Journal of Engineering and Applied Sciences 13 (3): 634-638, 2018
ISSN: 1816-949X

Real Time Emulation of IEC 61850 SV, GOOSE and MMS using NS-3

[1]Sung-Ho Hwang, [2]Yong-Soon Im, [3]Han-Chun Song and [4]Jae-Do Park
[1]Division of Electronics, Information and Communication Engineering,
Kangwon National University, 25913 Samcheok, Korea
[2]Department of Computer Information and Communication,
Kookje University, 17731 Pyeongtaek, Korea
[3]Department of Information and Communication Engineering,
Seoil University, 02192 Seoul, Korea
[4]Department of Electrical Engineering, University of Colorado, 80203 Denver, USA

Abstract: This study provides a method for generating real-time IEC 61850 traffic by combining the emulation function of Network Simulator-3 (NS-3) and real communication equipment. NS-3 emulation is used for International Electrotechnical Commission (IEC) 61850 traffic generation and Cisco network switches are used for network configuration. Generated IEC 61850 traffic is verified using wireshark. Performance analysis results show that NS-3 emulation satisfies performance requirements for IEC 61850 message types.

Key words: IEC 61850, NS-3, emulation, SV, GOOSE, MMS, wireshark

INTRODUCTION

International Electrotechnical Commission (IEC) 61850 is a communication protocol for power utility automation systems which are used for system installation, control and operation. However, IEC 61850 is an intricate and expensive protocol. If an easy-to-install and inexpensive test bed is constructed for IEC 61850, it will benefit algorithm development, application performance and prototyping.

Experiments conducted using computer simulation generally do not adequately represent actual network device performance. However, enormous resources are required to conduct experiments using actual networks and network devices. Therefore, we construct an IEC 61850 test bed combining real communication equipment and the emulation functions of Network Simulator-3 (NS-3) (Anonymous, 2017). We reduce resource requirements by leveraging a combination of real equipment and the NS-3. Our study confirms, via. Wireshark, that the IEC 61850 message traffic exchanged between real communication equipment and NS-3 is correctly generated. Performance analysis also confirms that the generated traffic meets IEC 61850 message requirements.

Literature review: IEC 61850 messages are classified into six different communication protocol stacks as shown in

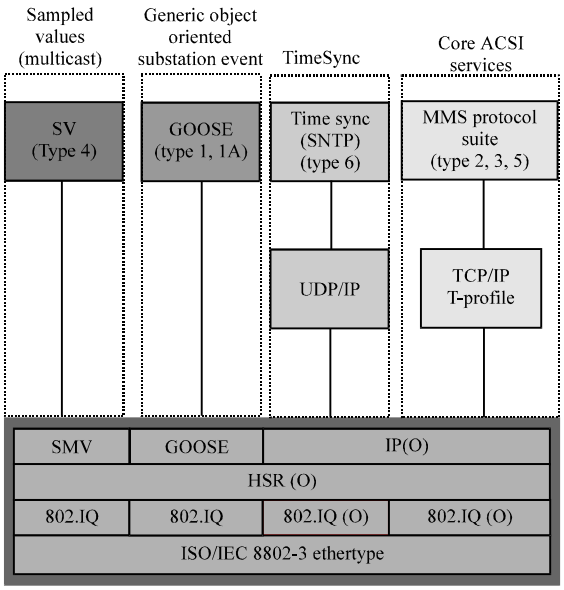

Fig. 1: Overview of functionality and profiles

Fig. 1. Sampled Values (SV) (i.e., type 4) and Generic Object-Oriented Substation Event (GOOSE) (i.e., Types 1 and 1A) require strict delay times (Anonymous, 2011a, b). Therefore, SV and GOOSE messages are transferred directly from the Media Access Control (MAC) layer to the application layer. Manufacturing Message Specification (MMS) transfersthe medium speed

Corresponding Author: Yong-Soon Im, Department of Computer Information and Communication,
Kookje University, 56 Janganut-gil, Pyeongtaek-si, 17731 Gyeonggi-do, Korea

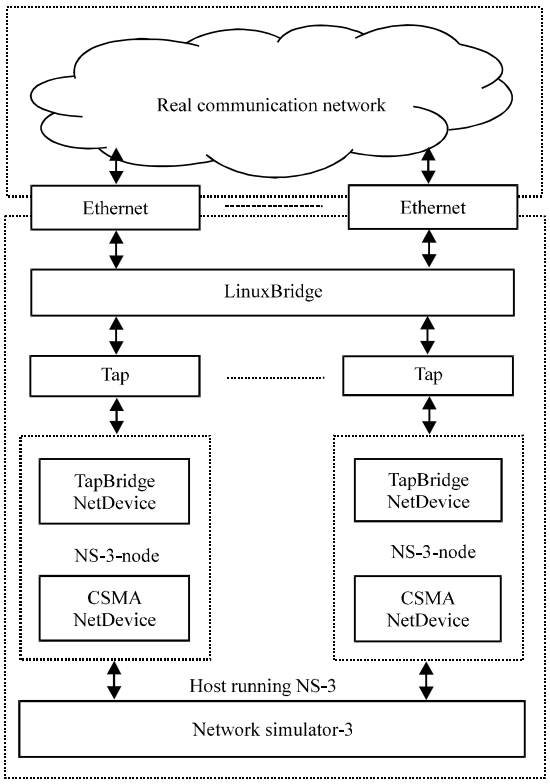

Fig. 2: NS-3 emulation for IEC 61850 communication

messages (i.e., Type 2), the low speed messages (i.e., Type 3) and the file transfer functions (i.e., Type 5) using the Transfer Control Protocol/Internet Protocol (TCP/IP) protocol stack. "Type 6" is used for command messages and file transfers via. access control (Anonymous, 2003a, b).

As shown in Fig. 2, the real communication network and the NS-3 communicate via. the NS-3's emulation function. The NS-3 connects to the real network, via. Ethernet, by connecting to the Linux Bridge through a Tap interface. The Tap interface connects to the Linux bridge like other computer network devices. The Linux bridge then connects Tap interfaces to other Ethernet devices. Traffic is exchanged between NS-3 emulation and the real communication network through these bridges and Tap interfaces.

Various protocols are required for IEC 61850 experiments. Table 1 summarizes the protocols available in the NS-3, the general L2 Switch and the Industrial L3 switch for IEC 61850 network experiments. The independent use of the devices shown in Table 1 can limit the range of available protocols. Therefore, if the NS-3, the general L2 switch and the Industrial L3 switch are connected, maximum-protocol experiments can be carried

Table 1: Comparison of network experimental tools for IEC 61850

Tool protocol	Network simulator-3	General L2 switch	Industrial L3 switch
Ethernet (IEEE 802.3)	O	O	O
IP routing	O	X	O
VLAN	X	O	O
STP	X	O	O
RSTP	X	X	O
PRP	X	X	O
HSR	X	X	O
IEEE 1588	X	X	O
Emulation	O	X	X

Table 2: Performance requirements of IEC 61850 message types

Message types	Performance class	Transfer time (msec)
Type 1-fast messages		
A "Trip"	P1, P2	≤3,≤10
B "Others"	P3	≤20
Type 2-medium speed messages (automatics)	P4	≤100
Type 3-low speed messages (operator)	P5, P6	≤500, ≤1000
Type 4-raw data messages (samples)	P7, P8	≤3, ≤10
Type 5-file transfer functions	P9	≤10000
Type 6-command messages and file transfer	P10	≤500
with access control	P11	≤1000
	P12	≤10000

out. The NS-3 provides the easiest way to add new protocols. Therefore, this study develops SV, GOOSE and MMS traffic using NS-3 emulation.

The general performance requirements of IEC 61850 message types are shown in Table 2 where performance classes for different message types and delays are summarized (Anonymous, 2013). IEC 61850 messages are classified into performance classes P1-P12.

MATERIALS AND METHODS

System design and implementation: First, we measure the delay time to ensure that IEC 61850 traffic generated via. NS-3 emulation meets the message type performance requirements of Table 2. SV and GOOSE messages are passed directly from the MAC layer to the application layer, as shown in Fig. 1. SV transfers messages periodically and GOOSE operations are event-driven. SV and GOOSE leverages one-way message transmission. MMS operations are also event-driven, use TCP / IP and run in a client/server environment.

The IEC 61850 communication network architecture, using NS-3 emulation is shown in Fig. 3. The NS-3 emulation function generates IEC 61850 SV, GOOSE and MMS traffic. SV and GOOSE traffic are multicast through a network switch. MMS traffic performs two-way transmission in a client/server relationship. The PC acting as an Intelligent Electronic Device (IED) handles all corresponding traffic.

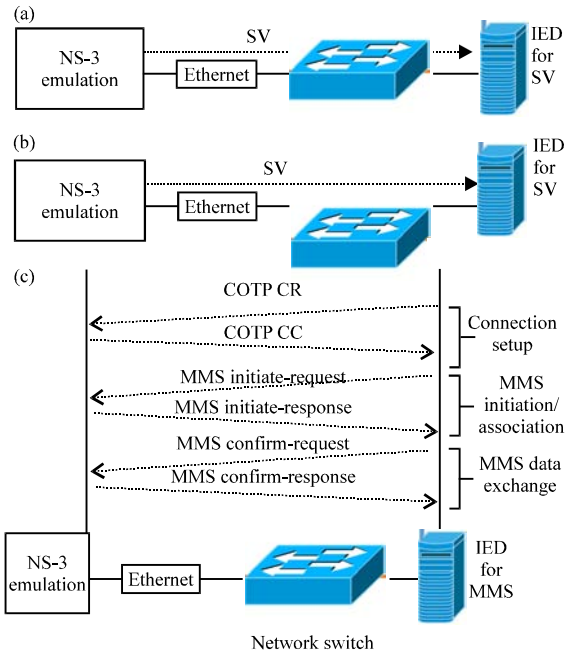

Fig. 3: Transfer scenario: a) SV; b) Goose and c) MMS

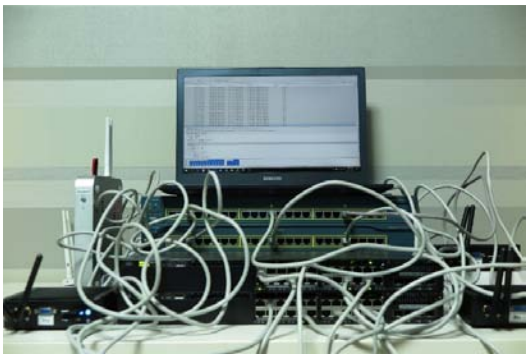

Fig. 4: Lab hardware configuration

SV messages use the MAC layer to transfer sampled current and voltage data from sensors via. a one-way transmission as shown in Fig. 3a. GOOSE messages use the MAC layer to transfer a control dataset between IEC 61850 devices in a one-way transmission, as shown in Fig. 3b. MMS messages use the TCP/IP protocol stack and operate in a client/server environment. If information is requested from the IED as shown in Fig. 3c, NS-3 emulation transfers the requested information. Here, the delay refers to the time between sending an MMS CONFIRM-REQUEST to the IED and receiving the MMS CONFIRM-RESPONSE from the NS-3 emulation after the initial setup is completed (Fig. 5).

Laboratory hardware is configured as shown in Fig. 4. Four Qotom Mini PCs are used for NS-3 emulation and IEDs. Two Cisco Catalyst 2950 L2 switches and two Catalyst 3650 L3 switches are used for network switching.

Wireshark is used for protocol analysis and IEEE 1588 PTP (Precision Time Protocol) is used for network time synchronization.

RESULTS AND DISCUSSION

Performance evaluation: Table 3-5 show the results of the IEC 61850 SV, GOOSE and MMS traffic as analyzed by Wireshark. Multicast addresses used for SV range from 01-0C-CD-04-00-00 to 01-0C-CD-04-01-FF where the Ethernet type is 88-BA and the Application Identifier (APPID) is 01. As shown in Table 3, the multicast address of SV is 01-0C-CD-04-00-07 (IEC-TC57-04: 00: 07).

Multicast addresses used for GOOSE range from 01-0C-CD-01-00-00 to 01-0C-CD-01-01-FF where the Ethernet type is 88-B8 and the Application Identifier (APPID) is 00. As shown in Table 4, the multicast address of GOOSE is 01-0C-CD-01-00-07 (IEC-TC57-01:00:07).

Table 5 shows the results of Wireshark capturing MMS traffic between the MMS client and the MMS server. If the MMS client first sends an MMS INITIATE-REQUEST message, the MMS server responds with an INITIATE-RESPONSE message. After the MMS client receives the INITIATE-RESPONSE message, data exchange begins between the MMS client and the MMS server.

The average transfer delay measured while transferring 10,000 frames/packet is shown in Fig. 6. The average transfer delay of SV, GOOSE and MMS traffic using NS-3 emulation is <3 msec. There is hardly any difference in delay between 100 MBps transmission using the Catalyst 2950 and 1 Gbps transmission using the Catalyst 3650.

SV and GOOSE operate in the MAC layer within one network segment, using one-way transmission with a delay of 1.2 msec. MMS operates in the internet layer, using two-way transmission and has a delay of 2.6 msec when measuring round-trip delay time. The delay will increase when connecting to devices of other network segments because MMS uses the IP address (Fig. 5).

SV corresponds to raw data message Type 4 in Table 2 and satisfies all performance criteria of class P7 and P8. GOOSE corresponds to fast message Type 1 and Type 1A in Table 2 and satisfies all the criteria of performance class P1 and P2. MMS corresponds to types 2, 3 and 5 in Table 2 and satisfies all the criteria of performance classes P4-P6 and P9, respectively.

Table 3: Frame/packet capture trace output with SV

Time	Sources	Destinations	Protocols	Length
9.256949	00:00:00_00:00:01	IEC_TC57_04:0004	IEC61850 sampled value	122
9.354513	00:00:00_00:00:01	IEC_TC57_04:0004	IEC61850 sampled value	122
9.353201	00:00:00_00:00:01	IEC_TC57_04:0004	IEC61850 sampled value	122
9.551816	00:00:00_00:00:01	IEC_TC57_04:0004	IEC61850 sampled value	122
9.650546	00:00:00_00:00:01	IEC_TC57_04:0004	IEC61850 sampled value	122
9.749144	00:00:00_00:00:01	IEC_TC57_04:0004	IEC61850 sampled value	122
9.847890	00:00:00_00:00:01	IEC_TC57_04:0004	IEC61850 sampled value	122
10.044873	00:00:00_00:00:01	IEC_TC57_04:0004	IEC61850 sampled value	122
10.143986	00:00:00_00:00:01	IEC_TC57_04:0004	IEC61850 sampled value	122

Table 4: Frame/packet capture trace output with Goose

Time	Sources	Destinations	Protocols	Length
6.948611	00:00:00_00:00:01	IEC_TC57_01:00:07	Goose	128
7.046744	00:00:00_00:00:01	IEC_TC57_01:00:07	Goose	128
7.145368	00:00:00_00:00:01	IEC_TC57_01:00:07	Goose	128
7.244146	00:00:00_00:00:01	IEC_TC57_01:00:07	Goose	128
7.342867	00:00:00_00:00:01	IEC_TC57_01:00:07	Goose	128
7.441646	00:00:00_00:00:01	IEC_TC57_01:00:07	Goose	128
7.539940	00:00:00_00:00:01	IEC_TC57_01:00:07	Goose	128
7.638941	00:00:00_00:00:01	IEC_TC57_01:00:07	Goose	128
7.737649	00:00:00_00:00:01	IEC_TC57_01:00:07	Goose	128
7.836638	00:00:00_00:00:01	IEC_TC57_01:00:07	Goose	128

Table 5: Frame/packet capture trace output with MMS

Time	Sources	Destinations	Protocols	Length	Info
6.948611	10:10:2.2	10.10.1.2	MMS	257	Initiate-request PDU
7.046744	10:10:1.2	10.10.2.2	MMS	228	Initiate-request PDU
7.145368	10:10:2.2	10.10.1.2	MMS	144	Confirmed-request PDU
7.244146	10:10:2.2	10.10.1.2	MMS	144	Confirmed-request PDU
7.342867	10:10:2.2	10.10.1.2	MMS	144	Confirmed-request PDU
7.441646	10:10:1.2	10.10.2.2	MMS	123	Confirmed-request PDU
7.539940	10:10:2.2	10.10.1.2	MMS	144	Confirmed-request PDU
7.638941	10:10:2.2	10.10.1.2	MMS	144	Confirmed-request PDU
7.737649	10:10:1.2	10.10.2.2	MMS	123	Confirmed-request PDU
7.836638	10:10:2.2	10.10.1.2	MMS	144	Confirmed-request PDU

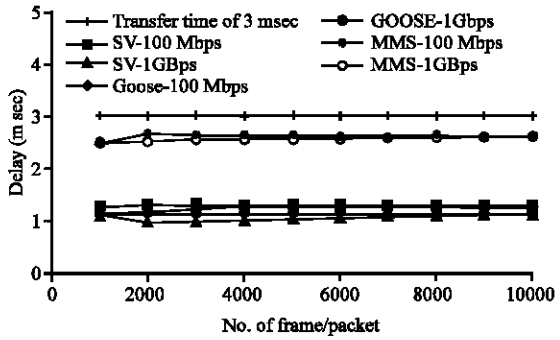

Fig. 6: Transfer delay

CONCLUSION

In this study, we generated SV, GOOSE and MMS traffic used in IEC 61850, using NS-3 emulation. The traffic generated using NS-3 emulation in the laboratory model was verified through Wireshark on a real communication network. We confirmed that SV, GOOSE and MMS traffic were generated correctly using NS-3 emulation. The delay of IEC 61850 traffic was measured using IEEE 1588. Results of the performance analyses showed that the IEC 61850 performance class delay criteria for messages were satisfied. In conclusion, the IEC 61850 traffic generation method using NS-3 emulation as proposed in this study can effectively be used to develop algorithms, applications and prototypes in an IEC 61850 environment.

REFERENCES

Anonymous, 2003a. ISO 9506-1, Industrial automation systems-manufacturing message specification-Part 1: Service definition. International Organization for Standardization, Geneva, Switzerland. https://www.iso.org/obp/ui/#iso:std:iso:9506:-1:ed-2:v1:en.

Anonymous, 2003b. ISO 9506-2, Industrial automation systems-manufacturing message specification-Part 2: Protocol specification. International Organization for Standardization, Geneva, Switzerland. https://www.iso.org/obp/ui/#iso:std:iso:9506:-2:ed-2:v1:en.

Anonymous, 2011a. IEC 61850-8-1, Communication networks and systems for power utility automation, Part 8-1: Specific Communication Service Mapping (SCSM)-mapping to MMS (ISO 9506-1 and ISO 9506-2) and to ISO/IEC 8802-3. International Electrotechnical Commission, Geneva, Switzerland. https://webstore.iec.ch/ publication/6021.

Anonymous, 2011b. IEC 61850-9-2, Communication networks and systems for power utility automation, Part 9-1: Specific Communication Service Mapping (SCSM)-sampled values over ISO/IEC 8802-3. International Electrotechnical Commission, Geneva, Switzerland. https://webstore.iec.ch/publication/6023.

Anonymous, 2013. IEC 61850-5: 2013 Communication networks and systems for power utility automation-Part 5: Communication requirements for functions and device models. International Electrotechnical Commission, Geneva, Switzerland. https://webstore.iec.ch/publication/6012.

Anonymous, 2017. NS-3 Open-source network simulator. Ns3 Projects, USA. http://ns3simulation. com/open-source-network-simulator/