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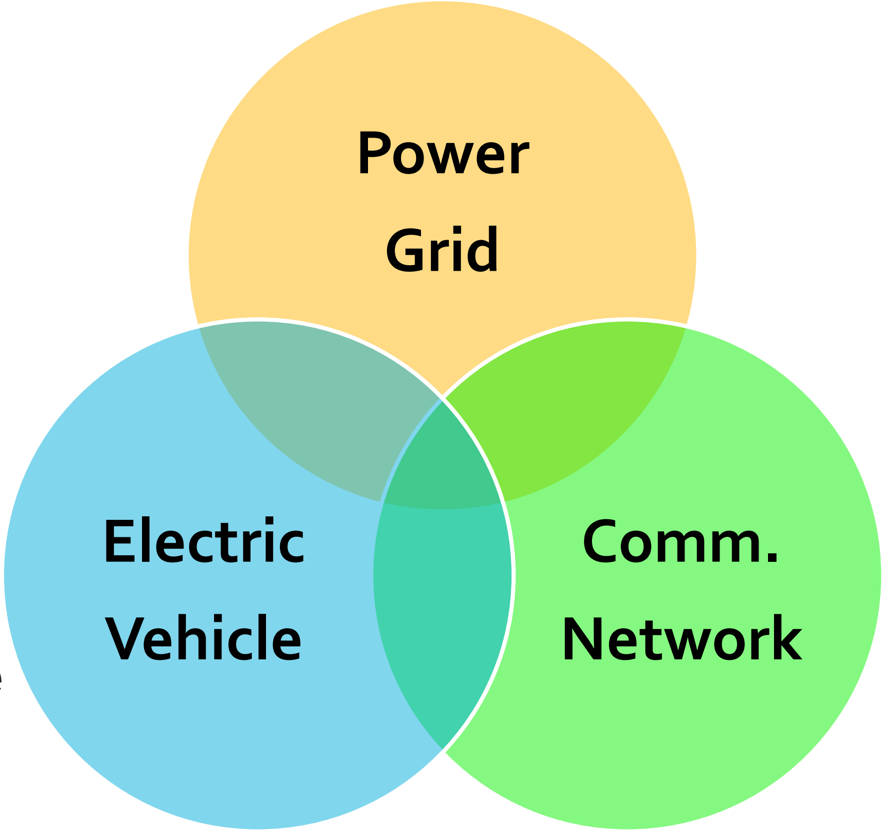
System Architecture based on IoT for Smart Campus Parking Lots

ICCAIS 2019
Riyadh, Saudi Arabia

Content

Future Trends

Future
Distribution Power System



Future
Electric Vehicle

Advanced
Comm. Network

Motivation

- ❑ **Smart grid is the future electric power system**
  - ✓ Support bi-directional energy and information flow between consumers and service provider
  - ✓ Enable improved reliability, stability and efficiency
- ❑ **Internet-of-Things (IoT) technology has received significant attention in various application domains**
  - ✓ Smart buildings, health care systems, agriculture, smart cities
- ❑ **IoT technology can be used for enabling smart grid achieving their goals in monitoring, protecting and controlling**
  - ✓ Incorporation of sensors, actuators and metering devices
  - ✓ Supporting various network functions and system automation
- ❑ **Smart grid is now supporting many new applications in the distribution power system**
  - ✓ Smart meters, distributed energy resources, electric vehicle and energy storage systems

Motivation

- **Electric vehicles are expected to play an important role due to**
  - ✓ Environmental and economic benefits
- **Integration of electric vehicles in the distribution power network represents complex problems**
  - ✓ Vehicles operation modes adopt a bidirectional energy flow between electric vehicles and the power grid
- **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
- **Less research work on the underline communication infrastructure for the electric vehicle system and even less for the comm. infrastructure of the distribution power system**

Objective

- Develop a management platform for charging electric vehicles in a university campus based on IoT technology

- Proposed architecture consists of three-layers
  - ✓ Power system layer
  - ✓ Communication network layer
  - ✓ Application layer

- Consider a real case study of a parking lot in a university campus

- Performance analysis and practical feasibility of communication network layer are evaluated and discussed

Campus Distribution Power System

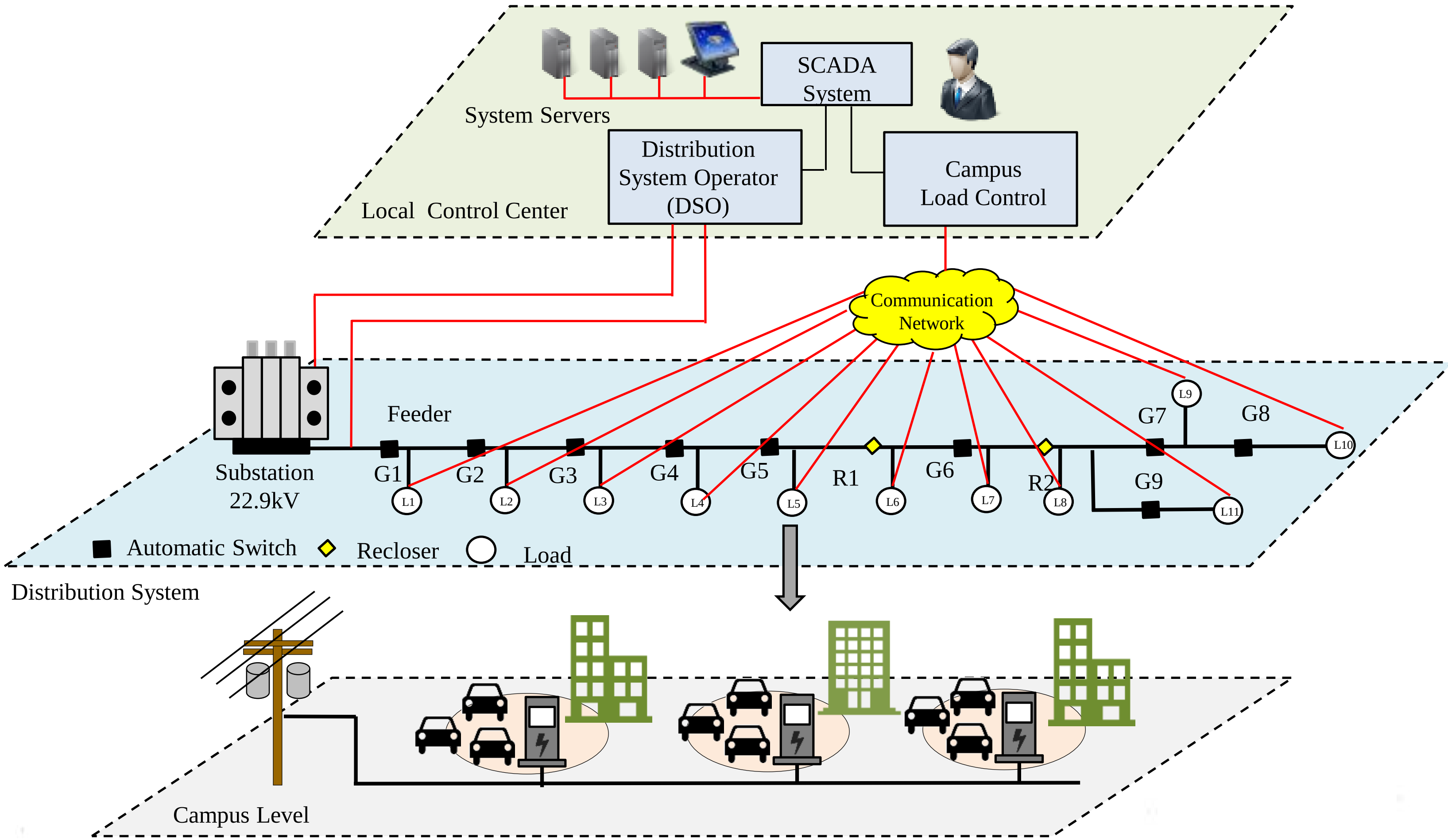
- **Power distribution systems represent an important part of electric power grid as it provide the final link between the transmission system and consumers where most of faults and outages occur**

- **In South Korea, the distribution system is operated and managed by Korea Electric Power Corporation (KEPCO)**
  - ✓ Total distribution automation system (TDAS) is responsible for monitoring and control of all the distribution systems

- **New technologies such as distributed energy resources and EVs**
  - ✓ Challenging task to control center operator and monitor and operate the distribution systems efficiently

- **Innovative utilization of communication network**
  - ✓ Supporting real-time monitoring and operation of the power distribution grid without a need for direct human intervention

Campus Distribution Power System



Campus Distribution Power System

- **The function of DAS can be divided into two parts:**
  - ✓ **management of the distribution power system**
  - ✓ management of end-user (consumer)

- **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
  - ✓ Fault isolation

Campus Distribution Power System

- **The function of DAS can be divided into two parts:**
  - ✓ management of the distribution power system
  - ✓ **management of end-user (consumer)**

- **Consumer management includes**
  - ✓ Customer power quality
  - ✓ Customer usage
  - ✓ Time-of-use (ToU)
  - ✓ Controlling of the end-user loads

IoT Architecture for Smart Campus Parking Lot

❑ Smart campus parking lot

- ✓ 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

- ✓ It consists of five basic components: electric vehicles, charging stations, electric power network, communication network and application system

IoT Architecture for Smart Campus Parking Lot

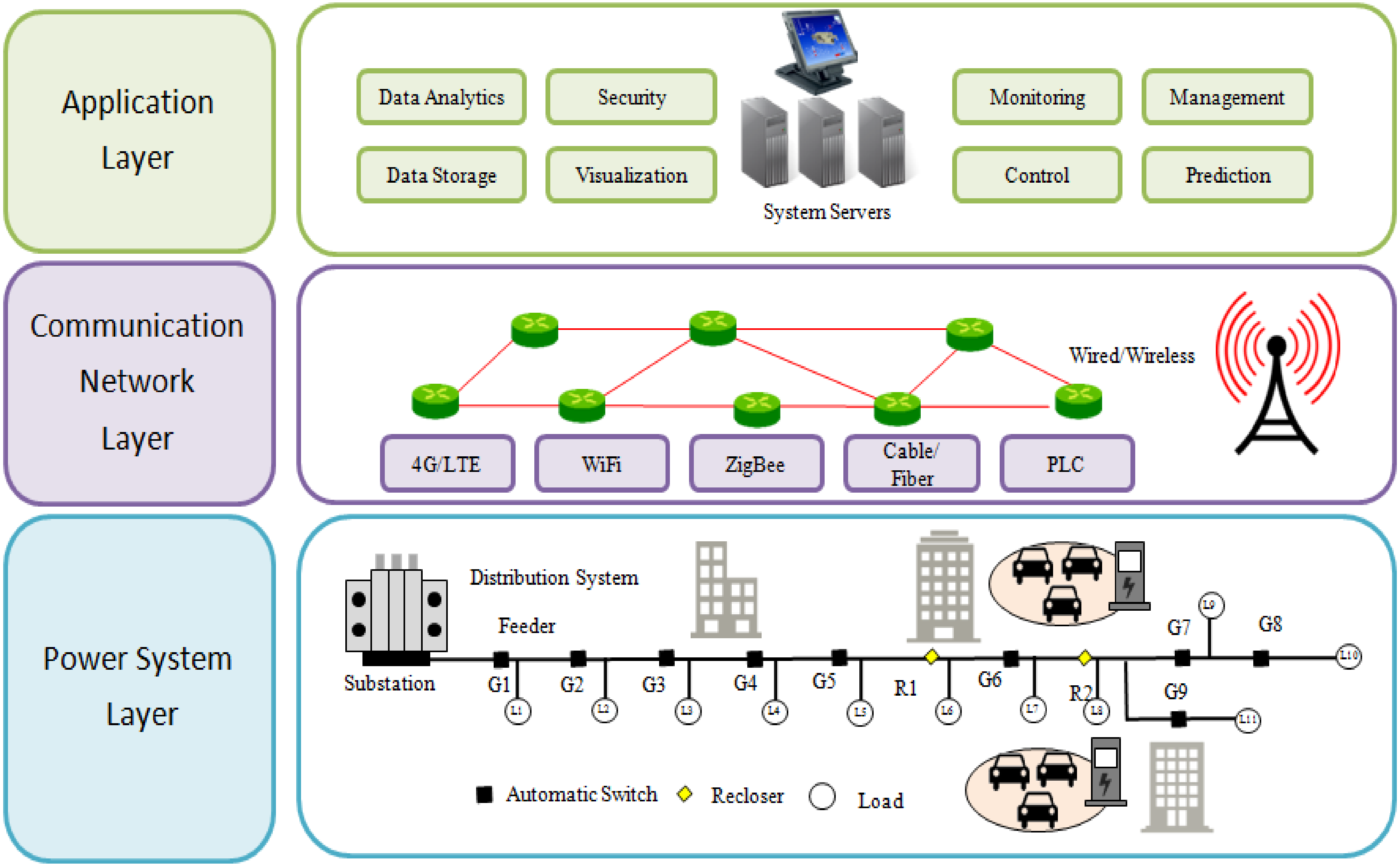
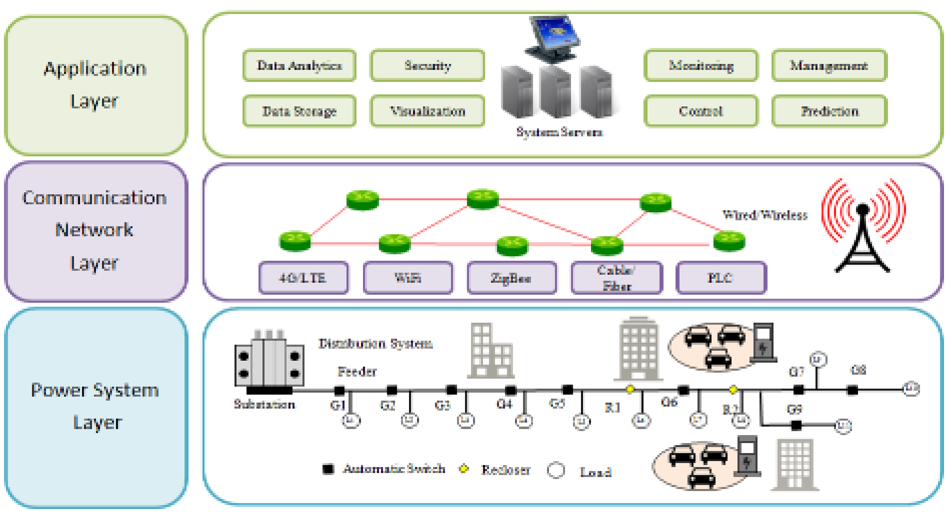


Fig. 1 IoT-based architecture for smart campus parking lots

IoT Architecture for Smart Campus Parking Lot

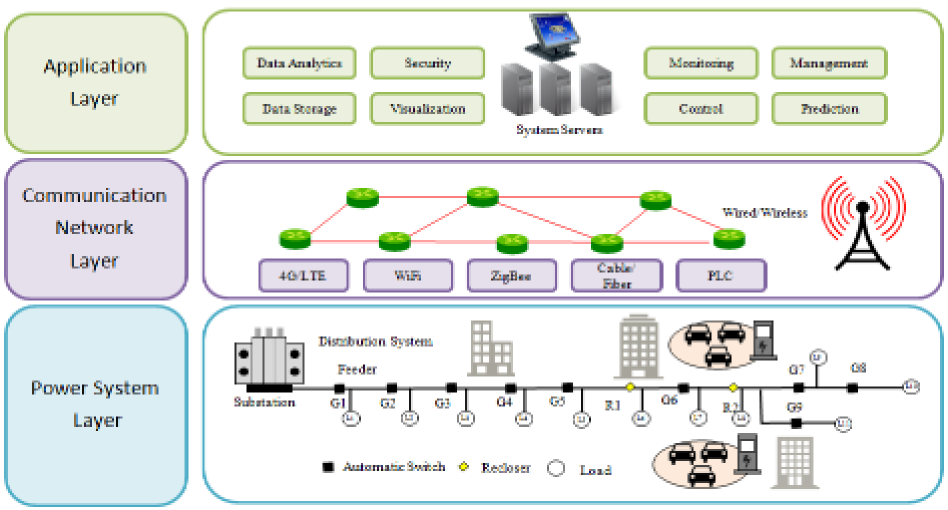
❑ Power System Layer

- ✓ Consists of electric vehicles, charging stations, metering devices, intelligent electronic devices, sensors and actuators
- ✓ Main objective 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



IoT Architecture for Smart Campus Parking Lot

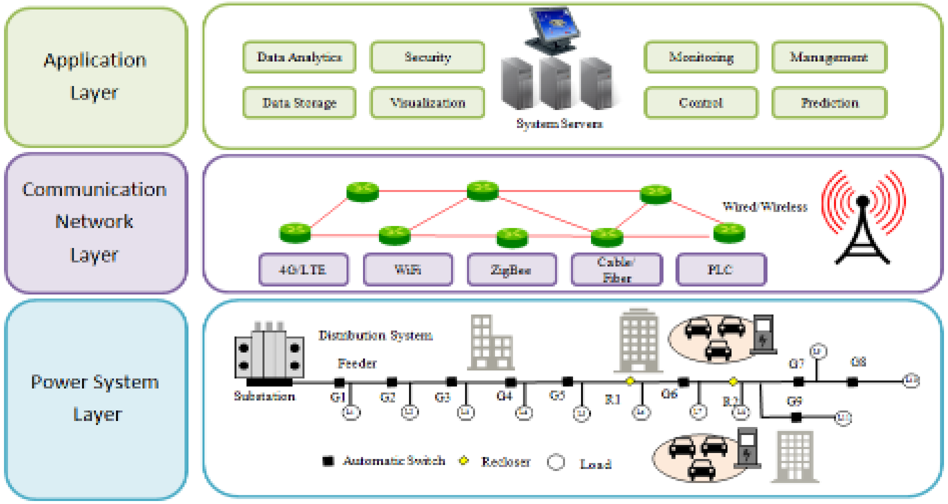
- Communication Network Layer
  - ✓ Main function is to transmit collected data from the electric vehicle system to the application layer
  - ✓ Various communication technologies which can be used
    - ✓ Wired: PLC, Ethernet, optical fiber, etc.
    - ✓ Wireless : WiFi, ZigBee, GPRS, 3G/4G, LTE, etc.
  - ✓ Different solutions can be implemented for different design configurations (based on the system requirements)



IoT Architecture for Smart Campus Parking Lot

❑ Application Layer

- ✓ Main function is real-time monitoring and control
- ✓ Data received from parking lot layer are processed for appropriate actions
- ✓ 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



Main elements of the smart campus parking lot

- **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)
  - ✓ Other elements including protection devices, CCTV, etc.
- **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

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

EPON Architecture for IoT-CAN

- **Ethernet Passive Optical Network (EPON) is considered for the campus distribution power system, which combines advantages of optical network technology and Ethernet**

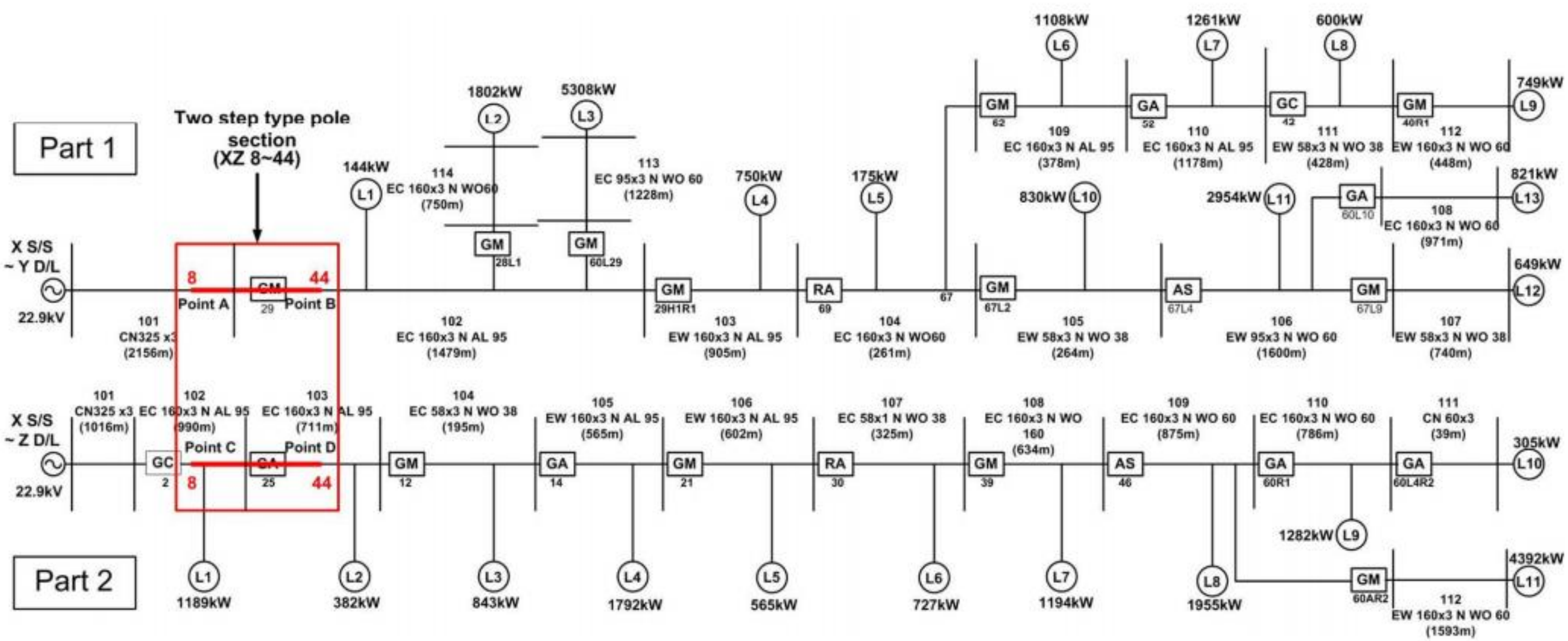
- **Communication network for the distribution power system supports low voltage transformers, smart meters, charging stations and distributed energy resources**

- **EPON consists of an optical line terminal (OLT), passive optical splitters (POSs), optical network units (ONUs), and optical distribution network (ODN)**

- **A real distribution power system is considered**
  - ✓ It consists of a substation, distribution lines, and loads
  - ✓ The system supports different types of protection devices such as automatic gas switches and automatic reclosers

EPON Architecture for IoT-CAN

- The **electric topology** consists of **two feeders** supplied by 22.9 kV
  - ✓ 22 protection devices and 2 reclosers
  - ✓ Power cables are concentric neutral cables and extra high voltage aluminum wire cables



EPON Architecture for IoT-CAN

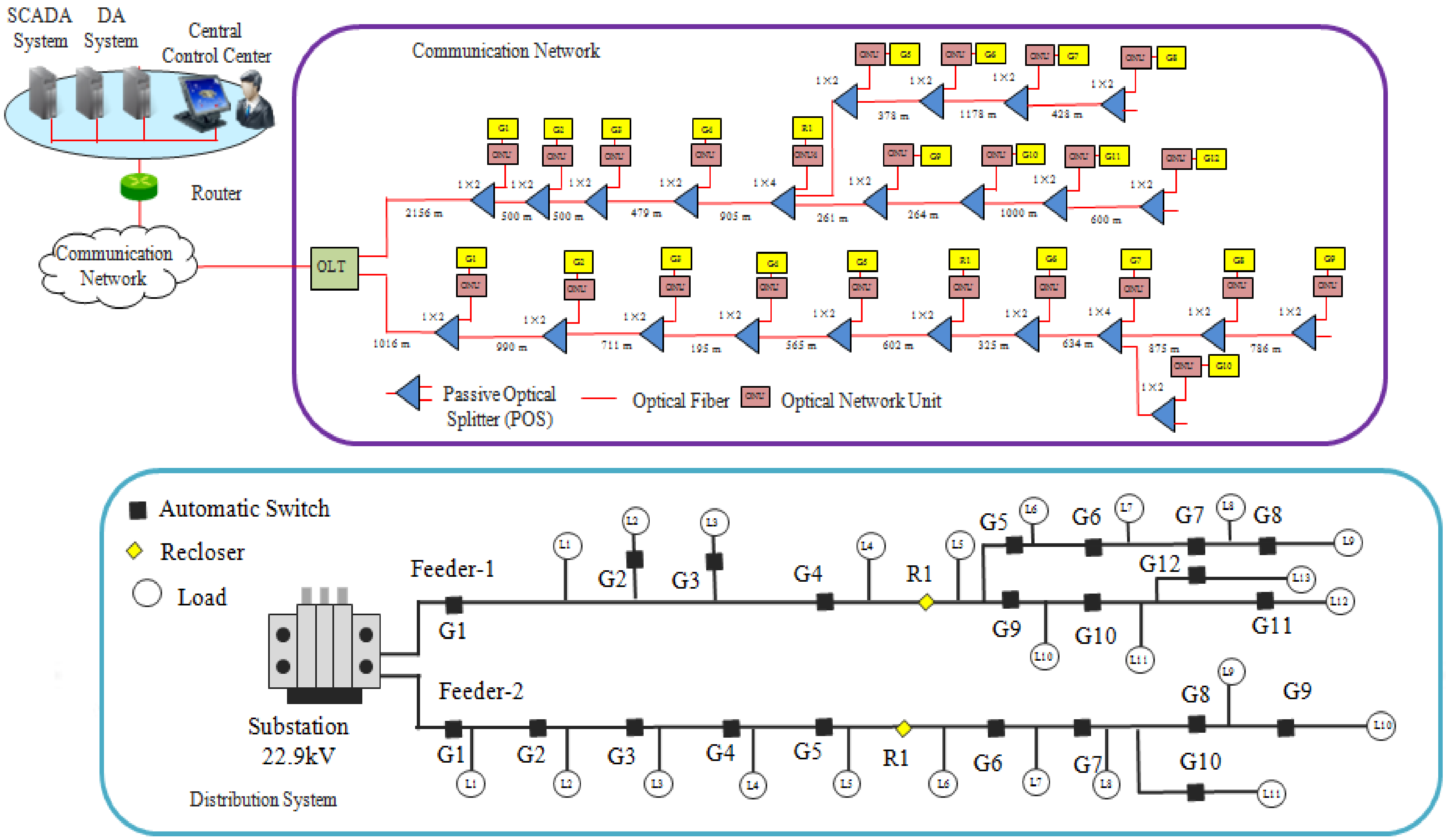


Fig. 2 Proposed EPON-based architecture for Campus distribution power system

Power Budget

- ❑ **Optical power budget is analyzed**
  - ✓ To ensure the received signal power is enough to maintain acceptable performance

- ❑ **IEEE 802.3ah → 26.0 dB → Upstream &Downstream**

$$\boxed{\text{Power Budget} = P_{tx} - P_{rx}}$$

P_{tx}, dBm → minimum transmitter launch power at the input of the optical link
P_{rx}, dBm → minimum sensitivity of the receiver at the output of optical link

IEEE STD 802.3 EPON Specifications

Parameter	Data rate	Standard	Power budget
EPON	1.25Gbps (D &U) 1000Base-PX20	IEEE 802.3ah	PX-20U 26dB PX-20D 26dB

Power Budget

❑ Sources of optical attenuation

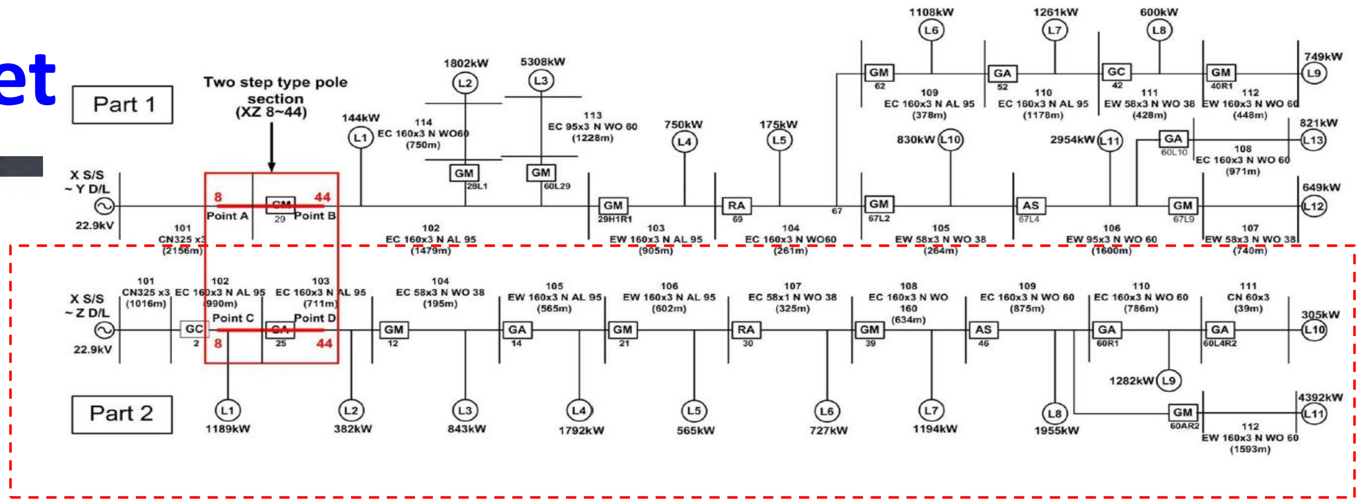
- ✓ Splitters (Loss POS)
- ✓ Connectors (Loss conn)
- ✓ Fiber cables (Loss fiber)

$$\Sigma \text{Loss}_{epon} = \Sigma \text{Loss}_{POS} + \Sigma \text{Loss}_{conn} + \Sigma \text{Loss}_{fiber}$$

Component insertion loss

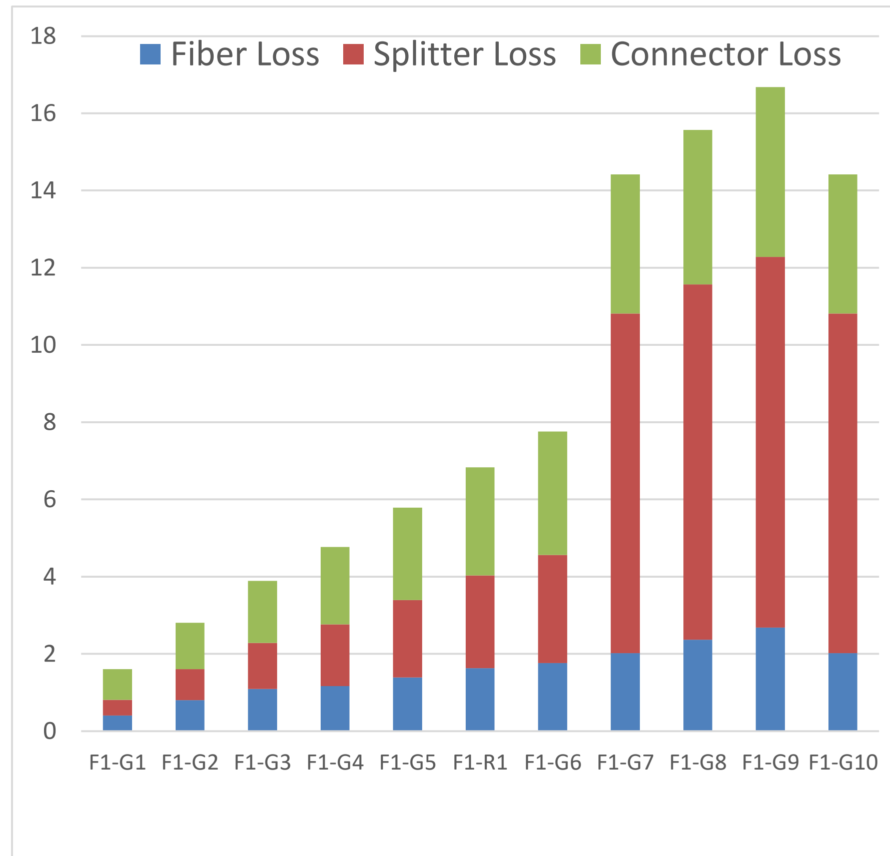
Parameter	Attenuation
Fiber	0.4 dB/Km
Connector	0.2 dB
Splitter	1×2 (5%:95%) 0.4 dB
	1×2 (50%:50%) 3 dB
	1×4 6 dB

Power Budget

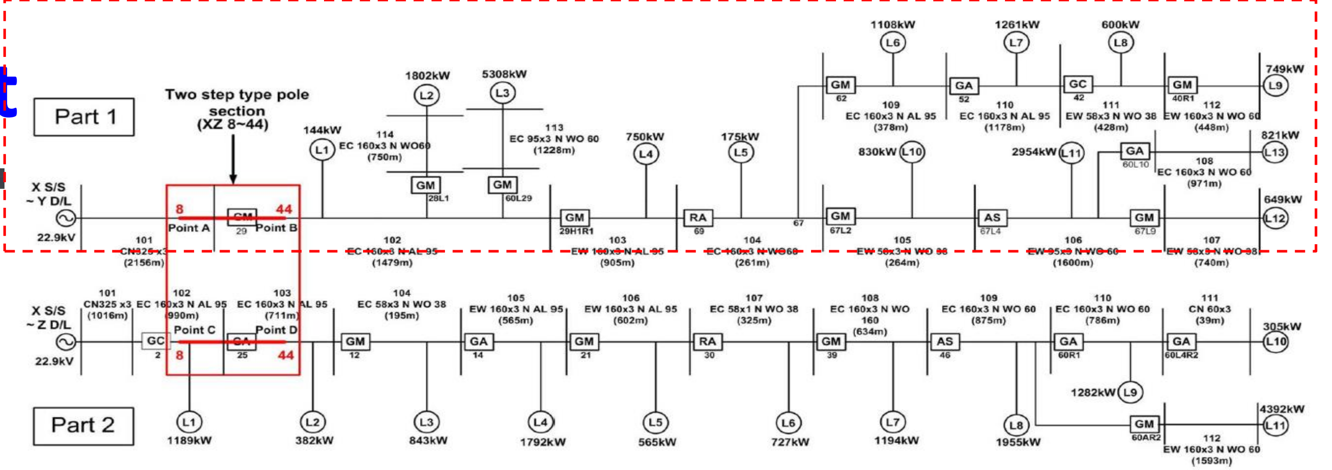


Results of power budget analysis for feeder 1

	Fiber Loss	Splitter Loss	Connector Loss	Total
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

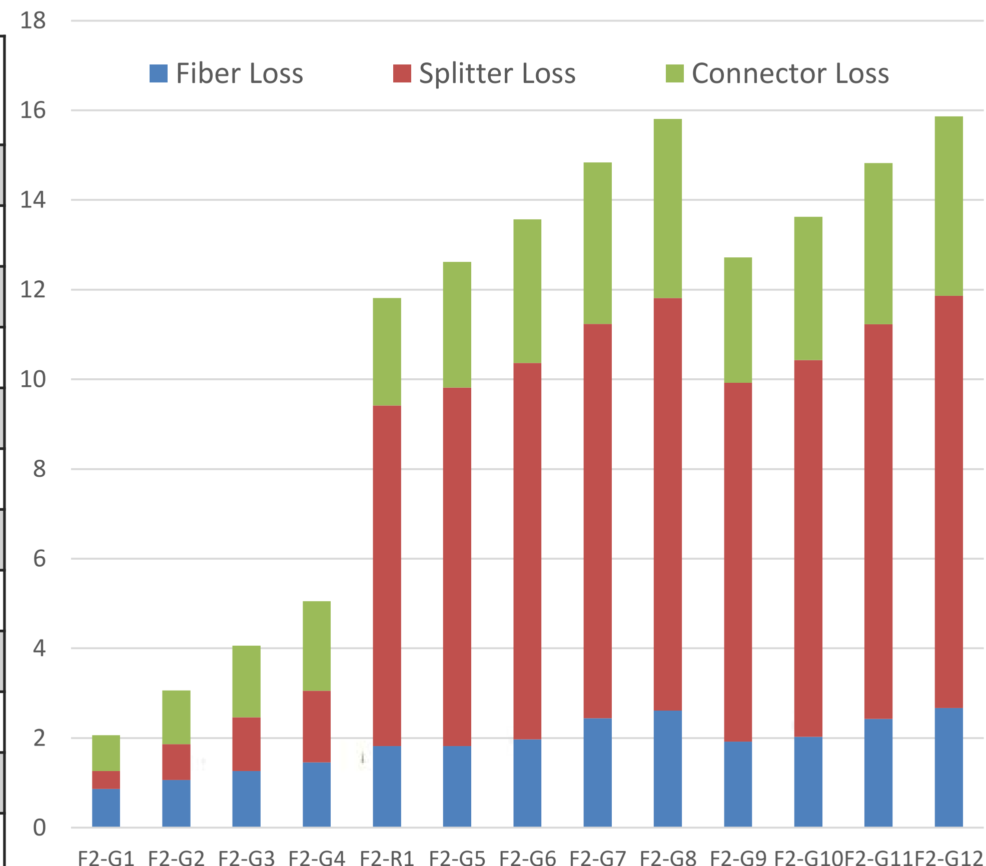


Power Budget



Results of power budget analysis for feeder 2

	Fiber Loss	Splitter Loss	Connector Loss	Total
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

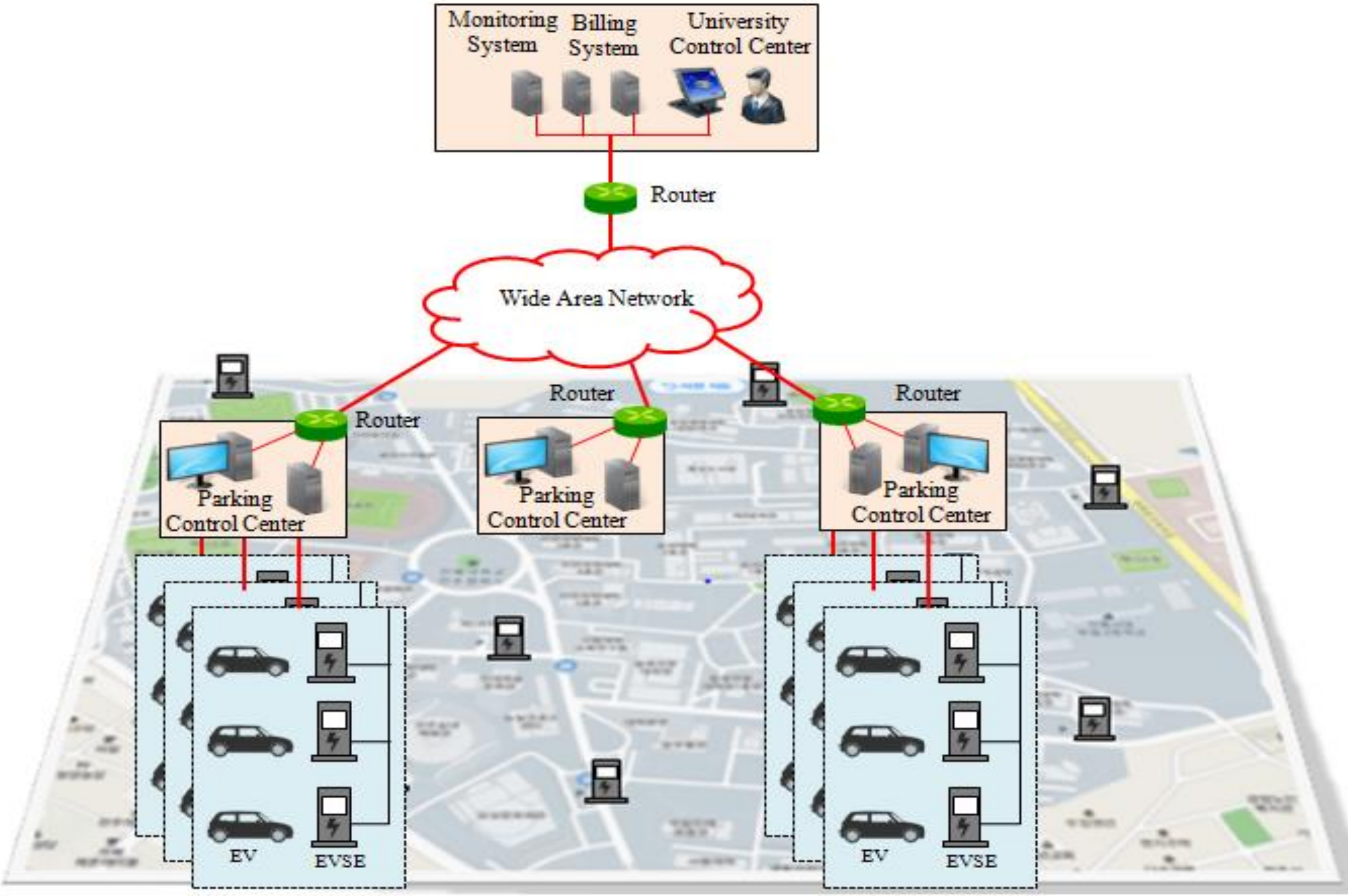


Network Modeling and Simulation

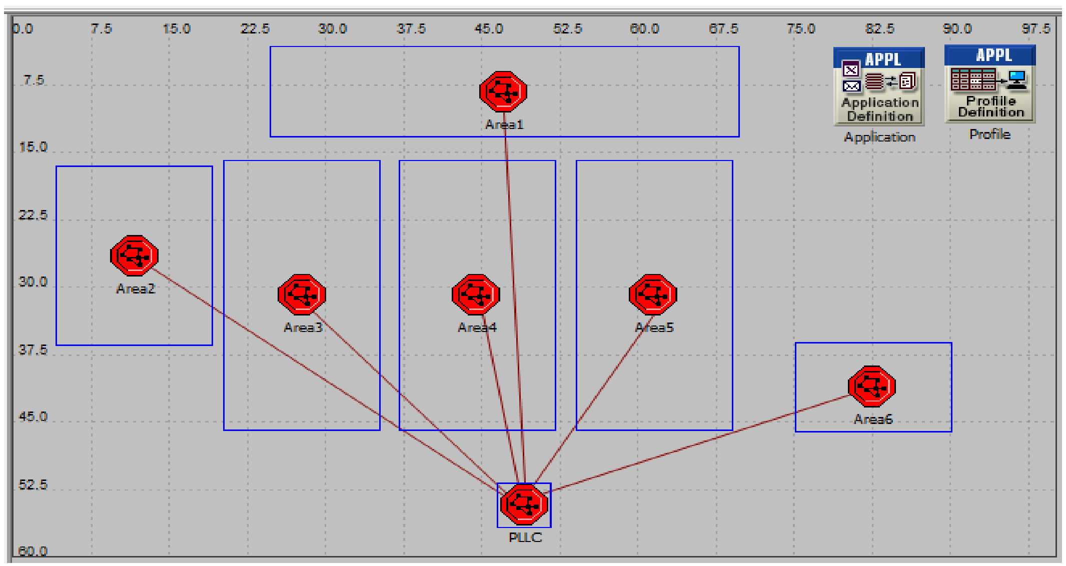
- **A simulation model is developed for a smart parking lot based on the real dimension of Engineering building (2-7) parking lot, Chonbuk National University, South Korea**
  - ✓ 100 parking spots

- **The communication network has been divided into seven subnets**
  - ✓ Six charging stations subnets
  - ✓ One local parking lot controller (PLCC) subnet
  - ✓ Communication network is configured with
    - ✓ Fast Ethernet (100 Mbps)
    - ✓ Gigabit Ethernet (1 Gbps)

Network Modeling and Simulation



Network Modeling and Simulation



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

Network Modeling and Simulation

- ❑ **Data transmitted through the communication network**
  - ✓ Charging stations information
    - ✓ station ID, charger ID, meter status and circuit breaker status
  - ✓ Electric vehicle information
    - ✓ vehicle ID, charging type, voltage, current, frequency, and power

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

Network Modeling and Simulation

Classification of EVCS data types based on operation modes

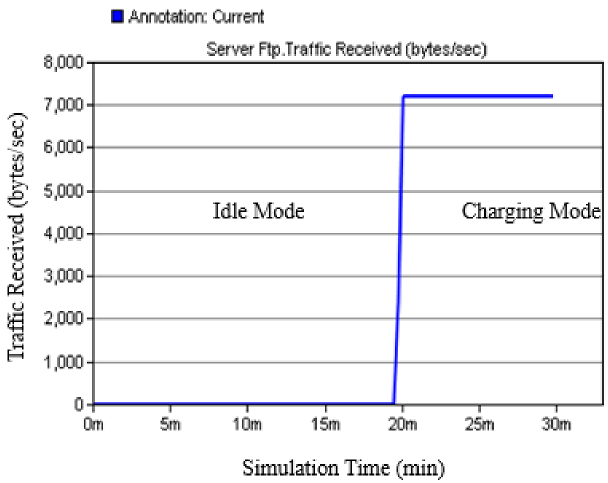
Data Type	Idle Mode	Charging Mode
Station ID	√	√
Charger ID	√	√
Meter status	√	√
Circuit Breaker Status	√	√
Vehicle ID	X	√
Charging Type	X	√
Voltage	X	√
Current	X	√
Frequency	X	√
Power	X	√

Measuring requirements for devices and sensors

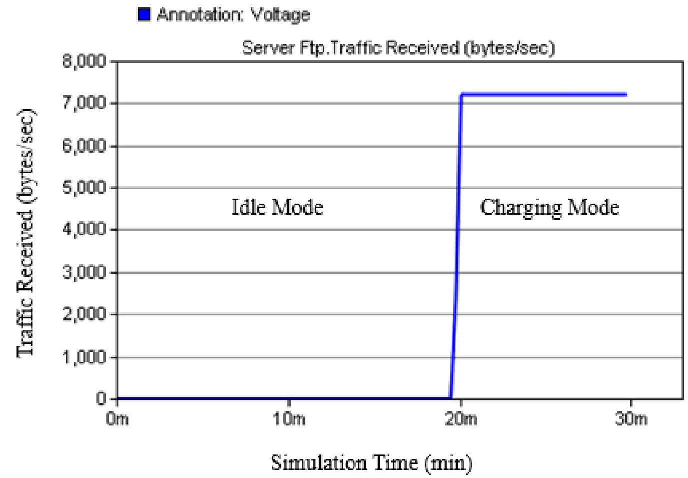
Measurement	Sampling Frequency	Data Rate (Bytes/s)	Direction
Status Information	1 Hz	2	PLLC/ Control Center
Power	5 Hz	10	
Frequency	10 Hz	20	
Voltage	360 Hz	720	
Current	360 Hz	720	

Network Modeling and Simulation

- Received traffic from IoT-CS at the parking lot control center with 10 charging stations (a) Current (b) Voltage (c) CB status (d) Meter status



(a)



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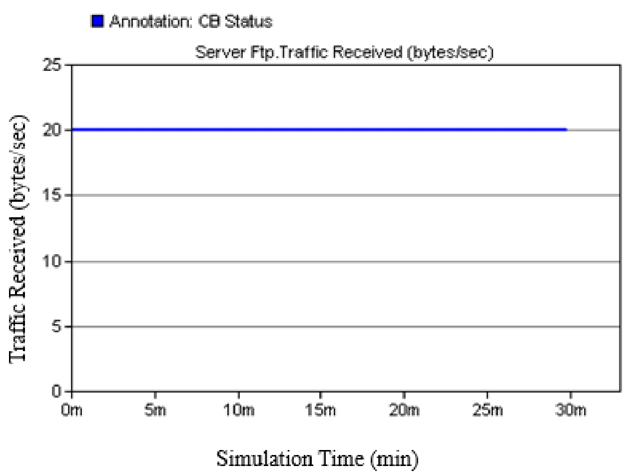
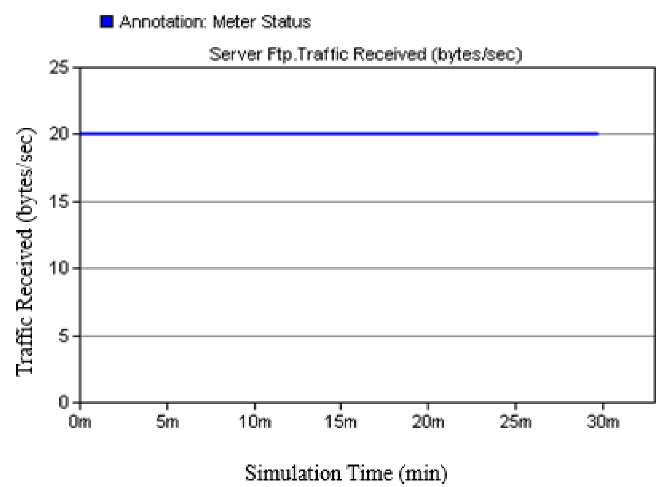


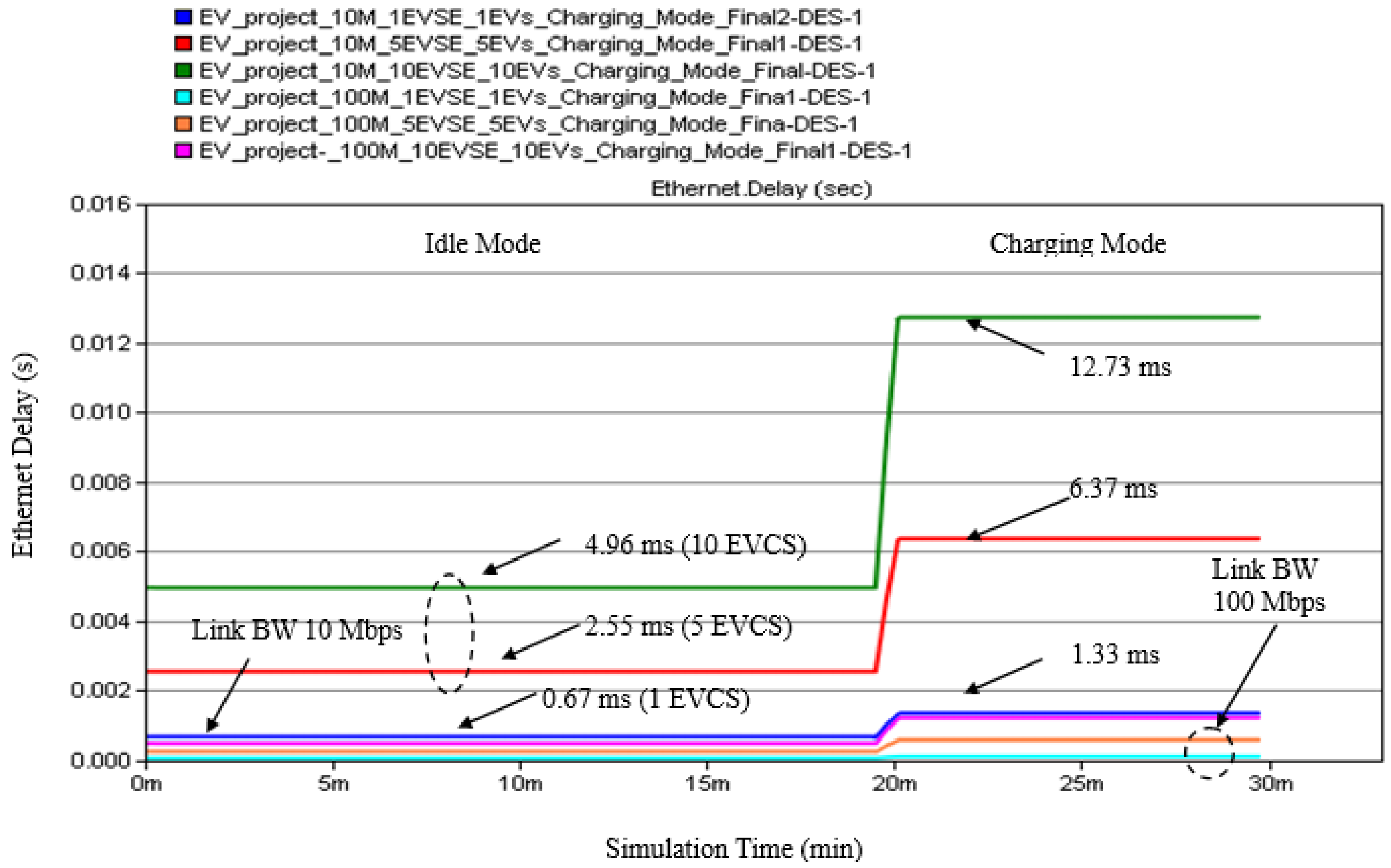
(c)



(d)

Communication Timing Requirements

- End-to-end delay for Ethernet-based architecture in a smart parking lot with 1, 5 and 10 charging stations



Communication Timing Requirements

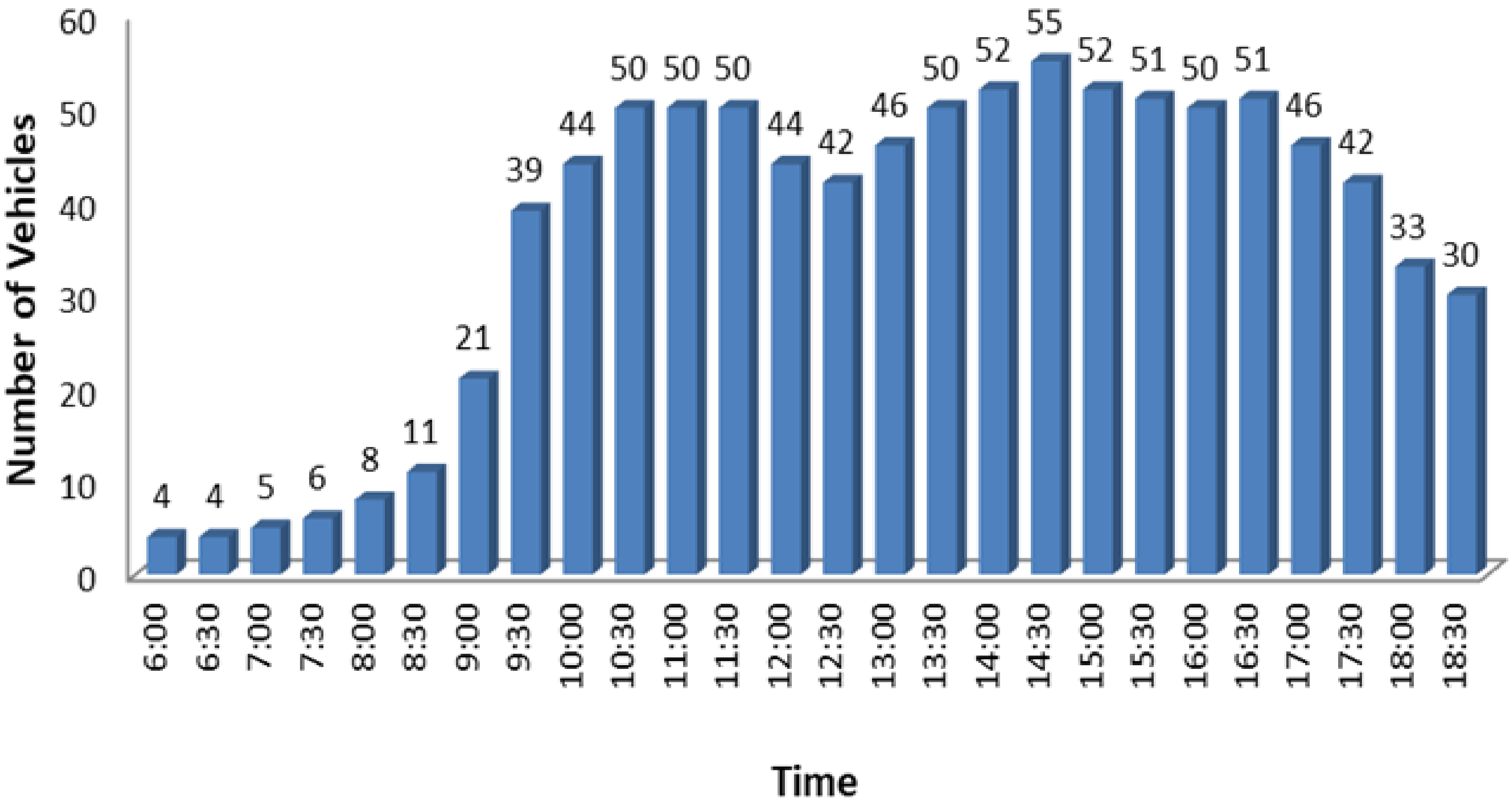
- ❑ **Latency requirements based on electric power system**
  - ✓ AM and SI are mapped for monitoring and control information
  - ✓ PCI from IED are mapped for protection information

Communication timing requirements based on IEEE 1646 standard

Information types	Delay Requirements
Protection Information	4 ms
Monitoring and Control Information	16 ms
Operation and Maintenance Information	1 s
Image files	10 s
Audio and Video data streams	1 s

Network Modeling and Simulation

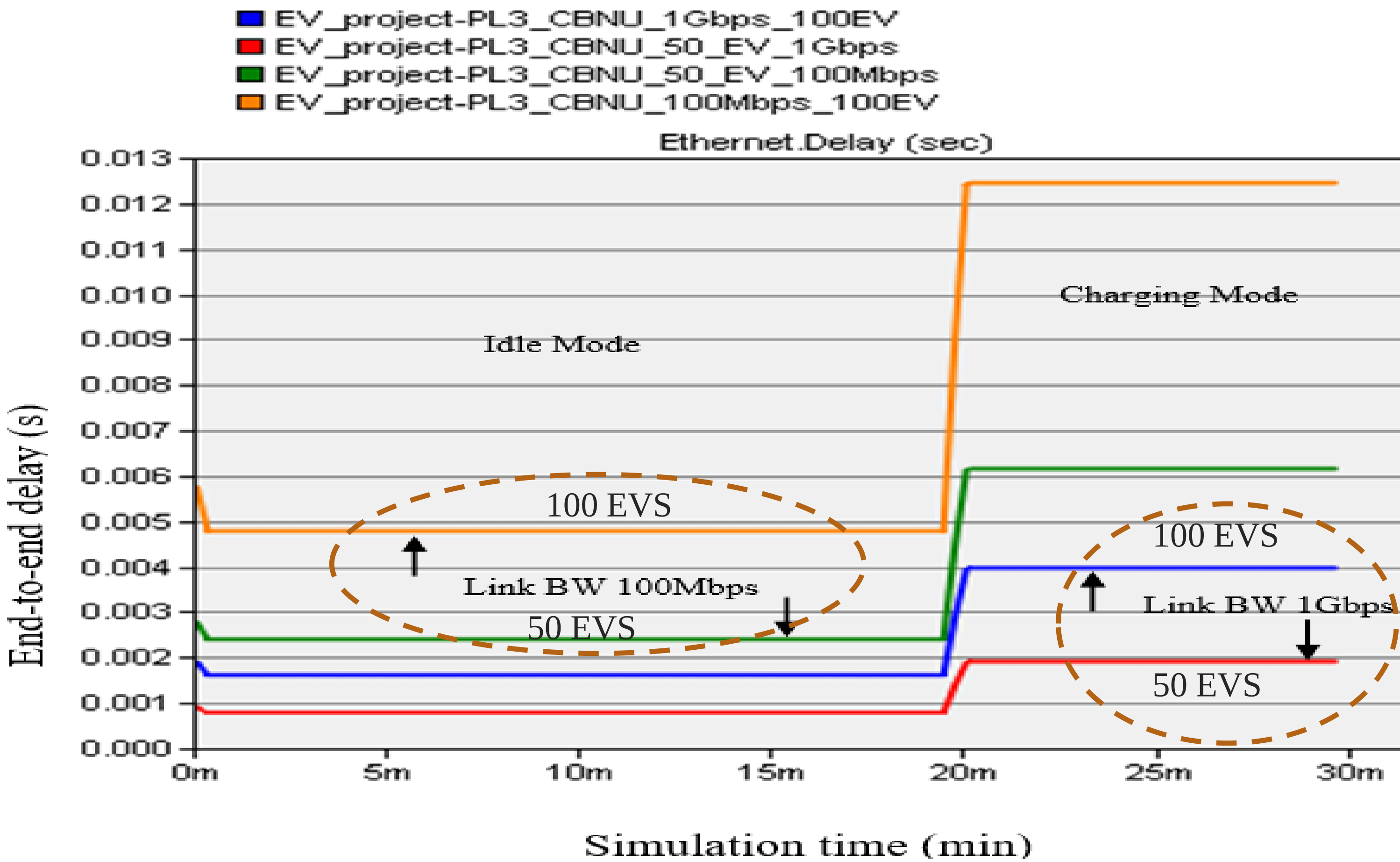
- A real vehicle arrival time is considered at engineering parking lot during a working day on 15 May, 2018



Typical parking utilization during weekdays (CBNU-PL3), 15 May 2018

Network Modeling and Simulation

- End-to-end delay for a smart parking lot with 50 & 100 charging stations



Conclusion & Future Work

- ❑ **Proposed a system architecture for monitoring electric vehicles charging system based on IoT in a university campus**
  - ✓ power system, communication network and application
- ❑ **Developed EPON-based communication network architecture for campus power network in order to monitor feeders, transformers and protection devices**
  - ✓ Optical power budget is analyzed showed that the proposed architecture is sufficient for operation
- ❑ **Built a communication network model for a smart parking lot based on OPNET**
  - ✓ A channel capacity with 1 Gbps was sufficient to ensure amount of latency required by electric power system
- ❑ **The work will be extended to support multiple parking lots of the university campus**

Questions/Comments

Thank you

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