

# Roaming Interoperability for Electric Vehicle Charging Networks

Abdulnasir Al-Tubuly

Thesis submitted to the  
Faculty of Graduate and Postdoctoral Studies  
In partial fulfillment of the requirements  
For the M.A.Sc degree in  
Electrical and Computer Engineering

School of Electrical Engineering and Computer Science  
Faculty of Engineering  
University of Ottawa

© Abdulnasir Al-Tubuly, Ottawa, Canada 2016

# ABSTRACT

The purpose of this thesis is to analyze the maturity and the performance of the currently available roaming solutions that provide interoperability and roaming services to Electrical Vehicle Charging Networks.

At least three different entities are involved in an Electrical Vehicle (EV) charging roaming scenario, namely the EV, the home charging network and the visited charging network. All of these entities have to interface and interact with each other on the physical and the communication protocols level.

The Open Clearing House Protocol (OCHP) roaming protocol is implemented and its performance is evaluated against the e-Clearing.net test platform. The protocol functionality for billing and its suitability for different scenarios is also evaluated. Furthermore, an extension to the protocol is proposed to support prepaid subscription, and its performance is also estimated.

The findings of this study have verified the performance and the maturity of the OCHP protocol, and strongly recommends the implementation of roaming protocols and clearing houses. The estimated performance of the proposed extension confirmed that both prepaid and postpaid billing can be realized using the tested roaming protocol and clearing house implementations.

## ACKNOWLEDGEMENT

I would like first to thank my thesis supervisor Prof. Hussein T. Mouftah of the School of Electrical Engineering and Computer Science at the University of Ottawa for his support and guidance during my research and thesis writing. His boundless dedication to excellence, enthusiasm and commitment will always inspire me.

I would also like to thank sincerely Harm van den Brink of ElaadNL and Max Dern of Smartlab for giving me access to e-Clearing.net test platform.

Finally, I must express my profound gratitude to my mother for her endless support and encouragement, and to my lovely wife Ibtihaj for her unfailing support, love and patience.

# List of Acronyms

2DS	2°C Decarbonization Scenario
ANSI	American National Standards Institute
API	Application Program Interface
BEV	Battery Electric Vehicles
BSS	Business Support Systems
CAN	Controller Area Network
CDR	Charge Detail Record
CPO	Charging Point Operator
CROME	Cross-border Mobility for EVs
eMI <sup>3</sup>	eMobility ICT Interoperability Innovation
ERTICO	European Road Transport Telematics Implementation Coordination Organisation
EV	Electric Vehicle
EVCI	Electric Vehicle Charging Infrastructure
EVCIX	Electric Vehicle InterCharge Network (Clearing House)
EVCN	Electric Vehicle Charging Network
EVCSO	Electric Vehicle Charging Service Operator
EVCSP	Electric Vehicle Charging Service Providers
EVSE	Electric Vehicle Supply Equipment
EVSEO	Electric Vehicle Supply Equipment Operators
EVSP	Electric Vehicle Service Provider
HAN	Home Area Network
ICE	Internal Combustion Engine
ICG	Internal Combustion Generator
ICT	Information and Communications Technology
IDE	Integrated Development Environment
ITS	Intelligent Transport System
NEMA	National Electrical Manufacturers Association

NSP	Navigation Service Provider
OCA	Open Charge Alliance
OCP	Open Charge Point Protocol
OEM	Original Equipment Manufacturer
OSS	Operations Support Systems
PEV	Plug-in Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicles
POI	Point Of Interest
RFID	Radio Frequency Identification Device
RPEV	Roadway Powered Electric Vehicle
SAE	Society of Automotive Engineers
SoC	State of Charge
TEPCO	Tokyo Electric Power Company
UML	Unified Modeling Language
WSSE	Web Services Security
XML	Extensible Markup Language

# Table of Contents

<b>ABSTRACT.....</b>	<b>II</b>
<b>ACKNOWLEDGEMENT.....</b>	<b>III</b>
<b>List of Acronyms.....</b>	<b>IV</b>
<b>Table of Contents.....</b>	<b>VI</b>
<b>List of Figures.....</b>	<b>IX</b>
<b>List of Tables.....</b>	<b>XI</b>
<b>Chapter 1:Introduction.....</b>	<b>1</b>
1.1 Background.....	1
1.1.1 Electric Vehicles and Onboard Batteries.....	3
1.1.2 Electric Vehicles Charging Ecosystem.....	4
1.2 Motivation and Objectives.....	6
1.3 Thesis contribution.....	10
1.4 Thesis Organization.....	11
1.5 Publications.....	11
<b>Chapter 2:Interoperability Protocols and Interface Standardization Survey.....</b>	<b>12</b>
2.1 Standardization Efforts.....	12
2.1.1 North American Standardization Efforts.....	12
2.1.2 European Standardization Efforts.....	15
2.2 Physical Layer.....	18
2.2.1 Electric Vehicle Supply Equipment (EVSE).....	18
2.2.2 EV Charging Plugs Standards.....	22
2.2.3 Communication Between EVs and EVSEs.....	26
2.3 EVSE User Identification.....	29
2.4 EVSE Network Management.....	30
2.5 EVSEO vs. EVSP.....	31
2.6 Business Model Compatibility.....	32
2.6.1 EVSE Owners/Operators Business Model.....	32
2.6.2 EV Driver/Owner View.....	34

2.7 The Need for a Clearing House.....	35
2.8 EV Roaming Protocols.....	39
<b>Chapter 3:Open Clearing House Protocol (OCHP) Dissection.....</b>	<b>43</b>
3.1 OCHP Background.....	43
3.2 The Role of The Clearing House.....	46
3.3 Charging Session.....	49
3.4 OCHP Protocol Messages.....	50
3.4.1 The Exchange of Authorization Data.....	50
3.4.2 The Exchange of Charge Data.....	54
3.4.3 The Exchange of Charge Station Information.....	56
3.5 Store and Forward CDRs.....	61
3.6 OCHP Direct (Peer to Peer).....	62
<b>Chapter 4:OCHP Implementation.....</b>	<b>64</b>
4.1 Programing Language, Libraries and IDEs.....	64
4.1.1 Programming Language.....	64
4.1.2 Development Environment.....	65
4.1.3 Libraries.....	65
4.1.4 Development and Testing Tools.....	66
4.2 Implementation Steps.....	67
4.2.1 Software Environment Setup.....	67
4.2.2 Oracle Database Schema Design.....	67
4.2.3 Web Service Client Library.....	70
4.2.4 Web Service Wrapper.....	71
4.2.5 Database Access.....	72
4.2.6 TestScenario1 Class.....	74
4.2.7 The executable package.....	75
<b>Chapter 5:OCHP Performance Analysis.....</b>	<b>76</b>
5.1 Test Environment.....	76
5.2 Test Procedure.....	77
5.3 Test Suite.....	81

5.3.1 Raw Measurements.....	82
5.3.2 Calculation Assumptions.....	84
5.3.3 Aggregated Values.....	84
5.4 Performance Analysis.....	85
5.4.1 Interpretation.....	93
<b>Chapter 6:Quasi-Real Time Billing Extension to OCHP.....</b>	<b>97</b>
6.1 Problem Description.....	97
6.2 Proposed Solution.....	97
6.3 Solution’s Performance Analysis.....	98
<b>Chapter 7:Conclusion and Future Work.....</b>	<b>101</b>
7.1 Concluding Remarks.....	101
7.2 Future Research.....	102
<b>References.....</b>	<b>104</b>
<b>Appendix A, Raw Data.....</b>	<b>112</b>
<b>Appendix B, Database Tables.....</b>	<b>115</b>

# List of Figures

Figure 1.1: EV Industry Ecosystem [BRBF15].....	6
Figure 1.2: Global EVSE outlets, 2010-15 [IEA16].....	8
Figure 1.3: Charging Station Membership Cards [CONN16].....	9
Figure 2.1: Inter and Intra-Network Protocols [MOLD14].....	14
Figure 2.2: Interface Standardization Reference Points [MOLD14].....	15
Figure 2.3: Green eMotion strategy [GREE15].....	16
Figure 2.4: Type 1 SAE J1772-2009 Plug.....	23
Figure 2.5: Type 2 IEC 62196 plug.....	23
Figure 2.6: CCS Combo Type 1 SAE J1772 DC Connector.....	24
Figure 2.7: CCS Combo Type 2 IEC 62196-3 Connector.....	25
Figure 2.8: CHAdeMO Connector.....	25
Figure 2.9: Tesla Supercharger connector.....	26
Figure 2.10: Control Pilot Equivalent Circuit [IEC12].....	27
Figure 2.11: SAE J2931/1 Proposed Communication Stack [SAE14].....	28
Figure 2.12: CHAdeMo CAN-Bus Interface [IEEE16].....	28
Figure 2.13: Efficiency of using a marketplace (clearing house) [CABA15].....	36
Figure 2.14: Hubject's roaming enabled EVSE QR code and logo.....	37
Figure 2.15: Hubject roaming architecture.....	40
Figure 3.1: Various roles in the EV charging market [OCHP15].....	44
Figure 3.2: Data flows between partners [OCHP15].....	45
Figure 3.3: Overall system architecture [OCHP15].....	47
Figure 3.4: Authorized Disconnection Stop [OCHP15].....	49
Figure 3.5: Physical Disconnect [OCHP15].....	50
Figure 3.6: CDR validation flow diagram [OCHP15].....	54
Figure 3.7: OCHP Direct Protocol [OCHP12].....	63
Figure 5.1: Internet bit rate graph while running the test.....	76
Figure 5.2: setRoamingAuthorisationList Response Time.....	86
Figure 5.3: getRoamingAuthorisationList Response Time.....	87

Figure 5.4: setChargepointList Response Time.....	88
Figure 5.5: getChargepointList Response Time.....	89
Figure 5.6: addCDRs Response Time.....	90
Figure 5.7: getCDRs Response Time.....	91
Figure 5.8: All Messages Response Time.....	95
Figure 5.9: All Messages Response Time Log Scale.....	96

# List of Tables

Table 2.1: AC charging electrical ratings (North America) [SAE16].....	20
Table 2.2: DC charging electrical ratings (North America) [SAE16].....	20
Table 3.1: OCHP protocol version history.....	43
Table 3.2: SetRoamingAuthorisationList message.....	51
Table 3.3: SetRoamingAuthorizationList fields.....	51
Table 3.4: UpdateRoamingAuthorisationList message.....	52
Table 3.5: UpdateRoamingAuthorisationList Fields.....	52
Table 3.6: GetRoamingAuthorisationList message.....	52
Table 3.7: GetRoamingAuthorisationList Fields.....	53
Table 3.8: GetRoamingAuthorisationListUpdates message.....	53
Table 3.9: GetRoamingAuthorisationListUpdates Fields.....	53
Table 3.10: AddCDRs message.....	55
Table 3.11: AddCDRs Fields.....	55
Table 3.12: GetCDRs/ConfirmCDRs message.....	55
Table 3.13: GetCDRs/ConfirmCDRs Fields.....	56
Table 3.14: SetChargePointList message.....	56
Table 3.15: SetChargePointList Feilds.....	57
Table 3.16: GetChargePointList message.....	57
Table 3.17: GetChargePointList Fields.....	57
Table 3.18: UpdateChargePointList message.....	58
Table 3.19: UpdateChargePointList Fields.....	58
Table 3.20: GetChargePointListUpdates message.....	58
Table 3.21: GetChargePointListUpdates Fields.....	59
Table 3.22: UpdateStatus message.....	59
Table 3.23: UpdateStatus Fields.....	59
Table 3.24: GetStatus message.....	60
Table 3.25: GetStatus Fields.....	60
Table 3.26: All valid live status combinations.....	61

Table 3.27: OCHP Direct Use Cases.....	63
Table 4.1: The names of all the tables used in the implementation.....	69
Table 5.1: OCHP message response time test plan.....	81
Table 5.2: Test run results, 10 samples example.....	83
Table 5.3: Aggregated values.....	85
Table 5.4: The percentage of SOAP overhead to message size.....	85
Table 5.5: setRoamingAuthorisationList Response Time.....	87
Table 5.6: getRoamingAuthorisationList Response Time.....	88
Table 5.7: setChangepointList Response Time.....	89
Table 5.8: getChangepointList Response Time.....	90
Table 5.9: addCDRs Response.....	91
Table 5.10: getCDRs Response Time.....	92
Table 5.11: Object sizes.....	93
Table 5.12: Processing time per object.....	94
Table 6.1: addCDRs and getCDRs Processing Time.....	99

# Chapter 1: Introduction

## 1.1 Background

By the end of 2015, electric cars on roads have passed the one million mark, up from mere hundreds in 2005 [IEA16][SAVE09]. It took more than ten years to reach this threshold. The market share of electric cars has risen above 1% in seven countries, namely, Norway, the Netherlands, Sweden, Denmark, France, China and the United Kingdom. With high achievers reaching 23% in Norway and 10% in the Netherlands [IEA16].

A target of limiting the global average temperature increase to less than 2°C by 2050, was set by the Paris agreement, announced in the United Nations Framework Convention on Climate Change (UNFCCC), held in Paris in December 2015. For a chance to reach this target, a substantial reduction in emission from transportation sector is needed. And that is because this sector alone contributed about 23% of the greenhouse gas (GHG) emissions in 2015 [IEA15][RIEN13].

Electric Vehicle Initiative (EVI) members, set a target of 7.2 million in electric Vehicle (EV) sales and 24 million of EV stock by 2020 [IEA13], which calls for an additional 23 million EVs to be sold in five years, given the 2015's 1 million stock. Meanwhile. The “Paris Declaration on Electro-Mobility and Climate Change and Call to Action”, pledged a global deployment target of 100 million electric cars by 2030 [IEA16]. Yet, International Energy Agency (IEA) 2°C Decarbonization Scenario (2DS) expects 150 million EVs on the roads by 2030 for a 50% chance of achieving 2DS emission targets.

In a bid to achieve these ambitious transport decarbonization by electrification targets, many national and local governments took significant steps to implement policies and incentives to promote the rapid adoption of electric cars. These incentives range from EV purchase cash backs, EV usage and circulation incentives and waivers on access restrictions to stricter tailpipe emission standards [IEA16][DOMU14].

A few obstacles have to be overcome first, before a wider adoption of EVs is to be seen. And that is due to the inherent consumers resistance towards any new technology that is perceived as unproven or alien [EGLO12]. Even though environmental benefits drive most of the governmental interest in EVs, it was found in a study conducted on a group of 481 technology enthusiasts, who most likely be early adopters of EVs, that environmental and sustainability benefits, influence consumers decision to purchase an EV, but they are ranked behind cost and performance. In the survey, this group ranked and expressed their concerns about EVs in the following order: (1) Battery range, (2) cost, (3) charging infrastructure, (4) reliability and (5) safety. Also, they ranked the appealing attributes of EVs in the following order: (1) decrease the use of petroleum, (2) less maintenance, (3) reduced greenhouse gases, (4) looks/style and (5) comfort [EGLO12].

Literature identified *Range Anxiety* (the psychological effect of the range of a fully charged EV battery, and the fear of running out of juice before reaching the destination) as one of the most significant barriers to mass adoption of EVs [EGLO12][DOSS15][SCHS14]. Even while the number of installed EV Charging Stations (EVSEs) is increasing, they are still irregularly and randomly located in metropolitan areas. In addition, they are usually invisible to the public [BRBF15]. To address the effect of range anxiety on purchase decisions, the range of EVs has to be significantly extended, either by remarkably improving the battery capacity or by improving the availability of EV charging and fast charging stations.

### **1.1.1 Electric Vehicles and Onboard Batteries**

Electric Vehicles (EV) is a term that is usually used to refer to all vehicles that are propelled by an electric motor, with or without relying on batteries as the source of electricity [FRKM13]. For example, fuel cell powered and solar cell powered vehicles are also electric vehicles, but they do not necessarily, rely on batteries as their primary source of power.

There are five main types of electrical vehicles equipped with onboard batteries. They mostly depend on them as a source of energy for propulsion either fully, as the only source of power, or partially where other sources like Internal Combustion Engines (ICE) are used to complement the batteries. The capacity of the onboard battery and whether it needs charging from external source or not, will vary depending on the range and the vehicle's configuration as follows [YSCN11][WAPA14]:

#### **1. Hybrid Electrical Vehicle (HEV)**

HEVs are equipped with two motors, an electric motor powered by an onboard battery and an Internal Combustion Engine (ICE) using regular petroleum fuel. The battery on this type of vehicle usually has a small capacity and is charged by recovering the otherwise lost kinetic energy of braking. The recovered energy is converted to electricity and then stored in the battery to be used later to power the electric motor for short distances. The range and speed of the HEV while in electric mode are very limited compared to the ICE mode. This type of electric vehicles does not need charging from external sources.

#### **2. Plug-in Hybrid Electric Vehicle (PHEV)**

A PHEV is basically an HEV equipped with a much larger battery, that can be charged by plugging it into an external Electric Vehicle Supply Equipment (EVSE). The speed and acceleration of this type of vehicles while in electric mode is quite comparable to the ICE mode, and the range is usually several dozens of kilometers [HYDR15].

### **3. Battery Electric Vehicle (BEV)**

BEVs rely solely on the energy stored in their onboard high capacity batteries as the only source of propulsion power. Depending on the battery capacity, their range may typically vary between 100 km and 400 km on a full charge [HYDR15]. The batteries are charged using an external source (EVSE) which is connected to the grid. The charging time can range from between several hours to 30 minutes, depending on, the battery capacity, the state of charge (SoC) and the EVSE type. Using a DC fast charger, the same battery capacity can be charged much faster than using a slow, low power single phase AC charger.

### **4. Extended Range Electric Vehicle (EREV)**

An EREVs is basically a BEV that has in addition to a high capacity battery to store electricity, an Internal Combustion Generator (ICG), that can generate enough electricity to power the vehicle's electrical motor. The ICG extends the EREV range to reach the final destination or to reach the nearest charging station, whenever the battery is fully depleted. This type of electric vehicles is made primarily, to address the *Range Anxiety* problem, which is an important concern of many current and would-be EV drivers [EGLO12].

### **5. Roadway Powered Electric Vehicle (RPEV)**

An RPEV is basically a BEV that can be powered and charged wirelessly while moving on the road using special charging equipment embedded in roads [CHRI15]. RPEVs are not in deployment yet because of the huge initial investment cost needed to install the charging equipment.

## **1.1.2 Electric Vehicles Charging Ecosystem**

Electric vehicles charging ecosystem is a complex system, and involves many diverse domains. According to EV Connect Roadmap, a report co-funded by the

European Union [BRBF15] (Figure 1.1), the EV charging ecosystem is divided into six main domains and one traversing domain as listed below:

**1. Electric Utilities Domain**

- Includes electricity producers, transmission system operators, Distribution system operators and retailers.

**2. Charging Infrastructure Domain**

- Electric Vehicle Supply Equipment (EVSE) manufacturers and Charging Infrastructure Operators.

**3. Information and Communications Technology (ICT) Domain**

- Includes Marketplace Operators, Clearing House Operators, Metering Operators and E-Mobility Service Providers.

**4. Original Equipment Manufacturer (OEM) domain**

- Includes Electric Motor Manufacturers, Battery Manufacturers, EV Manufactures and EV Suppliers.

**5. Regulators**

- Standardization Entities, Government Policy Makers and Fleet Managers.

**6. E-Mobility Customers**

- Assigned and Roaming Customers.

**7. Traversal Domain**

- Includes University & Research Institutes, EV and EVSE Associations, Battery Recycling Companies and EV Fleet Operators

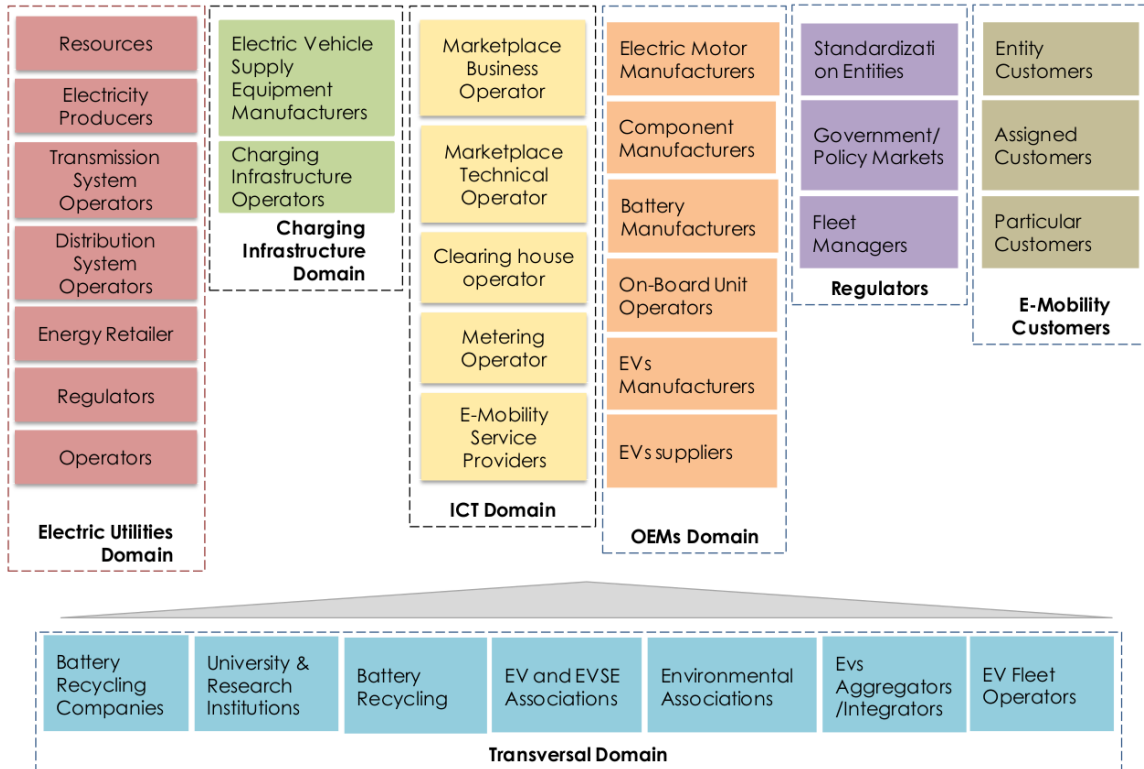


Figure 1.1: EV Industry Ecosystem [BRBF15]

## 1.2 Motivation and Objectives

A major barrier to mass adoption of EVs is *Range Anxiety* [EGLO12]. To address this problem, the usable range of EVs must be increased significantly. To do this, we can either remarkably improve the battery capacity or, assure EV drivers that they will not run out of battery charge before they reach their destination. In other words assuring the drivers that a *compatible* and an *accessible* Electric Vehicle Charging Equipment (EVSE) is *available* for them to use, whenever they feel a need for it along the route of their trip. In addition, the refilling (charging) time will be short (*fast charging*) comparable to alternative vehicle technologies, or at least, it won't be longer than a short bathroom visit or a coffee break.

The keywords that were identified for the EVSE solution to the range anxiety problem were *fast*, *compatible*, *available* and *accessible*, so let's examine them one by one.

***Fast:*** A Supercharger can add up to 270 kilometers of range to a Tesla Model S vehicle in just about 30 minutes [TESL16], and may be decreased further as charging technology and battery technology advance.

***Compatible:*** This mainly refers to the plug compatibility issue that will ultimately settle down as the EV market matures. Regardless, this issue can be watered down by providing multiple connectors at the EVSE or by using driver owned converters.

***Available:*** This refers to the situation where some EVSEs may be out of service or occupied. This, naturally renders them as unavailable to use. One solution for this problem is to be able to reserve a working charging station before arrival, using the vehicle's navigation system, the Internet or a smart phone app.

***Accessible:*** Refers to the ability to find a charging station, authenticate to it, get authorized to use it and properly billed for the service. This is a challenging problem because all of the currently installed EVSEs and the ones that are going to be installed in the future are most likely owned and operating by different entities using incompatible business models, interface protocols, and Information and Communications Technology (ICT) systems. One possible solution to this problem is to establish roaming services between all Electric Vehicle Service Providers (EVSPs). This will enable EV drivers to

locate and charge at any accessible EVSE, regardless of whether it belongs to their home EVSP network, or not.

Installed private electric cars charging equipment are growing on a one to one basis in relation to EV deployment growth rate. This assumption is based on the expectation that each EV owner will conveniently install a charging equipment at home or work for overnight charging. Publicly accessible EV charging ports growth rate also following the growth trend of the EV stock. In 2015, the number of publicly available slow charging EVSE equipment was 162,000 units. The number of publicly accessible fast charging EVSE equipment was 28,000 units, which closely follows the EV growth rate [IEA16] as can be seen in Figure 1.2.

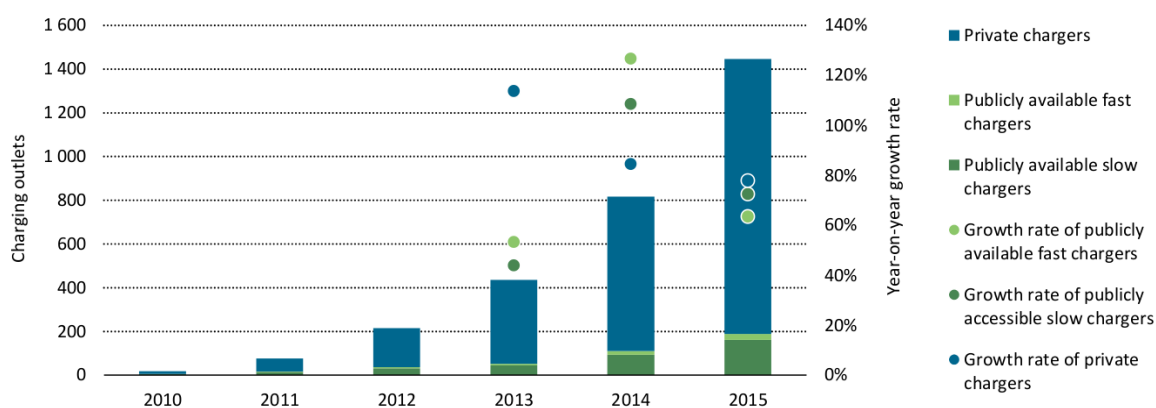


Figure 1.2: Global EVSE outlets, 2010-15 [IEA16]

Even while the number of EVSE equipment is increasing rapidly, they are still operated by different operators, each with their own business model and subscription modes [KHKS13]. This renders the EVSE of one operator, inaccessible to the customers of the other operators, which may further complicate the range anxiety problem. After all, what is the benefit of an available charging station if it can not be used to charge a vehicle!

The EVSP market is an emerging and fragmented one, where an increasing number of small operators compete for the same geographic area. This led many EV users, to

hold several subscriptions, one for each EVSP in their region, and each EVSP issues their own smart card and/or fob as shown in Figure 1.3 [CONN16].



Figure 1.3: Charging Station Membership Cards  
[CONN16]

Achieving seamless interoperability and compatibility between EVSE operators, combined with accessibility and ease of use, is an important milestone to address the range anxiety problem.

This thesis aims to analyze the various issues and solutions related to interoperability problems between Electric Vehicle Charging Networks (EVCNs) operated by different EVSPs. The primary focus will be on roaming protocols which enable EV drivers to charge their vehicles seamlessly, using any accessible and available EVSE port, utilizing only the credentials of one subscription to one operator. In addition, the other interface points where interoperability may be a concern, like customer authentication interface, EV to EVSE communication protocols and the physical connectors will be surveyed.

Some of the emerging and currently in use roaming protocols will be explored. And one of them, namely the Open Clearing House Protocol (OCHP) will be implemented, evaluated and performance tested against e-Clearing.net test clearing house platform. e-Clearing.net is a clearing and settlement platform, operated by Smartlab and ElaadNL on a none for profit basis. It assumes the role of the clearing house, in an EV charging ecosystem that implements the OCHP roaming protocol interface.

The implementation will focus on the client side of the clearing house interface, with an emphasis on Authentication, Authorization, Charge Details Recorded (CDR) exchange and EVSE's information exchange functionality.

## **1.3 Thesis contribution**

In this thesis, the various issues and solutions related to interoperability problems between Electric Vehicle Charging Networks (EVCNs) managed by different EVSPs are surveyed. In addition, the major interface points that need standardization and interoperability considerations are identified. Focus on roaming protocols that aim to allow EV drivers to charge their vehicles seamlessly, using any accessible and available charging station. Furthermore, some of the emerging and currently in use roaming protocols are explored.

Implementing the Open Clearing House Protocol (OCHP) as the roaming interface for the SecCharge (Secure Charging) system allows external charging network subscribers to use SecCharge's EVSE ports, and at the same time allows SecCharge registered subscribers to use other operators charging networks, utilizing only one set of credentials.

The performance tests and the functional analysis of the OCHP implementation, exposed the performance and the capabilities of the protocol, the implementation, and the e-Clearing.net clearing house platform. And a need for a functionality extension to OCHP was discovered.

An extension to the OCHP protocol is proposed to enable a quasi-real time online billing to be routed through the clearing house. This will enable EVSP operators to use the OCHP protocol for postpaid and prepaid roaming services. Moreover, the proposed extension maintains backward compatibility with the existing implementations.

## **1.4 Thesis Organization**

A survey of the various standardization efforts for protocols and interfaces involved in the EV charging and roaming ecosystems is performed in chapter two. The OCHP protocol is analyzed in chapter three and its implementation is described in chapter four. In chapter five, the performance of the clearing house and the protocol's main transactions are evaluated. A solution to the prepaid billing deficiency of OCHP and an extension to it is proposed in chapter six. The final concluding remarks and future research opportunities are stated in chapter seven.

## **1.5 Publications**

A. Al-Tubuly and H.T. Mouftah, "Roaming interoperability for electric vehicle charging networks in smart cities environment", The International Workshop on Green ICT and Smart Networking (GISN 2016) November 4, 2016 in Montreal, Quebec, Canada (Submitted).

# Chapter 2: Interoperability Protocols and Interface Standardization Survey

## 2.1 Standardization Efforts

### 2.1.1 North American Standardization Efforts

American National Standards Institute (ANSI) EV Standards Panel has identified three standardization gaps related to interoperability between EVSPs, and identified NEMA (National Electrical Manufacturers Association) as candidate for developing standards for them [ANSI13], and these gaps are:

**Gap 1:** “Charging of roaming EVs between EVSPs. There is a need to permit roaming EVs to charge at spots affiliated with a different EVSP” [ANSI13].

**Recommendation:** “Develop back-end requirements as well as an interface standard that supports charging of roaming EVs between EVSPs” [ANSI13].

**Gap 2:** “Locating and reserving a public charging station. There is a need for a messaging standard to permit EV drivers to locate a public charging spot and reserve its use in advance” [ANSI13].

**Recommendation:** “Develop a messaging standard to permit EV drivers to universally locate and reserve a public charging spot” [ANSI13].

- Gap 3:** “Access control at charging stations. There is a need to develop data definition and messaging standards for communicating access control at charging stations” [ANSI13].
- Recommendation:** “Develop data definition and messaging standards for communicating access control at charging stations” [ANSI13].

EVSPs use a mix of standardized and proprietary protocols in various communications and interactions between components of their charging networks. These connections, enable their Operations Support Systems (OSS) and Business Support System (BSS) to function properly, for the purpose of operating the network, authenticating users, EV charging management, customer billing, customer support, and interface to external entities like electricity grid providers, roaming partners and clearing houses.

NEMA has identified the interface points where a standardization effort is needed within its scope to facilitate inter EVSP roaming. Standardizing these interfaces will enable EV users to charge their vehicles in an external network utilizing the existing contractual relationship between them and their home EVSP provider [MOLD14]. Figure 2.1 shows the EVSP Inter-Network and Intra-Network protocols locations. The Intra-Network protocols are internal to the EVSP network, and EVSPs can use any mix of proprietary and/or standardized protocols that satisfies their needs. In contrast, the Inter-Network protocols, have to be standardized in order to facilitate interoperability between the increasing number of national and international EVSPs.

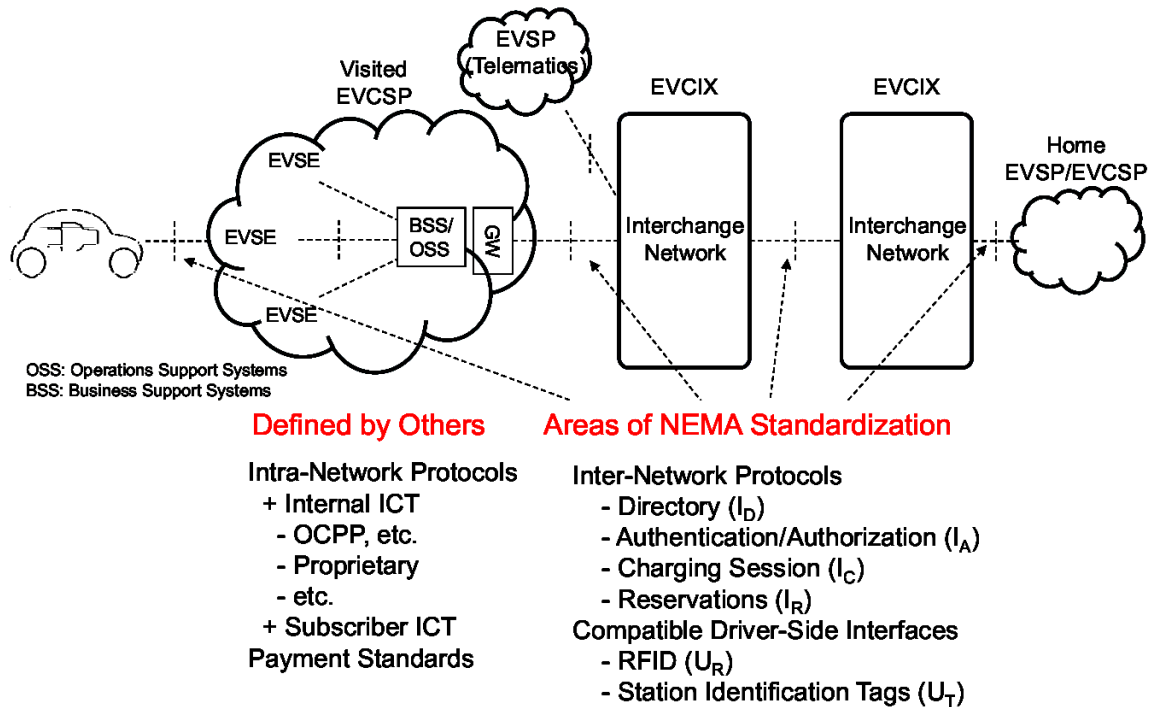


Figure 2.1: Inter and Intra-Network Protocols [MOLD14]

NEMA has developed a reference model for interfaces involved in various EV charging interoperability scenarios. These interfaces are grouped into two categories, Inter-Network Protocols ( $I_x$ ) and Compatible Driver-Side Protocols ( $U_x$ ) as follows [MOLD14]:

A. Inter-Network Protocols ( $I_x$ )

1. ( $I_A$ ) Authentication and Authorization
2. ( $I_D$ ) Station Directory and EVSE Real-Time Status
3. ( $I_C$ ) Charging Session Management, Control and Monitoring
4. ( $I_R$ ) EVSE Reservation

B. Compatible Driver-Side Interfaces ( $U_x$ )

1. ( $U_R$ ) Subscriber RFID Credentials
2. ( $U_T$ ) Station Identification Tags

### 3. (U<sub>V</sub>) Vehicle-Based Credentials

Figure 2.2 shows the locations and the relations to the EV user and the roaming EVSP partner.

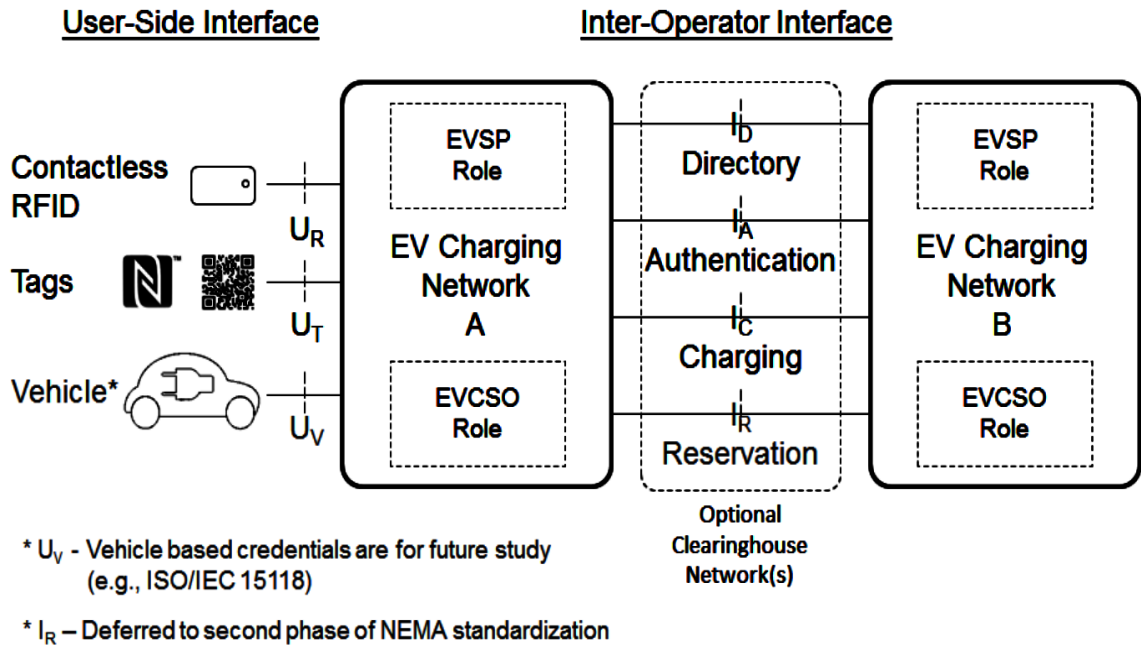


Figure 2.2: Interface Standardization Reference Points [MOLD14]

## 2.1.2 European Standardization Efforts

Recognizing the significance of the harmonization of technology and standards as an important step for mass roll-out of EVs in Europe, the European Commission decided to initiate several projects to promote and standardize the European electro-mobility market[LEKO15]. Transportation electrification was considered as a significant milestone towards achieving the ambitious European Union targets of CO<sub>2</sub> emission reduction.

### Green eMotion Project

A project launched by the European Green Cars Initiative (EGCI) in Brussels on March 31, 2011, as part of the European 2050 CO<sub>2</sub> emission reduction targets of an

ambitious 60%. The project's mission was to lay down within four years, the foundation for mass deployment of Europe-wide eMobility of electric vehicles. The total budget was set to €42 million of which €24 million was funded by the European Commission. Forty-three partners, including EV manufacturers, energy sector, research institutions, universities and municipalities decided to join forces to investigate the prerequisites of Europe-wide electro-mobility, and define a Europe-wide standards by conducting practical research in several European demo regions [GREE11].

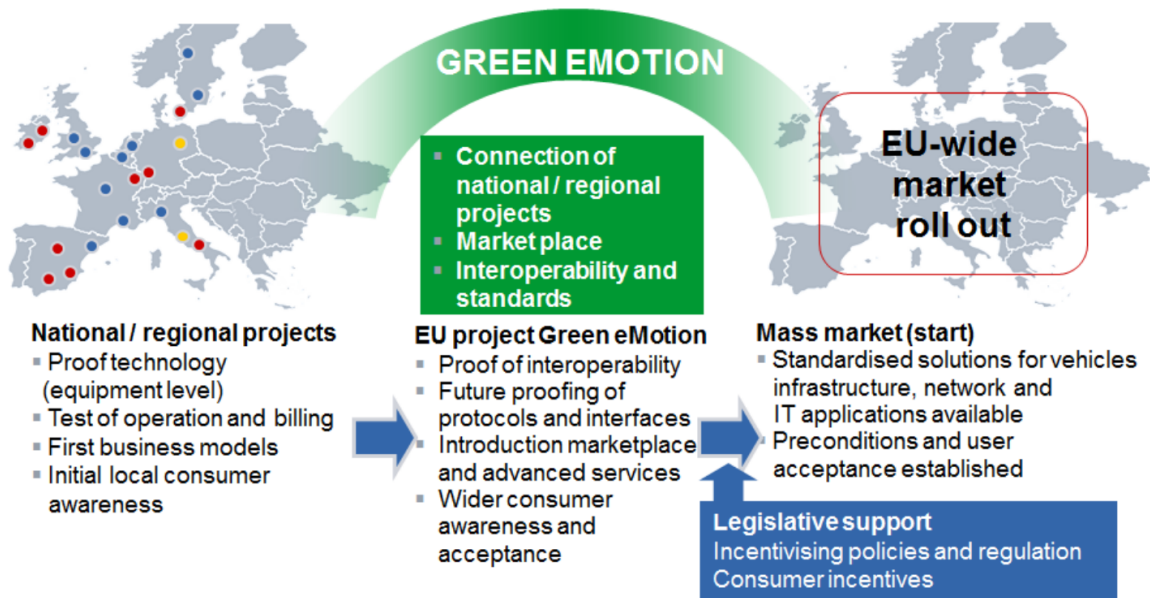


Figure 2.3: Green eMotion strategy [GREE15]

The Green eMotion strategy as shown in Figure 2.3, is to leverage the experience gained from national and regional demo projects, to evaluate marketplaces and standards requirement. These findings are then proposed to the European Commission to be supported by incentives, policies and regulations to promote an EU-wide roll out.

### **eMobility ICT Interoperability Innovation (eMI<sup>3</sup>)**

Under the umbrella of the “European Road Transport Telematics Implementation Coordination Organisation” (ERTICO), a collective of 38 organizations, recognizing the absence of standardized ICT interfaces to exchange data between all the entities

participating in the EV charging ecosystem, and being in a fundamental crossroads, decided to form the “eMobility ICT Interoperability Innovation” (eMI<sup>3</sup>) platform as a spin-off of the Green eMotion project.

Guided by the climate action of the European Commission, the main purpose of eMI<sup>3</sup> was set to the following: as stated in “Electro Mobility – Interoperability Challenges v1.0” document [PWAH15]:

1. Harmonizing existing ICT data and protocols, and proposing new ones if not yet defined. And the goal is to enable global EV service interoperability.
2. Harmonize cross-sector implementation and promote and improve them.
3. Promote the existing EV initiatives and projects.
4. Promote rapid market growth by speeding up the introduction of new services that provide compelling solutions to EV users.
5. Liaise and coordinate with current initiatives to minimize effort and increase interoperability.
6. Reduce commercial, technical, and organizational barriers by coordinating with regulation and standardization bodies.

Based on these targets, eMI<sup>3</sup> has formed five working groups to address various components of the ecosystem standardization as follows [EMI13]:

1. WG1 Use Cases & Services  
Provide a common “language” and understanding.
2. WG2 Architecture & Interfaces  
Creating and freezing the reference architecture and creating interface descriptions.
3. WG3 Business Objects & Identification  
Describe service transaction’s business objects used between EVSE OEMs and EVSPs.

4. WG4 Stakeholder Management & Liaison & Organisation  
Develop proposals for the eMI<sup>3</sup> board on eMI<sup>3</sup> legal and organizational structure, liaison and stakeholder management.
5. WG5 Charge Station Communication Protocol  
Analyze existing protocols and prepare a preliminary protocol descriptions.

## **2.2 Physical Layer**

### **2.2.1 Electric Vehicle Supply Equipment (EVSE)**

Both PHEV's and BEV's batteries are charged by connecting them to an external electricity source. All the components needed for charging that are not part of the EV, including cables, connectors, sockets, transformers and control and safety circuits, are commonly known as Electric Vehicle Supply Equipment (EVSE). EVSE equipment is usually categorized by using SAE J1772<sup>TM</sup> terminology [SAE16] into one of two groups AC Level 1 and 2, or DC Level 1 and 2 [MKBZ16].

As the name imply AC chargers supply alternate current to vehicles while DC chargers supply direct current to vehicles. Another difference is the location of the charging circuit, wherein AC Level 1 and 2 chargers, the actual charging circuit is located onboard the vehicle, while in DC Level 1 and 2 chargers, the charging circuit is located inside the EVSE unit.

The following are the characteristics of the different charging levels:

#### **1. AC Level 1 EVSE**

Most BEVs and PHEVs come equipped with a Level 1 charger on board which allows the EV owner to plug-in his or her vehicle into a standard 120V (230V in Europe) single phase alternate current (AC) utility wall socket, that is fed by a dedicated circuit connected to a dedicated circuit breaker. This charger represents the simplest form of EV charging, where a standard single phase AC cord is used

to charge the vehicle. A charging session to fully charge a completely depleted EV battery, usually lasts between 7 to 17 hours [SAE11], depending on the battery type and capacity. The maximum power supplied should conform to Table 2.1 as per the SAE J1772™ standard.

## **2. AC Level 2 EVSE**

AC Level 2 charging, requires the installation of a dedicated EV charging equipment at a private or a public location. This equipment supplies a single phase 240V alternate current (AC) to the vehicle. A charging session to fully charge a completely depleted EV battery usually lasts between 3 to 7 hours, [SAE11] depending on the battery type and capacity. The maximum power supplied should conform to Table 2.1 as per the SAE J1772™ standard.

## **3. DC Level 1 EVSE**

DC level 1 chargers supply a direct current with a DC volt range of 200V to 450V, and a maximum current of 80A (36kW) to the vehicle. A typical charging session to fully charge a depleted EV battery (20% to 100% ), usually lasts about 1.2 hours [SAE11], depending on the battery type and capacity. The maximum power supplied should conform to Table 2.2 as the per SAE J1772™ standard.

## **4. DC Level 2 EVSE**

DC level 2 chargers supply a direct current with a DC volt range of 200V to 450V, and a maximum current of 200A (90kW) to the vehicle. A typical charging session to charge a depleted EV battery (20% to 80%) usually lasts about 20 min, [SAE11] depending on the battery type and capacity. The maximum power supplied should conform to Table 2.2 as per the SAE J1772™ standard.

Table 2.1: AC charging electrical ratings (North America) [SAE16]

Charge Method	Nominal Supply Voltage (V)	Max Current (Amps-continuous)	Branch Circuit Breaker rating (Amps)
AC Level 1	120 V AC, 1-phase	12 A	15 A (min)
	120 V AC, 1-phase	16 A	20 A
AC Level 2	208 to 240 V AC, 1-phase	≤ 80 A	Per NEC 625

Table 2.2: DC charging electrical ratings (North America) [SAE16]

Charge Method	EVSE DC Output Voltage (V DC)	Max Current (Amps-continuous)
DC Level 1	50-500	80
DC Level 2	50-500	200

In Europe, the International Electrotechnical Commission (IEC) standard document IEC 61851-1 [IEC01] defines four modes for EVSE as follows:

### 1. Mode 1 EVSE

This is a residential charging mode that allows EV owners to plug their vehicles to the standard household alternating current (AC) single phase 250V socket, or the three phase 480V socket, with a maximum current of 16A. A typical charging session to fully charge a completely depleted EV battery usually lasts between 6 to 8 hours [LZVR16], depending on the battery type and capacity.

### 2. Mode 2 EVSE

This is a residential charging mode as well; which allows EV owners to plug their vehicles to the standard household alternating current (AC) single phase 250V

socket, or the three phase 480V socket, with maximum current of 32A. A typical charging session to fully charge a completely depleted EV battery usually lasts between 6 to 8 hours [LZVR16] depending on the battery type and capacity. Unlike Mode 1, Mode 2 requires a control box between the wall socket and the vehicle. This control box provides a control pilot function and a Pulse Width Modulation communication to the vehicle.

### **3. Mode 3 EVSE**

This mode is commonly used in homes and at public locations, it requires a wall box that houses the control box which provides the pilot and the PWM communication. This mode offers two capacities a 32A slow charging and 250A fast charging [IEC03]. A typical charging session to fully charge a completely depleted EV battery using slow mode usually lasts between 6 to 8 hours [LZVR16].

### **4. Mode 4 EVSE**

This mode is a DC charging mode, where the alternate current is converted to a direct current inside the EVSE before delivering it to the vehicle. Mode 4 supplies up to 400V direct current DC to the vehicle, with a maximum current of 200A.

The following are two EVSE DC chargers in actual deployment; that falls into SAE J1772™ DC Level 2 and IEC 61851 Mode 4 charger categories, but they are commonly referred to as DC Fast chargers or DC Level 3 chargers.

#### **1. CHAdeMO DC Fast Charger EVSE**

CHAdeMO is a standard developed by a Japanese consortium; that specifies a communication protocol, DC fast charging capacities, a socket and a plug. The socket and the plug were developed by TEPCO (Tokyo Electric Power Company). The charging station contains a charging circuit that delivers a DC current up to 126A and a DC voltage up to 500V directly to the EV battery. The instantaneous

amount of current and level of voltage is controlled by the EV charging control logic, to deliver an efficient charging profile [HYDR15].

## **2. Tesla Supercharger Station EVSE**

A proprietary EVSE, designed, installed and operated by Tesla Motors. The Supercharger can deliver both alternate current (AC) and direct current (DC) charging using a proprietary plug and socket with a sleek design. This charger can deliver up to 120kW, which can add about 270 KM of range in 30 minutes [TESL16].

### **2.2.2 EV Charging Plugs Standards**

The EV charging plugs market is heavily fragmented, geographically and across different electrical vehicles manufacturers. Standardization bodies compete for market share in Europe, Japan, China and North America. This fragmentation is negatively affecting the adoption of EVs and the deployment of EVSEs. The following is a survey of some of the commonly used plugs:

#### **1. Type 1 SAE J1772-2009 Plug (a.k.a. Yazaki connector)**

A Single phase AC plugs for 120V and 240V, used in North America and Japan.

It is rated for an alternate current of up to 80A Level 1 and Level 2 EVSE equipment, and can deliver up to 19kW of power. The J1772 connector has five pins, two for the power conductors, one for earthing, one for the control pilot and one for proximity detection [LZVR16][EVI14].



Figure 2.4: Type 1 SAE J1772-2009 Plug

## 2. Type 2 IEC 62196 Plug (a.k.a. Mennekes)

A Single phase AC and three phase AC connector for 250V and 400V used mainly in Europe. Rated for an alternate current of up to 63A single phase or three phase Mode 1 and Mode 2 EVSE equipment, and can deliver up to 43kW. Type 2 connector has 7 pins, AC Line 1, AC Line 2, AC Line 3, Neutral, Connection Confirmation, Control Pilot and Proximity Detection [LZVR16][EVI14].



Figure 2.5: Type 2 IEC 62196 plug

### 3. CCS Combo Type 1 SAE J1772 DC Connector

The SAE J1772 Combined Charging System (CCS), combines Type 1 alternate current connector (see specifications above) and a direct current (DC) connector. Rated for 200V and 500V used in North America and Japan. Rated for a direct current of up to 200A and can deliver up to 125kW. J1772 (CCS) Type 1 connector has 7 pins, AC Line 1, AC Line 2, DC power +, DC power -, Ground Pin, Control Pilot and Proximity Detection [LZVR16][EVI14].



Figure 2.6: CCS Combo Type 1 SAE J1772 DC Connector

### 4. CCS Combo Type 2 IEC 62196-3 Connector

The IEC 62196-3 Combined Charging System (CCS) plug combines Type 2 alternate current connector (see specifications above) and a direct current (DC) connector for 200V and 850V systems used mainly in Europe. Rated for a direct current of up to 200A and can deliver up to 170kW. IEC 62196 (CCS) connector has 5 pins, DC power +, DC power -, Ground Pin, Control Pilot and Proximity Detection [LZVR16][EVI14].



Figure 2.7: CCS Combo Type 2 IEC 62196-3 Connector

### 5. CHAdeMO Connector

CHAdeMO Yazaki Connector is a direct current (DC) only connector for 250V and 400V. Rated for a direct current of up to 120A and can deliver up to 60kW. CHAdeMO connector has ten pins, DC power +, DC power -, Reference GND, control EV relay [1 of 2], ready to charge control, Communication +, Communication -, proximity detection and an unused pin [LZVR16][EVI14].



Figure 2.8: CHAdeMO Connector

## 6. Tesla Supercharger connector

The Tesla connector is a direct current (DC) connector for up to 480V. Rated for a direct current of up to 200A and can deliver up to 120kW. The Supercharger connector has five pins, two pins for power, two for the control pilot and one earthing [LZVR16][EVI14][TESL13].

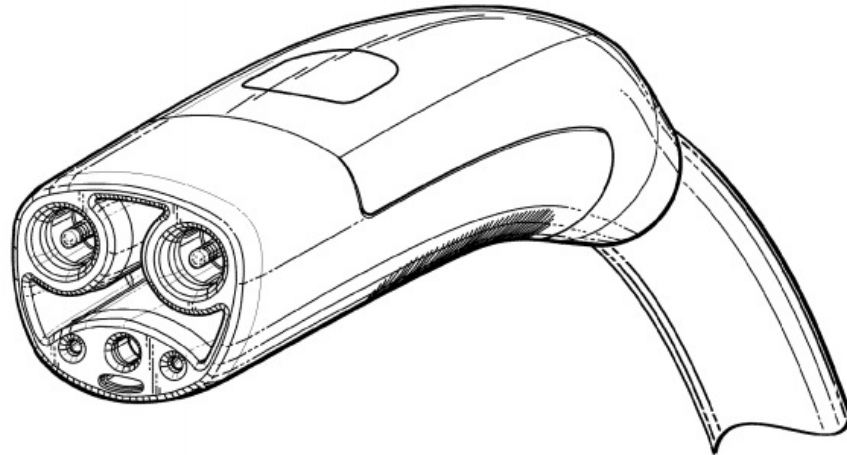


Figure 2.9: Tesla Supercharger connector

### 2.2.3 Communication Between EVs and EVSEs

The SAE J2931/1 document described the benefits of having digital communication between PEVs (plug-in Electric Vehicle) and EVSEs as[SAE14]:

1. Safe electronic energy transfer.
2. Secure interaction with the grid energy providers.
3. Communicate transaction information to the customer.

For charge mobility and roaming, EV to EVSE communication may provide the ability for the EVSE to identify the vehicle and any service contracts associated with it, using the communication link without user's intervention. This may significantly

facilitate authentication, authorization and subsequently billing in the home EVSP network, as well as in a visited EVSP network while roaming[RAGJ14][RTRT13].

### SAE J1772/IEC 61851-1 pilot communication

Both the North American standard SAE J1772 and the European IEC 61851-1 specify a similar, simple Control Pilot communication between the PEV and the EVSE using a Pulse Width Modulation 1 kHz and +12/-12 voltage signal. This allows the EVSE to indicate its readiness to deliver power and the available charging current. While the PEV can indicate its readiness to accept power using a simple switch that controls a voltage divider circuit that the EVSE can sense[IEC12][IEC01].

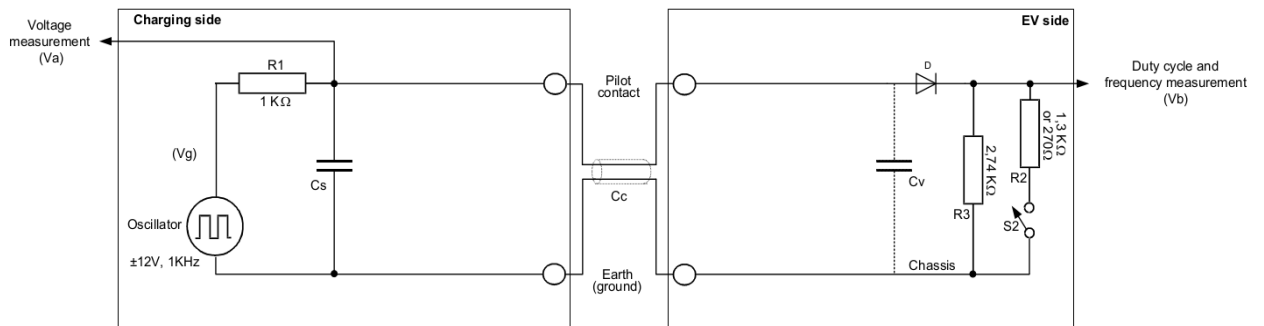


Figure 2.10: Control Pilot Equivalent Circuit [IEC12]

### SAE J2931 Communication

A physical link based on Power Line Communication (PLC), running over the power or pilot wire pines. It was proposed in SAE J2931/1 as an OSI model compatible stack. As shown in Figure 2.11. Its main purpose is to enable communication between the PEV and the Home Area Network (HAN)[LGSW12][SAE14].

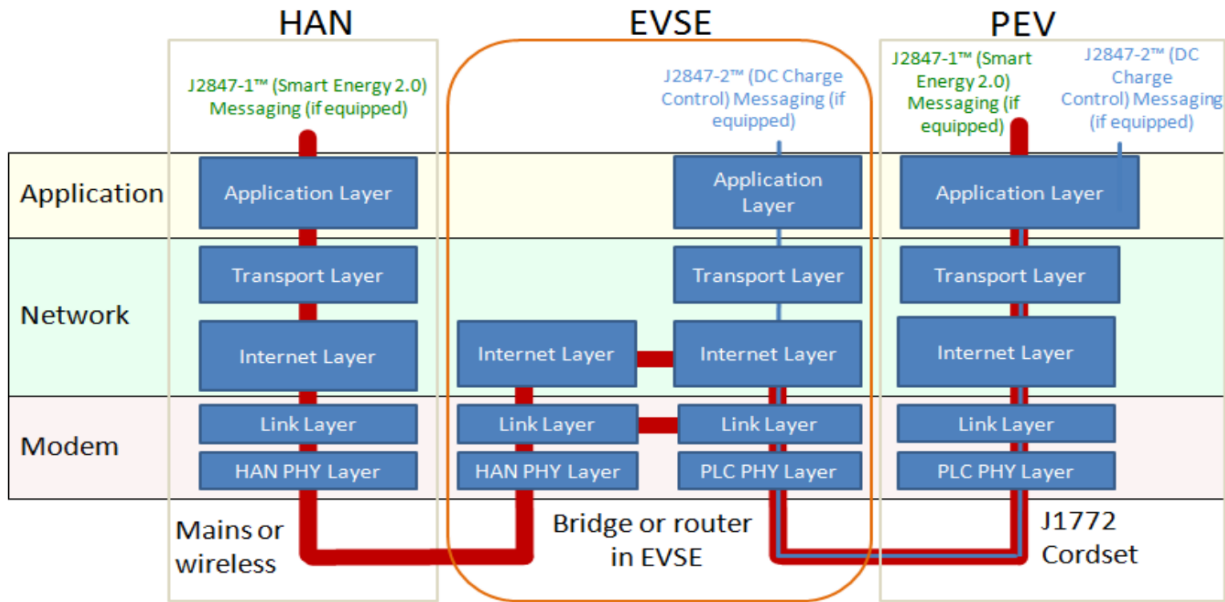


Figure 2.11: SAE J2931/1 Proposed Communication Stack [SAE14]

### CHAdEMO CAN-Bus Communication

CHAdEMO EVSE DC fast charger uses the standard CAN-Bus (Controller Area Network Bus) protocol, which is already in use by the automotive industry to link various electronic control units (ECU) inside the vehicle, together. CHAdEMO connectors communicate with the PEV, using the CAN 2.0B Active protocol, standard 11 bits ID length and a bit rate of 500kbps [RJHG10][IEEE16].

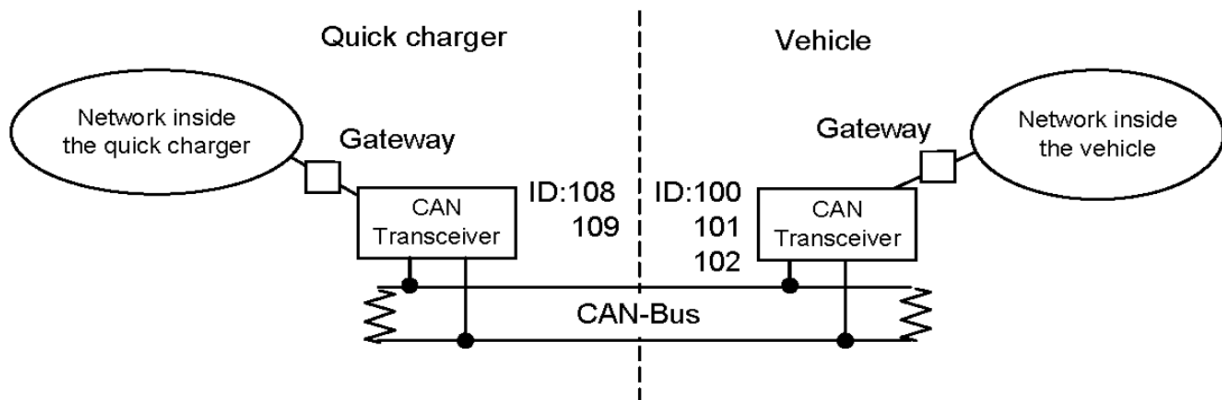


Figure 2.12: CHAdEMo CAN-Bus Interface [IEEE16]

Using the CAN-Bus network, the EVSE and the PEV can communicate, start/stop the charging, and enables the PEV to control the charging profile.

## 2.3 EVSE User Identification

EVSE equipment may demand that users must identify themselves to the network in order to authenticate and authorize them, and then deliver the service according to the terms of the contractual agreement between the EV user and the EVSP network. The user identification process may introduce some privacy concerns in contrast with the anonymous refueling of conventional vehicles at the gas pump, where usually no identification is required[MZKF14][TSEG12]. The following is a list of some of the widely used methods of identification [WESS14][LIDN16][RDSC14][EDEL15]:

1. RFID Card
2. Key FOB or dongle
3. A PIN number
4. Phone App, username and password or QR codes
5. Credit Cards
6. Call a phone number or send an SMS

NEMA has identified Contact-less RFID as the  $U_R$  interface in their Interface Standardization Reference Points [MOLD14] as shown in Figure 2.2. In 2015 NEMA issued a standard document describing this interface under the code “EVSE 1.2-2015”. The specification uses ISO/IEC 14443 as the contact-less proximity Radio Frequency Identification (RFID) and ISO/IEC 7816-4/5/8-based challenge/response application layer protocol. This is an important step towards standardizing this interface which will allow participating EVSPs to offer roaming services using standardized credentials [NEMA15].

## 2.4 EVSE Network Management

According to NEMA, EVSE interface to the EVSP's Operation Support System (OSS) and the Business Support System (BSS) is an Intra-Network interface. It is internal to the operator, and operators can use any mix of the standard and/or the proprietary protocols without affecting interoperability between EVSPs, as far as EV charging roaming is concerned [MOLD14]. Having said that, the standardization of this interface (EVSE to EVSP network interface) is very crucial in terms of the market penetration of EVSEs and the ease of deployment and management.

In the early days of EVSE deployments, EVSE manufacturers used proprietary protocols to manage their equipment. This introduced many problems for EVSPs, especially when their EVSE manufacturers go out of business or when a new manufacturer's equipment is introduced to the network. Adding a new manufacturer will usually require a complex and error prone software development and integration process.

OCPP gained acceptance as the de facto standard for EVSE to network interface communication protocol since its introduction in 2009, even though it is not yet ratified by any standardization body.

### **Open Charge Point Protocol (OCPP)**

OCPP was started by E-Laad Foundation in 2009 in the Netherlands, as an Open Charge Point Protocol Forum, to facilitate the development of an open protocol that allows charging stations to talk to various network management systems easily.

OCPP is now maintained by the Open Charge Alliance (OCA) which was formed by E-laad foundation, a North American EVSP called Greenlots and an Irish utility company called Electricity Supply Board (ESB) [OCA16][RTRT13].

The OCPP protocol was not adopted by any standardization body like ANSI in the US or IEC in Europe, and until recently there was no official compatibility certification process. This meant that compatibility and interoperability are still implementation specific. Yet, in June 2016, OCA started selling a testing tool for protocol implementers to test against [OCA16].

## **Open Chargepoint Network Protocol (OCNP)**

In July 2011 Coulomb Technologies Inc, currently known as ChargePoint announced that it is opening its EVSE to Network Management interface. This communication protocol is commonly known as OCNP and was released for use free of charge, and ChargePoint will offer an interoperability certification program to all EVSE manufacturers [CHAR11]. Yet, on December 6, 2013, the CEO of ChargePoint announced that ChargePoint will adopt OCPP for its Charging Stations in addition to its own OCNP [CHAR13].

## **2.5 EVSEO vs. EVSP**

An Electric Vehicle Supply Equipment Operator (EVSEO) is the entity that is actually in control of an EVSE by owning it or by being contracted to operate and maintain it. The EVSEO may or may not have direct contractual agreements with EV users. On the other hand, an Electric Vehicle Service Provider (EVSP) is an entity that owns the relationship/contractual agreement with EV owners/users. EVSPs may or may not own or operate EVSEs, and they may enter into agreements with EVSEOs to fulfill their obligations towards their customers. Having said that, one entity can assume both the role of EVSEO and the role of EVSP at the same time, and they may have a mix of owned and outsourced EVSEs[RAMK13].

The adoption of EV charging roaming on wide scale, and the deregulation of the charging market may promote the rise of pure virtual EVSEOs or Electric Vehicle Virtual Charging Network Operator (EVVCNO).

## 2.6 Business Model Compatibility

Business models vary widely between EVSP providers. Up until the development and the introduction of the DC Fast Chargers like CHAdeMO and SAE CCS on a large scale, the cost of the electricity drawn using the slower AC chargers was less significant compared to the costs involved in securing the sites for EVSEs and installing and operating them[FLLU11]. And that was naturally reflected in the business models[AMGA15][BEME15].

### 2.6.1 EVSE Owners/Operators Business Model

The following are the commonly used charging metrics by EVSE owners/operators to bill EV users for the charging service.

#### 1. Charge by time duration

Payment by a unit of time, say a minute or an hour, regardless of the amount of energy consumed by the charging session. This method is usually used to bill slow AC chargers.

#### 2. Charge by volume using the kilowatt-hour (KWh) unit

Kilowatt-hour (KWh) is the unit that the new EV drivers need to learn. It describes the amount of energy that the EVSE charger has delivered to the vehicle. It is analogous to the Gallon and the Liter as used to measure the amount of petroleum fuel purchased at the gas pump. This method is more suitable to bill for DC Fast charging where the amount of energy delivered is significant enough to make sense of charging by energy volume instead of time.

#### 3. Charge by the session

A fee per a charging session (per transaction) is billed regardless of how long it takes to charge the vehicle or how much energy (KWh) is consumed. This model makes sense in, for example, hotels and long-term airport parking lots.

**4. Charging by Subscription**

All-you-can-eat buffet module. By paying a subscription fee, the customer is billed a monthly rate or an annual fee, and the customer can charge anytime anywhere as many times as they want.

**5. Subscription + per session fee**

Customers pay a subscription fee, monthly or annually to access the network of charging stations and then pay per session for every recharge. Paying for a subscription fee, usually, entitles the customer for a preferential session rate compared to non-subscribers paying the standard per session rate.

**6. Subscription + per KWh**

Customers pay a subscription fee, monthly or annually to access the network of charging stations and then, pay per KWh for every recharge. Paying for a subscription fee, usually, entitles the customer for a preferential KWh rate compared to non-subscribers paying for the standard KWh rate.

**7. Free Charging Unrestricted**

EV drivers get a free charge unconditionally without any restrictions. In this case, the cost is usually subsidized by the local or the national government to promote electric vehicle sales in an effort to reduce air pollution and carbon footprint.

**8. Free Charging Bundled With Other Services**

EV drivers get a free charge if they pay for another service that is provided by the EVSE owner. They get a free charge if they shop in EVSE owner's mall, eat in their restaurant watch a movie in their theater or pay for the parking spot. For example, like when renting a parking space in a hotel or paying for long-term parking at the airport.

## 2.6.2 EV Driver/Owner View

EV drivers perceive paying for the charging service that they consume in one of the following ways:

### 1. Pay-as-you-go (pay at the pump)

This is the gas station model, where EV users drive to the charging station, plug-in their vehicles, complete the charge and pay for the transaction. The payment can be done using one of the following methods:

1. Pay using a smart phone app.
2. Pay by SMS.
3. Pay by a phone call.
4. Pay in cash or credit in the shop.

### 2. Monthly subscriptions (Postpaid, billed for service after)

This model has two scenarios as follows:

- A. Pay a subscription fee and get billed monthly or yearly for all you can eat service.
- B. Pay a subscription fee and get billed monthly for the subscription fee and then per transaction rate, either per session or volume (KWh).

### 3. Free Charging Stations (Nothing to pay)

EV drivers may expect to get a free charge in one of the two following situations:

- A. The charging station is subsidized by the local or the national government.

- B. Getting a complementary charge when buying another product or service like buying coffee, lunch or for example just visiting the local Ikea store.

## 2.7 The Need for a Clearing House

Roaming agreements and transaction clearing between charging network operators can be done on a bilateral basis. Each two operators interconnect their IT systems and perform the needed interoperability and compatibility tests [RAMK13][CABA15]. This solution is practical only if the number of players in the market is small. But in the case where the number of entities that want to participate in the roaming process is large, say hundreds or thousands (consider, for example, international roaming) this method becomes much less attractive or even unrealistic. One reasonable solution for this problem is to use a central clearing house (or a number of clearing houses), where each operator interconnects only with one (or more) clearing house, and transactions go through it and then routed to the proper partner. Figure 2.13 shows the case where bilateral interconnections between EVSPs restrict the available roaming networks only to the ones where the user's network has an interconnection with Figure 2.13A. Even though having a bilateral agreement with all the relevant operators seems to be a solution for the first case problem, the complexity of this solution is overwhelming as shown in Figure 2.13B. Whereas a central clearing house scenario, as shown in Figure 2.13C, reduces the number of interconnections needed to only one.

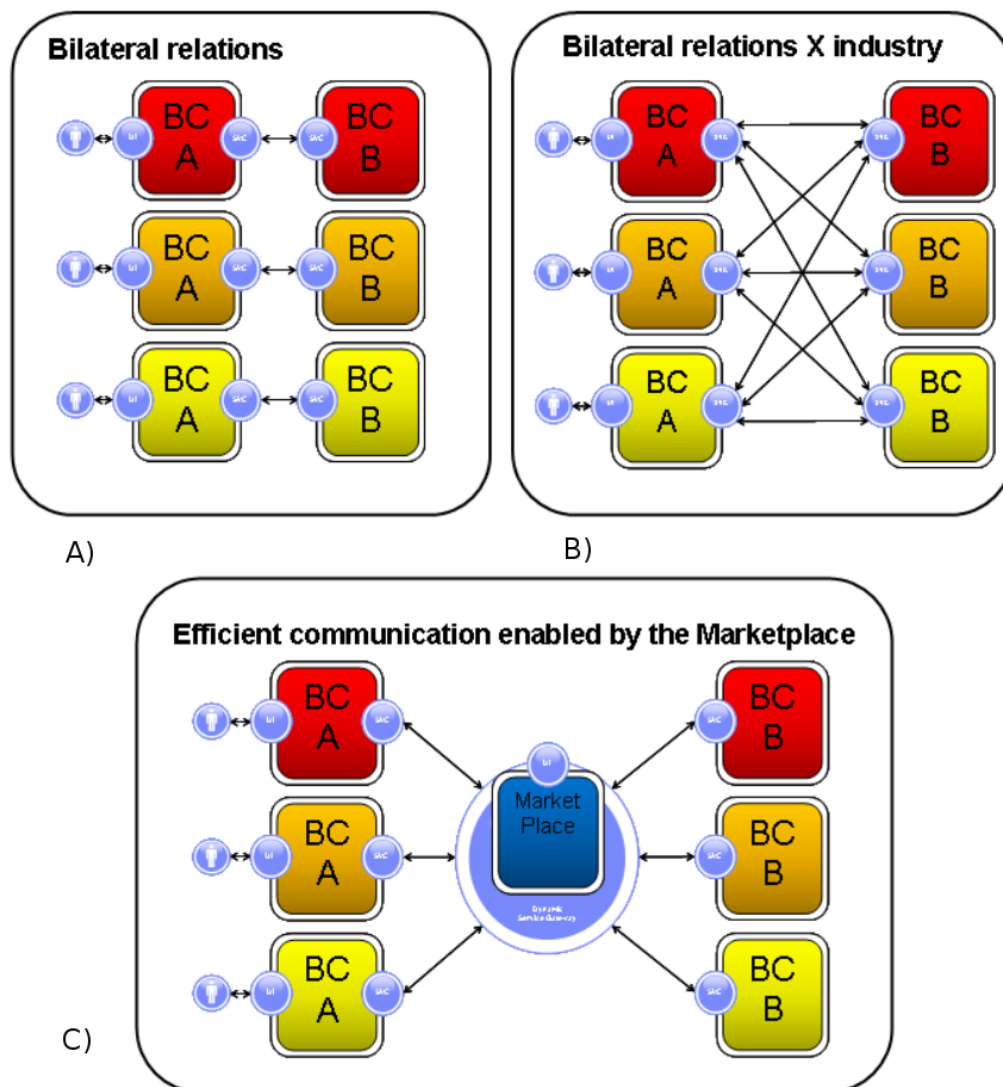


Figure 2.13: Efficiency of using a marketplace (clearing house) [CABA15]

The need of a clearing house to simplify roaming interconnections has resulted in several regional and international attempts to provide this component in the EV charging ecosystem. The following is a survey of some of the recently active attempts to provide a roaming clearing house platforms:

## Ladenetz.de

Ladenetz.de is a partnership between several German public utility companies, seeking to enable roaming services between their public electric vehicles charging EVSE

networks. They developed the Open Clearing House Protocol (OCHP), which enabled these partners to connect to a common clearing house operated by e-clearing.net. This platform was initiated by Ladentz.de, on which the OCHP is used to allow cross-border roaming [CABA15].

On March 30, 2012 ‘The Treaty of Vaals’ was signed by Ladenetz.de, the E-Laad Foundation from the Netherlands, BlueCorner and Becharged from Belgium, Estonteco from Luxemburg, Vlotte from Austria, ESBeCars from Ireland, and Inteli from Portugal. In this treaty, they declared their commitment to using the OCHP protocol for both national, as well as international roaming between their EVSE networks.

## Hubject

Hubject is a joint venture founded in 2012 by BMW, Bosch, Daimler, EnBW (regional utility), RWE (regional utility), and Siemens[BMW12]. Hubject enabled EVSE stations featuring a QR code, to be scanned by an app on an EV driver’s phone, that takes care of authenticating the drive, identifying the EVSE scanned and identifying the driver’s home EVSP. To realize this service, Hubject has developed a protocol to allow members to connect to the clearing platform under the name of Open InterCharge Protocol (OICP) [BUAM15].



Figure 2.14: Hubject’s roaming enabled EVSE QR code and logo

## **GIREVE**

Five large EV market players in France, namely, Caisse des Dépôts, CNR, EDF, ERDF and Renault joined forces to create the GIREVE joint-venture [CABA15]. The three primary objectives of this joint venture, as stated on its website is [GIRE16]:

- 1. Build a comprehensive charging spot database.**

Making EVSEs highly visible and accessible. By maintaining a Reference database of electric vehicle's Charging Points (RPC). This reference database contains all the EVSE's electromobility related data to facilitate the development of value-added services.

- 2. Develop roaming charging services**

Creating a B2B clearing platform to facilitate the exchange of usage and billing data, to enable roaming services between EVSP's networks, in a way similar to bank ATM machines and mobile telephony services.

- 3. Promote coordination between operators**

By promoting interoperability standards, supporting public authorities and supporting infrastructure investors.

## **CROME**

Cross-border Mobility for EVs (CROME), is a cross-border initiative between Germany and France to facilitate the cross-border charging in the French Alsace and Moselle regions and the German Baden-Württemberg region. Where travelers in these areas can use a single RFID card to charge using any station on both sides of the border[GJPF13][CABA15].

## **Collaboratev**

In March 2013, ChargePoint and ECOtality jointly announced a new joint-venture company, Collaboratev, LLC. Its mission was to enable members of any charging network to gain access to charging stations, operated by all other participating networks [ACQU13][ANDR13][WOLF13]. But on September 16, 2013, ECOtality filed for bankruptcy protection under Chapter 11, and the joint-venture did not materialize [SEC13].

## **ROEV Association**

In November 2015, at the Los Angeles International Auto Show, BMW, CarCharging/Blink, ChargePoint, EVgo and Nissan founded the ROEV association in the U.S. The association's main goal is to focus on adopting and promoting universal industry standards to provide drivers with accessible and convenient EV charging across multiple charging stations and charging networks [ROEV15].

## **Pan-European Initiative to Connect eRoaming Platforms**

On Mar 24, 2015, five major European EV charging roaming platform operators, namely GIREVE, e-clearing.net, Enel, MOBILE and Hsubject agreed to cooperate and interconnect their networks to facilitate EV charging roaming across national and international boundaries [HUBJ15]. This is an example of a hierarchical clearing house approach (The clearing house of the clearing houses).

## **2.8 EV Roaming Protocols**

There are many attempts to develop roaming protocols based on the concept of a central clearing house with varying success. But none of these protocols has achieved any recognition from the national or the international standardization bodies yet.

## Open InterCharge Protocol (OICP)

OICP protocol was developed by Hubeject, a joint venture between BMW, Bosch, Daimler, EnBW (regional utility), RWE (regional utility), and Siemens[BMW12], that operates a business and a data platform to provide roaming services to member EVSPs. Using Hubeject services EVSPs enable their customers to access all the available charging station using only their home networks contract and credentials.

OICP is a SOAP based web service protocol that facilitates the interaction between EVSPs and Hubeject's business platform.

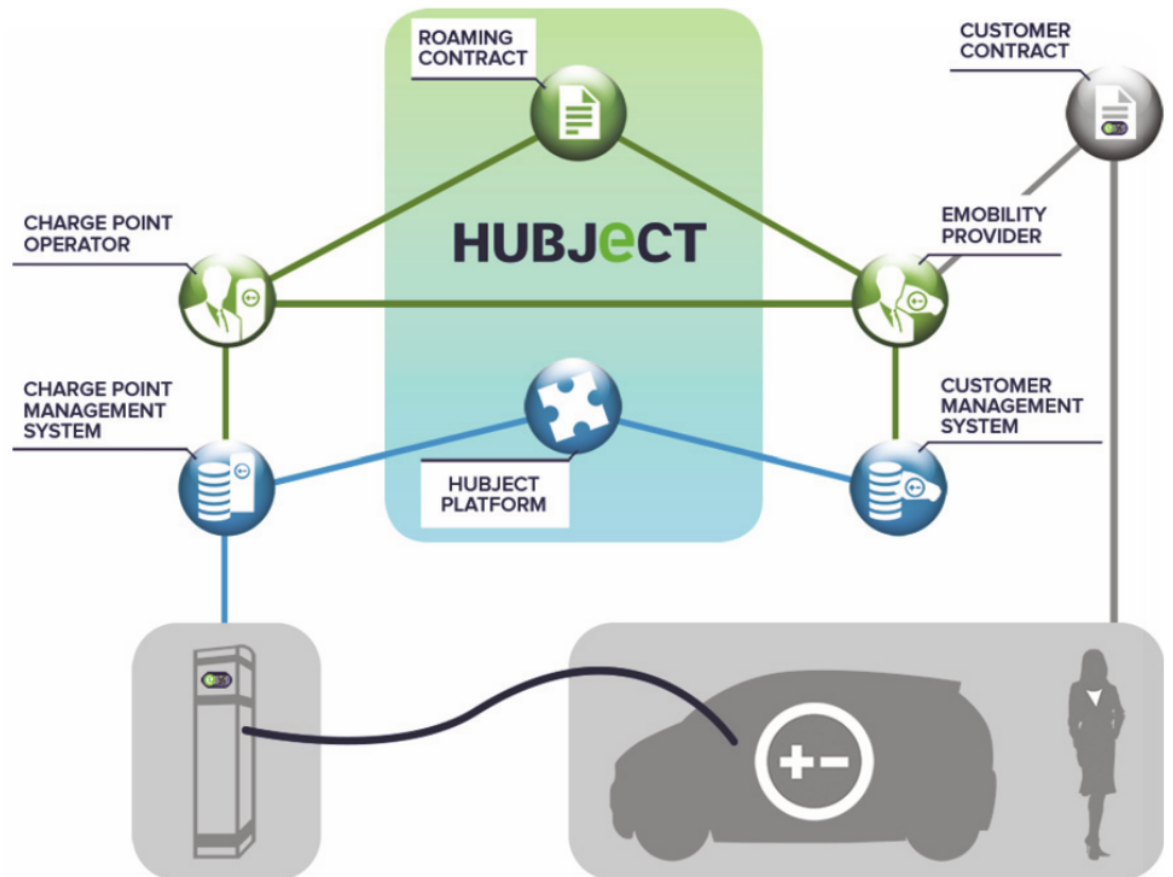


Figure 2.15: Hubeject roaming architecture.

Figure 2.15 Shows the position of Hubeit's business platform in a roaming scenario, and the interconnections serving an eMobility provider (EVSP), who owns the customer's contract and the charge point operator who manages the EVSE.

## **Open Charge Point Interface (OCPI) Protocol**

Initiated in 2014 (Github Nov 2, 2014) in the Netherlands by EV Box, The New Motion, ElaadNL, Greenflux and Last Mile Solutions. Version 2.0 was released in December 2015. The protocol's Github project page describes OCPI as a protocol that "allows for a scalable, automated roaming setup between Charge Point Operators and e-Mobility Service Providers" [OCPI16]. The protocol supports the authorization and the exchange of EVSE information including transactional data and charge detail records (CDRs) [OCPI16].

The Netherlands Knowledge Platform for Charging Infrastructure (NKL), the organization overseeing the development of OCPI, says that its objectives are [NKL16]:

1. Improving the exchange of information between service providers and charge point operators.
2. Providing better information to EV drivers about:
  - a. The status (availability and location) of charge points.
  - b. The associated costs before, during and after charging.
3. Improving access to charge points by developing an independent interface between the charge point and the charge point service provider.

To achieve these objectives OCPI offers the following functionality [OCGR16]:

1. Bilateral and/or via a hub roaming solution.

2. Location, availability and price information in real-time.
3. Exchanging the following data, before during and after the transaction.
  - a. Notification Data Records (start, stop, online, offline ...).
  - b. Charge Data Records. Before during and after the transaction.
4. Access any charge station without pre-registration.

### **Open Clearing House Protocol (OCHP)**

OCHP is an open source protocol that offers a uniform, SOAP-based, interface solution to enables national and international roaming for EV users holding a contract with a participating service provider. This is achieved by allowing them to charge in any charging station that is operated by any of the participating EVSPs. Using this protocol, E-laad.nl (Netherlands), ladenetz.de (Germany) and Blue Corner (Belgium) initiated a clearing & settlement platform under the name of e-clearing.net. This platform offers its members the opportunity to use their own systems to connect to it by implementing the OCHP protocol [ECLE12]. The platform was launched in October 2014 and is operated by smartlab and ElaadNL, as a none for profit organization.

# Chapter 3: Open Clearing House Protocol (OCHP) Dissection

## 3.1 OCHP Background

On May 21, 2012, the first official release of OCHP was announced by e-clearing.net. Whereas the latest release by the time of the writing of this dissertation was the release version 1.3, and it was released on Mar 27, 2015. Table 3.1 shows the version history of this protocol [OCHP15].

Table 3.1: OCHP protocol version history

Version	Date
0.2	21-05-2012
1	12-12-2013
1.2	17-06-2014
1.3	27-03-2015

OCHP enables a Clearing House (CH) to facilitate the interconnection of the organizations that assume one or more of the market roles defined by OCHP specification as follows [OCHP15]:

1. The EV user, who wants to charge his or her vehicle at an EVSE station managed by a participating EVSP, given that the user has a direct or an indirect service contract with one of the participating EVSPs.

2. The EVSP that grants access to an EVSE under its control and may also assume the market roles of an EVSE Operator and/or a Navigation Service Provider (NSP).
3. The EVSE Operator who operates charging stations.
4. The NSP (Navigation Service Provider) - offering a navigation service that allows an EV user to locate and gain access to status information about an EVSE.
5. The Clearing House Operator - running a software platform called a Clearing House to enable data exchange and clearing services to the roles 2, 3 and 4.

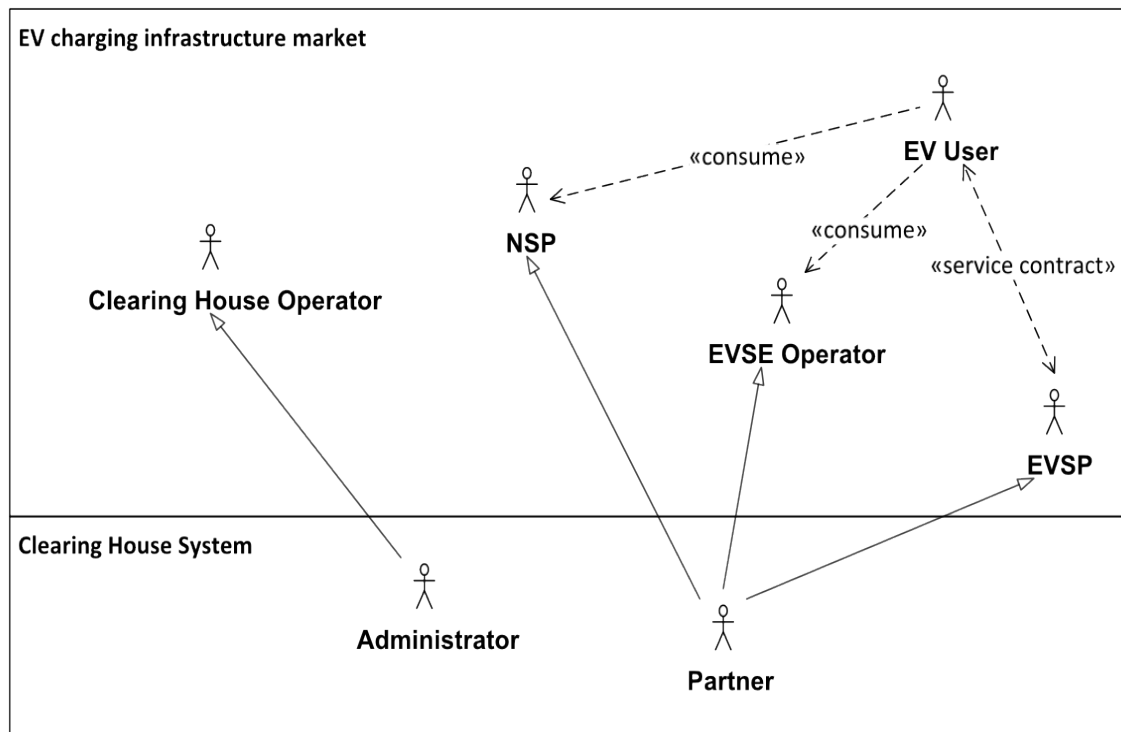


Figure 3.1: Various roles in the EV charging market [OCHP15]

As shown in Figure 3.1, EVSE Operators, EVSPs and NSPs associated with roles 2, 3 and 4 are classified as partners while role 5, the clearing house operator is known as

the administrator. Only the administrator and the partners interact with the clearing house. The EV user is not known to the system and does not interact with the clearing house directly in any way. EV users interact with the EVSP who owns their contract, the EVSE operator who operates the charging station and the NSP provider who provides navigation information to locate the EVSEs.

As shown in Figure 3.2, partners exchange three types of information:

1. Authentication/Authorization Tokens of EV users  
Owned by the EVSP as the Mobility Service Provider and consumed by the EVSE Operator.
2. Charge Detail Records (CDRs)  
Owned by the EVSE Operator and consumed by the EVSP.
3. EVSE Information, Point Of Interest (POI)  
Owned by the EVSE Operator and Consumed by the NSP.

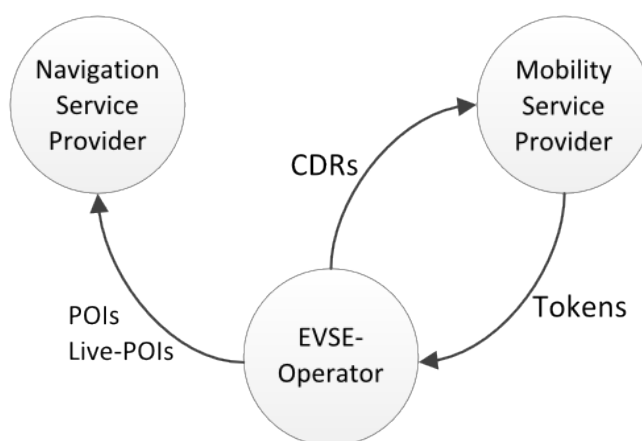


Figure 3.2: Data flows between partners [OCHP15]

## 3.2 The Role of The Clearing House

The purpose of having a clearing house in the EV charging ecosystem is to enable EV users roaming between EV charging partners in an efficient way. The roaming here means that an EV user can conveniently charge his or her electric vehicle using any charging station, operated by any participating EVSE operators.

The clearing house does not own any of the EV charging components nor the data that is generated or consumed by them, (except for the clearing house's ICT system, of course). Instead, they are owned by the partners. The main role of the clearing house is just to facilitate the exchange of this data, by validating, filtering and routing it from the generator to the consumer. The word clearing in this context means only the assignment of CDRs generated by an EVSE operator as a result of charging service events which were delivered to the customers of an EVSP, to that particular EVSP. Even though payment requests are negotiated and calculated based on the exchange of CDRs, the financial clearing in the sense of exchanging financial compensations for services delivered between partners is out of the scope of OCHP. Figure 3.3 Shows the interconnections going through the clearing house using the Unified Modeling Language (UML) notation.

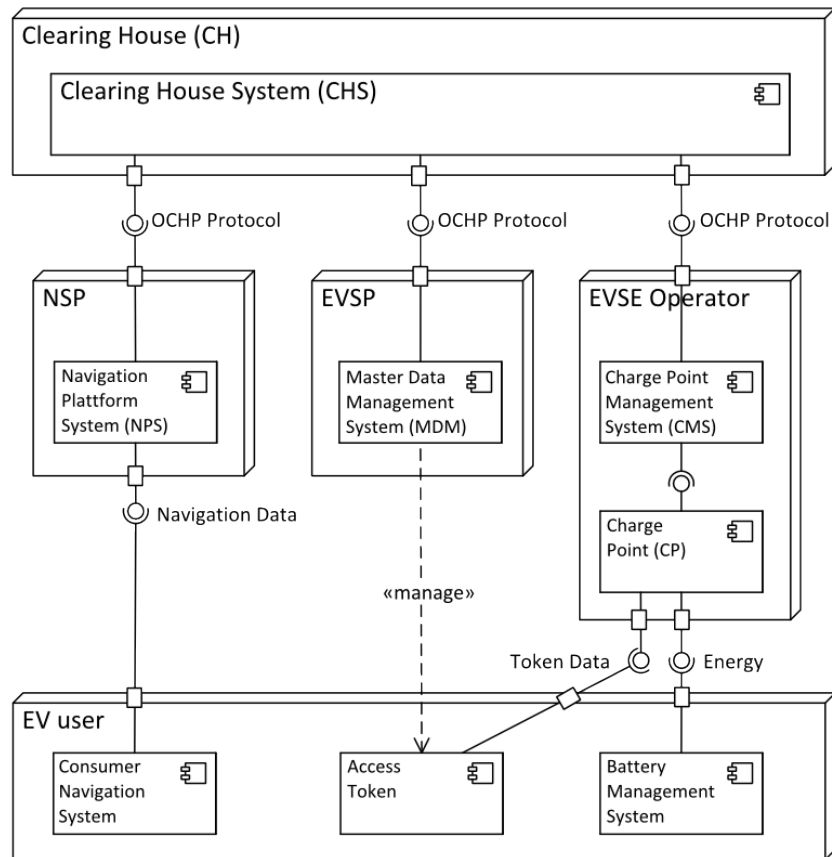


Figure 3.3: Overall system architecture [OCHP15]

A typical roaming scenario that is cleared through a clearing house that uses OCHP, operates as follows:

1. EVSE Operators load their EVSEs static (or dynamic) navigation data to the clearing house.
2. A Navigation Service Provider (NSP) downloads the static (or dynamic) EVSE navigation data from the clearing house.
3. A new EV user signs a service agreement with an EVSP with a roaming capability.

4. The EVSP assigns authorization credentials to the new EV user.
5. The EVSP uploads the new authorization data for the new user to the clearing house.
6. All EVSE operators that have a relation with that particular EVSP, download the new user's authorization data from the clearing house.
7. All EVSE operators involved will enable the new authorization data for the new user on all their charge points (or selectively as agreed).
8. The new user uses the NSP services to locate a charging station that is operated by any of the participating EVSE operators.
9. The new EV user can now charge his or her EV using the chosen charging station.
10. The EVSE operator generates a CDR for this charging event.
11. The EVSE operator uploads the CDR to the clearing house.
12. The clearing house filters, validates and routes the CDR to the EVSP.
13. The EVSP approves the CDR and calculates amount requested.
14. The EVSP pays the EVSE Operator the calculated amount.
15. The EVSP bills his new customer/user for the services consumed while roaming in the EVSE Operator network.

The clearing house is involved only in steps 1, 2, 5, 6, 11 and 12. Some of the other steps are based on data exchanged in the clearing house, but they are carried out without involving it.

### 3.3 Charging Session

There are multiple attributes associated with a charge session, for example, parking time, charging power and charged energy. A CDR may document all of these attributes. In OCHP, the charging session starts when the user is successfully authenticated and ends when one of the following actions takes place:

1. The user issues an authorized stop and then disconnect the vehicle. In this situation, there will be an interval gap between the charging session end and the physical disconnect. As shown in Figure 3.4.

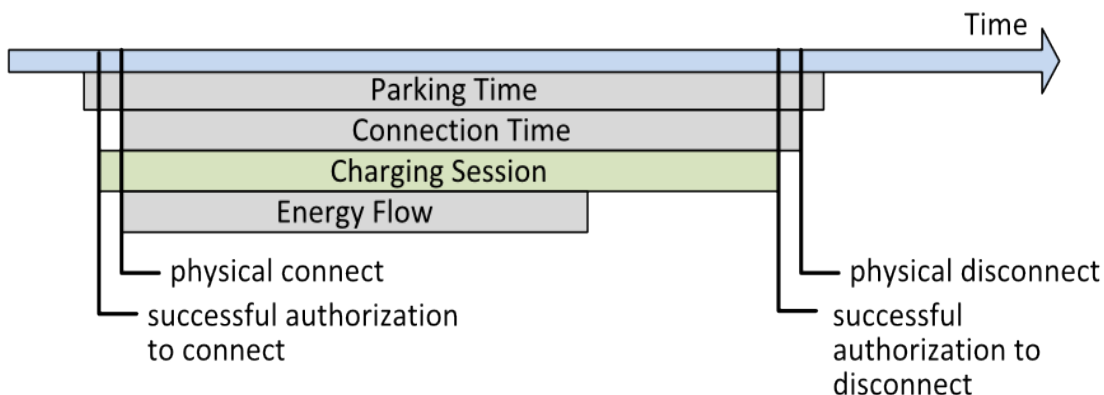


Figure 3.4: Authorized Disconnection Stop [OCHP15]

2. The vehicle was disconnected from the charging station by physically unplugging it before issuing an authorized stop, which results in the termination of the charging session, as shown in Figure 3.5.

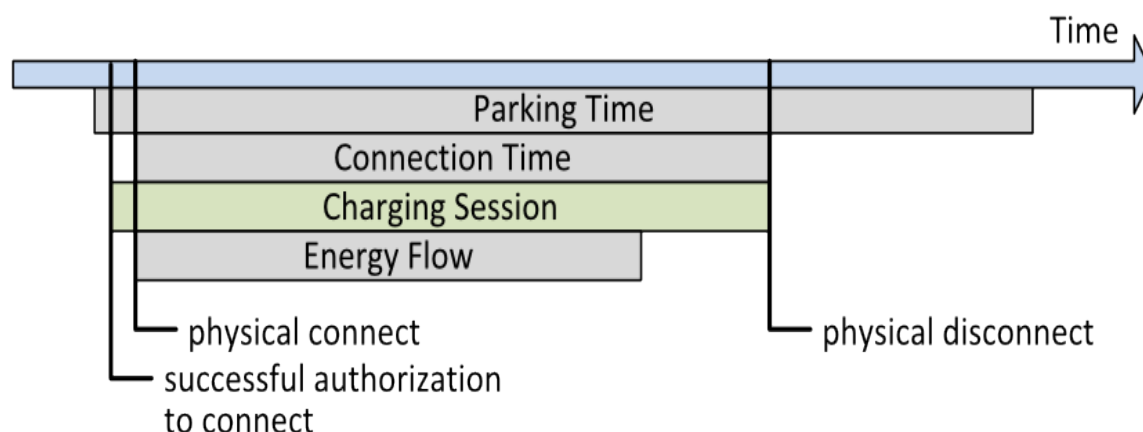


Figure 3.5: Physical Disconnect [OCHP15]

The charging session may extend over an extended period of time where the price of energy may change [MPMA14]. For example, when there is a difference in the day tariff, the night tariff and the holiday tariff. Therefore, OCHP uses the CdrPeriodType to define period characteristics like startTime, endTime, billingItme and billingValue. A CDR may contain more than one CdrPeriodType value to document for example different energy rates.

## 3.4 OCHP Protocol Messages

As stated earlier, the OCHP protocol enables partners to primarily exchange three types of data. This exchange is carried out using protocol defined messages and data types over a SOAP web service. The following is an overview of the main messages and fields passed between the clearing house and the various partners [OCHP15]:

### 3.4.1 The Exchange of Authorization Data

Four operations are defined to achieve the exchange of the authorization data between EVSPs and EVSE Operators as follows:

## 1. Upload EVSP authorization data

The EVSP sends their authorization database to the clearing house.

Table 3.2: SetRoamingAuthorisationList message

From	To	PDU
EVSP	CH	SetRoamingAuthorisationList.req
CH	EVSP	SetRoamingAuthorisationList.conf

Table 3.3: SetRoamingAuthorizationList fields

	Field/Field Type	Description
req	roamingAuthorisationInfoArray/ RoamingAuthorisationInfo	Array of authorization records.
conf	result/ Result	The result of SetRoamingAuthorisationList.req
conf	refusedRoamingAuthorisationInfo/ RoamingAuthorisationInfo	List of unacceptable authorization records.

## 2. Update EVSP authorisation data

The EVSP sends only the new records from the authorization database to the clearing house.

Table 3.4: UpdateRoamingAuthorisationList message

From	To	PDU
EVSP	CH	UpdateRoamingAuthorisationList.req
CH	EVSP	UpdateRoamingAuthorisationList.conf

Table 3.5: UpdateRoamingAuthorisationList Fields

	Field/Field Type	Description
req	roamingAuthorisationInfoArray/ RoamingAuthorisationInfo	Array of authorization records.
conf	result/Result	The result of UpdateRoamingAuthorisationList.req
conf	refusedRoamingAuthorisationInfo/ RoamingAuthorisationInfo	List of unacceptable authorization records.

### 3. Download global roaming authorization data

The EVSE Operator downloads the global authorization data from the clearing house.

Table 3.6: GetRoamingAuthorisationList message

From	To	PDU
EVSEO	CH	GetRoamingAuthorisationList.req
CH	EVSEO	GetRoamingAuthorisationList.conf

Table 3.7: GetRoamingAuthorisationList Fields

	Field/Field Type	Description
conf	result/ Result	The result of GetRoamingAuthorisationList.req
conf	roamingAuthorisationInfoArray/ RoamingAuthorisationInfo	Array of authorization records.

#### 4. Download updates in global roaming authorization data

The EVSE Operator downloads only the new global authorization records from the clearing house.

Table 3.8: GetRoamingAuthorisationListUpdates message

From	To	PDU
EVSEO	CH	GetRoamingAuthorisationListUpdates.req
CH	EVSEO	GetRoamingAuthorisationListUpdates.conf

Table 3.9: GetRoamingAuthorisationListUpdates Fields

	Field/Field Type	Description
req	lastUpdate/ DateTimeType	Array of authorization records.
conf	result/ Result	The result of GetRoamingAuthorisationListUpdate.req
conf	roamingAuthorisationInfoArray/ RoamingAuthorisationInfo	List of authorization records updated since lastUpdate.

### 3.4.2 The Exchange of Charge Data

A successful charging event while roaming should generate a charge detail record. On a bilaterally agreed intervals, EVSE Operators will send the accumulated CDRs to EVSPs through the clearing house. As soon as the CDRs arrive at the clearing house, they are marked as new, and then, they are verified for plausibility. If they pass, they are marked as accepted. Otherwise, they will be rejected, and the EVSE operator can correct the errors and send them again later. The accepted CDRs are then sent to the designated EVSP, who may approve or decline them. If approved they will be archived, or else, a case is opened to investigate them. Figure 3.6 shows the CDR validation state diagram.

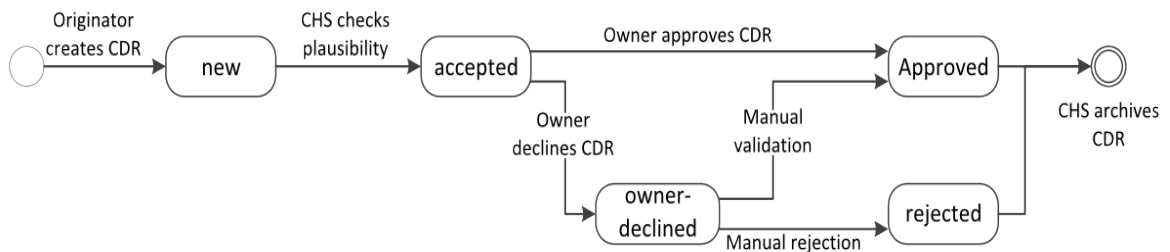


Figure 3.6: CDR validation flow diagram [OCHP15].

#### 1. Upload Charge Data Records

All CDR records are uploaded to the clearing house by the EVSE operator.

Table 3.10: AddCDRs message

From	To	PDU
EVSEO	CH	AddCDRs.req
CH	EVSEO	AddCDRs.conf

Table 3.11: AddCDRs Fields

	Field/Field Type	Description
req	cdrInfoArray/Array(CDRInfo)	One or more CDRs
conf	result/Result	The result of AddCDRs.req
conf	implausibleCdrsArray/ Array(CDRInfo)	Unacceptable CDR

## 2. Process Charge Data Records

EVSPs download their designated CDRs from the clearing house using GetCDRs.req and confirm or decline them using ConfirmCDRs.req.

Table 3.12: GetCDRs/ConfirmCDRs message

From	To	PDU
EVSP	CH	GetCDRs.req
CH	EVSP	GetCDRs.conf
EVSP	CH	ConfirmCDRs.req
CH	EVSP	ConfirmCDRs.conf

Table 3.13: GetCDRs/ConfirmCDRs Fields

	Field/Field Type	Description
GetCDRs.conf	result/Result	The result of GetCDRs.req
GetCDRs.conf	cdrInfoArray/ Array(CDRInfo)	The list of cleared CDR
ConfirmCDRs.req	approved/ Array(CDRInfo)	Approved CDRs
ConfirmCDRs.req	declined/ Array(CDRInfo)	Declined CDRs
ConfirmCDRs.conf	result/Result	The result of ConfirmCDRs.req

### 3.4.3 The Exchange of Charge Station Information

EVSE Operators send the information about the charging stations to the clearing house, which is then made available to the NSP providers to integrate it into their apps and devices.

#### 1. Upload charge Station information

All participating EVSE Operators upload the information about their charging stations to the clearing house.

Table 3.14: SetChargePointList message

From	To	PDU
EVSEO	CH	SetChargePointList.req
CH	EVSEO	SetChargePointList.conf

Table 3.15: SetChargePointList Feilds

	Field/Field Type	Description
req	chargePointInfoArray/ ChargePointInfo	Charging station information array
conf	result/Result	The result of SetChargePointList.req
conf	refusedChargePointInfo/ ChargePointInfo	Unacceptable charge station information record

## 2. Download global charge station information from the clearing house

NSP providers can download the charge station information from the clearing house and make it available to the EV users.

Table 3.16: GetChargePointList message

From	To	PDU
NSP	CH	GetChargePointList.req
CH	NSP	GetChargePointList.conf

Table 3.17: GetChargePointList Fields

	Field/Field Type	Description
conf	result/Result	The result of GetChargePointList.req
conf	chargePointInfoArray/ ChargePointInfo	Charging station information array

### 3. Update charge station information to the clearing house

EVSE Operators uploads only the updated charge station information.

Table 3.18: UpdateChargePointList message

From	To	PDU
EVSEO	CH	UpdateChargePointList.req
CH	EVSEO	UpdateChargePointList.conf

Table 3.19: UpdateChargePointList Fields

	Field/Field Type	Description
req	chargePointInfoArray/ ChargePointInfo	Charging station information array
conf	result/Result	The result of UpdateChargePointList.req
conf	refusedChargePointInfo/ ChargePointInfo	Unacceptable charge station information record

### 4. Download global updates to charge station information from the clearing house

NSP providers, download only the updated charge station information.

Table 3.20: GetChargePointListUpdates message

From	To	PDU
NSP	CH	GetChargePointListUpdates.req
CH	NSP	GetChargePointList.conf

Table 3.21: GetChargePointListUpdates Fields

	Field/Field Type	Description
req	lastUpdate/DateTimeType	The date and time since update
conf	result/Result	The result of GetChargePointListUpdates.req
conf	chargePointInfoArray/ ChargePointInfo	Charging station information array

### 5. Update the live status of the charge stations in the clearing house

EVSE Operators, update the live status of their EVSEs in the clearing house so that NSPs can show it to their users.

Table 3.22: UpdateStatus message

From	To	PDU
EVSEO	CH	UpdateStatus.req
CH	EVSEO	UpdateStatus.conf

Table 3.23: UpdateStatus Fields

	Field/Field Type	Description
req	evse/EvseStatusType	Status update for a charging station
req	ttl/DateTimeType	The time limit of the status update validity
conf	result/Result	The result of UpdateStatus.req

## 6. Download global live status information from the CHS

NSP providers, can download the live charge station information updates from the clearing house.

Table 3.24: GetStatus message

From	To	PDU
NSP	CH	GetStatus.req
CH	NSP	GetStatus.conf

Table 3.25: GetStatus Fields

	Field/Field Type	Description
req	startDateTime/DateTimeType	Status updates that are more current than startDateTime
conf	evse/EvseStatusType	Status update for a charging station

Live charging station status updates are the dynamic part of charging station information that is available for NSP to download. This dynamic information has a Time To Live (TTL) associated with it, after which the information is considered old and invalid. Table 3.26, list all the valid combinations of the Major Status and the Minor Status along with their meaning and the TTL field recommended values.

Table 3.26: All valid live status combinations

<b>Major Status</b>	<b>Minor Status</b>	<b>Description</b>
Unknown	n/a	The charging station status, is unknown. TTL is set to next expected check time.
Available	Available	The charging station available for use. TTL is normally set to five minutes or any reasonable near future value.
Available	Reserved	The Charging station is not in use but reserved for a user in near future. A charging session can be started now. TTL is set to the reservation start time/date.
Not Available	Charging	The charging station is in use. TTL is set the charging session's end time.
Not Available	Blocked	The parking spot is occupied and no charging session is ongoing. TTL is set to a time in the near future.
Not Available	Reserved	No charging can start now because the charging station is reserved. TTL is set to the time of the reservation end.
Not Available	Out Of Order	The charging station is unusable because of a failure. TTL is set to the end of the failure when known. The static status should be set to Inoperable.

### 3.5 Store and Forward CDRs

Charge Detail Records (CDRs) generation is initiated by a charging event at the charging station (EVSE). These CDRs are stored in the BSS/OSS system of the EVSE operator until they are uploaded to the clearing house. Once they arrive at the clearing house, the CDRs are validated and then stored until they are downloaded by the designated EVSP at a pre-agreed intervals.

This store and forward model used by the OCHP protocol may be compatible with pay after billing model (Postpaid), where the consumer is billed in regular intervals, say monthly or bi-weekly for the services consumed in the previous period. This renders marketing a pay as you go (prepaid) subscriptions in a way similar to the mobile telephony industry, quite challenging.

Nevertheless, given that the charging time is sufficiently long (more than 20 min for DC fast charging), a more frequent CDR upload and downloads say in 1 to 5 minutes, may prove practical enough for the EVSPs to market some prepaid products.

Currently, neither the OCHP protocol nor the e-Clearing.net that runs the clearing house mandates a frequency of CDR uploads or downloads, and it is left to the partners to agree upon, in their bilateral agreements. This means that if any EVSP wants to lower the CDR exchange intervals, it must renegotiate its roaming agreement with all EVSE operator partners. The OCHP Direct protocol extension (add in version 1.3) gives the EVSP provider, direct control over the charging process, but the CDRs are still routed through the clearing house using polling intervals.

In chapter 6, a protocol extension is proposed to address this issue.

### **3.6 OCHP Direct (Peer to Peer)**

OCHP Direct is a peer-to-peer protocol extension to the OCHP protocol that enables partners to talk to each other directly. In contrast with pure OCHP, where all transactions have to pass through the clearing house, this protocol extension enables an EVSP to control an EVSE operated by a participating EVSE operator directly.

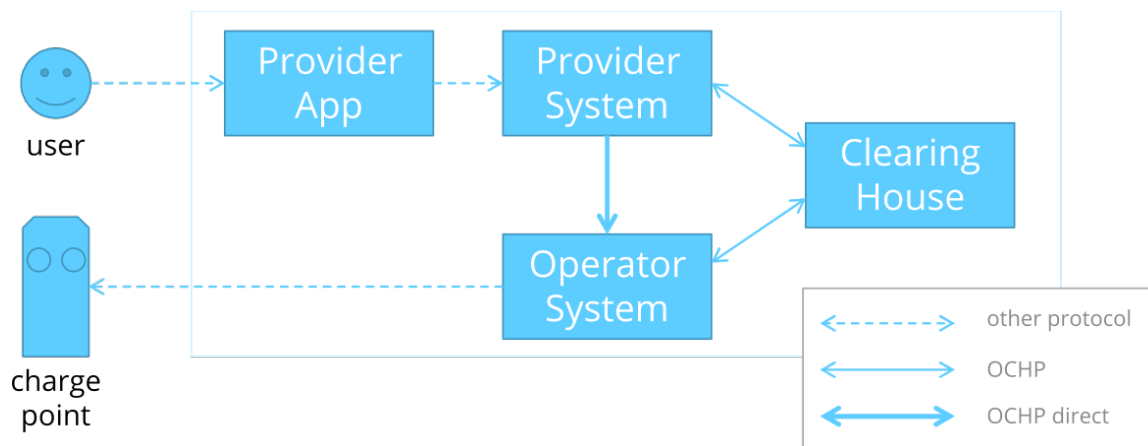


Figure 3.7: OCHP Direct Protocol [OCHP12].

A use case of this extension is to allow an EV user to control an EVSE equipment interactively in real time through an EVSP provider APP, to do the following:

Table 3.27: OCHP Direct Use Cases

Use Case	Description
Remote Start	Start a charging session at an EVSE using an APP
Remote Stop	Stop a charging session at an EVSE using an APP
Live Info	Get session information (progress information) using an APP
Charge Event	Get event notifications about the charging session
Remote Control	Remotely control the charging process using an APP
Remote Action	Trigger any non-session related action at the EVSE.

All CDRS are still cleared through the clearing house over the plain OCHP protocol using the store and forward model described earlier. In addition, this extension enables the EVSP to get intermediate status updates directly from the EVSE operator, during and at the end of the charging session, These updates, include some of the CDR data information like the time, the power and the amount of energy delivered.

# Chapter 4: OCHP Implementation

## 4.1 Programing Language, Libraries and IDEs.

### 4.1.1 Programming Language

Two programming language options, namely, Scala and Java, were examined as candidates for the implementation. The criteria for selection was:

- Compatibility With SecCharge system.
- Mature Integrated Development Environment availability.
- Developer familiarity and learning curve.
- Availability of mature SOAP Web Service libraries.
- Mature Oracle Database Drivers (the database used by SecCharge).

Both Scala and Java are compatible with the SecCharge environment because both are compiled into Java Virtual Machine (JVM) bytecode and can be run on an Apache Tomcat servlet container server.

Many Java libraries can provide SOAP based web service support, for Example, The Java™ API for XML-Based Web Services (JAX-WS) and The Apache CXF. Both libraries can be used in conjunction with both Scala and Java programming languages. Oracle provides two Java Database Connectivity (JDBC) drivers, the native OCI driver, and the thin Java driver. And both drivers are compatible with the two candidate programming languages.

Scala and Java are both supported by Netbeans and Eclipse Integrated Development Environments (IDE). Both IDEs are mature open source products with a large user base and support network.

The developer of the OCHP client implementation (the author of this dissertation) is quite familiar with Java/Tomcat/Netbeans combination but is also very interested in developing in Scala.

A decision to use Java™ programming language was taken because it was the language used in the SecCharge project and there is no additional benefit from using Scala in this context.

### **4.1.2 Development Environment**

Two Integrated Development Environments (IDEs) were considered for developing the OCHP protocol implementation and performance tests, namely Netbeans and Eclipse. Both IDEs have extensive support for Java and JAX-WS. Both IDEs were installed and tested.

A decision to use Netbeans was taken because of the developer previous experience using Netbeans, and there are no additional benefits from switching to Eclipse.

### **4.1.3 Libraries**

#### **SOAP Web Service**

Two web service libraries that support SOAP were considered for use in the OCHP protocol implementation, namely Java™ API for XML-Based Web Services (JAX-WS) and Apache CXF. A decision to use JAX-WS was taken because it is bundled with JDK 1.8 and the SOAP web service client requirements in this project were sufficiently met by it.

**Google Guava 19.0**

Google Guava is an open source library that provides a collection of commonly used utilities. Only the Stopwatch class from this library was used to time the OCHP protocol performance.

**4.1.4 Development and Testing Tools**

The following tools were used in the development and the testing process:

**Apache Tomcat 8.0.32**

Apache Tomcat 8 was used as a servlet container to host the OCHP implementation.

**Oracle 11g Express Edition Database**

Oracle 11g Express Edition was used to host the test data for compatibility reasons with the SecCharge system which uses the Oracle database as well.

**Oracle SQL Developer Version 4.1.3.20**

Oracle SQL Developer was used to create the Database Schema to represent the various data structures involved in the OCHP implementation. In addition, it was also used to develop and debug the stored procedures that are used to maintain and reinitialize the data for the different test scenarios.

**SoapUI 5.2.1**

SoapUI is an open source tool used mainly to test Application Program Interfaces (APIs) and supports multiple protocols such as SOAP, REST, HTTP, JMS, AMF and JDBC[SOAP16]. In this implementation, it was used only to test e-clearing.net's eCHS-OCHP\_1.3 endpoint, and analyze and clarify some protocol details.

**Ubuntu 16.04 LTS**

A Linux platform based on Ubuntu 16.04 was used to host the development and the test environments. The platform was installed on a computer equipped with a dual-core Intel® Core™2 Duo CPU L7100 @ 1.20GHz, 4G Bytes of RAM and an SSD hard disk.

## **4.2 Implementation Steps**

### **4.2.1 Software Environment Setup**

The following steps were taken to prepare the development environment:

1. Java Development Kit JDK 1.8 was downloaded from [www.Oracle.com](http://www.Oracle.com) and installed.
2. Netbeans IDE 8.02 was downloaded from Ubuntu 16.04 repositories and installed.
3. Tomcat 8.0.32 was downloaded from Ubuntu 16.04 repositories and installed.
4. Oracle 11g Express Edition was downloaded from [www.Oracle.com](http://www.Oracle.com) and installed.
5. Oracle SQL Developer 4.1.3.20 was downloaded from [www.Oracle.com](http://www.Oracle.com) and installed.
6. SoapUI 5.2.1 was downloaded from [www.soapui.org](http://www.soapui.org) and installed.

### **4.2.2 Oracle Database Schema Design**

To represent the various data structures used in the OCHP protocol implementation and test scenarios, several tables and stored procedures were created using Oracle SQL developer.

#### **Tables**

The following tables were created in three identical sets:

##### **Generic Tables**

Tables that represent the reference OCHP data structures.

**Local Data**

A generic tables copy that holds own local data representing the locally operated EVSE information, the customer's authentication records and locally generated CDRs, in a format that is ready to be uploaded to the clearing house via the OCHP protocol.

**Partners Data**

A generic tables copy that holds imported partners data, representing their operated EVSE information, their customer's authentication records and own customers remotely generated CDRs, in the format downloaded from the clearing house via the OCHP protocol.

Table 4.1 contains the names of all the table. For table column names and types, refer to Appendix B.

Table 4.1: The names of all the tables used in the implementation

Generic Tables	Local Data	Partners Data
AdditionalGeoPoint	AdditionalGeoPointOwn	AdditionalGeoPointPartners
AuthMethod	AuthMethodOwn	AuthMethodPartners
CDRs	CDRsOwn	CDRsPartners
CdrPeriod	CdrPeriodOwn	CdrPeriodPartners
ChargePointInfo	ChargePointInfoOwn	ChargePointInfoPartners
ChargePointSchedule	ChargePointScheduleOwn	ChargePointSchedulePartners
ConnectorType	ConnectorTypeOwn	ConnectorTypePartners
EvseImageUrl	EvseImageUrlOwn	EvseImageUrlPartners
ExceptionalPeriod	ExceptionalPeriodOwn	ExceptionalPeriodPartners
HoursType	HoursTypeOwn	HoursTypePartners
ParkingRestriction	ParkingRestrictionOwn	ParkingRestrictionPartners
RAuthorisationInfo	RAuthorisationInfoOwn	RAuthorisationInfoPartners
RegularHours	RegularHoursOwn	RegularHoursPartners
RelatedResource	RelatedResourceOwn	RelatedResourcePartners

## Stored Procedures

The following stored procedures were created to facilitate the maintenance of the data tables and housekeeping tasks needed to run the test scenarios.

### **ADD\_OWN\_RECS**

Used to generate test data by calling CREATCDR, CREATAUTH and CREATCPI. This stored procedure accepts one argument “num” which specifies the number of records needs to be generated.

**CREATCDR**

Used to create OCHP compatible CDR records with proper cdrids, ContractIds and EmtIds. In addition, this procedure populates the other fields with OCHP format compliant dummy charge details.

**CREATAUTH**

Used to create OCHP compliant Authentication records which contain a properly formatted EmtId data and expiry dates.

**CREATCPI**

Used to create OCHP compliant ChargePoint Information (CPI) with a properly formatted eMI<sup>3</sup> standard compliant EVSEid. This procedure also populates all the other fields with OCHP format compliant charge point information.

**TRUNC\_OWN**

Used to empty all Own tables.

**TRUNC\_PARTNERS**

Used to empty all Partners tables.

### **4.2.3 Web Service Client Library**

Using a Netbeans JAX-WS plugin, a set of SOAP web service client Java classes were generated to mirror OCHP clearing house requests and responses. The process starts by feeding the plugin with the Web Services Description Language (WSDL) URL that points to the XML file holding the definitions which describe the endpoints, the messages and the data types used the SOAP web service.

The URL used was “ <https://ech-s-q.e-clearing.net/service/ochp/v1.3?wsdl>”

The plugin generated classes that encapsulated OCHP JAX-WS library calls and data types.

The JAW-WS library does not easily allow “UsernameToken” Web Services Security (WSSE) to be used as required by the OCHP clearing house. Therefore, direct manipulation of the SOAP headers was performed before the SOAP request was sent to the web service server. To achieve this, a message handler was inserted into the JAX-WS handler chain to add the following WSSE headers to the SOAP envelope.

```
<soapenv:Envelope xmlns:ns="urn://stationoperator/charging/ws/2012/11/"
xmlns:soapenv="http://schemas.xmlsoap.org/soap/envelope/">
<soapenv:Header>
<wsse:Security soapenv:mustUnderstand="1" xmlns:wsse="http://docs.oasis-open.org/wss/2004/01/oasis-
200401-wss-wssecurity-secext-1.0.xsd">
<wsse:UsernameToken wsu:Id="UsernameToken-1" xmlns:wsu="http://docs.oasis-
open.org/wss/2004/01/oasis-200401-wss-wssecurity-utility-1.0.xsd">
<wsse:Username>theUsername</wsse:Username>
<wsse:Password Type="http://docs.oasis-open.org/wss/2004/01/oasis-200401-wss-username-token-profile-
1.0#PasswordText">thePassword</wsse:Password>
</wsse:UsernameToken>
</wsse:Security>
</soapenv:Header>
<soapenv:Body>
```

#### 4.2.4 Web Service Wrapper

A Java class was developed to wrap the used web service endpoint. The OCHP WSDL file defines two sets of endpoints one set for production servers and another set for testing servers as follows:

##### **eCH\_P-System**

Is the endpoint for the production system.

### **eCH\_Q-System**

Is the endpoint for the test system.

The wrapper class “ECHPort” wraps the eCH\_Q-System to provide access to the testing system managed by the e-Clearing.net organization. This class encapsulates the SOAP web service endpoint and takes care of the web service security (WSSE) headers authentication. The main two getter methods are:

#### **public EClearingNet getService()**

This method returns an EClearingNet object, which extends JAX-WS Service class that provides access to the web service.

#### **public OCHP13 getPort()**

This method returns an OCHP13 object which wraps all the WSDL defined messages.

## **4.2.5 Database Access**

The Thin Oracle JDBC driver was used to access the Oracle 11g Express Edition using a configuration stored in web/META-INF/context.xml file. A database wrapper class is used to do all of the data marshalings between the Oracle database and OCHP data structures.

The database wrapper class is called “ochpDB”, and the following is a list of the main methods:

#### **public java.util.List<ChargePointInfo> loadChargePoint()**

This method returns a List object that contains a list of OCHP ChargePointInfo objects corresponding to all the EVESs information records stored in “ChargePointInfoOwn” database table.

**public java.util.List<CDRInfo> loadCDRs()**

This method returns a List object that contains a list of OCHP CDRInfo objects corresponding to all the CDRs information records stored in “CDRsOwn” database table.

**public java.util.List<RoamingAuthorisationInfo> loadAuthInfo()**

This method returns a List object that contains a list of OCHP RoamingAuthorisationInfo objects corresponding to all the customer authentication information records stored in “RAuthorisationInfoOwn” database table.

**public void insertChargePoint(java.util.List<ChargePointInfo> cpl)**

This method accepts a List object that contains a list of OCHP ChargePointInfo objects which describe EVSE equipment belonging to roaming partners that were downloaded from the clearing house. These objects are converted into database records and then inserted into the “ChargePointInfoPartners” database table.

**public void insertCdrs(java.util.List<CDRInfo> cdrl)**

This method accepts a List object that contains a list of OCHP CDRInfo objects which encapsulate CDR records generated by roaming partners that were downloaded from the clearing house. These objects are converted into database records and then inserted into the “CDRsPartners” database table.

**public void insetAuthInfo(java.util.List<RoamingAuthorisationInfo> authl)**

This method accepts a List object that contains a list of OCHP RoamingAuthorisationInfo objects which encapsulate authentication information belonging to customers of the roaming partners, that was downloaded from the clearing house. These objects are converted into database records and then inserted into the “RAuthorisationInfoPartners” database table.

## 4.2.6 TestScenario1 Class

This class implements a servlet that runs on an Apache Tomcat servlet container server. The servlet runs the test suite that was developed to measure the response time of the major activities carried out by an OCHP based clearing house. This class hosts two main methods as follows:

### **purgClearingHouse()**

This method uses a specially crafted data records to force the clearing house to invalidate, and/or archive previously sent data. This effectively empties the clearing house buffers from old data to prepare it for the next round of tests.

To achieve this, the following steps are taken:

1. All previously sent CDRs are confirmed using OCHP ConfirmCDRsRequest messages. This forces the clearing house to archive old CDRs and removes them from the download buffer.
2. All previously uploaded ChargePointInfo records are updated with a status value equals to “closed”. This effectively tells the clearing house that these EVSEs are no longer installs and will never be used in the future, which forces it to remove them from the active EVSE pool and stop distributing their information.
3. All previously uploaded RoamingAuthorisationInfo records are updated with an expiry date in the past. This will invalidate them and forces the clearing house to archive them and remove them from the download buffers.

After each round of test, this method is called to reinitialize the clearing house for the next round.

**runTestSenario()**

This method runs the test suite one by one, and measures the response time for the web service call part only, excluding database access or any housekeeping code. To measure the response time, a Google Guava Stopwatch class is reset before the call, started and then stopped after the call immediately. As shown in the following code snippet as an example:

```
Stopwatch timer = Stopwatch.createUnstarted();
timer.reset();
timer.start();
AddCDRsResponse addCDRsR = ss.port.addCDRs(addCDRsRequest);
timer.stop();
```

The measured response time is then printed out to the console using the following code snippet:

```
System.out.format("addCDRs Num of Records: %d time: %s result code: %s\n",
loadCDRs.size(), timer.elapsed(TimeUnit.MILLISECONDS),
result.getResultCode().getResultCode());
```

**4.2.7 The executable package**

The compiled code is packaged in a war file under the name “ochpConnector.war” and deployed to an Apache Tomcat server. The test suite is triggered by a page request using a web browser, pointed to the URL `http://<Tomcat server IP>:8080/ochpConnector/TestScenario1` and the test results are collected from the Tomcat console.

# Chapter 5: OCHP Performance Analysis

## 5.1 Test Environment

A Linux platform based on Ubuntu 16.04 running on a dual core Intel® Core™2 Duo CPU L7100 @ 1.20GHz, 4G bytes of RAM and an SSD hard disk was used to host the test environment. The Internet connection was provided by the University of Ottawa. Several speed tests were run to gauge the bit rate between the University of Ottawa and the echs-q.e-clearing.net server that hosts the web service for the clearing house test system. All the tests confirmed the existence of a consistent 10 Megabits per second bit rate cap, as shown in Figure 5.1. Which shows the actual bit rate while running one of the tests.

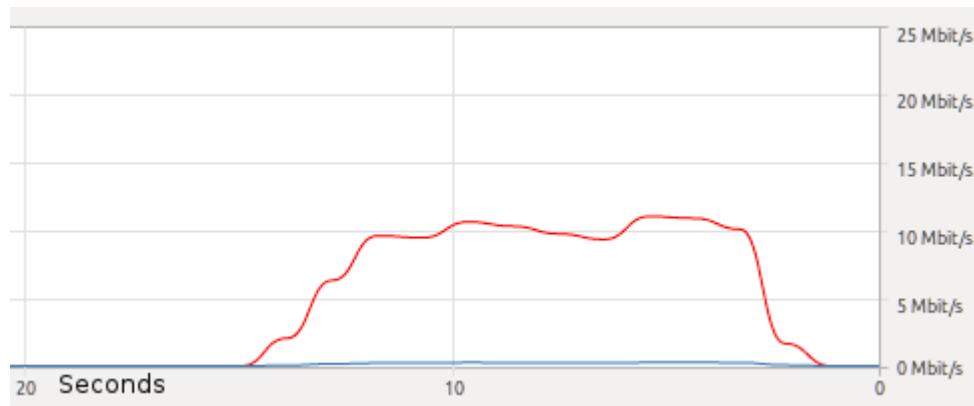


Figure 5.1: Internet bit rate graph while running the test

Before running the tests, the computer was restarted, and only the necessary tools to run the test were started.

## 5.2 Test Procedure

After initializing the test environment the following steps are taken in the following order:

1. The round trip delay between the test computer and the clearing house web service servers is measured by averaging the delay values collected from 100 ping PDUs sent and received. The address used for this measurement is “echs-q.e-clearing.net”, which points to the clearing house test platform.

2. Truncate all database table named \*Partners by calling the stored procedure TRUNC\_PARTNERS().

3. The clearing house is reinitialized for the test by forcing it to invalidate, and/or archive previously sent data. This effectively empties the clearing house buffers from old data and sets it to a known state.

- Get active roaming authorizations from the clearing house. The OCHP13.getRoamingAuthorisationList() method is called to get the RoamingAuthorisationInfo objects that were uploaded previously. The method ochpDB.insertAuthInfo() is called to save the data into the “RAuthorisationInfoPartners” database table.
- Get active charging stations list from the clearing house. The OCHP13.getChargePointList() method is called to get the active EVSE ChargePointInfo objects that were uploaded previously to the clearing house. The method ochpDB.insertChargePoint() is called to save the data into the “ChargePointInfoPartners” database table.
- Get the unconfirmed or undeclared CDRs from the clearing house. The OCHP13.getCDRs() method is called to get the CDRInfo objects that

were uploaded previously to the clearing house and waiting to be confirmed or declined. The method `ochpDB.insertCdrs()` is called to save the data into the “CDRsPartners” database table.

- All the records in the “RAuthorisationInfoPartners” table are updated to set the expiry date to some date in the past using the following SQL statement `[update "RAuthorisationInfoPartners" set "expiryDate"='2016-06-21T14:50:21Z']`.
- All the records in the “ChargePointInfoPartners” table is updated to set the status field to “closed” using the following SQL statement `[update "ChargePointInfoPartners" set "status"='Closed']`. The value “closed” means “discontinued charge point, will be deleted soon” which tells the clearing house to drop the EVSE data.
- Upload the modified data from “RAuthorisationInfoPartners” database table to the clearing house. The `ochpDB.loadAuthInfo()` is called to load the data into `RoamingAuthorisationInfo` list array, and then send it to the clearing house by calling `OCHP13.setRoamingAuthorisationList()` method. Upon receiving this data, the clearing house will delete or archive these roaming authorization records because their expiry dates are in the past.
- Upload the modified data from “ChargePointInfoPartners” database table to the clearing house. The `ochpDB.loadChargePoint()` is called to load the data into `ChargePointInfo` list array, and that sent it to the clearing house by calling `OCHP13.setChargepointList()` method. Upon receiving this data, the clearing house will delete or archive these Chargepoint records because they were marked as “closed”.

- Confirm all the CDRs listed in the “CDRsPartners” database table by first loading them into a CDRInfo list array using the ochpDB.loadCDRs() method and then send them to the clearing house using OCHP13.confirmCDRs() method. Upon receiving the confirmed CDRs, the clearing house will archive them and remove them from the download queue.

4- Now that the clearing house is initialized, a fresh set of test data is generated by calling the following PL-SQL stored procedures in the following order:

#### TRUNC\_PARTNERS

Used to empty all Partners tables.

#### TRUNC\_OWN

Used to empty all Own tables.

#### ADD\_OWN\_RECS

Used to generate test data by calling CREATCDR, CREATAUTH and CREATCPI. This stored procedure accepts one argument called “num” which specifies the number of new records needs to be created. This procedure creates the same number of records in “RAuthorisationInfoOwn”, “ChargePointInfoOwn” and “CDRsOwn”. In addition, it also populates all the supporting tables with the relevant information.

5. After all the relevant tables are properly populated with the desired number of records, the newly generated data is sent to the clearing house (Test Computer → Clearing House) and timed to measure the performance of the OCHP protocol implementation and the test clearing house.

- The `ochpDB.loadAuthInfo()` is called to load the data into a `RoamingAuthorisationInfo` list array from the “`RAuthorisationInfoOwn`” database table. The list array is then sent to the clearing house by calling `OCHP13.setRoamingAuthorisationList()` method.
- The `ochpDB.loadChargePoint()` is called to load the data into a `ChargePointInfo` list array from “`ChargePointInfoOwn`” database table. The list array is then sent to the clearing house by calling `OCHP13.setChargepointList()` method.
- The `ochpDB.loadCDRs()` is called to loading the data into a `CDRInfo` list array from the “`CDRsOwn`” database table. The list array is then sent to the clearing house by calling `OCHP13.addCDRs()` method.

6. All the newly uploaded data to the clearinghouse is then downloaded to the test computer (Clearing House → Test Computer) and timed, then stored in the `*Partners` database tables. The steps are as follows:

- The `OCHP13.getRoamingAuthorisationList()` method is called to get the `RoamingAuthorisationInfo` objects and the method `ochpDB.insertAuthInfo()` is called to save the data into the “`RAuthorisationInfoPartners`” database table.
- The `OCHP13.getChargePointList()` method is called to get the `ChargePointInfo` objects and the method `ochpDB.insertChargePoint()` is called to save the data into the “`ChargePointInfoPartners`” database table.

- The OCHP13.getCDRs() method is called to get the CDRInfo objects and the method ochpDB.insertCdrs() is called to save the data into the “CDRsPartners” database table.

The measurements data is collected and logged to a spreadsheet for further processing.

## 5.3 Test Suite

Five test groups are executed, each group is ran ten times, and the ten runs are averaged and then adjusted, for network delay and throughput. Table 5.1 shows the test plan.

Table 5.1: OCHP message response time test plan

Messages	Test Group 1	Test Group 2	Test Group 3	Test Group 4	Test Group 5
1. SetRoamingAuthorisationList	1	10	100	1000	10000
2. getRoamingAuthorisationList	Record	Records	Records	Records	Records
3. setChargepointList					
4. getChargePointList					
5 .addCDRs					
6. getCDRs					

10,000 was the maximum number of objects that follows the exponential  $10^x$  increments which can be sent to the server. This is because when sending 100,000 objects is attempted, the clearing house web service server, triggered an exception. The exception indicated that the max configured innerElementCountThreshold (500000) was reached.

Which means that this is a configuration limit. The following is a snippet of the received exception:

**com.sun.xml.internal.ws.fault.ServerSOAPFaultException: Client received SOAP Fault from server: reach the innerElementCountThreshold:500000 Please see the server log to find more detail regarding exact cause of the failure.**

at-

**com.sun.xml.internal.ws.fault.SOAP11Fault.getProtocolException(SOAP11Fault.java:178)**

at-

**com.sun.xml.internal.ws.fault.SOAPFaultBuilder.createException(SOAPFaultBuilder.java:116)**

at-

**com.sun.xml.internal.ws.client.sei.StubHandler.readResponse(StubHandler.java:238)**  
)

at-

**com.sun.xml.internal.ws.db.DatabindingImpl.deserializeResponse(DatabindingImpl.java:189)**

·  
·  
·

### 5.3.1 Raw Measurements

The following is a sample measurement set as printed out by the test suit. This represents one run of the group 10,000 records.

setRoamingAuthorisationList Num of Records: 10000 time: 36987 ms, result code: ok  
getRoamingAuthorisationList Num of Records: 10000 time: 11469 ms, result code: ok  
setChargepointList Num of Records: 10000 time: 172824 ms, result code: ok

getChargePointList Num of Records: 10000 time: 75272 ms, result code: ok

addCDRs Num of Records: 10000 time: 62715 ms, result code: ok

getCDRs Num of Records: 10000 time: 25526 ms, result code: ok

The six tested messages namely, setRoamingAuthorisationList, getRoamingAuthorisationList, setChargepointList, getChargePointList, addCDRs and getCDRs are selected for this test because they are the ones involved in moving the primary data sets between the partners and the clearing house.

The following is a sample spreadsheet table used to average the runs and compensate for network parameters.

Table 5.2: Test run results, 10 samples example

100 Ping average ms		150	Internet throughput bps	10,000,000		
setRoamingAuthorisationList		Record Size	286 Bytes			
Sample	Number of Records	Time ms	RTD Adjustment ms	Payload Size Bytes	Tx Time ms	Tx Time Adjusted
1	10000	35817	35667	2860000	2288	33379
2	10000	33154	33004	2860000	2288	30716
3	10000	35643	35493	2860000	2288	33205
4	10000	31540	31390	2860000	2288	29102
5	10000	33924	33774	2860000	2288	31486
6	10000	33732	33582	2860000	2288	31294
7	10000	36987	36837	2860000	2288	34549
8	10000	37811	37661	2860000	2288	35373
9	10000	34544	34394	2860000	2288	32106
10	10000	34796	34646	2860000	2288	32358
Average		34794.8	34644.8			32356.8

Table 5.2 shows the data collected from 10 separate runs of “setRoamingAuthorisationList” to send 10,000 objects of “RoamingAuthorisationInfo” where the average was 34794.8 ms. This average is adjusted for a 150 ms round trip network delay time to 34644.8 ms and then adjusted for the transmission time needed to send 2860000 bytes i.e., 2288 ms to 32356 ms.

### 5.3.2 Calculation Assumptions

- The assumptions made in calculating these response times are:
- The round trip delay time is accurate enough and is stable, in other words, the jitter is minimal.
- Each message is compensated for transmission time in one direction only, assuming that either the request or the response is very small, compared to the payload in the request or the response in the other direction.
- The effect of the SOAP headers overhead is negligible. And that is because the network throughput is high enough for a small number of objects and the overhead to payload ratio is small enough for large payloads.
- The network transmission speed is consistent and is 10 mbps as measured.

### 5.3.3 Aggregated Values

Table 5.3 contains the final performance data. This table contains the response time of the listed SOAP messages used to exchange OCHP objects. Each of the listed values represents the average of 10 sample points after compensation for network round trip delay and network throughput. These values are in milliseconds.

Table 5.3: Aggregated values

Values in ms	1 Object	10 Objects	100 Objects	1000 Objects	10,000 Objects
setRoamingAuthorisationList	54.3712	56.312	596.02	4231.6	32356.8
getRoamingAuthorisationList	49.0712	43.512	423.72	1512.8	6503.2
setChargepointList	47.2832	352.132	2061.02	16347.8	167172.6
getChargePointList	57.3832	121.332	1561.82	9327.8	65588
addCDRs	41.3368	394.268	1909.88	8869.1	55214.1
getCDRs	71.9368	79.068	724.88	3920.3	14663.9

For the full set of raw data points please refer to Appendix A.

## 5.4 Performance Analysis

The SOAP overhead is measured to be 788 bytes and is approximately the same for all messages and payload sizes. The effect of the headers overhead is more profound in SOAP messages with small payloads and becomes less and less significant as the payload size increase. This can be seen clearly in Table 5.4, which shows the percentage of the overhead to message size for all OCHP messages under test.

Table 5.4: The percentage of SOAP overhead to message size

SOAP headers 788 bytes	Object Size In Bytes	1 Object	10 Objects	100 Objects	1000 Objects	10,000 Objects
setRoamingAuthorisationList	286	73.37%	21.60%	2.68%	0.27%	0.03%
getRoamingAuthorisationList	286	73.37%	21.60%	2.68%	0.27%	0.03%
setChargepointList	1146	40.74%	6.43%	0.68%	0.07%	0.01%
getChargePointList	1146	40.74%	6.43%	0.68%	0.07%	0.01%
addCDRs	1329	37.22%	5.60%	0.59%	0.06%	0.01%
getCDRs	1329	37.22%	5.60%	0.59%	0.06%	0.01%

In all cases, the SOAP overhead affects only the size and the transmission time of the SOAP message. Nevertheless, the SOAP overhead adds only 788 bytes to the message, which represents only 0.63 ms of transmission time at 10 Mbps network throughput.

## setRoamingAuthorisationList

setRoamingAuthorisationList message, uploads roaming authorization information to the clearing house. The size of one object encapsulating one customer information as measured from the SOAP XML representation was found to be 286 bytes excluding all other SOAP headers. Figure 5.2 shows a plot of the results on both linear and logarithmic scale of the values shown in Table 5.5.

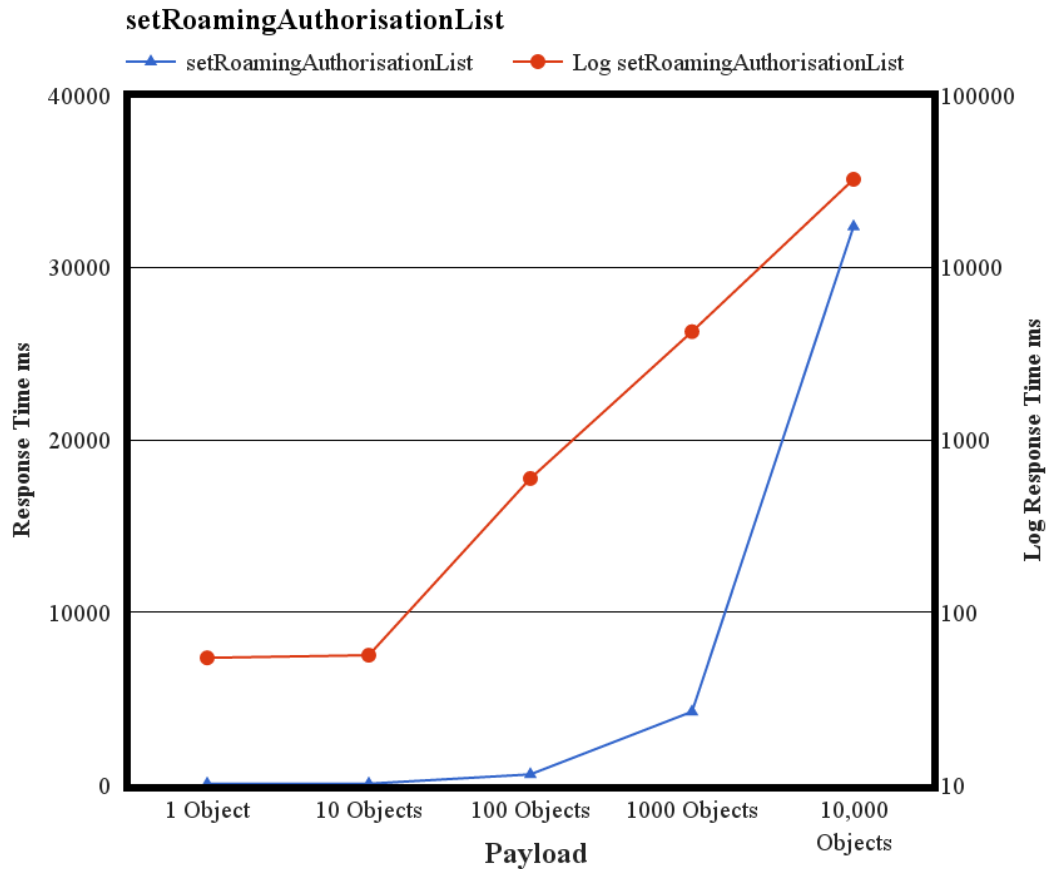


Figure 5.2: setRoamingAuthorisationList Response Time

Table 5.5: setRoamingAuthorisationList Response Time

Values in ms	1 Object	10 Objects	100 Objects	1000 Objects	10,000 Objects
setRoamingAuthorisationList	54.3712	56.312	596.02	4231.6	32356.8

## getRoamingAuthorisationList

getRoamingAuthorisationList message downloads the roaming authorization information from the clearing house. The size of one object encapsulating one customer information as measured from the SOAP XML representation was found to be 286 bytes excluding all other SOAP headers. Figure 5.3 shows a plot of the results on both linear and logarithmic scale of the values shown in Table 5.6.

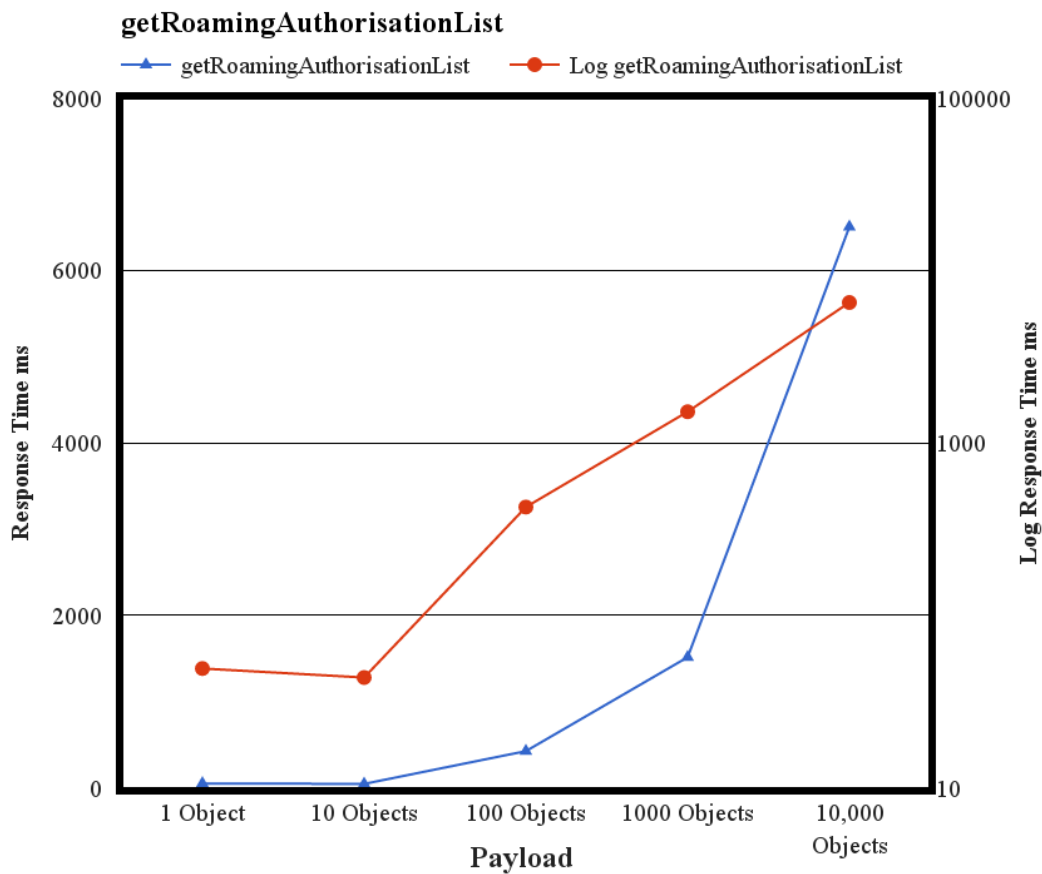


Figure 5.3: getRoamingAuthorisationList Response Time

Table 5.6: getRoamingAuthorisationList Response Time

Values in ms	1 Object	10 Objects	100 Objects	1000 Objects	10,000 Objects
getRoamingAuthorisationList	49.0712	43.512	423.72	1512.8	6503.2

## setChargepointList

setChargepointList message uploads EVSE equipment information to the clearing house. The size of one object encapsulating one charge point information as measured from the SOAP XML representation was found to be 1146 bytes excluding all other SOAP headers. Figure 5.4 shows a plot of the results on both linear and logarithmic scale of the values shown in Table 5.7.

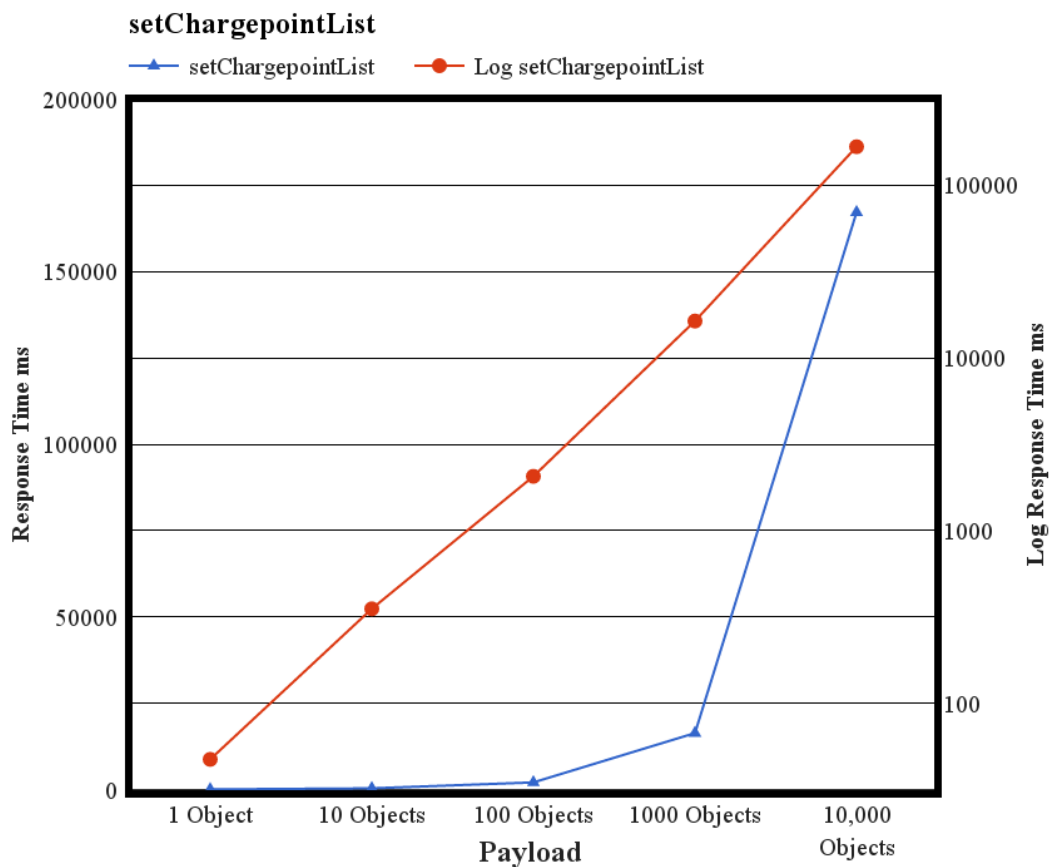


Figure 5.4: setChargepointList Response Time

Table 5.7: setChargepointList Response Time

Values in ms	1 Object	10 Objects	100 Objects	1000 Objects	10,000 Objects
setChargepointList	47.2832	352.132	2061.02	16347.8	167172.6

## getChargepointList

getChargepointList message downloads the EVSE equipment information from the clearing house. The size of one object encapsulating one charge point information as measured from the SOAP XML representation was found to be 1146 bytes excluding all other SOAP headers. Figure 5.5 shows a plot of the results on both linear and logarithmic scale of the values shown in Table 5.8.

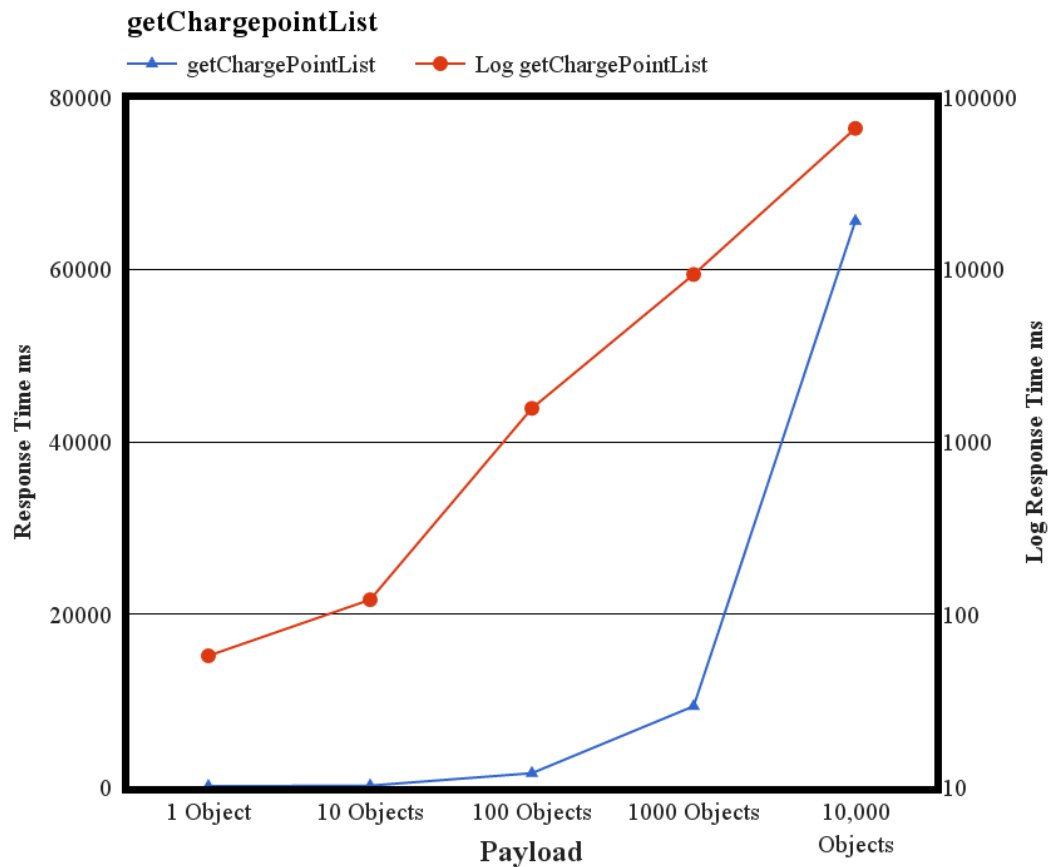


Figure 5.5: getChargepointList Response Time

Table 5.8: getChargepointList Response Time

Values in ms	1 Object	10 Objects	100 Objects	1000 Objects	10,000 Objects
getChargePointList	57.3832	121.332	1561.82	9327.8	65588

## addCDRs

addCDRs message uploads Charge Details Record information to the clearing house. The size of one object encapsulating one Charge Details Record information as measured from the SOAP XML representation was found to be 1329 bytes excluding all other SOAP headers. Figure 5.6 shows a plot of the results on both linear and logarithmic scale of the values shown in Table 5.9.

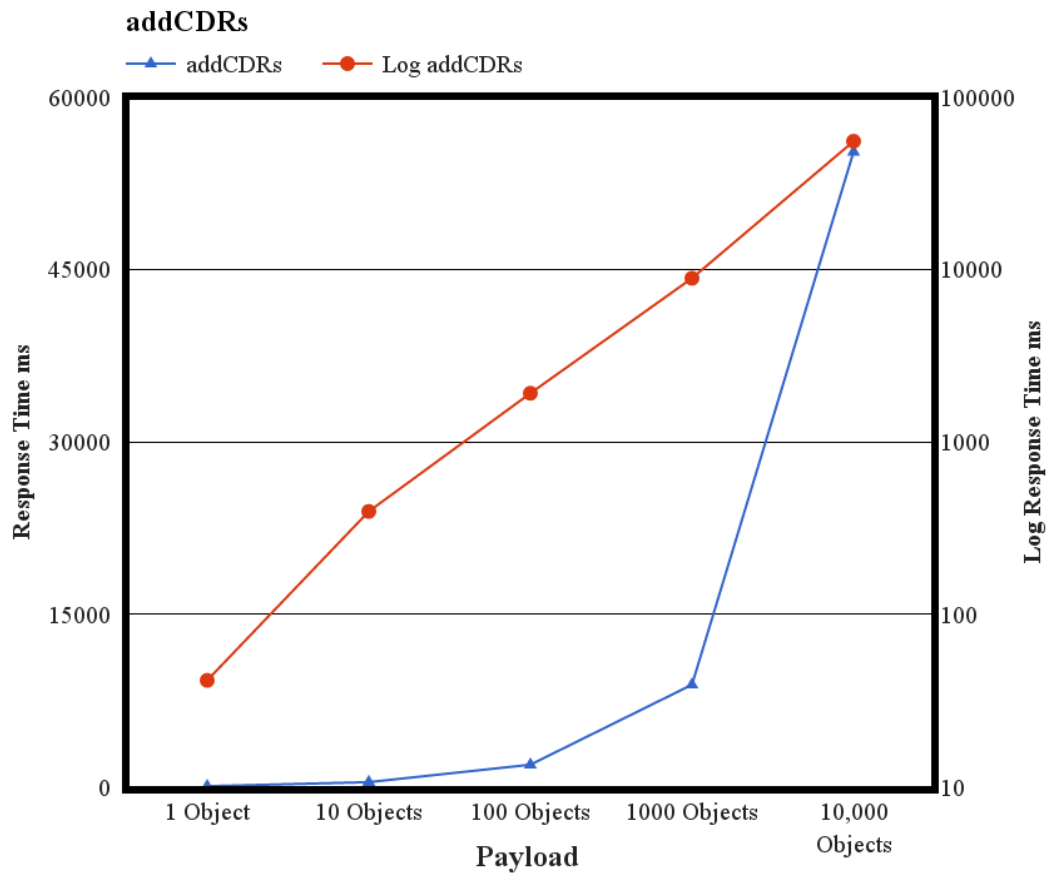


Figure 5.6: addCDRs Response Time

Table 5.9: addCDRs Response

Values in ms	1 Object	10 Objects	100 Objects	1000 Objects	10,000 Objects
addCDRs	41.3368	394.268	1909.88	8869.1	55214.1

## getCDRs

addCDRs message downloads the Charge Details Record information from the clearing house. The size of one object encapsulating one Charge Details Record information as measured from the SOAP XML representation was found to be 1329 bytes excluding all other SOAP headers. Figure 5.7 shows a plot of the results on both linear and logarithmic scale of the values shown in Table 5.10.

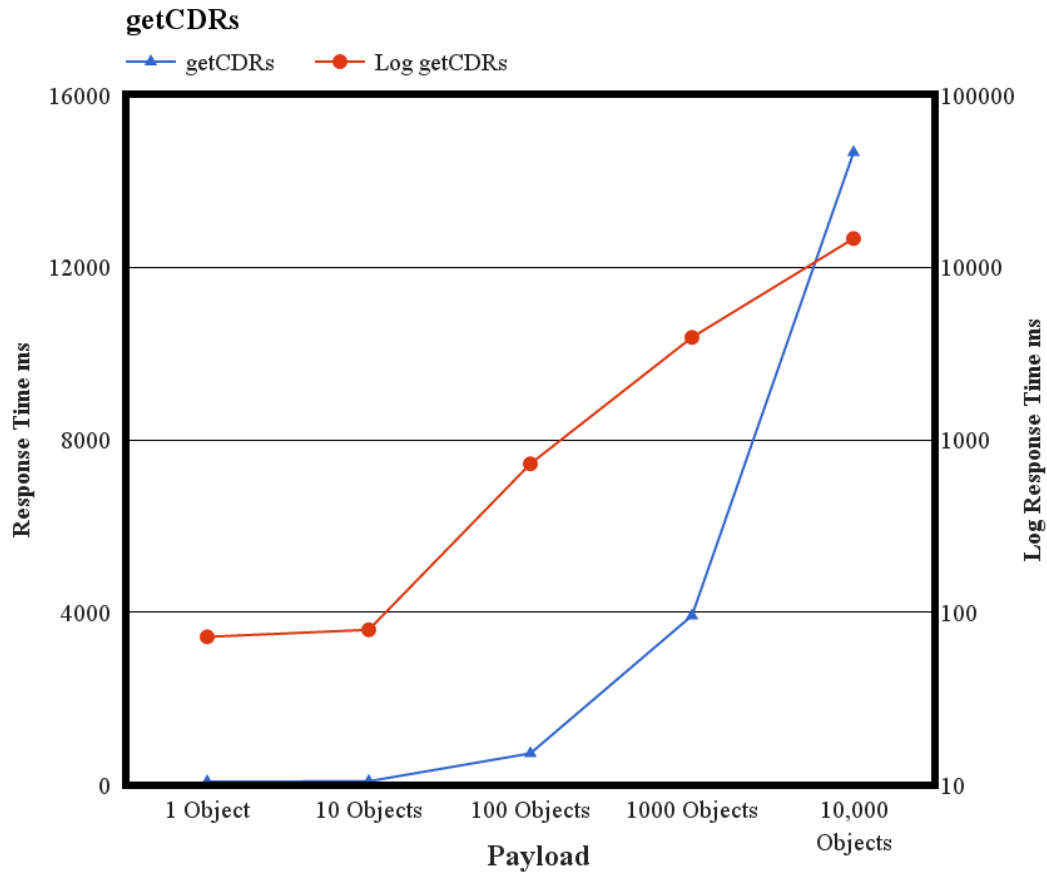


Figure 5.7: getCDRs Response Time

Table 5.10: getCDRs Response Time

Values in ms	1 Object	10 Objects	100 Objects	1000 Objects	10,000 Objects
getCDRs	71.9368	79.068	724.88	3920.3	14663.9

### 5.4.1 Interpretation

All the tests were run against the e-Clearing.net test clearing house platform. This is not the production version of the clearing house, even though it is hosting a lot of users. At the time of running the tests, the number of operators on the platform was about 280 operators, including few large companies like Siemens AG, Volkswagen AG, BMW, Audi AG and Bosch. In spite of that, the system is assumed to be ideal most of the time due to the fact that it is not a production system. Therefore this analysis will not account for the peak vs. off peak characteristics of a production system, which allows us to attribute the results to the performance of the OCHP protocol and the implementation of the clearing house web service and its business logic. Because no information was available on the internals of the test clearing house platform regarding hardware and software components, the platform is treated as a black box.

The amounts of data sent and received are still considered small enough compared to current commonly available server hardware capabilities, assuming that the business logic of the clearing house is simple enough, and the servers do only validation to the received data as declared in the OCHP protocol specification. The largest amount of data generated and transmitted in a single test was in the range of 13 megabytes for 10,000 CDRs. Table 5.11 show the messages and the object sizes used as measured.

Table 5.11: Object sizes

message	Object Type	Object Size
setRoamingAuthorisationList	RoamingAuthorisationInfo	286
getRoamingAuthorisationList	RoamingAuthorisationInfo	286
setChargepointList	ChargePointInfo	1146
getChargePointList	ChargePointInfo	1146
addCDRs	CDRInfo	1329
getCDRs	CDRInfo	1329

## Processing time

After compensating for the network round trip delay and the transmission time, what is left from the response time measurement, should be directly related to the processing time. Table 5.12 shows the processing time per object for messages carrying 1 object, 10 objects, 100 objects, 1000 objects and 10,000 objects.

Table 5.12: Processing time per object

Values in ms	1 Object	10 Objects	100 Objects	1000 Objects	10,000 Objects
setRoamingAuthorisationList	54.3712	5.6312	5.9602	4.2316	3.23568
getRoamingAuthorisationList	49.0712	4.3512	4.2372	1.5128	0.65032
setChargepointList	47.2832	35.2132	20.6102	16.3478	16.71726
getChargePointList	57.3832	12.1332	15.6182	9.3278	6.5588
addCDRs	41.3368	39.4268	19.0988	8.8691	5.52141
getCDRs	71.9368	7.9068	7.2488	3.9203	1.46639

Table 5.12 shows that all upload messages consume more processing time than the download copy of the same object. This is quite reasonable, given the store and forward business logic of a clearing house, where data is received, validated (processing time) and then stored in a database. While retrieving the same data, involve only fetching and transmitting.

setChargepointList message and consequently ChargePointInfo object are the most demanding in terms of processing time per object as shown in Table 5.12, even though CDRInfo is larger in size. 1329 bytes vs. 1146 bytes. But this is quite understandable, given the complexity of the ChargePointInfo structure vs. the simpler CDRInfo structure.

The consistency in setChargepointList processing time values between 1000 object and 10,000 objects, further confirmed the validity of processing time calculations.

## Response time

Figure 5.8 shows response times for all the messages on the same graph, which clearly shows that setChargepointList and getChargepointList are on the lead with longest response times because of, the complexity and the size of ChargePointInfo objects.

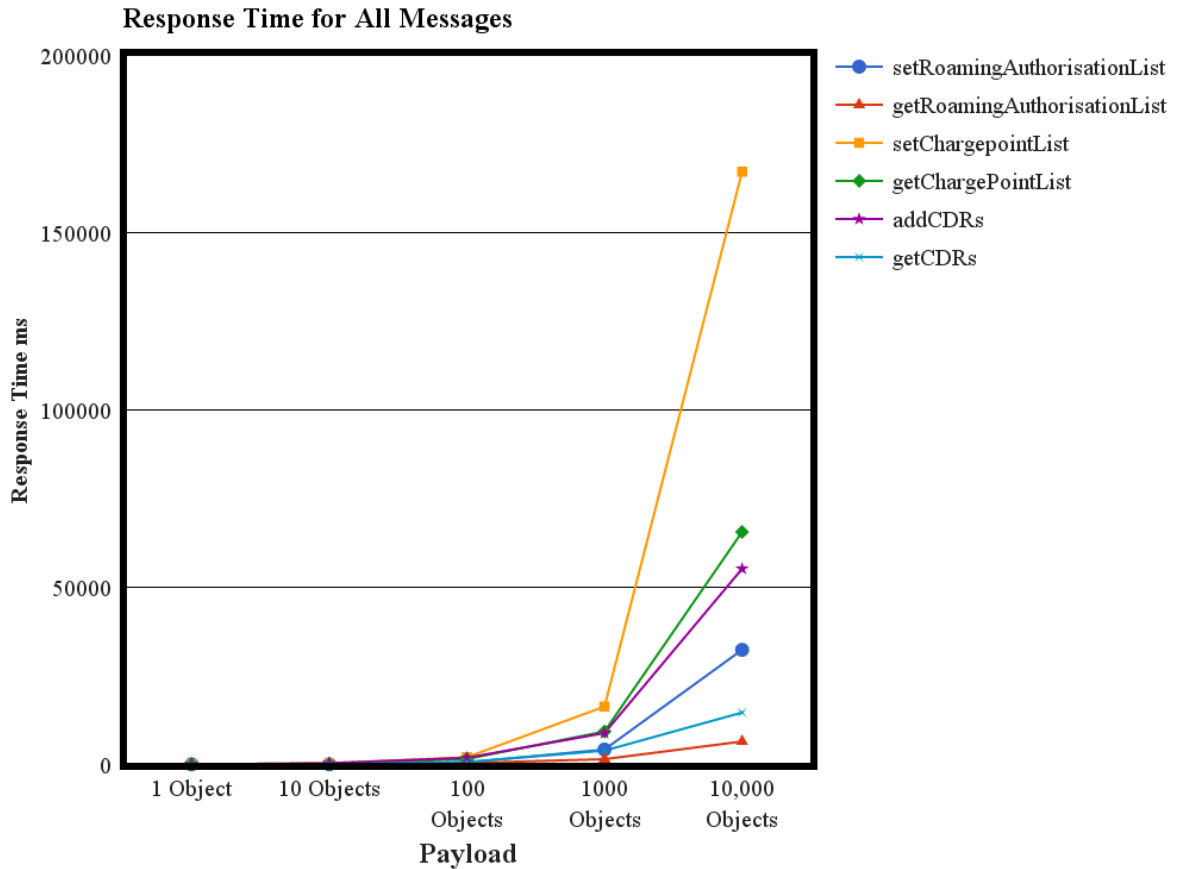


Figure 5.8: All Messages Response Time

As it can be seen from Figure 5.9, which shows the same data plotted on a logarithmic scale, the relationship between the number of objects and the response time is fairly linear. This is more visible for number of objects over 100.

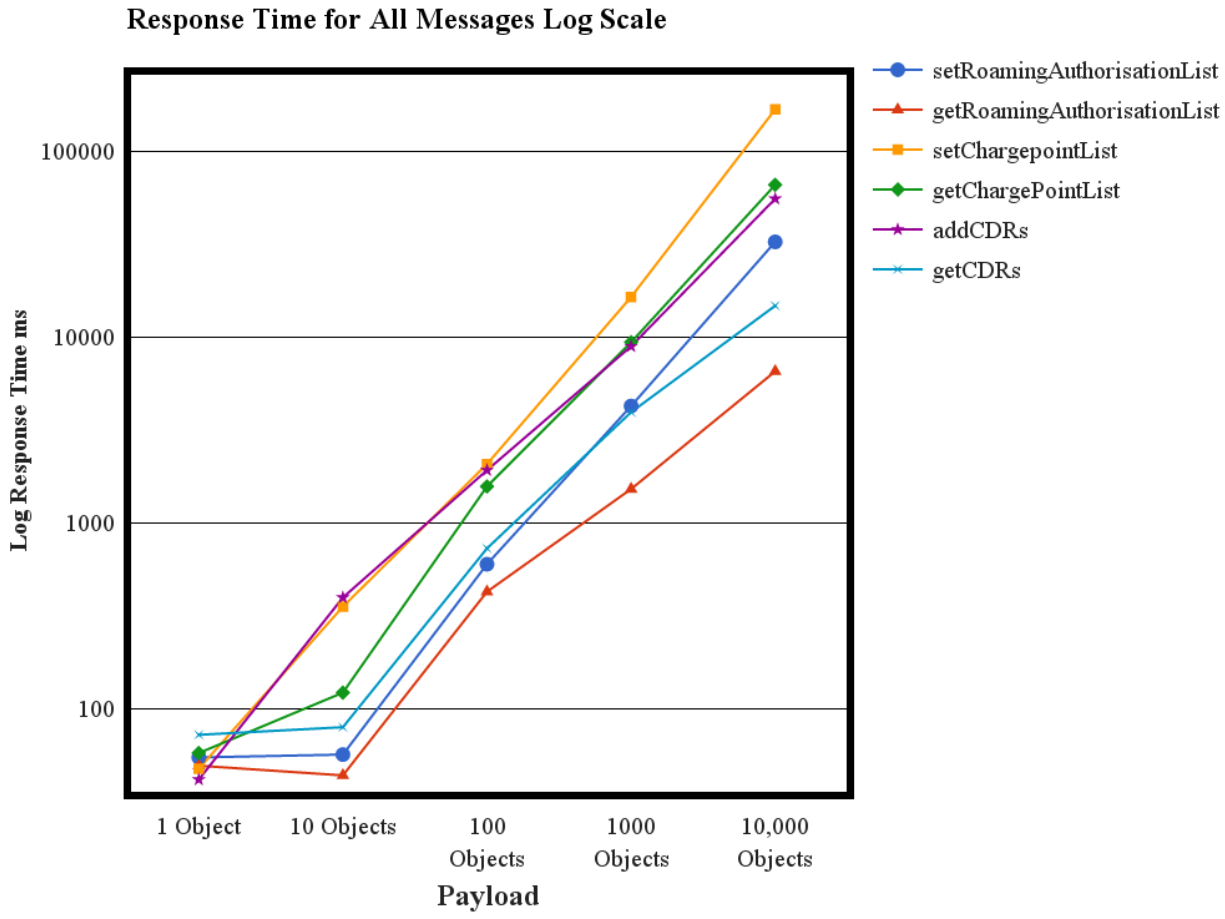


Figure 5.9: All Messages Response Time Log Scale

# Chapter 6: Quasi-Real Time Billing Extension to OCHP

## 6.1 Problem Description

The current specification of the OCHP protocol as of version 1.3, does not provide for online (real time) billing. The current billing model relies on a bilaterally agreed CDR exchange intervals, where partners bilaterally agree on the frequency of uploading and downloading CDRs, to and from the clearing house.

To be able to market a prepaid package, EVSPs need to be notified about their customer's activities in foreign networks in real time. This is not possible using the current polling architecture. Even the new OCHP-Direct extension that was released as part of OCHP version 1.3 does not address the billing issue. All CDRs are still passed through the clearing house using the traditional method.

## 6.2 Proposed Solution

To deliver the CDRs in real time as they are created to the EVSP's BSS (Business Support System), and still forward them through the clearing house, the clearing house must be able to notify the EVSPs immediately after validating a CDR, instead of waiting for the GetCDRs.req request polling interval timer to expire.

A simple, yet effective and backward compatible solution is proposed to solve this issue as follows:

- A digit from the instance part of the "ContractId" in the OCHP's RoamingAuthorisationInfo data type is reserved to indicate real-time billing

for that particular contract. For example, an instance part of this format “Rxxxxxxx” where x indicates any alphanumeric character as per the OCHP specification, indicates that this customer has to be treated as a real-time billing customer and available only through live authorization.

- Each EVSP provides the clearing house with a plain HTTP URL, by configuring it using the clearing house management web interface. This URL can be protected by a simple HTTP password digest security.
- EVSE operators must examine the instance part of the ContractId each and every time they authorize a charging session. If a ContractId with a real-time billing pattern is detected, that session’s CDR must be uploaded to the clearing house immediately after the charging session ends or periodically during the charging session, if the charging session extends for a long period.
- Upon receiving a real-time CDR, the clearing house validates, accepts and stores it, and then immediately issues an HTTP “get” request to the EVSP provided URL as a notification.
- As soon as an EVSP receives the HTTP notification, it issues a normal getCDRs request to the clearing house and retrieves all the accepted CDRs, including the real-time ones.
- EVSPs can update their real time billed prepaid customer’s account balance accordingly, and if necessary expire the account by issuing an UpdateRoamingAuthorisationList.req to the clearing house.

## **6.3 Solution’s Performance Analysis**

The chapter 5’s performance analysis of the e-clearing.net test platform, shows that the clearing house spends only 41 ms to validate and store a request that uploads only one

CDR (Table 6.1), and the number goes down to 5.5 ms per CDR, for a request that uploads 10,000 CDRs. On the other hand, a request to download one CDR needs only 72 ms of processing time, while the request to download 10,000 CDRs consumes only 1.5 ms per CDR.

Table 6.1: addCDRs and getCDRs Processing Time

Values in ms	1 Object	10 Objects	100 Objects	1000 Objects	10,000 Objects
addCDRs	41.3368	39.4268	19.0988	8.8691	5.52141
getCDRs	71.9368	7.9068	7.2488	3.9203	1.46639

To be able to estimate the performance of the online billing solution, the performance measurements of Chapter 5 are used, and the following assumptions are made:

- Both the EVSE operator and the EVSP provider are located in Ottawa, Ontario.
- e-Clearing.net test clearing house is used, and it is located in Germany using the “echs-q.e-clearing.net” endpoint and domain name.
- The round trip delay between the partners and the clearing house is about 150 ms as measured.
- The network throughput over the Internet is stable and is equal to 10 mbps.
- The processing time to issue an HTTP get request by the clearing house is negligible.

- The transmission time of one CDR is small enough and can be neglected.

Transmission time for only one real time CDR transaction is considered because multiple CDR transactions will consume less per CDR than a single CDR as shown in Table 5.12.

The real-time CDR transmission time  $T_{rCDR}$  is calculated by adding the time needed to send the CDR from the EVSE operator to the clearing house, the time needed by the clearing house to receive, validate, accept and store the CDR, the time needed for the HTTP get notification to reach the EVSP provider and the time needed to retrieve the CDR from the clearing house by the EVSP. The following equation (6.1) calculates the  $T_{rCDR}$ .

$$T_{rCDR} = \frac{1}{2}T_{rtd} + P_{addCDRs} + \frac{1}{2}T_{rtd} + T_{rtd} + P_{getCDRs} \quad (6.1)$$

$$T_{rCDR} = 2 \times T_{rtd} + P_{addCDRs} + P_{getCDRs}$$

$$T_{rCDR} = 2 \times 150 + 41 + 72 = 413 \text{ ms}$$

Where,

$T_{rCDR}$  The real-time CDR end to end transmission time.

$T_{rtd}$  The round trip delay which equals to 150 ms.

$P_{addCDRs}$  The time needed to receive, validate, accept and store a CDR.

$P_{getCDRs}$  The time needed to retrieve and send a CDR by the clearinghouse.

So the time needed to send, process and receive the CDR across the Atlantic, is roughly 400 ms. And this is achievable using the currently existing clearing house implementation and OCHP protocol specification with minor backward compatible extension. This value is very small compared to the time needed to charge a vehicle, which makes the extension suitable for online CDR exchange.

# Chapter 7: Conclusion and Future Work

## 7.1 Concluding Remarks

An important benefit of roaming between EVSP providers is, to reduce the impact of Range Anxiety on current and future electric vehicle drivers. This is achieved by alleviating their fear of running out of battery charge before reaching their destination, and that is because they know that they can recharge in any available charging station using their home network subscription credentials. This makes EV charging roaming one of the significant enablers of mass adoption of electric vehicles.

A clearing house is needed to simplify the interconnection between roaming partners, validate and distribute authentication information, navigation information and billing data.

In this thesis, the OCHP protocol was implemented, and the performance of the implementation and an OCHP based clearing house platform was investigated. The processing time of the clearing house was found to be stable, and fairly linear in relation to the number of objects processed.

The Open Clearing House Protocol (OCHP) has standardized the data types and the transactions between roaming partners and the clearing house. But it is designed only for post pay billing, where the Charge Detail Records (CDRs) are exchanged through the clearing house on bilaterally agreed intervals (polling intervals), using the store and forward paradigm. This makes packaging and marketing a prepaid solution difficult or impractical.

An extension to the OCHP protocol version 1.3 was proposed to enable online or Quasi-real time billing. Using this extension the CDRs of prepaid customers or, in other words, real-time billing customers, are sent to the relevant EVSP provider, immediately after generation, bypassing the traditional OCHP polling mechanism. The end to end CDR exchange time was estimated based on the performance results of the OCHP implementation and the test clearing house to be around 400 ms. This time is very small compared to the fastest EV charging technology (about 30 minutes for DC charging) and enables operators who decided to use the proposed extension, to package and market prepaid EV charging subscriptions more efficiently.

## 7.2 Future Research

In this thesis, only the client side of the OCHP protocol was implemented, and a third party clearing house was used to test the implementation. This resulted in the treatment of the clearing house as a black box, and not being able to control some test variable, like network parameters and server load. More work can be done by implementing a reference clearing house based on the OCHP specification locally. This will enable a deeper analysis of the protocol, by controlling the environment, and further investigate its capabilities and limitations.

Other competing roaming protocols can be implemented and compared against OCHP. Open ChargePoint Interface (OCPI) and Open InterCharge Protocols (OICP) are good candidates for that, because they are targeting the same market as OCHP.

In addition to testing the performance of the OCHP protocol, there are other aspects of the protocol specification that needs evaluation and analysis. For example its compatibility and interoperability with other protocols used in the EV charging echo system, like for example, the Open ChargePoint Protocol OCPP which is commonly used to control EVSEs.

Integration with Authentication, Authorization and Accounting (AAA) protocols like RADIUS, TACACS and DIAMETER, can be investigated as possible back-ends for providing high availability solutions.

## References

- [ACQU13] Acquire Media, “ECotality and ChargePoint Establish Interoperability Company, Collaboratev, LLC,” *Acquire Media*, 07-Mar-2013.
- [AMGA15] I. Amigo and M. Gagnaire, “Online electric vehicle recharge scheduling under different e-mobility operator’s pricing models,” in *2015 IEEE Symposium on Computers and Communication (ISCC)*, 2015, pp. 76–82.
- [ANDR13] Andrew Herndon, “Ecotality, ChargePoint to Link Electric Car Charging Networks,” *Bloomberg.com*, 07-Mar-2013. [Online]. Available: <http://www.bloomberg.com/news/articles/2013-03-07/ecotality-chargepoint-to-link-electric-car-charging-networks>. [Accessed: 30-Jun-2016].
- [ANSI13] ANSI, “STANDARDIZATION ROADMAP FOR ELECTRIC VEHICLES VERSION 2.0,” American National Standards Institute, May 2013.
- [BEME15] D. Beeton and G. Meyer, Eds., *Electric Vehicle Business Models*. Cham: Springer International Publishing, 2015.
- [BMW12] BMW, “Hubject aims at connecting public charging infrastructure for electric vehicles across European borders. Joint venture formed by the BMW Group, Bosch, Daimler, EnBW, RWE and Siemens presents portfolio of solutions.,” *BMW group*, 21-Nov-2012. [Online]. Available: <https://www.press.bmwgroup.com/global/article/detail/T0134530EN/hubject-aims-at-connecting-public-charging-infrastructure-for-electric-vehicles-acrosseuropean>. [Accessed: 05-Jul-2016].
- [BRBF15] G. Brusaglino, P. Bossche, and R. Font, “Roadmap for the deployment of the Electric Vehicle Charging Infrastructure,” EV-CONNECT, Jun. 2015.
- [BUAM15] I. Buamod, E. Abdelmoghith, and H. T. Mouftah, “A review of OSI-based charging standards and eMobility open protocols,” in *Network of the Future (NOF), 2015 6th International Conference on the*, 2015, pp.

- 1–7.
- [CABA15] A. Caramizaru and H. Barlag, “Deliverable 10.8 How to ensure the sustainability of Green eMotion activities,” Green eMotion, Apr. 2015.
- [CHAR11] ChargePoint, “Coulomb Technologies Releases OpenCharge Protocol and ChargePoint OnRamp Program - ChargePoint,” 14-Jul-2011. [Online]. Available: <http://www.chargepoint.com/news/2011/0714/>. [Accessed: 04-Jul-2016].
- [CHAR13] ChargePoint, “ChargePoint Hardware is OCPP Compliant - ChargePoint,” 06-Dec-2013. [Online]. Available: <http://www.chargepoint.com/news/2013/1206/chargepoint-adopts-ocpp-for-its-charging-stations/>. [Accessed: 04-Jul-2016].
- [CHRI15] S. Y. Choi and C. T. Rim, “Recent progress in developments of on-line electric vehicles,” in *2015 6th International Conference on Power Electronics Systems and Applications (PESA)*, 2015, pp. 1–8.
- [CONN16] P. Conner, “Cars With Cords: How to Charge an Electric Car (EV),” 25-Jun-2016.
- [DOMU14] R. Doolan and G.-M. Muntean, “Reducing carbon emissions by introducing electric vehicle enhanced dedicated bus lanes,” in *2014 IEEE Intelligent Vehicles Symposium Proceedings*, 2014, pp. 1011–1016.
- [DOSS15] P. Dost, P. Spichartz, and C. Sourkounis, “Charging behaviour of users utilising battery electric vehicles and extended range electric vehicles within the scope of a field test,” in *2015 International Conference on Renewable Energy Research and Applications (ICRERA)*, 2015, pp. 1162–1167.
- [ECL12] EClearing.net, “E-Clearing home page,” 30-Mar-2012. [Online]. Available: <http://www.e-clearing.eu/>. [Accessed: 06-Jul-2016].
- [EDEL15] S. Edelstein, “Roaming To Come To Electric-Car Charging Stations, Eventually,” 24-Nov-2015. [Online]. Available: [http://www.greencarreports.com/news/1101117\\_roaming-to-come-to-](http://www.greencarreports.com/news/1101117_roaming-to-come-to-)

- electric-car-charging-stations-eventually. [Accessed: 29-Jun-2016].
- [EGLO12] O. Egbue and S. Long, “Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions,” *Energy Policy*, vol. 48, pp. 717–729, Sep. 2012.
- [EMI13] eMI3, “Working Groups| EMI3,” *eMI3*, 16-Jan-2013. [Online]. Available: <http://emi3group.com/extra-side-navigation/>. [Accessed: 06-Jul-2016].
- [EVI14] EVI, “Plug-In Around the EV World.” Electrical Vehicle Institute, Dec-2014.
- [FLLU11] Fluhr J, Lutz T. Use case types for communication with and for Electric Vehicles (EV). In Concurrent Enterprising (ICE), 2011 17th International Conference on 2011 Jun 20 (pp. 1-6). IEEE.
- [FRKM13] B. Frieske, M. Kloetzke, and F. Mauser, “Trends in vehicle concept and key technology development for hybrid and battery electric vehicles,” in *Electric Vehicle Symposium and Exhibition (EVS27), 2013 World*, 2013, pp. 1–12.
- [GIRE16] Gireve, “GIREVE’s objectives - Gireve,” 2016. [Online]. Available: [http://www.gireve.com/en/objectives/gireve-objectives\\_103.html](http://www.gireve.com/en/objectives/gireve-objectives_103.html). [Accessed: 05-Jul-2016].
- [GJPF13] P. Gagnol, P. Jochem, M. Pierre, and W. Fichtner, “CROME: The French and German field demonstration of the interoperable mobility with EVs,” in *Electric Vehicle Symposium and Exhibition (EVS27), 2013 World*, 2013, pp. 1–8.
- [GREE11] Green eMotion, “Green eMotion Project || About us,” 31-Mar-2011. [Online]. Available: <http://www.greenemotion-project.eu/about-us/index.php>. [Accessed: 06-Jul-2016].
- [GREE15] “Deliverable 11.8 – Part 1 Final publishable summary report,” Green eMotion, Apr. 2015.
- [HUBJ15] Hubject, “Pan-European initiative to connect eRoaming platforms for customer-friendly charging of electric vehicles across national borders,”

*Press release, 24-Mar-2015.*

- [HYDR15] Hydro-Québec, “ELECTRIC VEHICLE CHARGING STATIONS Technical Installation Guide.” Aug-2015.
- [IEA13] IEA, “GLOBAL EV OUTLOOK Understanding the Electric Vehicle Landscape to 2020,” International Energy Agency, Apr. 2013.
- [IEA15] IEA, “CO2 Emissions From Fuel Combustion Highlights 2015,” International Energy Agency, 2015.
- [IEA16] IEA, “Global EV Outlook 2016 Beyond one million electric cars,” International Energy Agency, 2016.
- [IEC01] IEC, “IEC 61851-1 Electric vehicle conductive charging system - Precisions on the implementation of a pilot function through a control pilot circuit using PWM modulation and a control pilot.” International Electrotechnical Commission, 2001.
- [IEC03] IEC, “IEC 62196-1 Plugs, socket-outlets, vehicle couplers and vehicle inlets – Conductive charging of electric vehicles – Part 1: Charging of electric vehicles up to 250 A a.c. and 400 A d.c.” International Electrotechnical Commission, Apr-2003.
- [IEEE16] IEEE, *IEEE Standard Technical Specifications of a DC Quick Charger for Use with Electric Vehicles*. Piscataway, USA: IEEE, 2016.
- [KHKS13] Kang MS, Huang ZM, Kim TB, Song WC. Authentication for electrical charging of EVs in the private area considering E-roaming. In ICCE-China Workshop (ICCE-China), 2013 IEEE 2013 Apr 11 (pp. 41-42). IEEE.
- [LEKO15] W. Leal Filho and R. Kotter, Eds., *E-Mobility in Europe*. Cham: Springer International Publishing, 2015.
- [LGSW12] C. Lewandowski, S. Gröning, J. Schmutzler, and C. Wietfeld, “Interference analyses of Electric Vehicle charging using PLC on the Control Pilot,” in *Power Line Communications and Its Applications (ISPLC), 2012 16th IEEE International Symposium on*, 2012, pp. 350–355.

- [LIDN16] H. Li, G. Dan, and K. Nahrstedt, "Portunes+: Privacy-Preserving Fast Authentication for Dynamic Electric Vehicle Charging," *IEEE Transactions on Smart Grid*, pp. 1–9, 2016.
- [LZVR16] M. Longo, D. Zaninelli, F. Viola, P. Romano, R. Miceli, M. Caruso, and F. Pellitteri, "Recharge stations: A review," in *2016 Eleventh International Conference on Ecological Vehicles and Renewable Energies (EVER)*, 2016, pp. 1–8.
- [MKBZ16] G. R. C. Mouli, J. Kaptein, P. Bauer, and M. Zeman, "Implementation of dynamic charging and V2G using Chademo and CCS/Combo DC charging standard," in *2016 IEEE Transportation Electrification Conference and Expo (ITEC)*, 2016, pp. 1–6.
- [MOLD14] A. Moldoveanu, "EVSE Network Interoperability Standards (An Overview)," 16-Jan-2014.
- [MPMA14] S. Martinenas, A. B. Pedersen, M. Marinelli, P. B. Andersen, and C. Træholt, "Electric vehicle smart charging using dynamic price signal," in *Electric Vehicle Conference (IEVC), 2014 IEEE International*, 2014, pp. 1–6.
- [MZKF14] M. A. Mustafa, N. Zhang, G. Kalogridis, and Z. Fan, "Roaming electric vehicle charging and billing: An anonymous multi-user protocol," in *Smart Grid Communications (SmartGridComm), 2014 IEEE International Conference on*, 2014, pp. 939–945.
- [NEMA15] NEMA, "EV Charging Network Interoperability Standards Part 2: A Contactless RFID Credential for Authentication (U R Interface)." National Electrical Manufacturers Association, 30-Nov-2015.
- [NKL16] NKL, "Open Charge Point Interface OCPI, Projecten - Website," Apr-2016. [Online]. Available: <http://en.nklnederland.nl/projects/our-current-projects/open-charge-point-interface-ocpi/>. [Accessed: 05-Jul-2016].
- [OCA16] OCA, "Background, About us - Open Charge Alliance," 2016. [Online]. Available: <http://www.openchargealliance.org/about/background/>. [Accessed: 04-Jul-2016].

- [OCGR16] OCPI and Group, “Open Charge Point Interface 2.1.” OCPI group, 04-Aug-2016.
- [OCPI16] OCPI, “GitHub - ocpi/ocpi: The Open Charge Point Interface (OCPI) allows for a scalable, automated roaming setup between Charge Point Operators and e-Mobility Service Providers. It supports authorisation, charge point information exchange (incl transaction events), charge detail record exchange and finally, the exchange of smart-charging commands between parties.” 2016. [Online]. Available: <https://github.com/ocpi/ocpi>. [Accessed: 05-Jul-2016].
- [RAMK13] Ratej J, Mehle B, Kocbek M. Global service provider for electric vehicle roaming. In *Electric Vehicle Symposium and Exhibition (EVS27), 2013 World 2013 Nov 17* (pp. 1-11). IEEE.
- [RJHG10] L. Ran, W. Junfeng, W. Haiying, and L. Gechen, “Design method of CAN BUS network communication structure for electric vehicle,” in *Strategic Technology (IFOST), 2010 International Forum on*, 2010, pp. 326–329.
- [PWAH15] J.-C. Pandazis, K. Weber, S. Albertus, and C. Hahn, “Electro mobility – Interoperability Challenges,” *EMI3*, Jun. 2015.
- [RAGJ14] V. del Razo, C. Goebel, and H.-A. Jacobsen, “Reducing communication requirements for electric vehicle charging using vehicle-originating-signals,” in *Smart Grid Communications (SmartGridComm), 2014 IEEE International Conference on*, 2014, pp. 7–12.
- [RDSC14] G. Ritrovati, G. De Maso-Gentile, C. Scavongelli, and M. Conti, “Active role of a NFC enabled smartphone in EV-EVSE charging process,” in *Electric Vehicle Conference (IEVC), 2014 IEEE International*, 2014, pp. 1–8.
- [RIEN13] H. Ribberink and E. Entchev, “Electric vehicles—A ‘one-size-fits-all’ solution for emission reduction from transportation?,” in *Electric Vehicle Symposium and Exhibition (EVS27), 2013 World*, 2013, pp. 1–7.
- [ROEV15] ROEV, “With the ROEV Association, Electric Vehicle charging becomes

- more accessible > ROEV Association,” 19-Nov-2015. [Online]. Available: <http://www.roev.org/News-Events/Press-Releases/ID/23/With-the-ROEV-Association-Electric-Vehicle-charging-becomes-more-accessible#.V3w4j-0SW1J>. [Accessed: 05-Jul-2016].
- [RTRT13] A. Rodriguez-Serrano, A. Torralba, E. Rodríguez-Valencia, and J. Tarifa-Galisteo, “A communication system from EV to EV Service Provider based on OCPP over a wireless network,” in *Industrial Electronics Society, IECON 2013-39th Annual Conference of the IEEE*, 2013, pp. 5434–5438.
- [SAE11] SAE, “SAE Charging Configurations and Ratings Terminology.” SAE, 2011.
- [SAE14] SAE, “J2931/1 Digital Communications for Plug-in Electric Vehicles.” Jan-2014.
- [SAE16] SAE, “SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler.” SAE, Feb-2016.
- [SAVE09] A. Y. Saber and G. K. Venayagamoorthy, “One million plug-in electric vehicles on the road by 2015,” in *2009 12th International IEEE Conference on Intelligent Transportation Systems*, 2009, pp. 1–7.
- [SCHS14] M. Scott, D. Hopkins, and J. Stephenson, “Understanding Sustainable Mobility: The Potential of Electric Vehicles,” 2014, pp. 27–30.
- [SEC13] SEC, “ECOTALITY, INC. SECURITIES AND EXCHANGE COMMISSION report,” Sep. 2013.
- [SOAP16] Soapui, “SoapUI | Functional Testing for SOAP and REST APIs,” 02-Aug-2016. [Online]. Available: <https://www.soapui.org/>. [Accessed: 02-Aug-2016].
- [TESL13] Tesla Motors, “UPDATED: ‘How it works’ - SuperCharger Station | Tesla Motors,” 24-Jul-2013. [Online]. Available: [https://forums.teslamotors.com/en\\_CA/forum/forums/updated-how-it-works-supercharger-station](https://forums.teslamotors.com/en_CA/forum/forums/updated-how-it-works-supercharger-station). [Accessed: 02-Jul-2016].
- [TESL16] Tesla, “Supercharger | Tesla Motors Canada,” 2016. [Online]. Available:

- [https://www.teslamotors.com/en\\_CA/supercharger](https://www.teslamotors.com/en_CA/supercharger). [Accessed: 02-Jul-2016].
- [TSEG12] Tseng HR. A secure and privacy-preserving communication protocol for V2G networks. In 2012 IEEE Wireless Communications and Networking Conference (WCNC) 2012 Apr 1 (pp. 2706-2711). IEEE.
- [WAPA14] Z. Wang and R. Paranjape, "An Evaluation of Electric Vehicle Penetration under Demand Response in a Multi-Agent Based Simulation," 2014, pp. 220–225.
- [WESS14] P. Wessel, "EV Access, A Green Parking Council Webinar – January 23rd, 2014," 23-Jan-2014.
- [WOLF13] J. Wolf, "Electric Vehicle Charging Network Roaming and Clearing," Jul-2013.
- [YSCN11] A. S. O. Yu, L. L. C. Silva, C. L. Chu, P. T. S. Nascimento, and A. S. Camargo, "Electric vehicles: struggles in creating a market," in *2011 Proceedings of PICMET'11: Technology Management in the Energy Smart World (PICMET)*, 2011, pp. 1–13.

## Appendix A, Raw Data

Each of the following tables, shows the raw measured response times in milliseconds grouped by the OCHP messages that generated them. Each column lists ten samples for each transaction type and payload, 1 Object, 10 Objects, 100 Object, 1000 Object, 10,000 Objects.

setRoamingAuthorisationList					
Sample	1 Object	10 Objects	100 Objects	1000 Objects	10,000 Objects
1	187	189	777	4030	35817
2	171	196	733	4041	33154
3	154	193	703	5469	35643
4	203	212	706	5030	31540
5	223	186	719	6012	33924
6	290	290	720	4470	33732
7	198	221	1187	4449	36987
8	211	177	695	4668	37811
9	163	197	736	3997	34544
10	246	225	713	3938	34796

getRoamingAuthorisationList					
Sample	1 Object	10 Objects	100 Objects	1000 Objects	10,000 Objects
1	165	200	628	1851	9492
2	195	192	618	1119	12503
3	204	166	515	2036	6159
4	203	206	717	2014	8224
5	204	165	538	2146	8972
6	202	209	720	1935	8400
7	200	211	527	1933	11469
8	203	227	629	1954	8447
9	210	178	644	2024	10976
10	207	204	430	1904	4770

setChargepointList					
Sample	1 Object	10 Objects	100 Objects	1000 Objects	10,000 Objects
1	229	570	2216	16748	176455
2	195	483	2100	17379	178893
3	199	391	2212	17731	185601
4	195	516	2394	19151	176177
5	196	489	2229	18808	169620
6	196	511	2138	17395	175154
7	197	513	2650	16452	172824
8	197	513	2562	18130	170951
9	187	502	2183	16173	180051
10	191	625	2343	16179	179180

getChargePointList					
Sample	1 Object	10 Objects	100 Objects	1000 Objects	10,000 Objects
1	222	237	1847	10456	74749
2	204	298	1537	11297	73650
3	195	229	1655	10262	76136
4	204	229	2160	9753	73110
5	212	327	1849	10238	81014
6	205	349	1646	10631	74514
7	209	249	1756	10551	75272
8	206	238	1619	10043	70859
9	208	230	2373	10161	75366
10	218	419	1847	10554	74390

addCDRs					
Sample	1 Object	10 Objects	100 Objects	1000 Objects	10,000 Objects
1	144	442	2342	10606	63075
2	188	725	1258	11734	66442
3	180	548	2253	6882	104744
4	184	731	2482	8113	60961
5	186	720	2183	11788	67008
6	199	497	1950	10174	58940
7	184	259	2789	9009	62715
8	187	690	2180	12025	57151
9	290	246	2288	10826	60031
10	182	691	1937	9666	58894

getCDRs					
Sample	1 Object	10 Objects	100 Objects	1000 Objects	10,000 Objects
1	309	430	825	4925	18612
2	207	251	1242	5442	21096
3	207	226	925	5952	19083
4	204	203	1122	4606	30629
5	205	227	928	5132	35273
6	196	193	1066	5128	21222
7	204	239	965	5101	25526
8	206	201	912	5385	20072
9	202	205	1028	5134	37782
10	290	222	799	4530	25164

## Appendix B, Database Tables

The following table lists the table names and column names and column types for all the generic tables used to represent OCHP data types. This appendix dose not list the other two sets of tables that are used in the OCHP implementation, because they have the same structure and table names except that their table names ends with Own or Partners.

Table	#	Column	Type
AdditionalGeoPoint	1	Id	Number(22)
AdditionalGeoPoint	2	lat	Char(10)
AdditionalGeoPoint	3	lon	Char(11)
AdditionalGeoPoint	4	name	Char(255)
AdditionalGeoPoint	5	class	Char(10)
AuthMethod	1	evseId	Varchar2(20)
AuthMethod	2	method	Varchar2(20)
CDRs	1	cdrId	Varchar2(36)
CDRs	2	evseId	Varchar2(20)
CDRs	3	EmtIdInstance	Varchar2(512)
CDRs	4	EmtIdRepresentation	Varchar2(10)
CDRs	5	EmtIdType	Varchar2(10)
CDRs	6	EmtIdSubType	Varchar2(10)
CDRs	7	contractId	Varchar2(255)
CDRs	8	liveAuthId	Varchar2(15)
CDRs	9	status	Varchar2(20)
CDRs	10	startDateTime	Varchar2(30)
CDRs	11	endDateTime	Varchar2(30)
CDRs	12	duration	Char(9)
CDRs	13	houseNumber	Char(6)
CDRs	14	address	Char(45)
CDRs	15	zipCode	Char(10)
CDRs	16	city	Char(45)
CDRs	17	country	Char(3)
CDRs	18	chargePointType	Char(2)

CDRs	19	connectorStandard	Varchar2(30)
CDRs	20	connectorFormat	Varchar2(10)
CDRs	21	maxSocketPower	Float
CDRs	22	productType	Char(2)
CDRs	23	meterId	Char(20)
CDRs	24	chargingPeriods	Char(1)
CdrPeriod	1	cdrId	Varchar2(20)
CdrPeriod	2	startDateTime	Varchar2(30)
CdrPeriod	3	endDateTime	Varchar2(30)
CdrPeriod	4	billingItem	Varchar2(20)
CdrPeriod	5	billingValue	Float
CdrPeriod	6	currency	Varchar2(3)
CdrPeriod	7	itemPrice	Float
CdrPeriod	8	periodCost	Float
ChargePointInfo	1	evseId	Varchar2(20)
ChargePointInfo	2	locationId	Varchar2(15)
ChargePointInfo	3	timestamp	Timestamp(6)
ChargePointInfo	4	locationName	Varchar2(100)
ChargePointInfo	5	locationNameLang	Varchar2(3)
ChargePointInfo	6	images	Varchar2(1)
ChargePointInfo	7	relatedResource	Varchar2(1)
ChargePointInfo	8	houseNumber	Varchar2(6)
ChargePointInfo	9	address	Varchar2(45)
ChargePointInfo	10	city	Varchar2(45)
ChargePointInfo	11	zipCode	Varchar2(10)
ChargePointInfo	12	country	Varchar2(3)
ChargePointInfo	13	CPLLat	Varchar2(10)
ChargePointInfo	14	CPLLon	Varchar2(11)
ChargePointInfo	15	RLLat	Varchar2(10)
ChargePointInfo	16	RLLon	Varchar2(11)
ChargePointInfo	17	RLName	Varchar2(255)
ChargePointInfo	18	RLClass	Varchar2(10)
ChargePointInfo	19	timeZone	Varchar2(255)
ChargePointInfo	20	category	Varchar2(2)

ChargePointInfo	21	OTregularHours	Varchar2(1)
ChargePointInfo	22	OTtwentyfourseven	Varchar2(1)
ChargePointInfo	23	OTexceptionalOpenings	Varchar2(1)
ChargePointInfo	24	OTexceptionalClosings	Varchar2(1)
ChargePointInfo	25	ATregularHours	Varchar2(1)
ChargePointInfo	26	ATtwentyfourseven	Varchar2(1)
ChargePointInfo	27	ATexceptionalOpenings	Varchar2(1)
ChargePointInfo	28	ATexceptionalClosings	Varchar2(1)
ChargePointInfo	29	status	Varchar2(20)
ChargePointInfo	30	statusSchedule	Varchar2(1)
ChargePointInfo	31	telephoneNumber	Varchar2(20)
ChargePointInfo	32	location	Varchar2(20)
ChargePointInfo	33	floorLevel	Varchar2(4)
ChargePointInfo	34	parkingSlotNumber	Varchar2(5)
ChargePointInfo	35	parkingRestriction	Varchar2(1)
ChargePointInfo	36	authMethods	Varchar2(1)
ChargePointInfo	37	connectors	Varchar2(1)
ChargePointInfo	38	ratingsMaximumPower	Float
ChargePointInfo	39	ratingsGuaranteedPower	Float
ChargePointInfo	40	ratingsNominalVoltage	Number(22)
ChargePointInfo	41	userInterfaceLang	Varchar2(3)
ChargePointSchedule	1	evseId	Varchar2(20)
ChargePointSchedule	2	startDate	Varchar2(30)
ChargePointSchedule	3	endDate	Varchar2(30)
ChargePointSchedule	4	status	Varchar2(20)
ConnectorType	1	evseId	Varchar2(20)
ConnectorType	2	connectorStandard	Varchar2(20)
ConnectorType	3	connectorFormat	Varchar2(10)
EvseImageUrl	1	evseId	Varchar2(20)
EvseImageUrl	2	uri	Varchar2(255)
EvseImageUrl	3	thumbUri	Varchar2(255)
EvseImageUrl	4	class	Varchar2(20)
EvseImageUrl	5	type	Varchar2(10)
EvseImageUrl	6	width	Number(22)

EvseImageUrl	7	height	Number(22)
ExceptionalPeriod	1	evseId	Varchar2(20)
ExceptionalPeriod	2	periodBegin	Varchar2(30)
ExceptionalPeriod	3	periodEnd	Varchar2(30)
HoursType	1	Id	Number(22)
HoursType	2	regularHours	Char(1)
HoursType	3	twentyfourseven	Number(22)
HoursType	4	exceptionalOpenings	Number(22)
HoursType	5	exceptionalClosings	Number(22)
ParkingRestriction	1	evseId	Varchar2(20)
ParkingRestriction	2	restriction	Varchar2(20)
RAuthorisationInfo	1	contractId	Varchar2(20)
RAuthorisationInfo	2	EmtIdInstance	Varchar2(512)
RAuthorisationInfo	3	EmtIdRepresentation	Varchar2(10)
RAuthorisationInfo	4	EmtIdType	Varchar2(10)
RAuthorisationInfo	5	EmtIdSubType	Varchar2(10)
RAuthorisationInfo	6	printedNumber	Varchar2(150)
RAuthorisationInfo	7	expiryDate	Varchar2(25)
RegularHours	1	evseId	Varchar2(20)
RegularHours	2	weekday	Char(1)
RegularHours	3	periodBegin	Varchar2(5)
RegularHours	4	periodEnd	Varchar2(5)
RelatedResource	1	evseId	Varchar2(20)
RelatedResource	2	uri	Varchar2(20)
RelatedResource	3	class	Varchar2(20)