System Architecture based on IoT for Smart Campus Parking Lots

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***Abstract*—This work aims to design a system architecture of internet-of-things (IoT) for managing electric vehicles charging in a university campus. The electric vehicle management system is composed of electric vehicles, charging stations, parking lot local controllers and a university central controller. The proposed architecture consists of three layers: a power system layer, a communication network layer and an application layer. The electric vehicle system components, data traffic and communication requirements that should be taken into account are defined in order to implement the smart campus parking lots. The performance analysis and practical feasibility of implementing IoT-based architecture have been investigated for a smart parking lot in Chonbuk National University Campus, South Korea.**

Keywords- Electric Vehicles, Charging Stations, Smart Parking Lot, Internet of Things, Communication Network.

I. Introduction

Smart grid is the future electric power system, which supports bi-directional energy and information flow between consumers and service provider with improved reliability, stability, and efficiency [1]. Internet-of-Things (IoT) technology can be used for enabling smart grid achieving their goals in monitoring, protecting, and controlling through the incorporation of sensors, actuators, and metering devices while supporting various network functions and system automation [2, 3]. IoT technology has received significant attention in various application domains such as smart buildings [4], health care systems [5], agriculture [6], and smart cities [7].

With the advancement of technology, the smart grid is now supporting many new applications in the distribution power system, for example, smart meters, distributed energy resources, electric vehicle, and energy storage systems [8]. Among these applications, electric vehicles are expected to play an important role in the future smart grid due to their environmental and economic benefits. However, the integration of electric vehicles in the distribution power network represents complex problems due to vehicles operation modes that adopt a bidirectional energy flow between electric vehicles and the power grid. Information transfer and communication networks among electric vehicles, charging stations and controllers are essential elements in the electric vehicle system in order to enable the charging process and the bidirectional energy transfer.

Scheduling electric vehicles charging plays an important role in electric vehicle system, especially in parking lots due to uncertain parking time of electric vehicles, different charging demands, and long charging time [9]. With large-scale integration of electric vehicles, the charging process can overload the power system mainly during peak hours. Other factors that may affect the power grid may include voltage fluctuation, harmonics, frequency deviation, grid stability, and power outages. There has been less research work on the underline communication infrastructure for the electric vehicle system and even less for the communication infrastructure of the distribution power system.

Nevertheless, this work aims to develop a management platform for charging electric vehicles in a university campus based on IoT technology. Three layers make the proposed architecture, which are namely are power system, communication network and application, where the performance analysis and practical feasibility of communication network layer have been evaluated in a real life scenario.

The rest of this paper is structured as follows. Section II provides details on the power distribution system, and Section III elaborates on the architecture of the smart campus parking system, which incorporates IoT technology. Furthermore, the IoT network connectivity of the proposed system is presented in Section IV. While Section V sheds a light on the communication layer of the system, Section VI briefs out the simulation and modeling technique utilized in this research paper based on real dimensions of the parking lot. Finally, Section VII concludes the work.

II. Campus Distribution Power System

Power distribution systems represent an important part of the electric power grid as it provides the final link between the electric transmission system and consumers, where most of faults and outages occur [10]. In South Korea, for example, the distribution system is operated and managed by Korea Electric Power Corporation (KEPCO), where the total distribution automation system (TDAS) is responsible for monitoring and control of all the distribution systems. This includes real time monitoring, control, and data storage [11]. The advent of new technologies such as distributed energy resources (e.g., wind turbines and photovoltaic) and electric vehicles, it has become a challenging task to control center operator and monitor and operate the distribution systems efficiently [12]. However, it is expected that innovative utilization of communication capabilities of the network will play a key role in supporting real-time monitoring and operation of the power distribution grid without a need for direct human intervention [13].

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As defined by IEEE standards, the distribution automation system (DAS) enables the electric utility to remotely monitor and control the operation of the distribution power system in real time [14] with the target of improving the power quality, enhancing system reliability, decreasing the operation costs, enabling the grid integration of distributed energy resources (DERs), and reducing the power outage [15]. The DAS collects the operation data from the distribution subsystem such as voltage and current, and transmits it to the control center. Based on the collected data, the control center operator can manage and control remote terminal units (RTUs). The function of DAS can be divided into two parts: management of the distribution power system and management of end-user (consumer) [10]. Managing the distribution power system includes monitoring and control of power quality, power factor, feeder status information, feeder voltage quality, feeder switch control, recloser control, and fault isolation. This may be achieved through the master station level that implements the overall integration of the distribution automation functions such as Supervisory Control and Data Acquisition (SCADA) system and feeder automations. However, for a consumer, management includes customer power quality, customer usage, time-of-use (ToU), and controlling of the end-user loads, which can be performed through the terminal level that includes field devices and equipment. In reality, substation level enables data collected from terminal units to be transmitted to master station level. In addition, it enables commands transmission from master station level to terminal units. In order to support electric vehicles and new technologies, protection and control devices such as switches, breakers, reclosers, capacitors, fuses, and arresters are added, which also result in decreasing power outages in case of any failure in the power distribution grid.

III. IoT-based Architecture for Smart Campus Parking Lot

The smart campus parking lot is a system in which the status of electric vehicles and charging stations are collected from various parking spots and communicated to a central controller that determines an appropriate action in the system. The system consists of five basic components: electric vehicles, charging stations, electric power network, communication network and an application system. The proposed IoT-based architecture for smart campus parking lots is shown in Fig. 1.

A. *Power System Layer*

The power system layer includes electric vehicles, charging stations, metering devices, intelligent electronic devices, sensors, and actuators. The main objective of this layer is data collection from electric vehicle subsystem utilizing a variety of sensor nodes and measurement devices. Measured parameters such as the energy demand, vehicles identification, chargers status, and vehicles information are transmitted to the application layer through the communication network layer.

B. *Communication Network Layer*

The main function of the communication network layer is to transmit collected data from the electric vehicle system to the application layer. There are various communication technologies which can be used in the smart parking lots including wired (e.g., power line communication, Ethernet, optical fiber, etc.) and wireless (e.g., WiFi, ZigBee, GPRS, 3G/4G, LTE, etc.). Actually, different solutions can be implemented for different design configurations. Such configurations are typically selected based on the system requirements.

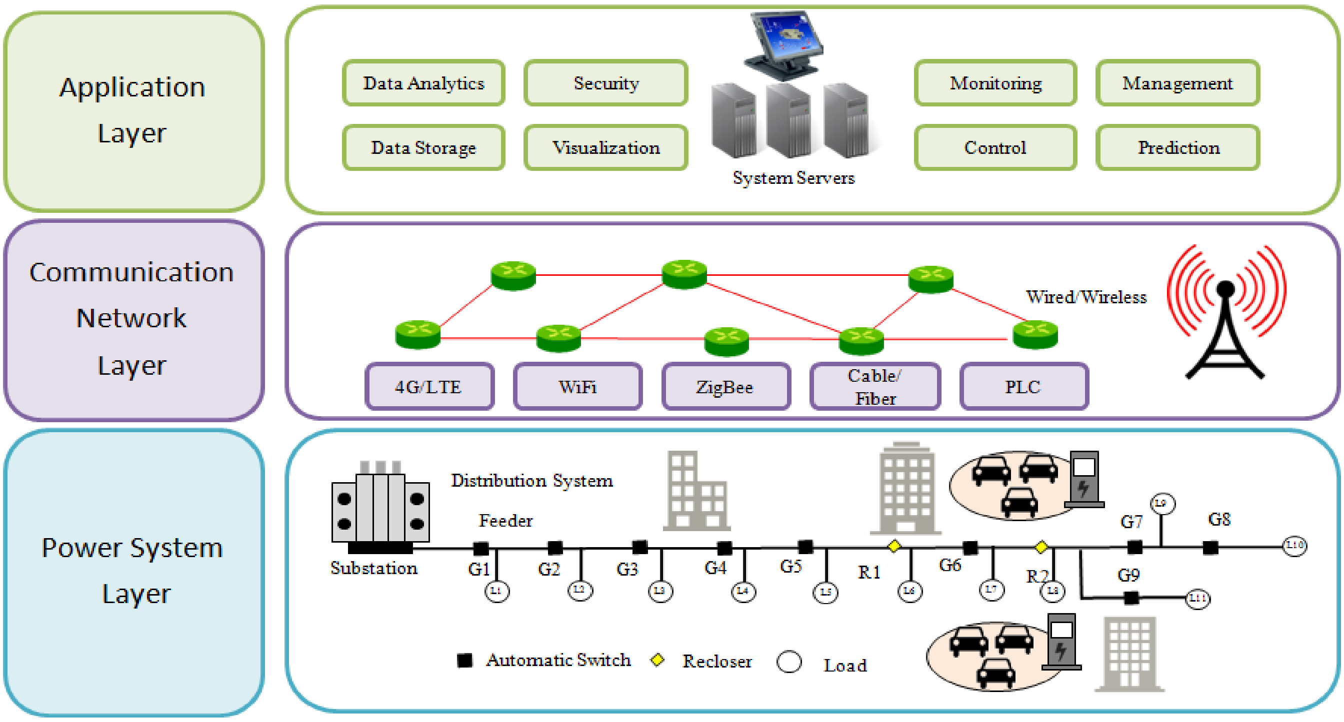

Figure 1. IoT-based architecture for smart campus parking lots.

C. Application Layer

The main function of the application layer is real-time monitoring and control. Data received from parking lot layer are processed for appropriate actions. The university global control center gathers all measurements from local controllers and determines the appropriate action for each charging station. All data received are stored, processed and analyzed.

IV. IoT Network Connectivity in Smart Campus Parking Lots

Electric vehicles (EVs) and charging stations (CSs) are considered as the basic elements in the electric vehicle system. IoT-EV and IoT-CS are defined as the main components in the smart parking lot. All IoT-EVs and IoT-CSs are connected as nodes in the IoT Parking Area Network (IoT-PAN). IoT-PAN is a communication network that connects various elements including vehicles, charging stations, protection devices, CCTV, etc. In fact, different technologies could be used to configure IoT-PAN using wired/wireless. All IoT-PANs are connected together through gateways. IoT-gateway (IoT-GW) is a router that connects IoT-PANs together with IoT-Campus Area Network (IoT-CAN). All IoT-PANs are aggregated and connected to IoT-CAN, which is defined as a wide area network that covers a large area. Table 1 lists the main elements of the smart campus parking lot.

TABLE 1. Main Elements of Smart Campus Parking Lot.

Component	Description
IoT-EV	IoT-Electric Vehicle
IoT-CS	IoT-Charging Station
IoT-PAN	IoT-Parking Area Network
IoT-GW	IoT-Gateway
IoT-CAN	IoT-Campus Area Network

V. EPON-based Architecture for IoT-CAN

The communication network for the distribution power system is a key element in realizing the future smart grid applications. Ethernet Passive Optical Network (EPON) is considered for the campus distribution power system, which combines advantages of optical network technology and Ethernet [16]. The communication network for the distribution power system supports low voltage transformers, smart meters, charging stations and distributed energy resources. The EPON consists of an optical line terminal (OLT), passive optical splitters (POSs), optical network units (ONUs), and optical distribution network (ODN) [17]. In this paper, a real distribution power system of KEPCO, South Korea is considered. The details system model is given in Ref. [18]. The system consists of a substation, distribution lines, and loads. The system supports different types of protection devices such as automatic gas switches and automatic reclosers.

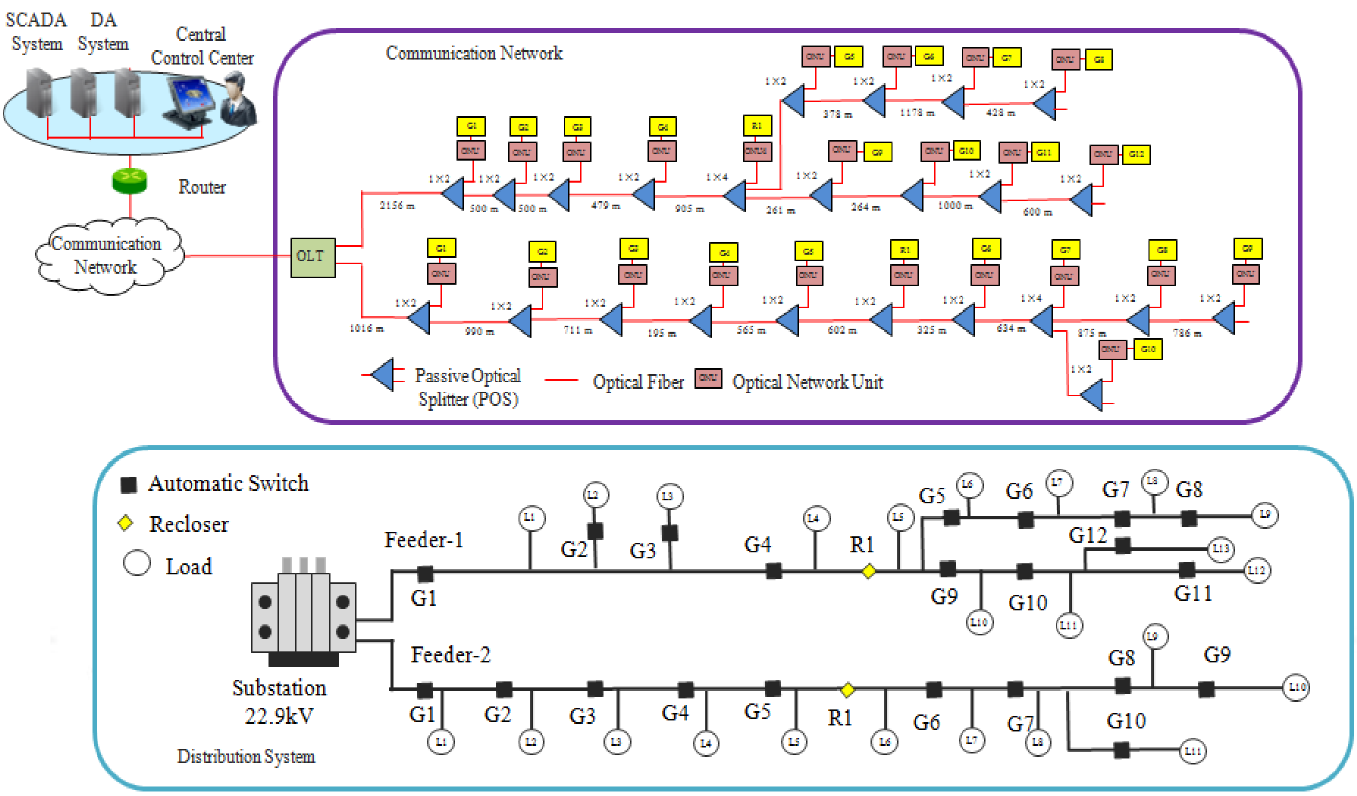

Figure 2. Proposed EPON-based architecture for Campus distrbution power system.

The electric topology consists of two feeders supplied by 22.9 kV. The protection system consists of 22 protection devices and 2 reclosers. Types of power cables are concentric neutral cables and extra high voltage aluminum wire cables. Figure 2 shows the proposed EPON-based communication network architecture for the campus distribution power system. The proposed architecture has been analyzed in view of optical power loss.

Total optical path attenuation (P_{Total}) is the summation of optical insertion losses for fiber cables (P_{Fiber}), connectors (P_{Conn}), and passive optical splitters (P_{Split}), which is given in the following equation.

$$P_{Total} = P_{Fiber} + P_{Conn} + P_{Split} \quad (1)$$

Table 2 shows the components insertion loss. The results of power budget analysis for feeder 1 and feeder 2 are given in Table 3 and Table 4, respectively. The total optical path loss of ONUs should be less than 24 dB [16]. The results show that the received power at the ONUs is sufficient for operation (maximum path loss is about 16.67 dB for F1-G9 and 15.86 for F2-G12).

TABLE 2. COMPONENT INSERTION LOSS.

Component	Attenuation
Fiber	0.4 dB/km
Connector	0.2 dB
Splitter	1x2→3.0 dB
	1x4→6.0 dB

TABLE 3. RESULTS OF POWER BUDGET ANALYSIS FOR FEEDER 1

	Fiber Loss	Splitter Loss	Connector Loss	Total Loss
F1-G1	0.4064	0.4	0.8	1.6064
F1-G2	0.8024	0.8	1.2	2.8024
F1-G3	1.0868	1.2	1.6	3.8868
F1-G4	1.1648	1.6	2.0	4.7648
F1-G5	1.3908	2.0	2.4	5.7908
F1-R1	1.6316	2.4	2.8	6.8316
F1-G6	1.7616	2.8	3.2	7.7616
F1-G7	2.0152	8.8	3.6	14.4152
F1-G8	2.3652	9.2	4.0	15.5652
F1-G9	2.6796	9.6	4.4	16.6796
F1-G10	2.0152	8.8	3.6	14.4152

TABLE 4. RESULTS OF POWER BUDGET ANALYSIS FOR FEEDER 2

	Fiber Loss	Splitter Loss	Connector Loss	Total Loss
F2-G1	0.8624	0.4	0.8	2.0624
F2-G2	1.0624	0.8	1.2	3.0624
F2-G3	1.2624	1.2	1.6	4.0624
F2-G4	1.454	1.6	2.0	5.054
F2-R1	1.816	7.6	2.4	11.816
F2-G5	1.816	8.0	2.8	12.616
F2-G6	1.9672	8.4	3.2	13.5672
F2-G7	2.4384	8.8	3.6	14.8384
F2-G8	2.6096	9.2	4.0	15.8096
F2-G9	1.9204	8.0	2.8	12.7204
F2-G10	2.026	8.4	3.2	13.626
F2-G11	2.426	8.8	3.6	14.826
F2-G12	2.666	9.2	4.0	15.866

VI. NETWORK MODELING AND SIMULATION OF IOT-PAN

A simulation model is developed for a smart parking lot based on the real dimension of Engineering building parking lot, Chonbuk National University, South Korea. The parking lot consists of 100 parking spots. The communication network has been divided into seven subnets: six charging stations subnets and a local parking lot controller subnet, which is shown in Fig. 3. The communication network is configured with fast Ethernet (i.e., 100 Mbps) and Gigabit Ethernet (i.e., 1 Gbps).

The data transmitted through the communication network is related to charging stations information and electric vehicle information. The charging station information includes station ID, charger ID, meter status, and circuit breaker status. However, the electric vehicle information includes vehicle ID, charging type, voltage, current, frequency, and power. Table 5 shows detail information about the generated traffic for both electric vehicles and charging stations.

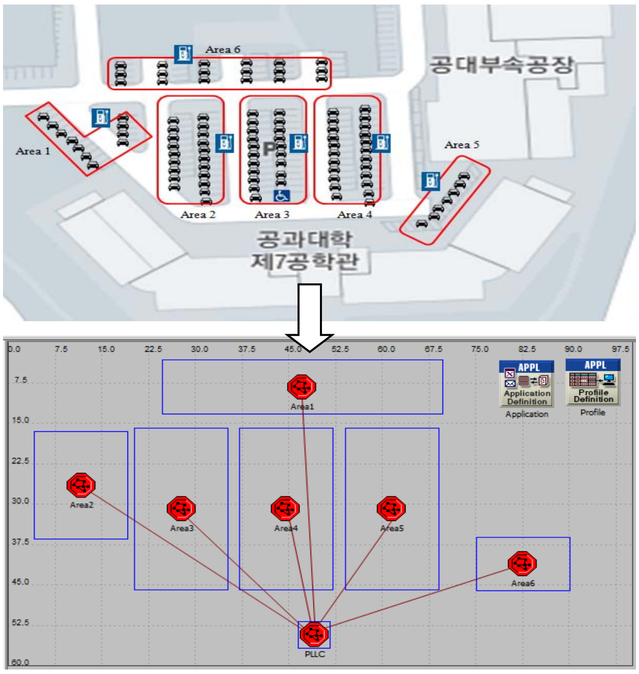

Figure 3. Simulation model of parking lot 3 (Engineering building 2-7).

TABLE 5. GENERATED TRAFFIC FOR ELECTRIC VEHICLE AND CHARGING STATION BASED ON IEC 61850

Data Type	Data Direction	Explanation
Analogue Measurements	IoT-CS→PLLC	Charging Voltage Charging Current Grid Frequency Active Power
Status Information	IoT-CS →PLLC IoT-EV→ PLLC	Meter Status Breaker Status
Control Information	PLCC→IoT-CS	Switch ON/OFF Immediate/Economy Charging
Protection Information	IoT-CS →PLLC	CB-IED P&C IED
Video Surveillance	IoT-CS →PLLC	CCTV
Internet	Internet→ IoT-CS	Internet connection

A real vehicle arrival time is considered at engineering parking lot during a working day on 15 May, 2018. Figure 4 shows the end-to-end delay for a smart parking lot with 50 and 100 charging stations. The simulation time is configured with 30 min where 20 min for idle operation mode (no charging) and 10 min for charging mode. The simulation results show that the maximum end-to-end delay is about 12.45 ms and 3.96 ms for channel capacity of 100Mbps and 1Gbps, respectively. Considering the requirements of end-to end delay of 4 ms for power system [19], the communication network with 1Gbps link capacity satisfy the power system requirements.

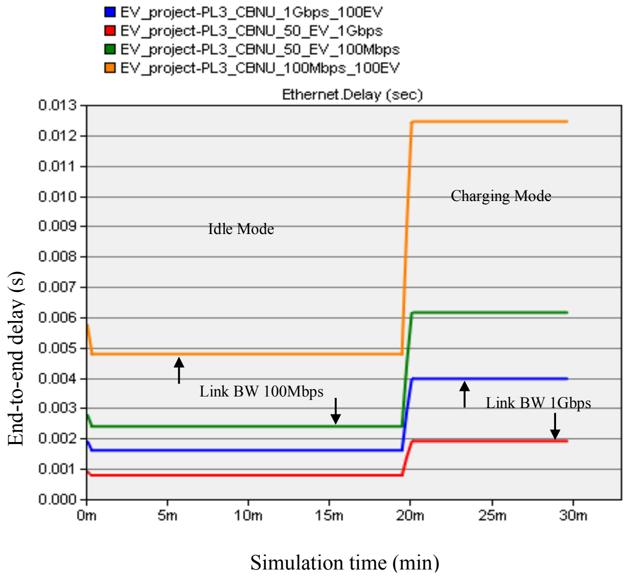

Figure 4. End-to-end delay for a smart parking lot with different channel capacity and different numbers of charging stations.

VII. CONCLUSION

In this paper, a system architecture was developed for monitoring electric vehicles charging system based on IoT in a university campus. The proposed architecture consists of three layers: a power system layer, a communication network layer and an application layer. EPON-based communication network architecture was developed for Campus power network based on a real distribution power system in order to monitor feeders, transformers and protection devices. The proposed architecture has been evaluated in view of optical path loss to ensure the received power at the ONUs. The simulation results showed that the EPON-based communication network architecture is sufficient for operation. Furthermore, we built a communication network model for a smart parking lot based on OPNET. The performance of the communication network model has been evaluated with respect to end-to-end delay. A channel capacity with 1 Gbps was sufficient to ensure amount of latency required by electric power system.

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