03	-99	-93	RF
18/2/2020	9:26:29 AM	230	0	0.03	-77	<-66	GSM
18/2/2020	9:27:03 AM	230	0	0.03	-77	-65	WI-FI
18/2/2020	9:27:38 AM	230	0	0.03	-77	-65	WI-FI
18/2/2020	9:28:14 AM	230	0	0.03	-77	-65	WI-FI
18/2/2020	9:28:44 AM	230	0	0.03	-77	-64	WI-FI
18/2/2020	9:29:18 AM	230	0	0.03	-77	-64	WI-FI
18/2/2020	9:29:51 AM	230	0	0.03	-77	<-66	GSM
18/2/2020	9:30:31 AM	230	0	0.03	-77	-64	WI-FI
18/2/2020	9:31:05 AM	230	0	0.03	-77	<-66	WI-FI
18/2/2020	9:31:38 AM	230	0	0.03	-77	<-66	WI-FI
18/2/2020	9:32:09 AM	230	0	0.03	-77	<-66	GSM
18/2/2020	9:32:44 AM	230	0	0.03	-99	-95	RF
18/2/2020	9:33:18 AM	230	0	0.03	-99	-95	RF
18/2/2020	9:33:53 AM	230	0	0.03	-77	-65	WI-FI
18/2/2020	9:34:25 AM	230	0	0.03	-77	-64	WI-FI
18/2/2020	9:34:59 AM	230	0	0.03	-77	-64	WI-FI

5. Conclusion

The SEM prototype with adaptive data transfer is constructed. A combination of three types of communication with a designated algorithm is proposed to overcome data communication failure during data transmission. Selection of the three types of communication is based on existing infrastructure, cost effectiveness, and market existing. In general, this study found that designated of SEM prototype with an adaptive data transfer algorithm is able to transfer data reliably to the DIS without failure.

References

(1) Syed, Z. I., Norman, M., Lutfi, O., Hashim, H., & Izham, Z.: "Dynamic communication for smart metering: Leading edge for sustainable energy and PHEV", Advanced Materials Research, 805–806, 1107–1115. (2013)

(2) Arafat, Y., Tjernberg, L. B., & Gustafson, P.A.: "Possibilities of Demand Side Management with Smart Meters", 23rd International Conference on Electricity Distribution. Lyon, 15-18 June 2015 (2015)

(3) Mohandass, S. N.: "Smart Meter Pilot Project in Tenaga National Berhad Malaysia: 3 Different Communication Technology Tested", Tenaga National Berhad, (2015)

(4) Yusoff, H. M., Arief, Y. Z., Noorden, Z. A., Adzis, Z., Bashur, N., Muhamad, N. A., … Sidik, M. A. B.: "Development of a Remote Accesible Electrical Power Measuring System for Domestic Customer, Jurnal Teknologi, 77(12), 105-108. (2015)

(5) Bilal, E., Ahmed, Z., & Faroqi, A.: "Implementation of Smart Meter Based on Smart Grid Smart Meter and Smart Appliances", 2nd Iranian Conference on Smart Grid, 23-24 May 2012 (2012)

(6) Lipošüak, Z., & Boškoviü, M., "Survey of Smart Metering Communciation Technologies", EuroCon2013, 1-4 July 2013, Croatia (2013)

(7) Erlinghagen, S., Lichtensteiger, B., & Markard, J.: "Smart meter communication standards in Europe – a comparison", Renewable and Sustainable Energy Reviews, 43 (2015) 1249-1262 (2015)

(8) King, C. L., & Microchip Technologies, I. "AN994: IEC Compliant Active-Energy Meter Design Using the MCP3905/6", Application Note, Microchip Technology, 1–18 (2005) Retrieved from http://ww1.microchip.com/downloads/en/AppNotes/00994a.pdf

(9) Devadhanishini, A. Y., Malasri, R. K., Nandinipriya, N., Subashini, V., & Padma Gowri, P. G., "Smart Power Monitoring System Using IoT", 2019 5th International Conference on Advanced Computing and Communication Systems, ICACCS 2019, (Icaccs), 813–816 (2019).

(10) Hlaing, W., Thepphaeng, S., Nontaboot, V., Tangsunantham, N., Sangsuwan, T., & Pira, C., "Implementation of Wi-Fi-Based single phase smart meter for internet of things (IoT)". 2017 International Electrical Engineering Congress, IEECON 2017, (March), 8–10. (2017)

(11) Nesa, B & Sarker, M. M., "Analysis of Signal Strength Variations for an Urban Public University Campus in Bangladesh", International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181, Vol. 9 Issue 07, (2020)

Haizum Hanim Ab Halim received BEng (Hons.) in Industrial Electronic Engineering from University Malaysia Perlis (UniMAP), Malaysia in 2010 and Master of Technical Education (Electrical Engineering) from University Tun Hussein Onn Malaysia (UTHM), Malaysia in 2012. She is currently pursuing her PhD degree with University Putra Malaysia (UPM), Malaysia. Her research interest includes Smart Meter, Energy Monitoring and communication in Smart Metering.

Nashiren Farzilah Mailah received BEng in Electrical and Electronic Engineering from University of Huddersfield from United Kingdom in 1999 and MEng in Electrical Engineering from University Technology Malaysia (UTM), Malaysia in 2001. She pursued her study and received her PhD in Electrical Engineering from University Putra Malaysia (UPM), Malaysia in 2010. Her research interest includes Power Electronics Converter and its application, Power Systems and Smart Metering.