Standardization of Edge Communication and Protocols

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***Abstract*— The concepts of "Smart Manufacturing" significantly affect the manufacturing industries as well as the design of the Industrial Internet of Things, requiring standardization of communication technologies and protocols applied in that context. An emerging architectural concept is the so called "Edge" and its associated components and applications. The edge computing paradigm requires standardization of protocols to enable vendor interoperability between the different involved products and across the architectural layers. The current results of the "Labs Network Industrie 4.0" pre-standardization testbed will be presented in this paper and a brief overview given on further organizations working on the standardization of implementations in the edge context.**

Keywords— Automation, Edge, Factory, Gateway, IT, OT, IoT, IIoT, Industrie 4.0, OPC UA, REST

I. Introduction

The concepts of the "Industrial Internet of Things (IIoT)" and "Smart Manufacturing", respectively "Industrie 4.0", are transforming the way data is being handled, processed, and delivered. The topic of IT/OT convergence [1][2][3] has emerged in this context, providing the concept of *Edge Computing* as one required paradigm, a networking philosophy focused on placing computing capability as close to the source of data as needed, in order to reduce transmission latency and bandwidth use, besides other advantages. One initial motivation for the edge computing paradigm was the reduction of operational costs by minimizing the amount of data that needs to be transmitted and processed in a centralized or cloud-based location and to provide some decentralized "offline capability". Beside ensuring the controllability and stability of the overall system, further motivational subject was the possibility of enabling new business models through distributed data-based applications on shared hardware (e.g. see the European GAIA-X project with its regulatory framework initiatives [4]). Because of the growth of IIoT generated data, the rise of real-time applications that need processing at the edge will drive the technology further.

Since the edge computing brings computation and data storage closer to the field devices where the data is generated, real-time related latency issues can be mitigated that otherwise might affect the application performance. An *Edge Gateway*, for example, can process data from a field device and then send only the relevant data back through the cloud, reducing bandwidth needs. In case of real-time application needs it can send data directly back to the edge device.

To support activities in this regard, the pre-competitive and non-profit German association "Labs Network Industrie 4.0 e.V." (LNI 4.0) [5] established the testbed "Edge Configuration" in 2018. The LNI 4.0 was founded in 2015 together with the German Plattform Industrie 4.0 and the Standardization Council Industrie 4.0 (SCI 4.0) [6], which is carried out jointly by DIN [7] and DKE [8] to support Industrie 4.0 standardization activities. LNI 4.0 was established by an alliance of major companies, industry associations, policymakers and researchers. The goal of LNI 4.0 is to support the pioneering work of small and medium enterprises (SME) in the area of digitalization of industrial production. LNI 4.0 acts as a competence and experimentation platform for these stakeholders.

The target of the testbed is to prepare the standardization in the context of manufacturing industry with respect to the emerging edge computing technology. The testbed focuses on the *Edge Configuration*, thus the configuration of the interaction between the edge and the edge management layer. Currently a suitable standard for this focus does not exist. The testbed will develop proposals for this aspect in the form of functional primitives including parameter sets (functional view), which afterwards must be implemented (implementation view). For this purpose concepts are developed, practically implemented and validated. The results and experiences will be made available to the standardization activities to feed them into the further or new development of standards.

The outline of the paper is as follows: Section II gives an overview on related activities in other organizations than LNI 4.0, whereas Section III presents the basic architecture definitions and Section IV explains the stakeholder viewpoints. Section V points to the anticipated functional view and Section VI points to implementation definitions on the protocol level. Finally, Section VII concludes this contribution.

II. RELATED WORK

The relevance of the subject becomes immediately visible by the range of recently emerged organizations that are dealing with the definition and implementation of edge infrastructure solutions, usually initiated by product vendors or solution providers with a focus on the implementation level. Nevertheless, high-level concepts are in most cases developed first and subsequently detailed in a top-down approach. Examples of these organizations are the association *Open Industry 4.0 Alliance (OI40A)* [9] with a focus on the European industrial automation market, the Chinese-based *Edge Computing Consortium (ECC)* [10], the *European Edge Computing Consortium (EECC)* [11], the US-based *Open Edge Computing Initiative (OECI)* [12], the *Industrial Internet Consortium (IIC)* [13] or the Japanese based *Edgecross Consortium* [14], as well as the Korean Electronics Technology Institute (KETI) IoT Edge Platform [15]. Even an *Automotive Edge Computing Consortium* [16] has been founded, dealing with the problem of big data from connected cars. In [17] the authors have even identified 75 edge computing related activities. Enterprise-oriented activities like Siemens' *Industrial Edge* [18,19] also play a significant role in shaping the landscape. A few of these activities will be presented in further detail below.

A. Industrial Internet Consortium

The Industrial Internet Consortium and the OpenFog Consortium recently combined their activities and claimed to become the largest and most influential international consortia in Industrial IoT (IIoT), fog and edge computing [20][21]. Figure 1 illustrates multiple examples of edge computing implementations based on differing business points of view. The examples progress from left to right as the edge layer becomes more complex and aggregates multiple system functions below. The computing layer moves up the architecture stack, aggregating processing capabilities, information and data from below.

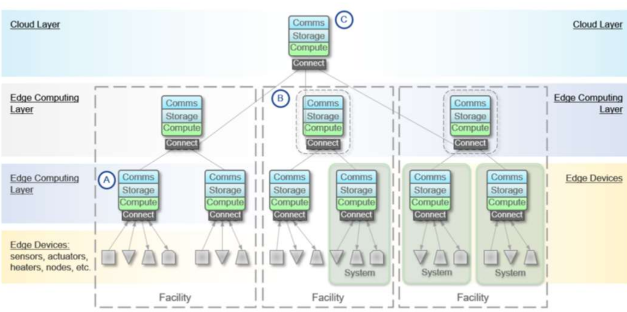

Fig. 1. Edge computing topology according to IIC [22]

B. European Edge Computing Consortium

The EECC started in 2018 and its mission is to build an international end-to-end Edge Computing ecosystem by streamlining preferred standards and thereby minimizing the number of potential technology combinations. The focus lies on the edge towards IT infrastructure for the manufacturing and other IIoT domains. Goals of this initiative include the specification of a Reference Architecture Model for Edge Computing (RAMEC), the development of reference technology stacks (ECCE Edge Nodes), the identification of gaps and recommendation of best practices by evaluating approaches within multiple scenarios (ECCE Pathfinder Projects), and the synchronization with related initiatives/standardization organizations and the promotion of the results. As shown in Fig. 2, the RAMEC model [17] adopts concepts of the Smart Grid Architecture Model (SGAM) and the Reference Architecture Model Industrie 4.0 (RAMI) [23] to describe the overall problem space the edge computing paradigm spans.

Fig. 2. ECCE adaption of the SGAM/RAMI concepts for Edge Computing

C. Open Industry 4.0 Alliance

The OI40A association was started in 2019 and aims at creating customer value by promoting holistically developed, interoperable Industry 4.0 solutions and services with a strong focus on the automation industry covering both the OT and IT domain. To achieve this, a common framework is both developed and powered by a group of industry leaders.

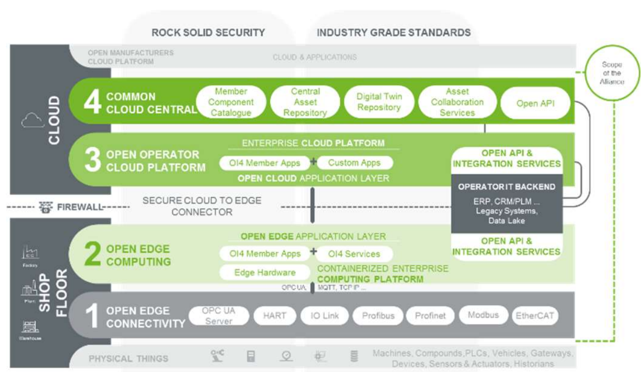

Fig. 3. Architectural framework of the OIA40 (reproduction)

D. Korean Electronics Technology Institute

The KETI Smart Factory IoT Edge Platform improves the manufacturing order fulfillment by enabling flexible capacity management and effective resource and equipment sharing. The technologies for factory-to-factory information technology (IT) and operational technology (OT) integration are utilizing edge IoT architectures based on OPC-UA, AutomationML, etc. The electronics equipment interoperability using the edge for the use case of manufacturing data analysis is of major interest.

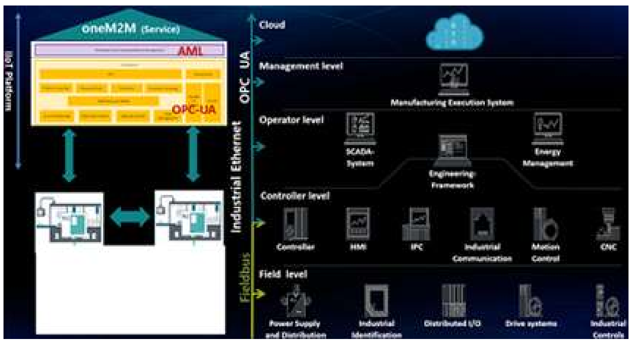

Fig. 4. KETI Smart Factory IoT Edge Platform

E. Siemens Industrial Edge

Industrial Edge offered by Siemens brings IT to the shop floor in an easy, flexible and secure way [18]. Figure 5 shows the overall concept consisting of an edge management, which provides a central infrastructure to manage edge devices, edge apps, which are software applications for intelligent data use, and edge devices, which build the secure, future-proof basis for running industrial edge applications.

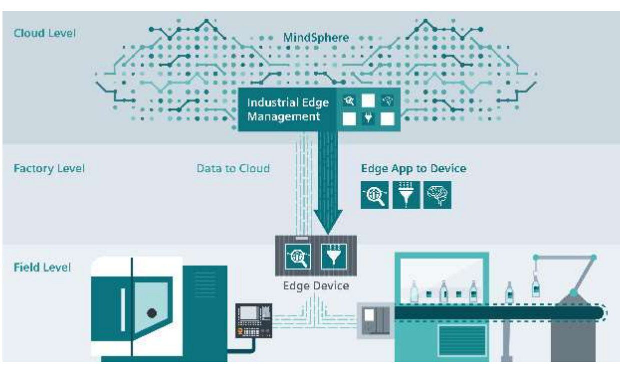

Fig. 5. Concept overview of Siemens Industrial Edge [19]

F. Summary

The main focus of the LNI 4.0 testbed's approach compared to the approaches described above is the ambition towards normative standardization and cross-vendor interoperability regarding *edge configuration*, which is seen as crucial for making the overall approach more sustainable and thus feasible for broad offerings and applications.

III. Architectural Context

From an architectural viewpoint, the work of the LNI 4.0 testbed *Edge Configuration* is based on a layered architecture as shown in Figure 6.

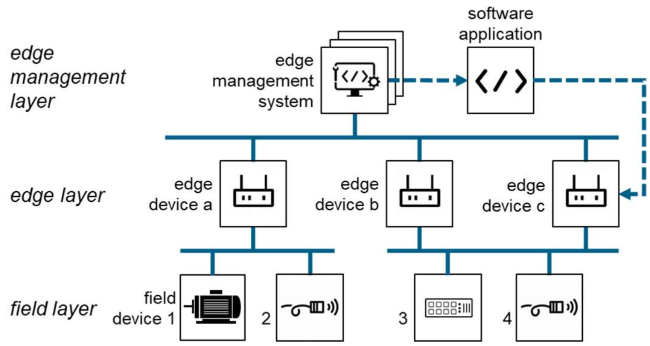

Fig. 6. Architectural context [24]

The following basic system entities have been identified:

A. Field device

Field devices are physical computing resources with often deterministic communication capabilities. Field devices communicate with edge devices, can be configured via parameters and the firmware of a field device can be updated. Field devices do not support the deployment of applications.

B. Edge device

Edge devices are physical computing resources with capabilities for communication and edge runtimes to be deployed on the edge device. Edge devices also can be configured by parameters and the firmware of edge devices can be updated. Edge devices can be connected to field devices and for each connected field device there is a data endpoint representing the communication capabilities between field and edge device. This data endpoint can be configured by an edge management system.

C. Edge management system

An edge management system is a software program deployed on an IT infrastructure. An edge management system can provide configuration capabilities for field devices and edge devices, an *application store* for providing software applications, edge runtimes and firmware, and configuration and deployment capabilities, which are provided via the application store of the edge management system.

D. Software application

Software applications are executable software-programs, which can be deployed, executed and configured on an edge runtime or an IT infrastructure. The software-programs are provided via the application store of an edge management system. These software applications are usually utilizing the information from connected field devices i.e. for data analysis. Basic applications for generic usage may be for example Asset Management [25] and System Monitoring [26].

IV. STAKEHOLDER VIEWPOINTS

The Industrial Internet Reference Architecture [20] defines a reference model of stakeholder concerns related to the technical IIoT system, called *viewpoints*.

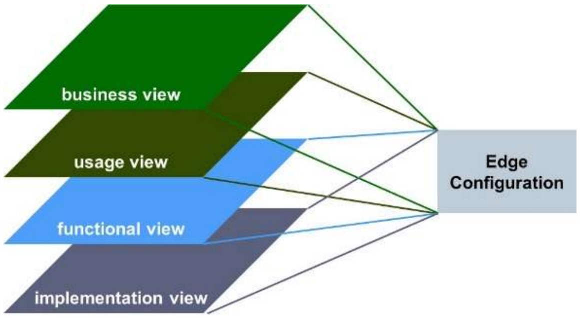

Fig. 7. Methodological classification according to IIRA [20][24][27]

This methodology is also applied by the LNI 4.0 testbed. A viewpoint is framing the description and analysis of specific system concerns. Based on this, various concepts (in Figure 7 called a functional view) and solution approaches (in Figure 7 called an implementation view) are currently discussed and developed within the LNI 4.0 testbed *Edge Configuration* working group.

Specific requirements were provided by the testbed partner companies with focus to the topic edge configuration [24], describing the business concerns of various companies and market stakeholders like users and operators. Most of these came from SME businesses, which are highly relevant in the automation domain.

A. BUSINESS VIEW

The business viewpoint attends to the concerns of establishing an IIoT system in a business and regulatory context and identifies the requirements how the IIoT system should support the business objectives through fundamental system capabilities. The following business stakeholders and their concerns have been identified (details being presented in [24]):

- **Component Supplier**: This is typically a manufacturing company offering components like drives, sensors, actuators, control or connectivity equipment to a machine supplier (or system integrator) to be integrated in a machine (or factory). Typically, the component supplier receives a one-time payment for the delivery of the component.

- **Data-based Service Provider**: This is typically a stakeholder which provides value-added services based on data. Typically, the Data-based Service Provider receives a one-time or consumption based (pay-per-use) payment for the usage from one of the other stakeholders.

- **Machine Supplier**: This is typically a manufacturing company offering machines like robots, tool machines or conveyor systems to a system integrator to be integrated in a factory. Typically, the machine supplier receives a one-time payment for the delivery of the machine from the machine user.

- **System Integrator**: This is typically a service company offering system integration services according to the specific needs of a machine user. This includes integration of physical systems as well as software application development and integration services. The system integrator is paid for the integration service by the machine user.

- **Machine User**: This is typically a manufacturing company operating a factory who pays for the physical components and systems integrated in the factory and the system integration services.

- **Edge Infrastructure Provider:** This business role will be typically assumed by a company offering edge devices including an edge runtime system. They are delivered either to a Machine Supplier to be integrated in a machine or to a System Integrator to be integrated in a factory. Typically, the Edge Infrastructure Provider receives a one-time payment for the delivery of an edge infrastructure.

- **Edge Management Provider:** This is a new business role, which offers a so-called edge management system. The Edge Management Provider will be paid for the usage of the edge management system, where different revenue mechanisms are conceivable, for example pay-per-use.

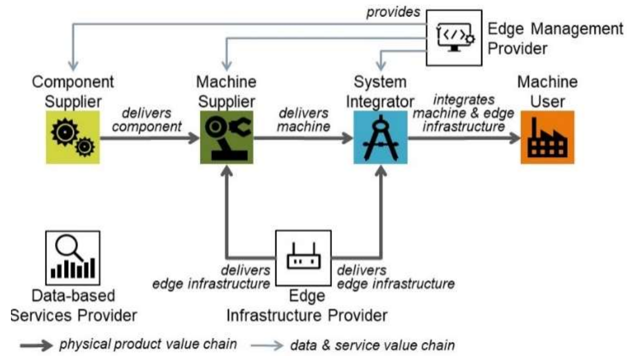

Fig. 8. Overall value network in manufacturing industries

A typical example of a more detailed business case is the following:

A drive manufacturer (component supplier) offers complementary data-driven services for his products and publishes the related software applications to different "application stores" (see Figure 8), utilizing capabilities like user management, payment handling and life-cycle-management of these application stores.

The targeted customers (machine builder, plant operator) access the offered applications through the store and utilize their edge management system for initial provisioning and configuration to the edge runtime. Since they have to integrate a variety of different components and applications within their machine or plant floor, they require an edge device and edge runtime that can support these heterogeneous components and applications.

Both the drive manufacturer and machine builder are paying for the capabilities of the application stores and edge management system. The drive manufacturer receives a service fee (e.g. pay per use) by the machine builder or plant operator. The machine builder and plant operator benefit from the increased value when using the application.

This business case is common for small and mid-sized enterprises that want to focus on their core competencies and do not want to develop an own edge device, edge runtime or edge management system.

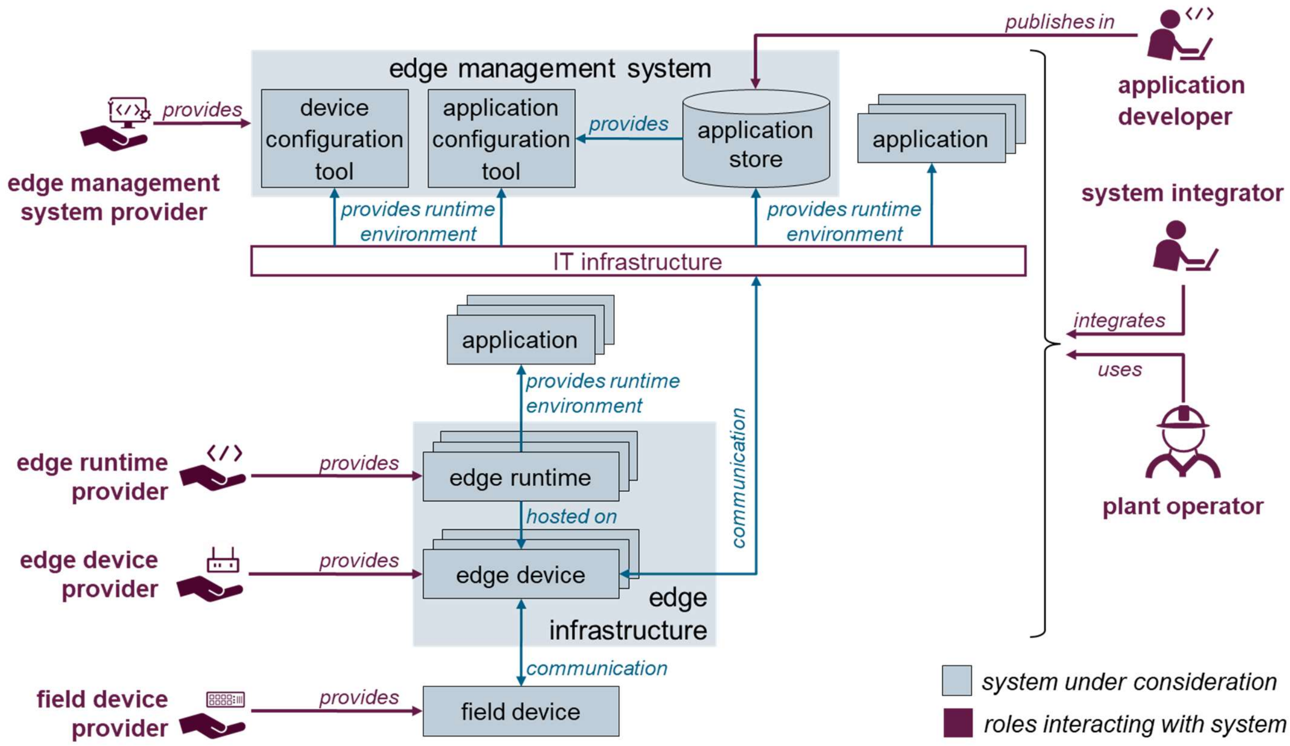

Fig. 9. Roles within the system

B. USAGE VIEW

The usage viewpoint addresses the concerns of the expected system usage. It is typically represented as sequences of activities involving human or logical (e.g. system or system components) users that deliver its intended functionality in ultimately achieving its fundamental system capabilities.

The stakeholders of these concerns are depicted in Figure 9, typically consisting for example of system engineers, product managers or developer as well as the logical user IT infrastructure who are involved in the usage of the considered IIoT system (details being presented in [27]).

1) System under Consideration

The System under Considerations is structured in three architectural layers according to Figure 6. The field layer consists of field devices, the edge layer consists of edge devices, where each edge may provide various edge runtimes for execution of applications, and the edge management layer consists of applications running on the IT infrastructure and the edge management system consisting of a configuration tool for configuring the various devices, an application configuration tool for configuring and deploying applications, and an application store for providing applications.

2) Roles

• **Field device provider**: The field device provider is an organization, which develops, manufactures and finally provides physical field devices and associated technical systems. As the vendor of one or more field devices, the device manufacturer is primarily interested in marketing the field device. In addition, the field device provider is interested in information on the usage of the field device to identify potential for optimizing the design and functionality of the field device. The field device provider provides the actual firmware for the field device and it is in the responsibility of the user of a field device to install it.

• **Edge device provider**: The edge device provider is an organization which develops, manufactures and finally provides physical edge devices and associated technical systems. The device manufacturer as vendor of such devices is concerned with the usability and capabilities of the edge device and the hosting capabilities of different edge runtimes. To increase interoperability of automation devices, the edge device provider has a high interest in using and setting standards for field device onboarding and management as well as edge runtime deployment. The edge device provider provides the actual firmware version for the edge device and it is in the responsibility of the user of an edge device to install it.

• **Edge runtime provider**: The edge runtime provider is mainly a software development organization providing an edge runtime, which can be deployed on an edge device. The edge runtime provider is interested in providing a system software application that can be easily deployed and managed on edge devices.

• **Edge management system provider**: The edge management system provider is mainly a software development organization providing an edge management system running on some IT infrastructure. The edge management system provider is interested in providing a software application for edge management to easily manage configurations of edge and field devices as well as deployed applications.

• **Application developer**: The application developer is a human actor providing an application, which can be deployed and executed on edge runtime on a edge device or the IT infrastructure. There may be applications, which are provided by an edge runtime provider or even edge device provider. The application developer must provide his ap-plications via the application store provided by an edge management system.

• **Plant operator and system integrator**: While the prior roles are primarily organizations concerned with providing the different products and solutions that constitute the system under consideration, the roles of plant operator and system integrator are the roles that acquire these products to operate and utilize them. The plant operator and system integrator are interested in minimizing efforts for different tasks, i.e. operation and adaptation of a plant (plant operator) and engineering and commissioning (system integrator). It is distinguished between these two roles because there are more technical skills required from a system integrator for installation and commissioning and "only" application specific configuration skills from a plant operator.

• **IT infrastructure**: The IT infrastructure is a technical system, provided and operated by some IT infrastructure operator. The IT infrastructure has capabilities to explore connected edge devices; this includes automatic detection including connection and disconnection of edge devices. In the case of mobile edge devices, this relates to automatic detection as soon as such a mobile device is in the "reach" of the IT infrastructure or leaves it again; this also includes a status monitoring to what extent an edge device is still "alive" or can be reached.

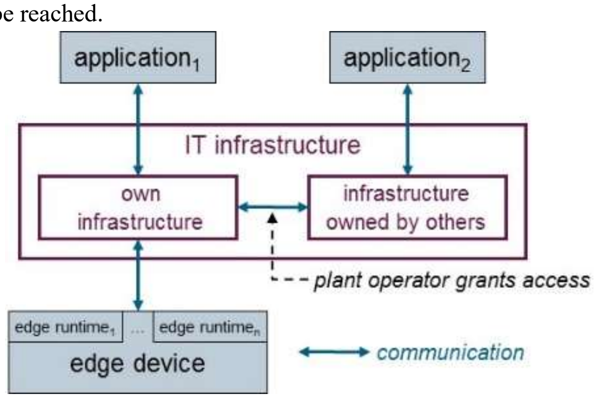

Fig. 10. IT infrastructure ownership problem

From a logical point of view, the IT infrastructure is divided into an area that is owned by the plant operator, who operates the field devices and edge devices, and an area that is not owned by him, see Figure 5. If applications are deployed on the foreign owned area and require access to applications deployed on the own area or on one of his edge devices, he must grant the access in order for the applications to work properly.

3) *Activities*

The following table lists the identified technical activities between system and roles that need to be further specified in the functional view (defining functional primitives) and implementation view (defining actual protocols).

TABLE I - ACTIVITIES AND ROLES

Activity	**Triggered by role**
Provision of entities	
Provision of a field device	Field device provider
Provision of an edge device	Edge device provider
Provision/Update/Discontinuation of an edge runtime	Edge runtime provider
Provision/Update/Discontinuation of an edge management system	Edge management system provider
Provision/Update/Discontinuation of an application (to the application store)	Application developer
Provision of a firmware update	Field device provider or Edge device provider
Adding entities	
Adding a field device	Field device provider or Edge device provider
Adding an edge device	System integrator
Adding an edge runtime	System integrator
Adding an edge management system	System integrator
Removing entities	
Removing an edge management system	System integrator
Removing an edge runtime	System integrator
Removing an edge device	System integrator
Removing a field device	System integrator
Setting up operational configurations	
Deploying am application	Plant operator
Updating a deployed application	Plant operator
Uninstalling a deployed application	Plant operator
Configuration of data provisioning and consumption	Plant operator
Update edge management system	Plant operator
Update edge runtime	Plant operator
Update firmware	System integrator or Plant operator

V. Functional View

The functional viewpoint focuses on the functional components in an IIoT system, their structure and interrelation, the interfaces and interactions between them, and the relation and interactions of the system with external elements in the environment, to support the usages and activities of the overall system.

These concerns are of particular interest to system and component architects, developers and integrators. The activities given in the Usage View document are analyzed and functional requirements derived from them. The outlook is that the functional requirements finally define the interfaces of the involved system entities.

A. Detection & Discovery

The area of detection and discovery functions is concerned with functionality that provides information about new or changed entities to any part of the system under consideration. The information provided can then be used by other functions to fulfill activities given in the Usage View document. The process for detection & discovery is expected to be either automatic or semi-automatic as to ensure ease of use.

B. Access Rights Management

Rights Management is necessary to protect from unauthorized access on Configuration functions that access data or parameters. These functions provide a basis for assigning and checking access rights of dedicated users with certain roles.

C. Configuration

Configuration functions are a category of functionality that allows manipulation of a system under consideration to make it fulfill a purpose given by external roles aiming at utilizing the system.

D. Parameterization

The Parameterization of entities encompasses changes to any sort of working parameter to be performed in order to alter the entities function. This may include communication parameters such as IP addresses or application enablement through defining available memory for an edge runtime, e.g.

E. Runtime Provisioning

The Runtime Provisioning functions are those functions provided by a runtime to its applications. As applications can be almost arbitrarily complex pieces of software, the runtime they are supposed to be run on must provide a certain set of functionalities that ensures seamless execution.

F. Application Provisioning

The installation of applications has to set a lot of parameters to ensure the correct running of the application. Application Provisioning functions are in place to guarantee the successful setting of these working parameters and for setting up the application environment.

G. Integrity Monitoring

To signal malfunctions or unforeseen outside influence that can have an impact on the system, Integrity Monitoring functions are required to detect and report such possibly problematic events and to trigger proper event handling procedures.

VI. Implementation View

The implementation viewpoint deals with the technologies needed to implement functional components (functional viewpoint), their communication schemes and their lifecycle procedures. These concerns are of particular interest to system and component architects, developers, integrators and system operators.

In the interaction between field layer, edge layer and application endpoints, REST based interfaces [28] and OPC UA [29] are seen as most promising candidates to design this interaction in the future, both technologically and via companion specifications. Regarding application deployment, it is a common understanding that a containerized approach seems to be most promising [30][31].

However, these implementation specifics on the *functional view* and the *implementation view* level are not only in the focus of this LNI 4.0 testbed, but mainly targeted by the organizations already mentioned in Section II. Since there is a strong personal interaction between the LNI 4.0 testbed and many of these other organizations, the approach is to align the definitions accordingly.

As a practical example of a REST API for configuration tasks in edge computing scenarios, an exemplary implementation is illustrated in Figure 11. This is how an eventual joint REST API design could look like [32]. Note that this is merely an example which is given to illustrate the proposed technology. It does not reflect the current status of the LNI 4.0 testbed.

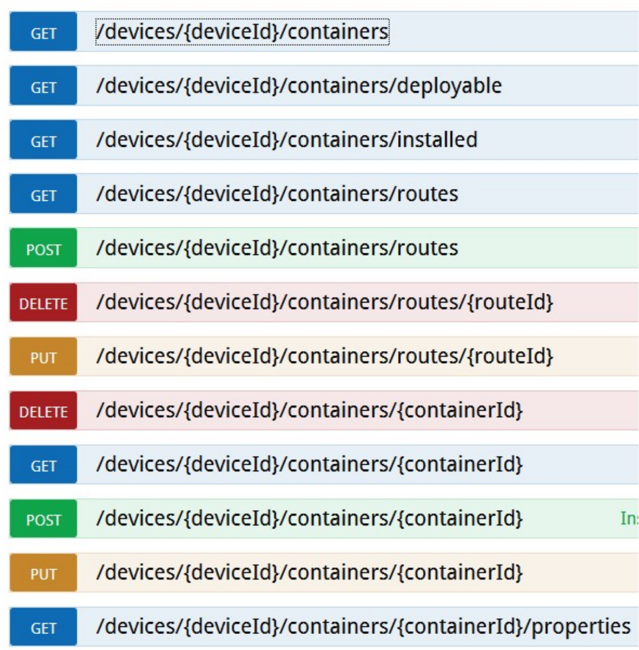

Fig. 11. Exemplary implementation of REST API functions for managing application containers deployed to edge devices, Hilscher [32]

VII. CONCLUSION & OUTLOOK

The key success factor for the acceptance of any communication system in the automation industry is standardization and easy integration into the existing infrastructure.

The pre-competitive and non-profit German association LNI 4.0 published recently a series of documents providing the key definitions regarding terminology, architecture, roles and interactions for the configuration of edge technology [22], [25]. The documents were developed in the corresponding testbed of LNI 4.0. Further documents dealing with the *Functional View* and *Implementation View* are currently under development. The next steps include the definition of the functional view regarding the interface primitives of the involved system entities, whereas the implementation view delivers concrete interface definitions. Alignment with "Plug and Produce" aspects as described in [33] needs also to be considered in this context.

For the upcoming work of the international standardization, the SCI 4.0 will give support and will ensure the international synchronization. For the necessary detailing for the implementation other organizations like the ones mentioned in Section II will refer to these documents.

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