Remote Monitoring of Electric Vehicle Charging Stations in Smart Campus Parking Lot

Mohamed A. Ahmed, Mohamed R. El-Sharkawy, and Young-Chon Kim

Abstract—**Smart parking lots are smart places capable of supporting both parking and charging services for electric vehicles (EVs). In order to manage EV charging, the parking lot local controller (PLLC) requires data exchange with EV charging stations (EVCSs) through communication infrastructures. However, data losses and communication delays are unavoidable and may significantly degrade the system performance. This work aims to investigate the underlying communication networks for remote monitoring of EVCSs in a smart campus parking lot. The communication network consists of two subnetworks: parking area network (PAN) and campus area network (CAN). PAN covers communication among EVs, charging stations and PLLC, while CAN enables dedicated communication between PLLCs and a global controller of the university. As one of the major obstacles in EV system is the lack of unified communication architecture to integrate EVCS in the power grid, we develope communication models for the in-vehicle system and EVCSs based on logical node concept of IEC 61850 standard. Furthermore, we implement network models for EVCSs using OPNET modeler. Different communication technologies and configurations are considered in modeling and simulations, and end-to-end delay is evaluated and discussed.**

Index Terms—**Communication network, electric vehicle (EV), electric vehicle charging station (EVCS), IEC 61850, OPNET, smart parking lot.**

I. Introduction

ELECTRIC vehicles (EVs) have been given a growing interest as an enabling technology to decrease carbon dioxide emissions and reduce oil dependence. To significantly achieve these targets, many countries have set ambitious plans for the deployment of EVs, supported by policies and regulations. In Korea, there are three ministries involved in implementing the EV policies, which are Ministry of Land, Infrastructure, and Transport (MOLIT), Ministry of Environment (MOE) and Ministry of Trade, Industry and Energy (MOTIE) [1]. By 2020, the estimated number of EVs in Korea would be around 200000. Among major provinces, Jeju Self-Governing Province announces a targeted plan of replacing all conventional vehicles to 100% electric models by 2030 [2].

Currently, the service of EV charging is provided in many parking lots and places, in some cases for free. However, the process of charging and discharging cannot be achieved without reliable communication among EVs, charging stations and power grid [3]. As the number of EVs is continuously increasing, the charging might not be visible without real-time monitoring. The EV system consists of EVs, EV charging stations (EVCSs), electric power connections, intelligent electronic devices (IEDs) and meters. In order to manage, optimize, and coordinate the integration of EVs in the power grid, sensor nodes, metering devices and reliable communication infrastructures are needed as fundamental elements in EV systems [4].

Many research work and studies have been conducted to investigate the influence of EV charging on the distribution system from the perspectives of power and communication. With respect to the power grid, the impact of EV charging is expected to be significant in view of power losses, power quality, voltage deviations, harmonics and frequency shift [5]-[7]. While most of the research has focused on optimizing the behavior of vehicle charging, communication network and the underlying communication infrastructures have been less defined and discussed [8]-[10]. Some studies have assumed that the communication channels between EVs and control operators are available [9], confidential and authenticated [10]. Table I shows various communication technologies considered for the EV system [11]-[18]. In Table I, SM stands for smart meter; CAG stands for central aggregator; LAG stands for local aggregator; EVSE stands for EV supply equipment; EMU stands for energy management unit; V2H stands for vehicle-to-home; V2V stands for vehicle-to-vehicle; WMN stands for wireless mesh network; PLC stands for power line communication; WiMAX stands for worldwide interoperability for microwave access; WAN stands for wide area network; and LAN stands for local area network.

Manuscript received: August 14, 2018; accepted: July 8, 2019. Date of CrossCheck: July 8, 2019. Date of online publication: November 26, 2019.

This work was supported by the National Research Foundation of Korea (NRF) grant funded by Korea government (MIST) (No. 2017R1A2B4004868).

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DOI: 10.35833/MPCE.2018.000502

TABLE I
COMPARISON OF COMMUNICATION TECHNOLOGIES USED IN EV SYSTEM

Network level	Communication technology	Objective	Reference
SM↔CAG LAG↔CAG	ZigBee, WMN, PLC Internet, 3G, 4G	Secure communication architecture and reward process for privacy in V2G	[11]
EV↔Charging spot Charging spot↔Concentrator Concentrator↔Back office	ZigBee ZigBee, PLC GPRS, UMTS	Communication architecture in private parking lots	[12]
Charging stations↔Control center	Ethernet	Communication network in a charging station	[13]
Charging devices↔Gateway Power meter↔Concentrator Power monitoring↔Gateway EV↔Gateway	Industrial Ethernet, CAN RS485 RS232 RF, WiFi	Network infrastructure and communication networking for EVs in a centralized charging station	[14]
EVs↔Control layer Control layer↔Application layer	SDN	SDN-based framework for EVs in the smart grid	[15]
EVs↔Central station	WiMAX	Wireless communication network based on V2G	[16]
EVSE↔EMU EMU↔Grid Mobile EV↔Control center	ZigBee, WiFi, HomePlug PLC,3G, 4G, WiMAX, LTE, 5G, DSL 3G, 4G, WiMAX, LTE, 5G, WMN	Survey on communication technologies for IoV	[17]
EV↔EV charger↔V2H V2V↔Microgrid V2G	HAN LAN WAN	Opportunities and challenges of V2H, V2V and V2G technologies	[18]

Many authors have presented different solutions in order to provide real-time monitoring for the EV system, including EVs and charging stations. Reference [11] proposes a secure communication architecture for achieving privacy for monitoring EVs as well as rewarding processes in vehicle-to-grid (V2G) networks. Reference [12] presents a communication architecture in private parking lots. Different communication technologies are considered at different levels. Reference [13] evaluates the performance of the communication network in a charging station using an optimized network emerging tool simulator. Reference [14] analyzes the network infrastructure and communication networking for EVs in a centralized charging station, while [15] proposes a two-tier software defined networking (SDN) framework for EVs in the smart grid. In the existing literature, the realizations of scheduling and control techniques that are used for EV charging coordination require appropriate communication infrastructures and two-way communications among EV subsystems. However, most of the literature above does not consider the underlying communication infrastructure as part of the EV system, while others assume perfect communication networks. These assumptions are not accurate as data losses and communication delays are unavoidable and may degrade the system performance.

The key to realize future smart grid applications such as EVs is to select appropriate communication technologies that support reliable end-to-end communication network. This work aims to address the knowledge gap of communication network modeling and simulation of the EV system by developing communication models for the in-vehicle system and EVCS based on logical node concept of IEC 61850 standard, in order to facilitate a seamless grid integration of EVs. A case study is considered for a parking lot in a university campus. There are several parameters that need to be considered in order to design the communication model for the EV system such as types of monitoring data, traffic volume, communication requirements and candidate technologies. The main contributions of this work are as follows.

1) Propose a framework to design, simulate and evaluate the performance of communication network architecture for campus parking lots, which consist of EVs, charging stations, local controllers of parking lot and a university control center.

2) Develop a communication model for the EV system and the EV charging station based on the logical node concept of IEC 61850 standard to facilitate the integration with the power grid.

3) Implement communication models using OPNET modeler for different scenarios applied to parking lots in Chonbuk National University, Jeonju, South Korea, as a case study.

4) Evaluate the performance of the proposed communication models for different communication technologies (Ethernet and WiFi) with respect to end-to-end delay and data loss.

This paper is structured as follows. The campus EV system is described in Section II. In Section III, we propose a two-layer architecture for communication network of campus EV system and develop a communication model for EV and charging station based on IEC 61850 standard. Section IV provides the performance evaluation of a case study of a university campus. Finally, Section V concludes the paper and gives directions for future work.

II. CAMPUS EV SYSTEM

The electric distribution network is the final part of the electric power system which interfaces with consumers and supports both consumers and charging stations [17]. Distribution feeders support the electric power transfer from the electric substation to end-consumers (residential, industrial and commercial) where different protection devices are used to improve power quality, safety and reliability. These protection devices include automatic switches, circuit breakers (CBs), reclosers, capacitors, lightning arresters and fuses [19]. Based on end-user voltage requirements, transformers are used to step down the voltage to an appropriate level for residential, industrial and commercial applications.

Figure 1 shows a schematic diagram for a campus EV system, where SCADA stands for supervisory control and data acquisition. The major components are EVs, charging stations, electric power connections and communication networks. The communication network layer plays a major role in real-time monitoring of both the EVs and charging stations. At the distribution system level, communication networks are responsible for gathering local measurements such as voltage, current and power from all feeders, transformers and charging stations. At the lower level, communication networks enable local control centers of parking lots to manage the charging operation of EVs.

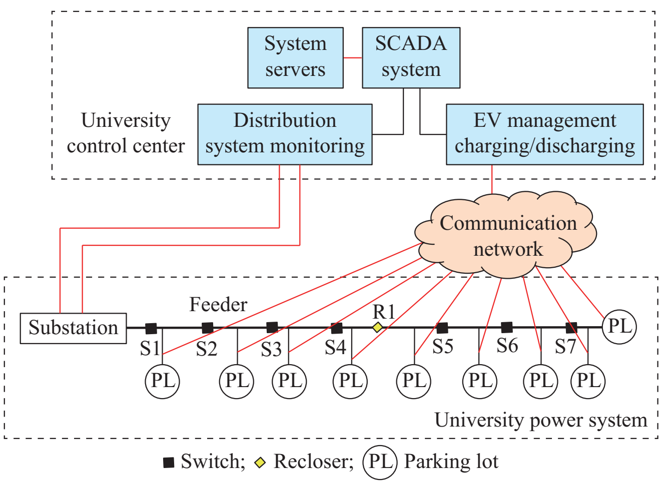

Fig. 1. Schematic diagram for campus EV system.

There are two types of strategies that could be considered for remote monitoring of EVCSs: centralized and decentralized. The centralized architecture requires direct communication between the university control center and individual charging stations in order to manage the charging operation, and control voltage deviations in the campus power network. Data collected from charging stations are processed and stored at the university control center. In the decentralized architecture, the charging operation and decision are taken individually at the level of parking lot.

Previous research works have attempted to schedule EV charging in order to overcome the peak load demand [20]-[29]. Different schemes and techniques have been considered for managing charging/discharging of EVs. However, most of these studies are lacking the underlying communication infrastructure. Communication infrastructures are crucial technologies which play an important role in the operation, monitoring and protection of EV systems. Various types of equipment (sensors, meters, protection devices, etc.) transmit measured information to the control center which will enable important decisions. Any failure in the communication infrastructure may affect system observability and result in a negative impact on the reliability and safety of the EV system.

III. Communication Network for Smart Campus Parking Lots

Figure 2 shows the communication network for the campus EV system. It consists of two hierarchical levels: parking lot local controller (PLLC) centers and a campus central control center (CCC). The function of PLLC is to monitor and control the EV charging based on local measurements from sensor nodes and measurement devices. Monitoring data from EVs could be collected using short-range communication while vehicles are plugged into the charging station. PLLCs are able to communicate with EVs, charging stations as well as the CCC. CCC gathers local measurements from the electrical power system such as voltage, current and power from all feeders and transformers.

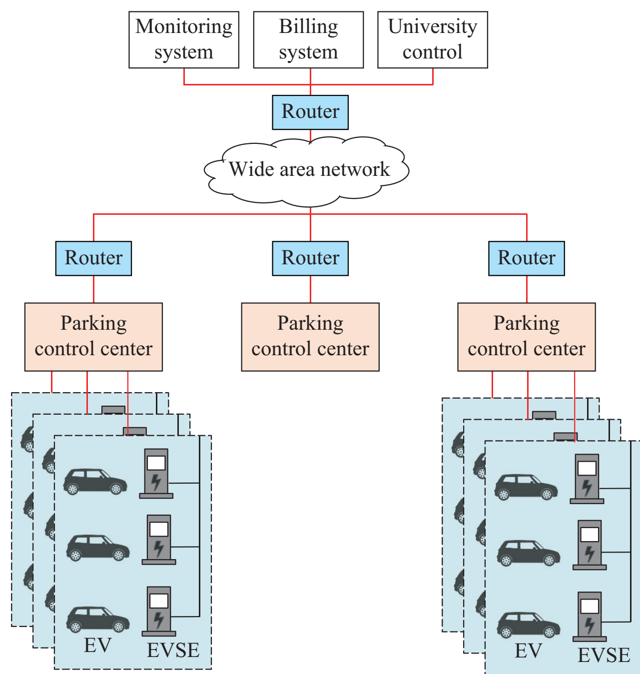

Fig. 2. Communication network architecture for campus EV system.

Monitoring data from EVCSs at different PLLCs are aggregated at CCC. The main role of the CCC is overall management and control of charging stations as well as the electrical power system. The CCC is the highest level in the system and all data received from different parking lots are stored and processed for appropriate decisions, as shown in Table II. The network connection between charging stations and the control center could be implemented using both wired and wireless communication technologies. WiFi and ZigBee are suitable wireless solutions that cover a small network size in parking area network (PAN) and building area network (BAN). The campus area network (CAN) is a middle range between PAN and WAN. The wireless communication between CCC and EVCSs could be realized through long-range communication technologies such as WiMAX, 2G/3G, LTE, etc.

TABLE II
MONITORING SCOPE OF EVCS

Level	PLLC	CCC
Monitoring	Local	Central
Monitoring scope	EVs, EVCS, IEDs	Feeder, substation
Network coverage	LAN, PAN	CAN, WAN

A. Monitoring of In-vehicle System

The major components of the in-vehicle system are a vehicle body, a frame, a battery, an electric motor, a motor controller, a battery management system (BMS), a plug-in charger, a wiring system and a braking system. The in-vehicle system includes many sensor nodes that provide information about internal battery status and enable communication with charging stations.

BMS is a critical part of the in-vehicle system which is responsible for monitoring and controlling the charging/discharging of the battery. Different sensor nodes such as temperature, voltage, and current are used to monitor the battery status [30]. During EV charging, BMS maintains monitoring the internal data of the battery to prevent abnormal conditions (e.g. overheating, overvoltage, etc.) [31]. If any monitoring parameter exceeds their values, BMS stops the charging and generates alarms that indicate the fault.

B. Monitoring of EVCSs

EVCS is the interface between the power grid and EV. The main function of an EVCS is to support EV charging/discharging during the connection. Charging stations are installed at different places including homes, parking lots and fast charging stations, based on the charging location of EV. We classify charging stations into two types: blind EVCSs and networked EVCSs. The blind EVCS system has the basic charging function. EVCS supports EV charging at low voltage. However, no external monitoring or control information is exchanged with the grid side. The networked EVCS system offers additional functions compared with blind EVCSs. It periodically transmits monitoring measurements (status information and analogue measurement) to a local controller in a smart house, a smart building, a parking lot or a charging station. During the service of charging, EVCS exchanges information with EVs such as charging mode, metering, and payment. Also, the maintenance system operator keeps receiving, storing and analyzing the monitoring data from all EVCSs. In the case of any fault or malfunction, the charging service is disabled till the unit is fixed.

IEC 61850 standard is an international standard used for the communication in substations. The standard is being extended to cover other domains in the electric power system. In this work, we define the measuring requirements of EV system based on the IEC 61850 standard, as shown in Table III. We consider the logical node data models in [32]-[35], which are an extension of IEC 61850 standard for EV charging.

TABLE III
LOGICAL NODE OF EV SYSTEM

Name	Symbol	Description
Metering	M_{MTR}	Metering and measurement
CB	C_{SWI} X_{CBR}	Switch controller CB
Charging station	Z_{INV} Z_{RCT} M_{MDC}	Inverter Rectifier DC measurement
DC switch	C_{SWI} X_{CBR}	Switch controller CB
Battery system	Z_{BAT} Z_{BTC}	Battery system Battery charger

In campus EV system, charging stations are considered as devices that generate monitoring data related to their status and communicate and exchange information with other domains such as EVs, electric power system and operation and maintenance (O&M) service. PLLC is able to manage and control the EV charging based on the charging request from the EVCS. Figure 3 shows the architecture model of the EV system and all associated logical nodes. The system consists of an EV, a DC switch, a charging station, a CB and measuring devices.

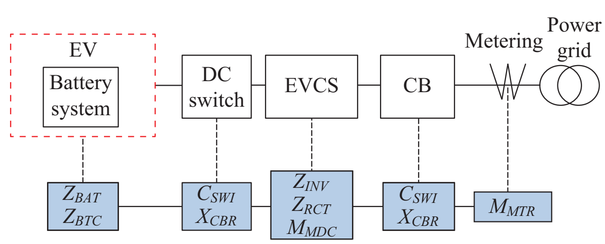

Fig. 3. Architecture model of EV system based on IEC 61850 standard.

Equations (1) and (2) show the logical nodes of EV EV_{LN} and EVCS $EVCS_{LN}$ which include the basic parameters and information required to manage the operation and interaction with end-user as well as the power grid.

$$EV_{LN} = \{Z_{BAT}, Z_{BTC}\} \tag{1}$$

$$EVCS_{LN} = \{Z_{INV}, Z_{RCT}, M_{MDC}\} \tag{2}$$

Both the DC switch SW_{LN} and the CB CB_{LN} are modeled by C_{SWI} and X_{CBR}, as shown in (3).

$$CB_{LN} = SW_{LN} = \{C_{SWI}, X_{CBR}\} \tag{3}$$

We define the architecture model of EVCS based on IEC 61850 standard. It consists of M_{MTR}, X_{CBR}, and supply equipment communication controller (SECC). The attribute of EVCS includes status information (SI), analogue measurements AM and control information CI. The status information of EVCS indicates the status of the meter and the breaker, whether it is switched on or off. The charging parameters of AM include measurements such as charging voltage EVCSPhV, charging current EVCSA, grid frequency EVCSHz, and charging active power EVCSW, as given in Table IV.

Charging stations are also equipped with different protection and control devices such as CB-IED and protection and control IED (P&C IED). These devices are responsible for exchanging protection and control information with PLLC.

TABLE IV
ATTRIBUTE OF EVSE BASED ON IEC 61850 STANDARD

Attribute of EVCS	Name of attribute	Explanation
SI	MeterStatus BreakerStatus	Meter status on/off Breaker status on/off
AM	EVCSPhV EVCSA EVCSHz EVCSW	Charging voltage Charging current Grid frequency Charging active power
CI	V2Genable EconCharge	Switch on/off V2G Immediate/economy charging

IV. NETWORK MODELING AND SIMULATION

This section presents network modeling and simulation using OPNET modeler. The OPNET modeler is one of the most widely used network simulators that include a comprehensive library of all network elements, models and protocols that allow network planners to implement and validate their future designs. We consider EVCSs that are deployed in a smart parking lot of a university campus. Table V provides a detail description of the network configuration.

TABLE V
NETWORK CONFIGURATION

Parking lot	Network content	Configuration
PAN	Charging station	1 workstation
	Ethernet switch	1 switch
	Wired media	Ethernet (IEEE 802.3)
	Wireless media	WiFi (IEEE 802.11)
Control center	Server	1 server
	PLLC	1 workstation

We develop a communication network model for a smart parking lot in OPNET. Each EVCS transmits their monitoring data continuously toward the PLLC server. In order to calculate the data size generated from sensor nodes and measurement devices, we define the sampling rate and the number of channels. We assume that the sample size is 2 bytes (16 bits) based on [36]. The data rate R is calculated according to (4).

$$R = 2N_c f_s \tag{4}$$

where N_c is the number of channels; and f_s is the sampling frequency.

Table VI shows the measuring requirements for different sensors and measuring devices.

Based on the battery state of charge (SoC), the EV charging is monitored in real-time using PLLC. The dimensions of the network are set as 100 m × 60 m. We consider two operation modes for EVCS: idle mode and charging mode. The average data transmission rate of EVCS R_{EVCS} is given in (5).

TABLE VI
MEASURING REQUIREMENTS FOR DEVICES AND SENSORS

Measurement	Sampling frequency (Hz)	Data rate (byte/s)	Direction
Status Information	1	2	PLLC/ control center
Power	5	10	
Frequency	10	20	
Voltage	360	720	
Current	360	720	

$$R_{EVCS} = R_{idle} P_{idle} + R_{charging} P_{charging} \tag{5}$$

where R_{idle} is the data transmission rate of EVCS in the idle operation mode; P_{idle} is the probability of the idle operation mode; $R_{charging}$ is the data transmission rate of EVCS in the charging operation mode; and $P_{charging}$ is the probability of the charging operation mode.

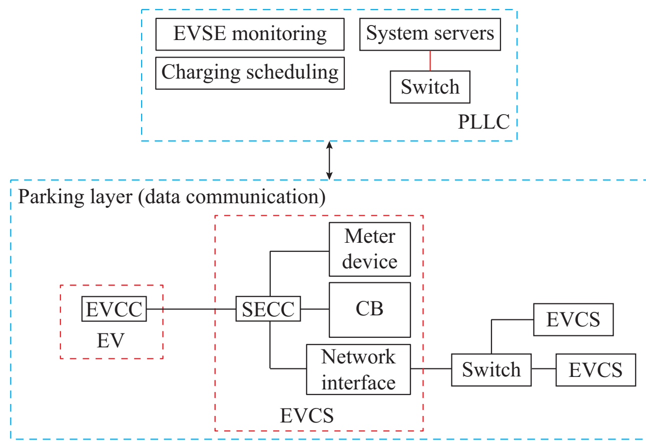

Fig. 4. Smart parking lot with EVCS.

Table VII shows the classification of data types and the operation modes of EVCS. Note that the monitoring data related to vehicle ID, charging type, voltage, current, and power are transmitted only during EV charging mode. We simulate different scenarios for monitoring EVCSs. Two different technologies are considered: Ethernet and WiFi. Each wired/wireless workstation represents an EVCS. For example, with 20 EVCSs, the Ethernet-based scenario consists of 20 workstations and one server, while 20 wireless workstations and one wireless server are considered for the WiFi scenario.

The following metrics have been considered in the performance evaluation.

1) Server FTP traffic represents the average bytes per second forwarded to the FTP application by the transport layer in the server node.

2) End-to-end delay of Ethernet is the amount of time in seconds for data to be delivered from source to destination along the communication path.

3) Wireless end-to-end delay represents the end-to-end delay of all packets received by the wireless LAN MACs of all WLAN nodes in the network and forwarded to the higher layer.

Figure 5 shows the total received traffic at PLLC server with 10 EVCSs. The total monitoring data received are 7200 byte/s, 7200 byte/s, 20 byte/s, 20 byte/s and 20 byte/s for current, voltage, CB status, EV-ID, and meter status, respectively. Note that no traffic receives from voltage and current sensors while the EVCS is in an idle mode. All transmission and reception of sensing data are received successfully.

TABLE VII
CLASSIFICATION OF EVCS DATA TYPES BASED ON OPERATION MODES

Data type	Idle mode	Charging mode
Station ID	√	√
Charger ID	√	√
Meter status	√	√
CB status	√	√
Vehicle ID	×	√
Charging type	×	√
Voltage	×	√
Current	×	√
Frequency	×	√
Power	×	√

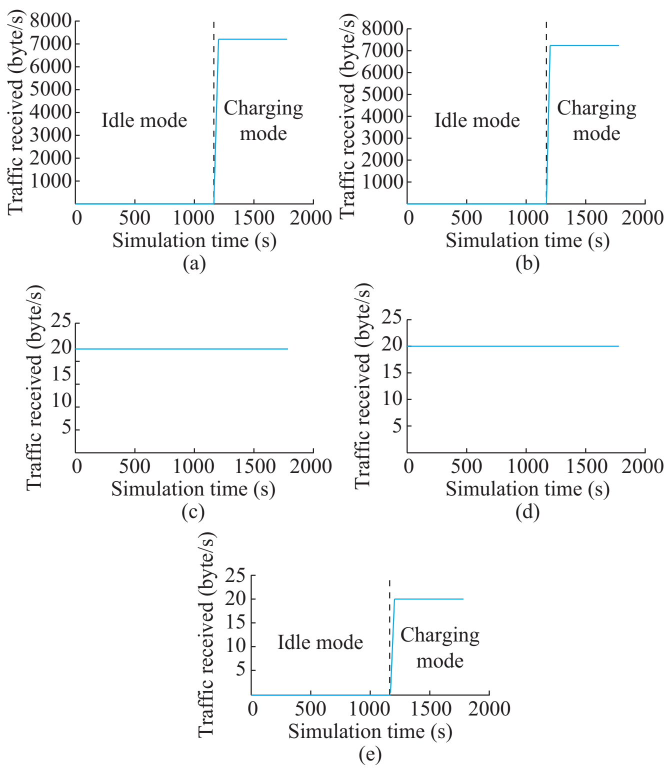

Fig. 5. Received traffic from EVCSs at the parking lot control center with 10 EVCSs. (a) Current. (b) Voltage. (c) CB status. (d) Meter status. (e) EV-ID.

Figure 6 shows the end-to-end delay for Ethernet-based architectures in a smart parking lot with 1, 5 and 10 EVCSs. With 10 EVCSs, the end-to-end delay is about 4.96 ms during idle mode and 12.73 ms during the charging mode, considering a link capacity of 10 Mbit/s, while the end-to-end delay is about 0.49 ms during idle model and 1.218 ms during the charging mode, considering a link capacity of 100 Mbit/s.

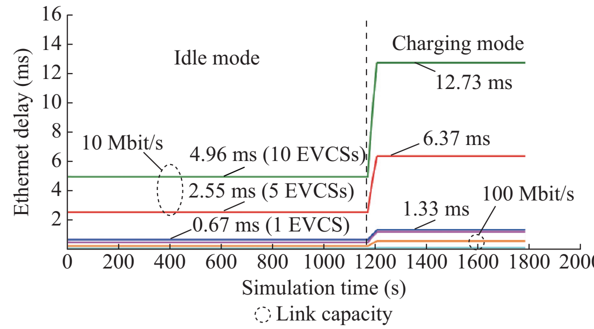

Fig. 6. End-to-end delay for Ethernet-based architecture in a smart parking lot with 1, 5 and 10 EVCSs.

Figure 7 shows the end-to-end delay for Ethernet-based architectures with 20, 40 and 80 EVCSs. Considering link capacity of 10 Mbit/s, the end-to-end delay increases from 8.80 ms (20 EVCSs) to 27.76 ms (80 EVCSs) during the idle mode and from 21.86 ms (20 EVCSs) to 71.66 ms (80 EVCSs) during the charging mode. In the case of 80 EVCSs with link capacity of 100 Mbit/s, the end-to-end delay increases from 2.85 ms during the idle mode to 7.37 ms during the charging mode. Table VIII shows the simulation results of end-to-end delay for monitoring data in the case of Ethernet-based architectures.

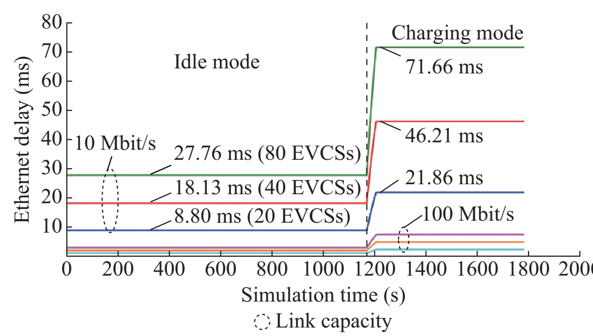

Fig. 7. End-to-end delay for Ethernet-based architecture in a smart parking lot with 20, 40 and 80 EVCSs.

TABLE VIII
END-TO-END DELAY FOR ETHERNET-BASED ARCHITECTURES OF EVCS

EVCS	End-to-end delay (s)			
	10 Mbit/s		100 Mbit/s	
	Idle mode	Charging mode	Idle mode	Charging mode
1	0.000679	0.001335	0.000069	0.000114
5	0.002550	0.006370	0.000250	0.000586
10	0.004960	0.012730	0.000490	0.001218
20	0.008801	0.021867	0.000915	0.002250
40	0.018136	0.046216	0.001877	0.004802
80	0.027766	0.071662	0.002853	0.007374

Figure 8 shows the wireless end-to-end delay using a data rate of 54 Mbit/s. The maximum end-to-end delays during the idle mode are 36.64 ms, 23.34 ms, 13.46 ms, 6.77 ms and 1.48 ms for 40 EVCSs, 20 EVCSs, 10 EVCSs, 5 EVCSs, and 1 EVCS, respectively. However, the maximum end-to-end delays during the charging mode are 109.57 ms, 43.99 ms, 26.18 ms, 17.48 ms and 3.73 ms for 40 EVCSs, 20 EVCSs, 10 EVCSs, 5 EVCSs and 1 EVCS, respectively. Table IX shows the simulation results of end-to-end delay for monitoring data in the case of WiFi-based architectures using a data rate of 54 Mbit/s.

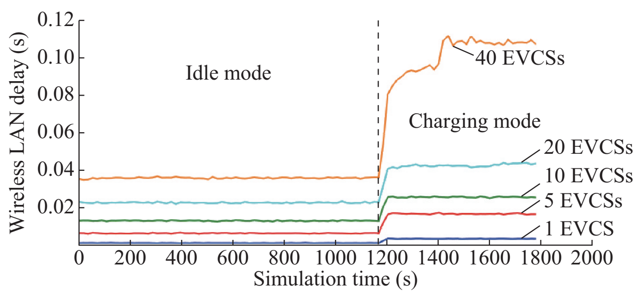

Fig. 8. End-to-end delay for WiFi-based architecture in a smart parking lot with 1, 5, 10, 20 and 40 EVCSs.

TABLE IX
AVERAGE END-TO-END DELAY OF WIFI-BASED ARCHITECTURE OF EVCS

EVCS	Average end-to-end delay (s)			
	Idle mode		Charging mode	
	Min	Max	Min	Max
1	0.0013060	0.0014808	0.003433	0.003737
5	0.0063040	0.0067739	0.016424	0.017486
10	0.0128860	0.0134655	0.025168	0.026184
20	0.0224360	0.0233471	0.041104	0.043993
40	0.0355109	0.0366470	0.080671	0.109576

Figure 9 shows the wireless end-to-end delay using a data rate of 11 Mbit/s. The maximum end-to-end delays during the idle mode are 54.43 ms, 27.70 ms, and 5.93 ms for 10 EVCSs, 5 EVCSs and 1 EVCS, respectively. However, the maximum end-to-end delays during the charging mode are 119.71 ms, 71.03 ms and 15.65 ms for 10 EVCSs, 5 EVCSs and 1 EVCS, respectively.

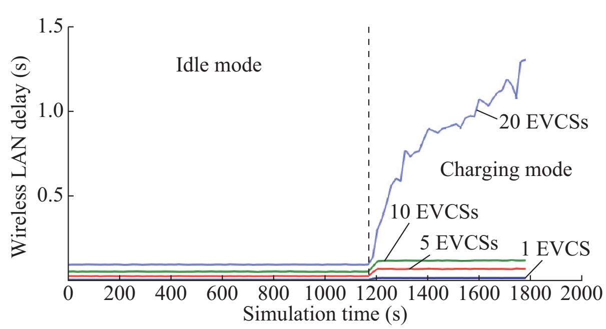

Fig. 9. End-to-end delay for WiFi-based architecture in a smart parking lot with 1, 5, 10 and 20 EVCSs.

Table X shows the simulation results of end-to-end delay for monitoring data in the case of WiFi-based architectures using a data rate of 11 Mbit/s. It is observed that using WiFi with a data rate of 11 Mbit/s is not sufficient for data transmission with 20 EVCSs. Figure 10 shows data loss in the received traffic at the parking lot control center with 20 EVCSs for CB status, charger ID and EV-ID.

TABLE X
END-TO-END DELAY OF WIFI-BASED ARCHITECTURE OF EVCS

EVCS	End-to-end delay (s)			
	Idle mode		Charging mode	
	Min	Max	Min	Max
1	0.005660	0.005930	0.015014	0.015650
5	0.025420	0.027700	0.067153	0.071030
10	0.051170	0.054430	0.116226	0.119711
20	0.935584	0.967786	0.562670	1.303990

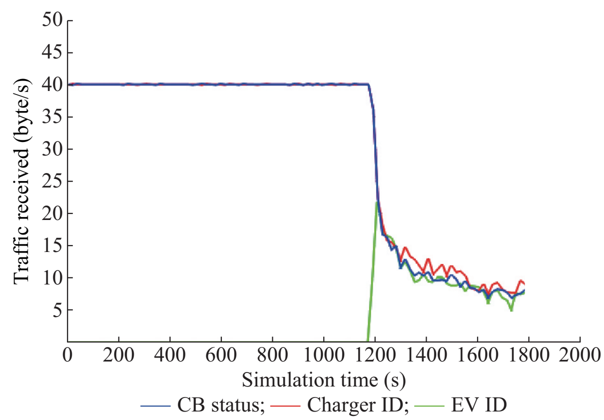

Fig. 10. Received traffic from EVCSs at the parking lot control center with 20 EVCSs using WiFi-based architecture with a data rate of 11 Mbit/s.

V. CONCLUSION

In this work, we investigate the design, simulation and evaluation of remote monitoring of EVCSs in a smart parking lot. A real parking lot in Chonbuk National University, Jeonju, South Korea is considered as a case study. We develope the communication network model for the EV system in OPNET modeler based on logical node concept of IEC 61850 standard. Types of monitoring data and traffic volume are defined, calculated and discussed. Ethernet-based and WiFi-based are two promising technologies considered and evaluated. Different scenarios are configured and simulated with respect to link capacity and end-to-end delay. Based on the simulation results, Ethernet-based architectures show better performance with a lower end-to-end delay compared with WiFi-based architectures.

The maximum end-to-end delay for monitoring 80 EVCSs is about 2.85 ms during the idle mode and about 7.37 ms during the charging mode, considering Ethernet-based architecture with a link capacity of 100 Mbit/s. In the case of WiFi-based architecture, the end-to-end delay is about 27.76 ms during the idle mode and about 71.66 ms during the charging mode, for a data rate of 54 Mbit/s. WiFi-based architecture using a data rate of 11 Mbit/s is able to support data transmission of up to 10 EVCSs. However, it is not sufficient to support data transmission with 20 EVCSs. The data received from EVCSs could be used for other applications such as energy management system and distribution automation. Based on communication requirements for V2G and grid to vehicle (G2V), the results of end-to-end delay for Ethernet-based architectures satisfy the power system requirements. This work will be extended to support the peer-to-peer energy trading among EVs in a university campus.

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