Categorization of industrial communication requirements as key to developing application profiles ⋆

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Abstract: Complex control algorithms base on the measurements of distributed sensors and the execution by distributed actuators. Consequently, communication networks are a vital part of modern automation applications. Currently, data are often exchanged using wired Industrial Ethernet networks, while the trend is moving towards wireless communication networks, as they provide flexible, mobile communication by retrofittable components.
This trend entails the necessity to formally test the performance of a communication network, as the quantitative key performance indicators of wireless technologies are typically smaller than of wired technologies. By this performance testing, a suitable technology is identified ahead of its implementation in a real application environment. But formal performance testing must base on precisely defined communication requirements, as only this allows a meaningful assessment of the testing results. However, these specifications are currently not available, although the specification of industrial automation applications' communication requirements is now being discussed for more than a decade.
By reviewing the discussion of communication requirements, this paper clarifies, why the specification of requirements is complex and provides the reader with necessary information enabling to follow and to join the ongoing discussion. Furthermore, a promising approach mitigating the current challenges is presented. The proposed approach is of interest to developers of automation algorithms, since the algorithms implicitly assume the existence of a suitable communication technology. The proposed approach enables developers to easily fit their specific control application to a given requirement profile by comparing the given and the target characteristic parameters. This paper intends to sensitize with regard to taking the communication needs into account when developing automation algorithms.

Keywords: Agile control, agile manufacturing, automation, automatic control, communication networks, data transmission, requirement analysis, telecommunication, transmission systems

1. INTRODUCTION

Communication networks enable control algorithms in various applications as they connect spatially distributed sensors and actuators to each other and/or to a central control. They deliver all needed information to and from the control algorithm. Due to this, communication networks are a key element in most modern, sophisticated automation systems. Their importance even increases along with increasing deployment of mobile entities such as autonomous guided vehicles (AGVs). In general, by using wireless communication networks additional sensors or even a video surveillance can easily be retrofitted. This entails a higher flexibility while reducing installation and maintenance costs.

Along with introduction of wireless communication technologies to industrial automation applications during the last two decades, the need to determine the industrial control application's requirements increased. Traditionally, wired communication networks are deployed in industrial applications. Starting from fieldbus systems, currently Industrial Ethernet-based networks (IENs) like PROFINET or ETHERCAT are state of the art. IENs are known for their deterministic and reliable performance, and as a consequence they enjoy general confidence. Currently, industrial automation applications typically do not fully exploit the transmission capacity or the short communication offered by IENs. Consequently, IEN performance parameters are not congruent to the served industrial automation application's requirements. Now, if a communication technology is to be deployed, that provides smaller quantitative performance parameters, the actual industrial automation application's requirements need to be known in order to assess its suitability, and they cannot be derived from the IEN performance parameters.

This necessity of clearly defined requirements of industrial automation applications now has been discussed for more than 10 years along with the introduction of wireless communication networks, which typically are more error-prone and provide a smaller data rate than IENs. Still

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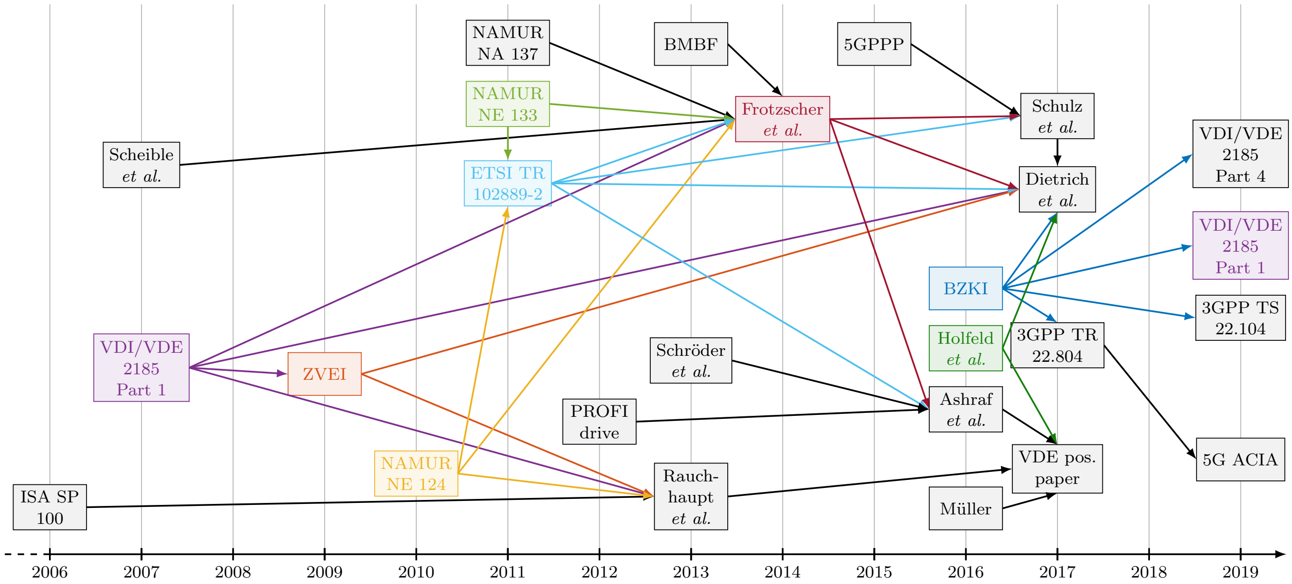

Fig. 1. Publications on industrial application's requirements and their connections.

there is no agreed specification. In this context, one of the challenges is that industrial automation applications are particularly diverse and have correspondingly diverse requirements. Several parties from automation industry, communication industry, academia and standard defining organizations (SDOs) have described the requirements of industrial applications, and naturally these descriptions are subjected to further discussions. Despite the dissent, all parties taking part in the discussion agree, that a common understanding and a commonly accepted description of application requirements is necessary. Consequently, the discussions are being continued.

Of course, all parties are invited to get involved in these discussions in order to find an answer, that is commonly accepted. The perspective of future control algorithms' developers would be a great addition to ensure, that these future industrial automation applications are covered by communication networks. In order to enable new parties – like the control algorithms' developers – to understand and to join the discussion, this paper provides an overview on the previous discussion related to the topic of industrial application requirements and motivates developers of control algorithms to take into account their algorithms' implementation as part of an industrial application as well. The previous discussion on industrial automation applications categorization is traced in Section 2. Here, two major perspectives visible in the discussion up to now are distinguished: The automation operator's perspective as addressed in Section 2.1 and the perspective arisen during 5G development as addressed in Section 2.2. Based on the review of the previous discussion, a proposal how to describe industrial automation requirements by so-called profiles is presented in Section 3. Section 4 concludes this paper.

2. INDUSTRIAL COMMUNICATION REQUIREMENTS

The availability of quantitative, practice-oriented requirements of industrial automation applications is crucial to allow the assessment of a communication technology. Fig. 1 depicts the development towards commonly accepted requirement specifications. The impact of each publication on later studies is visualized by arrows. The coloring only aims to facilitate the overview. The illustration of the work regarding industrial requirements reveals how diverse the discussion is. Also, the three perspectives present in the previous discussion – SDOs, automation industry and communication technologies – become clear. In general, the topic gained interest during the recent years as can be derived by the number of publications over time.

In the following, first the automation operator's perspective is revised as they started the discussion, while the 5G communication technology's perspective joined later. The contributions of SDOs is regarded in the area of their origin, e. g. 3GPP contributions are discussed in the 5G communication technology's perspective.

2.1 The automation operators' perspective

From 2006 to 2012 the studies and publications were authored independently. The small number of publications indicates, that the interest in this topic is yet little. Starting in 2013, the discussion gained momentum. The beginning marks the International Society of Automation (ISA) introducing a categorization distinguishing safety, control and monitoring ISA (2006). Further, subcategories are defined for each category. Within each subcategory, an individual application is further segmented by the importance and required timeliness. Finally, for every application the importance and required timeliness of different communication aspects have to be stated using six levels ranging from "always critical" to "non-critical". For example, an emergency action is "always critical", whereas certain sensor data in the same application could be "non-critical". The categories' description is mostly qualitative.

In VDI/VDE (2007) – the Guideline 2185 part 1 – industrial automation applications are systematically analyzed and grouped into categories while giving a comprehensive quantitative overview on their different requirements. Here, five categories were introduced: process automation, infrastructure plants such as wastewater treatment plants, building automation, factory automation and logistics. In the same year, Scheible et al. (2007) presented an early approach on specifying requirements of sensor-actuator-networks. This early approach is now considered to be deprecated.

ZVEI (2009) presents a study on the coexistence of wireless systems in the field of automation. The study discusses the application requirements from the coexistence's perspective and provides quantitative parameters for factory automation and process automation use cases. Another qualitative approach is introduced by the User Association of Automation Technology in Process Industries (originally German , NAMUR). NAMUR (2010, 2011b,a) are two recommendations – NE 124 and NE 133 – and one worksheet – NA 137. Here, applications are divided into three classes: Class A for functional safety, Class B for process management and control, and Class C for display and monitoring, which are similar to the classes defined by ISA in 2006. Compared to ISA, NAMUR presents a more complete picture of relevant parameters for a use case specification, and yet quantitative information is still unavailable. TR 102889-2 by ETSI (2011) points out central properties of cell level, factory level and plant level, i. e. from small to large spatial extent. It also provides quantitative values and had an impact on comprehensive studies, that were conducted later on.

Up to 2012, the categorization schemes were presented mostly without acknowledging each other. This changed in 2013 and 2014, when two independent, comprehensive studies were compiled and presented by Rauchhaupt and Meier (2013) and by Frotzscher et al. (2014). Together both compilations summarize the earlier work including BMBF (2013) and each adds a new perspective to the categorization. Rauchhaupt et al. developed a categorization of machine, factory hall, as well as indoor- and outdoor process plant. In Frotzscher et al. (2014), three major categories are introduced as subcategories of closed-loop control: Machine tools, printing machines and packaging machines. This definition of subcategories indicates, that the categorization of factory automation is too coarse to enable an efficient design of a communication system. Thus, the subcategories are further discussed in Schulz et al. (2017), which also takes into account 5GPPP (2015), and in Dietrich et al. (2017), which also clarifies that factory automation applications need a more precise definition compared to previous categorization efforts.

Based on PROFINET, which is managed by the PROFIBUS user organization PNO, key performance parameters named in the specification PNO (2012) and in Schroeder (2013), Ashraf et al. (2016) define requirements for Class A, B and C. These classes are similar to the definition introduced by NAMUR, but are reversely sorted. Here, class A comprises maintenance and diagnostics, whereas the most strict requirements are attributed to class C. Class B has intermediate requirements as set by storage and logistics or production lines.

In general, the interest in a comprehensive categorization rose during the years 2016 and 2017 due to a German research initiative called ZDKI (2017), which worked on wireless solutions for industrial automation applications. In addition to publications from individual projects – Holfeld et al. (2016); Ashraf et al. (2016); Dietrich et al. (2017); Mueller (2016) –, two reports summarize the overall ZDKI initiative's results compiled by the accompanying research in Gnad et al. (2017) and Schulze et al. (2017). The initiative's results had a major influence on several technical reports – 3GPP (2017); VDE (2017); VDI/VDE (2019a,b); 3GPP (2019); 5G-ACIA (2019) –, which are now considered as state of the art. Still, their categorization schemes and quantitative values are not yet coherent. The work is currently continued in associations like 5G-ACIA and 3GPP.

Summarizing the current state of discussion, there are two coexisting categorization schemes for field level applications, of which one originated from the automation perspective, and the other from the 5G communication technology perspective. The latter is rather new and yet focuses on future industrial applications, which becomes clear by the choice of parameters, e. g. not assuming a strictly equal communication cycle for all communication participants. Consequently, the more appropriate categorization for a modernization is that one introduced with automation background, since it was derived starting from currently deployed, industrial applications. As revealed by multiple studies that introduced subcategories to factory automation, a suitable communication technology does not need to fulfil all factory automation requirements simultaneously, but the requirements of a specific subcategory.

In summary, starting from qualitative descriptions, soon quantitative categorizations were developed. It turned out, that these categorization was to coarse, so several subcategories were introduced. In the next step, the 5G communication technology perspective was added to the discussion.

2.2 The 5G communication technology perspective

Starting in 2015, 5G stakeholders joined the discussion, as 5G technology is supposed to inherently address industrial applications. At this point, the discussion, which was up to now mainly driven from German inudstry and academia, becomes an international one. At first, the 5G community developed a categorization independently from previous categorizations in 2017. Up to now, the alignment with the automation operator's perspective is worked on.

In general, 5G addresses various so-called verticals, which were discussed in detail in TR 22.804 3GPP (2017). A vertical is a group of applications categorized by their operational environment, for example automotive, smart cities, manufacturing, energy and eHealth. Within a vertical, applications having differing target performance parameters such as latency, data rate and reliability. In order to address this variety, three types of traffic are distinguished: ultra reliable low latency communication (URLLC), massive machine type communication (mMTC) and enhanced mobile broadband (eMBB). 3GPP summarizes the requirements if these three categories in TR 38.913 3GPP (2018). However, the requirements stated are incomplete, e. g. a target latency is defined vor URLLC, but not for eMBB and mMTC. Seemingly, the description is extensive

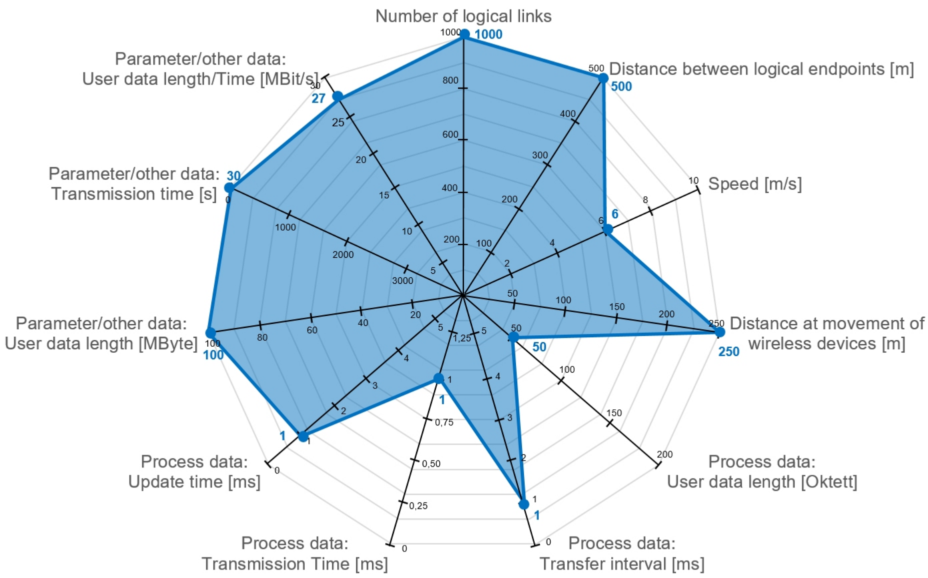

Fig. 2. HiFlecs Profile B including e. g. industrial plant with decentralized drive technology or robot cell with product feed and removal of the peripheral axes

enough to cover the relevant parameters for each category, but later discussions – especially between 3GPP and the 5G Alliance for Connected Industries and Automation (5G-ACIA) – revealed gaps.

The gaps are addressed in TS 22.104 3GPP (2019), where the contemplations published in 5G-ACIA (2019) are regarded. The 5G-ACIA gives an extensive overview on 5G use cases in typical industry-related verticals and their service requirements in 5G-ACIA (2019). While 3GPP differentiates in its “factory of the future”-vertical between the use cases printing machines, machine tools and packaging equipment, the 5G-ACIA summarizes these applications in the motion control category.

Recently 3GPP defined service requirements for cyber-physical control applications in TS 22.104 3GPP (2019). The applications are grouped by their operational environment, while the scope is much more focused than it is in e. g. the verticals. Comparing the values specified here to specifications from the automation operator’s point of view a beginning convergence is revealed.

In summary, the complementary perspective from the 5G context helped to detect the weaknesses of previous descriptions, and during 2019 a fruitful discussion arose leading to a common understanding.

3. COMBINING USE CASES TO A PROFILE

A communication network must meet the requirements of a category in order to be considered suitable for the applications of that category. However, when looking into the requirements of a specific automation application, it typically only requires a subset of the target values required by its category. Due to this, it is becoming increasingly apparent that the previous approaches basing on categorization by the operational environment still neglects the diversity of applications within one of these categories.

In order to address this gap, the introduction of requirement profiles is proposed. The concept of requirement profiles is explained in the following in accordance with the HiFlecs research project, which is e. g. presented in Bockelmann et al. (2017) or Schulze et al. (2017). At first, requirements of various applications independent from their actual operational environment are collected. It is important, that these specific application requirements are collected in a comparable, comprehensive manner. For example, guidelines VDI/VDE (2019a,b) provide an extensive list of parameters needed to comprehensively describe application requirements: Number of logical links, distance between logical endpoints, speed, distance at movement of wireless devices, user data length, transfer interval, transmission time, update time and user data length per time unit (data throughput). These characteristic parameters describe the application’s point of view, i. e. they are captured at the so-called reference interface, which connects the application and the wireless system. At the reference interface so-called logical endpoints are defined, which are each connected to a logical endpoint in the reference interface of another entity in the distributed automation system. The connection between logical endpoint is referred to as logical link.

Next, the application requirements are structured using the collected characteristic parameters. Application with similar characteristic parameters are grouped to a single profile. Consequently, each profile’s validity is defined by the underlying application requirements, but it is not restricted to them. On the contrary, new applications can be assigned to a profile, if its requirements are covered. This renders the approach of defining requirements profiles more flexible than the predominant categorization by an applications’ operational environment.

A communication technology, which might to be deployed in a use case covered by a profile, can be efficiently assessed by testing its performance with respect to the given target parameters. Also, using performance testing results of a specific communication technology, its suitability for

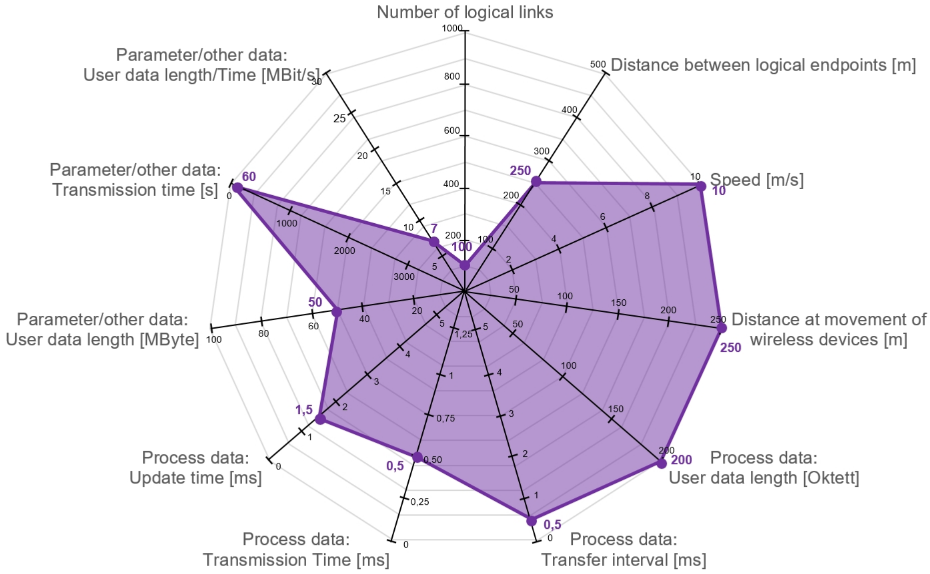

Fig. 3. HiFlecs Profile C including e. g. high bay ware house or robot cells with interchargeable tools

industrial automation application can be assessed by comparing the results to the predefined requirements profiles.

In the HiFlecs project, three requirements profiles were created. Profile B and profile C are exemplarily shown in Fig. 2 and Fig. 3, respectively. Profile B is based on the following use cases: Industrial plant with decentralized drive technology or robot cell with product feed and removal of the peripheral axes. In contrast to this, profile C is based on the following use cases: High bay ware house or robot cells with interchangeable tools. By the depiction it becomes clear that the requirements for communication technologies are distinct. For example, profile B has a high number of logical links, and the logical endpoints are distant, while its user data length is quite small compared to profile C. Profile C has lower requirements regarding the number of logical links and the distance between the logical endpoints.

4. CONCLUSION

Communication networks are already a vital part in any modern automation network, and their importance is currently increasing along with increasing interest in wireless communication technologies. They are the key enabler for realizing complex and decentralized control tasks. During the past decade, the actual communication requirements of industrial automation applications were extensively discussed. The discussion especially accelerated past 2015, where a major German research initiative and the 5G communication technology perspective joined the topic.

Although the importance of a common understanding and a generally accepted requirement specification is agreed, consensus is not yet achieved. Also, some relevant parties, which are absent from the discussion up to now, are invited to join and contribute their perspective on the categorization of industrial automation applications by their communication requirements. Consequently, an extended dialogue is desirable, maybe even necessary.

These open issues are addressed in the Industrial Radio Lab (IRL) project. On the one hand, it is planned to extent requirement profiles while also enlarging their reach within the community and inviting new relevant parties to join the discussion. On the other hand, existing wireless communication technologies, e. g. based on IEEE 802.11, or upcoming technologies, e. g. 5G, will be subjected to a systematic performance testing. Based on the testing results, the suitability will be assessed with respect to the specified requirement profiles.

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