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Eco-Friendly Monitoring and Management System for Electric Vehicle Charging Infrastructure

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Abstract: **Among the main problems faced in the context of electric mobility today, the management and monitoring of electric vehicle charging stations, the integration between the diverse types of technologies that make up its architecture, and its low scalability stand out. Therefore, we will present the implementation and complete integration of an electric vehicle charging system in an electric mobility pilot project being executed in the Amazon region in Brazil. Therefore, a literature review of related works will be presented, and its entire implementation will be addressed, from the charging infrastructure, through its back-end system and its Internet of things platform, to its front-end web system for monitoring charging stations. In addition, a complete prototype is created with a real testbed to verify the scalability of the implemented physical system. Based on the testbed evaluations performed, we observe that the implemented system performs well in receiving and sending data from up to 160 electric vehicle charging stations, achieving an average consumption of 26% for CPU and 95% for memory. In addition, it is important to mention that the deployed system supports horizontal scalability, enabling the connection of more charging stations and making it ideal for other integrated systems similar to ours. Based upon the main results obtained with the implemented system, the possibility of carrying out the management and monitoring of charging stations stands out; the integration of different technologies, from the back end and IoT middleware to its front end; a system that supports scalability, enabling the connection of more charging stations; and a reference architecture for charging station management and monitoring systems for the Amazon region.**

Keywords: **electric vehicles; open charge point protocol; IoT platform; Kubernetes.**

1. INTRODUCTION

Electric vehicles (EVs) can impact future transport systems' performance and are a promising option to contribute to energy diversification and reduction of greenhouse gas emissions [1,2]. EVs could consider information and communication technologies (ICT) to provide a new set of services and applications, changing urban mobility to smart electric mobility. In this way, ICT enhances the capabilities of EV systems, charging stations, monitoring and managing electric stations, energy storage systems, and photovoltaic systems, which are examples of smart electric mobility [3]. For instance, an EV system consists of EV charging stations and a central management system, enabling monitoring and managing the physical infrastructure. Hence, EVs and ICT are paving the way for a smart electric mobility era [4]. This migration from conventional urban mobility to smart electric mobility brings many sustainable and smart mobility benefits. As the EV market grows, the demand for charging stations increases, which requires a new structure to manage these electric charging demands [5]. Most EV charging stations are decentralized and have a very complex structure, making managing and maintaining these structures a hard process [6]. In this sense, understanding the real-time status of a charging Energies 2023 station can provide valuable information to users and the system administrator, such as availability, reservations, and the time to arrive at a particular station [7]. For instance, EV charging stations must be online continuously since vehicle drivers/users typically charge their cars through an Internet-connected app. However, the central management system must be informed as soon as a charging station goes offline since understanding the real-time status of the EV charging stations can provide valuable information. In this context, ICT, such as the Internet of things (IoT) and cloud-based systems, enable the collection, storage, and analysis of data from EV infrastructure.

2. RELATED WORKS

We divided the main related works into three categories: some works involving the OCPP use and EV charging station situations; other works that used IoT platforms for their proposals; and finally, some works that present integrated services or architectures related to EV process from charging to monitoring and also electric mobility pilot projects worldwide.

2.1. OCPP

Pruthvi et al. [6] reviewed the functionality that OCPP offers and how it can be used in the EV charging infrastructure. In this context, the authors demonstrated the implementation of a system based on OCPP, listing the main functionalities and associated messages typically implemented to provide basic functionalities to a charging station. Energies 2023, 16, 152 4 of 23 Alcaraz et al. [29] studied the main security properties of OCPP, e.g., communication between the charging stations and the energy management system. According to the authors, the use of protocol subversions, as well as communication with malicious entities, can lead to the destabilization of energy networks. Garofalaki et al. [38] also addressed the security and privacy issues of an OCPPbased EV charging system. According to the authors, among the main OCPP security requirements in this EV loading context, one can cite integrity, authenticity, confidentiality, and availability in the context of EV driver information, EV data about the state of charge (SOC), the microgrid's energy, and the billing service process. Antoun et al.

2.2. IoT Platforms

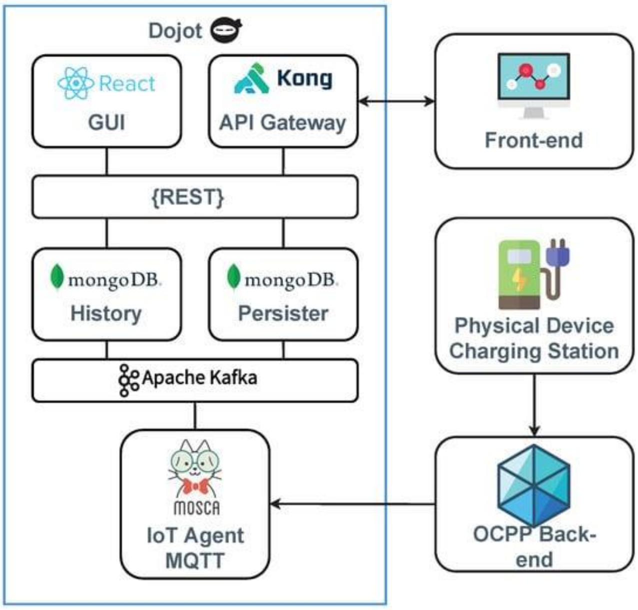
Today there are several IoT platforms available for use, such as Apache Kafka, Amazon Web Services, Dojot, FIWARE, Google Cloud Platform, Konker, Sentilo, and ThingsBoard, among others, and they can be applied in several areas [21,39]. These IoT platforms share similarities when they use protocols, offer certain resources, and have analogous working principles. However, some of them are open sources, while others are proprietary. Proprietary IoT platforms are limited concerning their use, where some functionality and even performance are compromised [39]. Therefore, we focus on open-source IoT platforms applied in different areas. Ottolini et al. [21] performed a qualitative and quantitative analysis of the interoperability and scalability of three IoT platforms: FIWARE, Konker, and ThingsBoard. These platforms were applied to two emulated IoT environments, one for smart city and the other for smart e-health. Each platform was deployed on two virtual machines with separate Amazon Web Services (AWS) infrastructures to assess how each platform manages its system resources. Another factor analyzed was the performance of each scenario with different workloads. According to the authors [21], FIWARE had the worst overall performance and crashed under high workloads.

2.3. Integrated Services and Pilot Projects

There are still not many works in the literature describing the complete integration of an EV charging system, from the back end to the front end, similar to the one proposed in this article. Among the works found is that of R˘aboac˘a et al. [14], who analyzed the OCPP specifications with an emphasis on application design based on the state-of-the-art progress. Therefore, the authors provided an overview of hybrid and electric vehicles, a classification of electric vehicle charging station topologies, a classification of OCPPs, and considered future research directions. They proposed integrated services involving all the charging processes; however, they did not analyze the scalability of their work. Ravindran et al. [35] presented a proposal for hardware and software, following Indian traffic patterns. Regarding the hardware part, the authors created what they call Electric Vehicle Supply Equipment (EVSE), based on the OCPP, which can be inserted into charging stations. Regarding the software part, the authors developed an application for EV users and a charging station management software.

2.4. Concluding Remarks

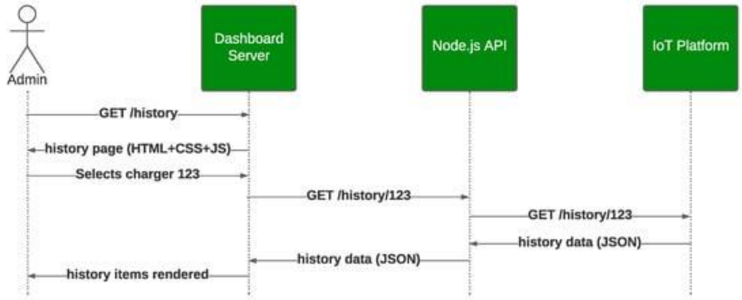
Based on the analyzed works, IoT platforms are mandatory to collect, store, and send data in smart electric mobility scenarios. These data can be accessed/used through APIs by various types of applications (i.e., front end) that, for the most part, are intended for monitoring the physical infrastructure. In addition, it was also observed that due to the large amount of data that many sensors can generate, it is essential that these platforms be scalable. Table 1 summarizes our analysis of the state of the art with the main approach used by their authors and the drawback regarding their proposals to work on a smart electric mobility scenario. To the best of our knowledge, as shown in our analysis presented in Table 1, none of the previous work integrated an efficient communication protocol to collect data from the EV physical infrastructure, together with an efficient and scalable IoT platform to deal with the large volume of data collected by the EV physical infrastructure, and an efficient data visualization on the front-end, while only SIMA combines every critical feature previously mentioned not provided by existing solutions. SIMA also stands out as a pioneer pilot project of electric mobility in the Amazon region, which is a key region that must address the use of eco-friendly energy use and enable sustainable projects. Thus, highlighting the innovation of this work through the use and integration of the technologies utilized will be described in the rest of this work. Energies 2023, 16, 152 7 of Summary of related works. Work Techniques Drawback Pruthvi et al. [6] Full presentation of the main functionalities of OCPP. It is only a presentation of features of the OCPP. Alcaraz et al. [29] Explored threat scenarios and vulnerabilities of the OCPP. It did not present a real testbed scenario involving multiple entities. Garofalaki et al. [38] A Survey on the Security Issues and Challenges of the OCPP. It only focused on security. Antoun et al. [30] Explored security assessment, such as cyber threats, in the EV infrastructure. It did not present a real testbed scenario involving multiple entities. Devendra et al. [31] Designed and projected an electric charger for e-scooters. It only designed and discussed a single entity in the EV infrastructure. Ruzmetov et al. [32] Presented a scheduler of EVs to the closest available charging stations. It depended on new technology involving communication among EVs and charging stations. Ottolini et al. [21] A full comparison regarding distinct IoT platforms. It only compared IoT platform alternatives. Sinaeepourfard et al. [33] Showed a centralized and decentralized approach to data management. It did not explicitly focus on EV data. Santos et al. [16] Proposed a testbed involving IoT devices, such as smart meters. It did not present a real testbed scenario involving EVs. Silva et al. [34] Proposed a sustainable plan for university campus management. It did not involve the use of EVs. R ˘aboac ˘a et al. [14] Presented an overview and classification of OCPP features. It lacked scalability tests. Ravindran et al. [35] Integrated services use case in India It is too specific to a certain country. Devendra et al. [36] Integrated



existing platform for charging processes. It lacked scalability tests. Dornberg et al. [41] The ICT solution, ENS, identified and provided EV and charging station information to the network. It only presented the results of mobility services in the enterprise environment. Del Rio et al. [37] The infrastructure was integrated through an ICT platform and deployed an Energy and EV Management Center. All project participants paid for the infrastructure and for the services offered. Fabbri et al. [42] Featured a system to manage the EV fleet and charging infrastructure. It only presented the pilot project and illustrated the proposed system. Energies 2023, 16, 152 8 of 23

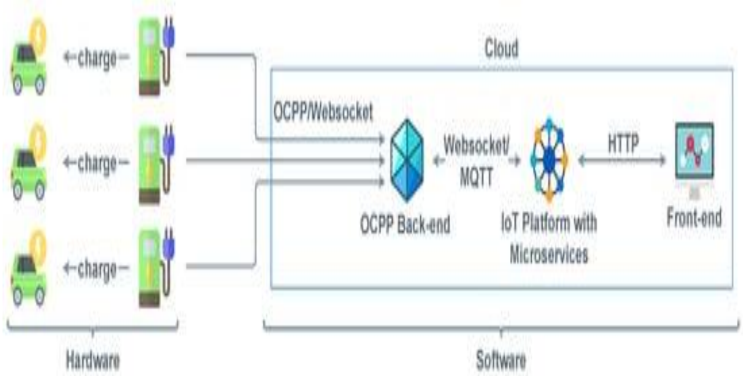
3. FROM CHARGING TO MONITORING EVS

This section presents the architecture of SIMA for managing EV charging stations via an efficient IoT and integration and a cloud-based system SIMA, which has two main steps: (1) IoT communication between the charging station and the central system through the OCPP; and (2) cloud-scalable IoT platform that receives EV charging information via Message Queue Telemetry Transport protocol (MQTT) [43], and store such information for further processing. The details of the architecture and the real testbed prototype will be described in the following.



3.1. Main Architecture

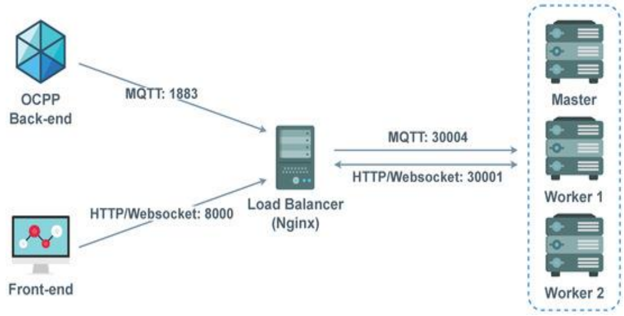
The architecture of SIMA is composed of a hardware layer and a software layer, as shown in Figure 1. The hardware layer is composed of EVs and



charging stations. The software layer is cloud-based, composed of OCPP back end, IoT middleware, and web application (front end), which follows a typical IoT architecture [16,21,33,34,36]. The EVs can be battery EVs, plug-in hybrid electric vehicles (PHEV), or hybrid electric vehicles (HEV). All the different types are just referenced in this work as EV since the type does not influence our system. The charging stations (also called charge points) have one or more electrical connectors (also called plug-ins), and each electrical connector is used to charge an EV. Finally, the server deploys the cloud-based system in terms of OCPP back end, IoT platform (Dojot), and front end. charge charge charge OCPP/Websocket OCPP Back-end IoT Platform with Microservices Front-end Websocket/ MQTT HTTP Cloud Hardware Software

3.2. IoT Communication between EV Charging Station and OCPP Back-End

The charging stations become easily accessible for remote support and maintenance via the OCPP communication protocol, enabling the collection of information for the management of EV charging stations. Specifically, OCPP is an open protocol standardized by the Open Charge Alliance (OCA) for communication between a charging station and the OCPP back end. In this work, we considered the OCPP version 1.6, which has the following features: JavaScript Object Notation (JSON) messages, Websockets technology, better diagnostics possibilities, more charging status, and the use of trigger messages. The JSON format is used to exchange data between the OCPP back end and the EV charging stations due to its smaller message size. In addition, the protocol supports smart charging for load balancing and the use of distinct user profiles during the charging moments. It is important to state that although we used a specific OCPP version, our proposal could also be used with newer versions [38]. OCPP features and associated messages are grouped in different profiles, namely: (i) the Core is the main profile responsible for the basic functionality of an EV charging station; (ii) the Firmware Management is responsible for managing firmware updates and diagnostic log file download; (iii) the Local Auth List is responsible for managing the local authorization list at the charging station.

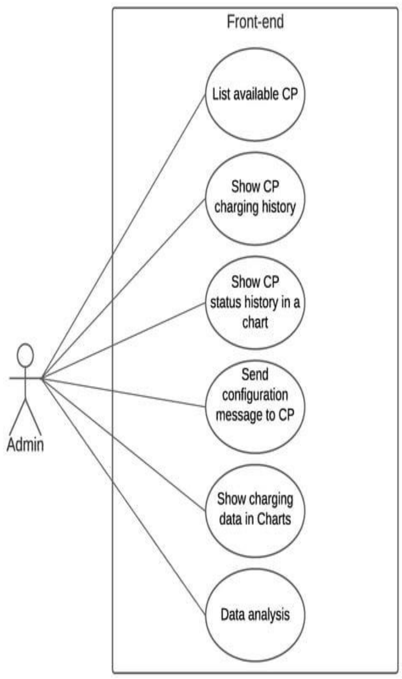


(iv) the Smart Charging is responsible for basic smart charging, for instance, using the control pilot. It is worth mentioning that an OCPP implementation must contain at least the Core profile because it is the profile with the main features and operations for the correct functioning of the charging stations.

3.3. IoT Platform to Handle the Large Volume of Data Collected by the EV Physical Infrastructure

The IoT platform enables storing the data in a database and provides the data to other external applications, such as the visualization in real-time on a web interface (front end) of the received data. In this sense, we considered Dojot version 0.7 [18] as an IoT platform since it is designed to collect and store large volumes of data from different IoT devices efficiently and by supporting horizontal scaling. Specifically, Dojot is a Brazilian opensource IoT platform that emerged to develop and demonstrate technologies to facilitate the development of IoT solutions [18]. The Dojot Platform has several modules, where each module represents a Dojot service and has a specific function. The user can configure a template or device or send data into Dojot using the graphical user interface (GUI) via HTTP requests. IoT devices at Dojot are virtual representations of real devices or entities, such as charging stations. In this sense, for each charging station connected to the OCPP back end, a virtual device is also created in Dojot through the Device Manager module, which uses Kafka. This device receives and stores the corresponding data in the MongoDB database through the Persister module. In addition, Dojot could have several IoT agents and a service specialized in dealing with a specific protocol, such as MQTT/JSON and HTTP/JSON. After configuring the IoT devices, the IoT agent will be able to handle data received from a specific IoT device via MQTT.

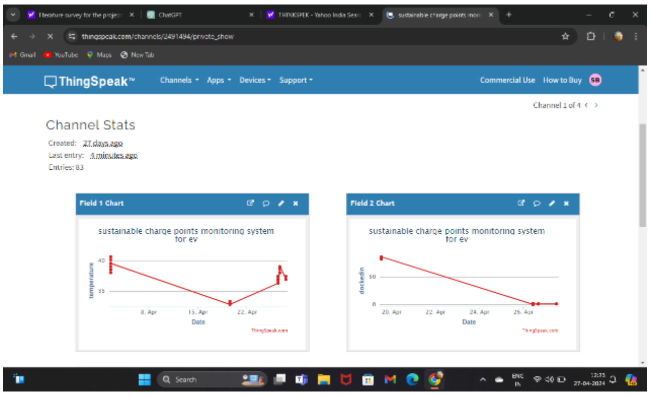
3.4. Front End

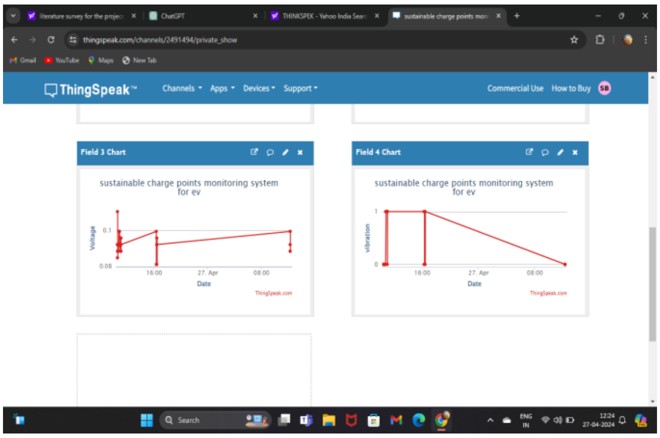


The front end needs to exhibit in full detail and with great scalability all the content required by the EV operator, whether for a simple conference or a deeper analysis. For instance, Figure 4 shows the use case diagram for the front-end service.

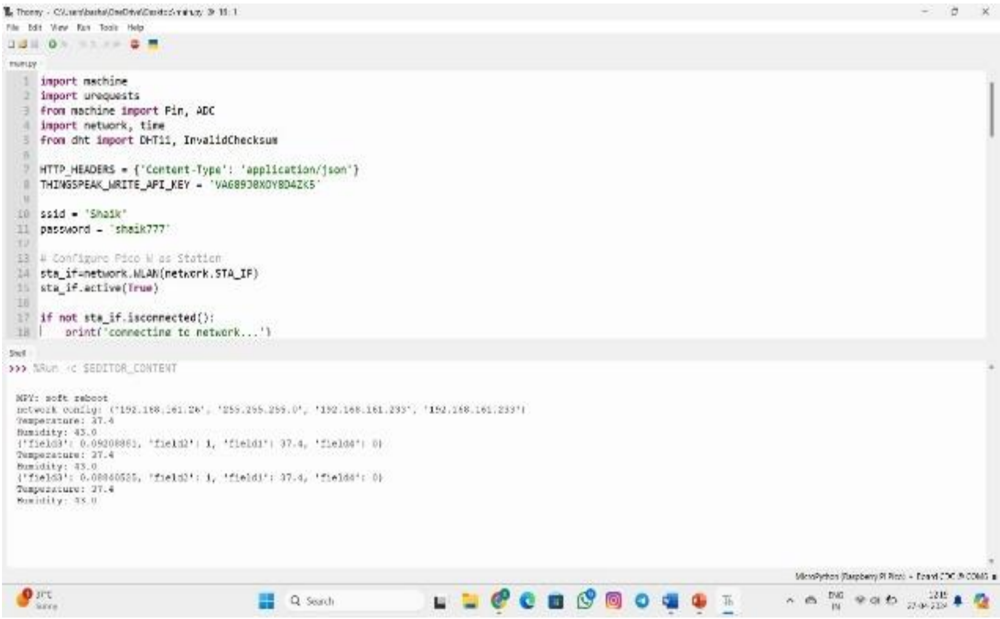
In our prototype, some electric buses are traveling around UFPA to serve the students and community that need to move between distinct buildings of the university, such as the main university restaurant, the university hospital, and the computer science building. In addition, there is also an electric bus traveling between two campuses 70 km far away. Therefore, the electric bus needs to charge, from time to time, before going back to the garage, where the bus driver requests to start the vehicle charging. In terms of computational infrastructure, there is a Power Edge T440 server connected to the local network, which uses Linux Ubuntu Server 18.04 operating system with 64 GB of RAM, an Intel Xeon Silver 4210 processor with 40 cores, and a storage capacity of 5 TB. We deployed the OCPP back end, IoT platform (Dojot), and the front-end application in virtual machines created on the server. Table 2 presents the number of resources allocated to each node. It is important to note that we allocated 700 GB of storage for each worker node since this amount of storage will be enough to allocate telemetry data for up to 100 years on the server, already considering a safety margin of 20%. To obtain this value, we considered the extreme case of 50 charging stations sending data to Dojot every 1 min, where each charging station can send up to 225 bytes every 1 min, achieving a total of 11,250 bytes. At the EV charging station, there are some charging points located where any driver can charge his/her vehicle. The charging station must evaluate the authorization requisition, validate whether the charging can be performed, and then enable starting the charging transaction. In this context, Figure 7 shows a sequence diagram of operations and messages exchanged via OCPP during a full EV charging session, and also the structure of StartTransaction request message operation sent to the OCPP back end during a charging session.

4. RESULTS





5. OUTPUT



6. EVALUATION

This section presents the full setup and the evaluation performed in our prototype scenario. In this sense, we perform a scalability evaluation to verify how machines with the IoT platform respond to the increasing number of charging stations (devices) sending data to it. For this, we performed evaluations with the OCPP back-end central system, containing several charging stations, simultaneously sending data to the IoT platform. Regarding the number of charging stations connected to the IoT platform and sending data, it was initially considered 10 charging stations. This amount increased exponentially every 10 min to 20, 40, 80, and 160 charging stations. We carried out the evaluations in two different environments, namely: (i) we deploy Dojot through Docker-Composer, on a single machine (which will be called "docker-compose"); (ii) we deploy Dojot in a Kubernetes cluster containing two worker machines as introduced before (which will be called "worker 01" and "worker 02"). Each of these two environments was tested separately for a period of 1 h each. The first testbed in the docker-compose environment was carried out on 28 June 2022, from 4 p.m. to 5 p.m. On the other hand, the second testbed in the Cluster Kubernetes environment was carried out on 29 June 2022, from 4 p.m. to 5 p.m. In both environments, the number of charging stations and EV were exponentially increased every 10 min, passing through 10, 20, 40, 80, and 160 devices.

7. CONCLUSIONS

This article introduced the prototype of a real case study from charging to monitoring EV, called SIMA. It enables us to verify how to execute the complete integration between EV charging stations with the OCPP management system, the IoT platform, and a front-end web application that constitutes the cloud part version. Regarding the OCPP central system, it is essential for communication and integration with EVs, since it allows the collection of various information for the user and for the system administrator from a simple loading.

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