PLATTFORM INDUSTRIE 4.0

DISCUSSION PAPER

Network-based Communication for Industrie 4.0 – Proposal for an Administration Shell

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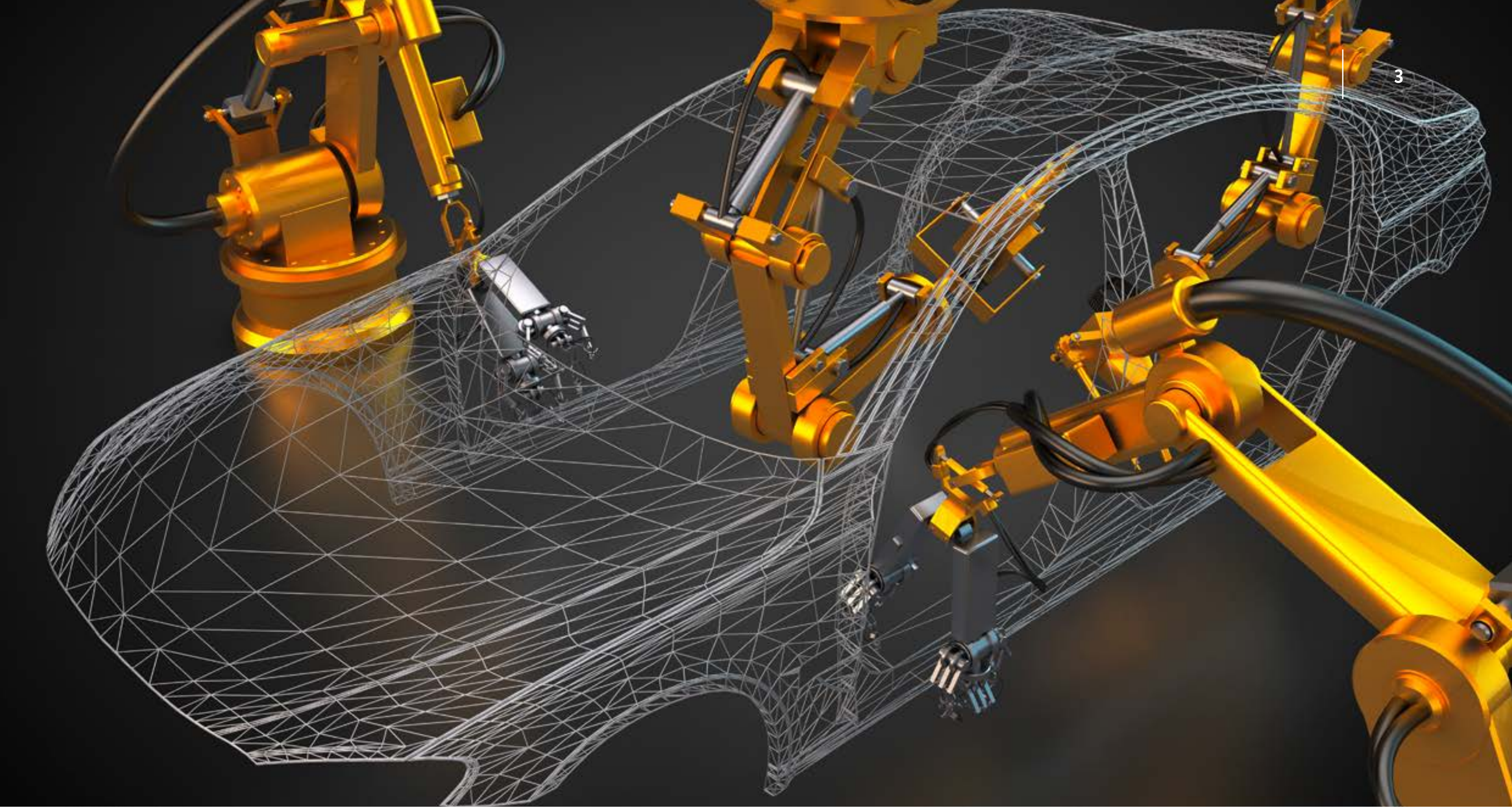


1. Motivation and Context in RAMI 4.0

1.1 Goals of sub-working group on Network-based Communication

The goal of the sub-working group on "Network-based Communication" in the WG1 on Reference Architectures, Standards and Norms within Plattform Industrie 4.0 is to prepare recommendations on the future development and standardization of solutions for network-based communication as part of Industrie 4.0. It will identify the main requirements for this kind of network-based communication and assesses existing standards and norms or those in preparation. To structure the various scenarios and requirements for network-based communication, a central field of activity of the sub-working group is to draw up a related recommendations and reference models as a supplement to the Reference Architecture Model Industrie 4.0 (**RAMI 4.0**).

1.2 Background

A foundation for Industrie 4.0 is the availability of all relevant information through the application-oriented networking of all instances along value chains. This means, that the **Communication Layer** in the RAMI 4.0 reference model needs to ensure a timely, reliable and secure data transport between different Industrie 4.0 components. The involved communication systems – consisting of communication technologies, networks and protocols – are consequently key **assets** in an Industrie 4.0 system. They need to have an **"Administration Shell (AS)"** in order to allow an Industrie 4.0 compliant end-to-end communication between various Industrie 4.0 components.

The scope of this document is to discuss basic requirements, concepts and definitions for this kind of Administration Shell. The first edition of this document is a follow-up publication based on the first discussion paper "Network-based communication for Industrie 4.0" issued by the sub-working group in May 2016 [1]. A second edition with more detailed descriptions (e.g. on wireless coexistence management) is planned for Spring 2017.

1.3 Motivation

The close relationship between communication requirements of flexible and automated production on the one hand and the request for efficient use of the network resources on the other hand call for unified methods of digitalization (e.g. data modelling, virtualization).

The scope of communication requirements ranges from the local segment with strict determinism to cross-company communication in a globally connected world. For example, a machine vendor who intends to provide a predictive maintenance service of a machine installed at a remote customer site faces the challenge of crossing both their own and the customer's network infrastructure in a secure but easy manner. More examples for communication scenarios can be found in Section 7.

Today, the establishment of these communication relationships needs a large degree of manual work, involves a multitude of different protocol technologies, vendors and protocol-/vendor-specific tooling. In particular, since communication aims at crossing the borders of components, delivery packages and entire legal entities, the related engineering faces additional organizational challenges with regard to security.

With the horizontal integration of production systems, operation technology (OT) and information technology (IT) within an enterprise need to interact much closer than in the past, even share common network infrastructures. The situation today stands in opposition to the flexibility which is expected from Industrie-4.0-conforming communication.

In conclusion, this means that towards Industrie 4.0 the main challenge is not the (real-time) performance of communication systems, but the seamless integration and self-configuration of network-based communication as a vital sub-system on an Industrie 4.0 automation system. Furthermore, the different life-cycles of production and information technology will demand new migration, integration and maintenance strategies, including an integrated network management.

As an **example**, the specific situation for wireless communication and wireless coexistence management (in a production environment) is described in the following:

The growing networking of production processes associated with increasing connection of mobile and movable products and equipment requires more wireless communication. These wireless communication applications are very different with respect to its application communication requirements. Therefore, different wireless communication solutions are implemented most likely using the same or adjacent frequency rage. Those wireless communication solutions support logical communication links with different levels of importance. For example transmission of control data have higher priority than transmission of data for process visualization. Because of the increasing flexibility of the processes the priority may change due to commercial needs. These circumstances require an automated management of the wireless communication medium, called coexistence management. The close relation between communication requirements of flexible production and the request for efficient use of the wireless medium require unified methods of digitalization (e.g. data modelling, virtualization). Therefore, it is recommended to describe assets that are closely connected to an automated coexistence management, according to IEC 62657-2 [2], using administration shells. Thus, the entire life cycle process of wireless communication solutions from planning, purchasing, commissioning, operating up to dismounting can be managed using the same approaches as developed for other production equipment.

1.4 Scope

Concluding from the previous section, the following shortcomings need to be addressed toward a standardized integration of communication technology for Industrie 4.0 solutions:

- Lack of vendor-independent configuration interfaces for communication equipment
- Lack of interfaces for media-independent end-to-end communication (e.g. IETF and ETSI approaches for "Intent-based networking[1]" [3], [4])
- Lack of interfaces for co-existence management, particularly for wireless networks

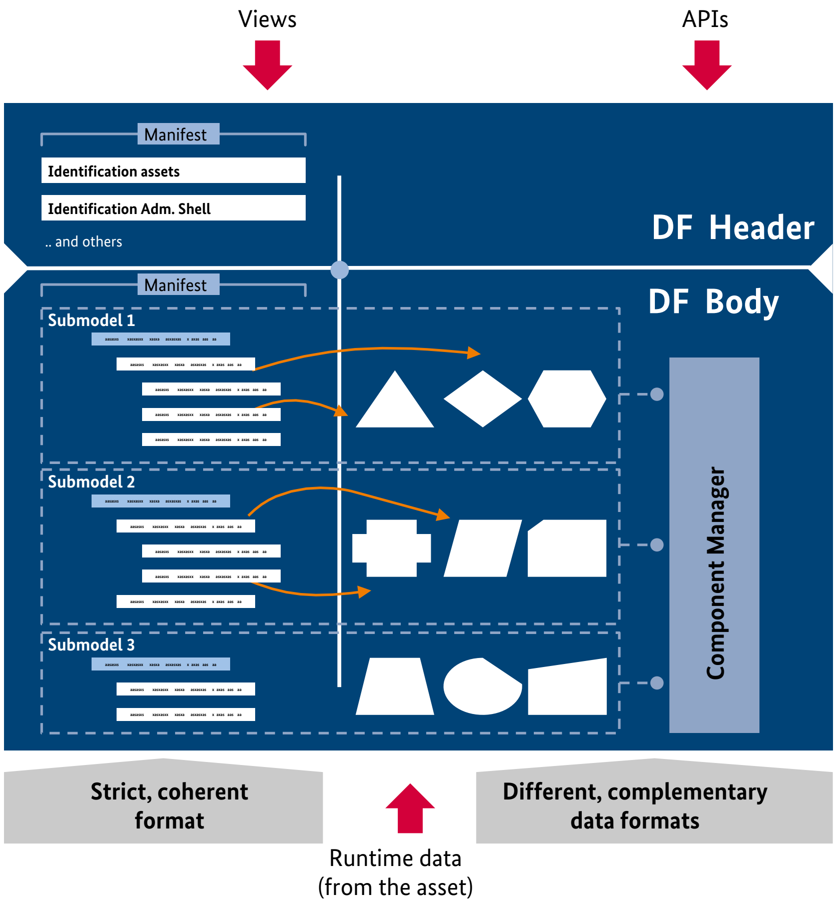
In consequence, these interfaces need to focus on *what* is expected from the communication network, not *how* these expectations are implemented:

- Negotiate the use of a communication layer asset (see Section 2)
- Supervise condition of negotiated use (e.g. be informed if negotiated Quality of Service (QoS) cannot be maintained for some reasons)
- Discovery of Industrie 4.0 compliant service hosts.

Communication is considered in the context of Industrie 4.0 as an asset represented in the information world by its administration shell. In other words, it is an Industrie 4.0 component. According to DIN Spec 91345 [5] the content of administration shells is characterized by **sub-models** as shown in Figure 1, where one of them will be the **communication sub-model** Industrie 4.0 containing all information about the Industrie 4.0-conformant communication. This document deals with content and the functions, which will be part of this sub-model for communication.

1 Intent-based networking focuses on what an application needs from the network. It is application centric. In Intent-based networking, the network provisioning or network automation is free to operate in any way it chooses as long as it provides the application the requested service.

Figure 1: According to DIN Spec 91345 the administration shell contains one or more sub-models



Furthermore, a proposal of an administration shell for network-based communication within the context of an Industrie 4.0 service-oriented architecture needs to consider the following prerequisites:

- Concepts related to the Industrie 4.0 administration shell
  - Including a common model for describing the properties of Industrie 4.0 components
  - Including the ability to negotiate about service quality
- Concepts of an Industrie 4.0 service architecture (as proposed by VDI/VDE GMA FA 7.21) [6].

It is important to consider two views on the network-based communication within the RAMI 4.0 (details see Section 1.5):

- Communication needs as **users** of data transport functions – in this case, interacting with an administration shell assumes that communication facilities are configured to support the related data access
- Communication capabilities as **provider** of data transport functions – in this case, an administration shell wraps communication facilities and allows negotiating about service quality.

The service hierarchy shown in Figure 2 and described in Table 1 picks up on this distinction.

Figure 2: Conceptual Industrie 4.0 Service Hierarchy [6]

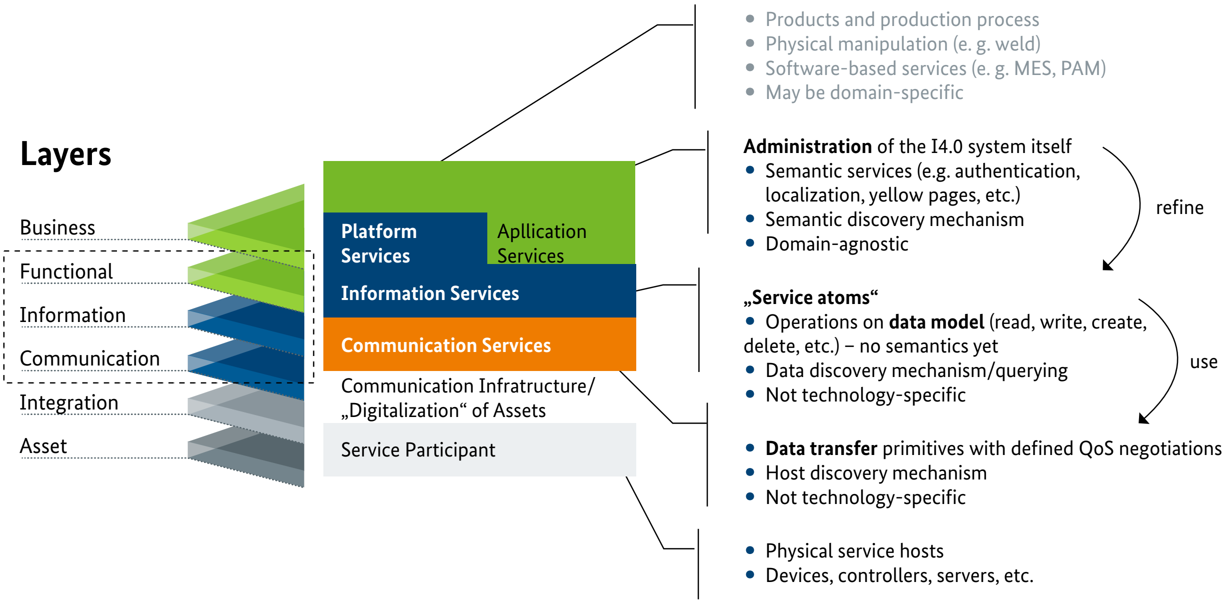


Table 1: Relationship between Industrie 4.0 service hierarchy, automation and ICT domain, and the communication administration shell

Service Layer	Functionality	General example in Automation Domain	Example in ICT	Role of communication administration shell (AS)
Communication services	Provide data transport and host discovery	OPC UA Sessions	Data plane	Provider of network-based communication
Information services	Interaction with information models including data queries	OPC UA Information Model	"Intent-based Networking" (see above)	User of network-based communication
Platform administration services	**Negotiate on network access, end-to-end communication, and QoS**	**OPC UA Companion Standards**	**Control Plane**	**Administration**

1.5 Views on Network-Based Communication

There are two ways to look at networks-based communication in the Industrie 4.0 context with regard to administration shell-related questions:

1. **Network-based communication as "subject" of Industrie 4.0** *(user of communication)*:
Industrie 4.0 components do have by definition communication capabilities in order to exchange data and information or to provide and use functions of remote devices. For this reason properties need to be specified for the Industrie 4.0 component describing the application communication requirements. These are e.g. type and length of data to be transferred, the required performance, the provided or expected interface between information/function layer and networks-based communication (serial or parallel, buffer or FIFO, services or protocols). These properties are elements of the communication sub-model in the administration shell of an Industrie 4.0 component. Based on the property values of the communication layer of an Industrie 4.0 component adequate networks-based communication system can be implemented. The components of the network have not necessarily to be Industrie 4.0 components by itself. However, the properties provided by the Industrie 4.0 components may support also the design of networks-based communication with a broad application scope e.g. in the sense of IoT.

2. **Network-based communication as "object" of Industrie 4.0** *(provider of communication)*:
The design, integration and life cycle management of systems for network-based communication systems will be the same as for other assets which are relevant for Industrie 4.0-compliant industrial automation systems. Therefore, the model elements according to RAMI 4.0 shall be considered in order to develop the content

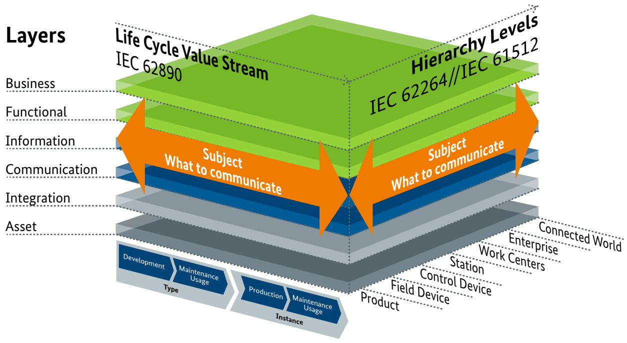
of AS. This enables a persistent management of network and application according to the fluently altering requirements of the production process. This is only required where network-based communication is a fundamental part of industrial automation applications.

To integrate both perspectives, we need an administration shell.

1.5.1 Network-based communication as "subject" of Industrie 4.0

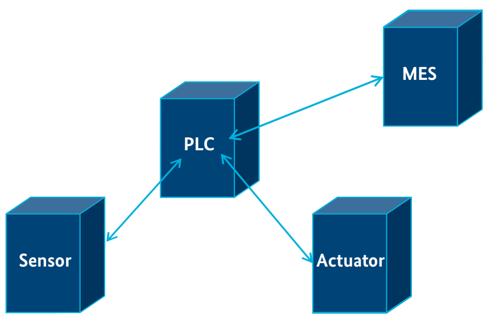
This section discusses the position of network communication within future industrial automation applications according to Industrie 4.0 concept. Communication is one aspect (layer) of RAMI 4.0 (see Figure 3). Communication capability is a precondition of each Industrie 4.0 component [5]. It has to be considered for all assets of the hierarchy levels throughout the entire value stream.

Figure 3: Subject "network-based communication" in RAMI 4.0



Assuming a spatially distributed industrial automation application as exemplary illustrated in Figure 4, the automation devices (sensor, actuator, programmable logic controller (PLC), and manufacturing execution system (MES)) are to interoperate in order to jointly execute an automation task.

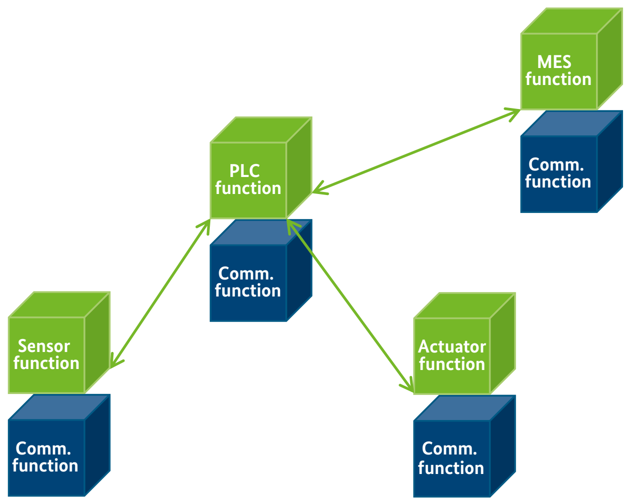
Figure 4: Spatially distributed industrial automation application



Every automation device of this application implements automation functions and communication functions (see Figure 5). According to the scope, the focus of this document is the network-based communication. However, as depicted in Figure 5, the automation functions define the requirements according to the logical topology and the properties of the data communication. This information is essential to be able to provide an adequate network communication. Thus, with respect to Industrie 4.0 concept, information for network communication is to be provided in the administration shell of the relevant assets. Relevant examples of assets are automation devices (material assets) and automation system planning documents (immaterial). For this purpose in an administration shell a sub-model "Communication" is considered. This part should include properties for:

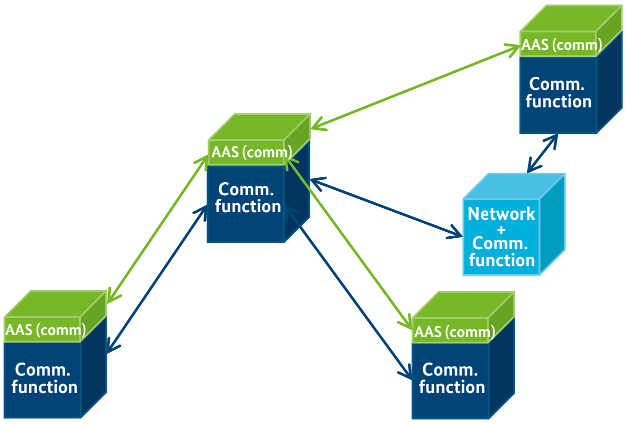
- automation system (e.g. spatial dimension);
- logical link (e.g. functional safety);
- communication services (e.g. user data length);
- quality of communication services (e.g. transmission time).

Figure 5: Automation and communication functions of the industrial automation application



Based on the information of the communication part of the administration shell, a suitable network communication can be provided and maintained. As depicted in Figure 6 the physical network topology may differ from the logical topology of the automation network. Reasons could be the distance between the logical endpoint implementations, different network access (wireless, wired), or network specifics (communication via base station). Thus, the aspect "Communication" of RAMI 4.0 describes the "WHAT" of network communication.

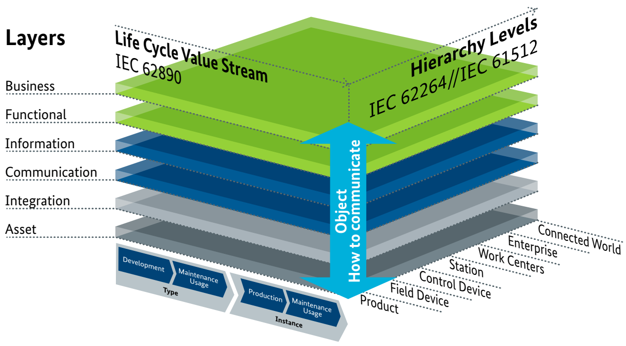
Figure 6: Automation network described by AS part "communication" and implemented network communication



1.5.2 Network-based communication as "object" of Industrie 4.0

In the previous section has been described which information automation assets should provide in order to plan, install, commissioning and maintain network communication. However, the items of network communication do not need to be Industrie 4.0 components. This means, negotiations between automation application and network communication using Industrie 4.0 methods would not be possible. For this purpose network communication has also to be considered as object of Industrie 4 (see Figure 7). Thus, for relevant assets of network communication the aspects (layers) of RAMI 4.0 should be taken into account in order to develop an administration shell.

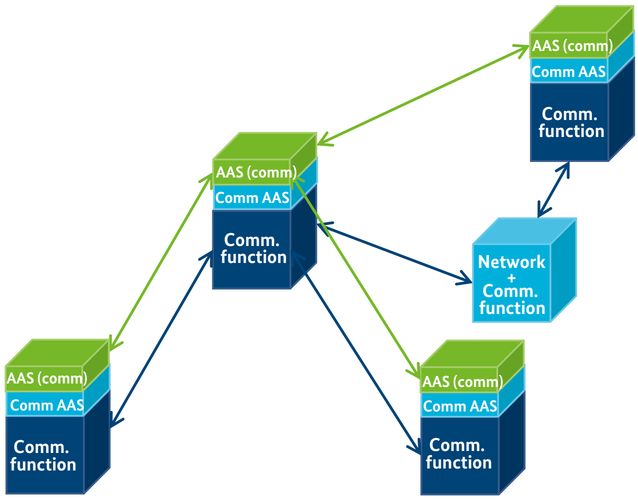
Figure 7: Object "network-based communication" in RAMI 4.0



As indicated in Figure 8 it is not necessary to describe the network communication complete. Mainly the characteristic of the network communication with respect to the reference interface has to be provided.

The provided information enables application related processes such as negotiation of communication services, relevant diagnosis methods or application related management such as wireless coexistence management using Industrie 4.0 methods and tools.

Figure 8: Automation network described by administration shell part "communication" and network communication described by specific administration shell



Thus, the administration shell for network communication assets describes the "HOW" of network communication.

1.6 Reference Model for network-based communication with an administration shell

In this section it will be described how Industrie 4.0 works "on top" of existing or future networking technology. The claim of the administration shell is not to replace each and every interface in networking technology. This is neither feasible nor needed.

The focus of the operational reference model is the manageability of Industrie 4.0-conforming network communication via an administration shell:

- Programmable network infrastructures
- Programmability at the data-plane
- Negotiation with control plane and
- Industrie 4.0 semantic-conforming administration (Contracts, Service Level Agreements – SLAs)
- Significantly reduce reconfiguration/response times in the network set-up and operations.

The task of the administration shell for network-based communication is therefore to expose the relevant properties and functions to allow information and application services to function on top of a distributed, inter-networked “connected world” without having to know details of networking technology and topology.

Designing and implementing the functionality of the communication infrastructure itself is not in scope of this document. Figure 9 illustrates this objective, while Chapter 2 provides details on relevant assets for which an administration shell needs to be defined (please also refer to Figure 13 for additional details).

This new requirement on network-based communication managed and interfaced (partly) by an administration shell via network control plane interfaces needs feasibility studies on regulatory, security, business and technical aspects.

As described in section 1.4, network-based communication in the context of Industrie 4.0 is considered as an asset represented in the information world by its administration shell. In other words, it is an I4.0 component. According to DIN Spec 91345 the content of administration shells is characterized by sub-models as shown in Figure 1, where one of them will be the communication sub-model Industrie 4.0. This sub-model contains the essential information about the Industrie-4.0-conforming communication, as illustrated in more detail in Figure 10. The data plane eventually provides the communication (data transport) services for Industrie 4.0, while the control plane represents the administration services represented in the fine-granular portion of the communication sub-model.

As indicated in Figure 10, the network management system of communication networks is a potential interface to the administration shell. Today, network management systems are often complex, partly proprietary and bound to the underlying network architectures and network elements.

Figure 9: Illustration of network-based communication as an asset – embedded in an Administration Shell

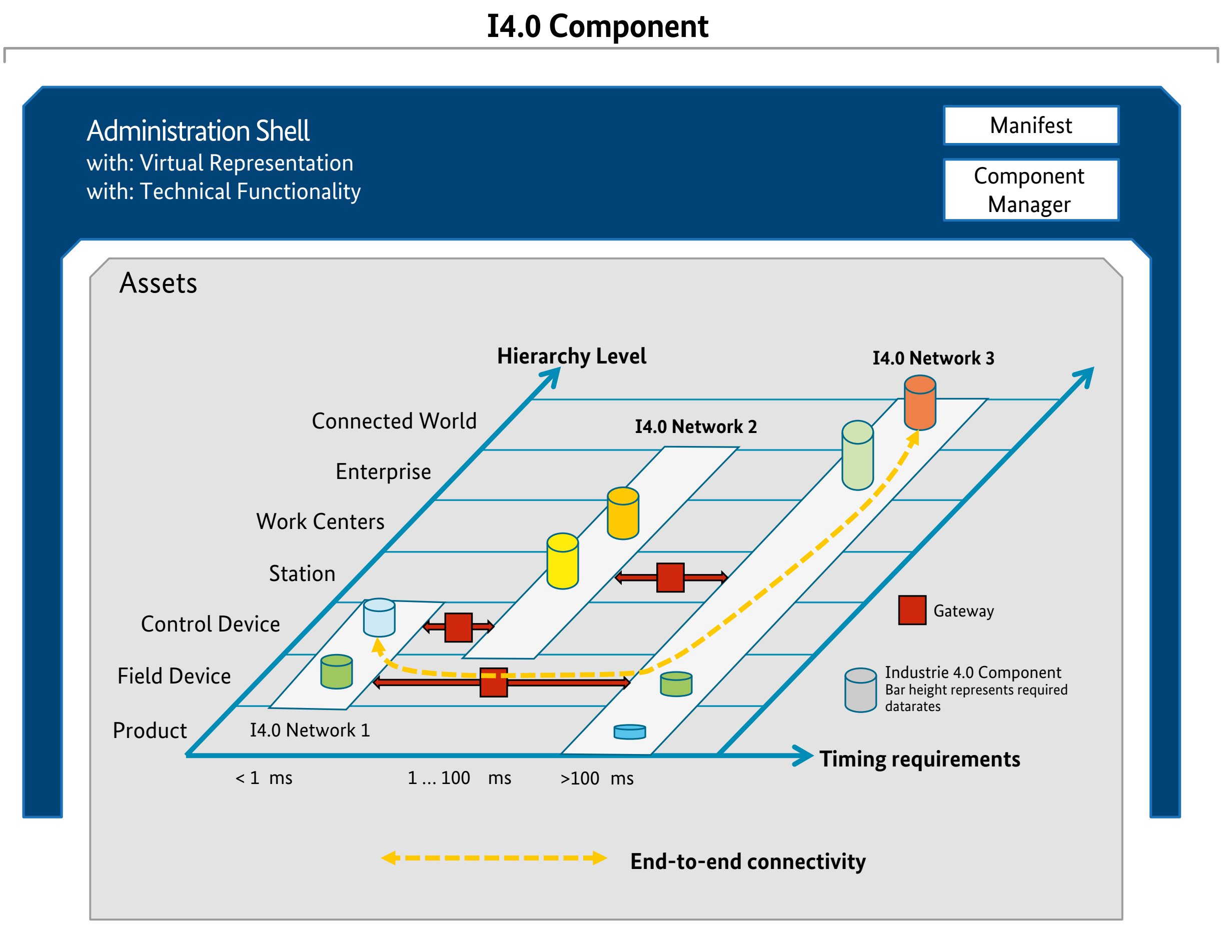
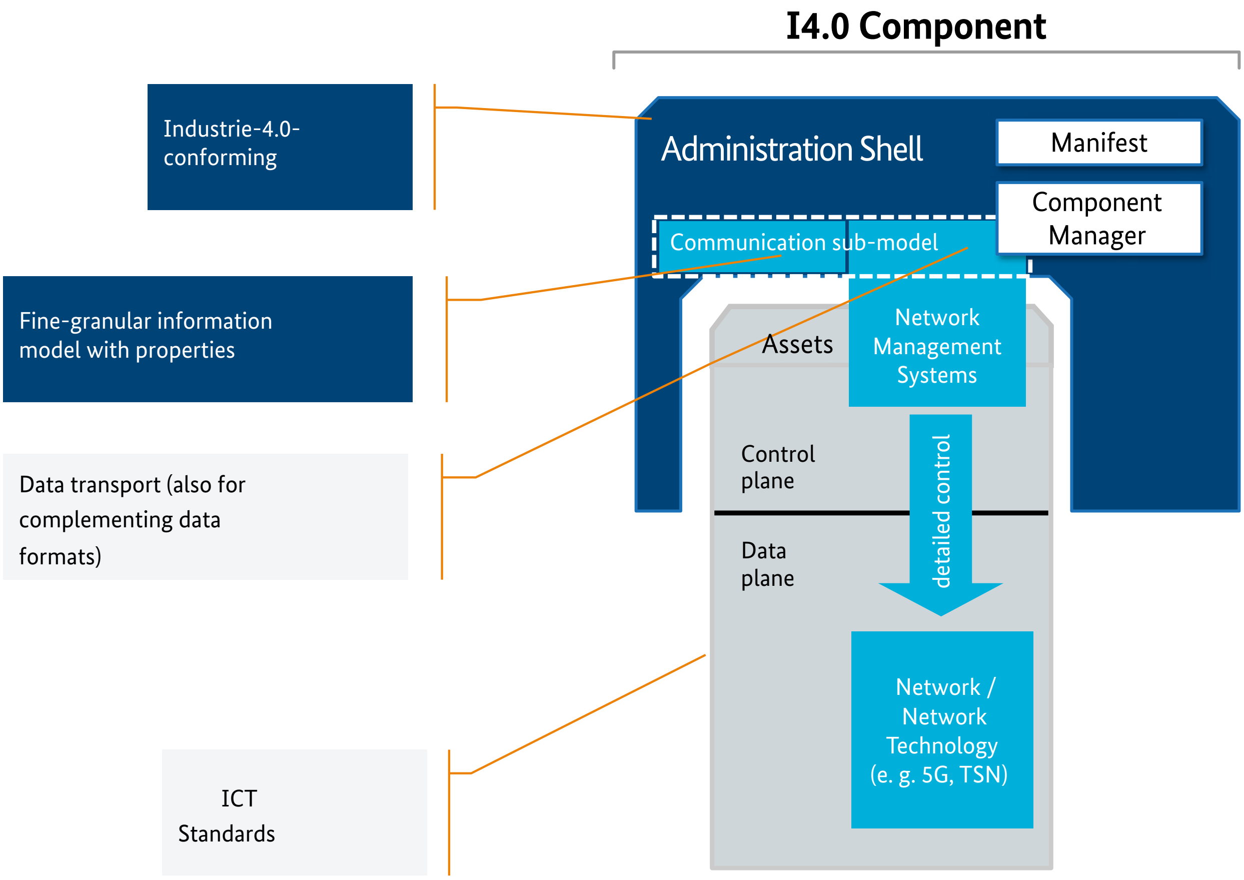


Figure 10: Conceptual model of operating networks through the administration shell



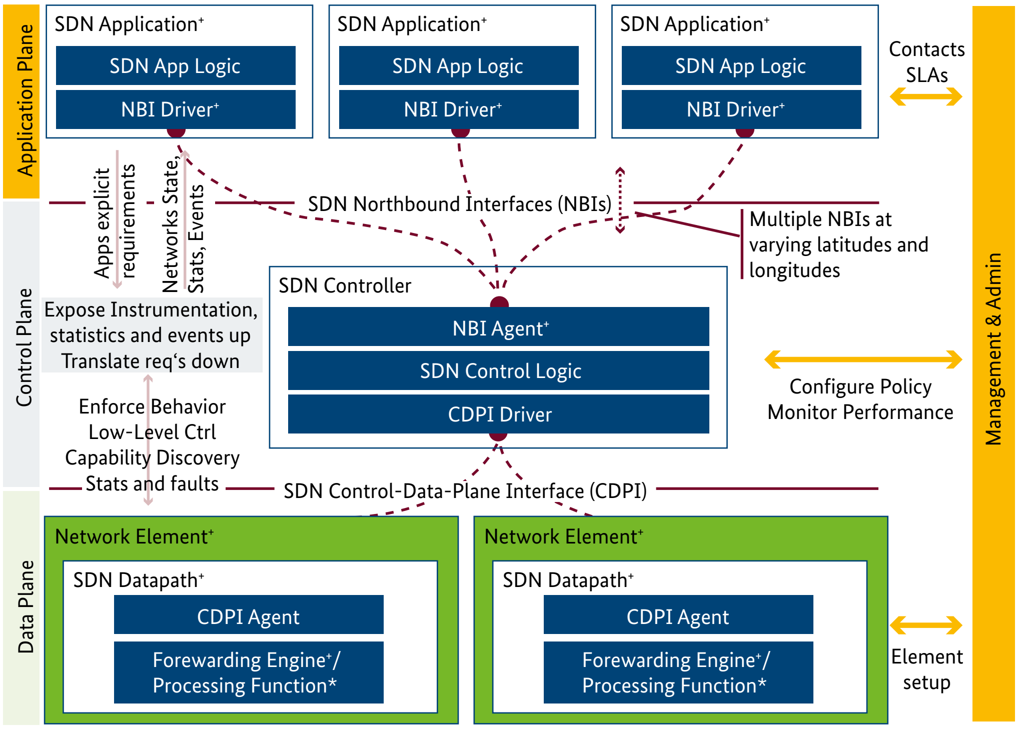
In the future, communication networks will move from a hardware-oriented to a software-oriented model. Network functions will be generated in a virtualized way, based on universal transport, compute and storage infrastructures (**Network Function Virtualization, NFV**). Compute and storage infrastructure can be hosted in centralized or de-centralized data centers ("cloud-based production"). In combination **with Software-defined networking (SDN)** architectures and functions, new opportunities for flexible network set-ups and the administration of network services towards "real-time" network and service management will be enabled. An overview of the SDN architecture is sketched in Figure 11.

One way is to consider the future Software-Defined Networking (SDN) Architecture in the conceptual model of operating networks through the administration shell is illustrated in Figure 12. Thereby, the Industrie 4.0 applications use the Network Communication administration shell to interact with an SDN controller, essentially taking the role of SDN applications without needing any knowledge of SDN technology. So, the Industrie 4.0 Network Communication offers access to network management services, which are providing for example discovery of networks, access control to (other) networks, and handling connection requests.

If the virtual RAMI 4.0 Communication administration shell in the real Industrie 4.0 environments is represented by an SDN application, the fulfillment of the RAMI 4.0 administration shell requirements are to be negotiated. It is expected that SDN-based negotiation procedures will be supported by future public networks.

Another important approach for future communication networks is the concept of network slicing. Based on SDN- and NFV-principles, it will be possible to establish different logical networks on the same physical infrastructure. Network slicing is considered as a key concept for 5G [7]. It is foreseeable, that for Industrie 4.0 dedicated network slices can be flexibly established based on the dedicated requirements for Industrie 4.0 applications. The detailed mechanisms for network slicing, including the establishment of network slices across operational domains, is currently under research.

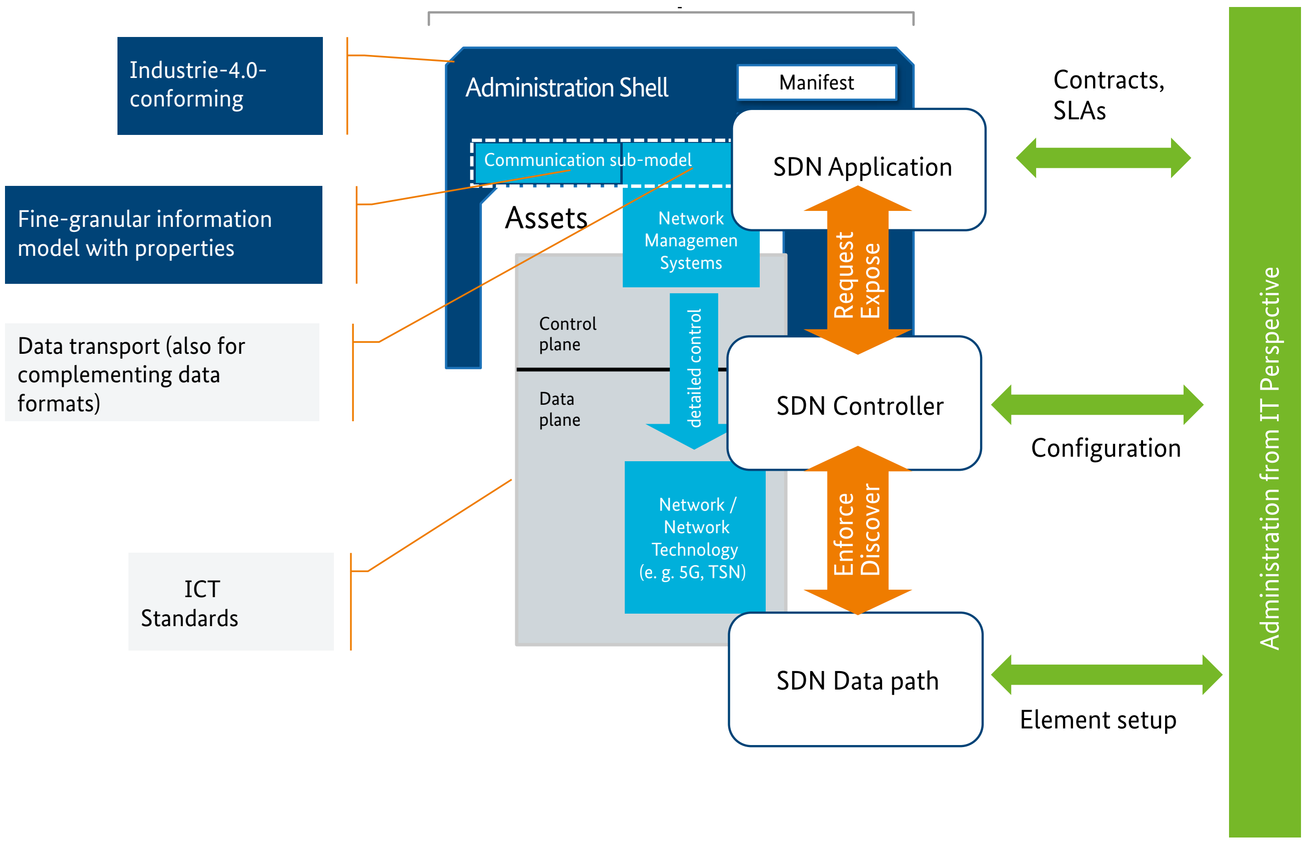
Figure 11: Overview of Software-Defined Networking Architecture



+indicates one oer more instances, *indicates zero or more instances

Source: Open Networking Foundation (Version 1.0 December 12, 2013), SDN Architecture Overview

Figure 12: Model of operating SDN enabled networks through an administration shell



2. Assets enabling Network-based Communication

2.1 Definitions

In the context of Industrie 4.0, an asset is defined as a concrete or abstract thing of value [5]. This includes both the products and production equipment as indicated in the RAMI 4.0. Complex production units are formed by placing equipment into a physical and functional collaboration context. This collaboration depends on the communication capabilities of its participants also indicated in the RAMI 4.0 communication layer. Regardless of the production process, the related communication resources, both physical and logical, therefore become essential assets of any Industrie 4.0 production.

In Figure 13 a structuring example for the communication Layer in RAMI 4.0 is depicted. The various communication networks used for network-based communication are depicted in these two dimensions. These differ depending on which of the hierarchy levels they are located in or which latency requirements can be met with the networks. The cylinders delineated in the networks illustrate Industrie 4.0 components that communicate with each other via a specific network and gateways.

Following Figure 13, the core communication assets are:

- **Communication networks**, representing allocations of physical or logical resources into a *management or policy* context. Examples for such resources are the physical network equipment, transmission lines, radio channels, and logical entities like network slices.

- **End-to-end communication relationships** (between Industrie 4.0 components), representing allocations of physical or logical resources into a *data exchange or collaboration* context. Examples are allocations in rate limits within Ethernet switches or adaptation functions in gateways between different networks.

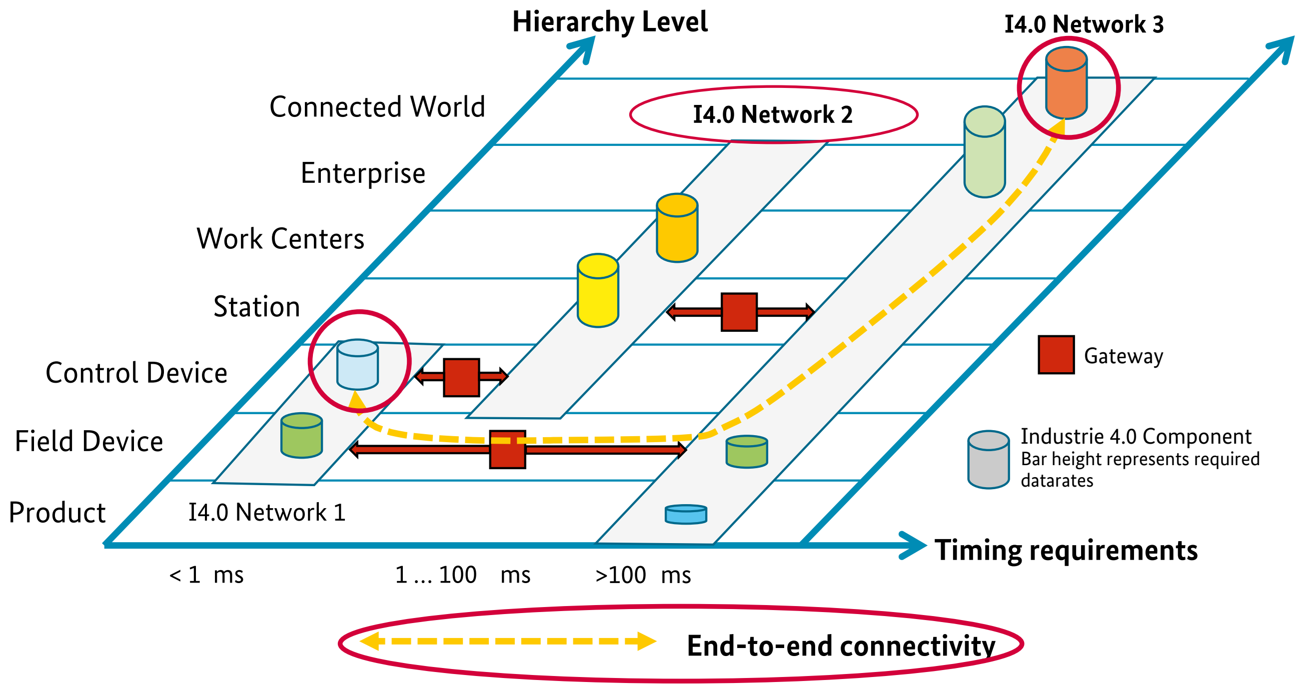
- Any **host of an administration shell** (or a part of it), i.e. any component supporting Industrie 4.0 conforming communication. Examples are field devices or controllers with embedded AS, field device integration (FDI) servers (IEC 62769-1), CMMS and ERP systems, etc.

- **Network management & control systems (NMS/NCS)**, which are responsible for allocating and monitoring the resources of communication networks to support a communication relationship with a defined service quality as requested by automation applications. Examples (at different abstraction levels) are SDN and Wireless LAN controllers.

Note that the achievement of the administration shell is to not expose but hide these complex properties and rather expose the functionality that networks, connections, etc. offer.

Industrie 4.0 applications require Industrie 4.0 conforming interfaces to negotiate with a network management system / network control system (NMS/NCS) about communication relationships (rather than individual resources). The administration shell of networks and communication rela-

Figure 13: Structuring example for the Communication Layer in RAMI 4.0



(communication assets indicated in red)

tionships must therefore interface with NMS/NCS system. To exert this control, the network control system may use non-Industrie 4.0 technologies such as SNMP, NETCONF, or proprietary protocols and CLIs (command line interfaces) to interact with the resources for which it is responsible. In particular, the involved communication resources are not required to be Industrie 4.0 components. Rather, we propose the use of standardized protocols and information models within the ICT domain as initiated for example with NETCONF/RESTCONF [8] and YANG [9]. In this sense, there is a great correspondence between the endeavors in the automation and the ICT domain – with the NCS acting as a gateway in between.

2.2 Basic assumptions for an administration shell for network-based communication

As indicated in Section 1.4, defining an administration shell (AS) for any type needs to consider concepts for structure and content of the administration shell, services to interact with any instance of an administration shell, in particular to negotiate contracts on the functionality of the asset. Currently, all these concepts are work in progress.

However, it is important to propose an administration shell for network-based communication already at this point in time because the RAMI 4.0 communication layer is an essential, mandatory aspect of building an Industrie-4.0-compliant system. In this sense, we consider ourselves as early adopters of the abovementioned concepts.

The purpose of this section is to explicitly state the overall assumptions and decisions guiding our proposal of an administration shell for network-based communication. We assume:

IP-based communication: With almost absolute certainty, all Industrie-4.0-compliant communication will be based on IP technology[2], both IPv4 and IPv6, including the principal ability for communication to be routed globally (common addressing and transport).

Default network: There is an Industrie 4.0 default network with a well-known standardized identifier and security criteria. This is used as a default for any component initially joining into an Industrie-4.0-conforming system (common communication boot-strapping).

2 Discussions on the application layer protocols are still ongoing, but there is an informal consensus in the community that OPC UA is the top candidate, possibly complemented by telemetry protocols such as MQTT or AMPQ (which has actually become a part of the OPC UA specification as part of the publish/subscribe extensions.)

Default communication capability of an Industrie 4.0 component: This refers to a minimum set of communication primitives which must be provided to participate in the default network.

Network management services: Each Industrie 4.0 network offers access to network management services, which provide discovery of networks, access control to (other) networks, and handling connection requests to participants of the Industrie 4.0 service system. Technically, such services are optional, but then the Industrie 4.0 system is restricted to the local default or pre-configured network (common access to network resources).

Secure identification: There are two security facets which impact network-based communication: secure identification of communication end-points (authentication) and secure data transmission (confidentiality and integrity). These topics are not within the scope of network-based communication alone, but need to be addressed together with the Plattform Industrie 4.0 AG3 Security. Further assumptions are stated in Section 4.

Network management hierarchy: To establish end-to-end connections across sites or companies, multiple network management systems within different organizational domains must collaborate. Their interaction must also be standardized. It seems feasible to have them use the same negotiation services that "regular" Industrie 4.0 components use, meaning they negotiate with each other acting as proxy for the component which initially requested a connection (scalability to the connected world).

Address resolution scheme: The purpose of the Industrie 4.0 administration shell is to offer easy access to information, i.e. data with known semantics (see also Section 5.3 in [6]). This also means that information must become accessible by referring to semantics, not addresses. In consequence, an Industrie 4.0 address resolution scheme is required along the following lines:

i. Semantic identifier of service type or piece information (by means of a semantic tagging of information models)

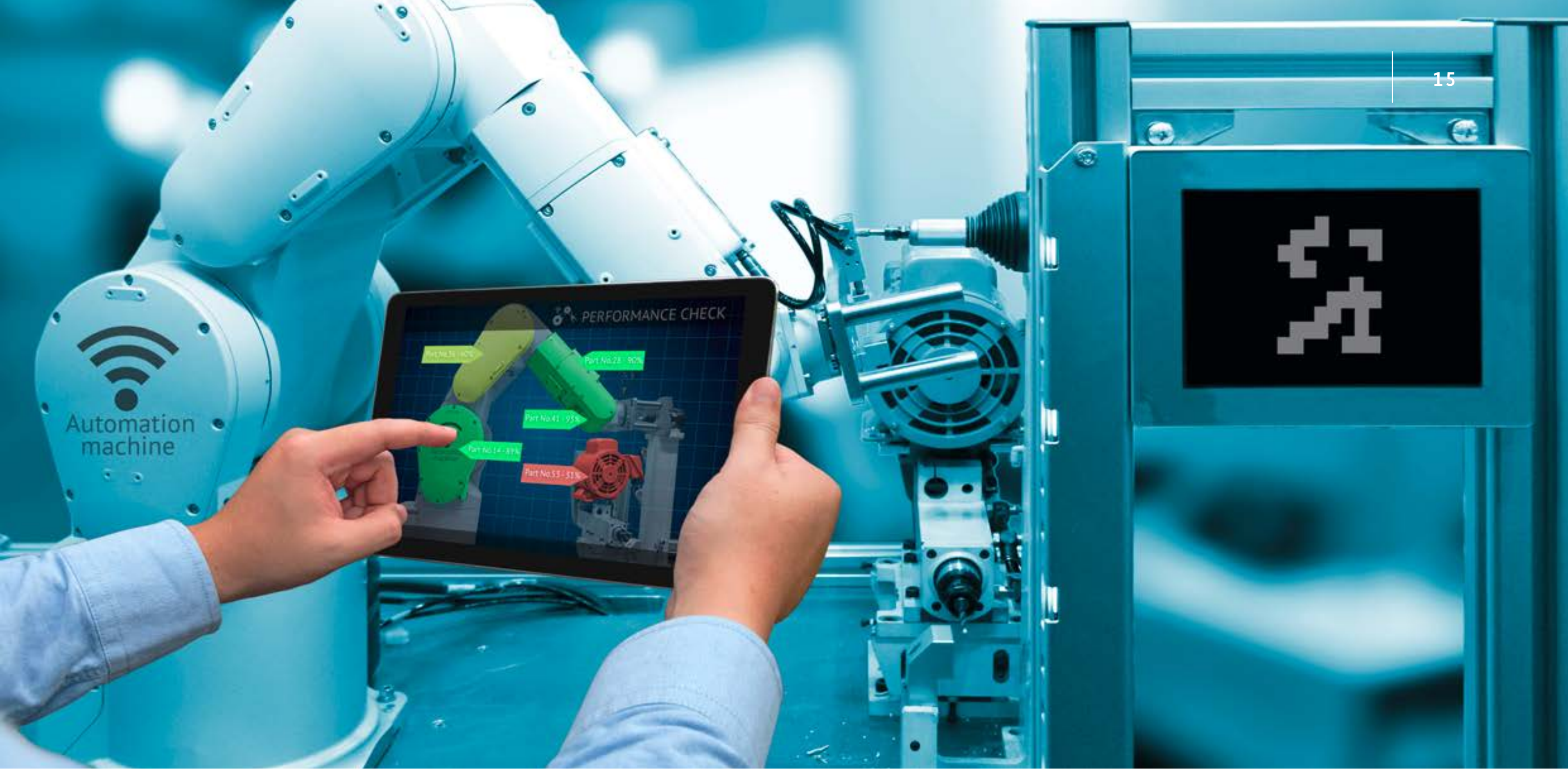
ii. Industrie 4.0 service host identifier

iii. OPC UA endpoint and browse-name of the addressed OPC UA node (object, variable, method)
   a. Including a DNS name (or directly an IP address) and a TCP port

iv. IP address and TCP port

v. MAC address.

The novelty again lies in steps i and ii, which go beyond the capability of current automation systems. Step i focuses on identification of semantics, step ii also include the authentication of the communication end-point. As opposed to the addresses (including DNS name) on ISO/OSI layers 1–7, the identifiers within the administration shell must be immutable.



3. Quality of Service aspects for network-based communication

Industrial applications need communication with defined behavior in terms of timing, throughput and reliability. These parameters need to be negotiated during the set-up of a connection between two Industrie 4.0 components via the administration shell.

Currently, different technologies are using their individual definitions as state-of-the-art. This section proposes a scheme of attributes starting from the requirements of industrial applications. An Industrie 4.0 conforming communication channel should be able to carry different services with their according QoS behavior. Basics on QoS parameters and definitions can be found for example in [10] and [11].

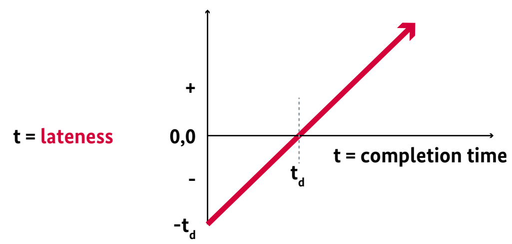
3.1 Response time

The response time needs not to be always as short as possible but predictable timing is absolutely essential.

3.1.1 Lateness

Lateness describes the derivation from a required time. This might be either positive (earliness) or negative (tardiness).

Figure 14: Illustration of Lateness



3.1.2 End-to-end delay time

Within the communication layer a mixture of different technologies is required to set up a connection between different assets.

End-to-end delay time is a highly relevant attribute for describing end to end services. This is valid for periodic as well as aperiodic services. End-to-end delay refers to the time taken for a packet to be transmitted across a network from source to destination. It is a common term in IP network monitoring, and differs from Round-Trip Time (RTT)

Figure 15: Example for end to end delay time

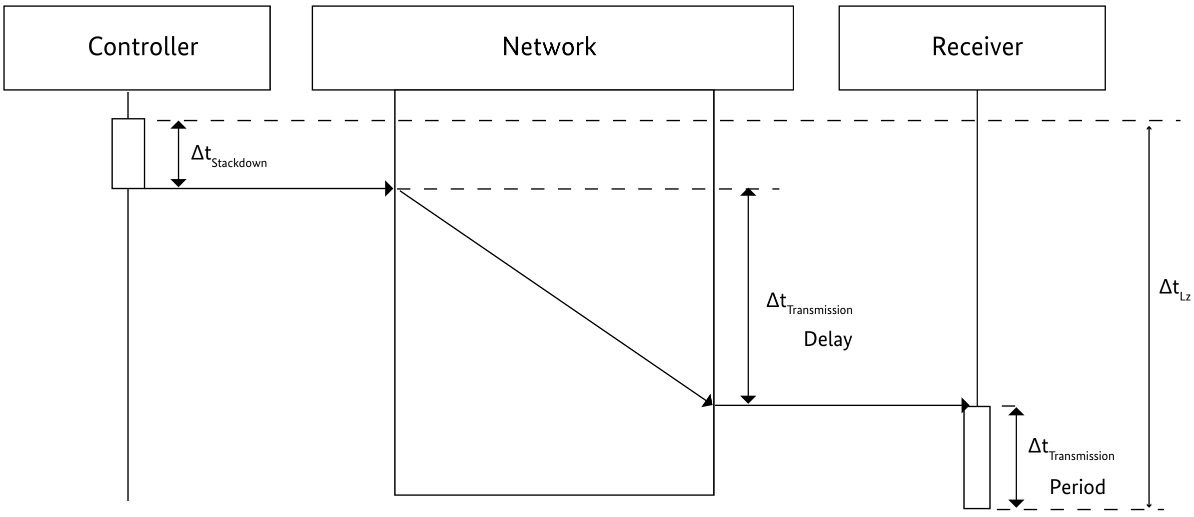
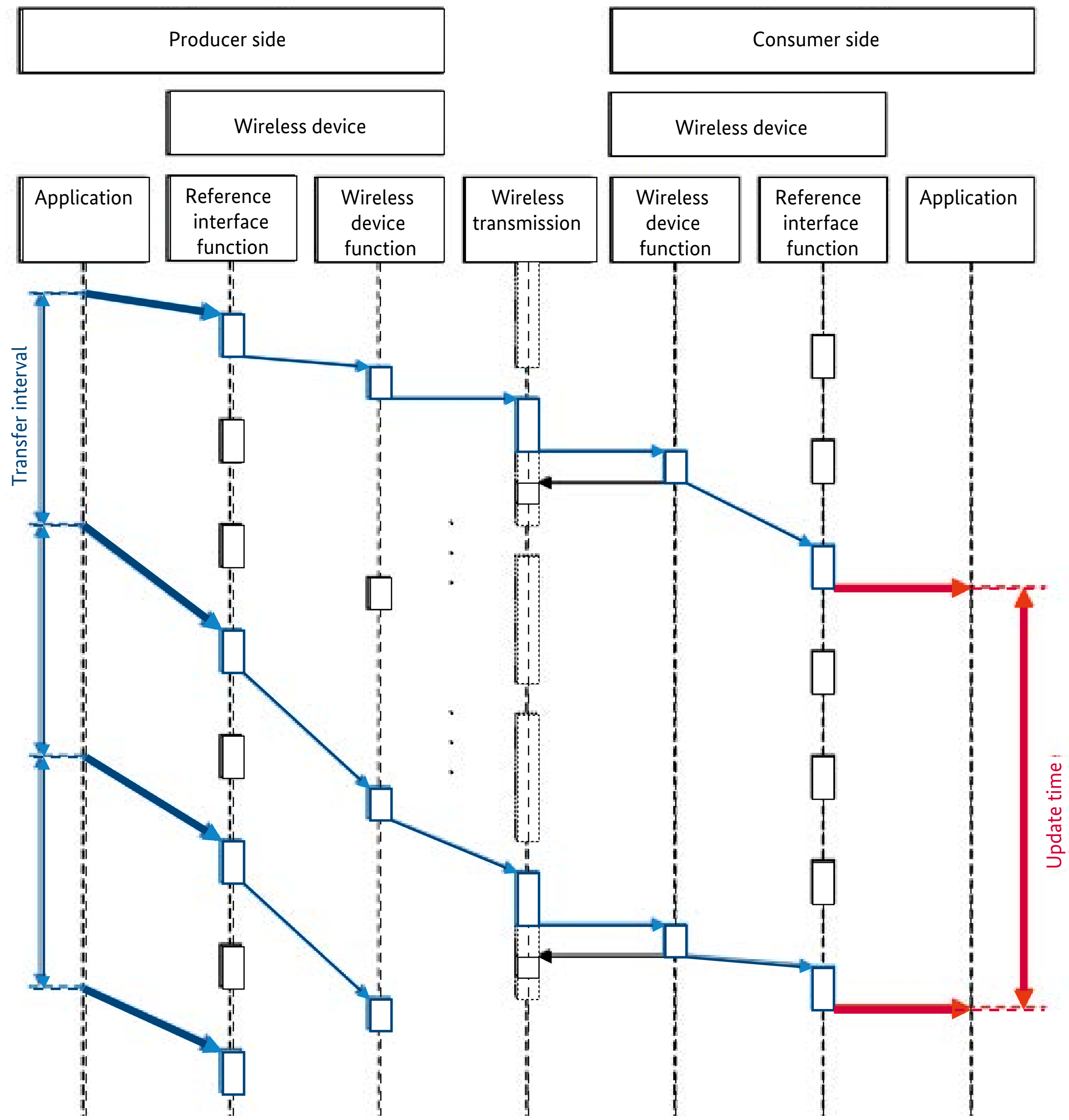


Figure 16: Example for Update Time



3.1.3 Update Time

The Update Time is important for describing periodic systems. Update time defines the time period between two consecutive reactions. Figure 16 shows an example for Update Time in a message sequence diagram.

3.2 Data throughput

The data throughput describes the rate at which the packets go through the network. The capacity of a logical link measured in messages or octets per time unit. Besides "Guaranteed bit rate" and "maximum bit rate" (see below) also average and minimum bit rate values might be useful for some applications.

3.2.1 Guaranteed bit rate

The guaranteed bit rate (e.g. in kbps) is defined as the guaranteed number of bits delivered within a period of time (provided that there is data to deliver), divided by the duration of the period. The purpose of this attribute is that it describes the bit rate that the communication service shall guarantee to the user or application.

3.2.2 Maximum bit rate

The maximum bit rate is defined as the maximum number of bits delivered within a period of time, divided by the duration of the period. The maximum bit rate is the upper limit a user or application can accept or provide. The purpose of this attribute is

- to limit the delivered bit rate to applications or external networks with such limitation and
- to allow maximum waned user bit rate to be defined for applications able to operate with different rates.

3.3 Dependability & Reliability

The ability to perform as and when required is called dependability. Dependability characteristics include availability and its inherent or external influencing factors, such as reliability, fault tolerance, recoverability, integrity, security, maintainability, durability and maintenance support. Dependability is also used descriptively as an umbrella term for time-related quality characteristics of a product or service, and it can also be expressed as a grade, degree, confidence or probability of fulfilling a defined set of characteristics. [12].

This mean that it is not sufficient to describe timing and throughput of a system under ideal conditions. It is also important to define limits for statistical occurring imperfections of communication technologies and imperfect conditions. In theory, a reliable product is totally free of technical errors. In practice, vendors commonly express product availability as a percentage. The Institute of Electrical and Electronics Engineers (IEEE) sponsors an organization devoted to reliability in engineering known as the IEEE Reliability Society (IEEE RS). With respect to data transmission, disturbances of the transmission (EMI) or the vulnerability of a communication channel (e.g. wireless) may influence the dependability of the communication.

3.3.1 Availability

Availability is the ratio of time a system or component is functional to the total time it is required or expected to function. This can be expressed as a direct proportion (for example, 9/10 or 0.9) or as a percentage (for example, 90%). It can also be expressed in terms of average downtime per week, month or year or as total downtime for a given week, month or year. Sometimes availability is expressed in qualitative terms, indicating the extent to which a system can continue to work when a significant component or set of components goes down. [13]

3.3.2 Error rates

The bit error rate (BER) is the number of bit errors per unit time. The bit error ratio (also BER) is the number of bit errors divided by the total number of transferred bits during a studied time interval. BER is a unitless performance measure, often expressed as a percentage [14].The packet error ratio (PER) is the number of incorrectly received data packets divided by the total number of received packets. A packet is declared to be incorrect if at least one bit is erroneous. From the application point of view the message loss rate and the residual error rate is of interest. The message loss rate is a measure for the number of messages that could not be reconstructed by error correction mechanisms and are therefore not provided to the application. The residual error rate is defined as the number of undetected wrong messages to the total number of messages sent.

4. Security aspects

Regarding security for the Industrie 4.0 in general and the asset administration shell in particular, there are ongoing activities by WG3 “Security of networked systems” of the Plattform Industrie 4.0 as well as by the ZVEI mirror group Security. One of those activities is addressing the question how a security model for the asset administration shell should look like and whether such a security model is sufficient to protect the entire I4.0 component. Such work needs of course to be discussed with other working groups and subgroups to arrive finally at a coordinated idea, recommendation, and standardization.

First, it should be stated that security requirements always depend on the actual use case, i.e., should be the result of a risk analysis process. Security capabilities, on the other hand, should be described as part of the asset model.

Regarding security capabilities, first[3] key topics needed for protecting the asset administration shell and its models have been identified. These topics are

- secure identities (authenticity) [15]
- secure communication (confidentiality, integrity) [16] when negotiating end-to-end connections (Sections 2.1 and 6.2), which becomes especially important for cross-company communication
- secure information access (authorization, RBAC)
- and logging (audit).

Whether security capabilities should be part of the communication model or the security model might still to be discussed. Information access rules, for instance, should likely be part of the communication model to have the authorization information always available along with the information to be protected. How to authenticate the identity of a communication partner, i.e., technical measures (e.g., certificate, username/password, chain of trust, or trust anchor) and actual security requirements might, on the other hand, be defined outside of the communication model; eventually, communication needs to know if a specific identity is authentic or not. This means, *authenticity can and must at least be quantified* as a property within a service participant.

Regarding the cryptographic measures, the state of the art constantly evolves – as the state of the art of breaking encryption does. This holds for all aspects, the authentication of communication partners, the encryption of communication content, the authorization of data access, and the protection of authorization and logging information. Unlike quality of service (see Section 0), there are however, no commonly agreed quantities to describe the needed/offered quality level of cryptographic mechanisms to ensure secure communication. IEC 62443, for instance, recommends defining security levels. The actual implementation of such security levels is specific to certain use cases, companies, or domains; in order to ensure interoperability across Industrie 4.0 as a whole it needs, however, standardized security levels or security policies, making the achievable security understandable to manufacturers as well as customers, but also allowing for machine-to-machine negotiations.

This means that much like quality of service (see Section 3), an agreed set of properties, i.e. a quantifiable way, is required to have Industrie 4.0 components negotiate about security levels for data exchange as part of their contracting. This is in line with the current suggestion to define the trustworthiness of a component in a quantifiable way, as discussed as part of the product criteria and the AG3 work on security model for the administration shell. A key decision will be how far security levels will be abstracted from the underlying (cryptographic) technology, i.e. whether we particular algorithms or key lengths will be referenced directly or not.

3 This is work in progress, so these topics might not be complete and/or final yet.

5. Service View for Network-Based Communication

The use of the administration shell for communication is the negotiation between an industry automation system in need to communication services and the Industrie 4.0 communication system (the communication network related assets wrapped by the administration shell) providing them. To this end, the AS must offer negotiation services which the automation system can use to call its communication needs, receive *offers* from the communication system, close *contracts* on a suitable offer (or escalate unsatisfactory situations), and eventually *transmit* data over the obtained communication services.

Overall, we propose the following services for the AS of the communication sub-system of Industrie 4.0 automation systems:

- Network access, allowing a service participant to enter into a resource (management) context (see section 2.1). This is the context in which negotiation on communication services takes place, meaning that the scope of connections and service quality is constrained by the resources belonging to the (logical) network. Services include:
  - Query addresses and network memberships
  - Request network access
- End to end connections, allowing a service participant to exchange data with another service participant with defined service quality. Services include:
  - Request end-to-end connection within or across networks
  - Notification on status changes
- Escalation of any kind of problem situation
  - Failure to enter a network
  - Failure to establish an end-to-end connection with desired service quality
- Horizontal negotiation, allowing network controllers within different organizational domains to collaborate. By establishing a common resource management context, machine-to-machine connections which cross company borders can be established, e.g. for 3rd party service applications.

Realizing these services is the task of network control systems as they are increasingly common in ICT systems.

6. Description of Administration Shell Facts /Sub-Models

6.1 Examples of Property Definitions for the Communication administration shell

Table 2 illustrates a technology-independent definition of properties related to communication functions. These properties might become part of the communication administration shell and they are to be referenced by the administration services introduced in Section 6.2.

The examples already indicate which kinds of discussions are needed. Does it make sense to directly use IP addresses or should the administration shell rather be restricted to (secure) Industrie 4.0 identifies (to be defined)? How to refine the notion of an address to its role, i.e. representing a network or a host address? Being network- or being host-related might simply be an additional semantic tag on the address variable.

Note that we do not propose specific identifier values for the individual services at this point.

Table 2: Examples of properties of network-based communication

Asset Type	IEC 61360 (excerpt)			
	Code	**Name**	**Short Name**	**Definition**
ISO/OSI Shared Network Vocabulary	*tbd*	network layer address	Address	IPv4 or IPv6 address
	tbd	network layer host address	HostAddress	Network part of IP address
	tbd	network layer network address	NetworkAddress	Host part of IP address
	tbd	host name	DnsHostName	DNS name of the host
ISO/OSI Application Layer Host Endpoint	*tbd*	Administration shell host identifier		AS host is also a component with a regular Code.
ISO/OSI Layer 1–4 QoS	*tbd*	quality of service vector	ServiceQuality	Vector of quality of service properties of a connection. For a network, this can be the lower bound of available service quality.
	tbd	Communication pattern	DataExchangePattern	Cyclic, event-based, etc.
	tbd	uni-directional delay	Latency	Pure communication latency. Higher level functions need to also indicate a processing latency. If rtt matters, we must use (latency-processing)/2 or the like.
	tbd	jitter	Jitter	
	tbd	availability	Availability	
	Tbd	reliability	Reliability	

6.2 Examples of Service Definitions for the Communication administration shell

To support the contracting of communication services, the services for negotiation these contracts are required as indicated in Table 3. Note that we do not propose specific identifier values for the individual services at this point.

It needs to be investigated if these different services for negotiation can be abstracted into a generalized negotiation service pattern where the subject of negotiation (network access, QoS) is passed as a topic using exactly identifiers (IDs) as indicated. Such an activity is ongoing within the Plattform Industrie 4.0 AG1 sub-working-group Ontoloty.

Table 3: Examples of negotiation services for communication (IEC61360 codes to be discussed)

Asset Type	IEC 61360 (excerpt)			
	Code	**Name**	**Short Name**	**Definition**
Industrie 4.0 Network	*tbd*	*Communication network interface*	*CommunicationNetworkInterface*	*Negotiation of network member-ship.*
	tbd	discover local networks	Discover	Obtain all locally available I4.0 networks. We presume there is a know default join network with a well-known identifier and credentials for bootstrapping communication.
	tbd	request network access	RequestAccess	Request access to the specified network, meaning essentially access to the related broadcast domain and being able to put forth connection requests from within that network.
	tbd	grant network access	RequestAccessResponse	Network management accepts or rejects the request with a reason.
Industrie 4.0 End-to-End Connection	*tbd*	*Communication connection negotiation interface*	*ConnectionNegotiationInterface*	*Negotiation of resource reservation for end-to-end connection. This does not mean there is an actively monitored connection.*
	tbd	query single QoS property	QuerySingleQoS	Leaving at most one QoS property blank, obtain the best possible value for that blank property.
	tbd	request connection	ConnectionRequest	Request end-to-end connection with defined QoS.
	tbd	offer connection	ConnectionOfferOrUpdate	Response to request, confirming the requested QoS level or offering an alternative. This may also be used to inform about degradation of a previously existing connection. Needs virtual reservation of resources, not necessarily in the network equipment but in the management component.
	tbd	accept offer	ConnectionAccept	Accept the offer to confirm the request.
	tbd	connection ready	ConnectionReady	Based on the acceptance of the offer, the network management component implements the resource reservations on the net-work and then signals readiness. Communication may now begin.
	tbd	release connection	ConnectionRelease	Indicate that the connection is no longer needed. This should be called only when the connection is not in actual use anymore. No confirmation is expected.

7. Reference Communication Scenarios

In section 0, we already identified connections and networks as assets.

Their management functions (and thus the related part of the administration shell) change with the context in which communication paths are established within or across networks and companies.

Table 4 defines a set of communication reference scenarios whose characteristics define the needed functions to be exposed in the administration shell. The scenarios are put in the context of typical automation applications and they reference the assets as defined in Section 2 (connections, networks, gateways, …)

Along the way from the "field to the cloud", see that the needs for availability and determinism relax while the need for security notably increases. Particularly security exceeds traditional expectations due to the flexibility with which connections are negotiated between autonomous machines.

Table 4: Reference scenarios for Industrie 4.0 communication

Application Example	Connection Scenario/Topology	Scenario Characteristics Requirements for involved network(s)	Administration Shell Features
Machine-internal communication (factory automation)	Within same local (module-internal) network	Very high expectations on determinism and availability, possibly very relaxed security requirements Any access from outside of that network only through (application-layer) gateway.	Note: This is not necessarily a subject for Industrie 4.0 in case of complete encapsulation of the network.
Device to controller (process automation),	Within same local network	High expectations on determinism and availability, possibly relaxed security requirements. Remote access on network layer conceivable with strict security constraints.	Vertical negotiation between devices and network management systems regarding network resources: • Network membership • deterministic end-to-end connections
Operation, engineering, monitoring, production planning, process optimization, data analysis	Other local network in same organization	Varying expectations on availability, relaxed determinism, basic security requirements. Remote access on network layer conceivable with strict security constraints.	Previous features plus: Discovery of end-points located in other networks.
Remote operation	Remote network in same organization	High expectations on availability, somewhat relaxed expectations on determinism. Very high security requirements.	Previous features plus: Interfaces for horizontal negotiation between network management systems regarding network resources and security.
3rd party service	Remote network in other organization	Relaxed expectations on availability or determinism. Extremely high security requirements.	See above.
Overarching network management (path negotiations across org. units, wired and wireless coexistence management)	Both local and remote networks (depending on where the end-points reside)	Access to communication resources entirely depends on the level of trust that can be established. This may easily differ within and among companies.	This in fact provides the AS whose features are discussed above.

8. Conclusions and Outlook

The current first edition of the discussion paper outlines basic concepts for an administration shell for network-based communication in an Industrie 4.0 environment. It is a first approach for integration of communication networks with Industrie 4.0-comforming industry automation. Foundation for the developed approach is the RAMI 4.0 model.

In summary, the following key points have been identified:

- Communication as essential enabler of Industrie 4.0:
  - Communication can be considered as an asset.
- There are two views on network-based communication:
  - Network-based communication as *"subject"* and as *"object"*
  - This corresponds to a *provider* and a *user* of communication functionality.
- The main goals for integrated of ICT into automation domain are:
  - Hiding of complexity, expose functionality of assets, not their detailed properties or conditions
  - Negotiate about this functionality
  - Key assets are therefore logical networks and connections, not networking equipment.
- It is essential to develop a standardized representation of communication functionality through properties
  - Standardized representation of QoS needs/capabilities through properties
  - Standardized representation of security aspects through properties.
- The administration shell exposes these properties and negotiation functionality.

These topics have a number of interrelationships to other working groups and sub-working groups within Plattform Industrie 4.0. Furthermore, the topics touch various Platform-external R&D- and standardization-related initiatives across Telco, IT and Industrial Internet areas. Many related

topics are still in an (early) research and/or standardization phase (e.g. the "Intent-based networking" at IETF). Therefore, a number of questions are still open and need to be further elaborated:

- The final properties and (negotiation) services need to be defined for
  - Network communication
  - Network management
  - QoS
  - Security; incorporate identification and authentication schemes from other working groups
  - Safety.
- A minimum sub-model for communication for any basic Industrie 4.0 component is required.
- Wired and wireless coexistence questions have to be investigated in the Industrie 4.0 and administration shell context.
- It has to be identified which interfaces and functions need to be standardized to ensure global interoperability.

References

1. https://www.plattform-i40.de/I40/Redaktion/EN/Downloads/Publikation/network-based-communication-for-i40.pdf?__blob=publicationFile&v=4

   https://www.plattform-i40.de/I40/Redaktion/DE/Downloads/Publikation/netzkommunikation-i40.pdf?__blob=publicationFile&v=7

2. IEC/EN 62657-2 Industrial communication networks – Wireless communication networks – Part 2: Wireless coexistence

3. https://tools.ietf.org/html/draft-hares-ibnemo-overview-01

4. ETSI GS NFV-EVE 005 V1.1.1 (2015-12) („NFV Ecosystem; Report on SDN Usage in NFV Architectural Framework")

5. DIN SPEC 91345:2016-04: Reference Architecture Model Industrie 4.0 (RAMI4.0)

6. [VDI/VDE GMA FA 7.21: Industrie 4.0 - Service Architecture – Basic Concepts for Interoperability, VDI/VDE GMA (Gesellschalft für Mess- und Automatisierungstechnik), Oktober 2016

7. https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf

8. RFC 4641, Network Configuration Protocol (NETCONF), https://tools.ietf.org/html/rfc6241

9. RFC 6020, "YANG - A Data Modeling Language for the Network Configuration Protocol (NETCONF)", https://tools.ietf.org/html/rfc6020

10. IEC/EN 62657-1: Industrial communication networks – Wireless communication networks – Part 1: Wireless communication requirements and spectrum considerations

11. QoS in Cellular Networks; Dushyanth Balasubramanian, Washington University in Saint Louis; Sept 2006

12. International Electrotechnical Commission Glossary, http://std.iec.ch/terms/terms.nsf/0/FC879D1A04286F52C125775B004B942D?OpenDocument

13. Network software glossary ; WhatIs.com/Techtarget

14. Jit Lim (14 December 2010). "Is BER the bit error ratio or the bit error rate?". EDN. Retrieved 2015-02-16.

15. Plattform Industrie 4.0, "Technical Overview: Secure Identities", Working Paper, http://www.plattform-i40.de/I40/Redaktion/EN/Downloads/Publikation/secure-identities.html

16. Plattform Industrie 4.0, "Technical Overview: Secure cross-company communication", Working Paper, http://www.plattform-i40.de/I40/Redaktion/EN/Downloads/Publikation/secure-cross-company-communication.html

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This paper summarises the research findings of the „reference architectures, standards and norms“
Group of the Plattform Industrie 4.0.