

Integrating an Electric Vehicle Supply Equipment with the Arrowhead Framework

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Abstract—Electric Vehicle Supply Equipment (EV, EVSE) are not just passive endpoints of the electric grid; they are high performance computing and communication systems. Their number is rising in a strained way to be able to feed Europe’s ever-growing EV fleet. The organization of the EVSEs into a dynamic and collaborative network with ICT systems of the electro mobility domain opens new horizons in front of the EV charging market. This means improved charging transactions and charge point management, smart grid integration, and the application of promising ancillary services. This paper presents the Arrowhead framework, a service oriented approach for the Internet of Things, as a possible networking platform for EV charging stations and related communication systems. The integration of a real charging station – developed by evopro Innovation Ltd. – with the Arrowhead framework is also described. The integration targets not only the verification of the electric mobility domain’s future use case scenarios, but also the verification of the newest generation of the Arrowhead framework.

I. INTRODUCTION

The Arrowhead Consortium works with the support of the European Union’s H2020 program to develop a technical framework for the Industrial Internet of Things. Its grand purpose is to enable new dynamic capabilities for the automation world using networked embedded devices. The project has defined several pilot domains to demonstrate the usage and benefits of the Arrowhead framework. One of them is electro mobility and particularly the electric transportation charging market [1].

The biggest challenge of the EV initiative is overcoming the barriers of electrical energy storage. Batteries can not reach sufficiently high energy density yet to compete with fossil fuels. That is why EV charging and supplementary servicing become crucial issues of electro mobility. EVSEs shall enable high quality services on behalf of many stakeholders by connecting to their ICT systems.

The main issues of this paper are the following:

- 1) How could the Arrowhead framework support the Electric Transportation Charging Market?
- 2) How can an electric vehicle charging station be integrated with the Arrowhead framework?

In order to find the answers to these questions, Section II presents the main concept and functionalities of the Arrowhead framework. The Electric Transportation Charging Infrastructure including its stakeholders and related tasks is described in Section III. Section IV proposes the integration of the charging market with the Arrowhead framework through three possible future use cases. The Arrowhead compliant charging station of evopro Innovation Ltd. is presented in Section V.

II. THE ARROWHEAD FRAMEWORK

The Arrowhead framework is based on the concept of the *Internet of Things*, *System of Systems* and *Service Oriented Architecture* to enable collaborative automation by networked embedded devices [2].

A *service* within the framework is a piece of information that is to be exchanged between communication systems. It can offer a variety of measurement data or the control over a remote switch or almost anything as far as it is accessible for authorized systems through a unique and registered interface. A service is reusable and is allowed to implement by multiple systems. It is defined as a simple function or a more complex process and the definition is technologically independent, that is, implementations of the same service are allowed to differ in communication profiles. The communication profile is identified by the following three characteristics: transfer protocol, security mechanism, and data format.

A *system* is an object that can produce and consume services. It is not necessarily bound to a physical device, however, a single computational resource is allowed to incorporate multiple Arrowhead systems. A system that is producing a particular service is called *Service Provider*, and similarly, a system that is consuming the service is referred to as *Service Consumer*. A single Arrowhead system can be the provider of one or more services and the consumer of other services at the same time. Examples for a system are a power meter, a temperature sensor or a backup server.

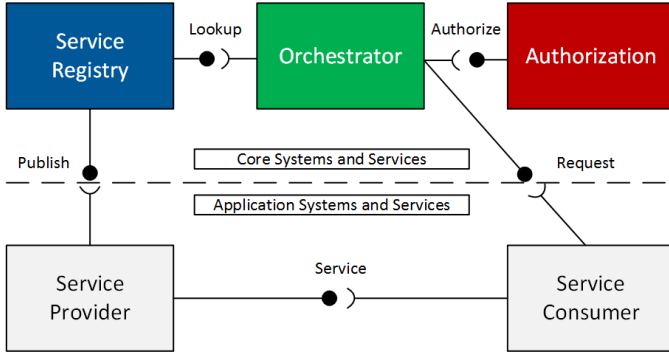


Fig. 1. Mandatory systems and services within the Arrowhead Local Cloud

A. Local Clouds and Core Systems

The natural environment of Arrowhead is a factory, where a limited number of interconnected sensor, controller and actuator nodes work together on effectively assembling a product. This motivates the *Local Cloud*, a unique approach in the field of IoT platforms [3]: the group of devices of a specific factory or company belong to a distinct cloud having common orchestration and security resources.

The Local Cloud is defined as a set of central and application entities as illustrated in Fig. 1. There are three mandatory core functionalities, that every Arrowhead Local Cloud has to implement, namely the Service Registry, the Orchestrator and the Authorization systems. The Service Registry stores the backend information of all the registered services and provider systems, the Orchestrator manages the communication of application systems and supports the reconfiguration of the cloud, and the Authorization system enables that only properly authorized systems can provide and/or consume services within the cloud.

The Local Cloud is allowed to implement other optional core systems. Two of them are of particular interest of this paper: the Gatekeeper, that is used for inter-cloud servicing and the Historian, which implements logging functionality. Both systems are presented in the following sections.

B. Application Systems

Application systems has to implement an interface towards the mandatory core entities in order to be able to produce and/or consume services, i.e. to be Arrowhead compliant. The project has defined maturity levels to distinguish the applied connection types of legacy application systems to the Arrowhead framework (see Fig. 2). Level 1 systems use a hardware adapter and therefore remain unchanged when interconnected with the framework. In contrast, level 2 systems are modified with a software adapter. Finally, level 3 systems implement the Arrowhead adapter natively. From the framework's perspective, all application systems appear alike, no matter what kind of adapter solution they use.

C. Inter-Cloud Servicing

The scalability of the Arrowhead framework is provided through global service discovery and inter-cloud communica-

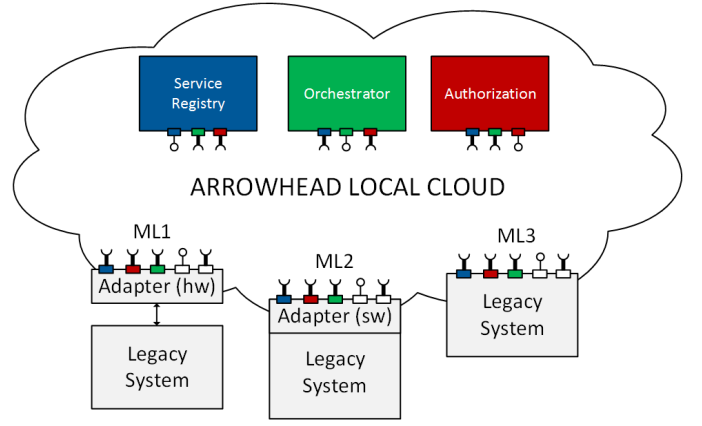


Fig. 2. Maturity levels of legacy application systems

tion. That is, member systems of different local clouds can collaborate, only the authorization and orchestration methods become more complex.

The Gatekeeper core system enables inter-cloud collaboration and was introduced in [4]. The Gatekeeper extends service discovery to neighbor clouds and assists in the orchestration process when application systems of different clouds build up communication with each other.

The main motivation for inter-cloud communication and the implementation of the Gatekeeper is the absence or malfunction of intra-cloud servicing. This can be the consequence of one of the following: there is no service provider locally, the existing provider(s) can not be reached or have no free resources, or the quality of service expectations can not be met within the home cloud at the moment.

D. The Historian

If there are interconnected sensor nodes and storage capacity in the cloud, then there is necessarily *Big Data*. However, *Big Data* itself is not valuable. Without proper filtering and interpretation processes, it remains just a big amount of meaningless numbers. Today the great challenge of cloud computing is turning *Big Data* into *Smart Data*, which is in contrast a restricted set of information, the appropriate base of decision making.

The Arrowhead framework proposes the Historian core system to aid this endeavor. It provides a service to store and retrieve structured sensor data, and basic filtering features as well. The Historian liberates sensor nodes from the burden of data storage and supervisory control systems from data acquisition and pre-processing.

III. THE ELECTRIC TRANSPORTATION CHARGING INFRASTRUCTURE

A. Stakeholders and participants

The electric vehicle charging market evolves and changes dynamically. In many countries temporary services and discounts are provided by the state for the participants of electro

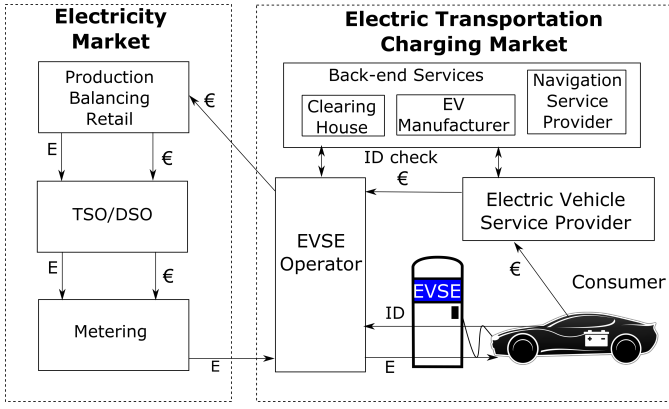


Fig. 3. The Electric Transportation Charging Market

mobility to facilitate the spread of electric vehicles. Meanwhile, proper regulation for the use of the charging infrastructure is not ready yet. In addition to this unsteady environment, electro mobility has a strong and special relationship with the energy market. Any description of the domain is therefore just a forecast of what is expectable in the near future. This paper follows the model proposed in [5] and illustrated in Fig. 3.

The primary actors of the EV charging market are the following:

- Consumer: a human owner of an electric vehicle.
- Electric Vehicle Service Provider (EVSP): a company that contracts EV users offering them charging (and other ancillary features) as a service.
- Electric Vehicle Supply Equipment (EVSE) Operator: an organization, most often a municipality or company that owns and operates charging stations.

The EVSP holds a list of contracted users and makes this list available for the EVSE operator. Through his charge stations, the operator charges the EVs of the authorized users, and then sends transaction related information back to the EVSP. Based on the charging record, the EVSP issues the invoice for the user and pays the operator the cost of the charging.

Secondary actors targets consumers with back-end services to further enhance the “charging experience”. The following enumeration contains several stakeholders of this group, but is not least a complete list:

- Navigation Service Provider (NSP): offering live charge point related information (status, availability, technical details, etc.) to help users find the most suitable EVSE in the remaining range.
- Electric Vehicle Manufacturer: the manufacturer is interested in the charging process, because it influences the life cycle of the battery, the most critical part of its vehicles. Thus, the quality of maintenance services are conducted to charging.
- Clearing House: as multiple EVSP networks may work in the same region, consumers should be able to charge everywhere, and not only on the charging station of their own EVSP. Similar to the financial world, where

ATM’s are able to serve foreign users, the electro mobility domain applies already clearing house solutions [6].

Charging EVs means basically electrical energy delivering. The participants of the electricity market is therefore unmissable stakeholders of the electric transportation charging market as well. Here are the following main functionalities:

- Production, Balancing and Retail: the generation and sale of electrical energy by power plants and power companies. Balancing means that generation always conforms to demand.
- Transmission and Distribution System Operators (TSO, DSO): delivering electrical energy from power sources to households and other end points such as public EVSEs.
- Metering: at every connection point of the grid a power meter has to be installed and inform stakeholders about the amount of consumed energy.

IV. INTEGRATION WITH THE ARROWHEAD FRAMEWORK

Managing EVSEs are different from managing petrol stations. EVSEs work in an automated way, they are organized into network and accessible remotely. Further on, they are expected to operate in a service oriented way, because many stakeholders of the electro mobility domain wish to use them in order to serve their consumers. A big task is therefore to create a dynamic and trusted infrastructure of charging stations and management centers that enables information exchange between market members’ ICT systems.

With the appearance of local energy production and storage, the next generation of the electrical grid – the so called *Smart Grid* – is on its way. EVSEs are intelligent and controllable energy consumers, however, they become producers soon, as the *Vehicle to Grid* technology enables the use of EV batteries for energy balancing. Integration with the *Smart Grid* is another grand task of the electric vehicle charging infrastructure.

The Arrowhead framework implies the opportunity to solve these challenges. The local cloud concept and the service oriented architecture enables dynamic and safe networking for the electro mobility domain. Three use cases are presented below to give an impression of the potential hiding under Arrowhead’s hood.

A. Charge Point Management

EVSE operators are free to manage different types of charge points from different vendors. Their charge point management system (CPMS) collects charging transaction related information from the charge stations. It is desirable to standardize the messages between CPMS and EVSEs in order to provide interoperability. Open Charge Point Protocol (OCPP) is an application layer protocol for this purpose and is widely used in Europe and Asia [7].

Charge points are statically routed to the CPMS and that means no problem if the operator wants to run only a static set of them. However, a dynamic network is necessary if independent EVSEs are spread. They work for more then one operator in different time slots of the day, and therefore need

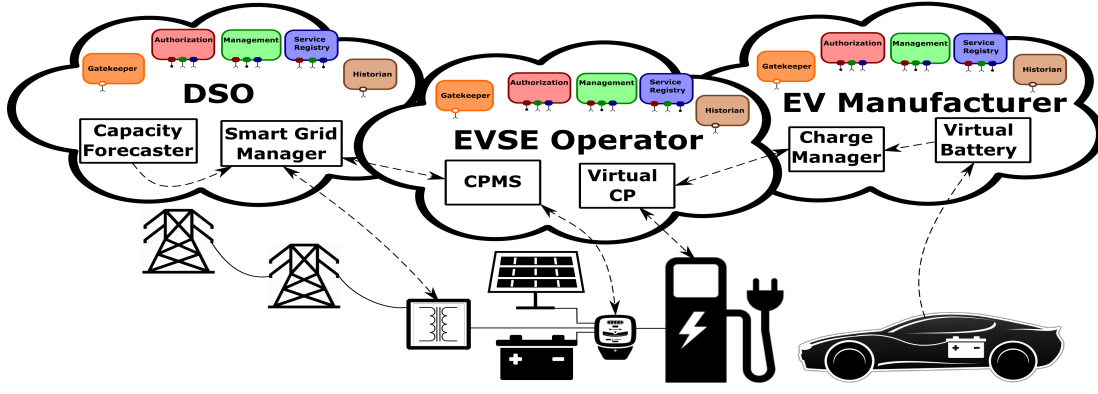


Fig. 4. Electro Mobility in the Arrowhead framework

to change OCPP connections occasionally. Another similar scenario is when the operator runs multiple backup servers on different locations, and EVSEs are dynamically routed to them according to the optimal resource utilization.

Arrowhead proposes dynamic service discovery and orchestration support to help charge points to find CPMS running OCPP servers. The operator registers the CPMS and its OCPP service into the Arrowhead local cloud and sets the authorization rights. After that, the charge points belonging to the same local cloud are able to discover and even consume the service on their own (in which case they have to be authorized). This method reduces the offline operation time of CPs as they are able to find equivalent CPMS running in the cloud (or even in another cloud) if the original servicing ceases.

It is important not to reject or override but to aid OCPP and other well functioning protocols. Arrowhead does not ruin the unified way of communication but creates lightweight, loosely-coupled and trusted connections between communication parties.

B. Smart Grid Integration

EV charging lasts long and requires great power. It stresses the grid significantly even during peak hours. The DSO must solve this problem, because the increased load risks the energy supply of normal consumers.

According to [8], this can be managed without capacity expansion by the application of the *Smart Charging* technique. The DSO calculates capacity forecast on a cable level in its network. The forecast is valid for the next 24 hours, but can be refreshed in every hour or even more often. It is based on historical consumption data and weather conditions. Every EVSE gets then capacity and orchestrates charging transactions according to the forecast.

Smart Charging protects the grid, but can result in increased charging times. EVSE operators become therefore interested in local energy generation and storage installation. So the electrical power capacity can be balanced and the charging transactions can be served with maximum power if necessary. The local energy storage is recharged during off peak hours.

Energy metering plays an important role in *Smart Charging* and in capacity balancing as well. Sensor data is the validator

of the forecast algorithm and the base of decision making when selecting the appropriate power source for the EVSE.

In the Arrowhead framework not only the EVSE operator, but the DSO may also have its own local cloud. Both of them could gather metering data and turn it to *Smart Data* with their Historian core systems. The local clouds could interconnect with each other by the help of the Gatekeeper core systems and collaborate to control energy distribution for EVSEs.

C. Battery Specific Charging

One of the promising use cases enabled by the Arrowhead framework is the individualized way of EV charging, which conforms to the needs of the specific battery pack under charging.

EVs continue to suffer the uncertainty of their batteries. The optimal charging profile depends on many parameters such as level of charge, age, temperature, humidity, etc. EV manufacturers or battery suppliers could offer the charge manager service to prevent battery health and to extend life cycle. Lee et al. [9] propose “Virtual Battery”, a cyber-physical model of EV battery package to simulate and predict behavior under various conditions. This model makes possible the calculation of the optimal charging profile for every transaction of every distinct electric vehicle.

Similarly, every EVSE may have a virtual twin in the cloud. Virtual EVSEs could simulate charging processes, and based on the results, the charge manager of the EV manufacturer (or battery supplier) would choose the best CP being capable to fulfill the desire of the electric vehicle. After arriving at the charge station, the charge manager would take the control over the charger to orchestrate the optimal charging process.

An Arrowhead-compliant charging station is able to act as a gateway between the EV, the Virtual Battery and the Charge Manager, and to perform the prescribed charging profile. Authentication and authorization is crucial to prevent batteries from random and harmful charging processes and therefore EVs should not trust CPs, but only the certificated core systems and the charge manager system. The built-in authorization functionality in the Arrowhead framework targets just these issues.

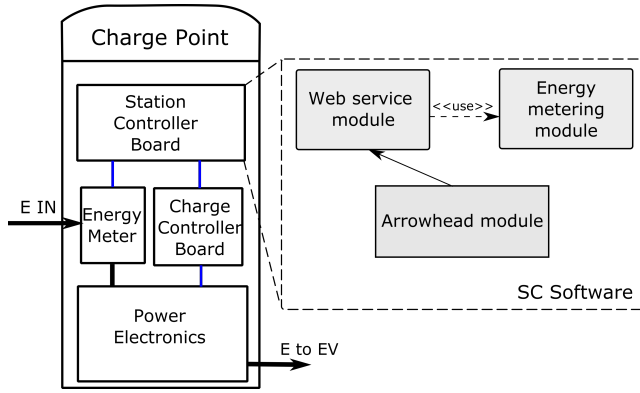


Fig. 5. EVSE's station controller

V. ARROWHEAD COMPLIANT CHARGING STATION

Arrowhead has to step further from theory to practice in order to convince the members of the electro mobility domain about its great benefits. Professional solutions of Arrowhead compliant products need to enter the market soon and beat legacy systems.

One of the first shots of this peaceful revolution is evopro's rapid charging station [10]. It is designed to be fully Arrowhead compliant and tested with the Arrowhead Generation 3.2 framework implemented at Budapest University of Technology and Economics (BME). This section briefly describes the most exciting parts of the charging station from the aspect of the Arrowhead integration.

A. The Station Controller

Fig. 5 illustrates the main hardware and software modules of the Arrowhead compliant EVSE. The charging station consists of power electronics, an energy meter, a charge controller (CC) board to guide the power transmission process from grid to EV and a station controller (SC) board to manage high-level tasks, e.g. user interaction, IP communication, consumption measurement, etc.

The rapid charger offers charging transaction related information to the Arrowhead local cloud in the form of web services. This includes energy readings from the EVSE's power meter. The Arrowhead module, which is part of the SC's software system is an adapter of maturity level 2 towards the Arrowhead framework. The power meter is connected to the SC through common industrial bus systems—Modbus [11] and Meterbus [12] are supported this time—and therefore the Arrowhead module together with the SC hardware board can be seen as an adapter of maturity level 1 and is reusable for other systems managing the same communication buses.

An SC board for an EVSE has a powerful architecture, but still it is an embedded platform with an embedded operation system. The proposed Arrowhead adapter is therefore implemented in Qt/C++ [13], in embedded Linux environment. The implementation makes use of Qt's network management and JSON handling tools to send HTTP messages to the core systems of Arrowhead over 3G network.

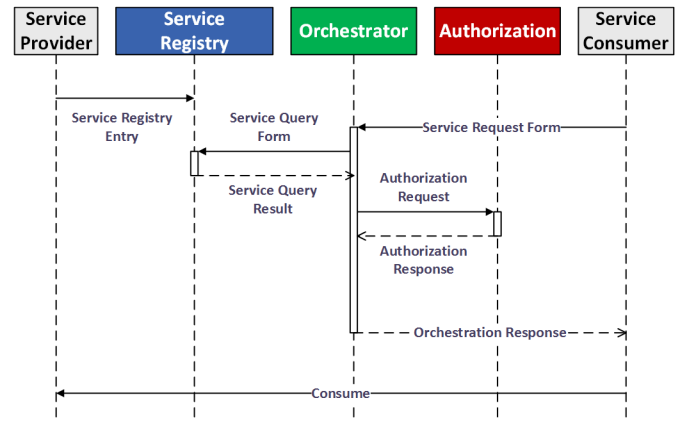


Fig. 6. Arrowhead orchestration process

B. Arrowhead adapter

The Arrowhead adapter for a charge point is expected to support both service production and consumption, as an EVSE should communicate in both direction, e.g. it consumes the service of the EVSE operator's management system and produces another service containing live power consumption information for the DSO.

Current implementation of Arrowhead Generation 3.2 framework provides RESTful interface to the core systems and defines the communication sequences between them and the application systems. In order to register a service, the provider systems has to send a *Service Registry Entry* message to the Service Registry's REST interface. The payload consists of the backend data of the provider system, the URI on which the provided service is available, optional metadata information and a *Transaction Signature Key*, which is required by the Domain Name Server.

The consumer sends a *Service Request Form* to the Orchestrator if it is looking for providers of a specific service. The form contains data about the requester system and the requested service. The requester is allowed to prescribe several options to the orchestration process as well as preferred providers. In response, the Orchestrator gives back the list of the matching providers, their backend data and the authorization token, which will be known for the provider system. The consumer is free to choose the provider that best suits its needs. The application servicing is not expected to be Arrowhead-specific, however, new services can be defined as well. Fig. 6 illustrates the registration and orchestration process.

C. EVSE application services

In the present network of charge points and management system, the end points communicate most often by the use of the OCPP protocol (as described above). Leading this method towards the Arrowhead approach, OCPP becomes an application service, which is provided by the management system and consumed by the charge points. In that manner, the integration of an EVSE is provided through the implementation of OCPP

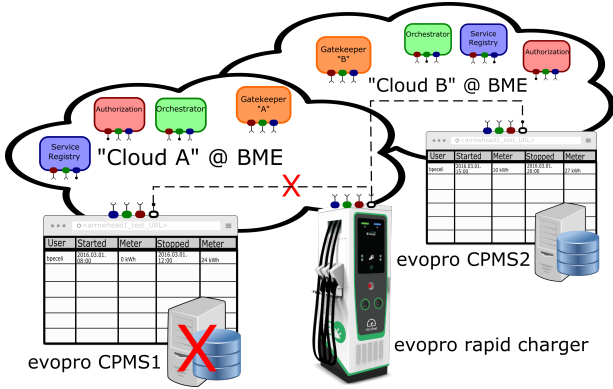


Fig. 7. Rapid charging station connected to the Arrowhead local cloud

(as before), however, considering it as a service and being able to discover and connect to its provider dynamically in run time.

OCPP gives data about power consumption, but the protocol adds too much overhead to the communication for stakeholders that are only interested in that particular information. The “Energy Metering” service is useful for EV manufacturers running a Charge Manager system in the cloud to validate pre-simulated charging processes and improve battery and charge point models. Similarly, a DSO could use the service to validate consumption forecast and provide smart charging opportunities.

VI. VERIFICATION

Fig. 7 shows the test case that was used for verification of both the Arrowhead Generation 3.2 framework of BME and evopro’s Arrowhead compliant rapid charging station¹. Two station management servers were set up at evopro’s office and registered in two different local clouds (“A” and “B”) running at BME. They have published the same management service in their own clouds. The charging station was registered in cloud “A” and had no previous information about the servers. However, it was able to turn to the core systems of its home cloud for orchestration about the management service. The EVSE had found the server of cloud “A” and the server of cloud “B” as well after the first one was shut down and therefore could not be reached.

VII. CONCLUSION

The Arrowhead framework is able to support the electro mobility market by providing a flexible and reliable local cloud based infrastructure. The service oriented architecture with dynamic service discovery improves the usability of existing protocols. Further on, the framework enables the smart grid integration of EVSEs and promising future use case scenarios e.g. battery specific charging. Integration of legacy applications such as charge points and charge point management

systems requires a lightweight, easy to use software component managing the communication with the Arrowhead core systems. The energy metering application service provided by the electric vehicle charge stations plays a primary important role in deepening the integration of stakeholder’s ICT systems and thus, enabling a higher quality of charging services.

However, the Arrowhead framework is not a mature platform yet. Future work must extend functionalities, strengthen authentication and authorization methods and prove robustness and usability through various and complex use cases to make Arrowhead a widely accepted and supported framework of the IoT world. The electro mobility domain needs professional devices and applications that improve both the user’s and the operator’s experience.

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¹This test case was demonstrated also on the Arrowhead project workshop in Budapest, on 2nd March 2016.