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Design of Wi-Fi-based new generation electricity meter for smart grids and smart building applications

Akıllı şebekeler ve akıllı bina uygulamaları için Wi-Fi tabanlı yeni nesil elektrik sayacı tasarımı

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Abstract

Smart meters are among the fundamental components of smart grids due to their features such as high-accuracy energy measurement, remote reading, and control. They are also utilized to reduce the rate of illegal electrical energy use in some distribution areas. This paper presents the development of a Wi-Fi smart meter and designing a smart plug-in device for customer-side energy management. In this way, a method that does not require additional infrastructure and extra investment for remotely reading the energy consumption in environments with common Wi-Fi networks, such as large shopping malls, business centers, community buildings, villa cities, and university campuses has been proposed. The Wi-Fi smart meter and smart energy metering module (SEMM) support various user-friendly applications in accordance with the infrastructure of the smart grid and smart building applications. The SEMM is capable of measuring, monitoring, and remotely managing each electrical device. Thanks to the developed mobile application, customers can monitor their Wi-Fi smart meter data and also the consumption of each electrical device through the SEMMs as well as remotely manage these devices. The application examples presented in this study are also aimed at increasing awareness of energy saving for customers.

Keywords: Smart grids, Wi-Fi smart meter, Smart energy metering module, Advanced metering infrastructure, Internet of Things.

Öz

Akıllı sayaçlar, yüksek doğrulukta enerji ölçümü, uzaktan okuma ve kontrol gibi özellikleri sayesinde akıllı şebekelerin temel bileşenleri arasında yer almaktadır. Akıllı sayaçlar bazı dağıtım bölgelerinde kaçak elektrik enerjisi kullanım oranını azaltmak için de kullanılmaktadır. Bu makale, bir Wi-Fi akıllı sayacının geliştirilmesi ile enerji izleme ve yönetimi için akıllı bir ölçüm-kontrol cihazının tasarımını sunmaktadır. Bu sayede büyük alışveriş merkezleri, iş merkezleri, toplu konut siteleri, villa şehirler ve üniversite kampüsleri gibi ortak Wi-Fi ağlarının bulunduğu ortamlarda enerji tüketimini uzaktan okumak için ilave altyapı ve ekstra yatırım gerektirmeyen bir yöntem önerilmiştir. Wi-Fi akıllı sayaç ve akıllı enerji ölçüm modülü (SEMM), akıllı şebeke ve akıllı bina uygulamalarının altyapısına uygun olarak çeşitli kullanıcı dostu uygulamaları desteklemektedir. SEMM, her bir elektrikli cihazın tüketiminin ölçülmesi, izlenebilmesi ve uzaktan yönetilebilmesine olanak sağlayacak özelliktedir. Geliştirilen mobil uygulama sayesinde, müşteriler Wi-Fi akıllı sayaç verilerini ve ayrıca her bir elektrikli cihazın tüketimini SEMM'ler üzerinden izleyebilmekte ve bu cihazları uzaktan yönetebilmektedir. Bu çalışmada sunulan uygulama örnekleri, tüketiciler için de enerji tasarrufu bilincini artırmayı amaçlamaktadır.

Anahtar kelimeler: Akıllı şebekeler, Wi-Fi akıllı sayaç, Akıllı enerji ölçüm modülü, Gelişmiş sayaç altyapısı, Nesnelerin interneti.

1 Introduction

Smart grids offer advantages beyond the existing grid operating structure, such as increasing efficiency, improving supply continuity, integrated load management, reducing manual operations to a minimum, dynamic tariff applications, follow-up of real-time demand, and advanced demand-side management [1]. Studies regarding smart grid technologies and their applications are generally based on smart meter systems. In Automatic Meter Reading (AMR) applications, one-way communication can be achieved with the meters. There is a need for a system that can communicate with the meter and send feedback in case of abnormal conditions such as interruptions and illegal interventions.

A closed-loop control system is formed by establishing two-way communication between the measurement systems at energy consumption points and the Meter Data Management System (MDMS) together with smart meter systems. Hence, it provides advanced technological applications such as reading and data recording, remote control, determination and reporting of illegal interventions to the meter, and detection of illegal use [2]-[4]. Smart meters play a significant role in preventing the illegal use of energy [5]. Besides, they also enable customers to be supported in making savings in their billings through dynamic tariff applications [6].

There are some studies on smart meters in the literature. Michalec et al. [7] have emphasized the importance of increasing communication potential in water and electricity meters. Arif et al. [8] have developed GSM and Zigbee-based smart meters. Abate et al. [9] have developed a low-cost smart meter that is compatible with the Internet of Things (IoT). This system supports the Advanced Metering Infrastructure (AMI) thanks to the wM-Bus communication currently used in the water and gas meters. Abujubbeh et al. [10] have envisaged that Wi-Fi could be an alternative technology for software-defined Wireless Sensor Networks (WSN) in smart grids. Parvez et al. [11] have suggested Wi-Fi-based WSN for the communication between meters and the main modem. Hlaing et al. [12] have developed a single-phase Wi-Fi smart meter for IoT applications.

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In addition to the smart meter systems, the smart home management systems and plug-in energy metering devices play an important role in helping customers to save energy [13]-[18]. The application of the Wi-Fi-based WSN architecture for remote meter reading applications brings advantages such as high-bandwidth, transmission capacity, coverage area, low cost, and easy expandability in data transmission [19]. Furthermore, with its high transmission rate and capacity, the Wi-Fi-based WSN architecture will play a key role in the Internet of Things (IoT) and smart grid studies in remote meter reading applications as well [20],[21].

An IoT-based compact smart energy meter for a commercial building energy management system is presented in [22]. Also, Wi-Fi-enabled smart meter for power quality-based tariff implementation [23] and IoT-based smart energy meters for residential energy management are developed [24],[25]. However, they have not been tested with Head-End software in a distribution network. Authors in [13]-[18] developed plug-in energy metering devices that help save energy, but do not have the structure to be monitored and controlled from the same platform with a smart meter. Studies in the literature have focused on the interaction of Wi-Fi technology between customers and home automation applications. This study shows a secure two-way communication architecture with MDMS for smart meters with Wi-Fi technology. Moreover, the developed Wi-Fi smart meter has been successfully tested with Head-End software in a real distribution network. Also, the Wi-Fi smart meter and SEMM data can be monitored via a developed mobile application for energy saving and customer awareness.

In this study, a single-phase active reactive meter is developed with Wi-Fi technology, and a SEMM with Wi-Fi technology is designed, fabricated, and tested. The experimental results of the study are verified over a distribution network Head-End software in real-time. The main contributions of this paper are listed below:

i. The integration of a single phase active-reactive meter with Wi-Fi module to enable it to communicate through the network,

ii. The application, configuration, security measures, remote reading, and controlling methodology of Wi-Fi technology in smart meters are presented and validated,

iii. AES-128 encryption and Cyclic Redundancy Check (CRC) method are performed to ensure secure communication between the developed Wi-Fi smart meter and MDMS,

iv. The design and fabrication of SEMM for remote controlling and management of some electrical appliances to support customer-side energy management.

The rest of the paper is organized as follows. Section 2 describes the background of commonly used communication systems. The materials and methods of this study are addressed in Section 3, and Section 4 presents the experimental results. Finally, Section 5 summarizes this article.

2 Background

The smart meter systems communicate with MDMS using commonly used communication infrastructures. These communication infrastructures are generally classified as Local Area Network (LAN), Neighborhood Area Network (NAN), and Wide Area Network (WAN) [26]. In the LAN layer, some technologies allow the demand-side to monitor their consumption data and communicate with the smart meter. In particular, smart home and building automation projects are included in this layer. In the NAN layer, there are technologies enabling communication between meters and data concentrators. Communication with all meters in this layer is provided through modems installed in the meter boards in the buildings or data concentrators placed in the transformers. In the WAN layer, some technologies enable communication between modems or data concentrators and MDMS. The data from meters in such areas is transferred to the MDMS through a modem or data concentrator. In the WAN layer, communication with the MDMS is performed in an encrypted way using communication protocols such as GSM/GPRS, TCP/IP, and Public Switched Telephone Network (PSTN) [27].

Smart meter utilizes wired or wireless communication technologies such as Power Line Communication (PLC), PSTN, GSM/GPRS, and Radio Frequency (RF). The technique where a carrier signal with a frequency in a defined range modulated with meter data is transmitted using power lines is called PLC. In the PSTN method, it is possible to communicate with smart meters over the existing telephone lines. Likewise, in the Digital Subscriber Line (DSL) technology, the existing telephone lines are used and the data transmission rate can be up to several Mbps [28]. GSM is the most popular cellular network used all around the world and is utilized in the 900 MHz and 1800 MHz frequency bands. The GPRS method is one of the most widely used communication technologies in smart grids. It is a packet-based data transmission technique using the same frequency bands as GSM. The GPRS method makes IP-based network applications possible over GSM, and higher data rates are obtained compared to GSM.

In the RF method, communication can be carried out without any physical connection between transmitting devices and receiving devices. Zigbee is a wireless, low-power communication technology defined by the IEEE 802.15.4 standard [29]. Wi-Fi technology, which is defined by the IEEE 802.11 standard, is one of the most commonly used wireless communication technologies. It is a convenient method for LAN applications thanks to its coverage area of 30-40 meters indoors and approximately 100 meters outdoors, and its ability to reach data transmission rates up to 54 Mbps [30]. Long Range (LoRa) is a low-power wide-area network (LPWAN) protocol and supports IoT infrastructures [31]. The WiMAX technology in the IEEE 802.16 standard can generally transmit broadband data using 2.5 GHz, 3.5 GHz, and 5.5 GHz spectra [32]. It can be effectively used in wide areas with its coverage area of up to 50 km and data transmission rate of 70 Mbps [33]. It can be preferred, especially for rural areas where there is no Internet access.

Each communication technology used in the smart meter systems has various advantages and disadvantages within their scope. The electricity distribution companies conduct their installations, preferring the most suitable communication technologies by taking into account the structure and physical conditions of the area where the smart meter will be installed. Compared to other methods, Wi-Fi technology has some advantages such as not requiring additional modems or data concentrators for communication, low investment and operation costs, and easy integration into IoT applications. Table 1 shows the pros and cons of communication technologies used in smart meter systems.

Table 1. Comparison of communication technologies.

Technology	Spectrum	Data rate	Coverage range	Investment cost	Operation cost
PLC	3-95 kHz	2-3 Mbps	1-3 km	high	low
GSM	900-1800 MHz	270 Kbps	1-10 km	low	high
RF	433-868-915 MHz	250 Kbps	100-1600 m	high	low
PSTN/DSL	< 1 MHz	1.3 Mbps	1-5 km	low	high
Wi-Fi	2.4-5 GHz	54 Mbps	20-100 m	low	low

The MDMS enables the collection and processing of all meter data, detailed monitoring of the status of data concentrators and modems in the field, and remote management of the meters, thanks to communication software, which is commonly called Head-End [34]. Thus, the needs for processing the collected data, their reportability, billing services, and meter automation are fulfilled.

3 Materials and methods

In this study, the Luna Smart Meter (LSM)-10 single phase active reactive meter, which is produced by Luna Electric Electronic Industry and Trade Inc., is equipped with a Wi-Fi module. The meter has some features, including mechanical and magnetic intervention detection and recording. It sends a notification to MDMS when an illegal intervention is made on the meter. A two-way communication methodology is created with MDMS by developing Web interfaces for Wi-Fi configuration operations. Also, SEMM with Wi-Fi communication is designed and tested for customer-side energy management.

The smart meter, LSM10, with an RS-485 communication port is used as an application material. Current and voltage signals are measured by sampling at 4096 S/s. Equation (1) and (2) are used to calculate the current and voltage Root Mean Square(RMS) values, respectively [35].

$$I_{RMS} = K_i \sqrt{\frac{\sum_{n=1}^{N} i^2(n)}{N}} \tag{1}$$

$$V_{RMS} = K_v \sqrt{\frac{\sum_{n=1}^{N} v^2(n)}{N}} \tag{2}$$

where

I_{RMS} and V_{RMS} signifies the RMS values of load current and voltage, respectively. $v(n)$ represent the voltage sample at a sample instant '*n*', while $i(n)$ represent the current sample at a sample instant '*n*'. N is the number of samples in 1 second. K_v and K_i are scaling factors for the voltage and current, respectively.

The active and reactive power are calculated by Equations (3) and (4) [35].

$$P_{ACT} = K_p \sqrt{\frac{\sum_{n=1}^{N} v(n)\ .\ i(n)}{N}} \tag{3}$$

$$P_{REACT} = K_p \sqrt{\frac{\sum_{n=1}^{N} v_{90}(n)\ .\ i(n)}{N}} \tag{4}$$

where

P_{ACT} and P_{REACT} are active and reactive power values, respectively. $v_{90}(n)$ is the voltage sample at a sample instant '*n*' shifted by 90° and K_P is the scaling factor for power. N is the number of samples in 1 second.

3.1 Wi-Fi smart meter

To ensure two-way communication between the smart meter and MDMS, the SimpleLink™ Wi-Fi® CC3220SF wireless microcontroller LaunchPad™ is used. The CC3220SF long range ultra-low power consumption 2.4GHz Wi-Fi Module provides an access distance of 20 meters indoors and 100 meters outdoors. All data can be read by the CC3220SF Wi-Fi module through the RS-485 port of the smart meter. Moreover, it allows GSM and PLC communications over the RS-485 port in areas where there is no Wi-Fi access. The architecture of the developed system is shown in Figure 1.

Since each device cannot access the Internet with its own IP address in the IPv4 addressing method, the Network Address Translation (NAT) method is employed as an alternative solution. In the NAT method, the devices in the LAN layer access the Internet via a Wi-Fi router. The IP address that enables Internet access to the devices is the WAN IP address of the Wi-Fi router.

Manual port forwarding should be enabled on the Wi-Fi router to remotely read and manage the developed Wi-Fi smart meter through the TCP/IP protocol. Thus, it is possible to direct the data coming from the forwarded port of the Wi-Fi modem to the smart meter. The remote reading methodology of the Wi-Fi smart meter is shown in Figure 2.

The Access Point (AP) mode configuration method is used to realize the Wi-Fi configuration of the smart meter. In this method, the smart meter starts its operation as a Wi-Fi modem. The configuration pages can be accessed by connecting to the Wi-Fi network, which is formed by the Wi-Fi-based smart meter and any mobile device. By this means, the configuration process can be performed using an easy, interactive, and secure method. The flow chart of the smart meter Wi-Fi configuration is shown in Figure 3.

3.2 Wi-Fi-based plug & play smart energy metering module

The meters allow monitoring of the total consumption of loads in the system. The Wi-Fi-based plug-in SEMM is designed and fabricated to measure and monitor the energy consumption of each device in the power system to which the meter is connected. The smart meter allows the monitoring of power parameters of connected loads. Similarly, the SEMM sends consumption data of each electrical device. The SEMM is a plug and play device that has some features such as measuring the electrical parameters of electrical appliances, extracting the consumption profile of the loads, and being remotely managed. Moreover, when the supply voltage of the device and the current drawn from the grid diverge from the defined limit values, SEMM can switch to protect mode and de-energize the device.

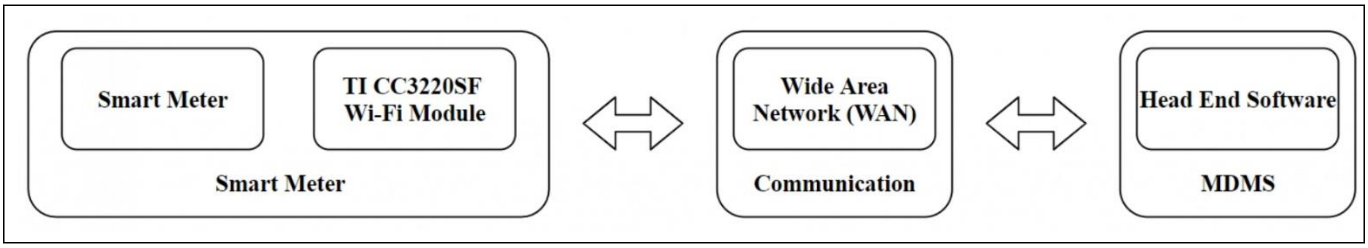


Figure 1. Block diagram of the communication architecture for the developed method.

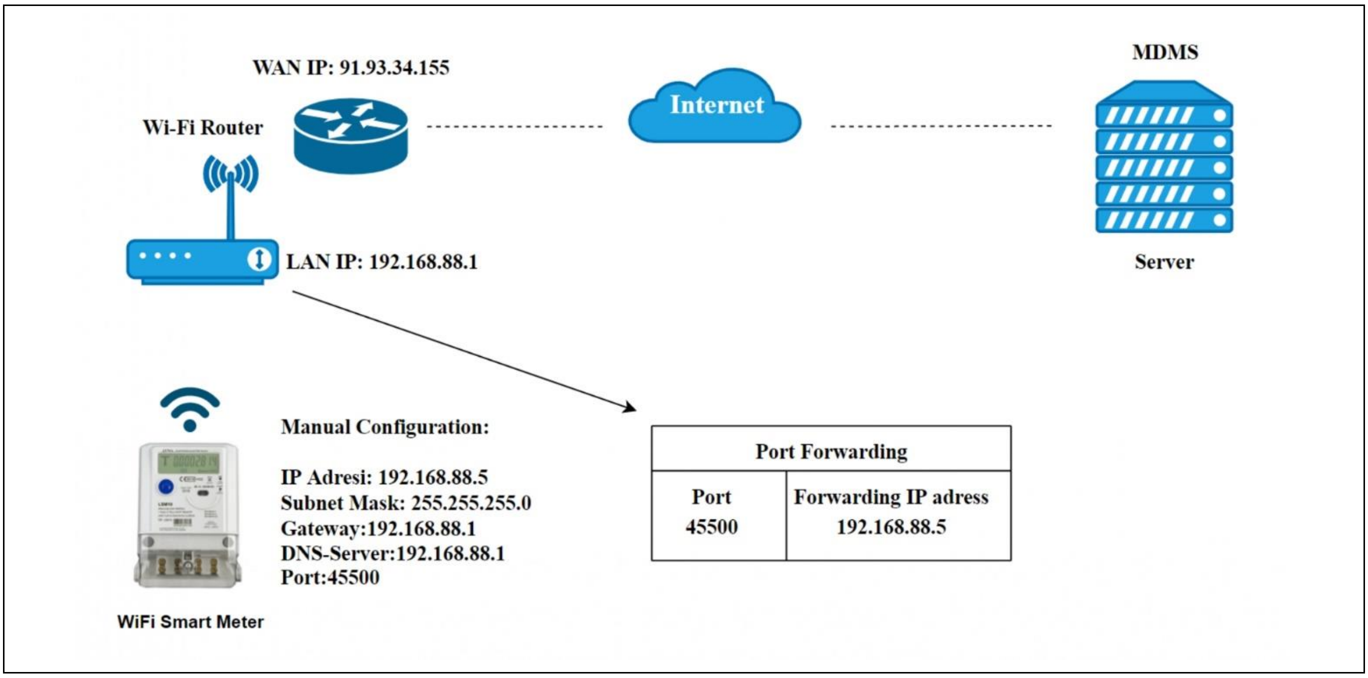


Figure 2. The Wi-Fi smart meter remote reading methodology.

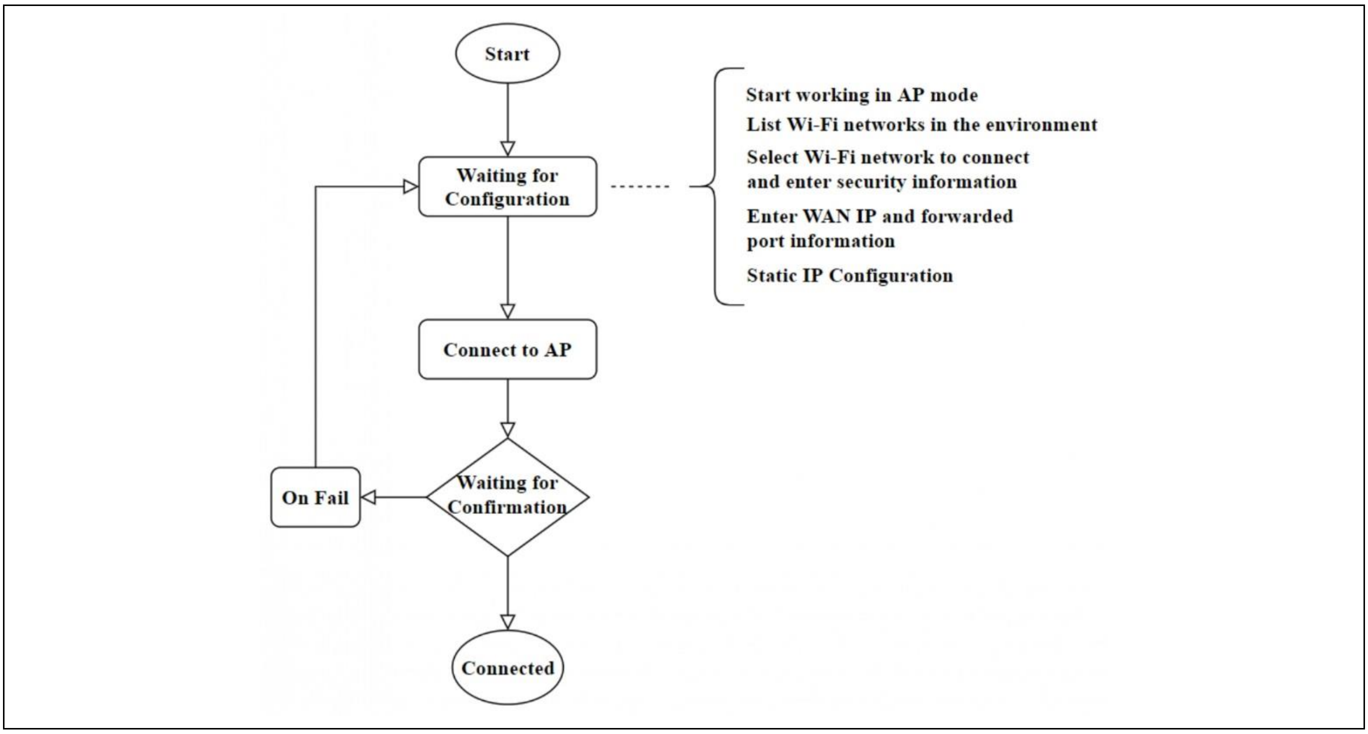
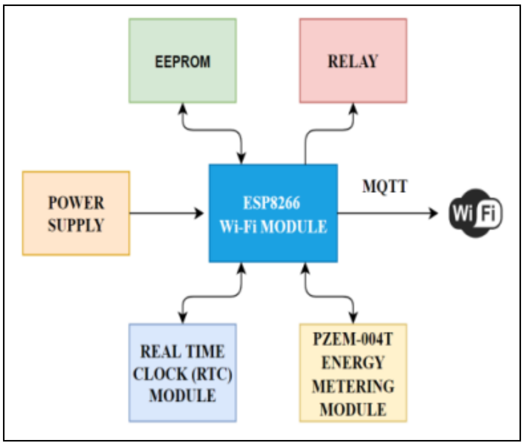


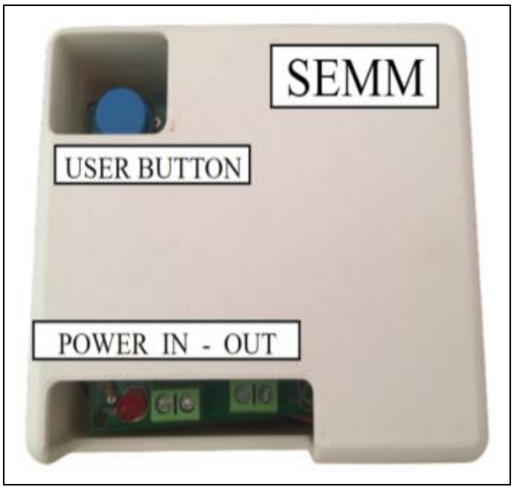
Figure 3. The flow chart of smart meter Wi-Fi configuration.

The fabricated SEMM is shown in Figure 4. The device uses NodeMCU ESP8266, which is a low-cost Wi-Fi module that is frequently used in IoT applications. Measurement of electrical parameters is realized by the PZEM-004T energy metering module.



(i)

(ii)



(iii)

Figure 4. The SEMM. (i): Block diagram of the device. (ii): Fabricated device. (iii): Front view of the device.

As with the smart meter, the AP mode configuration method is used to carry out the Wi-Fi configuration process of the SEMM. The SEMM starts its operation as a Wi-Fi modem. Upon connecting to the Wi-Fi network of the SEMM with any mobile device, the configuration process is performed automatically by enabling access to the configuration pages.

4 Results and discussion

4.1 Wi-Fi smart meter configuration

To conduct the Wi-Fi configuration of the smart meter, the meter commences its operation as a Wi-Fi modem and sets up its Wi-Fi network. It is possible to access the configuration pages presented by the module by connecting to the Wi-Fi network, which is displayed under the name LSM Wi-Fi (see Figure 5), with any mobile device. Configuration pages are designed using HTML, CSS, and JavaScript languages and it is ensured that pages work in a dynamic structure. The password information is entered to be connected to the smart meter's Wi-Fi network. The smart meter supports the configuration of WPA/WPA2 (Wi-Fi Protected Access) secure wireless network encryption developed by the Wi-Fi Alliance. In the first step, it accesses the configuration pages presented by the module with the "mysmartmeter" domain name (see labeled 1 in Figure 5). In the next step, the Wi-Fi networks in the environment under the profile tab can be searched and listed. The password information is entered by selecting any of these Wi-Fi networks (see labeled 2 in Figure 5). In the third step, following the recording of the network profile of the smart meter, the static IP configuration needs to be structured. The IP address for which the port forwarding is conducted in the Wi-Fi router to which the module will be connected is required to be assigned for the smart meter. The Static IP configuration is performed under the network tab of the developed system (see labeled 3 in Figure 5).

After the above-mentioned process steps, the smart meter is connected automatically to the Wi-Fi network in the environment. Provided that it is on the same network as the Wi-Fi module that is connected to the smart meter, the consumption data and credentials of the smart meter can be displayed instantly when the 192.168.88.5 IP address statically allocated to the Wi-Fi module is entered into the browser. Provided that it is connected to the same network as the smart meter, power parameters can be displayed instantly with the IP address of the smart meter in the browser (see labeled 4 in Figure 5). The steps of the process are given in Figure 5.

The smart meter supports various security precautions such as a secure file system, hardware crypto engine, WPA2 personal and enterprise security structure, and software IP protection. Also, it does not permit any other connections, excluding the defined IP address of the MDMS. Data transmission to MDMS is realized using the Cyclic Redundancy Check (CRC) method. In the CRC method, it is ensured that transmitted and received data are the same. If any deficiency or error occurs in data transmission, the data is re-transmitted. Thus, secure communication is provided between the smart meter and the MDMS.

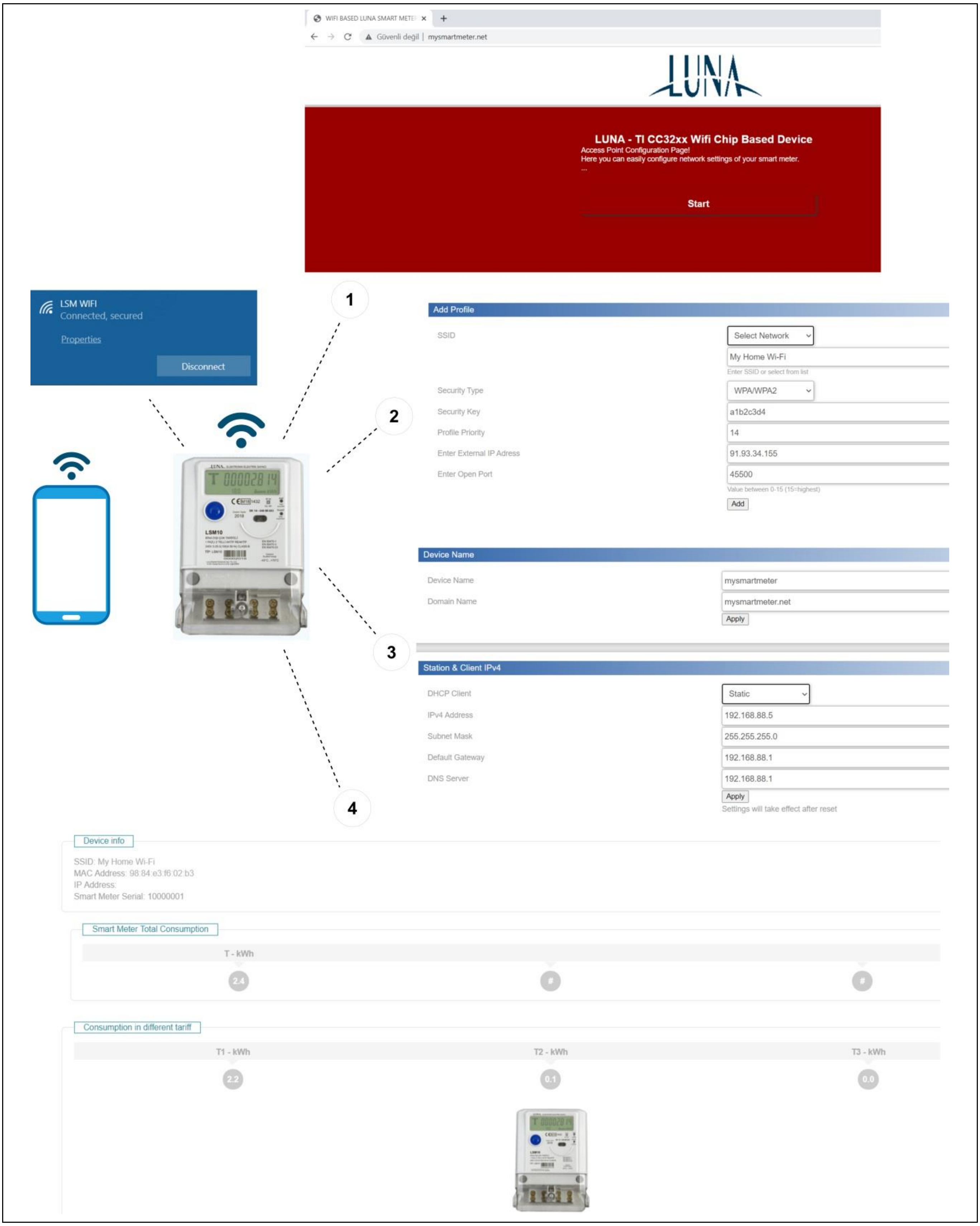


Figure 5. Wi-Fi configuration steps of the smart meter (1) Login page (2) Wi-Fi network configuration (3) The Static IP configuration (4) The smart meter consumption data.

4.2 Head-end software

The smart meter has successfully provided two-way communication with Luna Metrum®, which is currently used as Head-End software in a distribution network [36]. In order to reveal the communication structure of the smart meter with MDMS, the Head-End software has been developed using the C# programming language in the Microsoft Visual Studio environment.

This software allows users to read the smart meter data and manages it with features including On-Off control over the TCP/IP protocol. The connection can be ensured with WAN IP and port information from a remote server to the meter. Moreover, the smart meter sends its data to the Head-End software over port number 6000. In this way, all parameters of the meter data can be monitored both graphically and numerically. In Figure 6, the visual with regards to the reading of smart meter data via TCP server application prepared in the Microsoft Visual Studio environment is presented.

4.3 Wi-Fi configuration of Wi-Fi-based smart energy metering module

As in the smart meter Wi-Fi configuration, the AP mode configuration method is used for the SEMM. In this method, the module starts its operation as a Wi-Fi modem and creates its own Wi-Fi network. It is possible to access the configuration pages presented by the module by connecting to the Wi-Fi network, which is displayed under the name "My Smart Device" on any mobile device. The steps of Wi-Fi configuration of the SEMM are shown in Figure 7.

After it is connected to the Wi-Fi network provided by the SEMM, the user is automatically directed to the configuration interface. The Wi-Fi networks in the environment are listed in the configuration interface. The Wi-Fi network to be connected to is selected and the password information is entered (see labeled 2 in Figure 7). Moreover, the credentials of the MQTT broker service that the module will use must be entered (see labeled 2 in Figure 7). The CloudMQTT service is used for the modules and a user mobile application that have been developed within the scope of this study.

4.4 Measurement accuracy test of the SEMM

An experimental set-up is conducted to compare the SEMM measurement results with the smart meter validated by the 2014/32/EU Measuring Instruments Directive. Tests are carried out with selectable R and L loads. In every test, voltage, current, and active power data are collected from both the smart meter and the SEMM at 1 S/s. The Mean Absolute Errors of the results are calculated with the following equation:

$$MAE = \frac{\sum_{i=1}^{n} |y_i - x_i|}{n} \quad (5)$$

where

MAE=Mean Absolute Error, y_i=SEMM measurement value, x_i=Smart meter measurement value and n=total number of measurement sample. The experimental setup is shown in Figure 8.

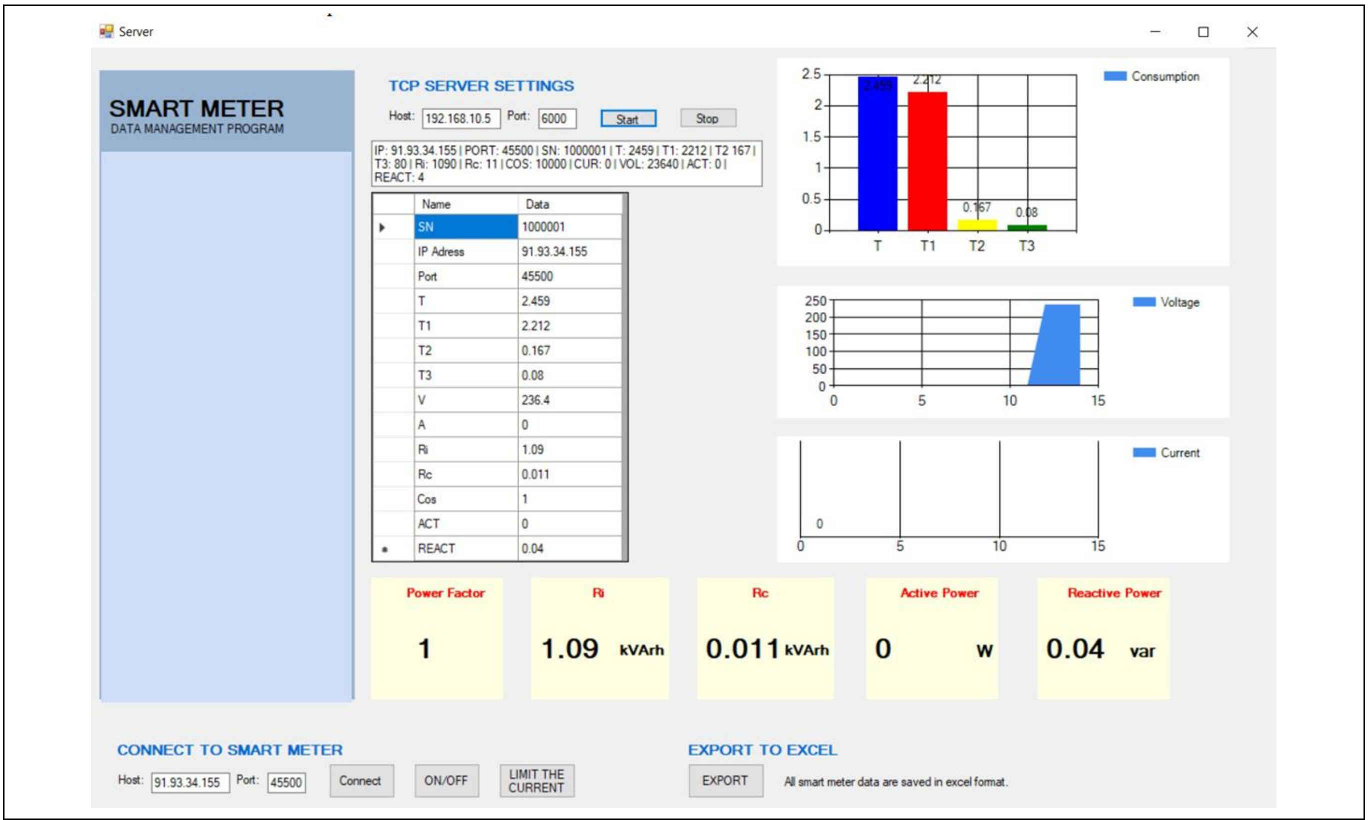


Figure 6. User-interface of online monitoring.

Figure 7. Wi-Fi configuration steps of the SEMM (1) Login page (2) Wi-Fi network configuration.

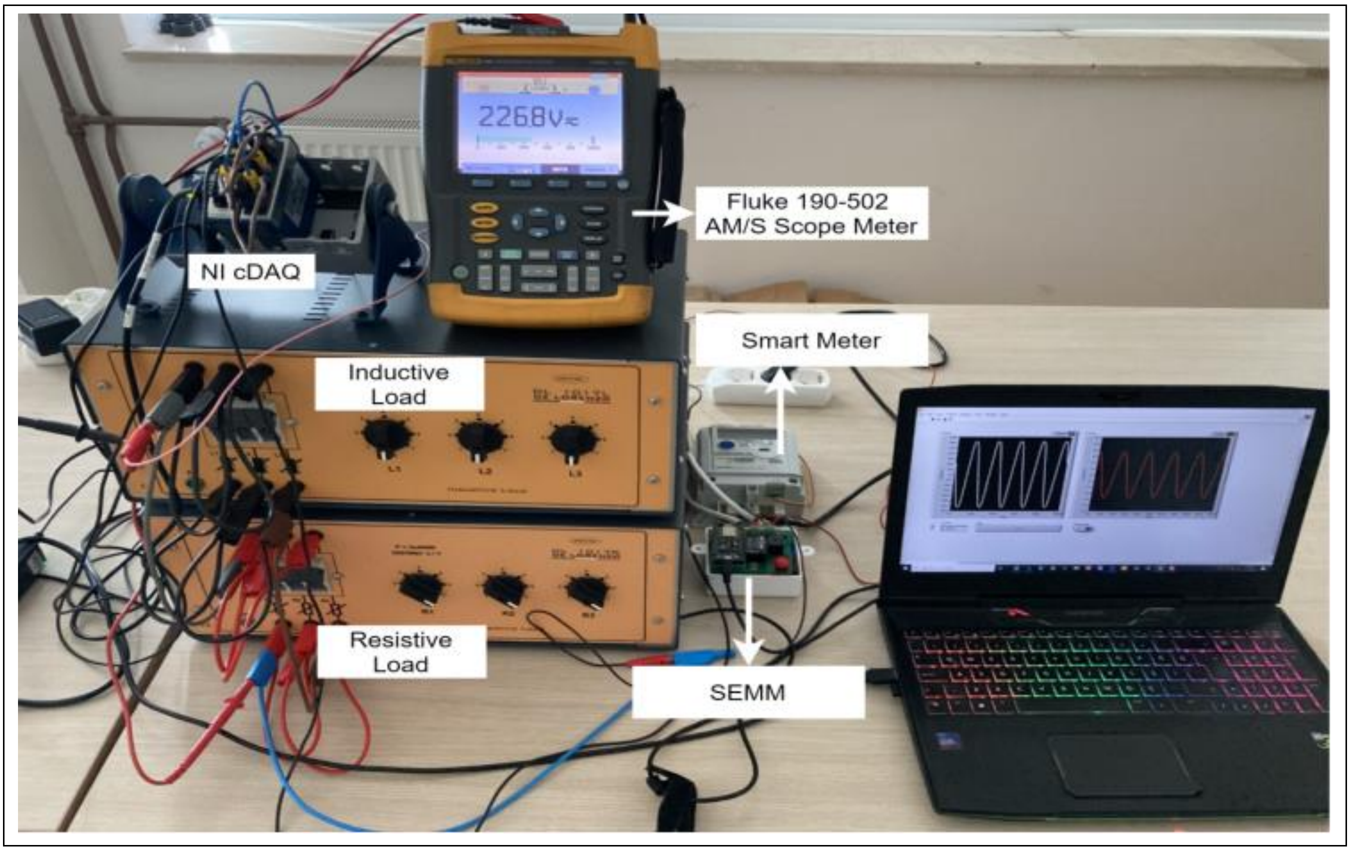


Figure 8. The experimental set-up.

The results of the tests performed with R and L loads at different levels are given in Table 2. In addition, the data obtained from the smart meter and SEMM regarding the operation of the load in Table 2 for 60 seconds are compared in Figure 9.

According to the test results, the measuring data of the SEMM is highly consistent with that of the smart meter. However, MAE results are shown in Table 2. In the SEMM module, to increase the accuracy of measurement results the energy metering module, which has a higher resolution than the PZEM-004T can be utilized.

4.5 User mobile application

A mobile application has been developed in the Android Studio environment to monitor both the smart meter and the SEMM data. Through a developed user mobile application, remote access can be provided to both the smart meter data and each of the SEMMs. The main screen and menu screens of the application are shown in Figure 10.

Table 2. Test results of electrical loads.

	$U_{average}$ (V)		$I_{average}$ (A)		$P_{average}$ (W)	
	Load1	Load2	Load1	Load2	Load1	Load2
Smart Meter	222.191	217.702	0.525	3.494	104.778	757.888
SEMM	221.825	217.595	0.52	3.50	104.211	760.205
MAE	0.448	0.301	0.006	0.01	0.575	2.342

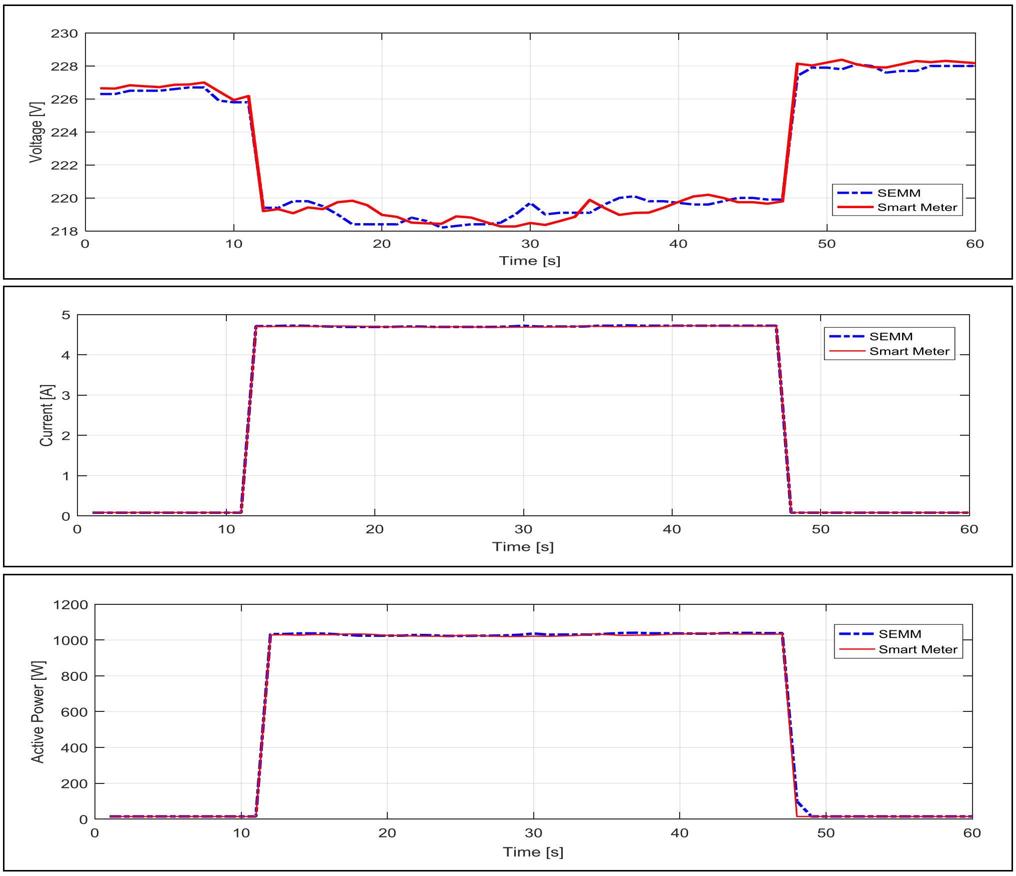


Figure 9. Measurement data comparing of the SEMM with the smart meter.

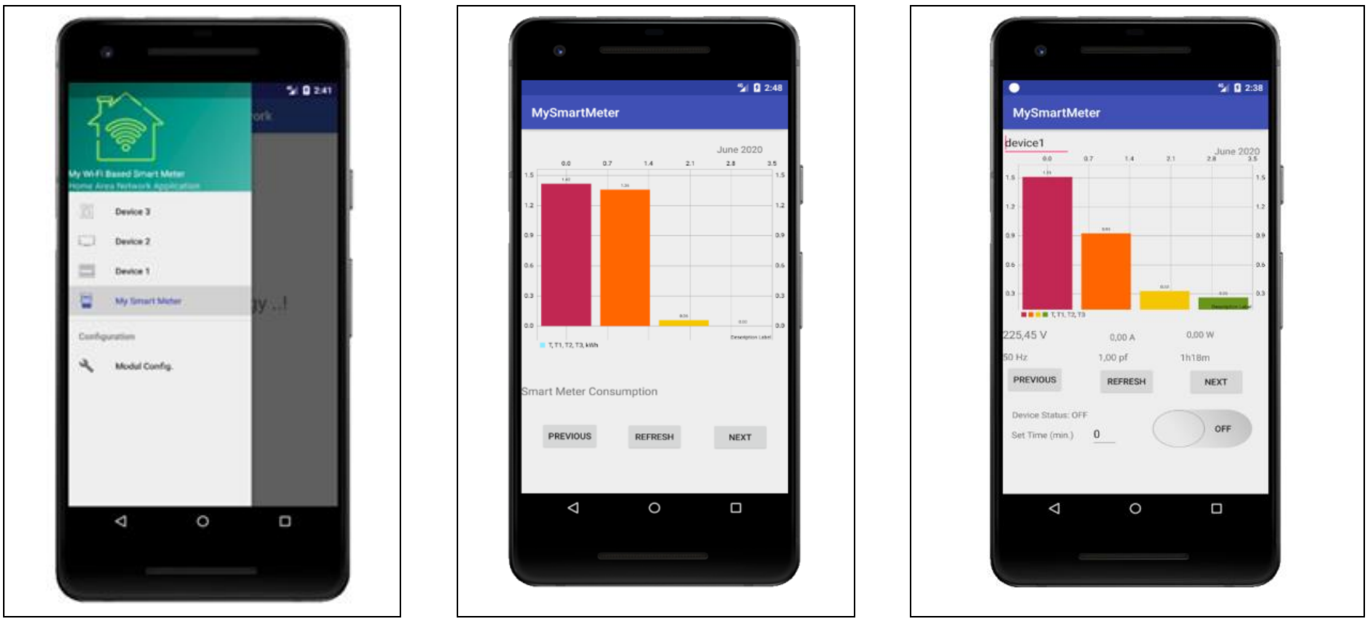


Figure 10. User mobile application of the Smart Meter.

The data of the relevant device can be accessed instantly by selecting a smart meter or any SEMM in the menu screen of the user mobile application. Since the relevant device is accessed as an MQTT client in the mobile application, the credentials of the MQTT broker service of each device are required to be saved on the configuration page of this application.

The consumption data of the electrical device to which each SEMM is connected can be displayed retrospectively. Besides, information on the current, voltage, active power, frequency, power factor, operating status, total up-time of each electrical device can be monitored. The SEMMs can be remotely managed as time adjusted or On-Off via the mobile application. To contribute to consumer awareness, information is sent to the user's mobile application and the consumption may be ensured to be directed to the low-cost energy tariff if the electrical device to which the SEMM is connected is operated outside of the low-cost energy tariff.

The block diagram of the communication protocols which enable the monitoring and managing of the smart meter and SEMMs with a mobile application is shown in Figure 11. The TCP/IP protocol is used for the smart meter to communicate with MDMS bidirectionally. Also, the smart meter sends consumption data to the mobile application using the MQTT protocol. Since the SEMMs are developed to create consumer awareness, there is no need for them to send data to MDMS. The SEMMs can send data to the mobile application with the MQTT protocol and can be managed remotely. In this configuration, many devices can be included in the system through any Wi-Fi network.

5 Conclusions

In this study, a smart meter application with Wi-Fi communication systems is developed for the smart grid and smart building applications. The developed meter is provided with two-way communication with MDMS over Wi-Fi. Furthermore, thanks to the SEMM, the electrical devices can be remotely controlled and their consumption can be monitored in real-time. The SEMM has the feature of extracting the consumption profile of the device to which it is connected and de-energizing the device when energy consumption other than the consumption profile is detected. Through the developed mobile application, a method has been presented for increasing the interaction of consumers with smart meter technologies and using energy efficiently with consumption awareness.

The presented smart meter with Wi-Fi feature will support a simple solution not requiring any extra infrastructure for remote reading, access, and control of meters of customers and stores in the environment, such as large shopping malls, mass housing sites, or villa cities where a common Wi-Fi network is available. In such environments, either each meter sends data directly to the MDMS, or all meters can transmit data to a modem over Wi-Fi and communicate with MDMS through the modem.

Further research will focus on the Wi-Fi-based WSN applications in smart meter systems. Thus, the water meters and electricity meters in the building can transmit data to a single modem over Wi-Fi, and the meter products in different services can be read from a single modem within the context of smart building applications. On the other hand, another application area can be the implementation of credit loading transactions through the Wi-Fi configuration pages offered by the smart meter interactively and securely in prepaid smart meter technology. Furthermore, it is possible to create hybrid communication systems by adding communication capabilities such as Zigbee, LoRa, PLC, and GSM to Wi-Fi smart meters. In this way, the functionality of smart meters can be increased.

6 Author contribution statement

In the present work, Bilal KARAMAN performed design, software and analyses, and literature review; Sezai TASKIN conceived the presented idea, supervised the work, and evaluated the results. Authors discussed the results and contributed to the final manuscript.

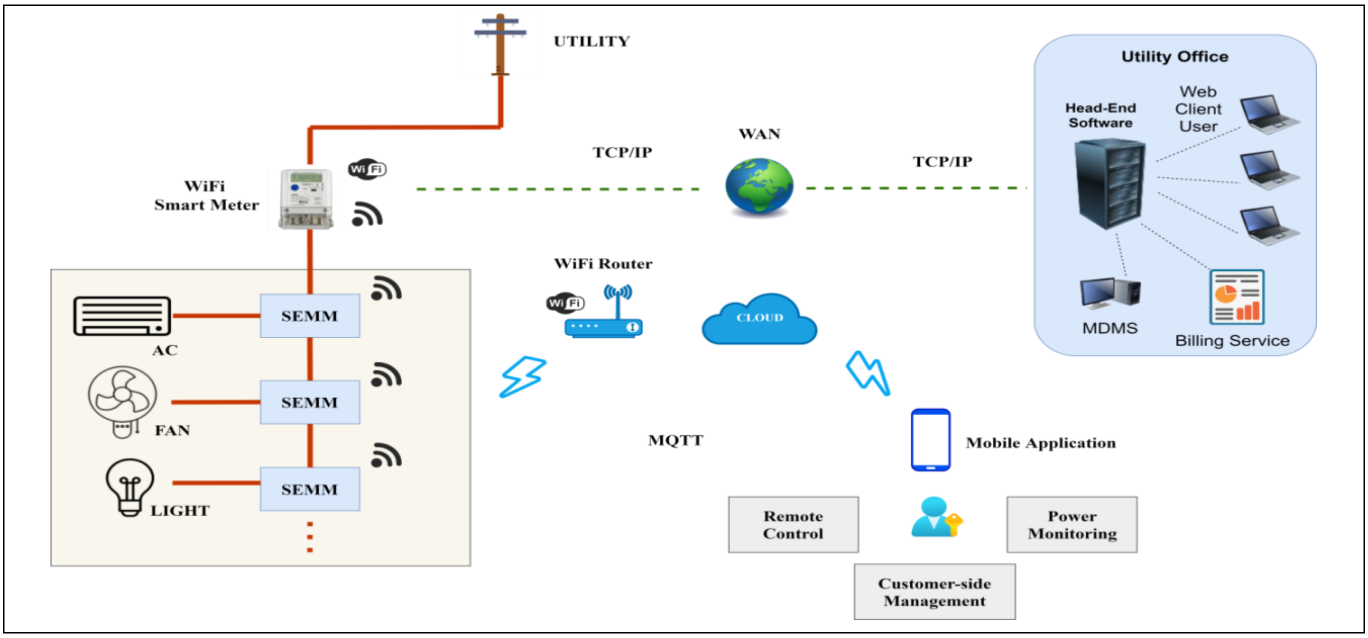


Figure 11. The block diagram of the communication protocols for the developed modules.

7 Ethics committee approval and conflict of interest statement

There is no need to obtain permission from the ethics committee for the article prepared.

There is no conflict of interest with any person/institution in the article prepared.

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