evRoaming4EU

Realising cross-border charging in Europe

Achieving interoperability for EV roaming: Pathways to harmonization

Report D6.2 for the evRoaming4EU project

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1. Objective of the evRoaming4EU project and Work Package 6 on achieving interoperability

This report is part of the Work Package 6.1 of the evRoaming4EU project. Section 1.1 introduces the overall project, Section 1.2 discusses the context, funding and consortium for the project, and Section 1.3 introduces the role of this specific report.

1.1 The evRoaming4EU project

The main objective of evRoaming4EU is to facilitate roaming services for charging Electric Vehicles (EV) and provide transparent information about locations and rates of charging in Europe, by making use of an open independent protocol. This will be demonstrated through regional and transnational pilots in four different regions, thereby promoting the creation of one European market for EV drivers and related products and services.

The project works towards two distinct goals. The first goal is maximizing interoperability of the EV charging market, especially the ability of different charging infrastructures to communicate with each other in an efficient manner either via a single protocols or multiple interoperable protocols. The second goal is to maximize adoption of a harmonized EV charging protocol, i.e. the number of parties using the protocol. The results of the project should give insight into how these goals can be achieved, and where trade-offs of achieving these goals have to be made.

More information is available on www.evroaming4.eu.

1.2 Project context, funding and consortium

The evRoaming4EU project is an EMEurope Research and Innovation (R&I) project. Electric Mobility Europe[1] is set up by 9 European national and regional government-related organisations with a strong interest in advancing electric mobility in Europe. It is an ERA-NET Cofund under the EU Horizon 2020 programme, aiming to further advance electric mobility in Europe and designed to take transnational e-mobility research and policy exchange towards deployable solutions. The evRoaming4EU project is one of the 14 project selected by Electric Mobility Europe Call 2016, and has grant number EME-31.

The evRoaming4EU consortium consists of Copenhagen Electric, Eindhoven University of Technology, E.ON Denmark, ENIO, MRA-Electric, Smartlab Innovationsgesellschaft mbH, Stromnetz Hamburg SNH, and project coordinator The Netherlands Knowledge Platform for Charging Infrastructure (NKL).

1.3 Objective of this report

This document is part of work package WP6 of the project evRoaming4EU. The objective of WP6 is to offer insights on how to achieve interoperability from a standardisation perspective, through a combination of desk research and stakeholder interviews.

[1] See https://www.electricmobilityeurope.eu

The WP explores whether achieving interoperability feasible (and best done) via harmonization of the different existing protocols into an independent internationally accepted protocol. If not, it will explore other options to achieve interoperability (such as 'gateways' that allow translation and interconnection between systems).

This report contains descriptions of several scenarios for how interoperability in EV roaming can be achieved. Currently, there are several communication protocols used for EV roaming. Based on a review of the standardisation literature and interviews with stakeholders we have identified six scenarios for how EV roaming could further develop. For each scenario, we describe advantages, disadvantages, and an assessment of the likelihood of occurrence. Furthermore, we provide a context for these scenarios by describing trends in e-mobility that are likely to have an impact on EV roaming.

The aims of this report are:

- Give an overview of trends in e-mobility that could have an impact on EV roaming
- Present scenarios for the further development of EV roaming protocols, including advantages, disadvantages, and likelihood of occurring
- Please note that it is not the objective of this study to make predictions about the position or future chances for specific, existing protocols such as OCHP, OICP, eMIP, or OCPI, bur rather aims at a higher-level analysis on how interoperability could be achieved in a context where multiple protocols already exist.

This report is one out of three reports produced in the context of WP6. The other two are:

- **D6.1. Comparative analysis of standardized protocols** for EV roaming. This report presents a comparison of the major existing EV roaming protocols in Europe. These are the Open Clearing House Protocol (OCHP), the Open InterCharge Protocol (OICP), the eMobility Inter-Operation Protocol (eMIP), and the Open Charge Point Interface (OCPI).
- **D6.3 Design principles for an 'ideal' EV roaming protocol**. In this report, we propose design principles for an 'ideal' e-roaming protocol, 'ideal' meaning in this case that it takes into account the interests of all e-mobility stakeholders to ensure seamless roaming for EV users, fits within the regulatory landscape, and allows for efficient use of public charging infrastructure in the EU.

The rest of this document is organized as follows. Chapter 2 presents our methodology. Chapter 3 discusses perspectives on the future of charging infrastructure. Chapter 4 presents six scenarios for achieving interoperability. Chapter 5 discusses our results and concludes the report.

2. Methodology and data sources

This report is based on a combination of desk research and stakeholder interviews. Our desk research allows us to investigate visions on the future of e-mobility and link them to historical standardisation processes. The stakeholder interviews provide insight in which developments in e-mobility are deemed important by practitioners, to what extent the lessons learned from the historical processes apply to e-mobility, and what scenarios are favoured by parties in the e-mobility ecosystem.

2.1 Desk research

We reviewed the scientific literature on e-mobility to investigate visions on the future of e-mobility, specifically as it relates to charging infrastructure business models and EV roaming. Furthermore, we reviewed the scientific literature on standardisation to investigate historical standardisation processes. In particular, we focussed on standardisation processes in EV plugs and roaming in telecommunications, since we expect these cases to by relevant for EV roaming. The literature review allows us to construct scenarios for achieving interoperability, which we could then discuss in our stakeholder interviews.

2.2 Interviews

We conducted interviews to investigate the stakeholder views on the future of charging infrastructure and achieving interoperability. In our selection of interviewees, we sought variety in position in the value chain, in which roaming protocols the interviewed party uses, and in geographical location. Figure 1 1 presents a representation of the various market roles, and how they relate to the overall EV ecosystem. The scheme was designed to guide us in our selection of interviewees and to discuss their specific market roles. We do not claim our scheme on the EV ecosystem to be definitive, there are other valid ways of representation. Furthermore, the EV field is still relatively new and developing, and new roles may emerge in the future. Yet, we believe this scheme allows to identify a relevant set of stakeholders to approach for interviews. Furthermore, we discussed the scheme with several interviewees, who agreed that it is a good overview of the current EV field.

Our interviews were semi-structured, and we sent a summary of the interviews to the interviewees for them to check for potential errors or misinterpretations. We investigated the strengths and weaknesses of the current protocols and explored views about the future of EV charging and the role of roaming therein. We asked questions on several topics, see Apendix A Interview protocol. Interview protocol for the complete interview protocol. In this report, we only use results from questions 4-6, which discuss the future of e-mobility and harmonisation and standardisation of roaming protocols.

We have conducted 35 semi-structured interviews with 38 roaming experts (three double interviews). We approached potential interviewees through the network of the project evRoaming4EU, by asking interviewees to point us to new potential interviewees, and through visiting the electric vehicle conference EVS32 in Lyon, 19-22 May 2019. We have spoken to stakeholders from the Germany (13), Netherlands (13), Austria (3), France (3), Portugal (2), Sweden (2), Belgium (1), and Spain (1). Our set of interviewees covers all the 11 roles introduced in Figure 1 1, except that of Automotive Supplier. We have approached several Automotive Suppliers to conduct an interview, but all of them declined. Five of the interviewees are experts on EV roaming but not captured in our scheme: two researchers, one consultant, and two representatives from sector interest organizations.[2] Appendix B. List of interviewees presents the names and organisations of our interviewees (except for eight interviewees who participated under the condition of anonymity).

Additionally, we interviewed an expert of roaming in telecommunications via e-mail to get further insight in how roaming is organised in that sector, see Appendix C. Interview protocol for telecommunications expert for the interview protocol.

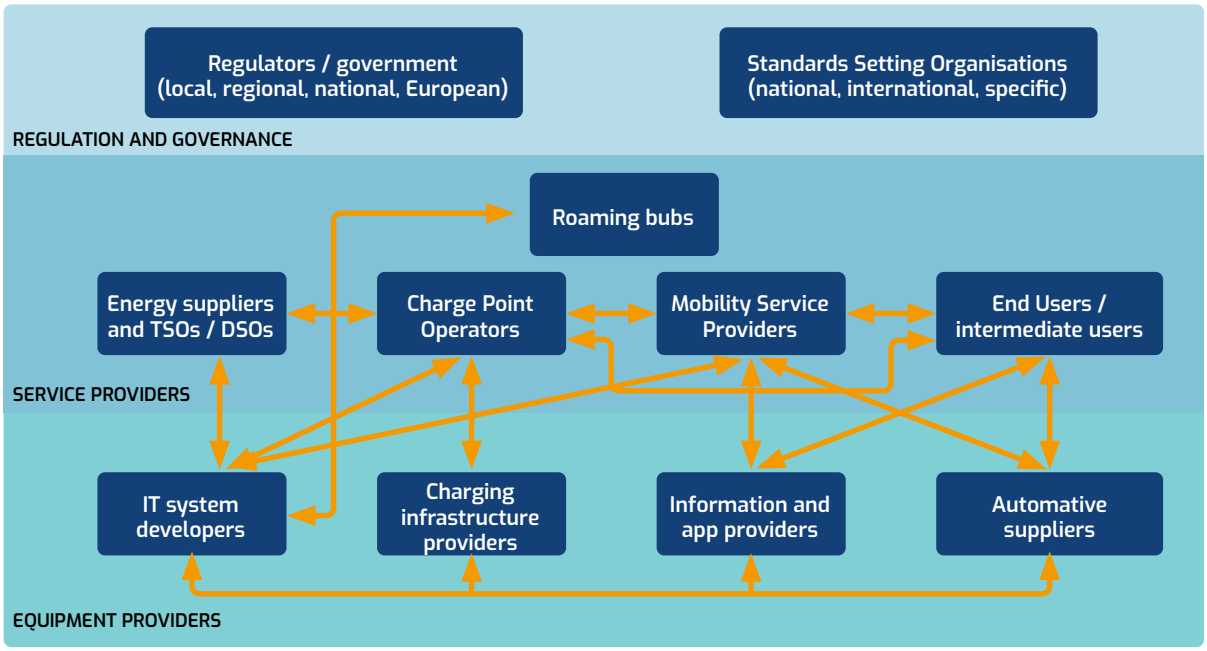

Figure 1. Market involved in the whole value chain roles and connections in the EV ecosystem. Note that we did not draw connections between the regulation and governance level to other stakeholders, since these stakeholders are involved in the whole value chain

[2] Please note that the way we identified interviewees (especially when we used our own networks) may have resulted, to some degree, in an overrepresentation of actors that use OCPI. While we did specific efforts also to include interviewees that used (only) other protocols, their final number is lower.

3. Current and future developments in public charging infrastructure for EV

This chapter starts with a shore note on the public EV charging context (Section 3.1), and then discusses the most distinctive feature of any roaming system: whether it is based on peer-2-peer operations or on the use of a roaming hub (Section 3.2). We then discuss eight important future market trends (Section 3.3) and finish by reflecting on the future market structure and consolidation (Section 3.4) and the future role of regulation (Section 3.5).

3.1 Public EV charging context

The e-mobility field is relatively new and developing rapidly. In Europe, various governmental levels are stimulating the build-up of public charging infrastructure. At EU level, the European Parliament and Council have committed member states to build sufficient public charging infrastructure to support their national EV fleet [1]. National governments have implemented a variety of policy measures, which include setting of national targets, information campaigns, and subsidizing public charging stations [2]. Electric vehicles can be charged at home, at public charging stations, charging stations at office buildings, and semi-public charging stations (for instance in parking garages or shopping centres) [3]. E-mobility business models are still developing. Factors differing between current business models are, for instance, charging power (defining how long a car will occupy a charging station), accessibility of the charge point, and charging fees (flat fee vs. pay per charge) [4]. Furthermore, new trends in mobility and energy give rise to other proposals for future business models such as car sharing, intermodal transport, vehicle-to-grid technology, battery swapping, and EV roaming [5].

Electric mobility can be seen as a complex system, with multiple actors involved and interrelated, including charge point operators, e-mobility service providers, and roaming hubs [4], [6]. Building an efficient and user-friendly charging infrastructure requires them all to communicate and exchange data relating to charge operations. This is especially true when one strives for seamless roaming (or seamless interoperability), which means that a user (EV driver) can charge at any public charge station, regardless of which CPO operates that charge station and regardless of which MSP the user has selected for mobility services and payment.
Envisioned future developments will require communication between even more parties. For example, in visions on e-mobility with smart charging actors from the mobility sector are interacting with actors from the energy sector, such as grid operators, energy producers, and aggregators [7]–[10]. Including charge points in navigation apps requires information on location, availability, and the tariffs of charging transactions. Finally, transnational EV roaming will require actors from different countries to communicate with each other. Protocols are key in ensuring efficient communication between all parties involved. Protocols both enable and limit the information that parties can share amongst each other, which parties can communicate with each other, and can both enable and hinder certain business models.

Because the future of e-mobility is so closely linked to the communication protocols it is based on, we asked our interviewees what they see as important developments in e-mobility and, specifically, public EV charging. This chapter presents the results from these discussions.

3.2 Peer-2-peer operations vs. roaming hub

A very distinctive feature of a roaming system is whether it is based on peer-2-peer operations, or on a roaming hub. For an introduction to these concepts, we refer to Section 3.3 in report D6.1 (see Section 1.3). Each approach has its own set of advantages and disadvantages, as shown in Table 1.

Table 1 Peer-2-peer vs. roaming hub: Advantages and disadvantages from the perspective of CPOs and MSPs

	Peer-2-peer operation	Roaming hub operation
Advantages	Flexible and customisable: parties can discuss and agree upon all technical and commercial aspects	Allows immediate access to all the other parties connected to that roaming hub Offers a single, harmonized set of technical agreements (protocols, implementation, etc.) Often implements, maintains and updates the roaming protocols May include a single, harmonized framework of commercial roaming agreements, and may managing changes these agreements, for instance due to legal changes, tariffs changes or operational changes May include certification / implementation testing services May allow connection between parties using different protocols (see also 'gateways in Section 4.4) May offer administrative services such as billing, invoicing, payment settlements, and netting
Disadvantages	Negotiating many individual roaming connections can be time-consuming and expensive Can require significant technical implementation costs, especially if implementation differs between individual connections	Lower span of control: roaming hubs decide what protocols to use, and may define the business rules Less possibility to customize or adapt to individual needs Roaming hubs will charge a fee for their services

Put in a somewhat simplified way, peer-2-peer operations are mostly attractive between large CPOs/MSPs, that have significant traffic between them, whereas roaming hub solutions are especially attractive for small CPOs/MSPs, that have fewer resources or less economics of scale, or large CPOs/MSPs that want to connect to many small CPOs/MSPs.

The above also implies that peer-2-peer operations and roaming hubs are complementary, and indeed, many interviewees indicate that in the future they expect hybrid systems, like a mix of peer-2-peer connections, business-2-hub connections, and hub-2-hub connections. In case of two or more roaming hubs, there is a need for meta-roaming agreements between hubs. Such a hybrid scenario has considerable analogies with the field of mobile telecommunications (see Box 1).

Since the 1980s, roaming agreements played a central role in mobile telecommunications. Historically, mobile operators have primarily had bilateral roaming agreements with each other, but in the last 5-10 years, roaming hubs have become more dominant. Especially smaller operators connect to other networks via roaming hubs. They do so because they have too little resources to negotiate and maintain roaming connections, but also because larger well-established operators are not too interested in making new roaming agreements (it is thus difficult to even start the negotiation). It is noteworthy that roaming in telecommunications has thus developed very differently, as roaming hubs only became more dominant when the market could already be characterized as mature. In contrast, in the e-mobility field several roaming hubs are already established, while the market is (most likely) still in an early stage. We note furthermore that in telecommunications, one often makes the distinction between a clearing house (an administrative role handling transactions) and a roaming hub (who make roaming agreements on behalf of multiple parties).

Box 1: Roaming agreements in mobile telecommunications

Yet, there were also several interviewees who thought that (large scale) roaming hubs disappearing from the e-mobility ecosystem is a realistic scenario. This could happen either via (1) consolidation of the market, with only a few parties remaining who have the resources to connect peer-2-peer, (2) EV drivers can access all public charging infrastructure ad hoc, and roaming disappears from the field, or (3) instead of large, centralized hubs, roaming can be based on small, cheap, and easy to set-up roaming hubs to fulfil services such as administration an billing, which could be based on blockchain technology. If roaming hubs indeed become less relevant, the existing hubs could remain relevant by focusing more on clearing services or aggregator services for smaller companies and start-ups.

3.3 Relevant future market trends

3.3.1 Fast charging versus opportunity charging

Fast charging will probably become increasingly popular mostly along highways or at special locations in urban areas. At the time of writing, many fast (DC) charging stations are equipped with 50kW chargers, but some are also rolling out faster chargers of 150, 175, 300, or 350 kW.[3] While many current EVs do not yet support these modes, this will likely change in the future.

Availability of increasingly fast charging services is likely to have an impact on where EV drivers charge their cars, and, consequently, for the need for roaming. The degree to which fast chargers will become dominant in public charging infrastructure is one of the most debated topics in the field. Proponents of fast DC charging reason that it makes the act charging an EV more similar to fuelling an internal combustion engine vehicle, which is what consumers would want. Opponents say that AC charging infrastructure is much easier to incorporate in the existing electricity grid, and that widespread AC chargers allow for opportunity charging (at work, shopping centres, etc.) that can fulfil EV drivers' needs.

3.3.2 Creating a seamless user experience

When EVs become more mainstream, EV drivers will increasingly demand ease of use. This means roaming functionality, car-based authentication (using, for instance, the plug & charge feature of the ISO 15118 standard[4]), and information on the availability, capacity of charge points, but also services surrounding charge points such as information on close by restaurants, entertainment available with the charge point. Companies will offer more full-service packages, for instance combining buying a charge point with an energy contract.

3.3.3 Higher quality of charge points

Today, many charge points still suffer from quality problems. Because of software bugs and other problems, they are not always working. Publicly financed charge points may be selected for lowest purchase costs, but this often comes at the expense of higher maintenance costs. Indeed, if charge points get replaced with new ones, parties will often go for a higher quality, because it saves maintenance costs.

3.3.4 Diverse mix in charging infrastructure

As the EV market matures, it is expected that a wider variety of EV models will be available, both in terms of technical specifications and price, and that these will be used by a wider variety of people and for a wider variety of purposes (e.g. carsharing, long distance trips). Hence, it is expected that there will also be a need for more diverse types of charging infrastructure to support these different functions, such as charge points with a larger variety of charging speeds, charge points at a larger variety in types of location, inductive (wireless) charging.

[3] See for instance Fastned, which offers fast charging services along Dutch highways: https://support.fastned.nl/hc/en-gb/articles/115015420127-150-kW-fast-chargers

[4] The plug & charge feature that comes with ISO 15118 enables the electric vehicle to automatically identify and authorize itself to the charging station on behalf of the driver to receive energy for recharging its battery.

3.3.5 Changes in charging behaviour

Several factors may lead to changes in charging behaviour. One factor is the increase of range offered by EV batteries, which may reduce the relative number of roaming sessions. Another factor is changes in mobility use, such as car sharing and autonomous driving, which in contrast may increases the need for roaming sessions. Furthermore, if the number of charge points is low compared to the number of EV drivers, 'social charging' will become important, i.e. encouraging EV drivers to move their EV away from a charge point when it is sufficiently charged.

3.3.6 Smart charging and vehicle-to-grid

EVs have the potential to contribute to load balancing via smart charging and vehicle-to-grid. Many interviewees argued that roaming protocols support these functionalities. At the same time, it is still unclear which business models will arise, and which type of party should be entitled to receive what type of data (e.g. CPOs, MSPs, grid operators, energy companies or the car itself).

3.3.7 Electrifying other modes of transportation

Currently, a lot of attention is paid to electrifying the consumer cars, but there is also a lot of potential in electrifying other modes of transport, such as smaller or larger trucks, and public transport. It is not clear how this will affect roaming.

3.3.8 Increased demand for price transparency

In the current situation, there is not much price transparency. It is expected that this topic will become more important when EVs become more mainstream, because it will become a topic of increased attention (and, perhaps, bigger concern) of governments and consumer associations.

3.4 Market structure and consolidation

One of the interesting aspects of EV charging infrastructure is that it is an emerging market, in which parties from several big industries enter the market. Energy companies and grid operators have an obvious interest in the field (supplying energy and managing the grid), but also traditional oil companies have entered the market via take-overs (e.g. Shell has taken over NewMotion, British Petrol has taken over Chargemaster, Total has taken over Pitpoint). Furthermore, car makers (often referred to as OEMs[5] in this context) are expected to invest more in charging infrastructure. Tesla is an obvious example, but traditional car makers such as Renault and BMW have also moved towards the market. Software companies will probably play a role in software and data management, but it is unclear whether they will be able to capture a large role, since many MSPs and CPOs already have their own IT teams. Some CPOs are also back office providers to others, providing IT and administrative services for other CPOs and MSPs (examples of CPOs offering these services are Greenflux, Last Mile Solutions, EVBox). Another uncertain factor is whether there is still room for start-ups in the market, given that many of the necessary roles are already fulfilled, and it is likely that MSPs and CPOs will offer full-service packages.

[5] OEM: Original Equipment manufacturer

Several interviewees thought that 'pure' MSPs would disappear, as they add too little value to the market. Finally, some interviewees thought that the future of roaming hubs is unsure, as discussed previously in Section 3.1.

There were disagreeing views on the number of parties that will be active in the EV charging infrastructure of the future. A commonly held notion was that there are currently too many parties active compared to the market size, and that in the coming years there will be a market shake-out, with only a few large parties remaining (though there may still be room for smaller, specialized companies). While none of the interviewees had real concerns about this, one interviewee highlighted that the EU should be careful that the EV charging infrastructure does not become a vertically integrated sector, as has happened with traditional automotive for instance. However, some interviewees pointed out that for the effort of building up the charging infrastructure for Europe's ambitions for electrifying transportation, a large number of parties will be needed to make this a reality. All interviewees stressed the uncertainty associated with their predictions, as the field is rapidly developing and there might be a struggle for market power by companies that have large amounts of capital available for investments. Another factor that makes predictions hard to make is that the market composition will depend on regional and local conditions. In Europe, for instance, energy companies play a large role in the market, while in the US, new entrants are more dominant. There are also differences within Europe. For example, in the Netherlands only a few parties are active in charging infrastructure, while in Germany and France, many local grid operators play an important role.

3.5 The role of regulation

So far, EU legislation has not played an important role in roaming protocol development or deployment. There is an EU-wide directive of 2014 [1] that charge points should always be accessible with ad hoc payments (i.e. without entering a contract with supplier or operator), but parties can decide for themselves how they enable this. Now that the market is maturing, national governments – and perhaps also the European Commission or the European Union - may want to play a bigger role.

One example of where governments see future rules is in the creation of the National Access Point (NAP) registers. Such registers aim to facilitate end users in finding charge point locations. One interviewee, however, expressed criticism on the creation of NAPs. NAPs require CPOs to provide information on the location of charge points and their availability status, which is too limited information to support many new services for EVs, including fleet management. Furthermore, the interviewee argued that CPOs should be compensated for sharing location data, which the interviewee in question considered to be as proprietary information.

4. Scenarios: possible routes towards harmonisation

All our interviewees saw interoperability as a crucial aspect of the future of EV charging infrastructure. At the same time, perspectives diverged on how wide-ranging interoperability could be achieved. This section presents the results from our discussions with interviewees, augmented with additional insights based on desk research on gateway technologies, and the historical standardisation processes in telecommunications and for EV plugs.

The six scenarios we discuss are:

- Scenario 1: Status quo (fragmentation) (Section 4.1)
- Scenario 2: Harmonization of existing protocols (Section 4.2)
- Scenario 3: Standards battle with winning protocol (Section 4.3)
- Scenario 4: Gateways (Section 4.4)
- Scenario 5: IEC 63199 becomes dominant (Section 4.5)
- Scenario 6: No roaming (ad hoc) (Section 4.6)

We will discuss each scenario using the same template (a description, overview of main advantages and disadvantages, and the likelihood that it will become the future dominant scenario).

4.1 Scenario 1: Status quo (fragmentation)

4.1.1 Description of scenario

In this scenario, EV drivers have a contract with one MSP (denoted as 'Service Provide' in the graphs). Typically, a MSP has peer-2-peer connections to some (but not all) CPOs, and to one or more roaming hubs. Yet, the roaming hubs are not connected to each other. Furthermore, multiple roaming protocols are in use. Because the actors are not all interconnected, full seamless roaming is not achieved, and the EV driver cannot access every charge point. This scenario reflects the status quo in e-mobility. Figure 2 presents a scheme of this scenario.

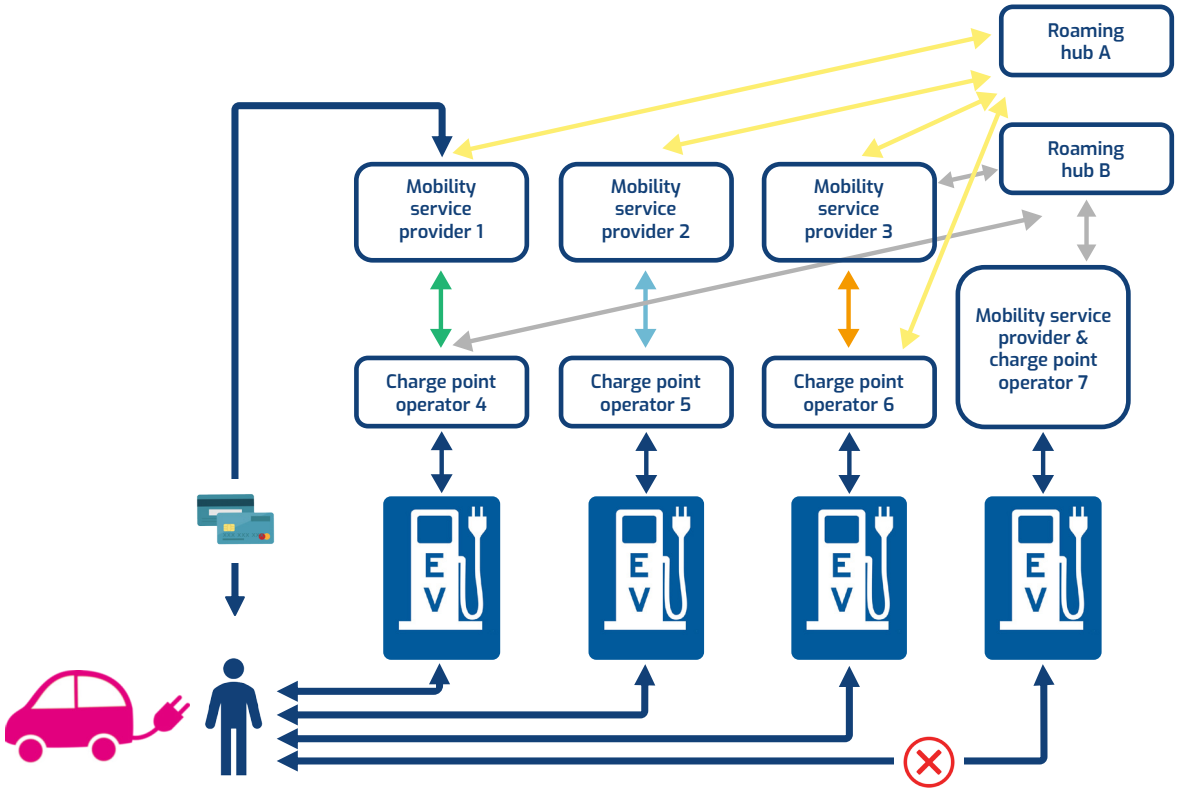

Figure 2 presents a scheme of this scenario.

4.1.2 Advantages and disadvantages

One advantage of this scenario is that there is competition between protocol developers, which could lead to better protocol design and a fast response to market demands. Furthermore, the protocol developers are relatively free, as they do not have to coordinate updates to the protocol with other protocol developers. This makes it easier to incorporate new functionalities in protocols, which will lead to more diverging protocols. Other parties can then choose to implement which protocol best suits their needs.

This scenario has a clear disadvantage for EV drivers, who cannot access all charge points. Furthermore, a common feeling in the "EV community" is that this scenario, which reflects the current situation, is very complex and 'messy'. The present use of multiple protocols creates uncertainty over what choices to make.

From the perspective of a CPO (or an MSP), implementing multiple protocols is costly (especially because protocols are continuously updated). Switching protocols is costly as well. Additionally, it is not clear whether diverging protocols are benefitting the field, as the protocol developers are responding to similar market demands (while there are some differences between current roaming protocols, they are evaluated by many as "very alike").

4.1.3 Likelihood to become the dominant future scenario

Given that for many players this is not the preferred scenario, it is not likely that the situation will stay like this. Many parties benefit from interoperability, and legislators find it important too. However, this situation could remain a reality when protocol developers are not or only limitedly cooperating, for instance because they rather compete with each other, and many CPOs/MSPs hold on to earlier implemented protocol for legacy reasons or a lack of resources to switch.

4.2 Scenario 2: Harmonization of existing protocols

4.2.1 Description of scenario

In this scenario, worldwide interoperability is achieved by harmonizing the existing protocols into a single, internationally accepted protocol. In this process, all relevant existing protocol functionalities are included in the resulting protocol. This harmonization can be achieved through cooperation between protocol developers, which could potentially be prompted by regulators. Figure 3 presents a scheme of this scenario. Note that while parties remain free to decide who they connect to, seamless interoperability would indeed be achieved when the roaming hubs interconnect.

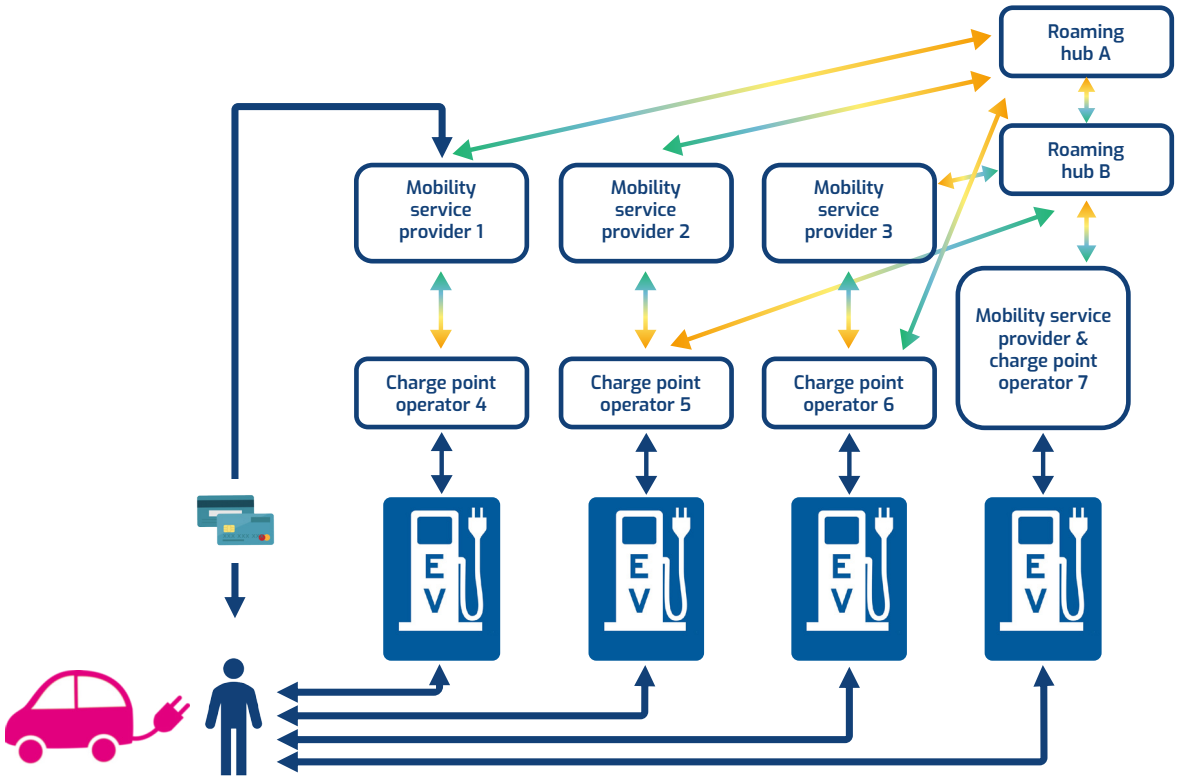

Figure 3. Scenario 2: Harmonization of existing protocols

4.2.2 *Advantages and disadvantages*

Most interviewees agreed that having a single standard is beneficial for the sector. For EV users, the advantage is that they can access all charging infrastructure, as long as CPOs/MSPs are connected to each other directly or via a hub (in some countries, such as Germany and France, there already exists legislation that charging infrastructure that is fully or partly publicly funded, must be connected to a hub). The main advantage for CPOs, MSPs, and roaming hubs, is that they only have to implement one protocol. Some interviewees argued that this scenario will stimulate innovation in the sector. Moving away from competition on protocols and from binding customers to hubs will allow the sector to compete on other services for the user, and will reduce pricing because the 'middle man' (hubs) will not be essential for roaming, which will benefit EV drivers.

Increased cooperation of protocol developers also has some disadvantages. Updating the protocol can go slow, because coordination amongst involved parties is needed. Furthermore, the protocol may not support all business models, thereby increasing the barriers to entry for parties that want to deviate from the supported business models. Also, lack of competition between protocols may result in fewer incentives and therefore less innovation.

4.2.3 *Likelihood to become the dominant future scenario*

The interviewees differ on their view on whether this scenario is likely. An often-heard argument is that there are too many parties that have a vested interested in their own protocol. Either because they have already implemented it and know how to work with it, or because, for the hubs, their business model depends on customers making use of their protocol, which could be described as a lock-in situation. If the roaming hubs do not have their own protocol, their customers might more easily switch. Other interviewees, while acknowledging this scenario is not easy to achieve, think that it will eventually happen, because it is cheaper. A trend that will favour this scenario is thus an increased sensitivity to price. It was argued, however, that currently, parties active in the field of e-mobility are not price sensitive, as their strategy is to establish a large market share, more so than to be cost-efficient. One interviewee said that the merging of protocols could go very slowly and almost unnoticeable. Some interviewees see a role for regulators in making this scenario happen.

4.3 Scenario 3: Standards battle with winning protocol

4.3.1 *Description of scenario*

One of the protocols could become dominant through widespread market adoption. Once a single protocol is dominant, the remaining parties will want to switch that protocol as well because of the advantages of one single standard and the costs of using 'losing' protocol. Variations on this scenario are that there will be two or three dominant protocols worldwide, or that a new proprietary protocol becomes dominant, or that the government steps in to select a winning protocol, as has happened with EV charging connectors. Figure 4 presents a scheme of this scenario.

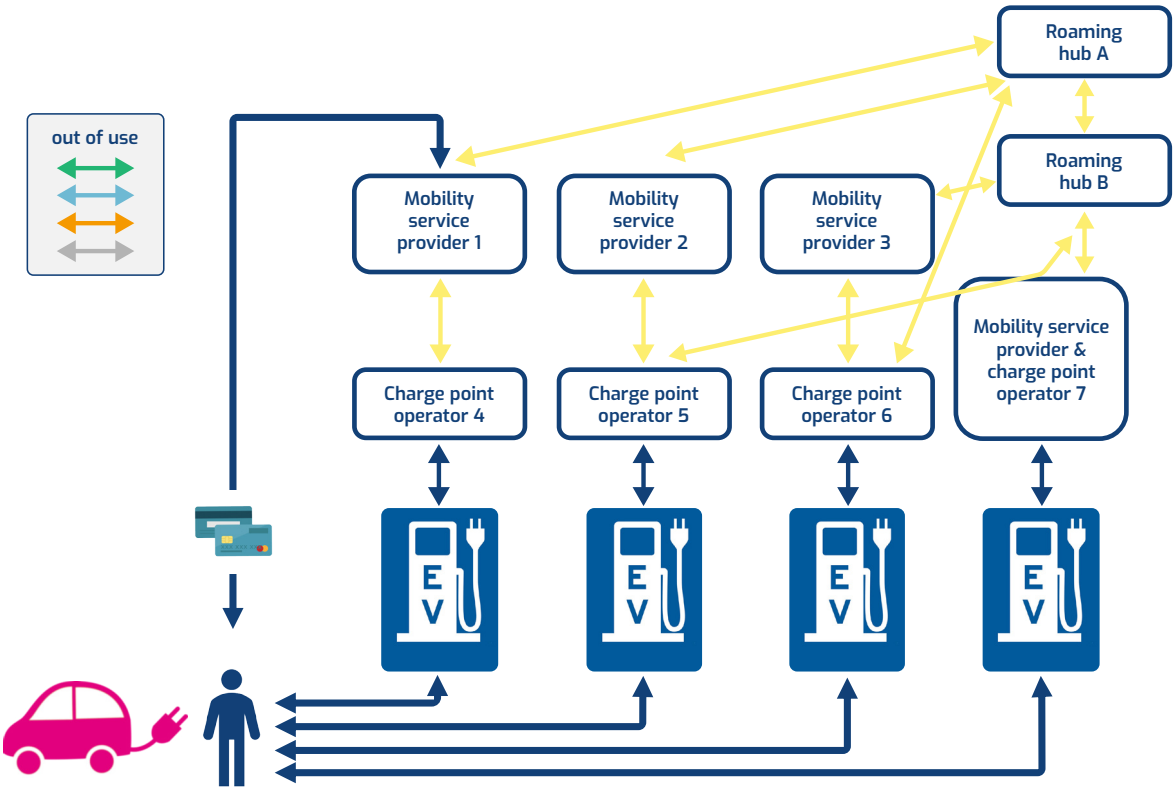

Figure 4. Scenario 3: Standards battle with winning protocol

4.3.2 Advantages and disadvantages

If one protocol becomes the dominant standard, full interoperability can be achieved by implementing only one protocol, which will save CPOs, MSPs, and roaming hubs resources. Whereas Scenario 2, above, also has only one protocol (as the results of a harmonization process), the advantage of a protocol becoming dominant through a standards battle is that updating of the protocol can go faster, as it is not based on cooperation between different parties. One interviewee thought that an advantage of a standards battle over a harmonization process is that a merging process probably requires the involvement of a coordinating body, while the market tends to make more pragmatic choices than governments.

A disadvantage of a standards battle is that a sub-optimal protocol may be selected. Furthermore, the owners of the winning protocol may become too powerful, especially when the protocol governance does not adhere to WTO TBT criteria of an open standard, see [11]. Just like a harmonized protocol, a winning protocol may not support all business models, thereby making the barriers to entry higher for parties with business models which are not supported.

4.3.3 Likelihood to become the dominant future scenario

A majority of interviewees saw this as the most likely scenario. Generally, the community would welcome it if the number of protocols (in active use) were to be reduced.

Protocols that support both peer-to-peer and hub connections (such as OCHP and OCPI) have a certain promise to become the dominant candidate if such a reduction takes place. One possible scenario here is that MSPs will increasingly adopt one of these protocols, both for their communications with roaming hubs and for their peer-to-peer. These roaming hubs may still use different protocols to communicate with CPOs. 'Newer' CPOs may already have selected the protocol that has become dominant for their operations. 'Older' CPOs may prefer to continue to use other protocols and not migrate existing equipment. At some point, however, when they roll out new equipment (on CPO back-end side), they may select the dominant protocol for it. While roaming hubs might initially have preferred their own-developed protocols, they might more and more use other protocols (that support both peer-to-peer and hub connections) in response to the market developments and needs of their clients. In the above process, other protocols would gradually and naturally phase out, but without unnecessary switching costs.

Another scenario is that one of the existing roaming platforms becomes dominant. This could happen in several ways. Firstly, it could be that one roaming platform is more and more perceived as offering the best service. Therefore, they attract the most parties, which in turn makes connecting to this platform more attractive (increasing returns, network effects). For this to happen, the existing roaming platforms do not open up their platform to each other (this is currently under discussion, but not yet the case). If the other roaming platforms become less relevant, and peer-2-peer does not become dominant, the platform might be so attractive that they achieve a monopoly position, using their own, proprietary protocol. Secondly, one of the roaming platforms might raise enough funds to take over the others. Finally, a roaming platform could become dominant by being compliant with certain conditions imposed by major players (either OEMs or CPOs), while other platforms failing to achieve such compliance.

In this scenario of a standards battle, an existing protocol could be the winner, but in principle it could also be a new protocol. A new protocol developed by market parties, however, was not seen as likely by our interviewees: they believed the current protocols already covered a lot of the market demands and there is little room for a new protocol to enter the market. A new protocol that would have, according to some interviewees, a realistic chance of becoming dominant is currently being developed by the International Electrotechnical Commission (IEC): IEC 63199. We discuss this protocol in scenario 5 (Section 4.5).

Another variation of this scenario is that regulators, for instance the European Commission (EC), steps in to select a standard. When a certain standard is considered a public good, governmental regulation may play an important part in the standardization process [12], [13]. For the EC to cut the standardization process short is exceptional, but has happened before in e-mobility with the standardization process for EV plugs [14].

Reasons for this decision were that it was believed to contribute to the EU's competitive advantage as a first mover in e-mobility, one of the competing standard already was a clear front-runner, and a lack of believe that consensus could be reached within CEN/CENELEC, the responsible body for this standardization process [14]. If similar things happen with the standardization process or roaming protocols, we could envision this to happen again.

4.4 Scenario 4: Gateways that connect different protocols

4.4.1 Description of scenario

In this scenario, multiple protocols coexist, and interoperability is achieved by connecting those via gateway technologies, i.e. systems that interface with two or more different protocols to the best degree possible. Figure 5 presents a scheme of this scenario. The location of the gateway is indicated in the figure by a red square. In principle they can be located on either side of a connection – after all, connections are two-ways in our examples. In our example, we use two remaining protocols, each 'tied' to one of the two roaming hubs. In practice however, there may be more protocols in use connected by gateways, and they may also be only used by MSPs/CPOs (not hubs).

The gateway scenario is already reflected in the current situation to a certain extent; existing roaming hubs are cooperating with each other, and some support multiple protocols, meaning that they act as gateways. However, this is now only happening at a limited degree, and not all platforms have opened up to each other.

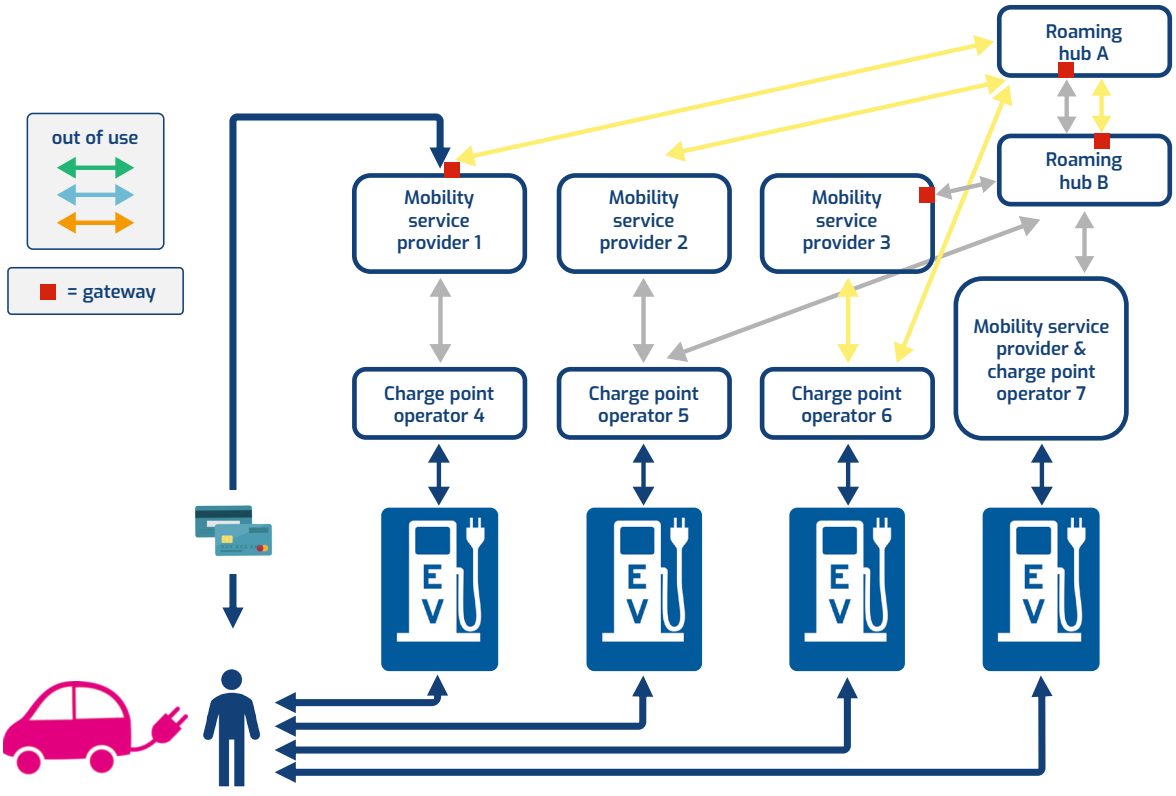

Figure 5. Scenario 4: Gateways

4.4.2 *Advantages and disadvantages*

Gateway technologies have some benefits, such as decreasing the chance of monopolies to arise [15]. Typically, gateway technologies are attractive when no single standard has emerged from the standardization process. Some interviewees thought that connecting different protocols via gateways would offer the benefit of full roaming, while at the same time leading to competition between protocol developers, which should lead to lower costs and more functionalities. According to one interviewee, gateway technologies may have the benefit that it will be easier to connect different sectors and countries to existing charging infrastructure, as these can choose their preferred protocol.

On the other hand, developing and maintaining gateways may come with extra costs and limited functionality [13]. At best, a gateway can offer functionalities that are already supported by both protocol it connects. In principle, gateways may also limit performance, though this may be less of an issue in this specific context (the protocols we talk about are about relatively simple data messages that do not require massive computing resources). Furthermore, updating protocols becomes more complex due to compatibility concerns (with gateways as well as the other protocols). Furthermore, one interviewee argued that this scenario will have lower price transparency for the consumers as compared to having a single standard, and that the charging infrastructure will be less stable because of errors in translating data from one protocol to the other.

4.4.3 *Likelihood to become the dominant future scenario*

As stated above, this scenario reflects the current situation in roaming to a certain degree, as there are already projects to develop gateways between existing protocols, the three currently existing roaming hubs (e-clearing.net, Hubject and GIREVE), now all are supporting more than one protocol. However, full interoperability has not been achieved yet. Several interviewees saw the gateway scenario as the most likely scenario, because they see the EV field as too diverse for all to adopt the same protocol. Even if one of the protocols becomes popular and the de facto standard, some 'older' CPOs may prefer to continue to use the protocol they have already implemented, due to a lack of resources to switch. In this scenario, roaming hubs would have the role to connect parties that remain on legacy protocols. Although this requires these hubs to invest in multiple protocols, this might be viable for them as it creates a business case. CPOs and MSPs, however, would not need to concurrently implement multiple protocols.

Interestingly, two different effects of a potential strong consolidation in the e-mobility field on the likelihood of this scenario were identified. On the one hand, a strong consolidation round will lead to a less diverse field, making this scenario less likely. On the other hand, if there are only a few parties left, these may prefer to connect peer-2-peer via their own, proprietary protocol, which easily integrates with their back-end system.

4.5 Scenario 5: IEC 63199 standard becomes dominant

4.5.1 Description of scenario

The currently used roaming protocols were developed locally and bottom-up, by relatively small organizations. A top-down approach would be to develop roaming protocols in large SSOs. Indeed, the International Electrotechnical Commission (IEC), a large, global and formal standard setting organisation (SSO) in the field of electrotechnology has started developing a roaming protocol, known as IEC 63119. It is still under development and may be market-ready in a couple of years. Because this protocol has been developed in through an international standardization process, it may become a widely adopted protocol, or even the dominant protocol. Figure 6 presents a scheme of this scenario, where the purple lines represent this new protocol.

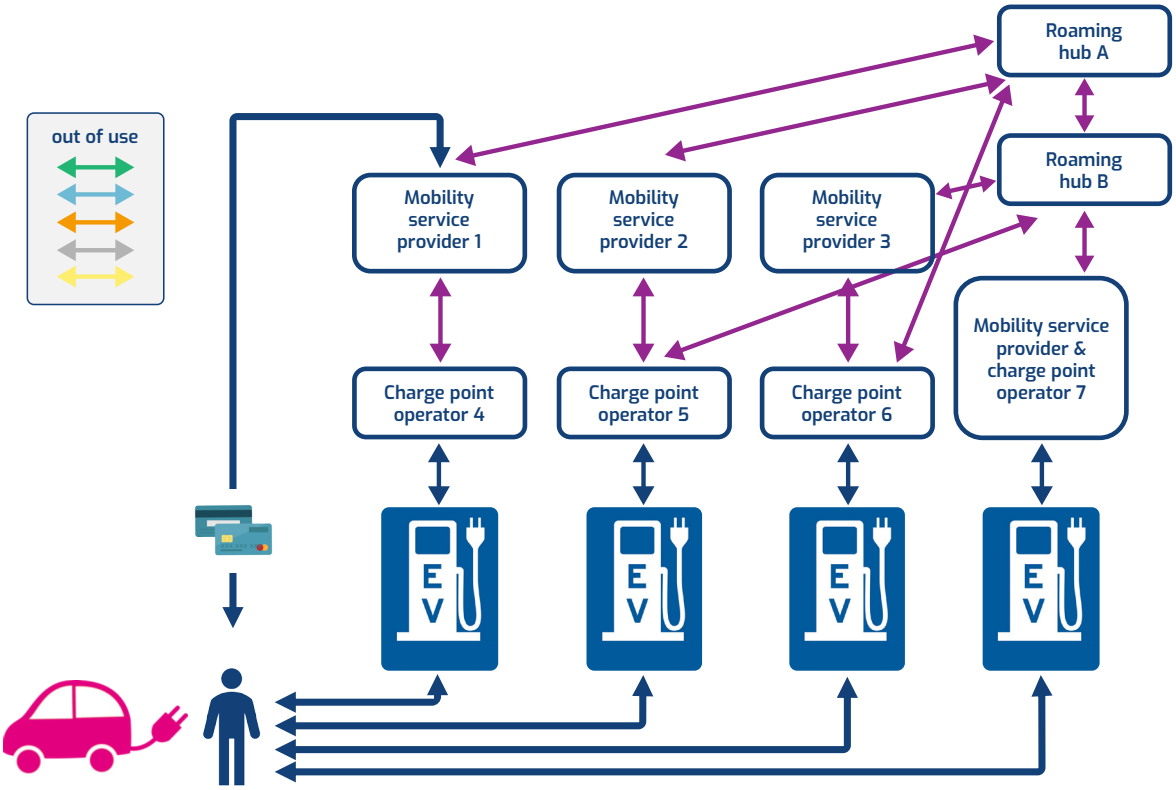

Figure 6. Scenario 5: IEC 63199 standard becomes dominant

4.5.2 Advantages and disadvantages

Most interviewees thought that on the long term, when the EV market has reached maturity, it is a good idea to have an internationally accepted standard protocol, which could be managed by a large SSO such as IEC. The major advantage would be that there is a single protocol to implement and maintain, which is thought to lead to a more efficient roaming system. Another perceived advantage is the international recognition that comes from such SSOs, and that countries can easily refer to such standards in their national legislation. (Note that the degree to which regulators can and do refer to technical standards in a binding way differs across nation states.)

Another advantage, expressed by one interviewee, is that an global organisation/ setting like IEC may be better equipped to consider and include market needs, preferences and context from countries all over the world, and provide all parties with better insights into where differences between countries/regions exist.
The perceived disadvantage is that the development will be slower, and it takes a lot of resources to be part of a working group and to participate in a meaningful way. One reason that development may be slow is the need to reach consensus, which is very difficult with parties from all over the world, which probably have their own view on how the EV market should work. With the EV market developing fast, slow development of communication protocols is not seen as desirable, since the protocols would not be able to timely facilitate new demands developing in the marketplace. This is why many interviewees thought it is too early for large SSOs to play a major role. One interviewee reached a different conclusion, stating that because international standardization processes go slowly, we should start these processes as soon as possible, so that by the time EVs are mainstream there is already a well-functioning and widely adopted roaming system in place. Though some interviewees recognize the latter point, they think this should be achieved in a different manner, with smaller management organizations. As a counterargument, one interviewee stated that one will never know when the EV market is mature, and that therefore developing a roaming protocol in a large SSO will never be a good idea. Despite holding this view, the interviewee thought that the involvement of large SSOs is unavoidable, but that next to these efforts other parties can continue to develop protocols independently, because the EV field benefits from the diversity of protocols.

Another concern that some interviewees mentioned is that the IEC 63119 working group is dominated by Chinese parties, and only a small number of parties from Europe and the USA are active in the discussions. One interviewee argued that the European protocol developers are too much focussed on competing against each other. This could become a problem, as China could dominate the standardization process, pushing their business model on the global e-mobility market. The Chinese e-mobility market is much more monopolistic and protectionist than the European market, and this is reflected in the views they bring into the IEC working group. Another interviewee argued that the protocol development process is too much dominated by European, Chinese, and Northern American parties, the rest of the world is not active and should be involved more.

An additional concern raised by one interviewee is that it is difficult to investigate how security is incorporated in standards from large SSOs. In this person's view, standards from large SSOs offer 'certificates for security, but not real security'.

4.5.3 Likelihood to become the dominant future scenario

This scenario becomes more likely if e-mobility moves to a globally integrated market. The interviewees differed in their perspectives on to what degree this will happen. Some interviewees thought that the way different countries organize their charging infrastructure is too different for global roaming to be realized.

Typically, these interviewees thought that there would be full roaming within large regions such as Europe and Asia, because most trips take place within such regions (and EV drivers typically do not take their own EV with them to another continent).

There was also a number of interviewees that did think e-mobility will be a globally integrated market. One interviewee said that an important driver for this are multinational corporations, who demand smooth roaming for their entire EV fleet. If this is indeed the case, the IEC protocol could be the most attractive protocol to base international roaming on, because it has a much better fit with the global e-mobility field than earlier developed standards. This could happen when the developers of existing protocol do not make a successful effort to include parties from all over the world in the development process.

4.6 Scenario 6: No roaming but ad hoc local payment instead

4.6.1 Description of scenario

This scenario describes the situation that that there is no interoperability via roaming protocols, but EV drivers instead access charge points through ad hoc payments. In this scenario, the market roles of MSP and roaming hub disappear, and EV drivers can access charge points and pay for charging sessions through means such as cash, debit card, credit card, or mobile apps. Current European legislation already requires ad hoc access at public charge points (but leaving it to member states how to implement this on the national scale) [1]. Figure 7 presents a scheme of this scenario.

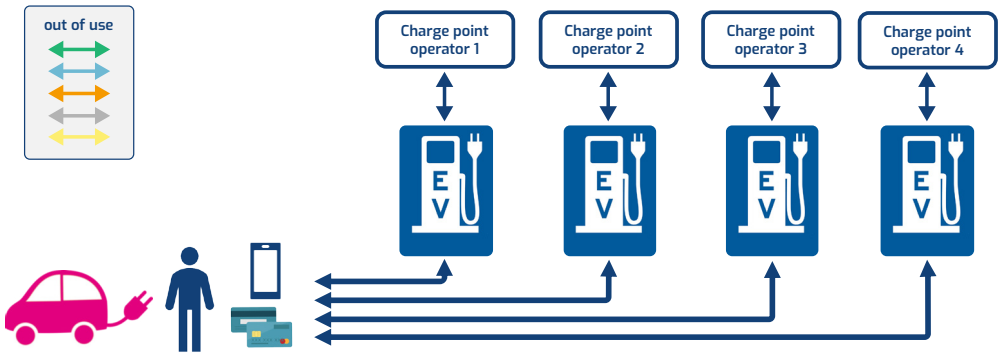

Figure 7 Scenario 6: No roaming (ad hoc local payment)

4.6.2 Advantages and disadvantages

Some interviewees were strong proponents of this scenario, because they see some major advantages for EV drivers. Reasons that were named were that ad hoc payments are closer to the current customer experience for gasoline distribution and many other markets, there are many possible payment platforms (debit card, credit card, PayPal, payment apps, etc.), and EV drivers will not be surprised by high roaming fees when the bill of the charging sessions arrives.

Most interviewees were opponents of ad hoc charging, or at least thought that it could not completely replace roaming, because they envision that EV charging will not work the same as fuelling a gasoline car. They argue that EV charging is all about services – planning where to charge, know about characteristics of the charge point, make a reservation for a session, and more. These services require authentication and can only be delivered via a roaming-like approach. Furthermore, there is a trend towards new forms of mobility, like mobility as a service, car sharing, leasing, etc. A system of ad-hoc payments, where the individual pays for the charging session, does not fit well in that pattern. Also with autonomous cars, roaming-based charging fits much better than ad-hoc payment charging, as autonomous cars are unlikely to include systems enabling ad-hoc payments.

Another disadvantage is that in this scenario, each charge location has to be equipped with a payment system and interface. This may place a considerable APEX and OPEX burden on the CPO. For a party operating a limited number of high-margin, fast DC charge points at highways this may not be an issue, but for CPOs that operate very large numbers of charging locations at in streets, in parking lots, campuses, at businesses, etc., these costs may be prohibitive, and roaming may be much more attractive.

4.6.3 Likelihood to become the dominant future scenario

One way this scenario could happen is if the costs for roaming (either via hubs or peer-2-peer) become too high, because not many EV users roam. If EV batteries become much larger, for instance, charging at home, work, or at one specific CPO only could suffice for most drivers. One interviewee did not see this as likely, because it is expected that even if EV users will roam relatively less than now, the total demand for roaming will increase because the market for EVs is expected to increase dramatically.

Several trends in mobility, such as mobility-as-a-service, car sharing, leasing, plug-and-charge, and autonomous driving, favour a roaming approach. Still, some interviewees thought that if cheap ad hoc payment systems win ground, for instance based on mobile phone apps, the market might still move to ad hoc payments as many consumers will prefer this option over roaming contracts.

Finally, it should be noted that charging session transaction in e-mobility are worth much more than transactions in telecommunications (which or often worth only a few Euro cents or Euros), and, even if EVs become mainstream, the number of transactions is much lower than in telecommunications, where mobile phone users create chargeable events every time an SMS is send, a phone call is made, or the Internet is accessed through the mobile connection. While roaming definitely makes sense for telecommunications as compared to ad hoc payments, it is not yet clear whether this is also the case for e-mobility.

5. Conclusions and discussion

The adoption of electrical vehicles (EV) is growing fast, but their battery capacity is by definition limited, creating a need for public charge facilities. These can come in a wide variation, ranging from public, fast DC charge stations along highways, to 'opportunity charging' in streets, parking lots, campuses, and businesses. Roaming services allow a user to pay for a charging session at a public charge point, and allow for additional services (such as locating such a charge point, or making a reservation for its use).

Currently, such roaming services are limited because multiple, incompatible protocols are in use between the Mobility Service Providers (MSPs), who offer roaming services, and Charge Point Operators (CPOs), who operate the actual charge points. As a result, a user can only use a limited number or charging points (or needs to obtain many different roaming services). Both policy makers and stakeholders agree that such obstacles hinder the adoption and use of EVs, thereby slowing the transition towards sustainable mobility. The desired situation is one of seamless roaming (or seamless interoperability), which means that a user (EV driver) can charge at any public charge station, regardless of which CPO operates that charge station and regardless of which MSP the user has selected for mobility services and payment.

The aim of our study was to investigate whether achieving seamless interoperability is feasible (and best done) via harmonization of the different existing protocols into an independent internationally accepted protocol. This report contains descriptions of several scenarios for how interoperability in EV roaming can be achieved. Currently, there are several communication protocols used for EV roaming. Based on a review of the standardisation literature and interviews with stakeholders we have identified six scenarios for how EV roaming could further develop.

Our results reveal that there is no commonly held view across the interviewees regarding the future of seamless EV roaming and the protocols that support it. This is partly because of (a) uncertainty regarding future behaviour of protocol adopters and developers (e.g. collaboration), and possible pressure (either from market parties or regulators) to move towards a single standard for roaming, and (b) uncertainty regarding external factors influencing the development of roaming (as discussed in Chapter 3).

In our report, we sketch a number of future scenarios. Amongst our interviewees, there was great variation on the likeliness of these scenarios, although Scenario 3 (a standards battle with winning protocol) was named most often as the most likely scenario, and Scenario 6 (no roaming at all) was least often named as likely. Note, however, that many of our interviewees are involved in offering roaming services, and their views might be influenced by this.

Another scenario that was often seen as most likely by our interviewees is Scenario 4 (where gateways connect different protocols). There is evidence that suggests Scenario 4 (where gateways connect different protocols) is a quite likely outcome, at least for the European market. There are several efforts to develop gateway technologies, as all the major roaming platforms have implemented multiple roaming protocols. Furthermore, while several MSPs/CPOs amongst our interviewees have implemented multiple roaming protocols (to connect to different roaming platforms or enable peer-to-peer connections), we do not know of any party that has actually completely switched protocols by stopping to use an already implemented protocol.

As mentioned above, there is also uncertainty regarding external trends in the EV market that influence the likeness of the scenarios (e.g. consumer preference, fast charging versus opportunity charging, centralized roaming or peer-2-peer, whether there will be consolidation, and which industries will have a strong market position). We can expect the situation to become clearer within the coming 5 years, when many interviewees expect the EV market to have become mature, at least in terms of the supply chain and the major parties active in the market (not in terms of annual EV sales). Specifically, we expect the consolidation phase to start (or not), see whether protocol developers move to cooperation or competition, new EU regulation, and the IEC protocol to be ready. On the longer term, developing consumer preferences as EVs become more mainstream, and new technologies such as blockchain could have a large impact on roaming.

Appendix A. Interview protocol

1. Roaming protocol development
Currently, there are several roaming protocols in use. We would like to discuss:

a. Your organizations' use of roaming protocols
b. Your awareness of the different roaming protocols
c. The technical and functional differences between the roaming protocols
d. Progress and challenges roaming protocol development
e. The role of regulation in roaming protocol development and innovation

2. Your current business model and support of existing charging protocols
We would like to discuss your organizations' business model and position in the value chain of EV charging. Here, we discuss charging protocols in the broad sense (i.e. not limited to roaming protocols). We would like to discuss:

a. Your business model and position in the value chain
b. How charging protocols you currently use support, but also hinder your business model

3. The future of your business model
E-mobility is relatively new and the field is developing rapidly. We would like to discuss:

a. The future business model of your organisation
b. New activities in the value chain
c. What functionalities charging protocols should have to facilitate these activities

4. Your view on the future of the public EV charging infrastructure
Related to the previous point, we would like to discuss your view on the future of the public EV charging infrastructure. We would like to discuss:

a. Trends in public EV charging infrastructure
b. Number of parties active in EV charging infrastructure in the future (many versus few firms with monopolistic tendencies)
c. Role of traditional automotive firms versus the role of new players and firms from sectors such as energy and ICT

5. Pathways to harmonization
There are several scenarios for achieving full roaming functionality between all public charge points worldwide. We can think of a scenario in which existing roaming protocols merge in one single standard and a scenario in which gateway technologies are used to achieve interoperability. Gateway technologies are systems that interface with two or more different protocols to the best degree possible. We would like to discuss:

a. Importance of achieving interoperability
b. Likeliness of both scenarios
c. Whether another scenario is likely

d. Advantages and disadvantages of the scenarios
e. Main lessons from sectors such as telecommunication, the Internet and banking in achieving a standard for roaming
f. Applying these lessons to e-mobility

6. Involvement in roaming protocol development

Currently several efforts are undertaken to set up organizations for the development and management of roaming protocols. We can also imagine a future in which such responsibilities are transferred to large standard setting organisations such as ISO, IEC, IEEE, or CEN/CENELEC. We would like to discuss:

a. Desirability of such efforts
b. Your interest in being involved in further developing these protocols and in what manner

Appendix B. List of interviewees

Table 8. List of interviewees. Eight interviewees participated under the condition of anonymity and are not presented in the list.

Interviewee	Organisation	Country
Michel Bayings	eMobility consulting	Netherlands
Gilles Bernard	AFIREV	France
Alfred Böhm	Stromquelle Energietechnik GmbH	Austria
Nuno Maria Bonneville	MOBI-E	Portugal
Diego García Carvajal	European Copper Institute	Spain
Onno Ceelen	EVBox	Netherlands
André Martins Dias	CEIIA	Portugal
Moritz Dickehage	Smartlab GmbH	Germany
Lonneke Driessen	ElaadNL	Netherlands
Roland Ferwerda	NKL	Netherlands
Christian Hahn	Hubject	Germany
Doris Holler-Bruckner	Austrian Sustainable Mobility Association	Austria
Daniel Kulin	Power Circle	Sweden
Kor Meelker	Allego	Netherlands
Freerik Meeuwes	EVBox	Netherlands
Anas Munir	Smartlab GmbH	Germany
Eric Munneke	Eco-movement	Netherlands
Fredrik Nordin	Bee Charging Solutions	Sweden
Christian Peter	Electro-Mobility Club	Austria
Arne Richters	Allego	Netherlands
Stephan Riechel	ENBW	Germany
Jean-Marc Rives	GIREVE	France
Maxime Roux	Freshmile	France
Ernesto Ruge	Giro-e	Germany
Martijn Santbergen	Vattenfall	Netherlands
Tobias Schneider	Innogy	Germany
Dietrich Sümmermann	Share and Charge	Germany
Kai Weber	Bosch	Germany
Ewoud Werkman	TNO	Netherlands
Kristian Winge	Sycada	Netherlands

Appendix C. Interview protocol for telecommunications expert

1. *How is roaming exactly arranged in mobile telecommunications?*
   a. Does everyone use the same technical protocols (GSMA's TAP3 Transferred Account Procedure)? Or are other protocols also used?
   b. How many roaming hubs / clearing houses are there, and are there significant differences in what they do / what they offer?
   c. What is the respective role of bilateral roaming vs roaming hubs/clearing houses? (In terms of volume, number of agreements, etc.)
   d. From an operator view, what determines the choice for bilateral roaming vs roaming hubs/clearing houses?

2. How did the roaming infrastructure develop? What it always clear that GSMA would develop the protocols? Were there other options conceived?

3. What can we possibly learn from mobile telecommunications roaming for the desire to create seamless roaming for charging Electric Vehicles (EV)?

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