An Architecture for a Large-Scale IoT e-Mobility Solution

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Abstract: The recent rapid uptake of electric vehicles is driving demand for charging infrastructure that must support the operation of the various stakeholders of the e-mobility ecosystem. The scale and complexity of the e-mobility domain that involves different types IoT devices and a plethora of connectivity standards makes developing a comprehensive solution challenging. E-mobility solutions and their integration into the wider context of smart city standards and technologies are the subject of extensive current research and rapid evolution, but at present there are not many comprehensive solutions that deliver the required functionality and reliability at scale. In this paper we present the Unicorn ChargeUp e-mobility solution designed to support the operation of e-mobility Service Providers, Charge Point Operators and Electric Vehicles drivers, and describe the ChargeUp software architecture that support reliable and scalable operation of thousands of users and IoT devices. We describe the underlying Unicorn Architecture and show how it supports the functional and non-functional requirements of the ChargeUp e-mobility solution.

1 INTRODUCTION

The Global EV Outlook 2021 (Zhongming et al., 2021) estimates that there were 10 million Electric Vehicles (EVs) on the world’s roads at the end of 2020. Electric car registrations increased by 41% in 2020, despite the pandemic-related worldwide downturn in car sales. According to some predictions, there will be a corresponding increase in charging stations reaching 14 million slow and 2.3 million fast public charging stations by 2030. There has been a rapid increase of publicly accessible EV charging stations in most European countries over the last five years and starting from 2019 a gradual increase of fast and ultra-fast charging points. Notwithstanding this notable expansion of EV charging networks, inequalities persist across Europe and within individual countries in terms of accessibility of charging points available to users; as of 2020 most European regions have less than 0.5 EV charging points per 1,000 inhabitants (Falchetta & Noussan, 2021). From the perspective of power grid systems, the introduction of electric vehicles presents many challenges, but also some opportunities. According to Golla et al. (Golla et al., 2021), due to the rapid acceptance of EVs in the car market, EV charging infrastructure is becoming a key requirement. To travel longer distances, EV drivers must be able locate nearby charging stations and establish their compatibility and availability. Numerous solutions are emerging to assist EV drivers to locate suitable charging points: for example, IoT-based monitoring system that assists EV drivers to plan their journey identifying optimal charging stations or an Android application for locating available charging points and estimating the charging time (Kharade et al., 2020). According to Galus et al. (Galus et al., 2019), uncontrolled charging where EVs are regarded as passive loads without any flexibility can lead to problems endangering secure operation of the electricity grid. The authors argue that the management of electric vehicles as a distributed resource fits well within the paradigm of smart grids. Using direct or indirect control approaches charging of vehicles can be managed more effectively, and additionally EVs can be used as distributed storage resource contributing to the stability of the grid system by frequency regulation, peak-shaving and by integrating fluctuating renewable resources. Solid-state switch-mode power converters have reached a

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level of maturity that allows precise regulation of voltage levels during bidirectional power flow operation. The paper discusses the role of aggregators that manage large fleets of EVs and the need for a regulatory framework that facilitates advanced modes of operation. An overview of the technical challenges of real-time monitoring and control of Energy Storage Systems (ESSs) for EVs and how the IoT technology can be utilized to address the challenges and improve the efficiency of Battery Management Systems (BMS) is given in (Mohammadi & Rashidzadeh, 2021). Others (Arras et al., 2020) have considered EV charging station infrastructure from both the EV driver (charging station user) and from the provider (charging station operator) perspectives with the view to optimize energy cost and the duration of charging. The energy source is selected based on availability and costs that vary depending on the time of the day, weather conditions, the grid load, and the specifics of the energy source. Energy-efficiency and optimal energy distribution are some of the most essential issues to address when supplying energy to EVs. In (Ouya et al., 2017), the authors propose a new communication protocol between EVs and charging stations that aims to improve energy management by extending existing protocol standards to include information for EV drivers about energy availability within charging stations and to facilitate Vehicle-to-Grid (V2G) energy exchange. The paper describes a proof-of-concept system that operates over LoRaWAN (Long Range Wide Area Network) and provides connectivity between EVs, charging stations and EMS (Energy Management System), demonstrating how the proposed system could work using a realistic scenario. It is evident that EV charging stations are a relatively recent addition to the multitude of smart devices and still need to be seamlessly integrated with the rest of smart city infrastructure so that they can instantly react to situations such as grid overload or fire alarms in the vicinity of a charging station. Recent proposals to address this issue include the application of oneM2M standard[1] in combination with the OCPP (Open Charge Point Protocol) (Devendra et al., 2021). According to Karpenko et al. (Karpenko et al., 2018) the lack of interoperability between the various IoT ecosystems (smart mobility, smart buildings, smart environment, etc.) hinders the integration between devices in different vertical IoT domains. The authors describe a practical example of using the O-MI/O-DF standards (Robert et al., 2016) to achieve interoperability in the smart city context and develop a proof-of-concept EV charging mobile application that demonstrates the feasibility of creating distributed bottom-up services based on open standards that unify the smart cities ecosystem. Another challenge is the lack of coordination of EV charging and the common practice of charging EVs to full battery capacity irrespective of the prevailing grid conditions. A mobile application that supports smart charging using IoT integration with charging station architecture taking into account individual user preferences was proposed and implemented (Meisenbacher et al., 2021). Phadtare et al. argue that the current lack of availability of charging stations combined with the lack of suitable parking is a major limiting factor for the acceptance of electric vehicles (Phadtare et al., 2020). The paper reviews IoT based smart parking solutions and compares combined parking and charging system with separate parking and charging system. An approach to run shared EV-charging infrastructures in the context of commercial real-estate facilities is described in (Gauss et al., 2022). The paper argues that CP sharing can help to improve the overall utilization of a charging infrastructure and can lead to a reduction of costs associated with EV charging equipment. Rajendran et al. (Rajendran et al., 2021) argue that the expansion of fast-charging networks will facilitate a sustainable transportation revolution by offering drivers versatile choice to charge EVs for longer journeys with state-of-the-art charging infrastructure allowing idle batteries or EVs to operate as distributed energy sources.

Clearly, EV charging infrastructure is a prerequisite for the wide adoption of EVs. Successful implementation of EV charging infrastructure requires a comprehensive solution for EV drivers and CPOs (Charge Point Operators), ESPs (e-mobility Service Providers) and other stakeholders of the e-mobility ecosystem. While there is extensive research in this area and several small-scale prototype solutions have been developed, there are few large-scale implementations that provide the required level of scalability and reliability to support thousands of concurrent e-mobility users. In this paper we present the Unicorn ChargeUp e-mobility solution developed by Unicorn (unicorn.com/en/) that supports the operation of ESPs, CPOs and EV drivers and can reliably scaleup to thousands of EV users, charging stations and other types of IoT devices. In the next section (section 2) we describe ChargeUp ESP and

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[1] https://www.onem2m.org/technical/published-specifications

ChargeUp CPO components of the system and discuss the non-functional requirements for their implementation. In section 3 we describe the ChargeUp application architecture and section 4 describes the Unicorn Architecture and its role in the implementation of the ChargeUp solution. Section 5 are our conclusions and discussion of future work.

2 UNICORN ChargeUp

The ChargeUp system is designed to support interactions between the various e-mobility stakeholders (EV drivers, e-mobility service providers, charge point operators and aggregators) and IoT devices (charging stations, smart parking systems, off-grid batteries), and in the future with smart grids and energy trading systems. As illustrated in Figure 1, The Unicorn ChargeUp system consists of two main components: ChargeUp ESP that supports EV drivers and ChargeUp CPO designed for Charge Point Operators.

2.1 ChargeUp ESP

The ChargeUp ESP application enables EV drivers to locate a suitable charging station and to charge the EV after a payment is made. This typically involves browsing the map on a mobile device locating an available CP (Charging Point), displaying the features of the charging station, and making sure that it has a compatible connector type. The application displays pricing information, charging limits and the current status of the CP. The EV driver selects a charging plan and a payment method (Figure 2). Once the payment is processed, the customer can start charging the EV with the application displaying information about the progress of charging including the remaining charging time and the amount of supplied energy. The application controls time and price limits in defined intervals (e.g. every 10s) and terminates charging when the limit is reached; the customer can terminate charging at any time using the application. Finally, a receipt is sent to the customer via email (Figures 3).

2.2 ChargeUp CPO

The ChargeUp CPO application manages all relevant charging station information including technical information needed for communication using the OCPP protocol standard. The application runs in a multitenant environment in which each CPO is assigned their own *application workspace* (a collection of application objects). Access to application objects is controlled using identities that are derived from *user roles* assigned to users. Each charging station connects to a workspace of the CPO application that controls the station and its charging points availability.

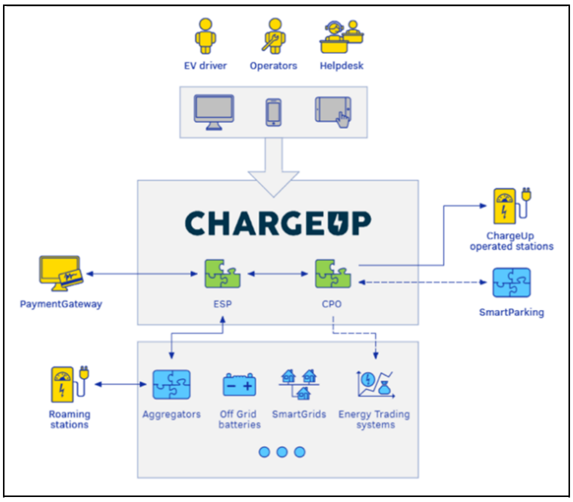
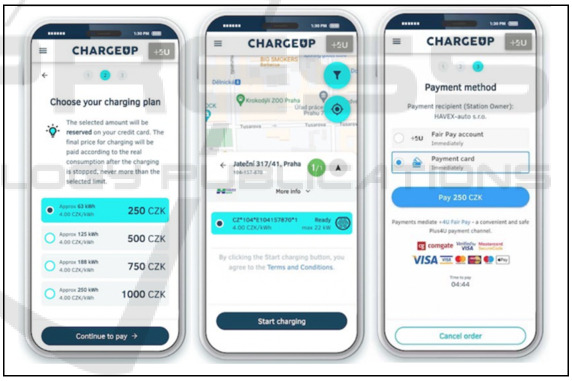


Figure 1: Unicorn ChargeUp system.



The selected amount will be **reserved** on your credit card. The final price for charging will be paid according to the real consumption after the charging is stopped, never more than the selected limit.

Jateční 317/41, Praha
104-157-870

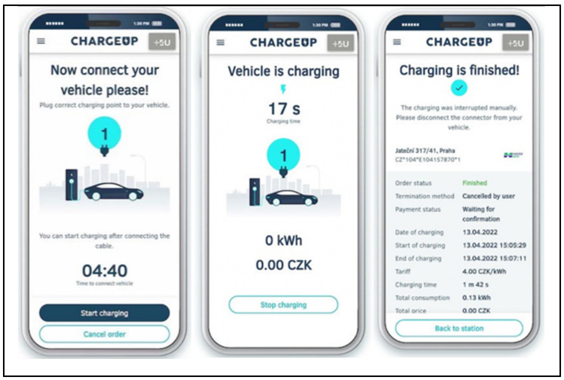
CZ*104*E104157870*1 Ready
4.00 CZK/kWh max 22 kW

By clicking the Start charging button, you agree to the Terms and Conditions.

Payment recipient (Station Owner): HAVEX-auto s.r.o.

Payments mediate +4U Fair Pay - a convenient and safe Plus4U payment channel.

Figure 2: Selecting a charging station and a payment method.



Plug correct charging point to your vehicle.

You can start charging after connecting the cable.

The charging was interrupted manually. Please disconnect the connector from your vehicle.

Jateční 317/41, Praha
CZ*104*E104157870*1

Order status: Finished
Termination method: Cancelled by user
Payment status: Waiting for confirmation
Date of charging: 13.04.2022
Start of charging: 13.04.2022 15:05:29
End of charging: 13.04.2022 15:07:11
Tariff: 4.00 CZK/kWh
Charging time: 1 m 42 s
Total consumption: 0.13 kWh
Total price: 0.00 CZK

Figure 3: Monitoring the charging process.

All communication between ChargeUp CPO and the charging station is logged to the communication log that records the timestamp, station identifier (each charging station has a unique code that the application uses to identify individual stations), type of OCPP operation, type of transaction and the error code, if an error arises. The ChargeUp CPO application displays a list of charging stations on a map and supports basic administrative functions that include viewing the detail station information and the status of each CP, unlocking connectors, terminating the charging process, and restarting the station. ChargeUp CPO creates a reservation of the charging point as soon as the selected amount is blocked on the EV user's credit card. The operator can generate reports that display the total energy used, total charging time, generated revenue and other performance indicators. There are two types of transactions: reservation and charging. The communication log records the start and end time for each completed transaction and stores information about the total power consumption and the cost of the charging transaction. During the charging session, the application stores information about power consumption and provides this information to the connected ESP to enable the ESP to monitor the charging process. The CPO deals primarily with wholesale customers (charging operators and aggregators), typically organizations that operate the ESP application for end users and offer charging services on the CPO's stations, or subjects that represent a group of customers (e.g. car fleet users) and who have agreed on wholesale pricing with the CPO. In addition to generating reports of customer details, assigned tariffs and total power consumption of individual charging stations, the application displays a dashboard that shows the overall status of the system, and supports the export of data for a defined time period that includes daily statistics for each charging point.

2.3 Non-Functional Requirements

The ChargeUp application is implemented in the form of SaaS (Software as a Service) and must satisfy a number of critical non-functional requirements. Application availability requirement is 99.97% with a 2-hour RTO (Recovery Time Objective). This requirement is achieved using the Unicorn Cloud Framework (uuCloud) that isolates failures to a specific microservice and supports automatic fail-over (Feuerlicht et al., 2020). The ESP application was designed to initially support 5,000 concurrent users and 10,000 charging transactions each day. The CPO application supports 500 CPO providers and up to 1,000 concurrent users (dispatchers and operators) controlling up to 10,000 charging stations. When the need arises, uuCloud infrastructure can scale-up to a larger number of charging stations and users while maintaining response times below 2 seconds for view and edit operations. The charging station OCPP messages are typically processed within 3 seconds from arriving at the ChargeUp CPO endpoint with a default timeout set at 30 seconds. The ChargeUp system is implemented using the UAF (Unicorn Application Framework) that ensures a high level of security via compliance with the OWASP (Open Web Application Security Project) ASVS (Application Security Verification Standard) level 2. All communication with the charging stations is handled via SOAP/HTTPS or Secure WebSocket protocol and all transmitted data is secured by encryption.

3 CHARGEUP APPLICATION ARCHITECTURE

The ChargeUp implementation is based on the microservices architecture and consists of two closely integrated applications: ChargeUp ESP and ChargeUp CPO with clearly defined interfaces (Figure 4). The applications use the standard OCPP protocol for the communication with charging stations and the communication with other systems is facilitated via documented interfaces that support standard electromobility protocols (OICP and OCPI). The system logs all events, recording event description, error identification and timestamps enabling operators to identify software and hardware issues as soon as they arise. The use of the uuHi GUI framework (described in section 4) ensures that the end user interface is consistent across all supported devices. Both applications consist of microservices (independent UAF sub-applications) with well-defined APIs (Application Programing Interfaces) to ensure scalability and reliable operation of the system.

ChargeUp ESP is divided into two core microservices:

- *Main* – a microservice that manages the interaction with charging stations via ChargeUp CPO Main. To ensure that the data and control of charging stations is strictly separated, each provider of charging stations has their own application workspace that includes this microservice.
- *Portal* – a microservice that supports communication between EV drivers and the ESP *Main* microservice. The *portal* is also responsible

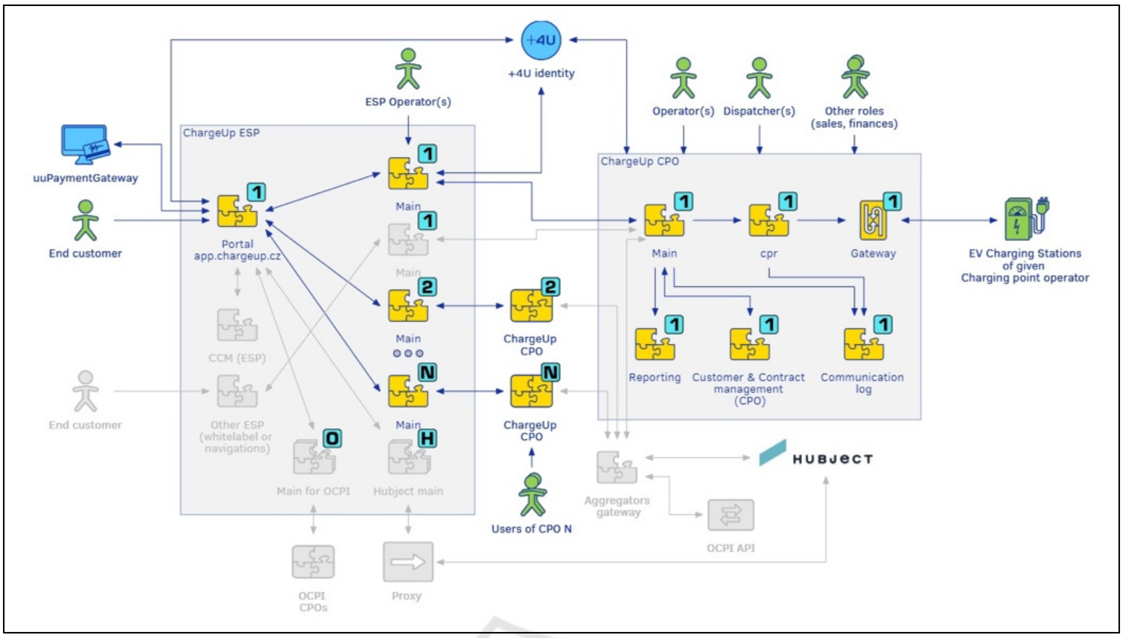


Figure. 4: ChargeUp application architecture.

for communicating with the payment gateway and for micro-transaction management.

ChargeUp CPO is divided into 6 separate microservices:

- *Main* microservice that manages charging stations and the charging process.
- *CPR* microservice that translates different versions of OCPP into a unified internal ChargeUp CPO API.
- *Reporting* microservice for the management of reporting data and generation of reports.
- *Communication log* microservice that manages the communication log and related audit functions.
- *Gateway* microservice that transforms WebSocket communication into the standard Unicorn Application Framework REST-like command calls.
- *Customer & Contract management* microservice that manages customer and customer contract information.

4 THE UNICORN ARCHITECTURE

In this section we describe the role of the Unicorn Architecture in the implementation of the ChargeUp system. The implementation of the ChargeUp system derives its functional and non-functional properties from the underlying architecture. The Unicorn Architecture supports a range of mobile and IoT devices and facilitates cloud deployment of enterprise applications utilizing standard state of the art technology components and services that include security and authentication services, GUI (Graphical User Interface) components and services for the deployment and operation of containerized microservices. The Unicorn Architecture is based on technology standards that implement various layers of the architecture and provide a stable basis for the implementation of enterprise applications. Unicorn Architecture consists of four interrelated frameworks:

uuHi - specification and corresponding framework services for the development of GUI components.

uuTi - specification and corresponding framework services for the management of IoT devices and various appliances that interact with enterprise applications.

uuAppServer - specification and corresponding framework services for the development of containerized microservices applications.

uuCloud - specification and corresponding framework services that support the provisioning of elastic cloud services.

The Unicorn Architecture frameworks play a key role in supporting the development and operation of the ChargeUp system. The uuHi GUI components based on the HTML5 specification (WC3, 2017), JavaScript (*JavaScript*, 2017), CSS3 (Storey, 2012) and React (*React - A JavaScript library for building user interfaces*, 2017) support rapid development of reliable and scalable cloud-based mobile applications for a wide variety of devices, including mobile phones, tablets, notebooks, smart TVs and desktop computers. The uuHi framework facilitates integration with React and other commonly used GUI libraries. This ensures that the application screens illustrated in Figures 2 and 3 are dynamically adjusted to a specific display environment without the need to customize the UI code.

The IoT uuTi framework provides integration with charging stations from different manufacturers via the OCPP protocol (v1.5 and v1.6) and supports a range of operations such as restarting the charging station, unlocking a charging point, checking for availability of charging stations and individual charging points, viewing the communication log, etc. The CPO gateway acts as a translator of WebSocket requests into HTTPS requests of the *CPR* microservice. As shown on Figure 5, incoming (from a charging station to the CPO application) WSS requests pass through the CPO gateway and are transformed into commands (API calls) of the *CPR* service. Outgoing WSS requests (from the CPO application to a charging station) pass through the CPO gateway, and SOAP/HTTPS requests are sent directly between the *CPR* service and the charging station.

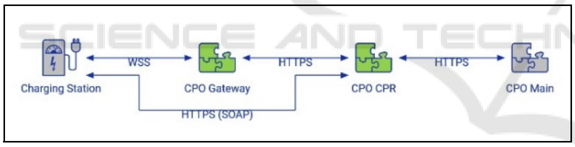


Figure 5: Processing of requests between a charging station and the CPO Main microservice.

The uuCloud framework (Beranek et al., 2018) maintains active information about all objects within the cloud environment and automates the deployment and operation of container-based microservices. To ensure portability, individual microservices are provisioned in the form of Docker containers (Docker, 2015) and deployed to the Microsoft Azure public cloud infrastructure, but could be deployed to another compatible cloud platform (e.g. AWS), if the need arises. Access to individual microservices is controlled using identity (uuIdentity) associated with *user roles* and assigned to individual users and system commands. uuIdentity authentication is managed by the *uuOidc* service that supports secure storage of data and integrates with third-party identity providers (e.g., Facebook, Google, etc.). The uuCloud security model is based on a combination of Application Profiles (collection of functions that the application can execute) and Application Workspaces (collection of application objects that the application can access). Access to Application Workspaces is granted according to identities associated with the corresponding Application Profile. The uuCloud framework supports multitenancy with each tenant (typically a separate organization, e.g., a CPO) assigned resources from a *Resource Pool* using the mechanism of *Resource Lease*. uuCloud unit of deployment is a *node*; each containerized microservice is implemented using a node image that contains the application code and a runtime stack that includes all the related archives and components needed to run the application (system tools, system libraries, etc.). Nodes are stateless and use external resources (e.g. MongoDB databases) for persistent storage. Nodes are classified as synchronous or asynchronous, depending on the behavior of the application that the node virtualizes and are grouped into *NodeSets* - sets of nodes with identical functionality. Horizontal scalability is achieved by creating additional instances (nodes) of containerized microservices on demand depending on the number of concurrent users and the volume of charging transactions. At runtime, a gateway (uuGateway) forwards client requests to a router that passes each request to a load balancer. The load balancer selects a node from a *NodeSet* optimizing the use of the hardware infrastructure and at the same time providing a failover capability by re-directing the request to an alternative node within the *NodeSet* if a particular node is unresponsive.

4.1 Infrastructure Services

In addition to the above frameworks, the Unicorn Architecture incorporates infrastructure services that provide common functions such as authentication and authorization, persistence, inter-service communications and other functions that are frequently used across different application systems. These include the *uuOidc* service based on the OpenID Connect standard (Sakimura et al., 2012), the *uuMessageBroker* service for fast, reliable, secure, and scalable event-based communication via queues, the *uuAsyncJob* service that supports running ad-hoc and scheduled jobs that improve the performance and scalability of applications by executing CPU-intensive application as background processes, and the *uuPaymentGateway* service that supports third-party payment gateways and integrates with various e-shops and partner websites. Additionally, the architecture includes multi-lingual and customization facilities that allow individual application workspaces to be configured for specific needs of different countries.

5 CONCLUSIONS

Increasing adoption of EVs in Europe and across the world is driving demand for EV charging infrastructure that must include reliable and scalable enterprise applications that support the operation of the various participants of the e-mobility ecosystem. The scale and the complexity of the e-mobility domain that involves various stakeholders (EV drivers, ESPs, CPOs, aggregators, etc.), different types IoT devices from various manufactures (charging stations, EVs, etc.) and a plethora of standards as well as demanding application requirements makes developing a comprehensive solution challenging. In this paper we have described the Unicorn ChargeUp e-mobility solution that supports the operation of ESPs, CPOs and EV drivers and is currently used by organizations in the Czech Republic and across Europe. As with most software projects of this scale and complexity, the implementation of ChargeUp involved some challenges. Integrating a set of heterogenous IoT devices (different models of charging stations from different manufacturers) and keeping their firmware up-to-date requires a continuous effort. Different vendor implementations of the OCPP necessitate extensive testing to ensure the stability of the system. Early versions of ChargeUp were implemented on top of our existing platform for energy-related projects designed to process large volumes of time-series data, but this platform proved not to be sufficiently scalable in an environment with a large number of users, IoT devices and a high volume of transactions. Implementing more recent versions of ChargeUp using the Unicorn Architecture ensures that both the functional and non-functional requirements described in sections 2 and 3 can be supported in the future with growing number of users and transactions. Another implementation challenge involved accommodating the diverse requirements of ChargeUp CPO and ChargeUp ESP applications that address different end-user scenarios. While charge point operators can be trained in the use of the application and related documentation, users of the ESP application (EV drivers) must be able to operate the application without training and without the comfort of office environment, typically using a small screen of a mobile phone. The design of the user interface must reflect these requirements. Currently, most charging solutions (including ChargeUp) use charging stations only for charging of electric vehicles. In the future, charging solutions will become an integral component of smart grids allowing for improved monitoring of the energy distribution network and optimization of energy consumption, avoiding usage peaks by motivating users to charge their vehicles during off-peak periods (Alyousef, 2021). Our current efforts include extending the ChargeUp system to include smart parking functionality and eventually incorporating support for *grid-friendly* EV charging with the ability to adjust the power demand to reflect the real-time status of the power grid. Data generated by the ChargeUp application will play an important role in balancing out the conflicting requirements of different stakeholders in an EV ecosystem.

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