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Architectural description of ERS: Analyzing implications of short and long electric road segments

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Summary

A common architecture is important when there are many different stakeholders involved to facilitate the management of a complex system-of-systems such as Electric Road System (ERS). While ERS has gained recognition as a technological solution, few studies address the necessary system from a holistic perspective. This work addresses the gap by presenting an architecture of a complete ERS. To achieve this, use cases covering many aspects of the electric road were created. The interface between the stakeholders in those use cases were analysed and the activities were broken down. The aim of this paper is to create a common architecture to clarify the interfaces of ERS and to enable interoperability through standardization. The architecture is then used to analyse implications for measuring energy consumption with regard to different electric road segment lengths.

1 Research Questions

In order to approach the field of system architecture scientifically, it is necessary to define the terminology as precisely as possible, and we will therefore introduce definitions of some key concepts. System is defined by Rechtin and Maier [1] as a set of different elements so connected as to perform a unique function not performable by the elements alone. Architecture is the fundamental organization of a system embodied in its components, their relationships to each other, and to the environment, and the principles guiding its design and evolution. Last but not least a system of systems (SoS) consists of multiple, heterogeneous, operationally, distributed, occasionally independently, operating systems embedded in networks at multiple levels that evolve over time, which is all true for an open ERS

The aim of this study is to present an architecture of ERS that can be used to analyse critical usage cases and create standardized protocols that are necessary to facilitate a large-scale deployment of ERS. The following research questions are addressed;

How can the interfaces of an ERS be described?

How can critical aspects of ERS usage cases be described and analysed?

What challenges does the different ERS technologies give raise to when it comes to managing ERS operations?

2 Methodology

The architecture description has been created based on available published system design of ERS and a series of stakeholder workshops [3]. The architecture was modelled using the Systems Modelling Language tool

(SysML) which is developed for the systems engineering domain and applied to analyse cases within the defence and telecom industries. SysML is based on the Unified Architecture Framework (UAF) which can capture concepts within an enterprise and therefore covers strategic and operational considerations, services, resources, important actors, enterprise phases, capabilities, requirements and as well as standards used or to be used. By using this methodology for creating an ERS architecture, stakeholders could focus on specific usage cases without losing sight of the wider system perspective.

3 Results

Electric road interfaces

The development of a common architecture is important to capture the internal structure of ERS interfaces and the stakeholder relationships. Figure 1 describes the architectural description of possible intended usages of the system stakeholders and its properties and also defines the communication between the stakeholders. Figure 2 describes the relationships between all logical elements. These ERS figures are rather complex to describe and interpret in this document, but functions as the basis for further analysis.

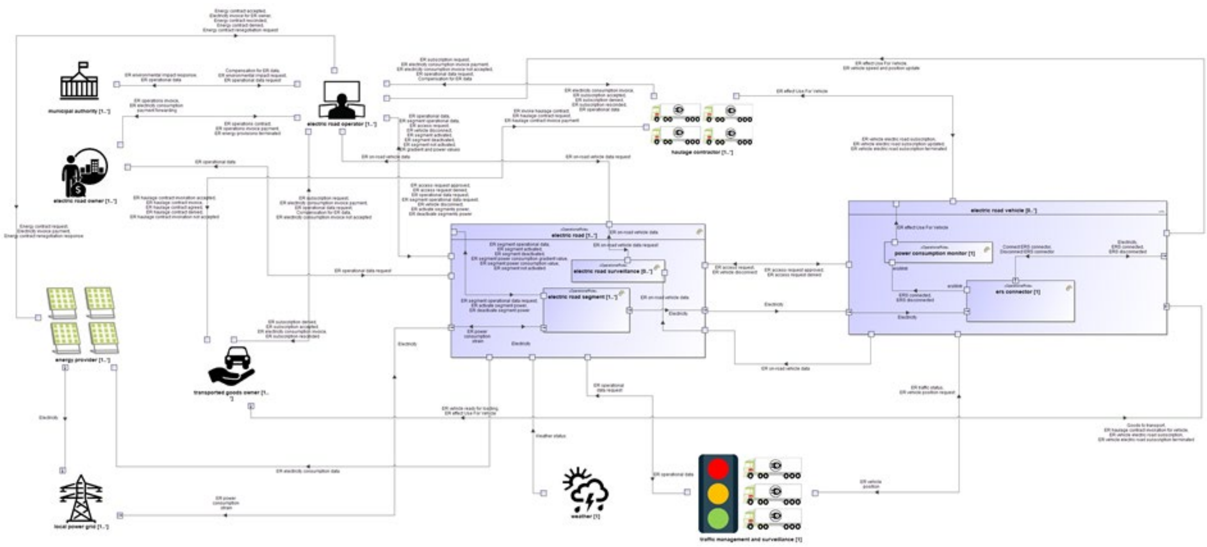

Figure 1- Architectural description of Electric Road Usage

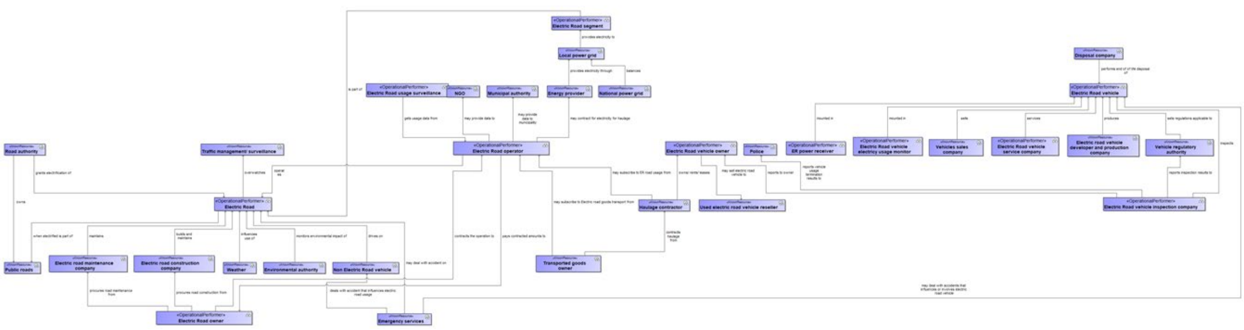

Figure 2 - Relationship between all logical elements

Electric road usage

An important underlying activity to analyse electric road usage is the Power Consumption Monitoring activity that is described in Figure 3. The electric road usage is derived from Figure 1 and focuses on the connection of vehicles to the electric road, the usage during the ongoing connection and lastly the disconnection from the electric road system. The signal for access approval to the electric road must be received before the monitor can engage in metering activities. The start metering parameter is an on-off switch to start recording the effect usage during the period when the metering is switched on. When it is turned off the total effect use is sent to requested outer activity.

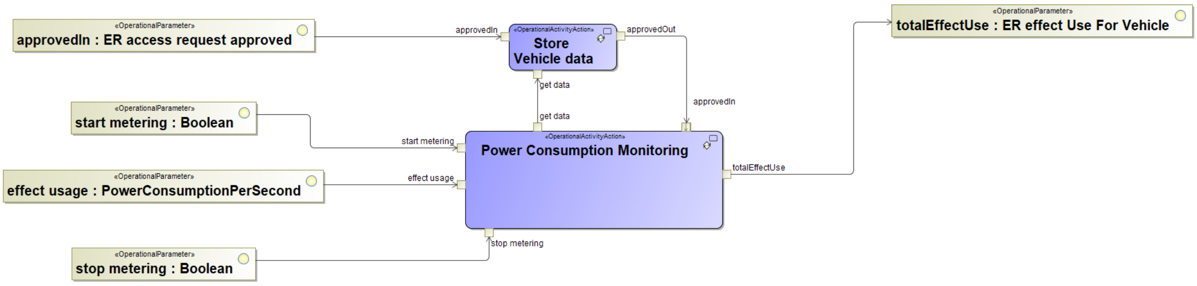

Figure 3 - Power Consumption Monitoring activity

To enable the connection to the electric road, a sequence of events is needed starting with the electric road vehicle requesting for access for the usage of the electric road. This must be approved by the electric road operator and if the request is denied the whole process will end there. If the request is accepted the operator will then activate the segments, one at a time, which the approved electric road vehicle will drive on.

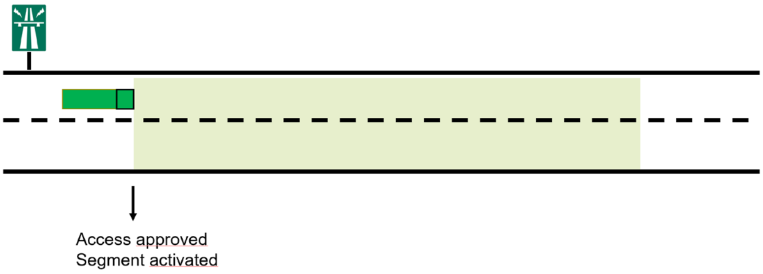

Figure 4 – ER connection start

The electric road vehicle will then connect to the ER power receiver to receive power in the form of electricity. The power consumption monitor will thus start logging the power consumption for invoice and monitoring purposes.

Challenges for short segments

At highway speed if a segment is 20 meters in length or less, it seems unlikely that more than one electric road vehicle could make use of an individual segment. The main challenge for short segments is that the segments depending on their length they need to be activated in advance as the electric road vehicle progresses through the electric road segments. The handling of this is highly dependent on the length of the segments. An electric road vehicle travelling at 36 km/h will pass 10 meters in one second. 72 km/h means 20 meters in one second and 108 km/h means 30 meters. How quickly segments can be activated or deactivated will also matter in determining how long in advance segments will need to be activated to prepare for the arrival of an electric road vehicle.

It is assumed that the vehicle can periodically transmit its speed and position to the electric road operator, making it possible for the operator to determine how fast the electric road vehicle is progressing though the segments and then deactivate or activate segments in advance to make the transition between segments easy. Obviously, if there are several vehicles present on the road, the activation and deactivation segments may overlap and this need to be considered, i.e. a segment cannot be deactivated if another electric road vehicle is already using it.

Another assumption is also made use of here, namely that the segments automatically should report to the Electric road operator regarding current power consumption as well as power consumption gradients. If this is done, the position as well as speed information can be correlated by the electric road operator with the segment power consumption for further verification.

Challenges for long segments

In cases where the segment is much longer, assuming for example 1 km, there will be multiple vehicles on each single segment. The sequence of activities is then not as complicated.

The disconnection process also starts with a request from the electric road vehicle. After a successful disconnection the vehicle must nevertheless be reported and keep the operator informed. The main reason is to stop the logging of the power consumption. For transparency reasons the summarized data is then sent to four interested parties.

To avoid, deter and punish unauthorized use of the ERS, it is important to understand the behaviour surrounding the connection process to the ERS. For unauthorized usage to be detected and dealt with, the following scenario needs to be managed. The segment lengths are such that more than one electric road vehicle can make use of each segment. Figure 5 illustrates a use case where a unauthorized usage is enabled because the authorized electric road vehicles is present or that the activation sequence has activated segments in anticipation of the arrival of the authorized electric road vehicle.

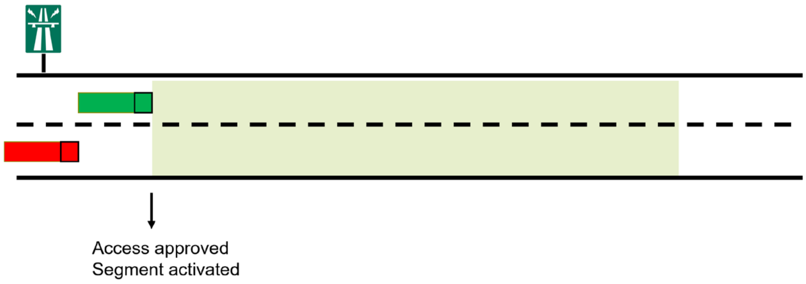

Figure 5 Possible scenario for unauthorized use

Figure 6 shows a usage case of ongoing unauthorized use on the ERS. Given the long electric road segments, unauthorized use can commence without being detected.

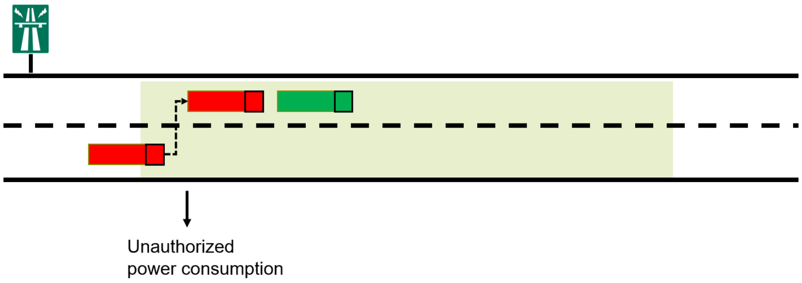

Figure 6 Ongoing unauthorized use on the ERS

In Figure 7, based on the received information from the electric road concerning segment power consumption as well as perceived gradients (changes in the consumption taken together with information concerning the subscription from the allowed access as well as the position and velocity information that the allowed access transmits to the operator), it should be possible to detect that an unauthorized access exists.

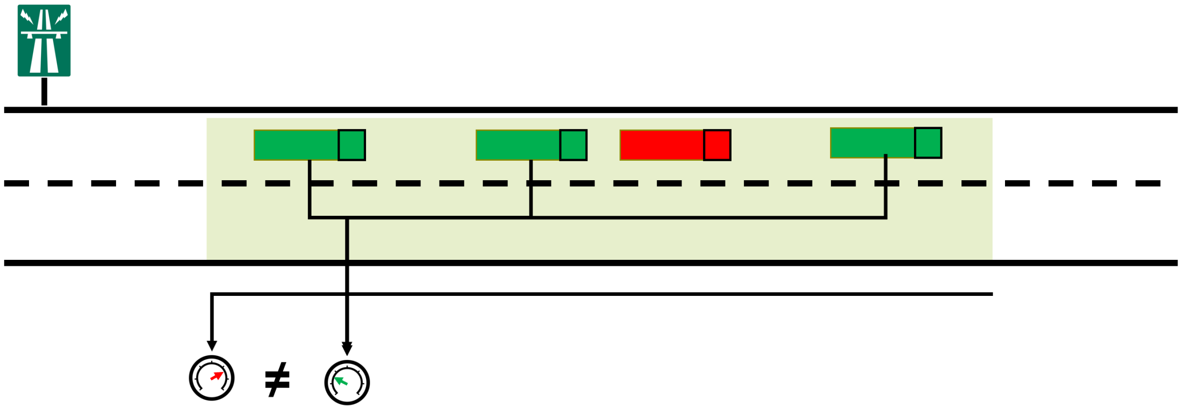

Figure 7 – Unauthorized usage detected due to changes in the perceived power gradients

Based on the data of where the unauthorized access is occurring or has occurred, the addition of ER surveillance equipment can be tasked with taking photos of the unauthorized access, see figure 8. To identify the unauthorized vehicle, there must be surveillance of a large portion of the segment. The positioning of the surveillance equipment should be strategically placed along the electric road to account for possible places where the unauthorized access can get off the road. Alternative surveillance solutions to could be the use of drones or patrol cars.

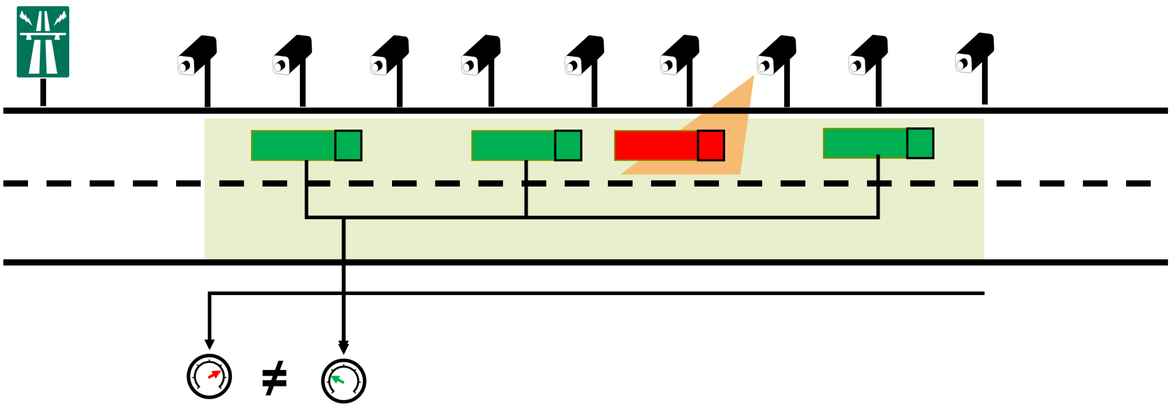

Figure 8: Unauthorized usage detected and identified

4 Conclusions

This work has proposed a systematic way of describing the interfaces ERS and the relationships between stakeholders. This description has then been used to describe critical usage case of electric road operations. Also, the main challenges for measuring energy consumption have been identified, based on different electric road segment lengths.

A conclusion is that for shorter segments, the main challenge is to cope with timing issues as well as the high number of switches needed between segments. For longer segments, the challenge is instead to identify possible unauthorized usage which could lead to lack of payment, but also more serious risk of damage of the infrastructure due to un-certified and checked power receivers.

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Stefan Tongur is Senior Researcher at RISE Viktoria and interested in socio-technical transitions and business models. He defined the concept of electric road systems (ERS) in 2010 and has continued to study the development of ERS since then. He is published in e.g. Technovation, Environmental innovation and societal transition, and IEEE conference on Energy, power, and transportation. In 2018, Stefan defended his PhD thesis entitled "Preparing for takeoff – Analyzing the development of electric road system from a business model perspective" at KTH Royal Institute of Technology.