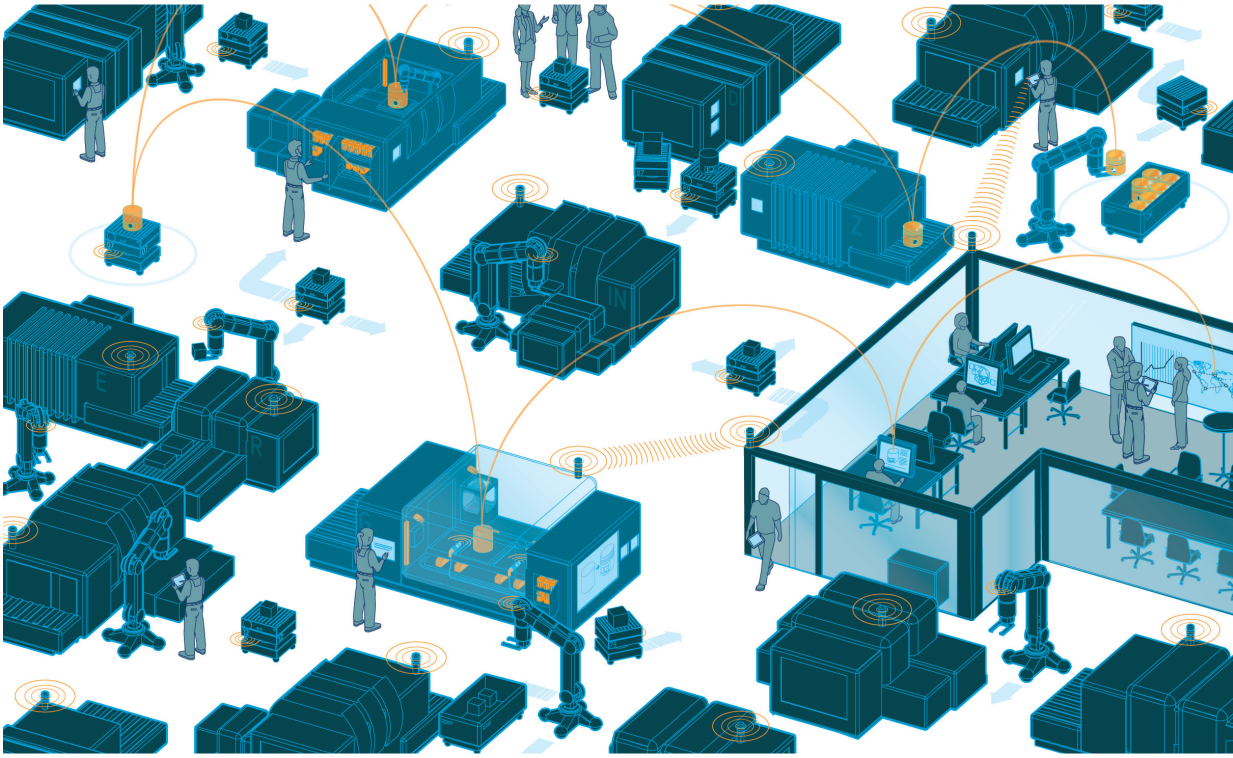
ZVEI: Die Elektroindustrie

Communication in the Context of Industrie 4.0

What challenges does industrial communication face regarding digitisation and Industrie 4.0?



White Paper – Part 4

Automation Division

Communication in the Context of Industrie 4.0

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Created by the working group System Aspects

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This White Paper is part of a series:

Part 1 – Industrial Software 4.0?

Part 2 – Electrical Connectivity for Industrie 4.0?

Part 3 – Consumer Devices in an Industrie 4.0 Environment

Part 4 – Communication in the Context of Industrie 4.0

... further parts to follow

A White Paper from the working group System Aspects in the Automation Division

Within the German Electrical and Electronic Manufacturers Association (ZVEI), the Automation Division works on topics and challenges from the perspective of manufacturers and users of automation equipment. By far the most discussed topic in this context is Industrie 4.0 and the associated potential, architectures, standards and technologies. The working group System Aspects is conscious of the significant importance of this topic area and has set itself the goal of examining and identifying the specific potential impact on basic technologies in our domains. This is being pursued as part of a series of white papers, and this document on the subject of industrial communication is the fourth part in this series. Industry 4.0 is inconceivable without connectivity and communication. The elements of the various value chains exchange different types of data for different purposes in order to fulfil their respective tasks. This will be achieved in the future by service-oriented architectures (SOA). The associated changes are discussed and the future potential and risks are described in this whitepaper.

Frankfurt am Main, March 2019

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1 Introduction

Network-based communication is the most important aspect of Industrie 4.0. In order to perform their respective tasks, the elements of the various value chains exchange a variety of data for different purposes. Most of this data is conventional process data, required to carry out productive functions such as measurement or positioning. Management functions (e.g. parametrisation and diagnostics) provide target value settings to the automation components defining the general requirement for productive function execution. Additionally, product- and function-related data (operating data) is generated in these components to indicate the status of the process and the components' condition. In the future, (big) data analysis and enterprise communication (convergence of information and operation technology – IT/OT) will play an increasing role. This is based on the assumption that the rather fixed system structures of today's classical automation pyramid will disappear. The future communication will be based on individual demands and in flexible structures changing dynamically over their lifetime.

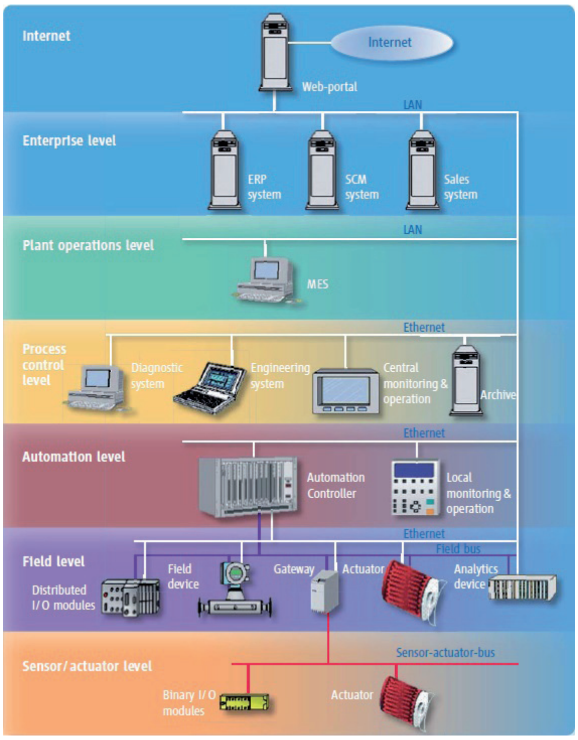
Specific optimized communication technologies have already been used in production for many years, such as real-time communication networks based on fieldbuses, Industrial Ethernet and Industrial Wireless. In addition, standard IT networks and protocols are increasingly being adopted, especially for less time-critical data transfers or for additional functions, like web-based solutions in automation, e.g. to configure devices using a web browser.

The increasing integration of classical IT structures and telecommunications, in particular mobile communications, and the evolution of the Internet of Things (IoT) influence the technological development of communication systems. Affordable new hardware components and configurable software stacks for communication protocols promise, on the one hand, requirement-oriented communication with high bandwidths and fast response times and, on the other hand, networking of a large number of widely distributed components with modest time requirements.

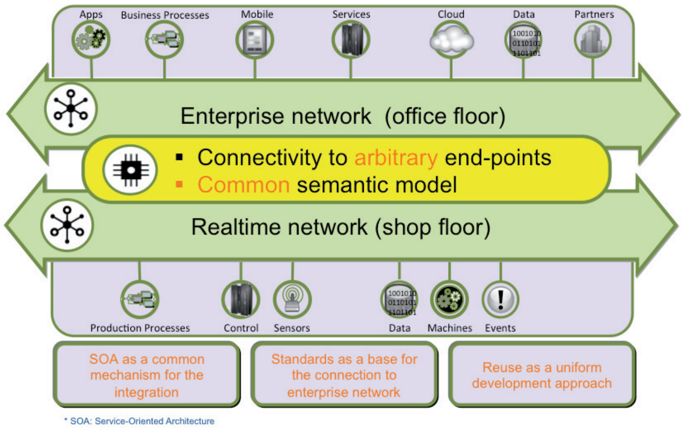
The situation described shows an increase in the complexity and heterogeneity of networking.

Ensuring that the network's properties are maintained requires a much more powerful and flexible network management than practiced today. On the other hand, heterogeneity requires a decoupling of the specific communication structure from the applications. This is achieved by introducing service-based concepts according to a service-oriented architecture (SOA), allowing an abstraction from the user viewpoint and hiding specific communication details.

Fig. 1: From the automation pyramid to Industrie 4.0



Source: Prof. Martin Wollschlaeger, TU Dresden



Source: ZVEI

Industrial communication, in the context of Industrie 4.0 and other developments such as 5G communication, is facing new challenges regarding the situation outlined above. Automation manufacturers, systems integrators and end users are increasingly confronted with questions such as: "How will the topics mentioned affect the implementation of communication in Industrie 4.0?", "What requirements can be developed based on this?", "What paradigms, technologies and solutions will be relevant in the future?". For this reason, we have published this white paper, "Communication in the Context of Industrie 4.0". Based on different scenarios, requirements for communication in the environment of Industrie 4.0 will be discussed. The requirements for security are, of course, adequately taken into account.

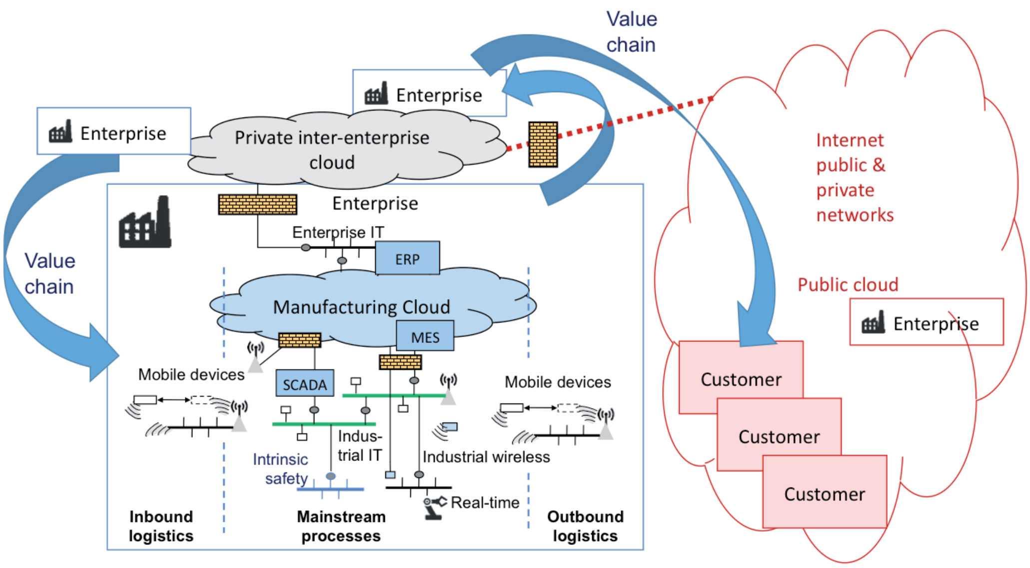
2 The Current Situation

Industrial automation is caught between dynamic technological developments and social and economic challenges. The adaptation of concepts and solutions from information technology affects the functionality and structure of automation solutions and their components just as much as changes and flexibilisation in business processes. Topics originating from the world of IT such as cloud and fog computing, Industrial Internet of Things (IIoT), big data and data analytics, middleware, virtualisation or wireless communication have established themselves in the world of automation and will continue to expand. They are also essential from a business viewpoint, as they allow the introduction of new paradigms and establishing dynamic interaction between the partners of the value chains. Substantial changes in the market regarding business models and partner structures can be expected at the same time.

Digital transformation will represent both an opportunity and a challenge for industrial automation. It will lead to new functionalities and system concepts, but also have to ensure the migration of existing solutions. Despite the great potential of disruptive innovations, it is neither financially beneficial nor feasible introducing new technical developments without paying attention to the specific requirements of the automation domain or incorporating existing models, system concepts and solutions. There is no doubt that these technologies have huge potential, and it is necessary to develop suitable concepts and solutions to increase it and make it accessible to those involved in the value chain.

Regarding the area of conflict described above, communication between the various systems and components becomes even more important [1] and the expected flexibility cannot be achieved without a variety of communication solutions. The traditional separation of communication solutions into process-oriented real-time communication (shop floor) and enterprise communication (office floor) is disappearing (Figure 2). The introduction of web technologies and Industrial IoT created additional communication paths for data exchange with the components of the shop floor (e.g. using IP-based protocols), for example accessing configuration and operating data. Especially data-driven functions such as condition monitoring, predictive maintenance, etc. are easier to implement compared to the classic networking hierarchy. On the downside, these additional communication channels can result in considerable heterogeneity, causing additional effort in terms of engineering, management and security.

Fig. 2: Aspects of communication in industrial value creation processes (based on [1])



Source: Prof. Martin Wollschlaeger, TU Dresden

The main task of industrial communication remains the production-related process communication (production processes in Figure 2). Various communication solutions are typically used here, optimized for their specific purpose. In addition to the demand for real-time communication, there are often requirements regarding the dynamics of processes and isochronous operation (e.g. in motion control), but also explosion protection and intrinsic safety, redundancy and availability. This has led to the development of specific communication systems such as field buses, sensor/actuator buses, Industrial Ethernet and Industrial Wireless. These systems are characterized by frequent updating and short life cycles for the transmitted data, and by small data structures. Often, two paradigms are used for communication. The first one is cyclic communication for production data, while the second one is acyclic, demand-driven communication for parametrisation, diagnoses and alerts.

These communication systems will be integrated vertically along the functional hierarchy, allowing data exchange with programmable logic controllers or automation controllers, with supervisory control and data acquisition (SCADA) solutions or complex control systems, with manufacturing execution systems (MES) and enterprise resource planning systems (ERP). Components will be integrated horizontally (within a functional level) and vertically (from the sensor to the control level and MES, right through to ERP). Especially for MES and ERP cloud-based systems will increasingly being used, even though this „manufacturing cloud" will often be a company-owned cloud (on premise).

The horizontal integration includes all parties involved in the value chain. It starts with the integration of logistics processes: production logistics within the production and processes for delivering raw materials (inbound logistics in the figure) or finished products (outbound logistics). Logistics information is often digitally accessible via mobile devices, mostly directly integrated into the warehouse and inventory management in the MES. Additionally, there is cross-company communication between the partners involved, increasingly implemented via a private, cross-company cloud ("inter-enterprise cloud").

The third integration dimension covers the temporal relation. It contains the communication between the different systems along the life cycle phases of a production system. Relevant topics are e.g. the provision of planning data at runtime, of specification data for process-related simulation and optimisation or for predictive maintenance, but also communication with end customers throughout the product lifetime with the aim of offering services and collecting information for product improvement (product life cycle management).

The availability of technology – under the keyword „Industrie 4.0" – as mentioned before permits end-to-end digitisation and networking, thus making it possible to cover the topics described above. These are also reflected in the use cases published by the Industrie 4.0 platform.

The continuous digitisation in Industrie 4.0 is intended to better meet the requirements of users. Regarding industrial communication, the following topics are particularly important:

Modernisation of existing automation solutions, migration capability of existing solutions (installed base)

Industrie 4.0 communication offers added value for customers if corresponding services allow continuous use of existing infrastructures. It shall be possible to „dock" on the various levels of the classic automation pyramid. Typically, the costs of replacement increase going closer towards the base of the pyramid. At I/O level, there are often large numbers of units associated with a cabling effort that should not be underestimated. When modernising automation components, existing communication infrastructure is often re-used. Installing new cables is costly and error prone. Replacing field bus components (e.g. changing from a classic field bus to an Ethernet architecture) is associated with considerable financial costs. An existing communication infrastructure should therefore be as easy to integrate as possible, will coexist with modern architectures over a certain period and then be replaced if necessary. By using appropriate gateways or proxies, these components can be reused with a good cost-benefit ratio. In connection with further software functions, existing plants or parts thereof can be made compatible with for Industrie 4.0.

Increased user benefits by components with extended communication capability

Components offering flexibly usable communication channels in addition to process data communication, generally allow an easier data exchange with other components. This enables the introduction of data-driven applications at diverse levels because the components can provide the required data much more easily.

Simplification of project planning and configuration of communication

Nowadays, communication components still need to be actively integrated into existing systems. This affects both the network configuration (address, net mask etc.) and the data provided. New participants in communication shall be able to be integrated as easily as possible into existing architectures in the future. Then the integration of a component into a network can take place automatically; the user may only confirm the interaction of the components. A new component in the communication network will be able to announce its functions and data, allowing other devices to access the information at runtime, e.g. maintenance data. Today, existing device data needs to be made further available, for instance in a process control system by project engineering. In the future, the process control system could subscribe to the data directly on the device (global data, publisher/subscriber models). In this way, plug & work scenarios could be implemented at network level in just the same way as at application level.

Communication in the context of the life cycle / the lifetime

This addresses the capability of products to obtain information about their use and their environment and to communicate this information not only to users, but also to the product's manufacturer. This covers all product life cycle phases and all lifetime phases of a product instance. This information is a key prerequisite for manufacturers for continuous improvement and further development of products, aiming to improve their functionality, achieve higher value, and ultimately increasing customer satisfaction. Communication across a product's lifetime, in particular the improvement of internal processes in engineering and operation, allows users to support e.g. predictive maintenance. Additionally, usage information is also needed for optimisation so that processes and resources can be adapted to fulfil a variety of requirements.

Improved utilisation features by new technologies

Introducing new, improved communication solutions should lessen or prevent the technological aging of components caused by long usage times. Regarding security, for example, the long usage time of plants and devices means that today there are still many communication protocols and devices in use for which security by design has not been implemented. This situation can be improved by integrating Industrie 4.0-compliant communication components and services. These then act as proxies, encapsulating the access to the old devices. At the same time, however, it has to be ensured that the new communication channels of the systems cannot be used as a gateway for cyber-attacks.

Improved component maintenance

Increasing the processing power in the components offers better possibilities for self-monitoring and optimisation. Additional components, integrated for example directly via IoT communication, support this trend. This results in more flexible system solutions, e.g. for maintenance tasks. However, this has an effect on communication, as new application relationships are created and corresponding communication relationships have to be established.

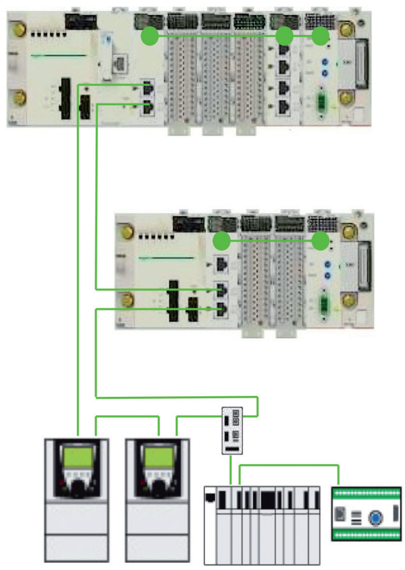
Improved interoperability

Integrated solutions offer especially added value for plant operators, if they can also be implemented in heterogeneous device structures. Communication services should ideally function the same way for devices from different manufacturers. Focusing on services and the associated abstraction of interfaces improves this interoperability and reduces integration efforts and costs.

3 Industrial Communication Requirements

Communication serves to fulfil application functions in a networked system. Requirements for communication solutions and the selection of suitable technologies are influenced by concrete application aspects. For a detailed requirements analysis and the selection of implementation options, the various communication aspects need to be described in more detail. Subsequently, this is done using a frequency converter as an example.

Fig. 3: Integration of drive technology into automation technology (example)



Source: Schneider Electric

Modern frequency converters are equipped with Ethernet interfaces. The device configuration may be done using integrated web servers, eliminating the need for special PC software tools and drivers as well as for special cables. Using an auto discovery service and identification via the device's MAC address, it is possible setting up a connection without having to activate a DHCP server or assigning a specific IP address.

In addition to the tasks of a frequency converter, to control drives in real time using set points, it can also perform a variety of other functions, such as measuring and storing energy values. They can be retrieved for analysis, which is a use case for big data and data analytics.

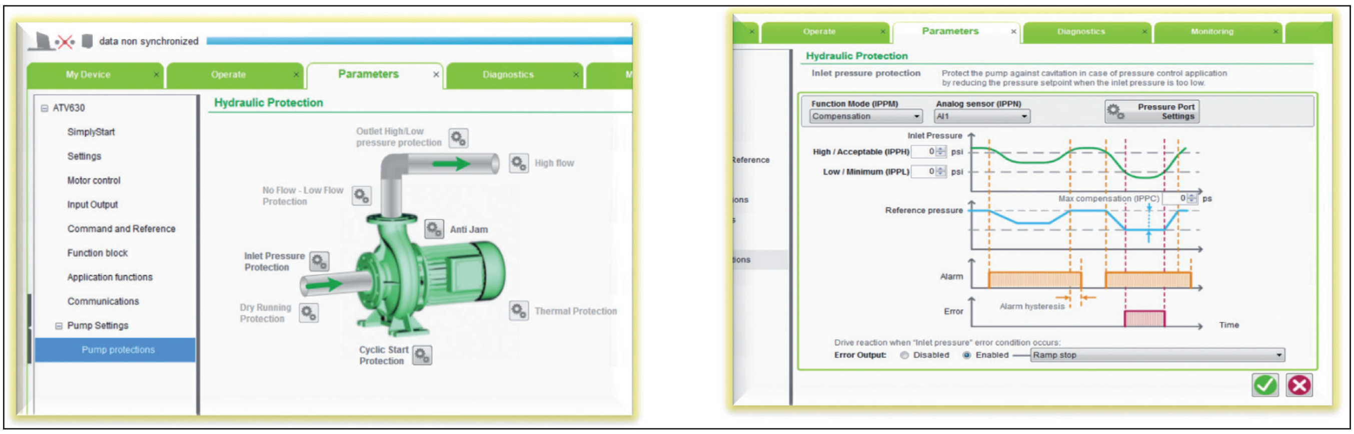
In Figure 3, the frequency converters as well as the decentralized rack of the automation system are integrated into an Ethernet network. The ring structure provides more fault tolerance. If it is interrupted at one point, communication can continue using the other route.

Engineering tools can be used for configuring and parametrising the drive functions and for connecting to the automation technology. In addition to data, these tools also contain specific dialogues (Figure 4).

In case of an error, frequency converters can simply be replaced using the "Faulty Device Replacement (FDR)" without the need to configure the device beforehand, for instance with an IP address.

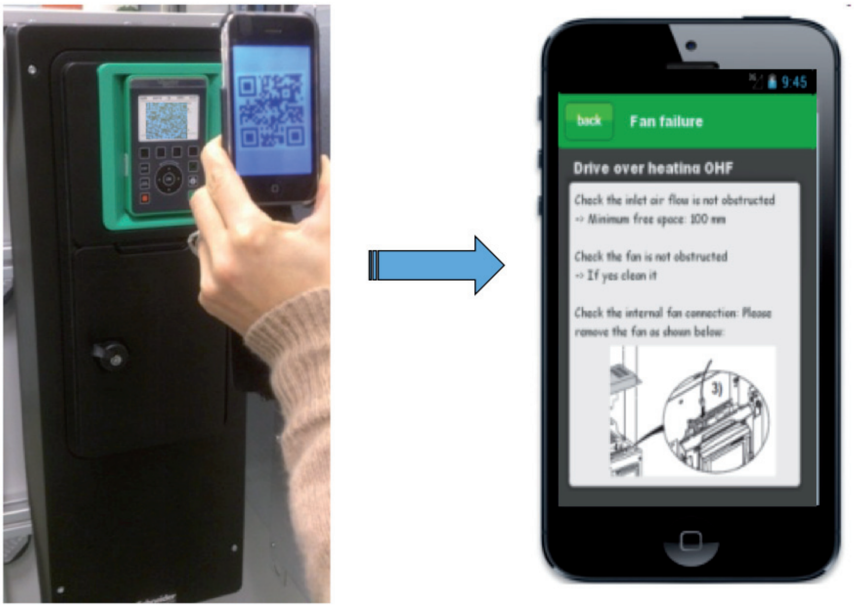
If the frequency converter detects an error during internal monitoring, it generates a dynamic QR code, appearing on its display. Additionally, the display turns to red for easy location in a plant installation.

Fig. 4: Examples of dialogues for configuring and monitoring a frequency converter



Source: Schneider Electric

Fig. 5: Using a dynamically generated QR code to transmit error information



Source: Schneider Electric

Using this QR code, the maintenance staff are able to obtain information about the error from the manufacturer's maintenance web site using a smart device, and instructions how to put the device back into operation (Figure 5). This function eliminates the need to carry digital or paper manuals and the manuals are always up to date. Additionally, the manuals are displayed in the corresponding language of the "smart device".

By further considerations and by drawing some generalisations, very different scenarios can be identified. Three will be discussed in more detail as typical candidates in the context of Industrie 4.0.

Scenario 1: "Real-time data communication in flexible production systems"

This scenario places an emphasis on process data communication. The main purpose of the communication is the adequate data provision for realising the networked functions in a production system. In the example, this refers to the communication of the frequency converter's set points and actual values. Functions such as measurement, controlling and positioning require specific communication characteristics. Typically, in this context the term Quality of Service (QoS) requirements is used.

In this scenario, one key QoS requirement is to guarantee data delivery in real time, depending on the dynamic behaviour of the application. In addition to data being provided on time this often includes data being provided equidistantly. This requires both a sufficient bandwidth or low transmission time, and a low variation (jitter) in the telegram arrival times. The typical data structures are rather small (only a few bytes per measurement value or setpoint). The transmission of such data is typically cyclic and sometimes event-based.

Another substantial requirement is the response time for asynchronous events such as process or system alarms. They have considerable relevance for supervising the process and shall be communicated with high priority and reliability. Additionally, there are events generated in the network infrastructure components that are relevant for the communication network's operation. Besides the correct sequence of events, which can be ensured using timestamps, the reliability of the transmission, e.g. supported by acknowledgement mechanisms, also plays a key role.

It can be assumed that in the future the current process data communication requirements will increase regarding transmission frequency and individual data size due to the introduction of new sensors (image data). It is also to be expected that the overall communication volume will increase, for example, providing additional process data for a real time analysis or as a result of increasing function distribution in an Industrie 4.0 system.

In addition to these transmission-specific aspects, further requirements are also already covered today like the communication system's availability, or security and safety properties. These requirements will most likely increase in the future, especially with respect to a more flexible and open value chain.

Today's communication systems have been developed and introduced with a focus on meeting the mentioned requirements, such as field buses, Industrial Ethernet and Industrial Wireless. It is expected that the technological development will lead to much more heterogeneous systems in which different transmission technologies and protocols have to work together.

Scenario 2: "Communication for engineering and asset management"

This scenario focuses on the usually acyclic data transmission of typically less timecritical data, used for configuration and parametrisation as well as for providing status information of functions and resources. This includes tasks such as engineering of functions, devices and network as well as condition monitoring, optimisation and asset management. The parametrisation of the frequency converter is such an example. Regarding the relevance of engineering information, users frequently demand confirmed communication services to ensure the reliability of engineering. Moreover, an additional guarantee of data integrity is often required, which is especially important for engineering safety and security functions. In addition to individual parameters sets, larger data quantities (bulk data) are often exchanged, supported by appropriate services.

Engineering relies on communication between a software tool and a component either in a dedicated "network" (e.g. in a workshop), or directly in the production system. Regarding the production system, the priority of the process data communication has to be ensured.

Digitisation is resulting in new opportunities for engineering, such as digital provision of descriptions, documents, simulation models, etc. leading to a reduction in commissioning time and providing a direct benefit.

Nowadays, asset management tasks are implemented partly on the device (e.g. self-monitoring [2], self-adjustment) and are partly executed based on status data in superimposed systems. The increase in processing power in the components will lead to improved data aggregation and to a reduction in data exchange, but there will also be increased communication with other components to obtain context information. Data provision through monitoring also leads to increased communication. It can be assumed that traceability (audit trail) of changes in the components will become increasingly important, especially if the changes need to be documented reliably throughout the typically long usage times of automation systems. This will also lead to an increase in communication together with the provision of other usage-relevant data obtained in the device over the lifetime.

Today's communication solutions offer optimized functions for acyclic communication of parameters and status data. Additionally, IT protocols based on TCP and UDP such as the OPC UA Binary Protocol, SNMP for network management or HTTP for web-based solutions are increasingly being used. Here as well the heterogeneity of communication networks will lead to additional requirements related to coexistence and functional continuity in the future.

Many of the functions described address the management of networked components and are made available in Industrie 4.0 through their asset administration shells. This includes engineering functions at runtime (diagnosis and information functions, plug & produce, self-adaptation, etc.), as well as access to documentation, simulation data and life cycle data at type and instance level.

Industrie 4.0 therefore defines service-based communication providing simple, semantic-free transfer services, management and interaction services (platform services) as well as application-specific services with explicit semantics. Both tight and loose couplings between the partners involved are used here. For an efficient implementation and use of the asset administration shell concept, it will be essential to efficiently map these services to the specific transmission protocols and to support platform services. For example by using explicitly defined network functions and by the self-description of network components and functions.

Scenario 3: "Product data communication over the life cycle"

For the efficient use of (automation) products in the value chains of "plant and process development" or "plant construction and operation" as per [3], it is becoming more and more important to specify their properties when planning or designing the products (type data) and collecting data during production (instance data). The provision of data from the engineering and the usage context of a product instance is becoming increasingly important for maintenance and optimisation tasks.

Furthermore, it is essential for the "product and product line development" and "product production and after-sales services" value chains [3] to obtain information from product instances in operation in order to optimally support the continuous improvement and further development of the product. Looking at the example of the frequency converter, the manufacturer could thus access the life cycle data of installed frequency converters in agreement with the user and analyse this data to improve the product.

There are various options for communicating such information. On the one hand, a product could store and process the data itself, transmit it – continuously or intermittently as required – to the product manufacturer resp. receive such data. On the other hand, the data could be collected, prepared and made available using the system's production network in which the product is used as a component.

If the product transmits its data independently via a dedicated communication system, for instance using mobile communication, general aspects of coexistence shall be considered. If the communication takes place using the production network, there are not only requirements regarding the data quantity (bulk data), but also for authorisation and security in general.

If via product data communication, a specific instance will be affected, for example by a firmware update, it is important to pay attention to the organisational prerequisites, such as manufacturer approval [4], and the technical and application requirements such as the plant operation status.

The scenarios described lead to different requirements for industrial communication. In some cases, it is possible to draw quantitative conclusions, while in other cases only qualitative statements can be made. Various technical committees have prepared and published documents that help users to specify their requirements and advise communication solution manufacturers on how to describe their products' capabilities. The clear definition of core variables and influencing factors in [5] shall be mentioned in particular. Further requirements can be found in [6] and [7].

Table 1 sums up the relevance of typical requirements for communication solutions. The criteria listed in this table do not claim completeness, but are simply intended to provide a rough idea of how to formulate requirements based on the specific application case. They are therefore based on the scenarios described and avoid to provide specific values.

Table 1: Relevance of typical communication solution requirements

Requirement	Process data (real-time) communication			Communication for Engineering and Asset Management	Product data communication
	Process automation	Factory automation	Motion control		
Timing aspects					
Data rate	+	++	++	+	–
Jitter	–	+	++	–	–
Cycle time	++	++	++	–	–
Update time	++	++	++	+	–
Synchronisation	+	+	++	–	–
Time stamping	++	++	++	+	+
Application aspects					
Small data structures	++	++	++	+	-
Large data structures	–	–	–	++	++
Device replacement at runtime	++	+	+	–	–
Robustness aspects					
Availability	++	++	++	+	–
Redundancy	++	+	+	–	–
Recovery Time	+	++	++	–	–
Safety	++	++	++	+	–
Security	++	++	++	++	++
Coexistence	++	++	++	+	–
Mobility					
Mobile Assets	+	+	++	+	++
Network coverage	++	+	+	++	+

++ high relevance, + relevance, – low relevance

Source: ZVEI

There are further general requirements for communication solutions that can be derived from the environment in which they are used. This includes the specific environment conditions (temperature, vibration, humidity, EMC, etc.), which require robust solutions correspondingly. Interoperability between products from various manufacturers has always been a key requirement, which is likely to augment, regarding the increasingly heterogeneous nature of systems. The requirements list also includes the qualification and certification of solutions.

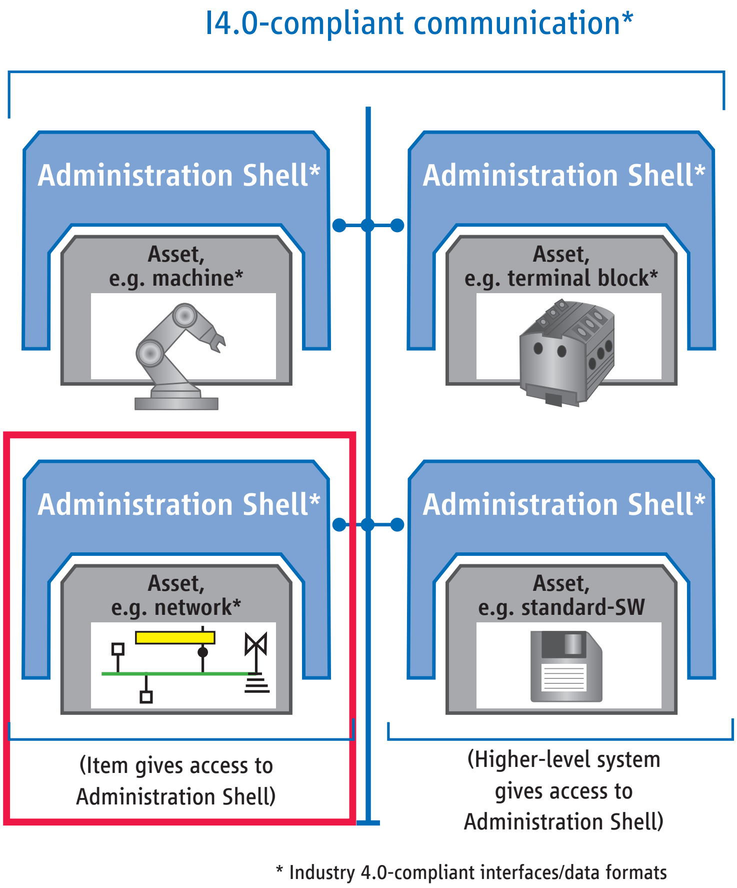
4 Communication in Industrie 4.0

All the integration processes described are addressed in the context of Industrie 4.0. This means that it is also necessary to support all the specified interactions and communication relations. Communication solutions shall meet the requirements resulting from the interactions.

To implement a single technical solution that covers all the specified requirements will hardly make economic sense. It can be assumed that a heterogeneous communication structure will be implemented in an Industrie 4.0 system. For this to be implemented and used with reasonable effort, the solutions for the associated engineering, operation and management need to be as standardized as possible.

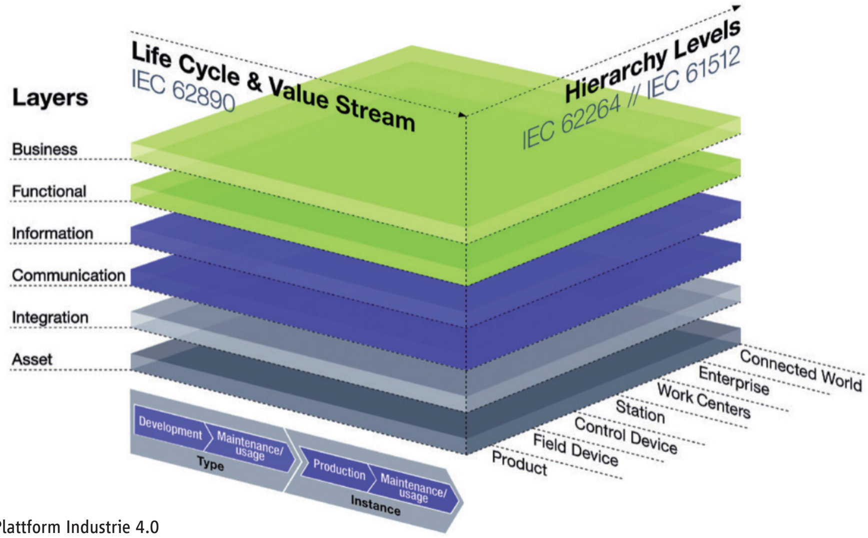
One suitable solution for this is the concept of the Industrie 4.0 component [8]. An asset administration shell in Industrie 4.0 not only transforms physical assets such as a device or machine into Industrie 4.0 components (Figure 6), but also intangible assets such as plans or functions. Even a communication relationship or an entire network can constitute such an asset. The asset administration shell covers the relevant aspects of the asset, following the specifications for the "layers" (Figure 7) detailed in the reference architecture model for Industrie 4.0 (RAMI 4.0) [9].

Fig. 6: Asset and asset administration shell form an Industrie 4.0 component (based on [8])



Source: ZVEI

Fig. 7: Classification of communication in the reference architecture model for Industrie 4.0 (RAMI 4.0)



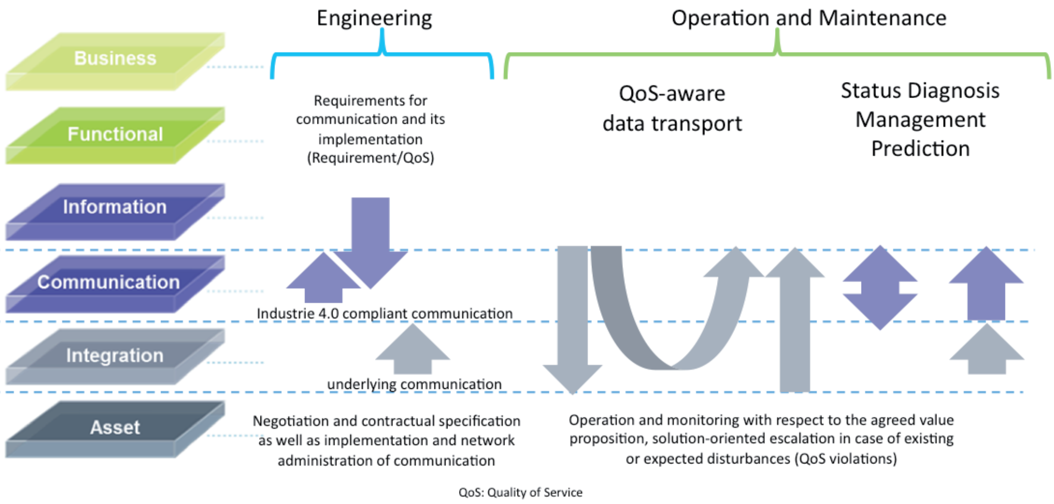
Source: Plattform Industrie 4.0

Based on the Industrie 4.0 component concept, the properties of a communication relation or network are represented in corresponding sub-models in the asset administration shell. The process of establishing the concrete design of the sub-models has just begun and will be continued. The sub-models are accessed using Industrie 4.0-compliant services. As a result, the properties of a component can be accessed in a standardized way. This mode of access takes place for the tasks of engineering and communication management.

The various phases in the life cycle require different interactions between the components. In the engineering phase, particularly the requirements for the later process data communication during operation are defined. Resulting are the QoS requirements, which are implemented by a selection of suitable components. The requirements also serve as basis for developing the service level agreements contracted between the communication partners involved or with the infrastructure providers. In the operating phase, the adherence to these agreements is monitored. An appropriate escalation strategy and reliable system behaviour (e.g. substitute value strategies, graceful degradation) shall be established to ensure that the system is always operational.

Process data communication between the components can also take place in a non-Industrie 4.0-compliant way. This permits

Fig. 8: Communication in various phases of the life cycle



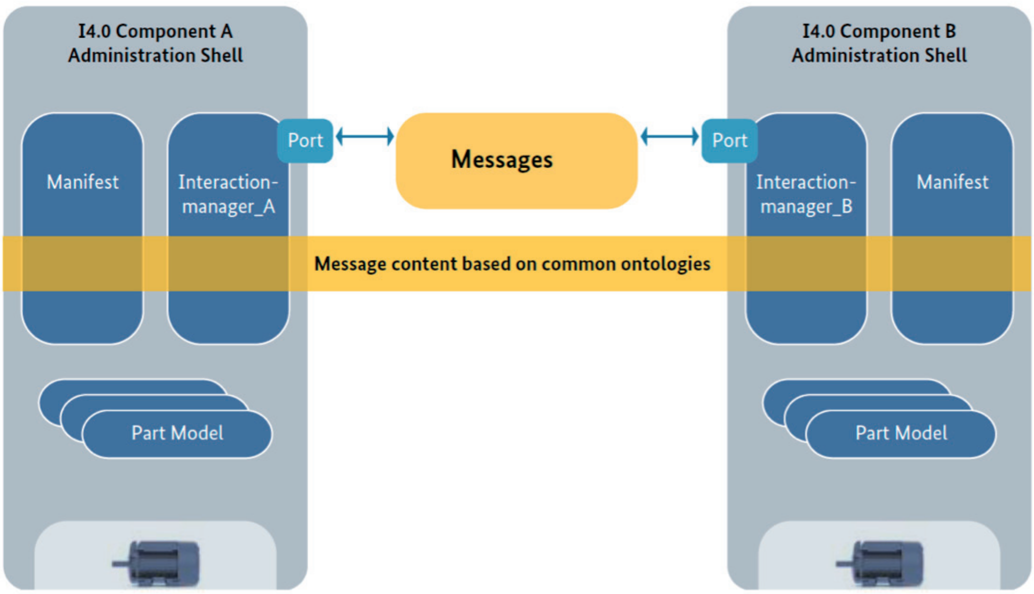
Source: Johannes Kalhoff, Phoenix Contact taking into account application-specific requirements in the sense of Quality of Service, for instance regarding real time. Such communication is assigned to the integration layer of RAMI 4.0. In contrast, Industrie 4.0-compliant communication is service-based and defines the communication layer in RAMI 4.0.

Considering the concept of communication from the application viewpoint, it can be divided into various sub-areas. Besides the actual application relationship, where data is exchanged between applications as interaction or function calls occur, it is also necessary to consider the production services, administrative services and transfer protocols, which ultimately implement the communication. Therefore, a heterogeneous service and protocol environment is used here to map an application relationship using several paths (communication relationships).

The functions, data and objects of the communication partners involved are relevant for the application viewpoint. Unified and to some extent standardized data models such as OPC UA have gained significance in automation for this purpose and will play a key role in the future. In the context of Industrie 4.0, these developments are integrated using the sub-models of the components' asset administration shells. The functions belong to the functional layer of RAMI 4.0, whereas the data structures are located in the information layer. By using semantic descriptions, the required flexibility in the application relationships during the usage phase is achieved.

Significant here is that the requirements from the application viewpoint determine the communication requirements, including the cycle time of data calls, the required data volume and possible real-time conditions. It is necessary to derive quality of service (QoS) definitions to achieve this. The mapping – negotiated dynamically (by interaction managers in Industrie 4.0) – of the application relationship to concrete communication relationships depends on this (Figure 9).

Fig. 9: Negotiation of requirements and properties by interaction managers [10]



Source: Plattform Industrie 4.0

Fig. 10: Service hierarchy

Source: Prof. Martin Wollschlaeger, TU Dresden

The application relationships are increasingly mapped to services. This requires the services to be structured [11]. The application- and domain-specific services (application services) constitute the topmost level of a consistent service model (Figure 10) in Industrie 4.0. They are supplemented by domain-independent administration services (platform services), for example comprising identification and information functions, registration or localisation functions. For data access to the asset administration shells, generic, technology-independent services (information services) are provided, which map the functions for reading and writing in the data model as well as for creating, locating or deleting data objects. The explicit transport-based aspects are implemented by means of communication services, taking into account the communication paradigms and the QoS aspects of the communication. Provided the services are described in compliance with the Industrie 4.0 specifications, they are assigned to the RAMI 4.0 communication layer.

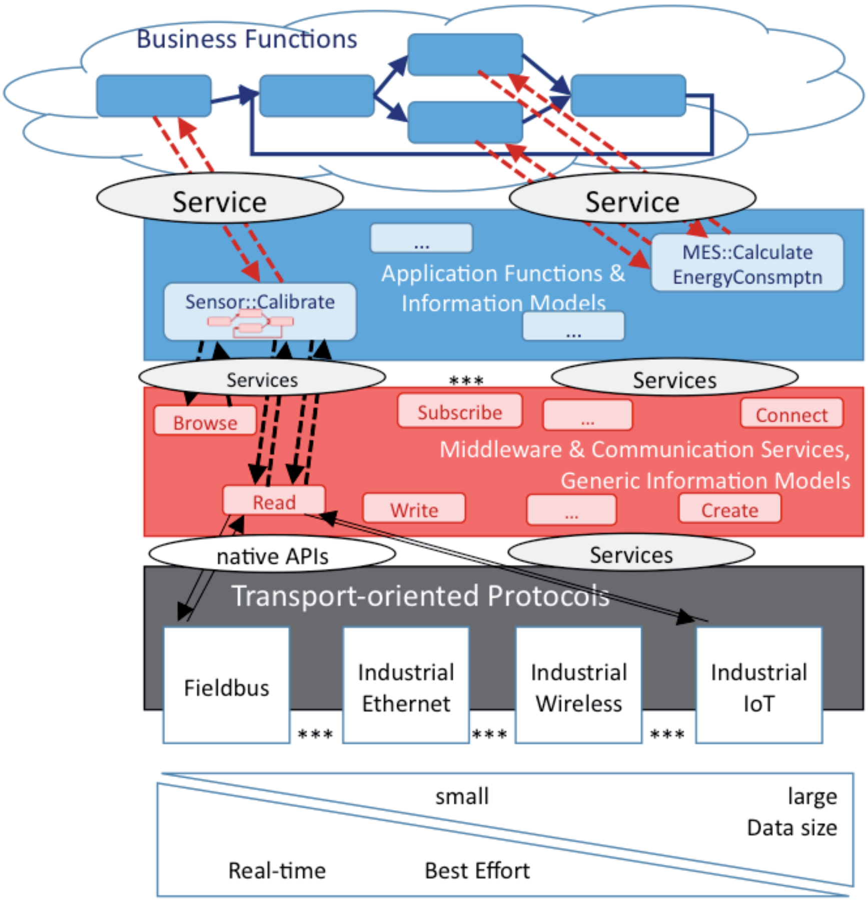
5 Technical Challenges

The above-listed communication requirements in the context of Industrie 4.0 need to be implemented using appropriate measures. In addition to the technical details, different roles shall be further developed. While, on the one hand, users of industrial communication will have to define the specific quality of service requirements for individual application relationships more concrete than before, they shall on the other hand increasingly rely on services. The manufacturers of components and systems shall offer and describe such services and shall incorporate suitable flexible implementations in their products. Network and network infrastructure providers shall finally offer flexible solutions to meet the user requirements. This also includes contractual aspects (service level agreements). There will be a shift towards offering connectivity as a service (network as a service). This enables users to purchase planning, construction, configuration and operation of the network from a service provider.

The integration layer of RAMI 4.0 contains the transport protocols to which services are mapped. Suitable protocols are selected according to the requirements and paradigms as well as under the aspect of system formation. A wide heterogeneity exists here today, due to different requirements and application areas (hierarchical levels). This heterogeneity will increase due to current developments in the context of (Industrial) Internet of Things (IIoT), 5G communication, Time-Sensitive-Networks (TSN), middleware transport services and the like.

Time-Sensitive-Networks are a recent development in network communication, based on Ethernet Ethernet-Audio-Video Broadcasting (AVB) and standardized by the IEEE. This technology assumes that specific

Fig. 11: Levels of industrial communication – application functions, communication services and middleware, transport protocols (based on [1])



Source: Prof. Martin Wollschlaeger, TU Dresden

transmission requirements exist for the data flows in certain communication channels. The basic idea is to use prioritized processing in the infrastructure components (Switches, Routers) to handle these data flows appropriately (Stream-Reservation). The mechanisms defined in IEEE 802.1p/Q are insufficient for this. IEEE 802.1 therefore specifies a more advanced solution, now implementing QoS aspects by using algorithms for "traffic shaping". According to IEEE 802.1Qbv, for example, a "Time-Aware-Shaper" is able to control network access for classes with different communication requirements. Such "Traffic-Shaper" can be modified in network engineering. This is also an interesting solution for automation, addressing scenario 1.

According to [12], communication systems of the fifth-generation (5G communication) integrate existing wire-based communication solutions with wireless solutions. Both can be operated by users themselves or under provider's responsibility. From an external perspective, this forms a homogeneous system, providing aligned services with reliable quality of service for the end user domains (verticals). This shall be achieved by establishing virtualized network functions that are flexibly and dynamically mapped to the communication infrastructure.

In this area, the management of the infrastructure - being transparent to the application - and its components is essential. Aspects like address assignment, routing, security management, performance, diagnostics and monitoring are becoming increasingly important to fulfil the application requirements. This requires a suitable network and system management concept incorporating recent developments such as Software-defined Networks (SDN) and Network-Function-Virtualisation (NFV).

Software-defined networks (Figure 12) separate the data forwarding function realized in hardware in the "data plane" from its "control plane". Implementing the control function using an SDN-Controller's software permits influencing the forwarding rules much more flexible. This way, networks can be implemented, which offer finer granularity, and greater flexibility. Finally, such networks are easier to adapt to specific application requirements.

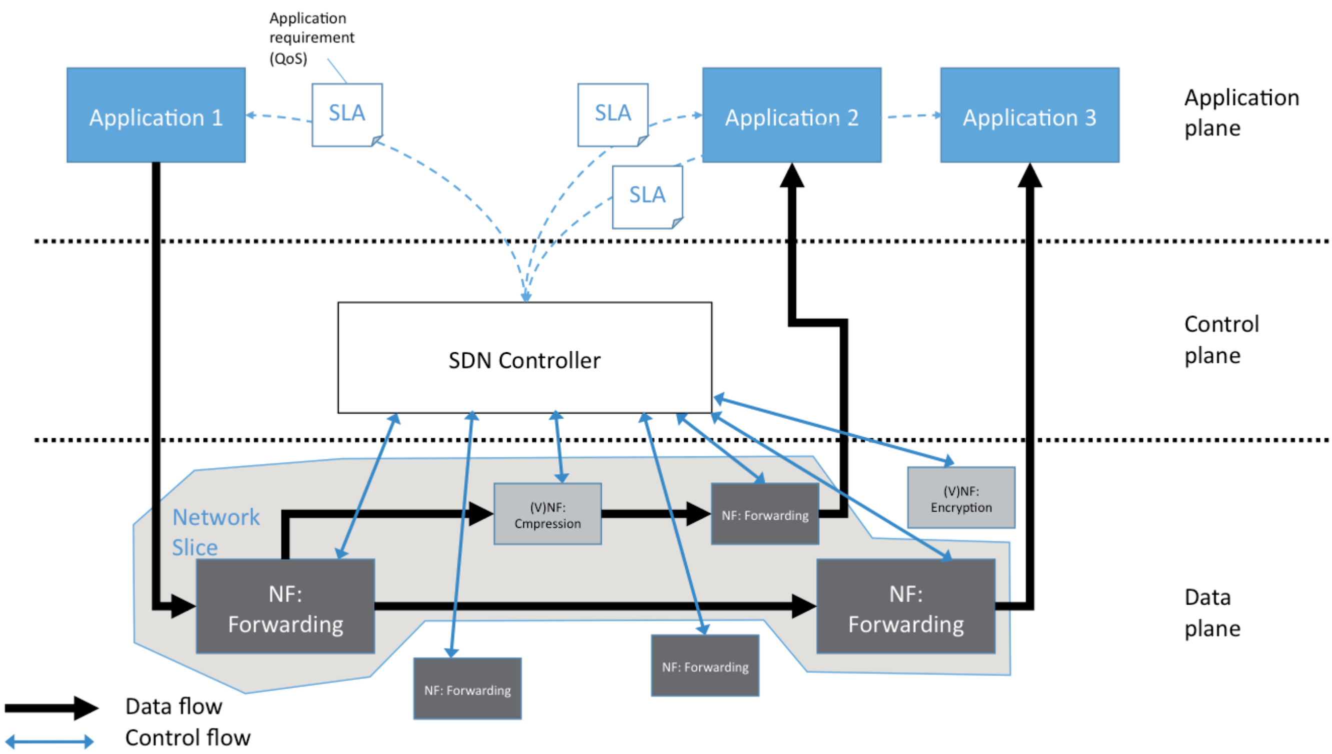
The term "Network-Function-Virtualisation" defines a concept including the provision of network functions (NF) and infrastructure in virtualized environments. Applications can access explicitly available functions (e.g. for forwarding, compressing and encrypting data). The functions are provided by virtualisation and are physically implemented in different ways, meaning that they can run on different resources. This simultaneously decouples the transport-oriented protocols from the middleware services.

The application's requirements are passed on to the SDN-Controller, which controls and monitors the available network functions and resources according to these requirements. For this purpose, the applications and the network controller agree on a contract (service level agreement, SLA). The physical network functions (NF) and virtualized network functions (VNF) that are relevant from an application viewpoint can be combined in a logical network (network slice). Network slices are thus similar to virtual local networks (VLAN) in switched Ethernet networks.

It can be expected that the transport-oriented protocols will develop further in the future. The dynamic development of new communication technologies such as 5G, SDN or IoT protocols will emerge new possibilities for communication. However, it is important that the application requirements are optimally met. This results in an increasing diversity for the integration layer in RAMI4.0, increasing the heterogeneity of the networks.

At the same time, new solutions for managing the networks and protocols will emerge. Merging engineering and operation will moreover influence the processes performed in these phases. This includes the activities and tools for planning the network topology, for load balancing and function distribution as well as security. The mechanisms for automated network management will increase, such as automatic address assignment or initial IPv6 configuration. Solution providers will cover the full technological

Fig. 12: Example of a software-defined network, network functions and network slice



Source: Prof. Martin Wollschlaeger, TU Dresden diversity with their product portfolios. However, technological details may only reach end users if they expressly whish this. This means that the management of heterogeneous networks shall be standardized using a comprehensive, function-oriented approach for network and system management. This shall encapsulate details towards the user. For automatic mechanisms to take effect, a self-description of the communication properties is required, along with procedures for automatic documentation. The overall objective here shall be to support users with feasible management solutions.

Processing aspects are closely related to communication requirements. The expected flexible distribution of application functionality among different networked resources – from edge devices to fog and cloud solutions –leads to different, possibly dynamically changing communication relations between the elements of a distributed application. Application requirements will cause specific communication requirements, which need to be covered by the appropriate selection or combination of communication solutions.

From the application viewpoint, for example, it is irrelevant whether a condition monitoring function is implemented directly in a field device, in a PLC or in a cloud – as long as the necessary data can be provided according their dynamic requirements. However, this has a substantial effect on the networks. In the case of implementation in field devices, default values with low dynamic need to be communicated to the device, whereas in the case implementation in a cloud, a large amount of highly dynamic data have to be continuously transferred. The situation for function distribution in a system is similar: if the deployment structure changes from centralized to decentralized, additional communication requirements will come up.

6 Commercial Aspects

Not only technical properties of future communication solutions will develop further, also new roles will emerge in the value chain. While users usually set up, operate and manage networks in current installations themselves, it can be expected that network and telecommunications service providers will assume full or partial responsibility for these tasks in the future. Such structures will be typical in the case of 5G systems. Important from the automation viewpoint will be, that the communication requirements are clearly formulated. Based on this, reliable assurances will be needed from providers, guaranteed by means of service level agreements. Some initial requirements in this respect are described in [7]. The demand to enable the installation and operation of future 5G systems under the user's responsibility is also defined there. The future will show to what extent this can be achieved.

A holistic view and an abstraction of communication networks - as given in the previous chapters - consistently leads to a paradigm "network as a service". In this paradigm, only the technical requirements and capabilities are mapped to one another from the application viewpoint, while the concrete technical implementation no longer plays a role. Providers of "connectivity" and "infrastructure as a service" already exist today, but their role will most certainly become more important in the future. Numerous providers of platforms ("Platform as a Service") and of networked processing resources ("Software as a Service") are already existing on the market. Besides the classic virtualisation and cloud solutions for large application systems, a continuous development towards IoT platforms can be recognized, with the clear goal of supporting applications in the Internet of Things. These developments are already an integral part of automation today. Terms such as IIoT (Industrial Internet of Things) and M2M communication (Machine to Machine) are established meanwhile. Providers of such solutions in the application context of automation will have to coordinate with the users about realising and guaranteeing their requirements.

For users, this means having to relinquish part of their sovereignty over "the network". On the other hand, it provides an opportunity to reduce workload and costs, given that the network provider offers corresponding – automation-oriented – guarantees regarding network availability. The impact on qualification and certification processes can currently only be predicted to a very limited extent.

Future networks will also provide a series of network functions besides mere network usage. This will include functions for logging on to the network, encrypting data, billing and data storage. The current discussion about such functions and their use in automation is only just beginning, but will lead most likely to providers of "network functions", creating a further player in the value chain.

One immanent topic of networking is security. Here, too, solutions exist in the IT domain that can principally be applied to automation. Of course, automation-specific forms of requirement prioritisation (Availability-Integrity-Confidentiality) shall be considered. The up to now well-organized – but rigid – networking structures in automation will change, allowing a much greater degree of flexibility. The frequently used security concepts based on "trusted zones" will no longer be sufficient. Role-based, integrated solutions with strict policies shall be implemented, as well as secure identities and comprehensive security management functions. This requires appropriate infrastructure measures for key exchange, and it calls for components being able to store keys and certificates securely. In addition to supplying security at the network level, security requirements for data usage and storage will also need to be met. Activities such as Industrial Data Space [13] are interesting approaches for this. Various activities with an emphasis on security topics are conducted in the context of Industrie 4.0.
Flexibility and dynamic adaptation of communication via different networks are also leading to changes in terms of billing for communication use. Process-oriented communication solutions were particularly almost fully under the control of users as private operators. Therefore, they did record usage details for billing purposes. In future, it will probably become necessary to reimburse service providers for offering

services. Appropriate billing models need to be agreed on. What concretely these billing models will look like (pay per use, time, volume or contingent models, flat rates, etc.) is very much dependent on the application case and certainly requires further discussion. Main prerequisite for this is the exact recording of the actual usage and the clear assignment to a using party. Future components – end devices as well as infrastructure ones – will have to implement such functions.

The communication requirements will be shaped differently along the life cycle. Similarly, the communication stakeholders will also vary for different phases. In the 5G and SDN context, abstractions are discussed to accommodate these different requirements and to separate the application-related network view of an end user from the one of an infrastructure provider. Logical networks or "network slices" allow to map different requirement profiles dynamically to an existing infrastructure. It is conceivable that in future providers of such slices will develop.

7 Predictions for the Future

Digitisation will be the key industry trend in the future. Providing digitally represented models and corresponding software to use them permits reducing effort, time and costs for implementing processes along the various value chains. Topics such as flexibilisation and individualisation are being addressed at the same time. The technical developments in electronics and information technology act as catalysts.

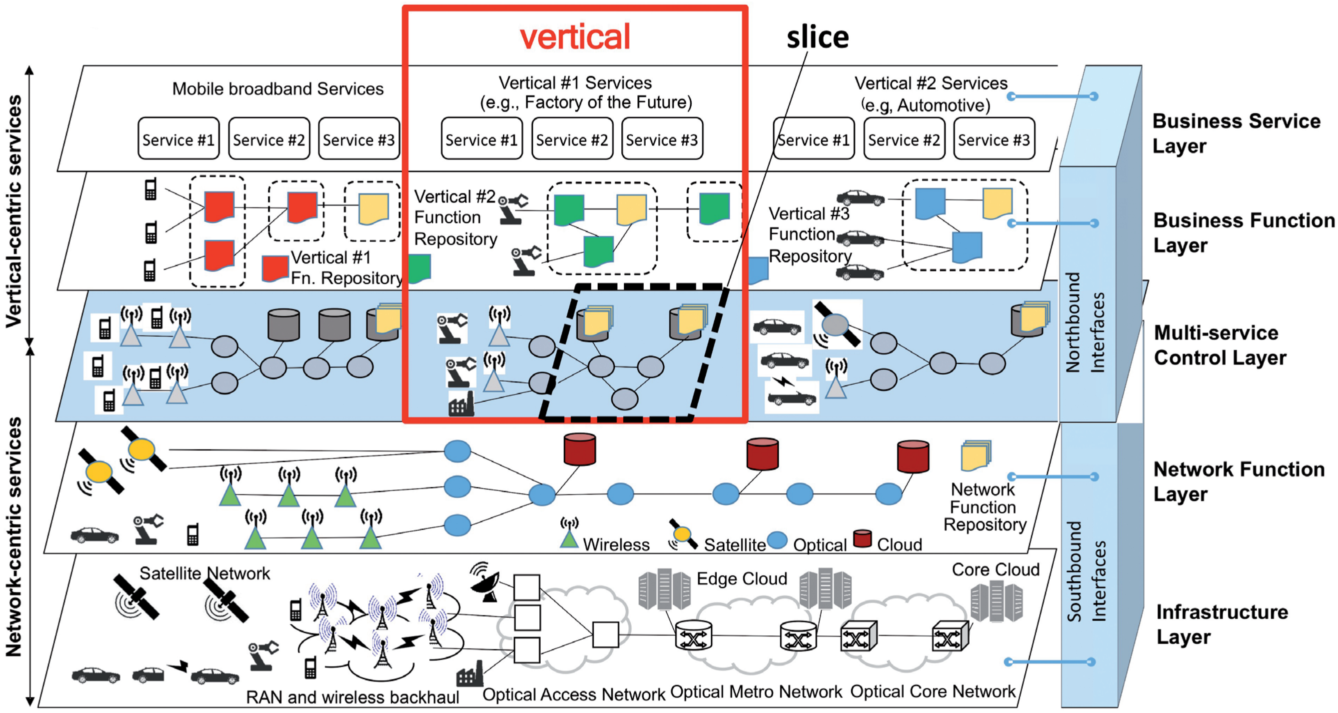
Trends in industry such as (I)IoT and Industrie 4.0 are thus merging the traditionally separate areas of information technology (IT) and operation technology (OT). In this process, numerous IT technologies are being introduced and adapted that have not necessarily been developed for OT. It is therefore necessary to formulate the general conditions and requirements for these technologies from an OT viewpoint.

Very different system architectures will be used in the future. They will influence the traditional hierarchical implementation strategy. Cloud, edge and fog computing topics are already being discussed in automation. They are partly in the process of implementation and they will be put more and more into the focus by the increasing performance of the components and the penetration of IIoT. This trend requires a clear separation between functional system structures – which will also follow a hierarchy in the future – and implementation or deployment structures. Communication requirements can be derived from the functional viewpoint, while the deployment viewpoint determines the concrete communication paths – which shall meet these requirements, especially regarding real time. The flexibility demanded for future automation solutions will cause a growing interest in modular, function-oriented concepts and abstracted solutions for communication, for example based on services. It is important for all parties of the value chains to get involved and to develop open, standardized solutions.

These activities shall be coordinated with the developments and standardisation strategies of relevant committees. The European 5G initiative plans, for example, the incorporation of vertical industries, which also include "Factories of the Future". In Fehler! Verweisquelle konnte nicht gefunden werden.] a future system architecture (Figure 13) is proposed that should allow the functional application structures of the verticals to be mapped flexibly to a general infrastructure. Of course, QoS requirements shall be considered here.

Communication forms without doubt the backbone of modern production systems. From the users' point of view, it is therefore advisable to proactively deal with the developments and influence of communication in their application environment, in order to establish communication structures with a forward-looking view to new technologies. In addition to the expected changes in the system architectures and their influence on the communication structure, special attention should be paid to the transition from communication systems fully under own responsibility towards services-based approaches, such as "network as a service". Strategic corporate decisions need to be taken, and, in view of the long usage times in OT, migration paths need to be developed in time.

Fig. 13: Integrated 5G architecture for mobile broadband applications and vertical services [12]



Source: Prof. Thilo Sauter nach [12]

The providers of communication services, components, systems and solutions shall be able to provide a description of their products' properties (capability profiles) in a way that users can identify with little effort whether their requirements will be met. The increasing heterogeneity in communication let expect consequences for engineering and network management processes. It will be increasingly important being able to offer automated solutions and tools for this. The expected flexibilisation of production processes in Industrie 4.0 requires changes to the functional structure of these systems – and by that the deployment and communication structures as well. The traditional engineering phase is more and more coinciding with the operation phase. The frequency of changes will furthermore increase, also due to the incorporation of new services and functions. Seeing the heterogeneity and complexity of networking, automatic modifications during runtime are becoming more important. This can only be realized by appropriate software support of the network. Technologies like TSN and especially SDN allow this flexibility and adaptability, for instance using network controllers at SDN. Formalized descriptions of network properties and self-descriptions of components and systems are required for this.

The transition to flexible networking and the inclusion of IT technologies creates new partners in the value chain and offers chances for new business models. Besides traditional systems integrators, specific IT and service providers will become stakeholders. They will not only offer computing and storage services based on virtualisation concepts, but also include "Infrastructure as a Service" or "Network as a Service" products in their portfolio. The orientation on services and accordingly adapted middleware solutions facilitate dealing with heterogeneity.

8 Summary

Communication is the basis for flexible, distributed system structures in automation. Technical developments are causing IT and OT to merge. This allows and demands new communication technologies and paradigms in automation and opens up new application possibilities. Efficient mapping of functional hierarchies to resource structures (deployment) will be a key in the future to guarantee the required flexibility of production systems. To achieve this, it is becoming increasingly important to know exactly the requirements from an application viewpoint.

Future networking structures in automation will be more complex and heterogeneous, requiring adapted methods and tools to ensure the optimal realisation of communication requirements from the application viewpoint. Beside technical developments, there will also be organisational changes, in particular due to new operating models such as "Network as a Service".

This white paper attempts to sensitize users, providers and integrators for this topic. Coming from exemplary scenarios, main technical and organisational aspects are described. It should be emphasized again that the focus is not on the completeness of the analysis, but on outlining fundamental developments.

Progressing digitisation and topics such as Industrie 4.0, cyber-physical systems and IoT will have a drastic influence on engineering and operation of production systems. This will require strategic corporate management decisions – by users and providers as well. A collaboration of users, providers and systems integrators as partners is essential to unlock this huge potential.

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