PLATTFORM INDUSTRIE 4.0

DISCUSSION PAPER

Network-based communication for Industrie 4.0

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Content

1. Introduction

Motivation

A cornerstone of Industrie 4.0 is the availability of all relevant information through the application-oriented networking of all instances along value added chains. This networking must have flexible parameters and deliver the required quality of service, based on internationally standardised wireless and wireline solutions for local, regional and global communication.

Network-based communication is a major element for transforming the classical industrial production pyramid into an integrated network of distributed systems. It will facilitate the reorganisation of current business relations and help to create new value added networks.

Purpose of the 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 under Plattform Industrie 4.0 is to prepare recommendations on the future development and standardisation 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 reference model as a supplement to RAMI 4.0. A major part of this reference model consists in services through which applications can negotiate the required Industrie 4.0-compliant network parameters. This makes up an essential part of the self-configuration of production systems in Industrie 4.0.

2. Foundations

Definition of terms

Particularly as Industrie 4.0 will entail the close interlinkage of diverse technical disciplines with little previous interaction (such as mechanical engineering with information and communications technology), achieving the above-mentioned objectives calls for a clear definition of key terms. Many basic concepts and definitions for Industrie 4.0 have been compiled by the VDI/VDE GMA 7.21 technical committee [1] or are currently in development [2]. Of special importance for the SWG in particular are terms such as Industrie 4.0 components, administration shell, assets, security, availability and quality of service (QoS).

The following definition has been proposed for network-based communication:

> Network-based communication for Industrie 4.0 comprises all technologies, networks and protocols needed to enable a communication relationship among two or several Industrie 4.0 components. Applications must be able to negotiate their end-to-end communication via Industrie 4.0-compliant interfaces. The network resources deployed can also be orchestrated via non-Industrie 4.0-compliant interfaces.

Available and emerging standards and norms

Already available or in development, a variety of wireless and wireline standards for communication networks are relevant in industrial manufacturing or for Industrie 4.0. They differ by range and can be clustered as follows:

Standards and norms for wide-area or global networks:

- Owing to their broad availability, **mobile networks** are often deployed to interconnect widely distributed (e.g. throughout an entire country) or mobile (e.g. in logistics) assets. Unlike local radio communication, mobile communication standards rely on licensed frequency bands. Many of these applications designated till now as machine-to-machine (M2M) are based on GSM networks. They are, however, restricted to data rates of a few 100 kbit/s, whereas substantially higher data rates are possible with 3G or LTE networks. To be able to network a large number of distributed, local (battery-operated) sensors or actuators efficiently, low-power wide-area (LPWA) scenarios are currently in development for 3GPP standards that can be seen as supplementing the already available solutions. Of note here is that wireless technology mostly covers access networks, i.e. the 'last mile', whereas global networking is then implemented with wirelines.

- **Wireline solutions** that also include the Internet in the broadest sense are a suitable means for the national or global networking of stationary endpoints, such as several distributed business locations. The state-of-the-art technology are connections secured through virtual private networks (VPN) with fibre-optic cabling. In part, DSL networks or satellite-based solutions are also applied for network access.

Standards and norms for production cells and local area networking:

- Various **wireline** fieldbuses and Ethernet-based industrial communication systems have been primarily used in this sector so far, particularly for applications with very high reliability and latency requirements. The Ethernet standard is currently being upgraded for guaranteed cycle times under IEEE 802.1 in the Time-Sensitive Networking (TSN) Task Group.

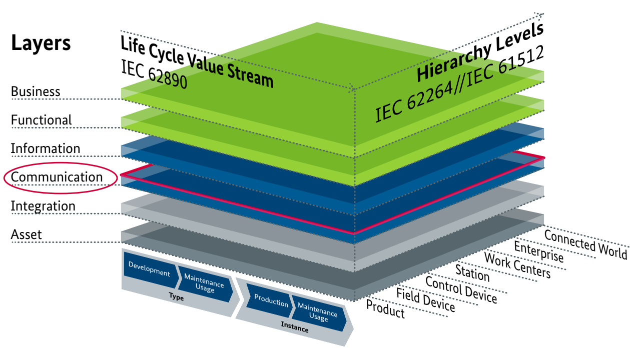
- Wireline networking solutions are supplemented with diverse general standards for **wireless** local area networks, e.g. Wi-Fi, DECT ULE, Bluetooth or 6LoWPAN, which have been partly specifically modified (hardened) for industrial use (e.g. multiple transmission for improved reliability). There are also specific standards for local wireless networks in production environments, e.g. WirelessHART according to IEC 62591. So far, however, the available wireless standards have usually failed to meet the stringent latency and reliability requirements for application in a production cell, e.g. for motion control. These are being upgraded under IEC 62948, for example (Industrial networks: Wireless communication network and communication profiles). The Federal Education Ministry programme, Reliable Wireless Communication in Industry (ZDKI), is also concerned with this issue.

In all the cited sectors, IP convergence affords an opportunity for continuous end-to-end communication on the application side. This, however, calls for overarching network management from the local production cell up to global networks in a Connected World.

Relevance to RAMI 4.0

The Internet of Things – meaning IP-converged local and global communication infrastructures – is at the very core of Industrie 4.0. Communication is one of the core layers of the Reference Architecture Model of Industry 4.0 (RAMI 4.0) now globally established [3], which amalgamates all important lifecycle and hierarchy-level aspects, including process- and IT-based levels, in one generic model for Industrie 4.0. The Communication Layer on which network-based communication is implemented is the link between the Integration Layer, which makes the properties of the physical world accessible to computer systems ('digitises' assets), and the Information Layer, which contains the functional data and thus represents both destination and source of transmitted information (Figure 1).

Figure 1: RAMI 4.0 with Communication Layer



Source: Plattform Industrie 4.0 and ZVEI

This poses the following central questions for the SWG on network-based communication:

1. What communication functionality does the Information Layer need, which describes/contains the data and functions described in the Industrie 4.0 administration shell [4]? Questions about these requirements must be answered by the information users, i.e., the functional level.

2. How will the communication functionalities be made available via Industrie 4.0-compliant interfaces? In other words: What must the administration shells of the communication assets look like? This must be specified by the Information Layer to ensure the interoperability of Industrie 4.0 systems.

3. What are the relevant security aspects and how will these be taken into account in the reference architecture?

Layers 1-4 of the ISO/OSI (Opens Systems Interconnection) Model for communication systems essentially become assets, and together with their administration shells they become full Industrie 4.0 components. The administration shells thus encapsulate the resources and security mechanisms of the communication layer. This way, applications and/or communication partners can use the administration shells of the communication infrastructure to make administrative requests for its resources and functions with a defined quality of service.

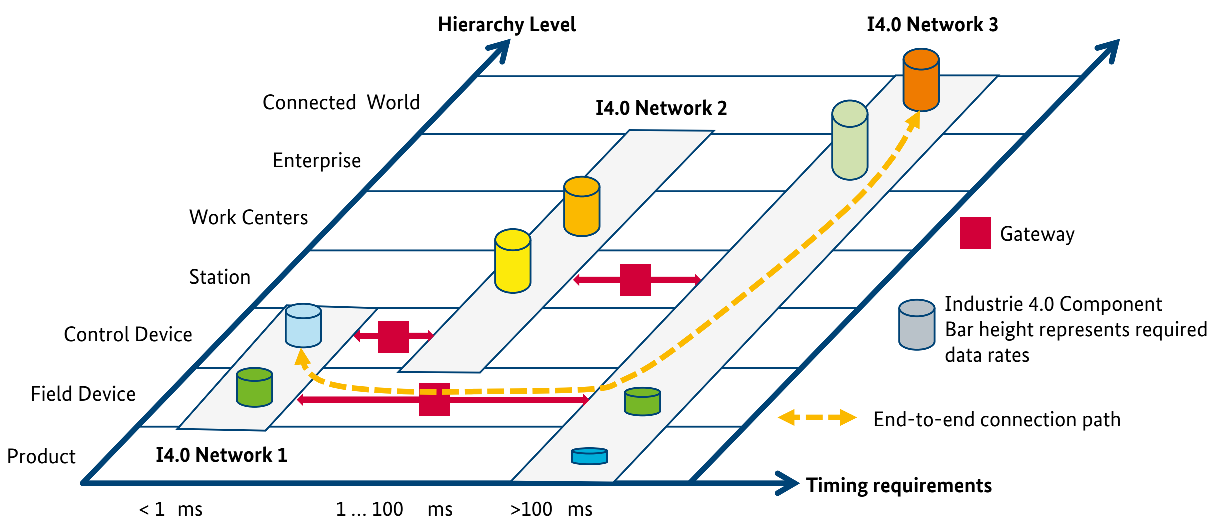
Model for network-based communication in Industrie 4.0

To be able to describe the relevant requirements, functions and interfaces for the Communication Layer in structured form, a model for network-based communication needs to be designed as an extension of and supplement to the RAMI 4.0 model. As a step in this direction, a Communication Layer structuring has been proposed as outlined in Figure 2.

One dimension describes the so-called Hierarchy Layer of RAMI 4.0 and the other contains the latency requirements. 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.

A major point in the reference model are the gateways connecting the various networks. This kind of gateway can, for example, act as a transition from a local network inside the company to the global network of a network provider. Industrie 4.0-compliant end-to-end connections are made inside the Industrie 4.0 networks (connected via gateways).

Figure 2: Design of Communication Layer with an example of an end-to-end connection path



Source: Plattform Industrie 4.0

3. Requirements assessment

Besides conducting a status quo analysis, to achieve its objectives the SWG must conduct an assessment of the basic requirements for future network-based communication solutions and review relevant, current national and international standardisation and R&D activities.

Basic requirements

Various reference scenarios have been defined in Plattform Industrie 4.0 [5]. The resultant requirements for application-based network-based communication are very diverse. They can be basically divided up into three categories:

1. Security

This comprises the sectors a) network and data security, b) secure identities and c) functional security. Points a) and b) are addressed in WG3 of Plattform Industrie 4.0 [6], [7]. The SWG on network-based communication collaborates with WG3 on these points and WG3 cooperates on security and functional security with the DKE-TBINK Working Group – IT Security and Security by Design.

IEC 61784-3 places demands on functional security, which must be taken into account when defining new systems.

2. Availability

Availability denotes the property of processes and data of being available on time and capable of being put to proper use. Authorised users may not be denied access to information and systems.

3. Quality of service (QoS)

Quality of service requirements for Industrie 4.0 can mainly be divided up into three categories:

- Latency requirements, including jitter
- Reliability of data transfer, e.g. measured by maximum bit or packet error rates
- Data rate requirements

Questions of coexistence in spectrum use are very important for wireless communication systems to be able to comply with the above-mentioned QoS parameters (see also IEC 62657-2 and VDI/VDE Guideline 2185).

The table below shows the quantitative range of relevant quality of service parameters for three requirements examples [8].

	Motion Control	Condition Monitoring	Augmented Reality
Latency/ Cycle Time	250 µs – 1 ms	100 ms	10 ms
Reliability (PER[1])	1e-8	1e-5	1e-5
Data Rate	kbit/s – Mbit/s	kbit/s	Mbit/s – Gbit/s

1 (Residual) Packet Error Rate

To translate the requirements described into Industrie 4.0-compliant functions in the context of RAMI, these must be represented in an administration shell.

4. Assessments and initial recommendations

Analysis of gaps

a) Need for wireless networking solutions

In order to meet the demand for flexibility up to a 'batch size of one', production will have to be more mobile and tools will need to be more adaptable and logistics more dynamic as well. Wireline systems quickly come up against technical and economic limits. To cope with the large forecasted number of future sensors and actuators in industrial production, there is no alternative to an efficient wireless solution. Due to their large commercial use, Bluetooth and wireless LAN have interesting cost structures, but only very restricted mechanisms for interferences, security and response times. Single industry solutions are confined to a few frequency bands and are often not very economically efficient due to the small number of units.

This is why research activities are currently being conducted in the Federal Education Ministry programme, Reliable Wireless Communication in Industry (ZDKI). In the medium term, 5G (see below) will play a major role here.

b) Flexible, secure, quality-assured end-to-end connections

A core requirement for Industrie 4.0 is end-to-end communication that is as flexible and secure as possible with the broadest quality range. This is frequently carried out across various networks and – in the global context – also across various network operators. The important thing here is to achieve the best possible continuity.

Based on this it will be possible to apply M2M protocols, such as OPC UA (IEC 62541), in interaction with TSN (see below).

Gateways play a major role for these transitions. An Industrie 4.0-compliant gateway between a factory and a wide-area network should have the following attributes, for example:

- Configurable, application-based establishment of tunnelling and security protocols with the shortest possible connection setup and disconnection times
- Facility for the flexible roll-out of monitoring and analytical functions
- Priority management per application
- Translation of QoS parameters among various network operators

Particularly in connection with 5G, the use of network function virtualisation (NFV) and network slicing mechanisms will help enhance flexibility and reduce inflexible gateways in the medium to longer-term.

c) Administration shell of network-based communication

So that applications can make secure and flexible use of the above-mentioned capacity of the Communication Layer, these communication functions must be made available to them in conformity with Industrie 4.0. This is done by representing the functions of the communication infrastructure in an Industrie 4.0 administration shell, so that applications can request and resubmit these via Industrie 4.0-compliant communication. This administrative shell must therefore support two fundamental use cases:

- Request and/or negotiation of end-to-end connection paths between Industrie 4.0 components with defined quality of service and security features, ideally independently of the specific communication protocols applied

- Initial configuration (bootstrap) for new additional Industrie 4.0 components to gain access for the first time to the administration shell of the communication infrastructure, ideally with minimum preconfiguration input

d) Internationalisation of standardisation

So far, many different standards have been applied in production and automation technology with only national or regional scope. For Industrie 4.0 to be successful in global competition, international standards are essential. It would also make sense to consolidate standards to reduce their number. The vision of a globally successful application of network-based communication cannot therefore be confined to a regional, European solution; it must amalgamate the strengths of German and European industry, that is, mechanical and plant engineering and the automation industry with global technology trends in communications and the Internet to generate synergies. In close collaborative liaisons, a very large number of international standardisation bodies and consortiums are presently seeking to create an integral standardisation landscape in the context of Industrie 4.0/smart manufacturing.

5. Outlook for future communication standards

SDN and NFV

At the lower technical layers of the Open System Interconnection Model (OSI), software-defined networking (SDN) enables new opportunities for flexible production and the administration of network services. This is made possible by the concept of separating the control and data planes of data networks and virtualising the lower functional levels (network function virtualisation – NFV). The cost-efficient and ad-hoc available high-security connections enabled by this, such as virtual private networks (VPN), make up a major building block of the Industrial Internet. The main original driver of this development were the scaling needs for infrastructure as a service (IaaS) facilities in the Business Cloud. This technology, also to be a key component for 5G, will in future support industry in the secure relocation of process and control elements from local instances to the Cloud, which will make networking operations along the whole value added chain simpler and more powerful by a multiple. Open source-based solutions will play an increasingly important role for SDN and NFV, which facilitate so-called network slices for different requirements and user scenarios. Put simply, this will enable industrial users to gain access to their own virtual global network, including data centres at the right locations.

5G

With the standard for digital mobile communication, the Global System for Mobile Communications (GSM) of the European Conference of Postal and Telecommunications Administrations (CEPT) has created a new market. 2G/GSM was, for example, ideal for digital voice and international roaming, but the data services subsequently added, GPRS and EDGE, are limited. Although 3G/UMTS can provide voice and data very efficiently, HSPA was the first to enable efficient Internet access. 4G/LTE, in contrast, is optimised for broadband access to the Internet. 5G is a future global telecommunications standard that will support a large variety of application scenarios. Its standardisation has begun and the users of the industrial solutions in particular must now submit their requirements for the technology. The first commercial networks are anticipated for 2020. Besides higher data rates (up to 10 Gbps) and extended connectivity (100 billion terminals worldwide), 5G will above all include deterministic behaviour (with a latency of about 1 ms), which is needed wherever time-critical processes and functional security are required.

Ethernet will need Time-Sensitive Networking (TSN, IEEE 802.1) to meet these requirements. Unlike wireline transmission, when using the medium of mobile communication account also has to be taken of interferences, diffraction and reflections. 5G will be standardised to be able to cope with use cases requiring different qualities of service.

From the present standpoint, 5G will have the following features:

- Economies of scale
- Deterministic behaviour
- Wide range of licensed and unlicensed frequency bands, from 300 MHz to 300 GHz (mm wave)
- Integration with Industrial Ethernet
- Support for Cloud/Edge computing and big data analytics via the core network
- Technology innovations such as software-defined networks (SDN) and network function virtualisation (NFV) will be part of the concept right from the beginning
- High flexibility and new services enabled by virtualisation

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5 – Plattform Industrie 4.0, Abbildung der Anwendungsszenarien auf die Forschungsroadmap *(Depiction of application scenarios on the research roadmap)*

6 – Plattform Industrie 4.0, Technischer Überblick: Sichere Identitäten *(Technical overview: secure identities)*

7 – Plattform Industrie 4.0, Technischer Überblick: Sichere unternehmensübergreifende Kommunikation *(Technical overview: secure cross-company communication)*

8 – Dr. Andreas Müller, Robert Bosch GmbH 2015, Contribution to the discussion session on "Radio communication for Industrie 4.0" on May, 28th, 2015 at the ITG-expert comittee 7.2 radio systems

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