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Inter-Operator Charging Station Access Simulator

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Abstract

The use of battery-based electric vehicles (BEV) continues to increase, so the ease of using the Public Electric Vehicle Charging Station (SPKLU) infrastructure for recharging electric vehicle batteries must be considered to enhance public confidence. One of the problems in using electric vehicles is the concern about long-distance travel (range anxiety) due to limited battery capacity and the minimal number of SPKLUs. This research aims to provide a tool to simulate access to charging stations across operators using the EV roaming method. In this approach, charging station users only need to register with one SPKLU operator to access charging stations owned by other operators. This research develops a set of simulation models, called the EV Roaming Simulator, to simulate several EV roaming scenarios concerning the basic functionality of four state-of-the-art EV roaming protocols. The simulator consists of three Open Charge Point Protocol (OCPP)-based models: the Charge Point Model, the Central System Model, and the National Access Point Model, each representing charging stations, central systems, and roaming hubs. The simulator is capable of executing the given EV roaming scenario. It has the potential to be further developed and used in developing various newly proposed EV roaming systems.

Keywords: *electric vehicle battery; SPKLU infrastructure; long-distance travel; EV roaming; simulation*

1. Introduction

Battery-based electric vehicles (BEV) are increasingly used in various countries, including Indonesia. Electric vehicles are considered an important part of a sustainable transportation system, as they have the potential to reduce carbon emissions, improve air quality, and strengthen the resilience of national power grids. According to a report by the International Energy Agency (IEA), the number of electric cars worldwide is increasing significantly, with nearly 40 million on the road by 2023, compared to 26 million units in 2022 (IEA, 2024). In addition, the IEA also predicts that the number of global electric vehicles will reach 85 million units by 2025 and 270 million by 2030, with these predictions excluding two-wheelers and three-wheelers (IEA, 2022).

According to the Indonesian Automotive Industry Association (Gaikindo), there has been a significant increase in sales of electric cars in Indonesia, as shown in **Figure 1**. Meanwhile, the Indonesian government targets 2 million electric cars to be used in Indonesia by 2030. It will accelerate supporting infrastructure development to realize the national electric vehicle ecosystem (Ministry of Energy and Mineral Resources, 2024).

Publicly accessible electric vehicle battery recharging infrastructure generally refers to charging stations connected to the grid and equipped with socket outlets to deliver power to electric vehicles. A vehicle inlet receives the power on the electric vehicle side. These two parts are connected by a cable with an interface as a plug at one end and a vehicle connector at the other, as shown in **Figure 2**. This accessory terminology is defined in the IEC 62196 standards published by the International Electrotechnical Commission (IEC). The battery in an electric car can be recharged with alternating current (AC) or direct current (DC). In AC charging, the On Board Charger in the electric car converts AC to DC to store energy in the battery, as shown in **Figure 2**. Meanwhile, in DC charging, the conversion from AC to DC is performed by the charging station (Dini et al., 2023). Of course, the converters in charging stations have much greater capabilities than those in electric vehicles. Therefore, some charging stations, known as ultra-fast chargers, can deliver up to 350 kW and recharge electric car batteries quickly.

Currently, electric vehicle drivers can only access charging stations belonging to the operator with whom they are registered as users. There is no collaboration among Public Electric Vehicle Charging Station (SPKLU) operators in Indonesia to enable inter-operator access to charging stations. There is no agreed-upon

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roaming protocol among SPKLU operators for EV roaming. As a result, electric vehicle drivers have been unable to use charging stations operated by other providers. This is a problem because the charging infrastructure needed to support long-distance electric vehicle travel is still very limited (Yang et al., 2021). On the other hand, it is not easy to share real-time data among SPKLU operators, mainly due to interoperability constraints of data communication networks on electric vehicle charging infrastructure (Asensio et al., 2021).

To support the realization of SPKLU operators in Indonesia, the government has issued Minister of Energy and Mineral Resources Regulation Number 1 of 2023 concerning the Provision of Electric Charging Infrastructure for Battery-Based Electric Motor Vehicles. Article 14 stipulates the obligation of each SPKLU operator to have an online application for the recharging process of battery-based electric vehicles. The online application must provide features that are interoperable with online applications managed by other SPKLU operators. It must be integrated with the single gateway system owned by the Directorate General of the Ministry of Energy and Mineral Resources. This integration must be done one year after promulgating the ministerial regulation.

Charging stations generally implement the Open Charge Point Protocol (OCPP), which has been de facto accepted as a standard. In OCPP, it is stipulated that the charging station (Charge Point) communicates with the central system (Central System) in the charging cycle of the electric vehicle within the internal SPKLU operator. The charging station is the client, and the central system is the server (Open Charge Alliance, 2017). Tokens, such as smart cards, access the charging stations. OCPP 1.6 is the most popular version, which provides the option of Simple Object Access Protocol (SOAP) or JavaScript Object Notation (JSON) via a WebSocket connection (JSON/WebSocket). This research chose

Table 1. Basic functionality of EV roaming protocols (Kam & Bekkers, 2020)

Basic Functionality	OCHP 1.4	OICP 2.2	MIP 0.7.4	OCPI 2.2
Roaming via hub	√	√	√	√
Peer-to-peer roaming	OCHPDirect 0.2		√	√
Remote start/stop	√	√	√	√
Authorization	√	√	√	√
Billing	√	√	√	√
Synchronous data exchange		√	√	√
Asynchronous data exchange	√	√	√	√

Table 2. Data element description of DataTransfer.req() in OCPP (Open Charge Alliance, 2017)

Data Name	Description
vendor	Required. Implementation identification code.
messageId	Optional. Additional identifier code.
data	Optional. Data in the form of a string object with no length requirement.

Table 3. Data element description of DataTransfer.req() in OCPP (Open Charge Alliance, 2017)

Data Name	Description
status	Required. A status that indicates whether or not the data transfer was successful.
data	Optional. The response contains the requested data.

Table 4. List of supporting devices for EV Roaming Simulator development

No.	Device	Specification / Version
1	*Smart* cards and *readers*	ISO/IEC 14443
2	Computer	Windows 10 OS
3	*Java* programming IDE	Apache NetBeans IDE 19
4	Central system platform	RWTH Aachen University SteVe 3.4.5
5	*Java* JDK Package	JDK 18.0.2
6	WebSocket API	Java-WebSocket 1.5.1
7	JSON Package	json 20190722
8	Smart card API	jnasmartcardio 0.2.7

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Table 5. Parameters for National Access Point Model

No.	Parameters	Description
1	service_port	WebSocket port number to provide the service (e.g., '9095')
2	nap_service	Service availability info access point (e.g., '/NAP/checkpoint/CPO')
3	endpoint	Access point for Central System Model (e.g., '/NAP/endpoint/')
4	cpo_id	Central System Model identifier code (e.g. 'CPO')
5	known_token	Recognized token code (e.g., '0102030409')
6	other_central_ system_uri	Other central system service access points (e.g., 'ws://192.168.1.7:9000/ steve/websocket/service/')
7	charge_box_id	Identifier code for obtaining services from other central systems (e.g., 'BRINTEST')

Table 6. Parameters for Central System Model

No.	Parameters	Description
1	service_port	WebSocket port number to provide the service (e.g., '9090')
2	nap_service_uri	Access point to ensure the availability of EV roaming services from the National Access Point Model (e.g., 'ws://192.168.1.7:9095/ NAP/checkpoint/CPO')
3	endpoint	Access point for Charge Point Model (e.g., '/service/endpoint/')
4	charge_box_id	Charge Point Model identifier code (e.g. 'CP')
5	known_token	Recognized token code (e.g., '0102030408')
6	national_access_point_uri	EV roaming service access point of the National Access Point Model (e.g., 'ws://192.168.1.58:9095/NAP/endpoint/CPO')

JSON/WebSocket-based OCPP 1.6 because the latest version no longer supports SOAP.

This research develops a set of OCPP-based application programs called EV Roaming Simulator to simulate the basic functionality of four state-of-the-art EV roaming protocols, namely Open Clearing House Protocol (OCHP), Open InterCharge Protocol (OICP), eMobility Inter-operation Protocol (MIP), and Open Charge Point Interface (OCPI). The basic functionalities of the four protocols include (1) roaming via a hub, (2) peer-to-peer roaming, (3) remote start/stop, (4) authorization, (5) billing, (6) synchronous data exchange, and (7) asynchronous data exchange, as shown in **Table 1** (Kam & Bekkers, 2020). In the context of EV Roaming Simulator, OCPP is used to communicate between the central system and charging stations within the SPKLU operators and EV roaming among SPKLU operators. Meanwhile, due to technical considerations, the remote start/stop feature is not included in the implementation of the EV Roaming Simulator.

Figure 1. Electric Car Sales Trends in Indonesia (Gaikindo, 2024)

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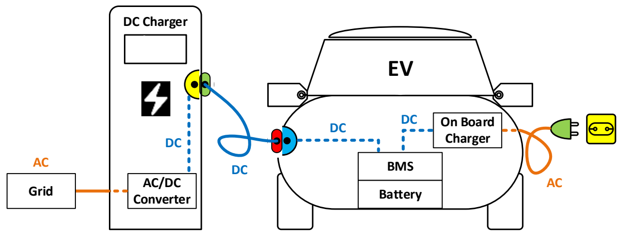

Figure 2. AC and DC battery recharging scheme

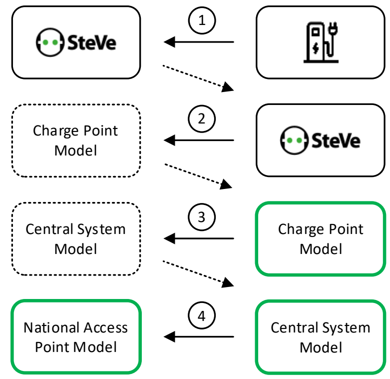

Figure 3. Simulation model development procedure

The significance of the EV Roaming Simulator, session across SPKLU operators without using actual products, in this case, actual charging station products and electric vehicles; can be used as a reference to understand charging sessions within SPKLU operators and in EV roaming among SPKLU operators; release dependence on EV roaming protocols managed by overseas parties,; can be used as a basis for charging standards and regulations across SPKLU operators in Indonesia and; can be further developed to simulate various EV roaming systems, which are new proposals.

2. Materials and Methods

The EV Roaming Simulator consists of three simulation models: the National Access Point Model, Central System Model, and Charge Point Model, representing the roaming hub, central system, and electric vehicle charging station. The methods used in the development include WebSocket cascades to connect the Charge Point Model to the Central System Model to the National Access Point Model, as well as OCPP functionality enhancement through the utilization of DataTransfer protocol data units to encapsulate the functions required in EV roaming.

The details of the actors and roles applied to the EV Roaming Simulator are, The National Access Point Model functions as a roaming hub that supports EV roaming and is programmed as a WebSocket client and WebSocket server. The Central System Model performs central system functions in the internal SPKLU operator and is programmed as a WebSocket client and a WebSocket server. The Charge Point Model performs the function of an electric vehicle charging station internal to the SPKLU operator and is programmed as a WebSocket client.

DataTransfer is a flexible protocol data unit that allows adding functionality that is not yet available. In EV roaming, DataTransfer can bring a variety of new functionalities by placing them as JSON objects on the 'data' data element. This data element is capable of handling string objects of unlimited size. The data element details of DataTransfer (request-response pair)

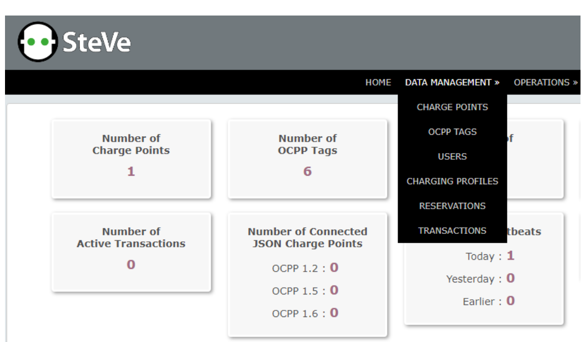

Figure 4. SteVe platform interface

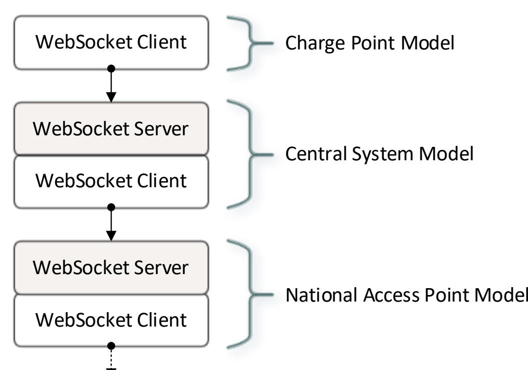

Figure 5. EV roaming simulator with WebSocket cascade

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are shown in **Table 2** and **Table 3**. Meanwhile, Gebauer et al. (2022) discuss using DataTransfer for confidential data exchange.The list of hardware and software supporting the development of the EV Roaming Simulator, among others, is shown in **Table 4**.

Java was chosen as the programming language for all three simulation models. Here, an open-source central system platform developed at RWTH Aachen University, called SteVe (IDSG, 2020), serves as a functional reference in generating all required simulation models. The interface of the SteVe platform is shown in **Figure 4**. Steve supports up to OCPP 1.6.

In **Figure 3**, it is illustrated that after confirming the reliability of SteVe as a central system in handling

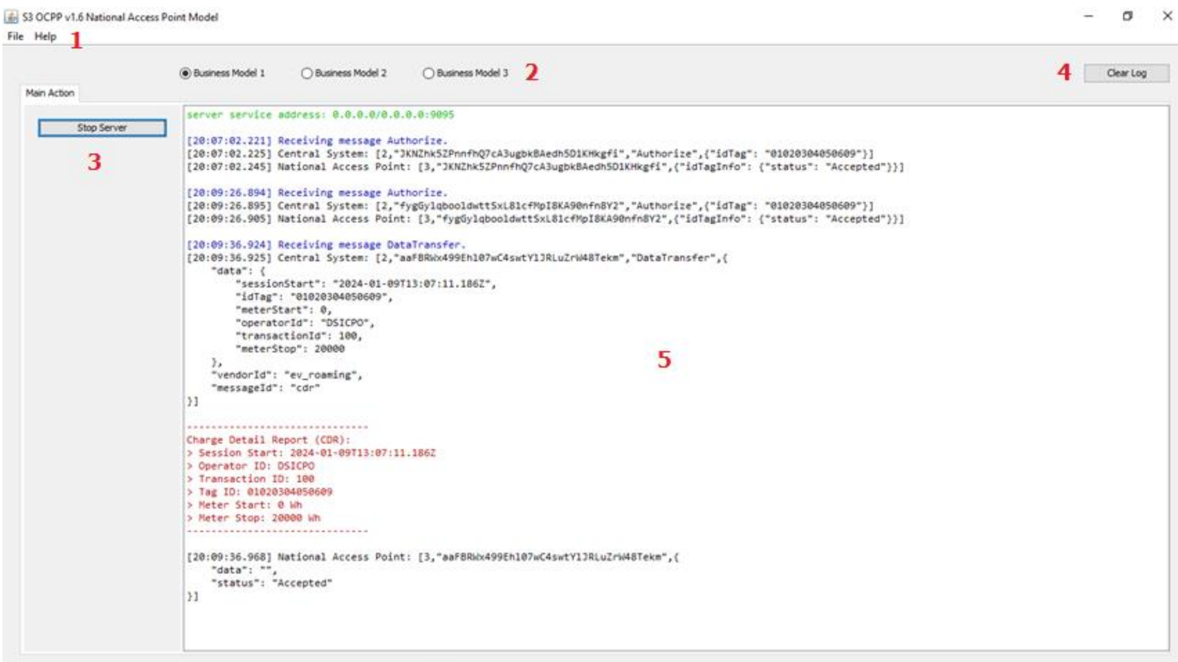

Figure 6. National Access Point Model Interface

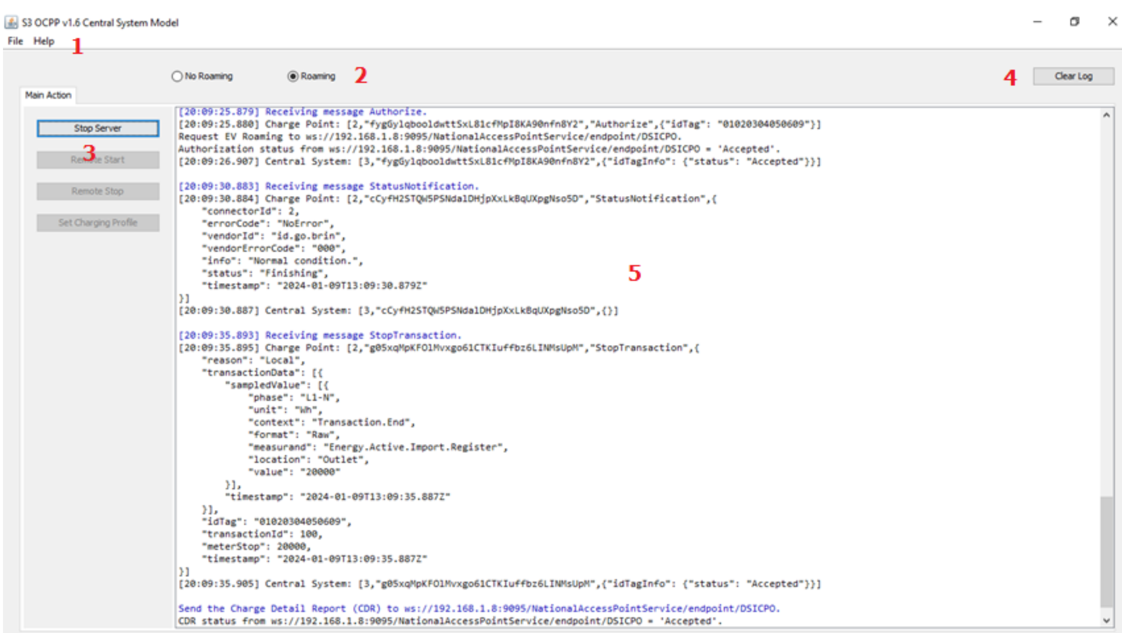

Figure 7. Central System Model Interface

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Table 7. Parameters for Charge Point Model

No.	Parameters	Description
1	central_system_ URI	Central System Model service access point (e.g., 'ws://192.168.1.12:9090/ service/endpoint/')
2	charge_box_id	Charge Point Model identifier code (e.g. 'CP')
3	authentication_ data	The code of the token that made the transaction (e.g., '0102030407')
4	delay_per_ message	Time lag in milliseconds for communication between the Charge Point Model and the Central System Model (e.g., '2000')
5	meter_value_ iteration	Number of energy consumption data notifications informed to the Central System Model in one charging cycle (e.g. '4')

actual charging stations, SteVe is used as a reference for creating the Charge Point Model. The same method is applied when creating the Central System Model, which takes the created Charge Point Model as a reference, and the National Access Point Model, which takes the created Central System Model as a reference. The Charge Point Model, Central System Model, and National Access Point Model are connected using the WebSocket cascade method, as shown **in Figure 5**. This connection creates a virtual channel for two-way data exchange that supports seamless communication for EV roaming or other purposes. When a WebSocket client actor sends data to a WebSocket server, the server can forward it to another server via another WebSocket connection, and so on, until the data reaches its final destination.

In the three simulation models, namely the National Access Point Model, Central System Model, and Charge Point Model, some parameters must be set before each simulation model is run. The parameter values for each simulation model are contained in the "app.conf" file. The details are shown in **Table 5**, **6**, and **7.**

3. Results and Discussion

The user interface of the National Access Point Model is shown in **Figure 6**. The features in the user interface of the National Access Point Model are, the File menu contains the <Exit> option to end the National Access Point Model, and the Help menu contains the <About> option to display information about the National Access Point Model. <Business Model 1>, Business Model 2>, and Business Model 3> run scenario two, scenario three, and scenario four, respectively, as described by (Priyasta et al., 2023). The <Start/Stop Server> button starts or ends the National Access Point Model service, the <Clear Log> button clears the

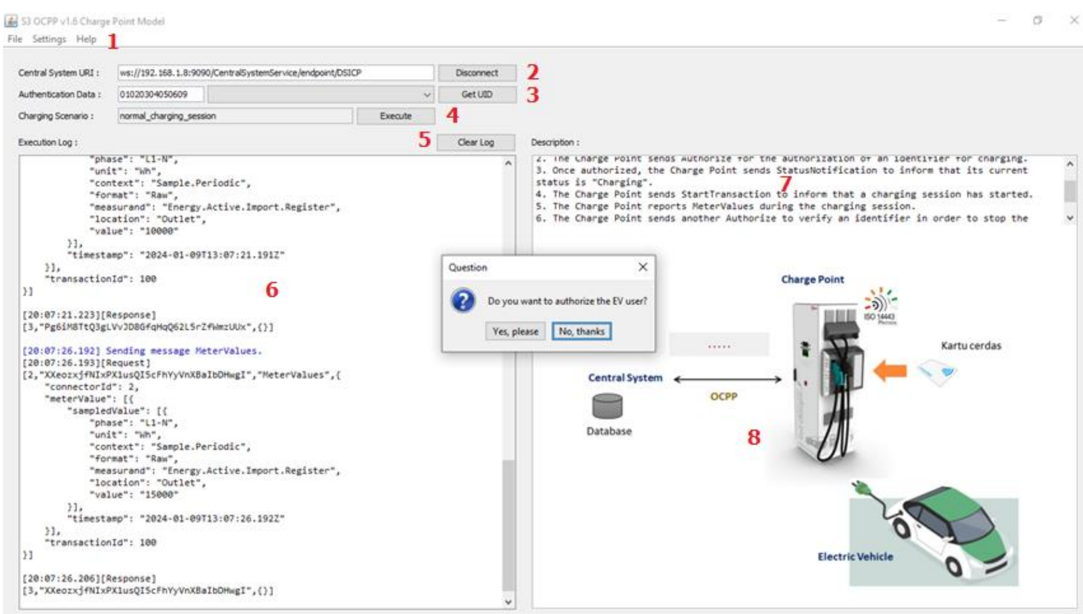

Figure 8. Charge Point Model Interface

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communication records in the log panel section, the log panel is used to display communication records.

The user interface of the Central System Model is shown in **Figure 7**. The features in the user interface of the Central System Model are as follows, the File menu contains the <Exit> option to end the Central System Model, and the Help menu contains the< About> option to display information about the Central System Model. <No Roaming> and <Roaming> are options not to run and run EV roaming, the <Start/Stop Server> button starts or ends the Central System Model service, the <Clear Log> button clears the communication records in the log panel section, the log panel is used to display communication records.

The user interface of the Charge Point Model is shown in **Figure 8**. The features present on the user interface of the Charge Point Model are, the File menu contains the <Exit> option to end the Charge Point Model, and the Help menu contains the <About> option to display the Charge Point Model information. The section labeled Central System URI contains the Central System Model access point parameters whose default values come from the "app.conf" file, and the <Connect/Disconnect> button is used to connect or disconnect with the Central System Model. The section labeled Authentication Data contains the token data parameters of the user performing the transaction, with the initial value (default) coming from the "app.conf" file, and the <GetUID> button is used to get the user token data through the smart card reader, in this case, the Unique Identifier (UID) of the smart card. The <Execute> button executes the charging session based on the EV roaming scenario. The <Clear Log> button clears the communication records in the log panel section. The log

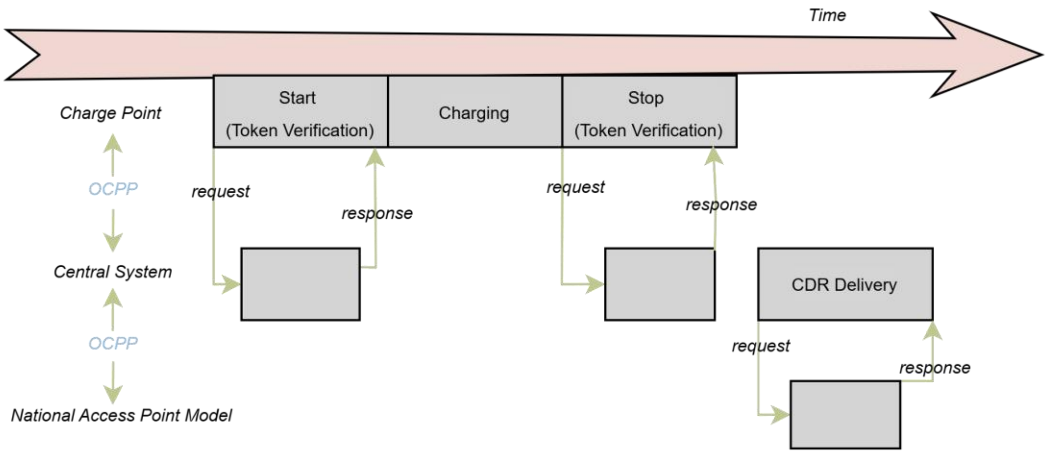

Figure 9. An example of scenario 1 in EV roaming

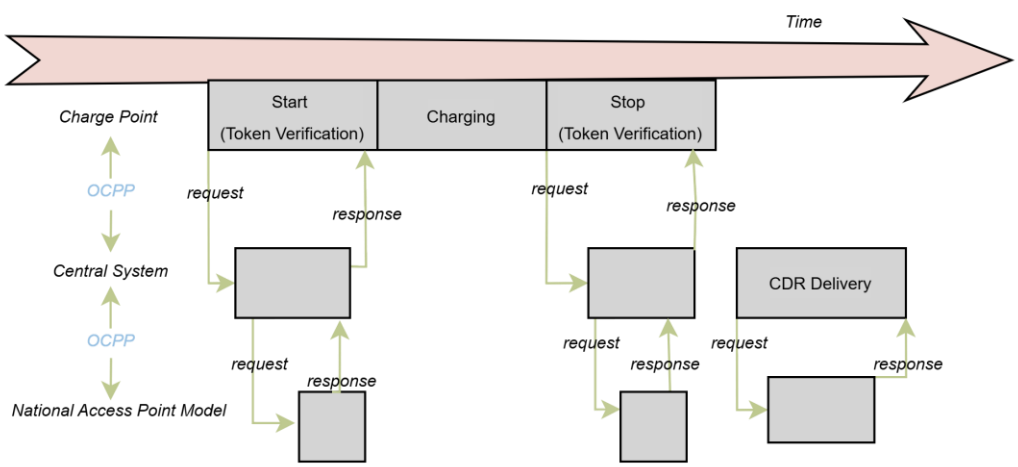

Figure 10. An example of scenario 2 in EV roaming

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panel is used to display communication records. The upper description panel explains the textual communication. The bottom description panel is used to depict the communication taking place visually.

An example of scenario 1 in EV roaming described by Priyasta et al. (2023) and executed by the EV Roaming Simulator is shown in **Figure 9**. The electric vehicle driver, *D*, is registered in the Central System owned by SPKLU operator 1, C_1, and receives an authorized user token, *T*, to access the Charge Point operated by C_1. Then, C_1 shares the authorized user token data with the National Access Point, *N*, to authenticate electric vehicle drivers who want to use the Charge Point across operators. The same applies to other SPKLU operators. Currently, *D* needs to access the Charge Point owned by SPKLU operator 2, C_2, using *T*. Here, C_2 has a data set of authorized user tokens originating from *N*. Therefore, C_2 can verify *D* to get access permission to Charge Point operated by C_2. After *D* finishes using the Charge Point, C_2 sends the billing as a Charge Detail Record (CDR) to C_1 through *N*. According to **Figure 9**, the charging session starts with the Charge Point requesting the Central System to verify the token's validity that triggered the transaction. The Central System verifies the token's validity using the list of authorized token data sets (whitelist) from the National Access Point. The same authorization procedure applies when ending a charging session, the same token must be used. Finally, the Central System sends the Charge Detail Record (CDR) to the National Access Point for billing.

Meanwhile, an example of scenario 2 in EV roaming described by Priyasta et al. (2023) and executed by the EV Roaming Simulator is shown in **Figure 10**. The electric vehicle driver, *D*, is registered in the Central System owned by SPKLU operator 1, C_1, and receives an authorized user token, *T*, to access the Charge Point operated by C_1. Currently, *D* needs to access the Charge Point owned by SPKLU operator 2, C_2, using *T*. Here, both C_1 and C_2 have shared the authorized user token data with the National Access Point, *N*, for authentication of electric vehicle drivers who want to use the Charge Point across operators. Therefore, *N* can verify *D* to get access permission to the Charge Point operated by C_2. After *D* finishes using the Charge Point, C_2 sends the billing as a Charge Detail Record (CDR) to C_1 through *N*. According to **Figure 10**, the charging session starts with the Charge Point requesting the Central System to verify the token's validity that triggered the transaction. The Central System then forwards the request to the National Access Point, which verifies the token's validity using a whitelist of authorized tokens from all SPKLU operators. This process aims to authorize the use of charging stations across SPKLU operators. The same authorization procedure applies when ending a charging session; the same token must be used. Finally, the Central System sends the Charge Detail Record (CDR) to the National Access Point for billing.

4. Conclusion

The use of electric vehicles continues to increase in various countries, including Indonesia. On the other hand, one of the problems in using electric vehicles is range anxiety due to limited battery capacity and minimal number of SPKLUs. One strategy many are implementing to increase SPKLU access is EV roaming, which allows users registered with other SPKLU operators access to charging stations.

This research develops a computer program called the EV Roaming Simulator to simulate access to electric vehicle charging stations across SPKLU operators. The developed simulator consists of three OCPP-based models, namely the Charge Point Model, Central System Model, and National Access Point Model, representing charging stations, central systems, and roaming hubs.

The methods implemented in the EV Roaming Simulator include a WebSocket cascade to connect the Charge Point Model to the Central System Model to the National Access Point Model, as well as enhancement of OCPP functionality through the utilization of DataTransfer protocol data units, which are used to encapsulate the functions required in EV roaming. With this approach, OCPP is used to communicate between the central system and charging stations within SPKLU operators and EV roaming among SPKLU operators.

The EV Roaming Simulator is developed in Java. It can execute the given EV roaming scenarios to simulate the basic functionality of state-of-the-art EV roaming protocols, which include roaming via hubs, peer-to-peer roaming, authorization, billing, synchronous data exchange, and asynchronous data exchange. This simulator has the potential to be further developed and utilized in the development of various newly proposed EV roaming systems.

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