Research Article

Investigation of Wireless IEC 61850 MMS using Raspberry Pi

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Abstract: IEC 61850, a smart grid standard, uses Ethernet to perform standardized information exchange. However, if wireless LAN techniques rather than Ethernet are applied, it enables lower installation cost, sufficient communication speed, and easy arrangement. In this paper, the experiment platform of substation automation based on IEC 61850 MMS is fabricated using wireless LAN. To utilize a wireless LAN, the access point is materialized using a low-cost Raspberry Pi. Libiec61850 software is used for MMS communication between substation Intelligent Electronic Devices (IEDs) at the experiment platform. IEEE 1588 was used for synchronization between Raspberry Pis, and an MMS packet is captured and analyzed through Wireshark for analyzing the results. The transfer time measurement was performed to identify whether the wireless IEC 61850 MMS traffic produced herein satisfy performance requirements depending on the IEC 61850 message type. On the basis of the results, the transfer time of IEC 61850 MMS traffic herein was confirmed to meet IEC 61850 performance requirements.

Keywords: IEC 61850, MMS, Raspberry Pi, libiec61850, Wireshark

1.Introduction

IEC 61850 is a communication protocol used for substation automation systems, and it takes charge of system installation, control, and operation. However, IEC 61850 is a complicated and expensive protocol. Establishing an experiment platform for IEC 61850 using easy-to-install and cost-effective equipment helps develop algorithms, applications, and prototypes.

The IEC 61850 communication is basically provided using Ethernet **(Kanabar & Sidhu, 2011)**. Wireless LAN is included in the smart grid roadmap of the National Institute of Standards and Technology **(Dollen, 2009)**. Studies have also demonstrated that wireless LAN technology can be applied instead of Ethernet **(Cena, Bertolotti, Valenzano & Zunino, 2007)**. Moreover, wireless LAN techniques are expected to be applicable in smart distribution substation applications attributed to more strict performance demand and limited installation investment cost **(Gungor, Bin & Hancke, 2010; Parikh, Kanabar & Sidhu, 2010)**. For substation protection, control, and monitoring related to the application, international institutes provide the potential of wireless techniques **(Kropp, 2008)**. Goods producers for electric equipment have initiated the development of robust wireless LAN substation automation equipment. A few studies utilized wireless applications for the substation **(Abdel-Latif, Eissa, Ali, Malik, & Masod, 2009; Cleveland, 2006)**. However, the performance analysis of wireless LAN for the time-delay requirement criteria specified in IEC 61850 part 5 has not yet been clearly performed. Therefore, investigating and exploring the materialization of a digital substation experiment platform that has fewer errors at a lower cost and can more effectively apply IEC 61850 technique is necessary.

In this study, a cost-effective and open platform, Raspberry Pi, is utilized and the access point using Raspberry Pi is materialized. To produce IEC 61850 traffic, an open-source, i.e., libiec61850 software, is used. To identify whether the wireless IEC 61850 traffic is accurately produced, Wireshark is used for the verification. IEEE 1588 is utilized to conduct time synchronization between Raspberry Pis. It also checks whether the transfer time of wireless IEC 61850 MMS traffics generated by the experiment platform satisfies the performance requirements of MMS according to IEC 61850 message type.

2.Related Works

The IEC 61850 standard defines performance requirements depending on the message type. Messages transmitted inside a smart substation include Manufacturing Message Specification (MMS), Sampling Value (SV), and Generic Object Oriented Substation Event (GOOSE).

Table.1. IEC 61850 Protocols and Requirements

Function Type	Message	Protocol	Maximum Transfer Time	Application
1A. Fast Messages, Trip	GOOSE	Layer-2 Multicast	<3 ms	Protection
1B. Fast Messages, Other	GOOSE	Layer-2 Multicast	<20 ms	Protection
2. Medium Speed	MMS	IP/TCP	<100 ms	Control
3. Low Speed	MMS	IP/TCP	<500 ms	Control
4. Raw Data	SV	Layer-2 Multicast	<3 ms	Process Bus
5. File Transfer	MMS	IP/TCP/FTP	<1000 ms	Management
6. Time Synchronization	Time Sync	PTP (layer 2)		General Phasors, SV
7. Command	MMS	IP		Control

MMS messages transmit status data, report data, fixed value data, documents, and control data from a long distance. SV transmits sampling data from the merging unit. GOOSE messages transmit control and status data.

In IEC 61850, messages can be classified into seven types. The transfer time for different message types is tabulated in table-1. Type-1 fast messages include commands such as “trip,” ”close,” ”start,” ”stop,” or “block” along with status data at one location. The message transmitting the “Trip” command is called Type-1A, and other fast messages are called Type-1B. Type-1A message has strict timing requirements and is more important than other fast type messages. Type-2 medium-speed messages are not critical in terms of time and include transmission of normal state information. The medium-speed message category includes the client–server type of periodic MMS messages and event-triggered MMS messages. Type-3 low-speed messages and Type-7 command message categories include messages utilized for slow auto-control functions, event record transmission, and reading/changing setpoint values. Type-4 raw data message category includes cyclic/periodic sampling messages in instrument transformers. Type-5 file transfer message category includes most data comprising recorded files, information files, and setting files. Type-6 time synchronization message category includes synchronization messages for the internal clocks of IED inside SAS.

MMS messages such as medium-speed messages, low-speed messages, and file transfer messages, are classified into Type-2, Type-3, and Type-5, respectively, depending on their function. SV messages are classified as Type 4 as original data, while GOOSE messages are classified as Type 1 as fast messages. SV and GOOSE messages are time-critical messages. SV messages have a transfer time of a maximum of less than 3 ms.

For the generation and reception of MMS, SV, and GOOSE traffic of the experiment platform, the tests were performed using Raspberry Pi 4B (1.5 GHz, ARMv8-64-bit microprocessor, 2-GB SDRAM with the embedded open-source operating system Raspbian). Raspberry Pi 4B has several communication ports (i.e., one built-in Ethernet port, four built-in USB ports). The built-in WiFi of Raspberry Pi is utilized for an access point (AP) and wireless LAN. In this study, IEEE 802.11ac of 5GHz along with IEEE 802.11n and IEEE 802.11g of 2.4GHz are used.

RaspAP can easily set up an AP for Debian-based devices including Raspberry Pi and manage WiFi. RaspAP provides network services such as DHCP setting, OpenVPN, SSL, and security audits. RaspAP also provides an IEEE 802.11 wireless mode option for the provided hardware. In this study, Raspberry Pi 4B is used; therefore, the wireless mode option was applied and IEEE 802.11ac was used at 5 GHz whereas IEEE 802.11n and IEEE 802.11g was used at 2.4 GHz. Figure 1 presents the example of a wireless mode option setup.

Libiec61850 project was prepared in C language for SV, GOOSE, and MMS communication protocols. The API of libiec61850 is composed of the client and server parts for MMS and the publisher and subscriber parts for GOOSE and SV. Libiec61850 follows the GPLv3 license policy. The objective of the libiec61850 project is to provide portable implementation between different models. If libiec61850 is utilized, the time and effort required to materialize the IEC 61850 traffic generation can be significantly reduced. Figure-2 shows the libiec61850 server architecture.

Figure.1. Example of setting up the wireless mode option

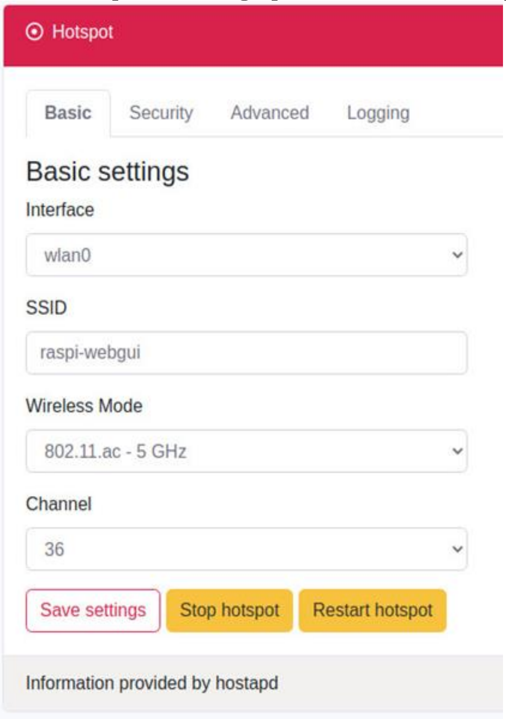
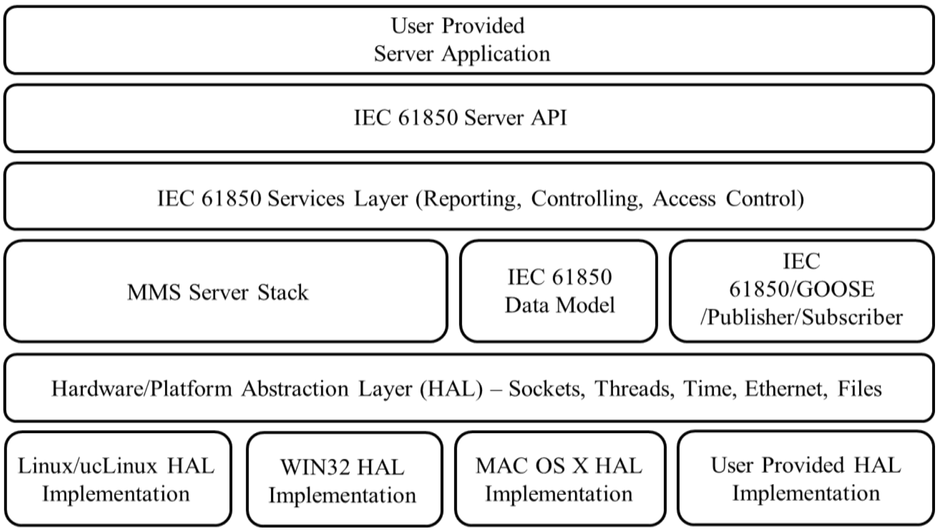


Figure.2. Libiec61850 server architecture



Using unique time references through all substation automation systems (SASs) is highly important to appropriately manage complex tasks and monitor substation behavior. In this regard, the utilization of IEEE 1588 known as precision time protocol (PTP) is important for synchronizing system components. IEEE 1588 can synchronize the IEC of all 61850 levels (Station, Bay, and Process) within the error range of less than 1 μs. This level of accuracy is suitable for synchrophasor measurement and IEC 61850-9 implementation that digitalizes current and voltage.

Wireshark is an open-source network analyzer utilized for troubleshooting analysis as well as software development and education. Wireshark is a cross-platform software available for Linux, Unix, Raspbian, and Microsoft operating systems. In this study, it is used as a third-party software to capture and analyze wireless IEC 61850 MMS traffic occurring at the experiment platform.

3.System Design And Implementation

At the station level of a smart substation, the IEC 61850 MMS protocol is selected to materialize unifying collection, storage, modeling, and configuration for mutual action of intelligent equipment. Communication between Raspberry Pis utilizes wireless LAN by installing RaspAP at Raspberry Pi and generating an AP to create an experiment platform of substation automation based on the IEC 61850 MMS using wireless LAN.

Figure.3. Typical equipment and network structure at the Station Level

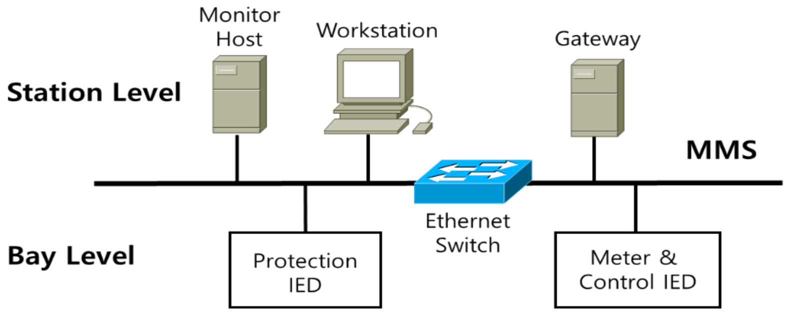


Figure-3 presents the typical station-level composition using Ethernet. There is a workstation, monitor host, and gateway at the station-level exchange MMS traffic with IED at the bay level using an Ethernet switch.

Figure.4. Wireless IEC 61850 MMS using Raspberry Pi

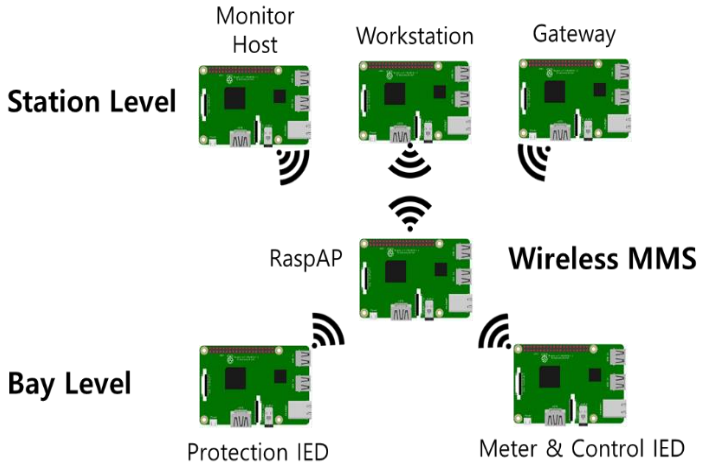
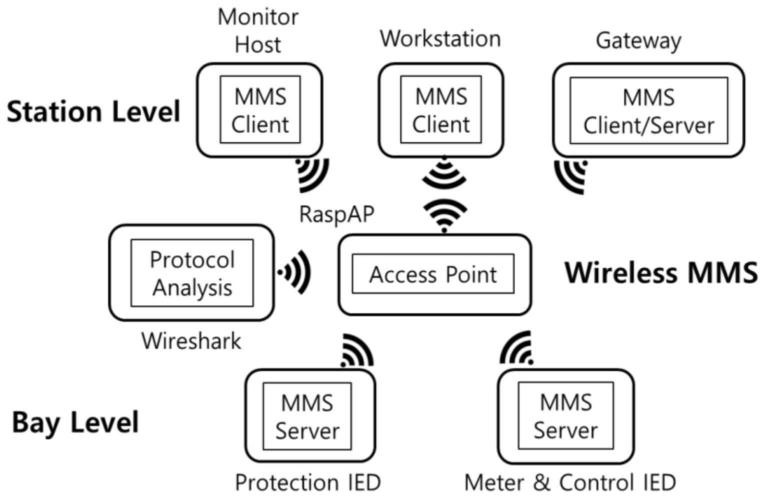


Figure-4 presents the composition of the experiment platform composed using Raspberry Pi 4B. Bay level includes a protection IED and meter & control IED, while station level comprises workstation, monitor host, and gateway. The AP is composed using RaspAP, and exchanges MMS traffics with IEDs at the bay level. Wireless IEC 61850 MMS message uses the TCP/IP protocol stack and operates under client/server environment. When an MMS client requests information, the MMS server delivers the desired information.

Figure-5 shows the design of the experiment platform of this study. MMS client–server communication mode of libiec61850 library is used between the workstation, monitor host, and gateway of the station level and IEDs of the bay level. The workstation function of the station level is materialized using the MMS client of libiec61850 and Raspberry Pi. Protection IED and meter & control IED of the bay level is materialized utilizing the MMS server of libiec61850 and Raspberry Pi. APIs of IEC 61850 include functions to provide reading and writing data objects, configuration and reception of reports, handling data sets, and sending and receiving files.

For the function providing reading and writing data objects, simple or complex data attributes and objects can be read or written using IedConnection_readObject and IedConnection_writeObject. Before using these functions, the connection should be established at the server. A first argument is a connection object of the established connection. The second argument is a pointer about the IedClientError variable. The third argument is an object reference of data attribute/object for access. The fourth argument is a functional constraint.

Figure.5. Design of the experiment platform



For the function providing configuration and reception of reports, reports are used for events based on message transmission. Reports are used to ensure that the state of variable reporting is updated without periodically sending read requests to the server. Reports can conserve network bandwidth in case of values sporadically changing. Reports are defined for data sets. The server typically includes pre-configured report control blocks (RCB). The client should reserve, configure, and activate RCB before receiving report messages from the server.

In the function providing handling data sets, data sets are groups of data attributes (DA) or functional constraint data objects (FCDO). It is used to simplify access to variables of a functionally related group when it is required to read important status values of the server but not to read it individually.

For the function providing sending and receiving files, file transfer includes recorded files, information files, and setting files transmitted whenever the receiver requests. This data can be divided into smaller blocks for other network activities. The typical file transfer protocol (FTP) message is included in the Type-5 message.

4.Performance Evaluation

The hardware system of this study is shown in figure-6. To transmit wireless MMS, one Raspberry Pi 4B is utilized for RaspAP performing the role of an access point. Three Raspberry Pi 4B are used for the monitor host, workstation, and gateway of the station level. Two Raspberry Pi 4B are used for the protection IED and meter & control IED of the bay level. For protocol analysis, one Raspberry Pi 4B is used to use Wireshark. Therefore, seven Raspberry Pi 4Bs were utilized.

Figure.6. Hardware system

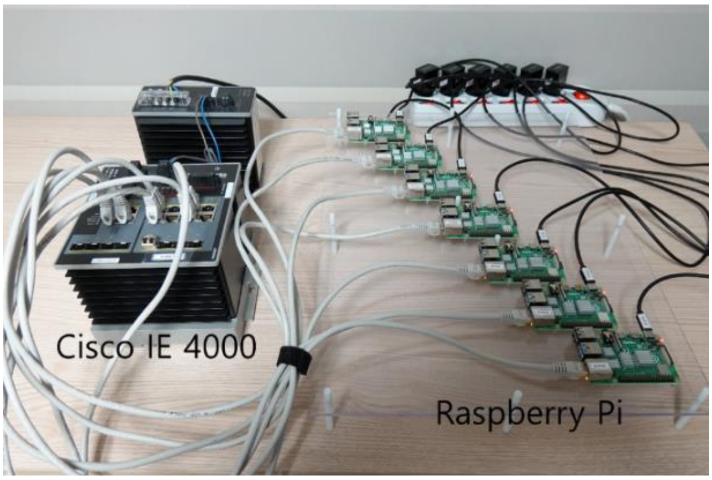
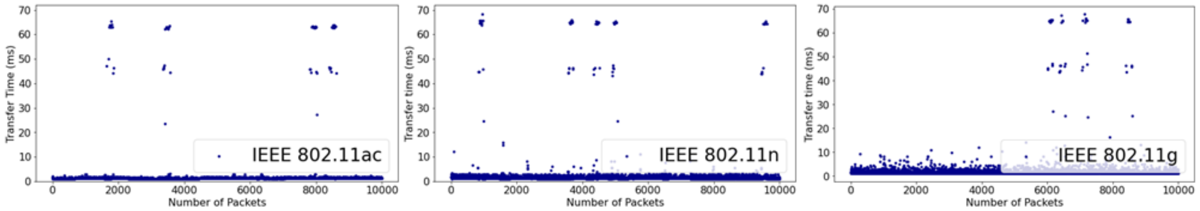


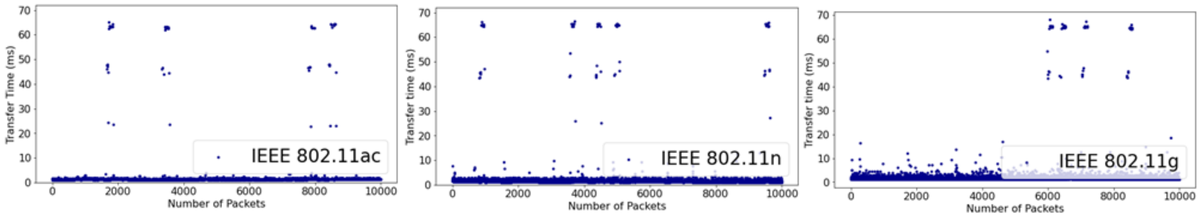
Figure.7. Successful MMS communications startup sequence

	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	10.3.141.226	10.3.141.142	TCP	74	56816 → 102 [SYN] Seq=
2	0.179601370	10.3.141.142	10.3.141.226	TCP	74	102 → 56816 [SYN, ACK]
3	0.180965926	10.3.141.226	10.3.141.142	TCP	66	56816 → 102 [ACK] Seq=
4	0.181754852	10.3.141.226	10.3.141.142	COTP	88	CR TPDU src-ref: 0x000
5	0.182967426	10.3.141.142	10.3.141.226	TCP	66	102 → 56816 [ACK] Seq=
6	0.183106092	10.3.141.142	10.3.141.226	COTP	88	CC TPDU src-ref: 0x000
7	0.184315741	10.3.141.226	10.3.141.142	TCP	66	56816 → 102 [ACK] Seq=
8	0.186368574	10.3.141.226	10.3.141.142	MMS	253	initiate-RequestPDU
9	0.187577963	10.3.141.142	10.3.141.226	TCP	66	102 → 56816 [ACK] Seq=
10	0.187917815	10.3.141.142	10.3.141.226	MMS	209	initiate-ResponsePDU

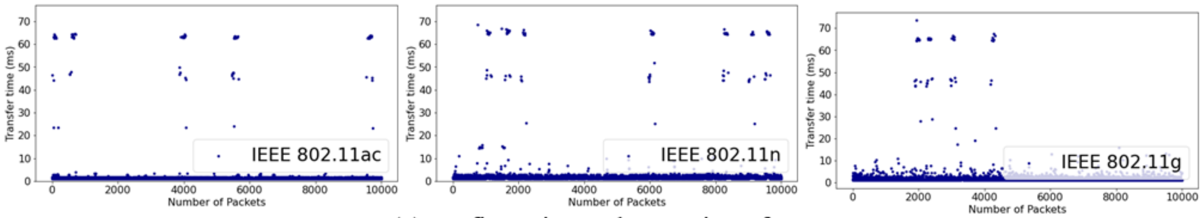
Figure.8. Spread of transfer time



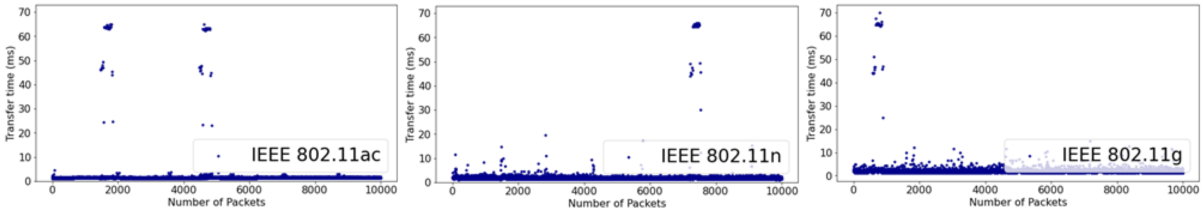
(a) reading data objects



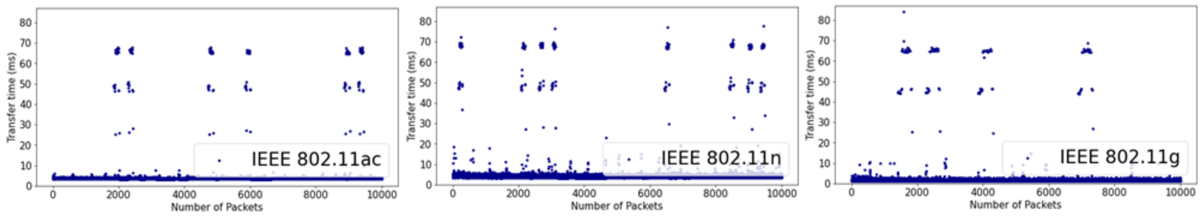
(b) writing data objects



(c) configuration and reception of reports



(d) handling data sets



(e) sending and receiving files

An MMS connection comprises three steps. The first step is where a TCP socket connection is achieved, the second step is where a COTP connection is achieved, and the third step is where MMS initiates data is exchanged. The results of this procedure captured with Wireshark is presented in figure-7.

In this study, the round-trip time is used to calculate transfer time. The round-trip time is the time from the time point when a client sends the MMS packet to the server to the time point when the client receives a response from the server. Transfer time is calculated by dividing the round-trip time into two. In this study, the transfer time was measured by transmitting 10,000 wireless MMS packets according to the libiec61850 API function. On the basis of the experimental results, 10,000 wireless MMS packets were completely received.

The scatter diagram of transfer time of wireless MMS packets according to the libiec61850 API function is shown in figure-8.

Table.2. Mean transfer time

Function	**Protocol**

	IEEE 802.11ac	IEEE 802.11n	IEEE 802.11g
Reading data objects	1.477 ms	1.764 ms	1.651 ms
Writing data objects	1.445 ms	1.755 ms	1.706 ms
Configuration and reception of reports	1.646 ms	2.101 ms	1.691 ms
Handling data sets	1.564 ms	1.549 ms	1.674 ms
Sending and receiving files	4.330 ms	5.044 ms	5.866 ms

Table.3. Maximum transfer time

Function	Protocol		
	IEEE 802.11ac	IEEE 802.11n	IEEE 802.11g
Reading data objects	65.405 ms	68.272 ms	67.644 ms
Writing data objects	65.113 ms	66.417 ms	68.035 ms
Configuration and reception of reports	64.411 ms	68.516 ms	73.490 ms
Handling data sets	64.911 ms	65.994 ms	69.790 ms
Sending and receiving files	67.792 ms	77.790 ms	83.983 ms

Table.4. Standard deviation of transfer time

Function	Protocol		
	IEEE 802.11ac	IEEE 802.11n	IEEE 802.11g
Reading data objects	4.109	4.672	3.875
Writing data objects	3.913	4.451	4.390
Configuration and reception of reports	4.719	5.420	4.050
Handling data sets	4.026	2.957	2.974
Sending and receiving files	6.947	8.216	5.794

The mean value of the transfer time of wireless MMS packets according to the libiec61850 API function is presented in table-2. All mean transfer times are appeared to be below 6 ms. Table-3 presents the maximum value of transfer time of wireless MMS packets according to the libiec61850 API function. All maximum transfer times are observed to be below 84 ms. The standard deviation of MMS packets according to the libiec61850 API function is tabulated in table-4.

Both the mean transfer time and maximum transfer time of MMS packets are below 100 ms. Therefore, it satisfies the maximum transfer time of MMS packets shown in table-1.

5.Conclusion

In this study, the experiment platform of a digital substation based on the IEC 61850 MMS using the wireless LAN technique was manufactured utilizing Raspberry Pi, RaspAP, libiec61850, and Wireshark. On the basis of the results, the transfer time of wireless IEC 61850 MMS traffic satisfied the MMS performance requirements depending on the IEC 61850 message type. Therefore, the experiment platform proposed herein is proven to be materialized by utilizing the IEC 61850 technique at a low cost. Furthermore, the experiment platform has a simple structure, is intuitive, can be materialized without complex development procedures, and can allow people who are new to IEC 61850 substation automation to easily learn techniques.

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