White Paper

Information models
PI Strategy for Industrie 4.0

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Prepared by PI Strategy Team for Information Models

In this specification the following key words (in **bold** text) will be used:

may: indicates flexibility of choice with no implied preference.

should: indicates flexibility of choice with a strongly preferred implementation.

shall: indicates a mandatory requirement. Designers **shall** implement such mandatory requirements to ensure interoperability and to claim conformance with this specification.

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1 Motivation

The industrial development toward smart factories needs the data of automation systems so that the vision of Industrie 4.0 can be put into practice. In the operational area, the data primarily consist of information from the sensors, actuators and controllers that are the source and sink of this data. Parts of this data is already processed in the functions of the classic automation pyramid. IT applications extend this use through data processing, e.g., for “Data Analytics” and “Advanced Asset Management”. In addition to the hierarchical structures of the automation pyramid, new information channels are added. These channels transport data independently from today's communication channels between automation devices and IT applications. This is the task of vertical communication. This process not only creates the link between the operational automation structures and the IT applications, but also requires information models that make the data from the devices, machines, and systems understandable for IT applications. Making this data understandable means that it can be interpreted in IT applications. For this purpose, the data is supplemented by descriptions that contain the properties and relationships between the data. These descriptive properties and their relationships structure and enrich the data with semantic content and the data becomes information that can be interpreted by machines in this manner. Self-describing information models emerge. These information models considerably simplify the coupling of IT applications to systems.

Industrial communication, especially the PROFIBUS & PROFINET International (PI) technologies PROFINET and IO-Link, are the backbone of automation systems and offer all the prerequisites for vertical communication. It therefore makes sense to perform the necessary integration of the information models into the canon of PI technologies so as to ensure a seamless further development of the existing device technology.

Sensor-to-cloud connectivity is an essential building block of Industrie 4.0, in which OPC UA has become a permanent fixture in automation technology. OPC UA assumes the role of an interface technology with an integrated information model. The industrial communication systems fade into the background for these applications so that the IT application can focus on processing the information. OPC UA-based information models have therefore been developed for PROFINET and IO-Link mappings, which provide device and diagnostic data to IT applications without much effort. This is an example for vertical communication. Data analytics and predictive maintenance scenarios or asset management, for example, can be implemented in the system in this way.

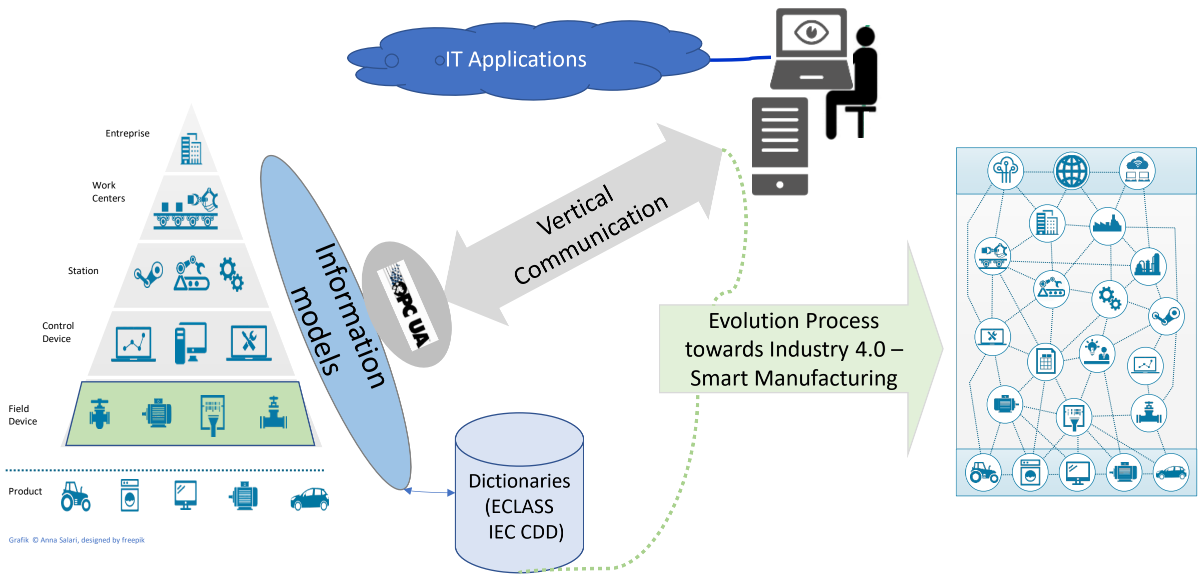


Figure 1: PI strategy for vertical communication

The information models are derived from the fieldbus profiles, which have been in use for a long time. The different periods of origin and areas of application of the profiles have partly led to different definitions of the same variables, parameters and even functions, which is unfavorable for the engineering of IT applications. This issue can be compensated within PI for in the information models by making corrections directly in the OPC UA information model and by referring to a neutral technology-independent dictionary in which a jointly usable definition is stored. Variables, parameters and functions may have different names for PROFINET and IO-Link, but they are traced back to a common definition if this applies to all of them. Examples of such dictionaries are ECLASS [ECLASS] and IEC CDD [IECCDD].

2 Vision

Machine-interpretable semantic descriptions can be generated for all data provided by devices and components using PI technologies. Standardized, open information models are available for this data and its semantic descriptions. The information models are closely interconnected so that IT applications can evaluate them at any time in such a way that the meaning of the data can be interpreted and the information behind it processed, allowing the correct application actions or functions to be derived. The information models are self-describing and thus machine-interpretable. The vertical communication does not influence control tasks and it is equipped with the necessary IT security measures. This forms an essential contribution to digital transformation and the implementation of smart manufacturing. PI has embraced this vision and, in the interest of achieving this goal, launched activities in workgroups and initiated collaborations with relevant organizations to further develop their technologies in line with Industrie 4.0.

OPC UA and ECLASS are used as information modeling technologies to implement the vision. OPC UA has established itself on the market as an interface technology with an information model and ECLASS is the standard for the classification and unique description of data in Industrie 4.0 Platform. For PROFIBUS, PROFINET and IO-Link, the communication and profile specifications are the starting point.

PROFIenergy can be taken as an example. Already today, the profile provides a means to collect energy measurement values in plants across manufacturers and therefore make them available to other applications, such as an energy management app, without much effort. For this purpose, this profile is also available as a so-called OPC UA Companion Specification. Such a profile could also be transferred to an administration shell. For this purpose, additional information shall be included, such as manuals, catalog data, certificates and other data associated with the component. This would make it easy for device manufacturers to provide these energy readings to the administration shell with their PROFIenergy-enabled devices.

3 Target audiences

Innovations and technological progress are successful when the addressees and their benefits are clearly identifiable. The value of information models in the context of industrial communication only really comes into focus for IT applications through vertical communication. System operators, device manufacturers, and system integrators, as well as PI workgroups, are all involved in the successful implementation.

- System operators
    - The production process is subject to constant monitoring and is also continuously improved, requiring detailed knowledge of the process flows and their interactions. In this context, data analytics applications are a supplement to the classic KPI metrics that need to be fed with additional data. Vertical communication and information models are a necessary prerequisite for their use. Changes in a plant are not only reflected in the dynamic process variables; structural changes (change of device configuration, device replacement) are also important information for operators. Progressive automatic documentation or even the life cycle files for devices and components are important sources of information for the efficient operation of the plant.
- Device manufacturers

  - Automation devices are also undergoing continuous further development. Data from their operational use, e.g., regarding operating conditions or correlations between stresses and service life, provide valuable input information, which can only be obtained from such operational use. Therefore, device manufacturers are also interested in the topic of vertical communication and information models.

- System integrators

  - Both the initial commissioning and any ongoing changes have to be implemented in terms of planning and practice. In the process, the configuration of the vertical communication and the information technology integration into IT applications are essential components. Clear structures and unambiguous, cross-manufacturer standards, especially for information models, provide vital support. If the expenditure decreases, more value-added projects can be implemented.

- PI workgroups

  - PI workgroups are characterized by employees of device manufacturers and integrators. This is where the know-how of the contents of the information models and the technological and practical feasibility of vertical communication lies. These workgroups lay the foundation for the successful use of new IT applications.

This document describes the emergence and role of information models from different perspectives. For this purpose, the document is structured as follows. Chapter 4 presents the main technologies used in the context of information modeling. This concerns a problem statement, from which the information models are derived, some basics about OPC UA and the use of dictionaries, which essentially support the assignment of meaning to the parameters in the information models. Chapter 5 places vertical communication in the PROFINET communication architecture and shows how the information model-relevant data is transported and integrated into OPC UA servers. Chapter 6 is the core of the white paper and dedicated to the description of the PI facet model. Facets are information models that describe aspects of the devices or the communication architecture. They are presented in more detail. The diagnosis aspect is in principle included in all facets. Therefore, the text is framed in color. Chapter 7 shows how PI facets can recognize the particular context in which a device is located by interacting with system-oriented information models. In the following chapters, the next steps are explained and a summary and outlook are given. The document is rounded off by the bibliography and a glossary.

4 State of the art

4.1 Information models for automation devices

Data becomes information when it can be interpreted by the recipient. For example, in humans it can be said that he or she can understand what is being said or decipher a picture, or read a message. People can do this if they can recognize the stimulus they have received and if they place it in their world of knowledge.

In the technical world, the process is basically the same, except that the devices first have no general knowledge about the world and no understanding of it. A classic example is the control program that processes sensor and actuator data. It is developed by an engineer who uses the device descriptions (usually available as a PDF) to learn how control programs interact with the sensor or actuator, what the data means, and how to access it. These descriptions are provided by the manufacturers of the devices, which introduce the software in the devices accordingly. The understanding in the control program development about the data is therefore the same in both interaction partners (transmitter: sensor and receiver: controller). Both people (device developer and control program developer) had the same information. In operational mode, only the data, e.g., a measured value with floating point data type, is then sent. In the control program, this data is used in the correct place. Transferring data without describing it is very efficient for time-critical applications.

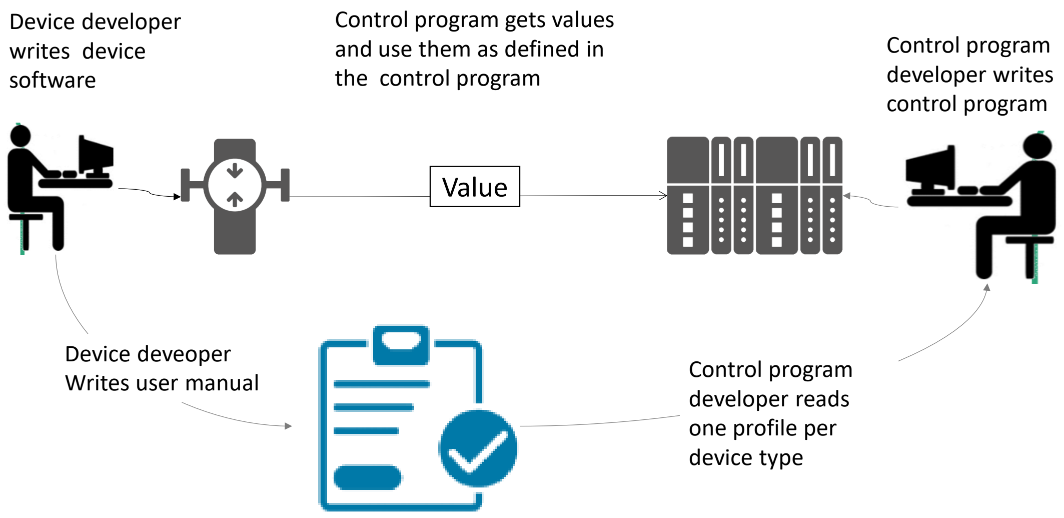


Figure 2: Classic procedure for creating control programs

Now, the fact is that, in industrial systems, there are very many different devices from different manufacturers. For control development, therefore, all descriptions must be read carefully, understood and implemented accordingly in the program. That is a lot of effort. For this reason, so-called profiles, that define standardizations for the same device types (Figure 3), have existed for many years. These profiles describe which data with which meaning are provided for exchange, how the data can be accessed, and which properties these data have –in other words, the information required for program development. Profiles are agreements between device manufacturers on how the data should be presented for communication, especially with the controller, including relationships and dependencies between data, e.g., the assignment of a unit of measurement to a measured value, as well as alarm and warning limits or damping. This is helpful because, for program development, only a few descriptions must now be read. The descriptions, however, were intended for human use only and could not be used directly for program development. Humans had to understand them and then manually incorporate the information into the program source code.

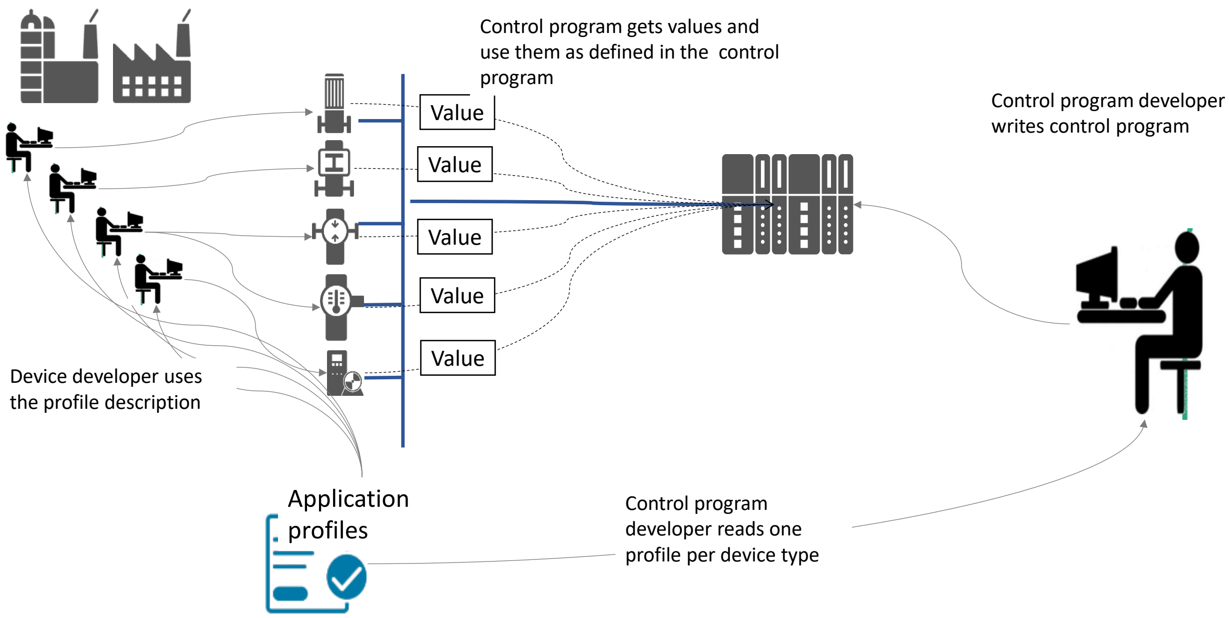


Figure 3: Profile-based approach to creating control programs

There are classes of devices, however, that do not have profiles or that do not follow profiles for various reasons. Here, the problem starts all over again – the manuals of the devices must all be read and understood so that they can then be used accordingly in a control program. This becomes particularly acute when new applications are to be developed outside of controllers, as is the case for data analytics tasks and modern asset management, condition monitoring, and optimization applications. Edge computing is the key phrase here. These additional applications access devices in parallel to the controller and retrieve the data needed for their specific application. The manual approach has proven to be a distinct hindrance, as the effort required to develop access to the data accounts for a significant portion of the overall effort and, in some cases, significantly reduces the added value of the application. Manual work must be replaced by machine-assisted methods.

One essential prerequisite is in place. The profiles already describe the required information. They must become machine-interpretable. The description of the data always follows similar rules. These rules can be summarized in a model and then described with a language that can be interpreted with the existing software. This is the starting point of the information models.

Just as there are standardized interfaces for PROFIBUS and PROFINET that simplify data access when supplemented with profiles, a standardized interface is also required for the transfer of information via vertical communication. OPC UA has proven to be particularly suitable for this purpose (4.2 and 4.3). As with PROFIBUS and PROFINET, OPC UA offers services for data access and supplements data identification with the possibility of describing each data item as well as their relationships to each other. This description is noted in XML and serves as configuration for the OPC UA server. The application can access the data and its description. With OPC UA, the information models can therefore be developed and implemented in a machine-interpretable format.

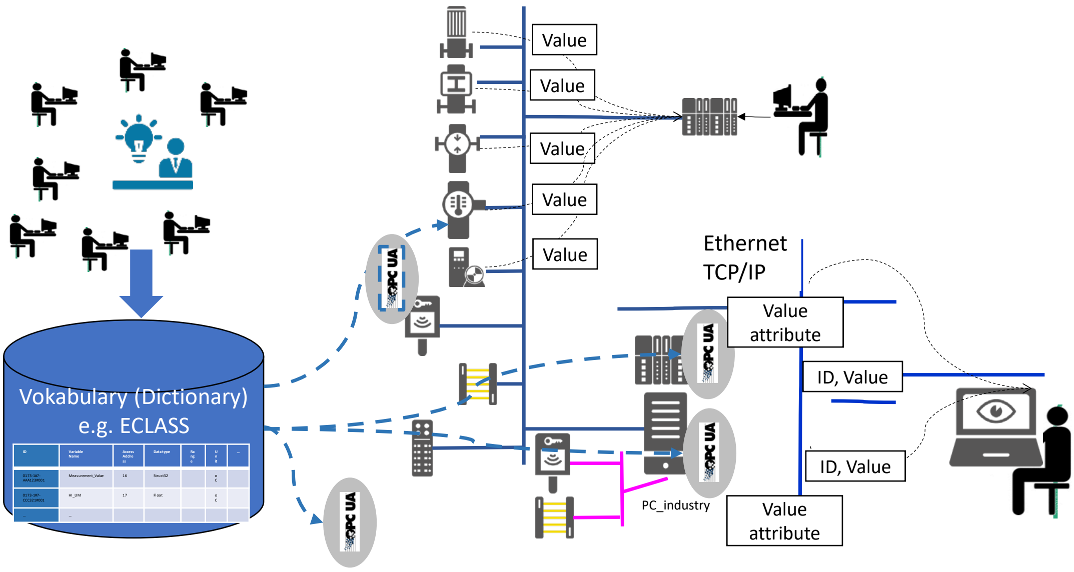


Figure 4: Use of a dictionary for the identification of field device parameters

If profiles are described using the capabilities of OPC UA, the application can access both the values themselves and their descriptions, which contain the semantic information. The engineering effort is significantly reduced since the description information required for processing is also available in machine-readable form at the same location as the values. They no longer have to be entered manually by humans. In addition to the time saved, the quality of the information also increases, as errors no longer occur during editing. Much larger volume frameworks can also be connected to applications in a reasonable amount of time.

There is another problem to solve. The devices and the profiles for PROFIBUS, PROFINET and IO-Link are created in different groups with different usage and, as a result, the same data, e.g., measured values and units of measurement, might not be described in the same way. From the application point of view, e.g., for the processing of a temperature, this data appears in the OPC UA information model with a different description. Such a situation is unfavorable because, once again, manual effort is required. This is where generally applicable vocabularies, also known as dictionaries, come in handy. They have been used for tenders and for bid comparisons for quite some time. Representatives of such a vocabulary include IEC CDD and ECLASS (4.4). Only a small addition is needed in the information model. A unique identifier is added to the description of each data item. This identifier is an alpha-numeric value assigned according to standards. As a result, it can occur only once. Different namings can now be used in the information model for a particular data item, e.g., temperature reading, PV or Out. They all receive the same identifier, which is stored in the information model of OPC UA. The application can therefore make a clear assignment of the data to its meaning.

The OPC UA servers equipped with the information model therefore provide machine-interpretable and unambiguous access to both the data and the semantic descriptions of the field devices. They are a technological advancement of the profiles. OPC UA servers can also be used in controllers or directly in devices in addition to edge components. An IT application therefore finds a harmonized landscape with which it can also access the semantic aspects.

4.2 OPC UA usage for information modeling

OPC UA, specified in the open standard IEC 62541, defines both a uniform interface protocol and an information modeling procedure that has established itself as a standard in Industrie 4.0. A distinction is made between a connection-oriented client/server model and a publisher/subscriber model. Communication is based on standard Internet technologies, such as TCP/IP, HTTP and web sockets. It is fault tolerant. Security mechanisms such as authentication, signing and encryption are also taken into account. The architecture is clarified in Figure 5.

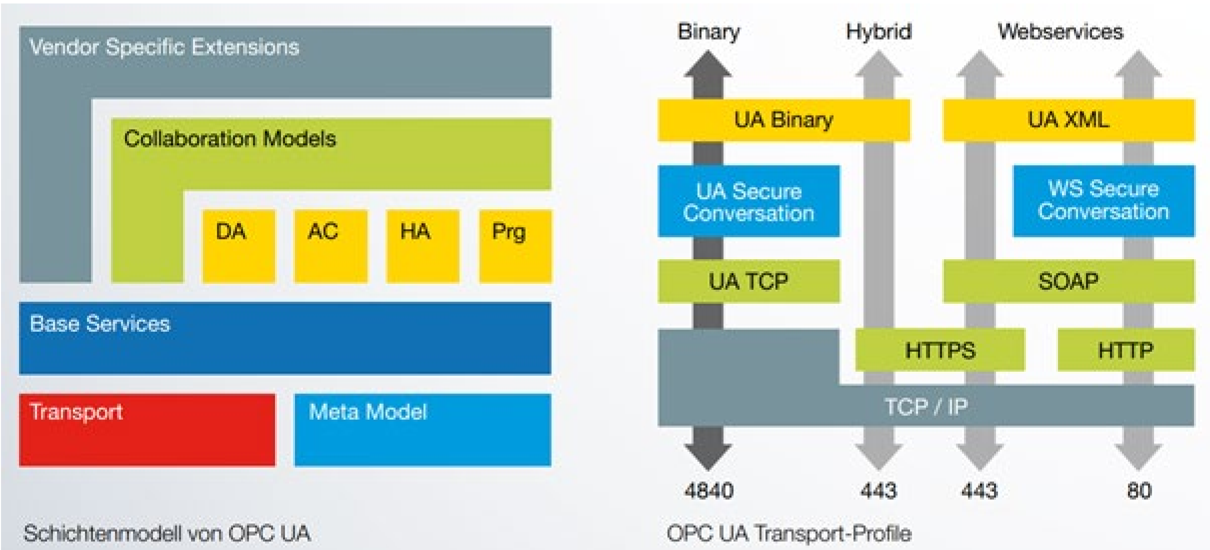


Figure 5: OPC UA layer model and transport profiles

The Basic Information Model Framework provided by OPC UA allows complex information to be easily created as objects in an address space that can be accessed with standard services. Objects in turn consist of nodes connected by references. There are different classes of nodes to choose from (Figure 6). The Variable node represents a value with a certain data type and can be read or written. The Method node represents a function that can be called. Each node has attributes, such as a unique identifier NodeId[1] and a BrowseName. A TypeDefinition node is always referenced, which describes the semantics and the structure. This meta model can be used to describe any device, function or system information.

[1] Node Identifier

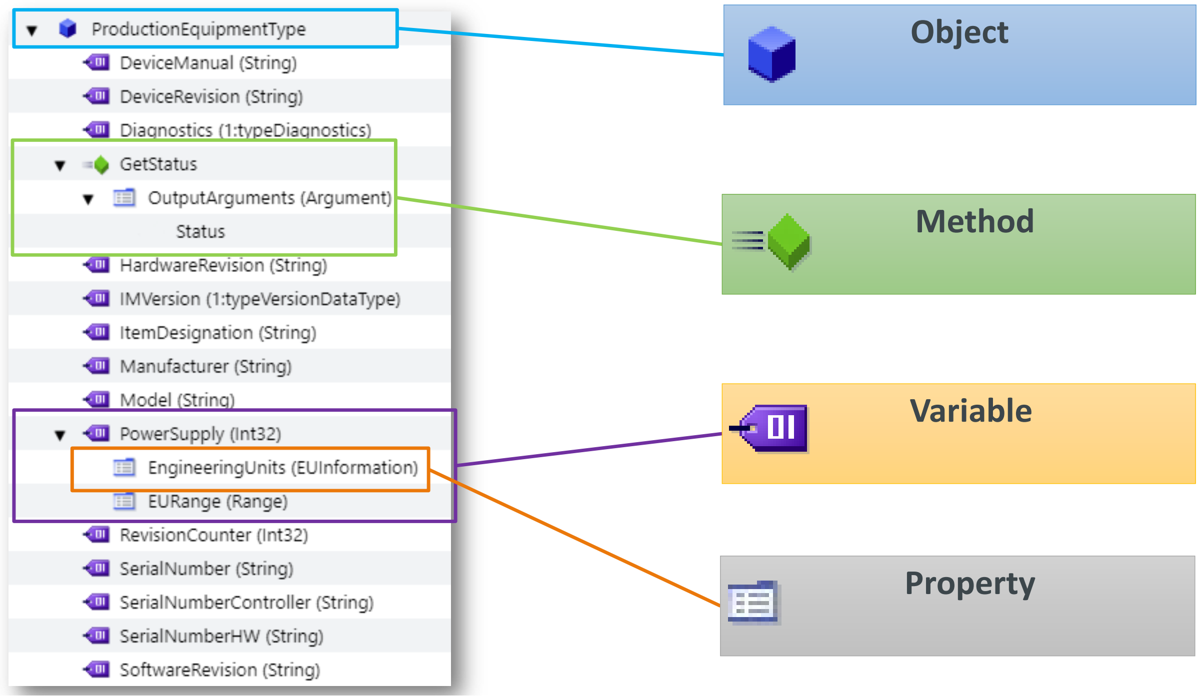


Figure 6: Essential elements of the OPC UA information model

The following figure describes the special notation used for modeling.

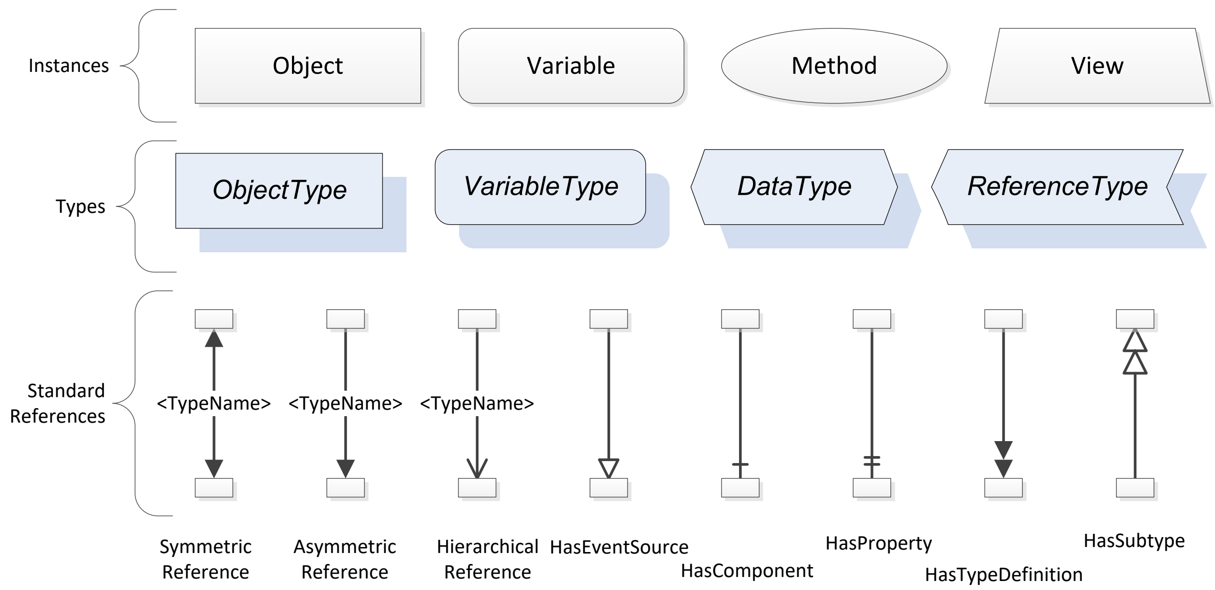


Figure 7: OPC UA information model notation

4.3 OPC UA companion specification

Special information models created by industry groups based on the OPC UA standard model are called Companion Specifications (CS). Suitable data point structures are defined for industry-specific applications and objects (Figure 6). Examples of Companion Specifications are Euromap77 (injection molding machines), umati (machine tools/CNC), PackML/ISA95 and PA-DIM, as well as PROFIenergy, PROFINET, IO-Link and others provided by PI. Not only the communication is therefore standardized, but also the stored data models.

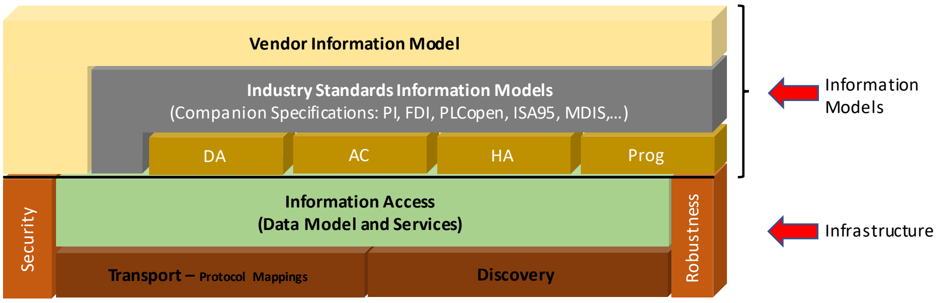


Figure 8: Information model architecture

Companion Specifications provide a standardized application view. Comprehensive functionality therefore becomes available at the information and communication level. A flexible coupling to different protocols is possible. Figure 7 shows the logical levels of the OPC UA specification.

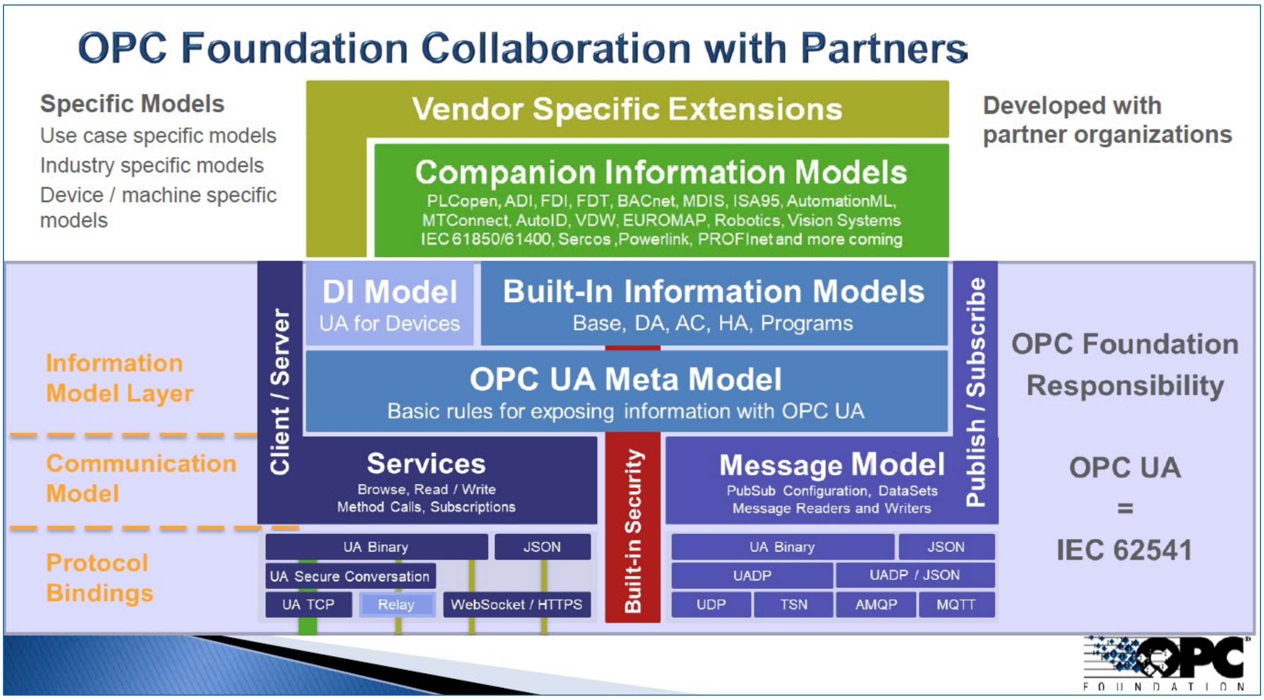


Figure 9: OPC Foundation Companion Specification developed in cooperation with domain partners

4.4 Use of data dictionaries (vocabularies) in the PI information models

The extension of communication to include vertical access from IT applications that are outside the classic automation pyramid (also see Chapter 5.1) necessitate the introduction of supplementary measures for interoperability. The IT applications are usually not integrated into the engineering process of the automation system and must nevertheless receive the necessary information for the configuration and parameterization of the communication paths. Above all, parameters and variables of different device types, profiles and application areas are used. Parameter and variable definitions must also be standardized so that applications can interpret them semantically correctly. For interpretation, the correct understanding, based on these definitions, must be present in the IT applications. A reference to these definitions is therefore made for the transfer of the parameter and variable. The term “semantics” stands for the assignment of meaning, contained in the definitions, to names or symbols. Figure 10 is the goal to be supported in the process.

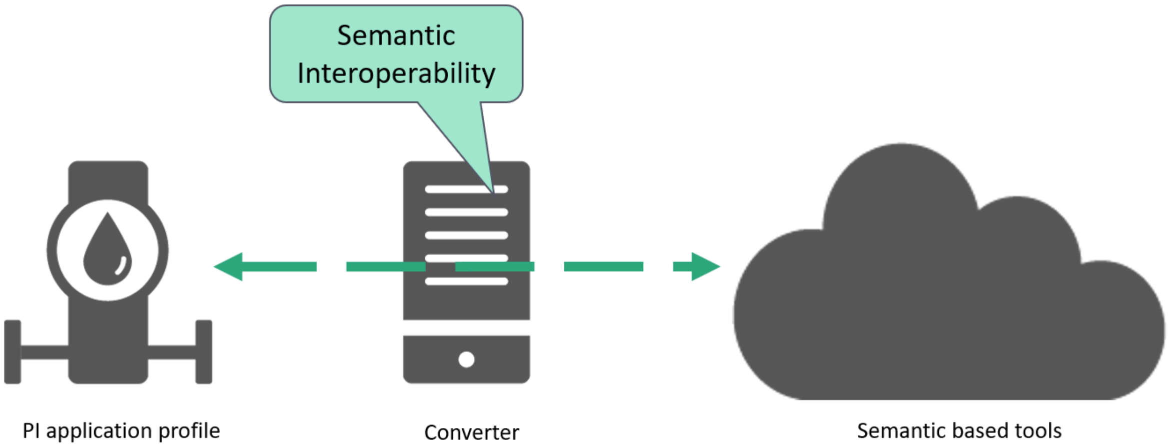


Figure 10: Semantic interoperability by means of converters

Until now, the meaning of a symbol (value) has been described in profiles (or the manuals of the devices) in a way that can be read by humans and has been coded out accordingly in software. Figure 11 shows that the same descriptions must be used on both sides when implementing the field devices and the control programs for the data transport. In operational mode, only the values themselves are transferred; the meanings have been implicitly taken into consideration during programming.

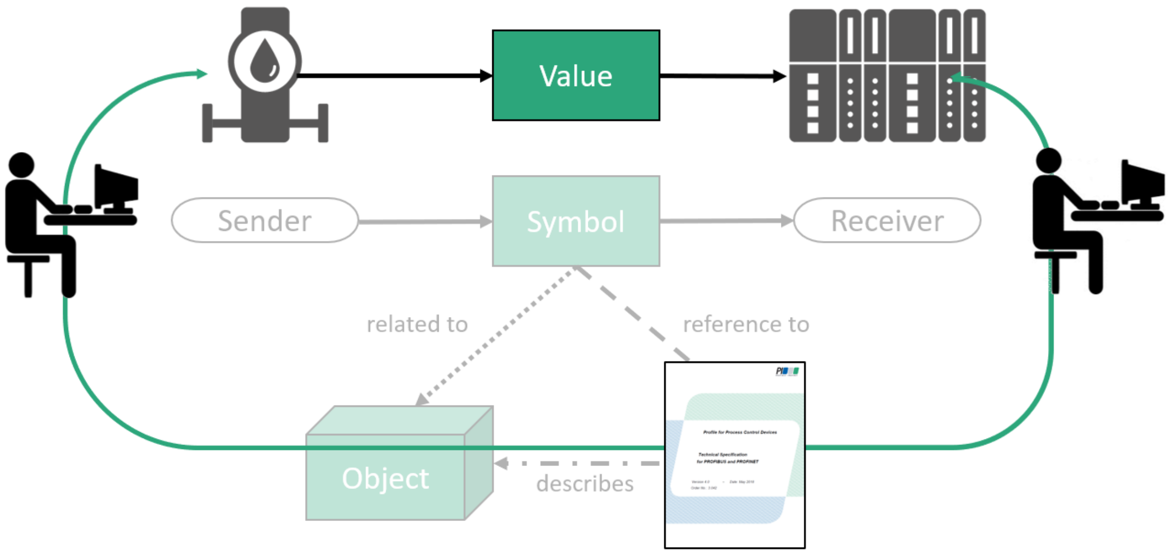


Figure 11: Semiotic triangle applied to PI application profiles

The future approach provides for an additional identification (ID) that references a machine-interpretable description (Figure 12). This procedure follows the so-called semiotic triangle. It describes that only a symbol (which stands for a word, a number or a pictorial representation, for example) is exchanged between a transmitter and a receiver, but this symbol refers on the one hand to the object to be designated and, on the other hand, to a description, which must be known to both the transmitter and the receiver. Only then can both understand each other.

Such descriptions are available, for example, in PI profiles, but are initially usable only by humans. For machine interpretation, these symbols must be unique identifiers (ID). Therefore, special standardized alphanumeric strings are used for this purpose, which are additionally available to the application (Figure 12). These identifiers are references to a machine-readable description in which important attributes, such as the data type, default values, units of measurement, and the unique definition are stored.

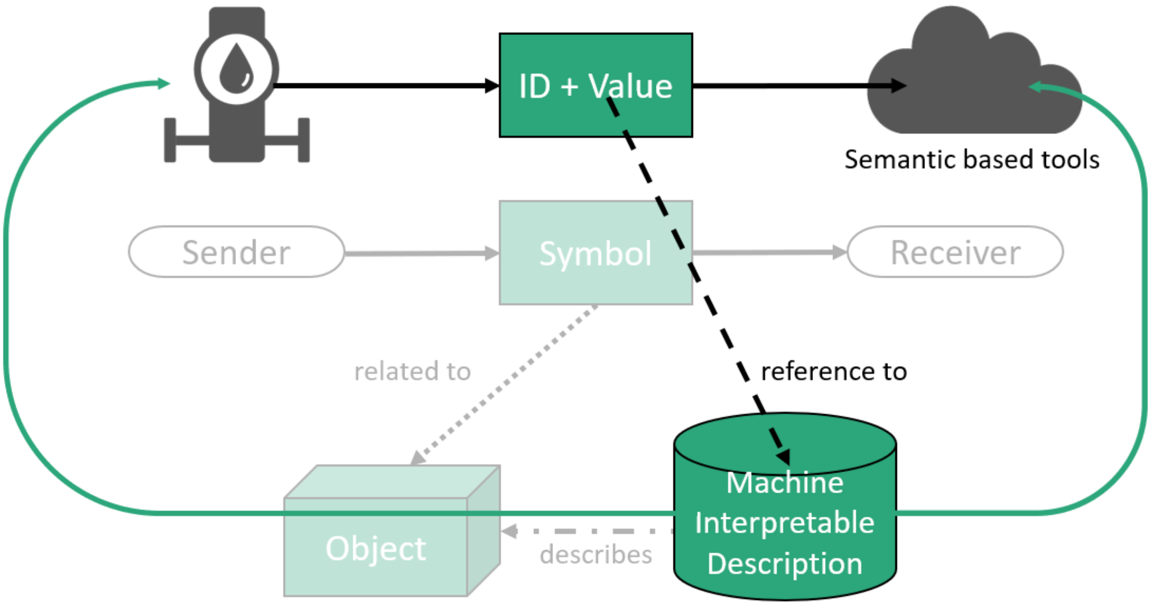


Figure 12: Addition of an ID for PI profiles to the parameters and variables

There are several standards for these machine-readable descriptions. At this point in time, ECLASS and the IEC CDD are particularly important for PROFIBUS and PROFINET technologies.

ECLASS, like IEC CDD, is a cross-industry master data standard for classifying and uniquely describing products and services digitally. It is an ISO/IEC standard-compliant international industry standard (Figure 13).

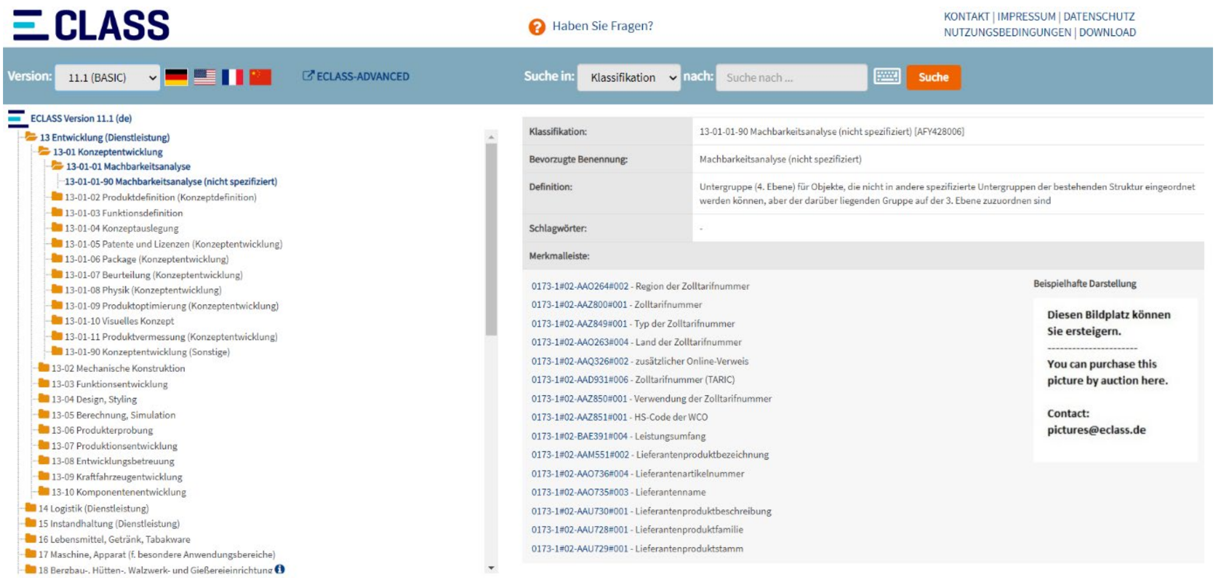


Figure 13: ECLASS catalog view

In the “Semantics for PI Application Profiles – Cooperation PI and ECLASS” white paper, a mapping is therefore made between the profile parameters that are not described in a machine-interpretable way and those characteristics defined under ECLASS, i.e., marked with an ID and include machine-interpretable descriptions (Figure 14). These ECLASS IDs are included in the OPC UA information model and the IT application can therefore access the standardized ECLASS description. In principle, this procedure is also possible with other standards, such as IEC CDD.

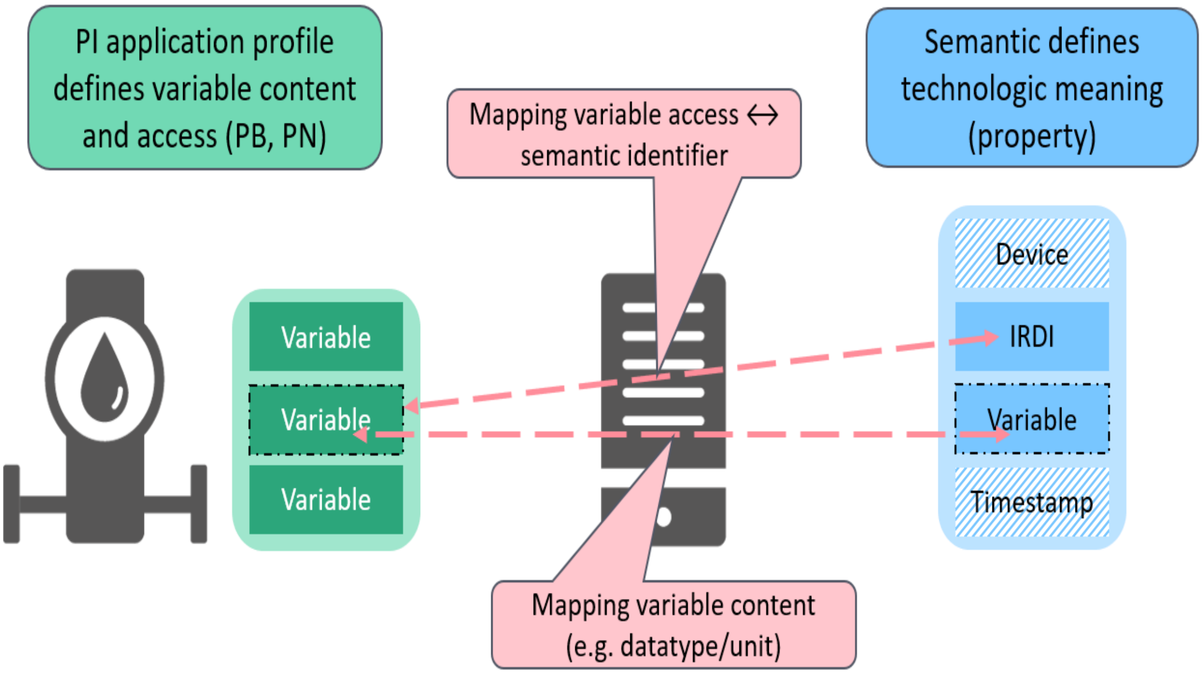


Figure 14: Mapping model between PI profiles and ID-based characteristic definitions

In the collaboration between PI and ECLASS, parameters and variables of existing PI specifications are mapped to the characteristics of ECLASS and are therefore extended by a semantic identifier. The PA profile was selected at the beginning. Here, relationships between PA profile parameters and variables and ECLASS characteristics are established by means of the assignment of IRDIs. The relationships are stored in XML specifications. They can then be used by IT applications through the creation of mappings in both directions. In an upcoming version, this will be incorporated into the profile specification. This helps PI application profiles to achieve semantic interoperability and facilitates integration into tools designed for this purpose. The profile does not have to be changed in the process.

5 Vertical communication

5.1 Vertical communication from the automation device to the application

Before looking at the information models, the data flow should be explained. Figure 15 shows the device architecture oriented to the classic automation pyramid on the left. The field devices are connected directly or via Remote IO or IO-Link master to the controllers (PLC) using PROFINET. In addition to the field devices, more complex components, such as drives or robots, can also be connected. All automation devices are referred to here as "devices" for short. The controller typically interacts cyclically with the devices and other components. This communication can also be supplemented by PROFIsafe for system components with functional safety. For their part, the control systems interact with the controllers in a hierarchical sense. In addition to the data flow with the control system, the applications, such as those shown in Figure 15, access the devices at various field and control levels. The vertical communication already present in the control system is supplemented here by an additional path. Both paths can be visualized as a "Y", the devices are the same (lower middle line), but the paths to the different application divide.

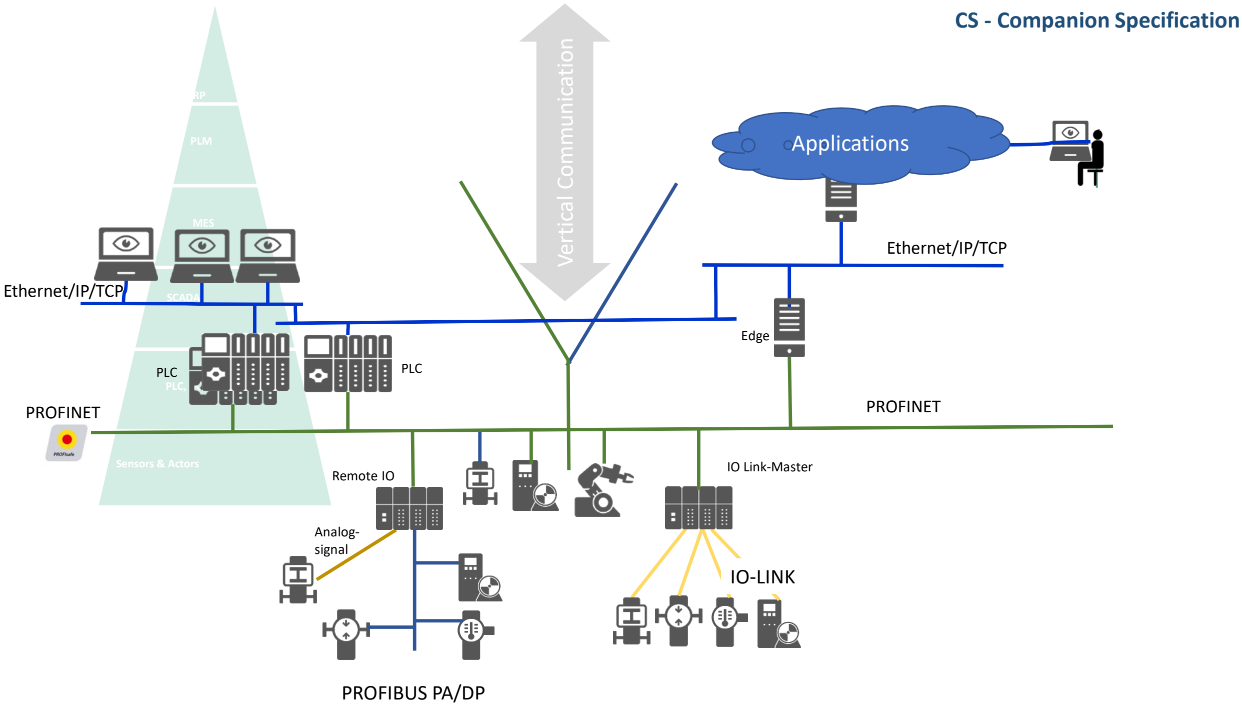


Figure 15: "Y"-oriented vertical communication in the automation system

Figure 16 shows the connections that are possible across all levels of the automation pyramid. On the left side, the field devices and other components are listed as examples. Along the dotted vertical line is the progression of time. An edge device and an application are also shown on the right with vertical dotted lines. The brown arrows are acyclic PROFINET (or PROFIBUS) services that access parameters; the blue ones are those of OPC UA. In each case, the addressing parameters are specified for PB/PN slot, subslot and index and, in the case of OPC UA, the BrowseName or NodeId. The green arrows symbolize the cyclic communication between the controller and the automation devices. This is repeated periodically. During the times when no cyclic communication is running, additional acyclic PB/PN services can be handled, for example, through edge devices. In principle, however, every device can also be equipped with an OPC UA server. This server is addressed by the OPC UA client. The time gaps of cyclic communication are also used for this purpose. If the controller has an OPC UA server, it can also be queried. Figure 16 only tries to clarify the principle; it only looks at communication in a general manner. The actual communication processes are even more complex.

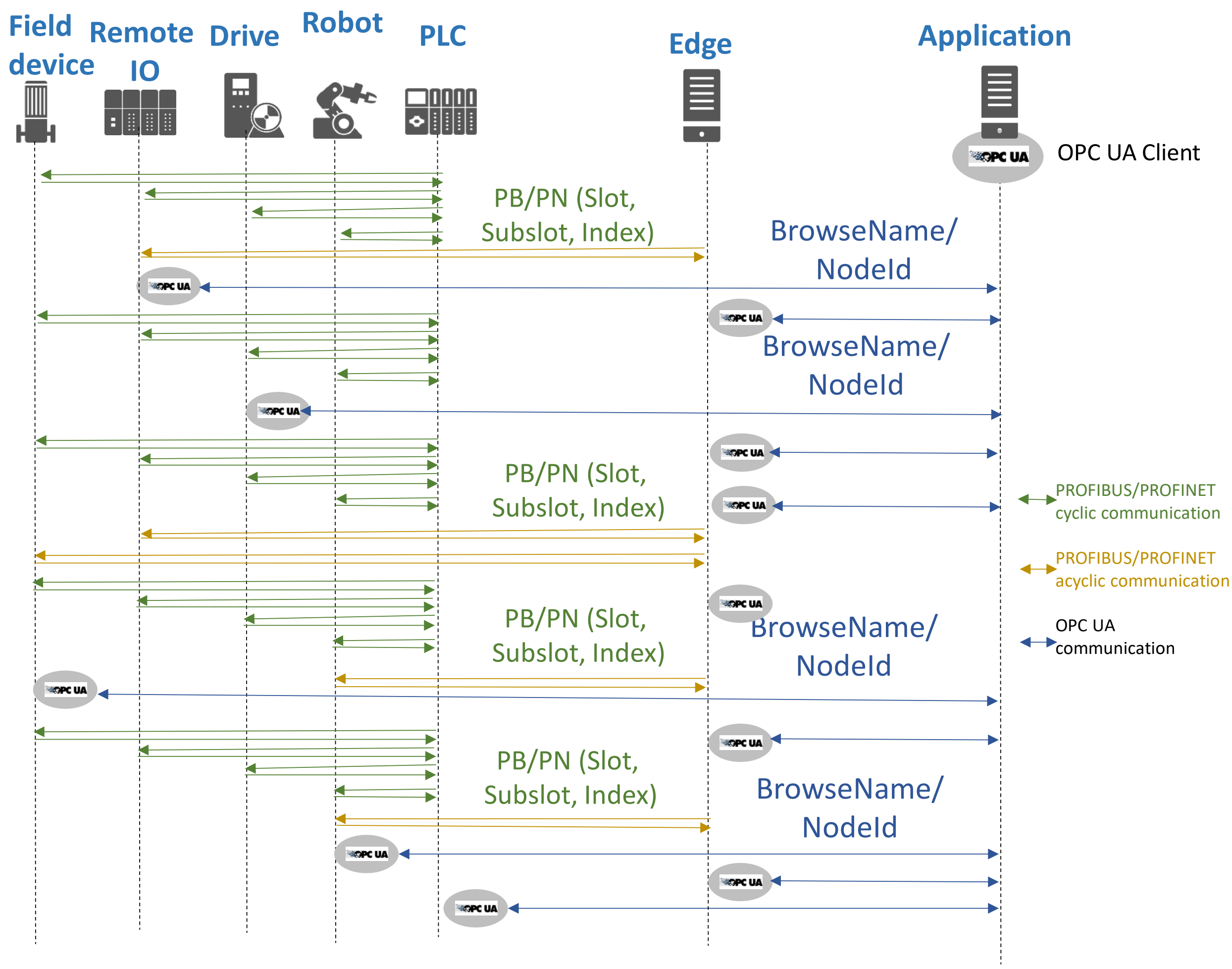


Figure 16: Communication principles in vertical communication

Figure 17 once again shows a detailed view of possible communication paths. The data is stored internally in the devices (Figure 17 – (1)). By the mapping rule from the corresponding profiles, they are offered at a certain slot/index (if PROFIBUS) or slot/subslot/index (if PROFINET) for the communication services (here typically ‘Read’) (Figure 17 – (2)). Master class 2 (if PROFIBUS) or Supervisor (if PROFINET) trigger these services (Figure 17 – (3)). If these devices have an OPC UA server, they shall store the contents of the data communicated by the services in the correct node (e.g., variable) in the OPC UA server (Figure 17 – (4)). To do so, they shall perform a mapping. The OPC UA client can then access the BrowseNames defined in the Companion Specification or the NodeIds that can be derived from them (Figure 17 – (5)). For a better understanding by the people who configure the OPC UA servers or write the application (Figure 17 – (6)), the BrowseNames are based on the profile names. If a PROFINET device itself has an OPC UA server, the transport steps from PROFIBUS and PROFINET are omitted and the device can perform the mapping between the internal data and the storage in the OPC UA server in the device (Figure 17 – (1) – (4)).

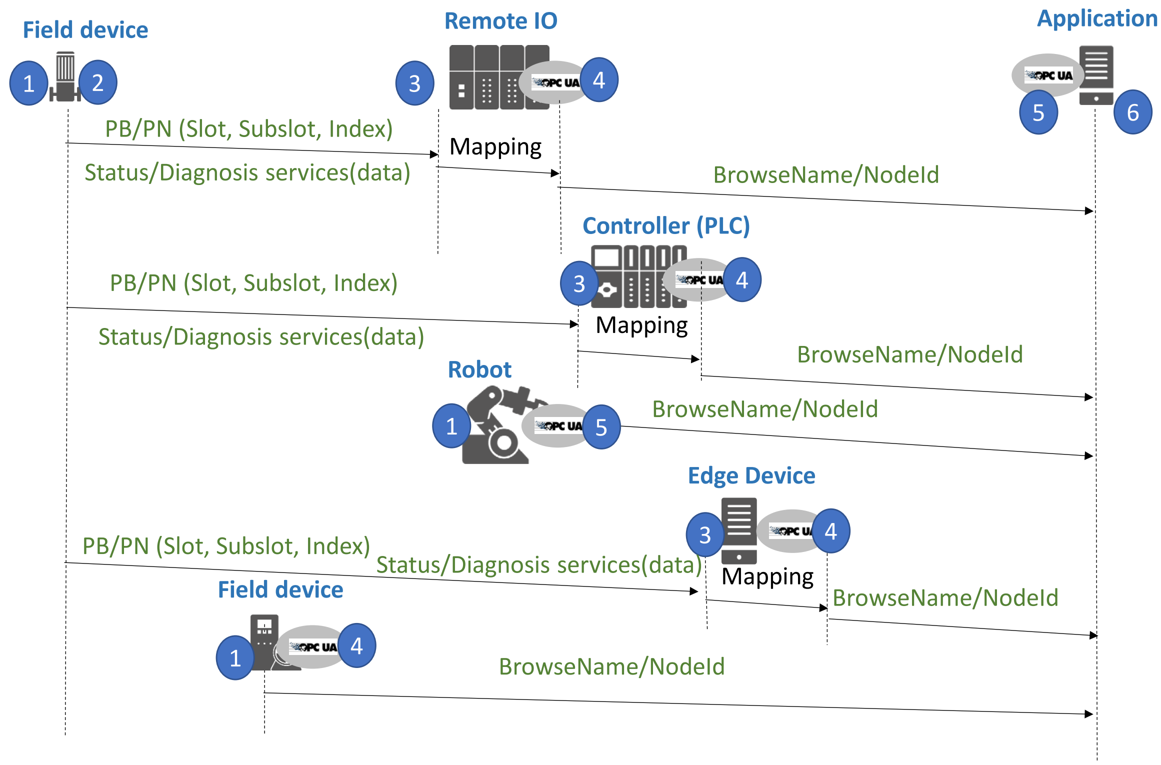


Figure 17: Data point addressing and diagnostics along the data path from the field device, drive, Remote IO or robot to the application

In addition to cyclic and acyclic communication, the field devices can also send status and diagnostic messages to the controller, which can also be retrieved by the vertical communication application. Status and diagnostic messages are provided by all device types. The status and diagnostic information of the devices are also provided by OPC UA. The status and diagnostic information can refer to the system in which the field devices are used, to the devices themselves, and also to the communication system. Diagnosis is therefore a cross-sectional task that is integrated into the respective information models.

Figure 18 focuses on the different types of information sources and their implementation in OPC UA information models. PROFINET forms the backbone of the system (Figure 18 – (1)), which can be operated with or without PROFIsafe. It contains the topology information. The devices are connected to PROFINET directly or via Remote IO (Figure 18 – (2)) and (Figure 18 – (3)) or IO-Link master (Figure 18 – (4)). These devices contain asset information, such as the nameplate.

The information is brought into OPC UA servers in each case. A Companion Specification exists depending on the device domain.

- Topology information is defined in the OPC UA Companion Specification “OPC UA for PROFINET” (OPC 30140). It can be contained in the controllers or in edge devices (Figure 18 – (7)).
- For process field devices, PA-DIM defines the nameplate information and other use-case-related objects (OPC 30081 [OPC2018] (Figure 18 – (8)).
- The OPC UA for IO-Link information model ([OPC2019] (Figure 18 – (6)) contains, for example, the nameplate information from the “IOLinkDeviceType” of the base profile as an OPC UA object. For all PROFIBUS and PROFINET devices, the nameplate information is uniformly defined in the OPC UA for the PROFINET Companion Specification in the object with BrowseName “IM” (Figure 18 – (4)).
- In principle, OPC UA servers that do not yet comply with a Companion Specification could also be included, as shown in (Figure 18 – (5)).

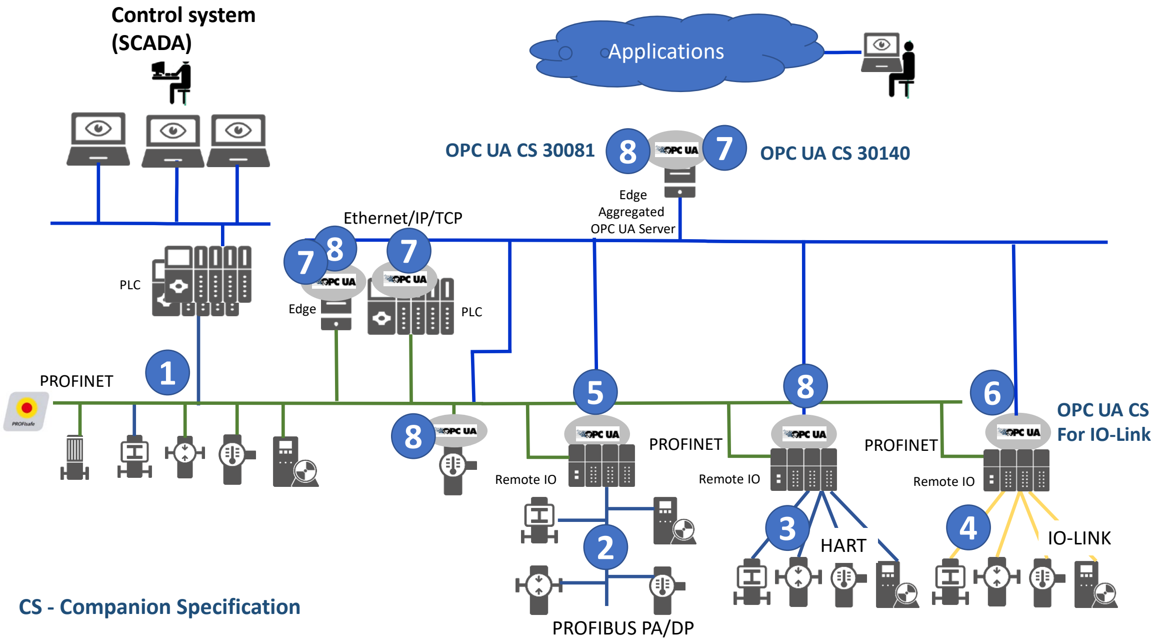


Figure 18: Information flows in an exemplary topology structure

The illustration in Figure 18 is exemplary and shows only a small number of possibilities. In practice, topology structures and the OPC UA servers embedded in them will have a high variance.

5.2 Use cases

Users of a production plant change their view of the data based on the condition of the plant and the life cycle phase of the plant components. Different roles (e.g., mechanics, electrics, communication, security, safety, control engineering, measurement technology, actuation technology and software) with different tasks, such as planning, commissioning, support of operations, maintenance, optimization, and asset management each use a different section of the available data. They have a different view of the production system and therefore of the data provided, because they are each focused on their own use case.

Another dimension is the assignment of the data to the components about which they provide information. A measuring device, for example, initially has data about the process variable it is supposed to measure, i.e., the component on which it is mounted or the product in which it is in contact. But it also has data about its own condition and provides diagnostic information. In addition, it carries information that serves to identify the device (e.g., manufacturer, model type, serial number) and to classify it in the PROFINET network in connection with the corresponding configuration parameters. This is additional data that is not used for basic automation (control or condition monitoring in the PLC). In addition to the field device-control communication, a communication is created that forms its own path to further applications. This is referred to here as vertical communication. Use cases must therefore be selectively provided with the data required for them. Horizontal communication between controllers (also called controller-2-controller communication) is not addressed here from an information modeling point of view since the mutual variable assignment is carried out manually by programmers.

The call for information models arises wherever IT applications are to be used in addition to basic automation (closed-loop control, open-loop control, condition monitoring) to improve the flexibility and performance or the value of systems, machines, components and devices. End users want more precise knowledge about system performance and conditions from process and component data, e.g., using data analytics, or predictive information for the course of further production. Information models help to mask the different communication technologies installed and to provide a consistent picture of the system. If you take a closer look at these applications, you will always find data processing functions behind them that use data from the devices to calculate other data that is important for increasing flexibility and optimizing value or performance. For the optimal functioning of these application algorithms, the correct assignment of the data from the field to the variables of the application algorithms is essential. Hence the requirement can be derived that the application engineer must uniquely identify the data from the field and also be provided with a communication path. He or she does not want to put a lot of effort into this task because the added value is achieved with the algorithms, not with the data transport. So, data access and access path configuration must be made as simple as possible. This is not easy due to the large variety and number of devices. The classic means of dealing with large volumes is to structure them. This is exactly what information models do.

If a vertical communication path is looked at a little more closely, a datum (e.g., diagnostic value) is created in a device. Then it is transmitted through a communication system to be stored or processed in another device (Figure 19). The data in the devices have a data type, a permitted range of values and/or possibly a unit of measurement. The devices are integrated in the communication system and have a communication address in this system, for example. For one application, the data can come from devices connected to different communication systems. The datum must also be addressed for communication and therefore also has an address at which it can be reached. If a datum is stored in an edge device, this device also has a classification in the communication topology with a device address. The way the data is addressed depends on the communication system, which means that, depending on the communication system used, an edge device will also have a different address for the same datum. These few examples show that a variety of information is necessary to correctly transport a datum to the IT application interface and uniquely identify and describe it for the application.

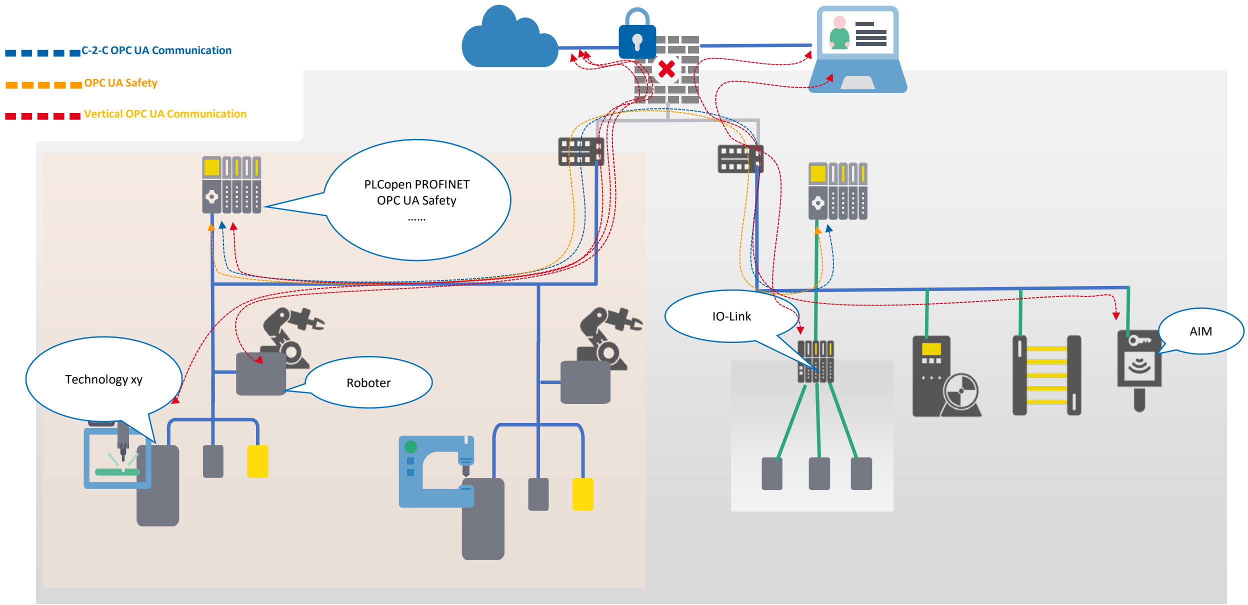


Figure 19: Different data sources connected with different technologies are provided by OPC UA

It is hardly possible to list the multitude of use cases here. Therefore, some essential use cases that currently use information models will be named as examples:

- Clear identification of all devices and components in a system
- Comparison between planning documents and the actually constructed system
- Device condition monitoring, asset diagnostics
- Communication system monitoring and diagnostics
- Data analytics for devices and machinery and equipment
- Life cycle tracking of devices (life cycle file)
- Digital shift log
- Analysis of the correct dimensioning of the installed devices and components

- Comparison of a planned and actual configuration of a device
- Workflow support during calibration (order receipt by the technician, execution, filing of protocols, etc.)

5.3 Principles and requirements

Automation devices provide a large part of the data that is processed in the application. The devices are assigned to the communication structures according to their position or connection to the machines or system components. In principle, requirements for the access paths through which the data flows can be described as follows (Figure 19):

- Data access via the PLC
    - The application has dependencies on the PLC control program
    - Use of symbolic naming and semantics of the data from the control program
    - Prepared data is required
    - Use of the advantage that the PLC manages the I/O level as a subnet with regard to addressing
    - The amount of data required by the application should have no impact or only a reasonably disruptive impact on PLC performance
- Data access via edge devices
    - Preprocessed data is required
    - “Brownfield” devices can also be integrated, which are located below the edge
    - Data is read from many devices in “greenfield” plants
    - A central location for data, network devices and security configurations is needed
    - The devices are connected with different and also proprietary communication protocols
- Direct data access in the PROFINET device
    - The device must be available with OPC UA or other protocols in “greenfield” environments
    - Devices provide device-specific diagnostic data
    - The PLC or edge should not be stressed with additional communication
- Security
    - The protection of access and the data are to be taken over by the security mechanisms of OPC UA or PROFINET security. Details can be found in the corresponding PI Security documents.

5.4 Positioning of information models in the PI technology canon

As described in Chapter 5.2, the added value of the data obtained in vertical communication arises in the application functions. In the application algorithm, the origin and transport route of the data is no longer crucial. The information models help to provide the data of the devices, including their semantic description, as well as the data needed to describe the communication paths for coupling the application algorithms. At the application interface, all required semantically described information is made available by means of an OPC UA Companion Specification (CS) (Figure 20). In this way, the information model forms the cohesion between the different PI technologies (PI technology canon) in that all information can be clearly assigned to each other and therefore the access paths are transparent for the user.

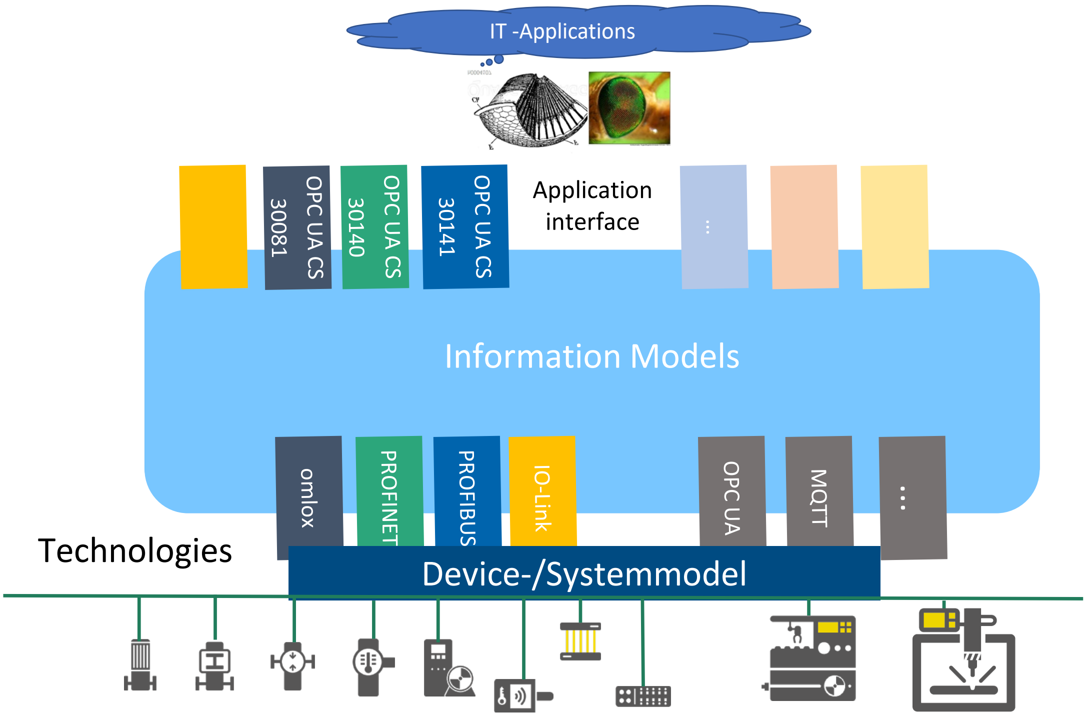


Figure 20: Information models provide cohesion between the different PI technologies

6 The PI information model

6.1 The facet model – Concept and benefits

There is a wide variety of automation-related devices that can be implemented with PI technologies and that are used in different use cases in the life cycle of the plants. The use cases may require different information from the devices, i.e., different views of the devices, for example, device-identifying information, their classification in the communication architecture, or their functions and parameters. Despite the diversity of devices, the devices have characteristics and functions that are important across device classes and technologies. For example, system-related physical variables are independent of the type of treatment in the devices (a measured value or actuating value is in principle universal) while technical organizational characteristics such as identifying characteristics (manufacturer's name, serial number) are also universal. For the different views however, the characteristics and functions are compiled into information models tailored for them. Depending on the use case, one or a combination of information models can then be used. Therefore, the PI information model is designed in a modular way. The modular structure of the information models maps the different aspects of the devices and support their system integration.

The individual information models describe

- the devices themselves - the physical view,
- the functions and parameters of the devices – the functional view and
- the communication view – PROFINET view.

Included in each view are the diagnostics that map the specific conditions of the component. As an example, these views are described for a compressed air generation system in Figure 21.

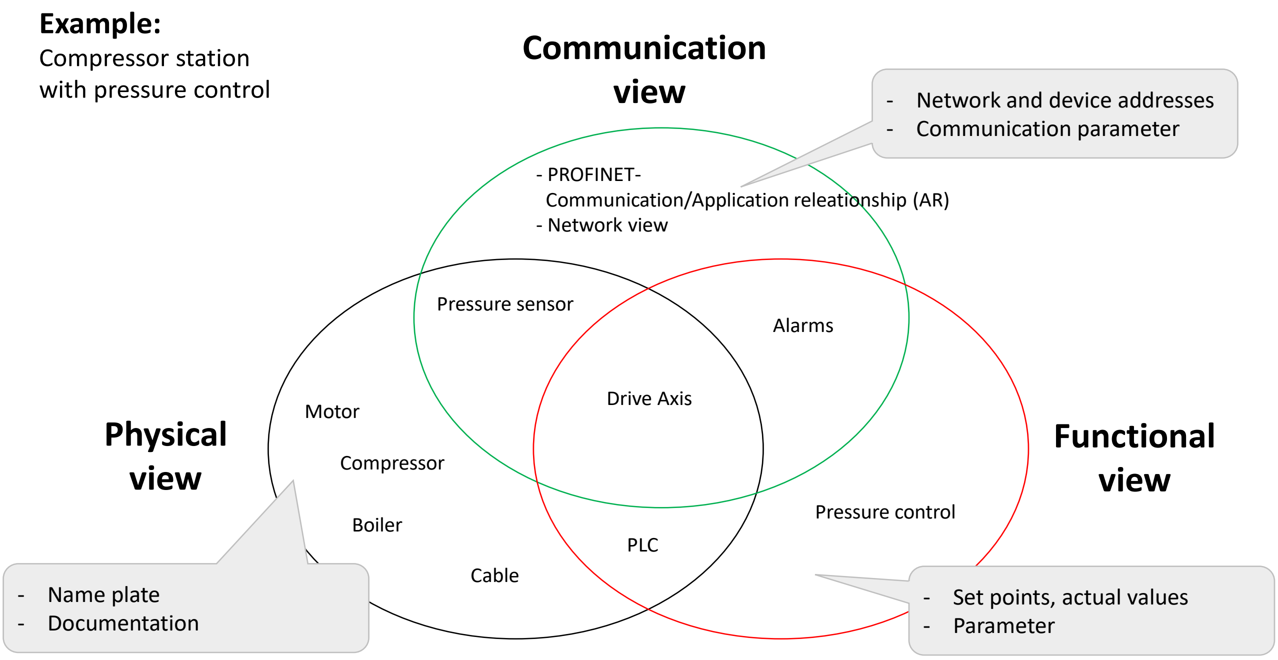


Figure 21: Views from which information models are composed

If the general views are further broken down and refined, a modular structure is created that allows the modules to be combined with each other depending on the application requirements and use case. For example, the different device types, different function groups and the communication system are separated from each other. The elements of this breakdown are called facets[2]. As a result, individual partial information models are created that are combined in the PI concept as communication, physical (asset) and functional facets and collectively describe an automation device (automation entity) (Figure 22). Similar to the compound eye of some insects, a whole is therefore created from parts.

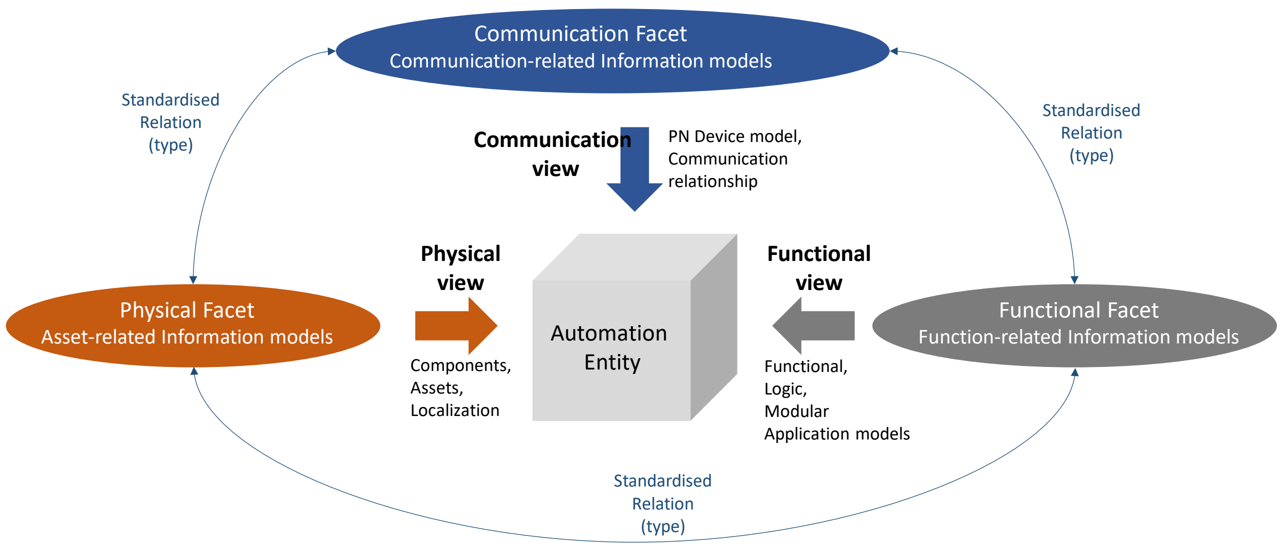


Figure 22: Facets collectively describe the automation devices and form the views

The **communication facet** includes the connection of the devices and components to the communication media and their topology, i.e., to the network, and is referred to as the **network facet** (from an OSI reference model perspective, layers 1-3, primarily addresses and network-related parameters, such as baud rates, net topologies). The communication-related device names and

[2] The facets refer to the different aspects of devices and communication systems and are not to be confused with the term "facet" of OPC UA

the addressing of the applications resulting from the PROFNET device model (slot, index) are referred to as the **PROFINET facet**.

Physical aspects of the devices and components, such as the nameplate, but also the catalog data or certificate documents, are summarized in the **physical or asset facet** (see Chapter 6.2).

The **functional facet** forms another very important part of the information model, in which technology-independent function-related data is described from the point of view of the application. The data is structured according to individual functions (e.g., measured temperature value) or function groups (e.g., energy management). These functional facets form the building block box from which the technology-specific information models are then assembled (see Chapter 6.4).

Each facet contains the status and diagnostic information specific to that component. This information is named in the respective chapters 6.2 to 6.4 (each at the end in a color-coded box). The facets can be assembled according to the specific application. For this purpose, references are defined between the elements of the information models of the facets (see Chapter 7). The **use cases** can then access structured information even across facets.

Figure 23 shows the refinement of the PI information model. From the user's perspective, the facets each cover different information needs. The focus can therefore be on identification (asset) or on the integration of the devices into the communication network (topology). This information is independent of the functionalities offered by a device. They are therefore shown separately in Figure 23. The functionalities are initially independent of specific technologies. They are described with their information models separately by function type. All facets of the PI information model are mapped to the OPC UA information model individually or in certain compositions. In OPC UA, these device or machine type specific models are called “Companion Specifications”. These models are the different facets. The use cases each access the parts they need. An example will briefly illustrate this situation. A drive is integrated in a PROFINET network and drives a pump. The drive has a variable speed function and can move along speed trajectories or use torque control. These are functional facets. If a diagnostic message now occurs, the application must assign it to the motor. For this purpose, the location in the communication network must be known, since the diagnostic message is bound to the communication address. The PROFINET Companion Specification is provided for this purpose. On the other hand, the diagnosis must be assigned to the functionality of the engine. This then requires the PROFIdrive profile and potentially a corresponding OPC UA Companion Specification.

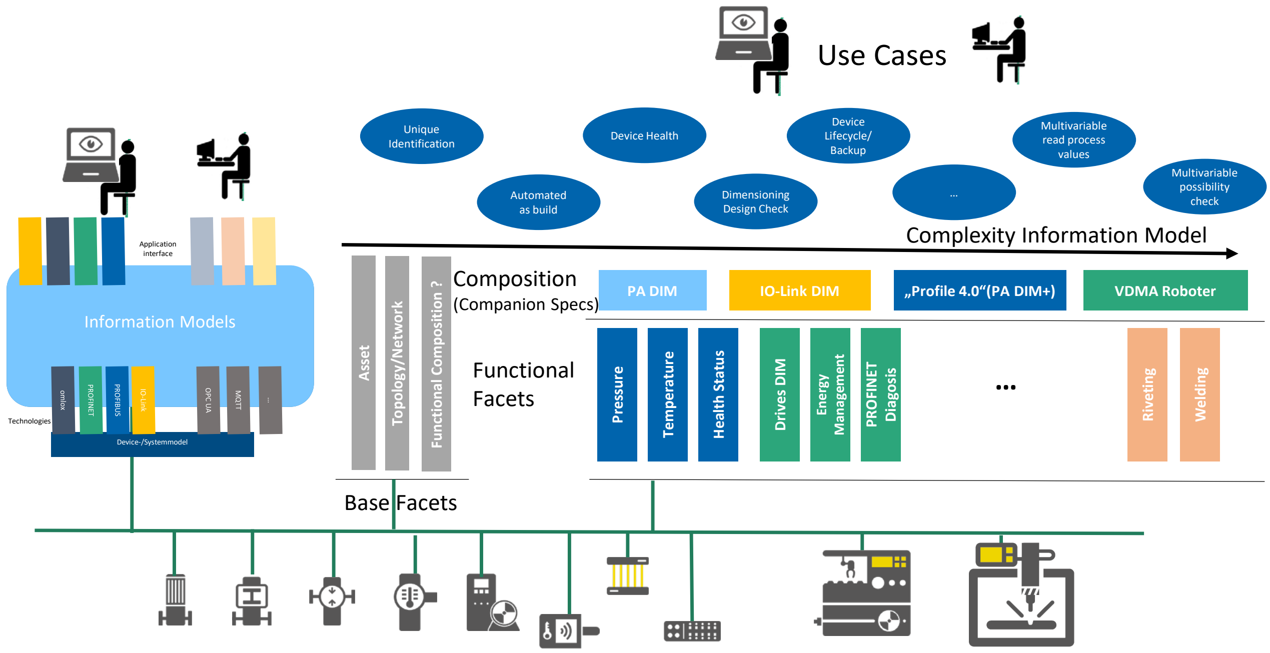


Figure 23: Overview facets of PI information models

Details of each facet are described below.

6.2 Asset facet

For the purposes of this white paper, the assets are PROFIBUS, PROFINET, and IO-Link devices. All these devices must be clearly identifiable. The identifying information comes from the nameplate of the devices (Figure 24 – (1)). The nameplate is located on the device and in its supplied documentation.

Typical **use cases** include:

- Documentation of the plant as it is actually installed
- Identification of devices for which a service case exists, e.g., firmware updates

This information should also be read out from the devices. For this reason, it is specified for PROFIBUS and PROFINET that all devices must have so-called "I&M characteristics" (Identification & Maintenance - PI Profile Order No: 3.502) that are readable (Figure 24 – (2)). Important characteristics are named in Table 1. The nameplate information is also provided in readable form for IO-Link devices. The details are stored in the IO-Link Common Profile (order no: 10.072) under the "DeviceIdentification" object (Figure 24 – (4)). The device manufacturer derives these properties from the nameplate information. These parameters can therefore be accessed by corresponding communication services from the IO Link Master.

The "I&M characteristics" and the "DeviceIdentification" are each implemented in the OPC UA Companion Specification (Figure 24 – (6), (7) and (8)).

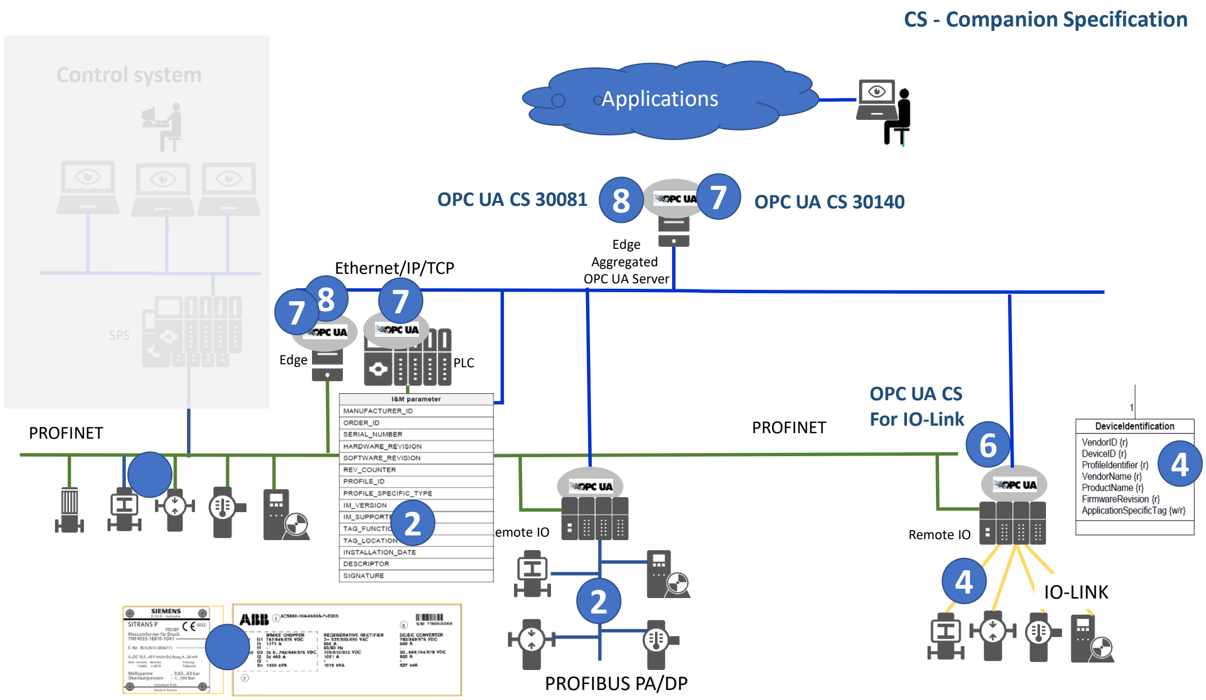


Figure 24: Information in the asset facet

Each of these properties has a defined description in the PA and IO Link profiles, which are the basis of the information model. An example can be seen in Table 2. The name, the number of octets (size) and the data type are defined and an example is provided. The values can be assigned by the manufacturer in the firmware or by the user. Taken together, the I&M functions describe the information model of the asset facet.

The transport of the data corresponds to the variants shown in Figure 17, depending on the placement of the devices in the topology.

Table 1: Important characteristics of the I&M profile

I&M parameter
MANUFACTURER_ID
ORDER_ID

SERIAL_NUMBER
HARDWARE_REVISION
SOFTWARE_REVISION
REV_COUNTER
PROFILE_ID
PROFILE_SPECIFIC_TYPE
IM_VERSION
IM_SUPPORTED
TAG_FUNCTION
TAG_LOCATION
INSTALLATION_DATE
DESCRIPTOR
SIGNATURE

Table 2: Description of the “Order_ID” characteristic

Name	Size	Data type	Initiator	Action
ORDER_ID	20 octets	Visible string	Firmware	-
			USER	-
			Production	E.g. “3xy-0AE00-0AB0”

There is no status or diagnostic data for the devices, i.e., the assets, with regard to the name-plate information. During the self-monitoring of the devices, the following information is generated:

- Revision counter
    - This parameter is incremented by 1 (one) each time a parameter is changed in the device. This makes it possible to detect whether the parameterization and configuration of the device has been changed during operational use.

6.3 Communication facet

6.3.1 PROFINET facet

PROFINET is the automation communication standard of PI. It is the network solution for production and process automation, with applications such as functional safety, drives and isochronous motion control. Application profiles allow a wide range of use.

Data exchange is based on the provider/consumer model, with the controller and device sending data independently. PROFINET defines the device classes: IO Controller, IO Device and IO Supervisor. An IO Controller is typically a PLC with the automation program. The IO Devices are located in the field and are assigned to one or more IO Controller(s). The IO Supervisor can be a programming device, HMI, or PC, and can be used during commissioning and for diagnostic purposes and is usually temporary in the network.

The information model describes the structuring of the devices (both IO Controller and IO Device) from the point of view of the PROFINET network and maps their interfaces. Here, as shown in Figure 25, the Ethernet ports of the switched full-duplex line are brought together with the modular structure of the application (RealSubmodules). The information model mainly contains the assignment of addresses to the respective elements of the devices.

Typical **use cases** include:

- PN Controller: device configuration / data / alarms
- PN Supervisor: device diagnostics / status/control / parameterization

Figure 25 illustrates the relationships between network objects of a single-port PROFINET device and a four-port Ethernet switch. All elements result in objects in the address space. CommLinkTo references show the relationships. The OPC UA server is therefore able to map the physical network topology of the PROFINET network.

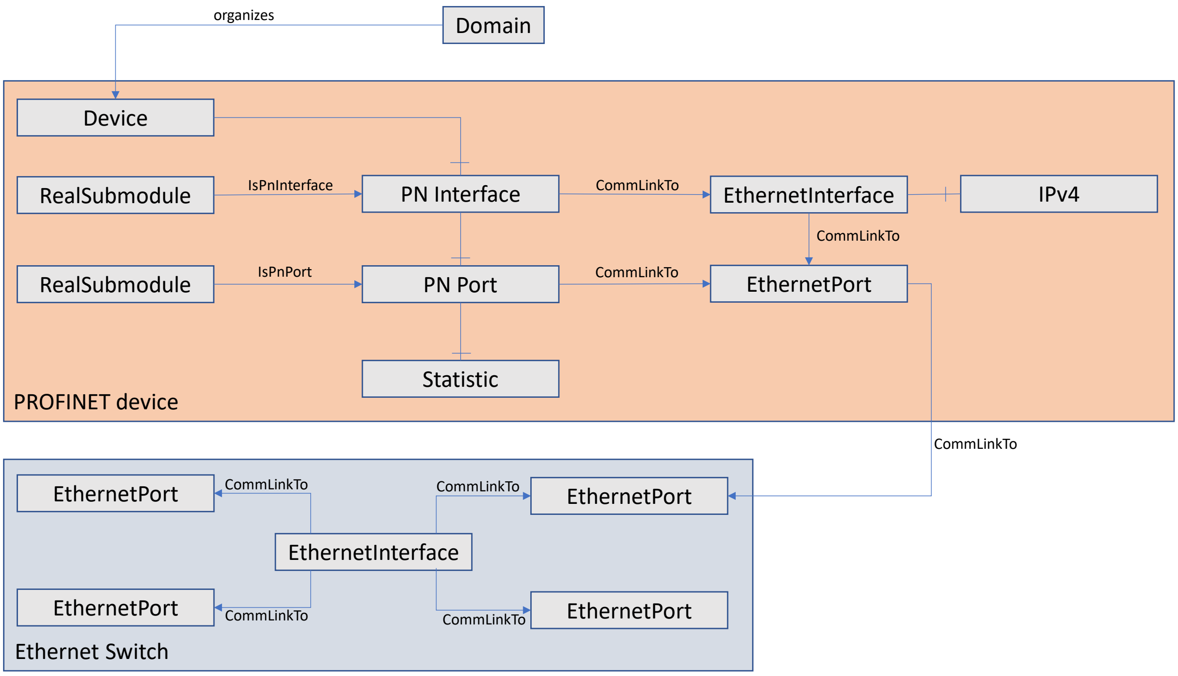


Figure 25: Physical network topology of a PROFINET network [PN1158-5]

> The model for diagnostics in PROFINET is shown in Figure 26 . The device application deletes or adds diagnostic information according to the status of the real periphery. The diagnostic source is API, slot, subslot, channel and direction. Diagnosis ASE – the database – stores the current diagnostic information for each submodule. This can also be queried by external applications (Diagnosis Query), whereby filter options are offered. To inform the IO Controller about diagnostic changes, the AR: alarm class used.

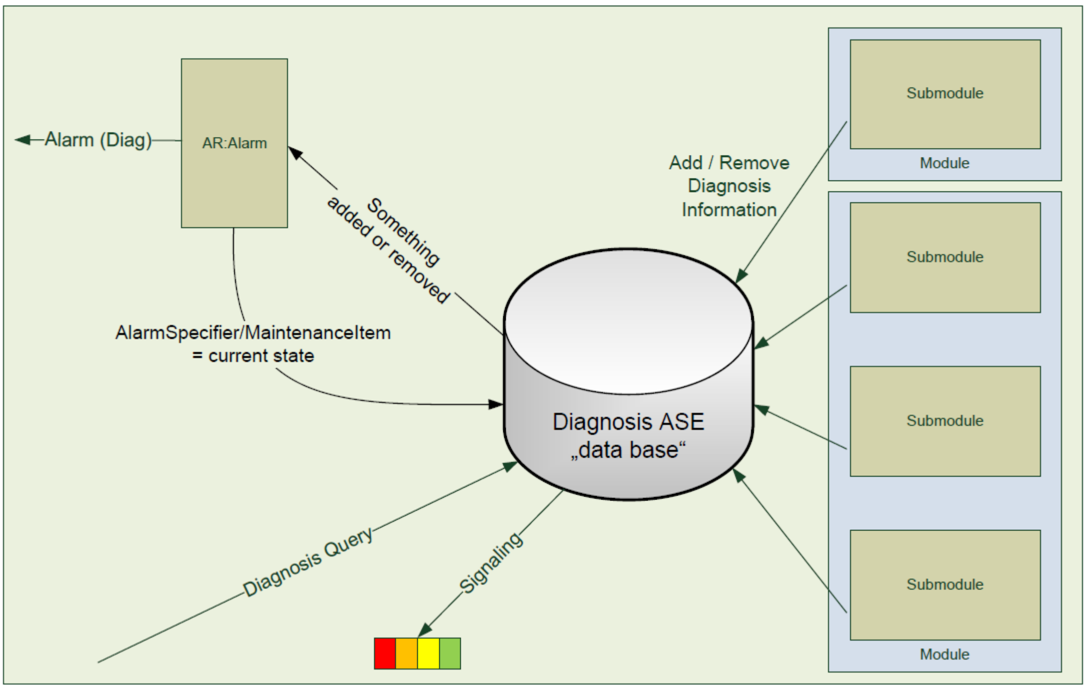


Figure 26: Diagnosis base model in PROFINET [PN1158-5]

The following figure illustrates a typical network topology for PROFINET. PROFINET is compatible with Ethernet and allows and uses a wide range of IT protocols. The central element are the IO Controllers, mostly in the form of a PLC (Figure 27 – (2)). These controllers can map the associated devices into the OPC UA information model. Controllers transport configuration, process data and alarms. The communication between controllers, also called C2C, is based on OPC UA via a Pub-Sub model or a Client/Server model. The Supervisor (Figure 27 – (3)), which is usually temporarily available in the network, can be used to retrieve diagnostic information, influence status/control and carry out parameterization. Devices can be found in the network in various forms (Figure 27 – (4-7)). The simplest case is when devices are mapped by the controller alone (Figure 27 – (5)). Individual devices can also include their own integrated OPC UA server (Figure 27 – (4)) and therefore represent themselves. Subordinate Remote IOs can be mapped in the same way (Figure 27 – (6)). However, a single OPC UA server might combine a group of devices (Figure 27 – (7)). Edge devices can browse the network and find devices with PROFINET services (Figure 27 - (1, 8)).

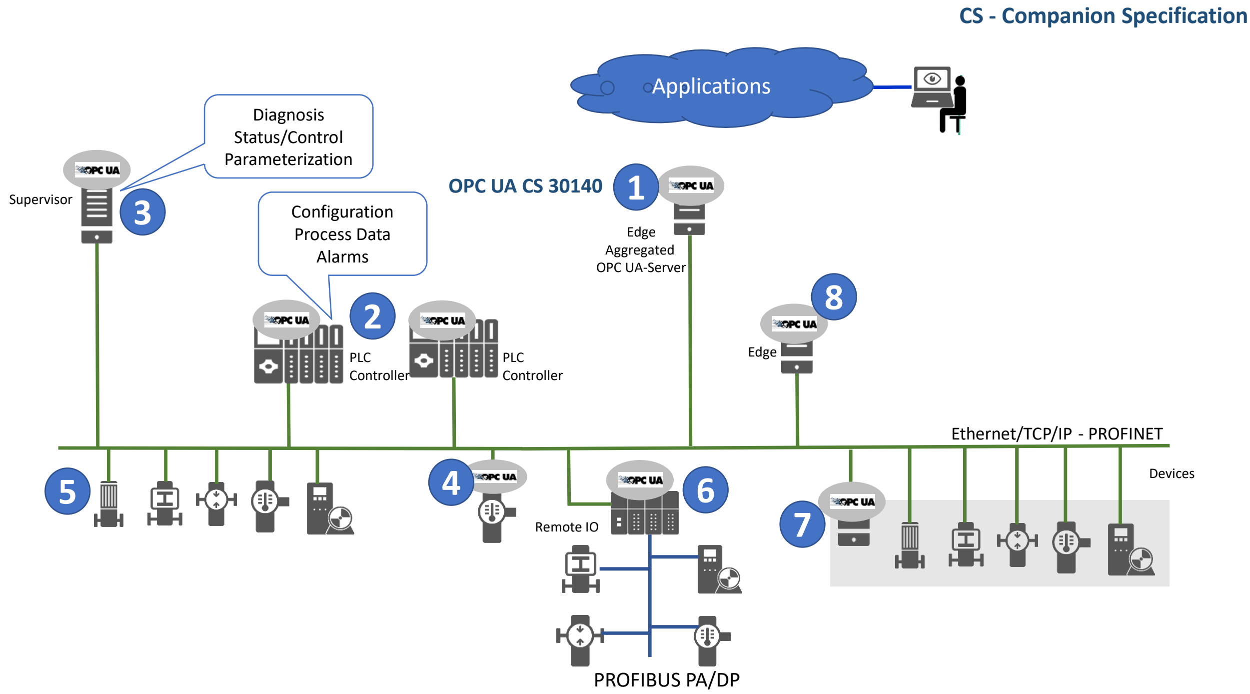


Figure 27: Topology of a PROFINET network

Asset management is performed during the service life of a system. A variety of information is used, which is compared with engineering information such as device information (VendorID, DeviceID, DCP type identification, DNS Name of Station, IP Address), information on the physical topology (neighboring information via LLDP) and the real device configuration (plugged modules). Furthermore, I&M (identification and maintenance) information is transported.

6.3.2 Network facet

The network facet is based on the OPC UA network model. It is currently still in development. An overview is presented in Figure 28. The model represents the interfaces of the networks connected via OPC UA with their properties. In addition, the communication channels (streams) of TSN (Time Sensitive Networks) are included in the model. This results in a network description that can be linked to the asset and communication facets and ultimately to the functional facets of the devices (see Chapter 7).

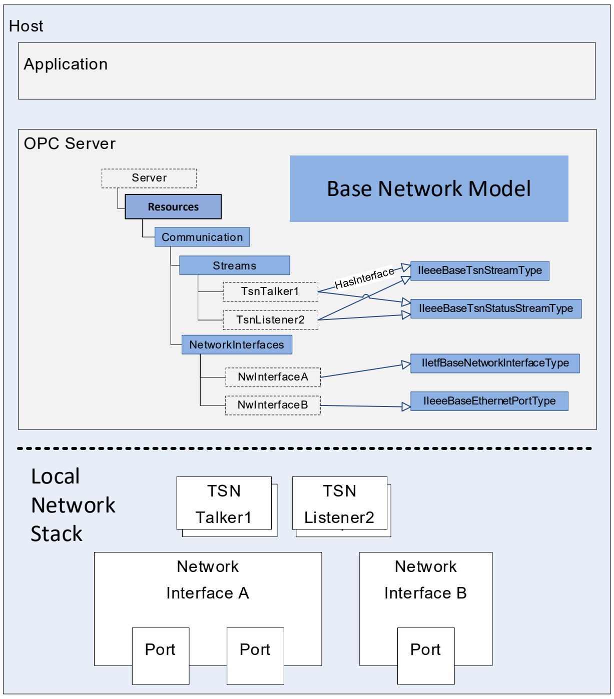


Figure 28: Overview of the OPC UA network model (OPC UA 10000-22)

6.4 Functional facet

6.4.1 Process-engineering field devices – PA profiles

Process-engineering field devices are also referred to as PA (process automation) devices. Each PA device has a profile for both PROFIBUS and PROFINET in which essential identifying and functional parameters are defined. Examples include analog and discrete inputs and outputs, i.e. for measured variables (temperature, pressure, level, flow, pH, conductivity) and for manipulated variables (for controlled or switching drives). The profile contents are implemented in the corresponding PA devices and are available at the PROFIBUS or PROFINET interface respectively (Figure 29 – (2)). Ethernet Advanced Physical Layer (APL) is an additional transmission technology that allows intrinsically safe two-wire devices to be connected directly via Ethernet, allowing Ethernet-based services to be provided directly in these devices.

Typical **use cases** are compiled in NAMUR Recommendation NE 176. They include, for example:

- “Automated as built” use case
- “Unique identification” use case
- “Check of device design” use case
- “Check for multivariable devices” use case
- “Readout of multivariable process values” use case
- “Life cycle backup for devices” use case
- “Health monitoring for devices according to NE 107” use case

For this purpose, NAMUR has selected a range of profile parameters for these use cases in NE 176. Based on these requirements, an OPC UA Companion Specification has been created (OPC 30081), which enables standardized access to these parameters in the OPC UA Server. This OPC UA Companion Specification is called PA-DIM (Process Automation – Device Information Model). The OPC UA servers can be flexibly implemented in Remote IO, in edge devices or even in the field devices themselves if these PA devices have a PROFINET connection (Figure 29 – (8)).

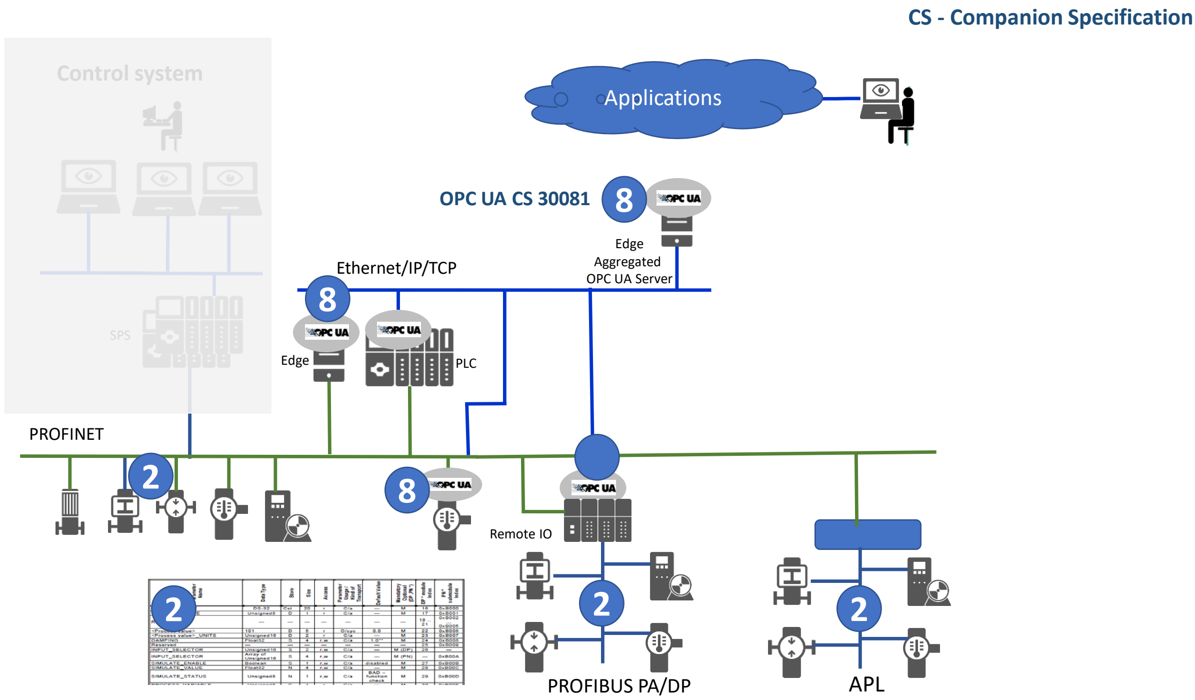


Figure 29: Typical integration variants of process equipment (PA devices) in the communication network

An example excerpt from the PA profile is shown in Figure 30. The parameters can be recognized with their attributes. The mapping definitions of the profile define the PROFIBUS and PROFINET communication services to the parameters. The OPC UA server then maps to the OPC UA information model according to the specifications in the PA-DIM Companion Specification.

Parameter Name	Data Type	Store	Size	Access	Parameter Usage / Kind of Transport	Default Value	Mandatory Optional (DP ,PN *)	DP * module Index	PN * submodule Index
BLOCK_OBJECT	DS-32	Cst	20	r	C/a	—	M	16	0xB000
CURRENT_MODE	Unsigned8	D	1	r	C/a	—	M	17	0xB001
Reserved	—	—	—	—	—	—	—	18 .. 21	0xB002 … 0xB005
<Process value>	101	D	5	r	O/cyc	0.0	M	22	0xB006
<Process value>_UNITS	Unsigned16	D	2	r	C/a	—	M	23	0xB007
DAMPING	Float32	S	4	r,w	C/a	1.0**	M	24	0xB008
Reserved	—	—	—	—	—	—	—	25	0xB009
INPUT_SELECTOR	Unsigned16	S	2	r,w	C/a	—	M (DP)	26	—
INPUT_SELECTOR	Array of Unsigned16	S	4	r,w	C/a	—	M (PN)	—	0xB00A
SIMULATE_ENABLE	Boolean	S	1	r,w	C/a	disabled	M	27	0xB00B
SIMULATE_VALUE	Float32	N	4	r,w	C/a	—	M	28	0xB00C
SIMULATE_STATUS	Unsigned8	N	1	r,w	C/a	BAD – function check	M	29	0xB00D
PROCESS_VARIABLE	Unsigned8	C	1	r	C/a	—	M	30	0xB00E

Figure 30: Parameters with their attributes of a PA profile of the analog input function block

Figure 31 shows the classification of the analog and discrete values in the OPC UA information model. These values then form the rule for how the PA device parameters are to be offered in the OPC UA server.

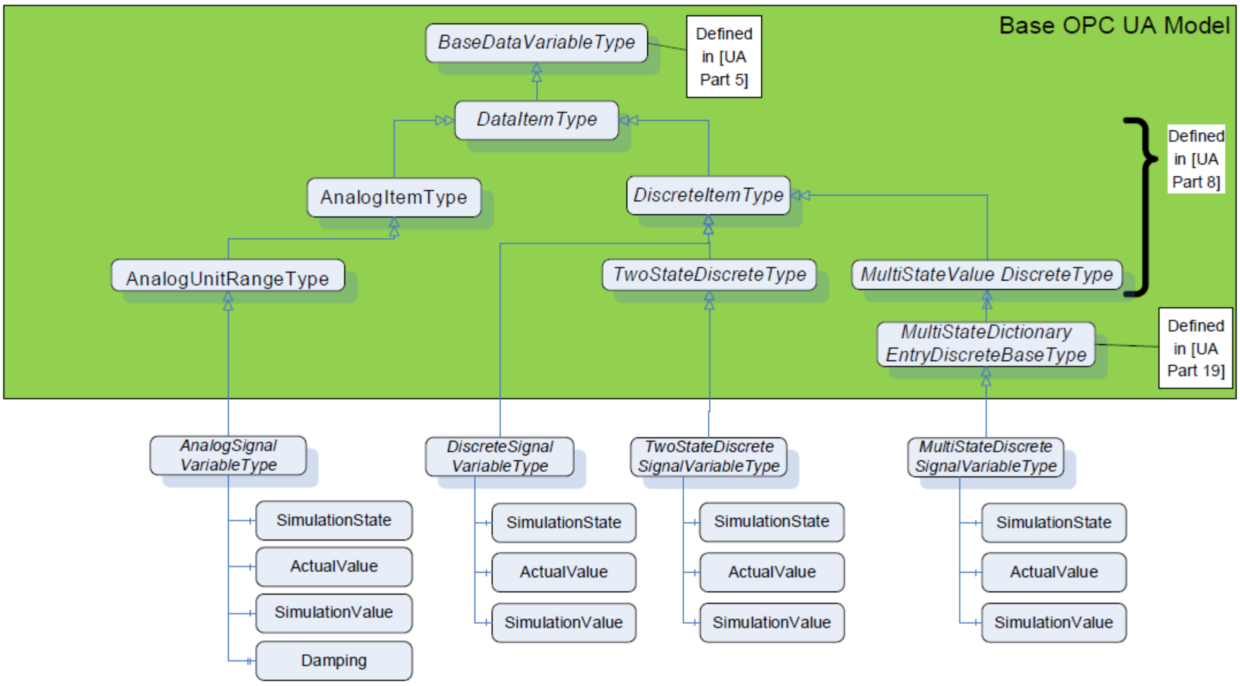


Figure 31: Extract from PA-DIM information model – analog and discrete values

The PA-DIM OPC UA Companion Specification is one of the few information models that already consistently include and specify the references of parameters and variables to a dictionary. In this case, the IEC Common Data Dictionary (IEC CDD) is used. In the language of OPC UA, this reference is called "HasDictionaryEntry". In Figure 32, this relationship can be seen for each variable, and for methods (see "FactoryReset"). The designation "IRDIDictionaryEntryType" indicates the data type in which the entry of the identifier of the variable and method definition is located. The identifier starts with "0112", which stands for the IEC CDDs. The "2" embodies the version of the standard indicated by the number 61987. The variable- and method-specific identifier is the six-character alphanumeric identifier. A definition according to IEC 61360 is then stored behind this identifier, which provides the developer of the application software with the necessary information so that the value of the variable can be uniquely interpreted. The exact structure of the IRDI can be found in [PNOECL], for example.

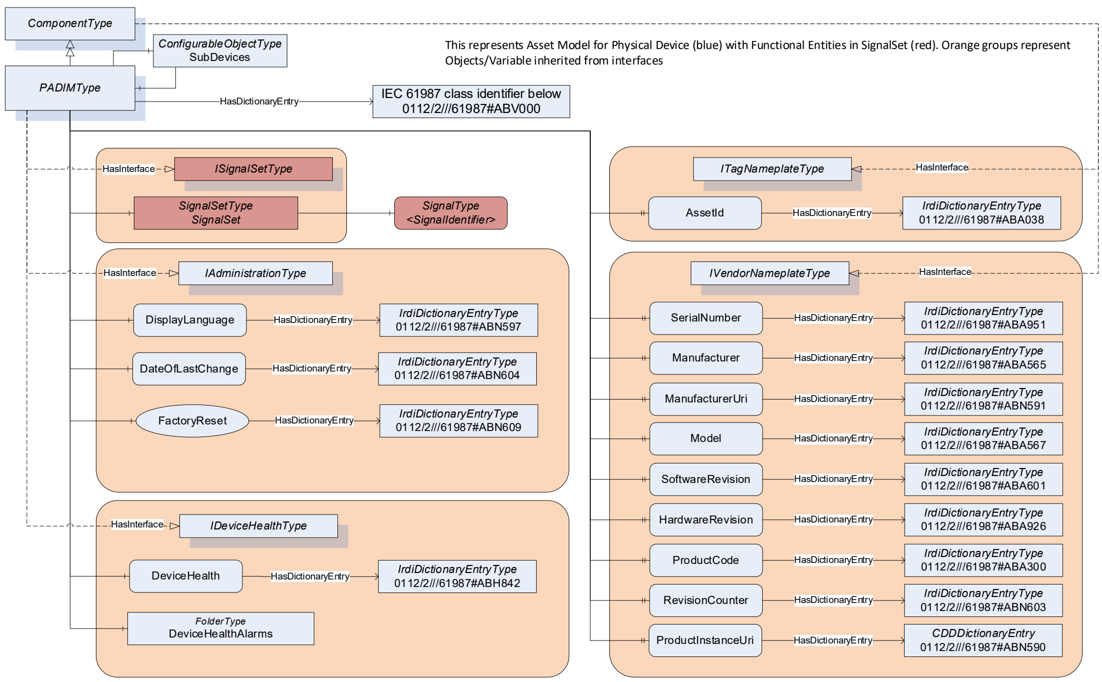


Figure 32: Extract from PA-DIM information model – references to IEC CDD

Process engineering field devices provide a wide range of status and diagnostic information. It can relate to the process in which they are used and to the device itself. A comprehensive compilation is provided in NAMUR Recommendation NE 107. The following information is named here as an example:

- Field device-related status and diagnostic messages
    - NORMAL, MAINTENANCE_REQUIRED, OFF_SPEC, CHECK_FUNCTION, FAILURE
- Process-related diagnostic messages
    - Bubble formation in liquid (e.g., in a flowmeter)
    - Cavitation at control valve

6.4.2 Drives – PROFIdrive

Drives are automation devices that are used in a variety of machines and systems, either individually or in a network. The PROFIdrive profile primarily models variable-speed drives that can be connected to PROFIBUS and PROFINET (Figure 33). The functions of the drive are contained under “Functional Object” in the PROFIdrive devices. Both the controllers and other stations access PROFIdrive-enabled devices for parameterization, configuration, and diagnostics/monitoring.

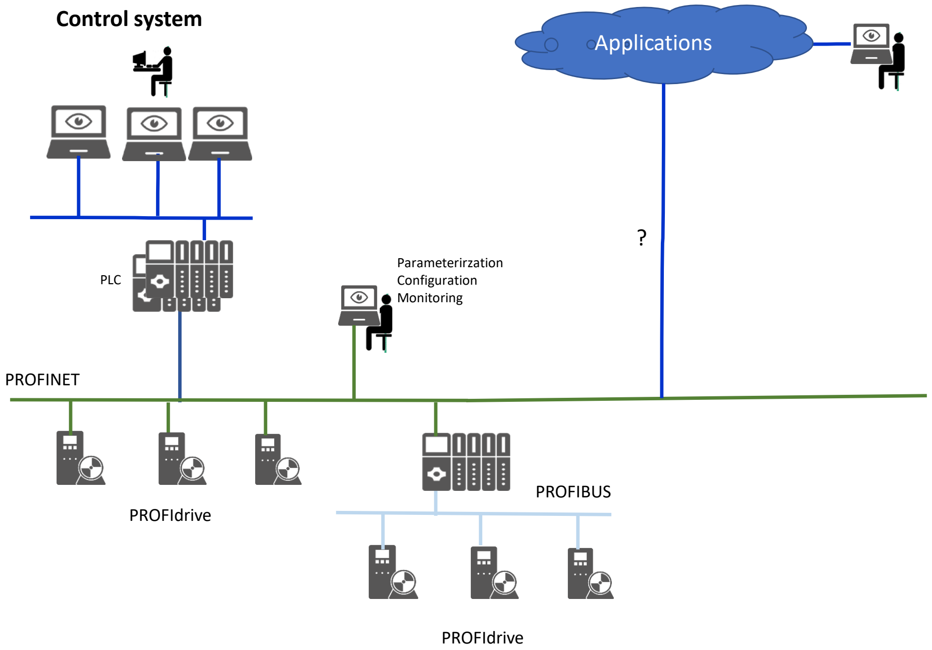
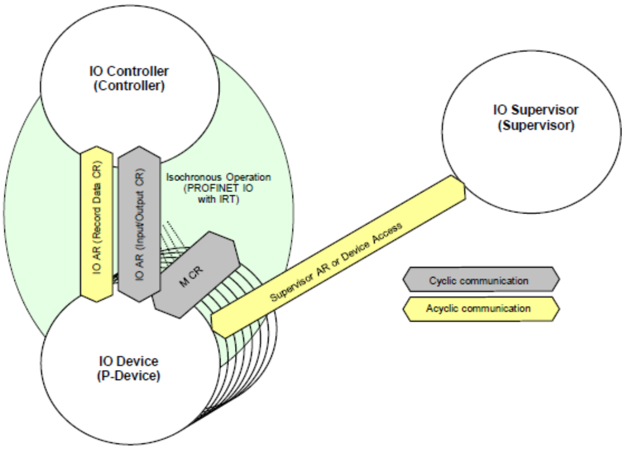


Figure 33: Typical integration variants of PROFIdrive devices

The following principal information is modeled by the PROFIdrive profile:

- Setpoints and actual values for time-synchronous exchange between the controller and drive
- Status and control word for time-synchronous exchange between the controller and drive
- Parameters for adapting the drives to the respective application
- Firmware update
- Time synchronization of the clocks in PROFIdrive devices
- Alarm handling



Signal No.	Significance	Abbreviation	Length 16-/32 bit	Sign	Description
1	Control word 1	STW1	16		Refer to 6.3.2.2
2	Status word 1	ZSW1	16		Refer to 6.3.2.5
3	Control word 2	STW2	16		Refer to 6.3.2.3
4	Status word 2	ZSW2	16		Refer to 6.3.2.6
5	Speed setpoint A	NSOLL_A	16	with	N2 normalised Refer to 6.3.4.5
6	Speed actual value A	NIST_A	16	with	N2 normalised Refer to 6.3.4.5
7	Speed setpoint B	NSOLL_B	32	with	N4 normalised Refer to 6.3.4.5
8	Speed actual value B	NIST_B	32	with	N4 normalised Refer to 6.3.4.5
9	Sensor 1 control word	G1_STW	16		Refer to 6.3.6
10	Sensor 1 status word	G1_ZSW	16		Refer to 6.3.6
11	Sensor 1 position actual value 1	G1_XIST1	32		Refer to 6.3.6
12	Sensor 1 position actual value 2	G1_XIST2	32		Refer to 6.3.6
13	Sensor 2 control word	G2_STW	16		Refer to 6.3.6
14	Sensor 2 status word	G2_ZSW	16		Refer to 6.3.6
15	Sensor 2 position actual value 1	G2_XIST1	32		Refer to 6.3.6
16	Sensor 2 position actual value 2	G2_XIST2	32		Refer to 6.3.6
17	Sensor 3 control word	G3_STW	16		Refer to 6.3.6

Figure 34: Parameter overview for PROFIdrive and its access paths

PROFIdrive devices create a specific diagnostic list in the profile in addition to the usual diagnostics in the its profiles (“Error”, “Maintenance required” and “Demanded”), which are supported by the devices. The following error messages are provided as examples:

- Low Voltage Supply
- DC Link Overvoltage
- Short Circuit
- Overtemperature Electronic Device
- Power Electronic
- Isolation Fault

6.4.3 Position and speed encoder – ENCODER

Encoders are automation devices that determine rotational speed and position. They are closely linked to drives and the encoder profile has direct references to the PROFIdrive profile. The encoder profile consists of: the base model adopted from the PROFIdrive profile, the application model containing the cyclic variables exchanged with the controller, the acyclic parameters for parameterization and control of the encoder, and additional functions for use in safety applications.

The profile can be used for general automation and enhanced motion control **use cases**. The following encoder classes are derived from these use cases and, in turn, provide different functions for them (excluding “Safety”):

- Encoder class 1:
    - Standard encoder (position value) with preset functionality. Isochronous mode is not supported.
- Encoder class 2:
    - Standard encoder with basic parameter access, preset functionality, speed value and additional scaling functionality. Isochronous mode is not supported.
- Encoder class 3:
    - Clock-synchronized operation, encoder with basic parameter access and PROFIdrive position feedback interface. Isochronous mode is supported.
- Encoder class 4:
    - Class 3 encoder with additional scaling and set/shift home position functionality. Isochronous mode is supported.

An information model is mainly relevant for those parameters being exchanged acyclically. For the parameters, their addresses, data types, and optional/mandatory assignment to each encoder class are provided. They are accessible via PROFIBUS and PROFINET. An OPC UA Companion Specification is not available yet.

PNU	Significance	Data type	effect.	R/W	Class 1	Class 2	Class 3	Class 4
900	Setpoint telegram (EO IO Data)	OctetString	-	R	O	O	O	O
907	Actual value telegram (EO IO DATA)	OctetString	-	R	O	O	O	O
922	Telegram selection	Unsigned16	Reset	R/W	M	M	M	M
925	Number of Controller Sign-Of-Life failures which may be tolerated	Unsigned16	Reset	R/W	-	-	M	M
944 to 952	PROFIdrive fault buffer	See definition in [1]	See [1]	See [1]	O	O	O	O
964	Drive Unit identification	Array[n] Unsigned16	Reset	R	M	M	M	M
965	Profile identification number	OctetString 2	Reset	R	M	M	M	M
971	Transfer into a nonvolatile memory	Unsigned16	Instantly	R/W	O	O	O	O
972	Drive reset	Unsigned16	Instantly	R/W	O	M	O	M
975	EO identification	Array[n] Unsigned16	Reset	R	M	M	M	M
979	Sensor format	Array[n] Unsigned32	Reset	R	O	O	M	M

Figure 35: Parameter overview for encoders and their access paths

Encoders have created a specific diagnostic list in the its profile, which is supported by the devices. The following are named as examples:

- Position error (hardware and signal quality)
- Position error (frequency/speed exceeded)
- Position inconsistent (for incremental encoders only)
- Preset failed (speed to high)
- Preset failed (preset value out of range)
- Command not supported
- Undervoltage
- Overvoltage
- Short circuit
- Overtemperature
- Excessive vibration

6.4.4 Energy management – PROFIenergy

The PROFIenergy profile consists of energy management, the provision of measured variables, and device-identifying data. The control of the standby regime of the profile device is one of the core function of PROFIenergy. The data is obtained either explicitly from the systems and machine components (e.g., heater, drive and pump) or their controls, or implicitly from measuring devices that provide energy-relevant measured values (e.g., current and voltage).

Typical **use cases** include:

- Control of the load behavior of systems
- Avoidance of load peaks in systems
- Display, analysis and documentation of energy-relevant data

The information model of the profile was converted into an OPC UA Companion Specification by a workgroup between PI and the OPC Foundation (OPC UA CS 30141). This means that the profile can be accessed directly by means of PROFIBUS and PROFINET (Figure 36 (2)), as well as by an OPC UA server (Figure 36 (3)).

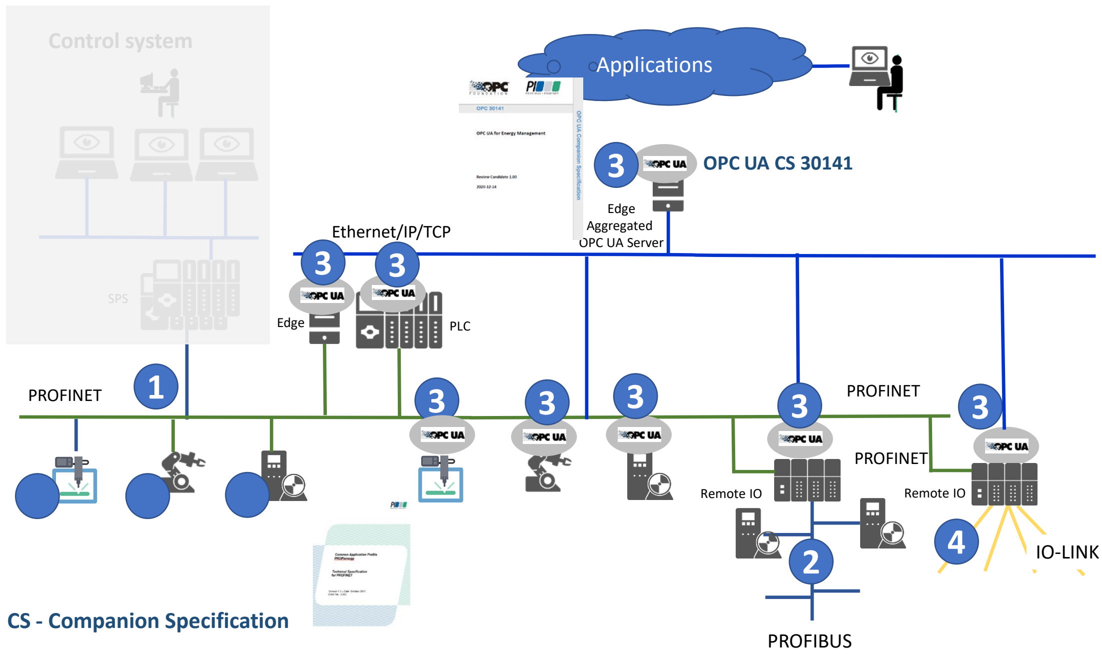


Figure 36: Typical integration variants of PROFIenergy in the communication network

An exemplary excerpt from the PROFIenergy profile is shown in Figure 37. One or more PROFI-energy instances can be located in a device, each consisting of the standby management, the measured variables, and additional characteristics. The profile parameters and commands can be accessed via the PROFIBUS or PROFINET interface. The OPC UA server adopts these specifications in the Companion Specification (OPC UA CS 30141) by modeling corresponding measured values, the elements of the standby management and the characteristics (not shown in Figure 37).

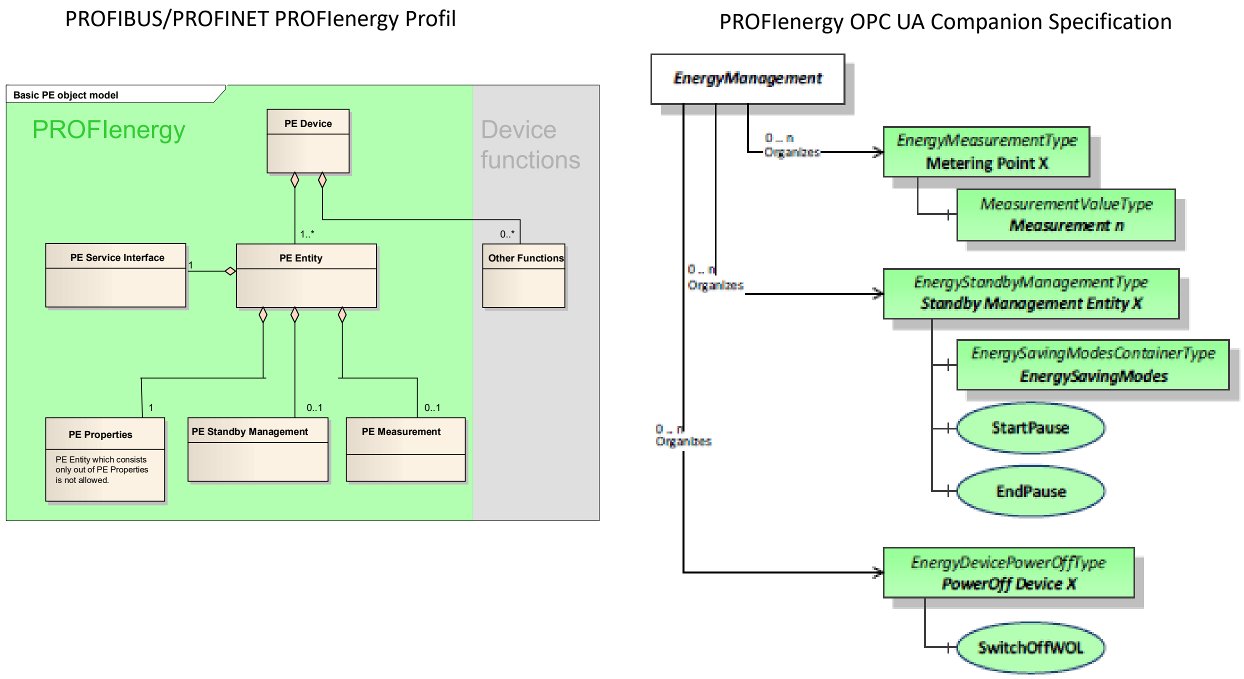


Figure 37: Basic structure of the profile and its mapping in the OPC UA Companion Specification

The PROFIenergy profile provides the following status information:

- Standby management state
- Current energy saving mode

6.4.5 Simple smart sensors - IO-Link sensors

A large number of different sensors are used in factory automation. Due to their built-in microcontrollers, these sensors are capable of not only sending measured variables, but also performing some preprocessing. Most of these sensors are “switching sensors”. With the help of an individual parameterization or teaching process (“Teach-in”), the sensors receive information about their "switching mode" and the setpoints. In addition, the sensors also offer diagnostic functions. This widely used type of sensor is called a “smart sensor”.

The purpose of IO-Link is to overcome the limitations of the classic sensor interfaces DI, DO, AI and AO by means of a digital point-to-point communication and to offer identification, parameterization, and diagnostic functions in addition to binary and/or analog information. Unifying rules and specifications are made for this information in the Smart Sensor Profile, which supplements the IO-Link Common Profile.

Typical **use cases** include:

- Transfer of analog and binary sensor values to the controller
- Parameterization and configuration of the sensors by a corresponding workstation

IO-Link is a point-to-point connection through which digital data is transported in addition to the actual measured value. IO-Link devices are connected either directly in PLC modules or to an IO-Link master and/or a Remote IO (Figure 38 – (4)). The Smart Sensor profile has also been defined within the OPC UA Companion Specification (Figure 38 – (6)), which can be implemented in the IO-Link master, in the Remote IO, or in an edge device.

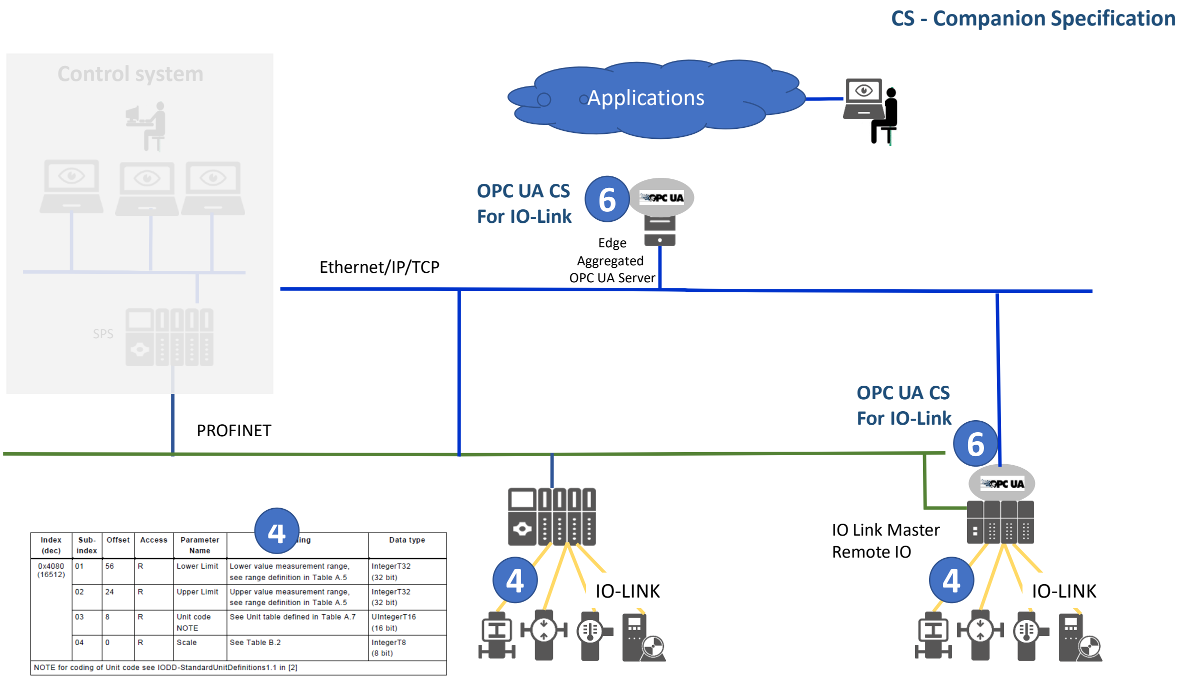


Figure 38: Typical integration variants for the IO-Link smart sensor

The IO-Link Common Profile provides information on identification, binary and analog measurement data and commands (Device Operation), parameterization and configuration, and diagnostics (DeviceStatus) (Figure 39). This information is mapped in the OPC UA Companion Specification as objects, variables and methods. In Figure 39, only a small section is shown.

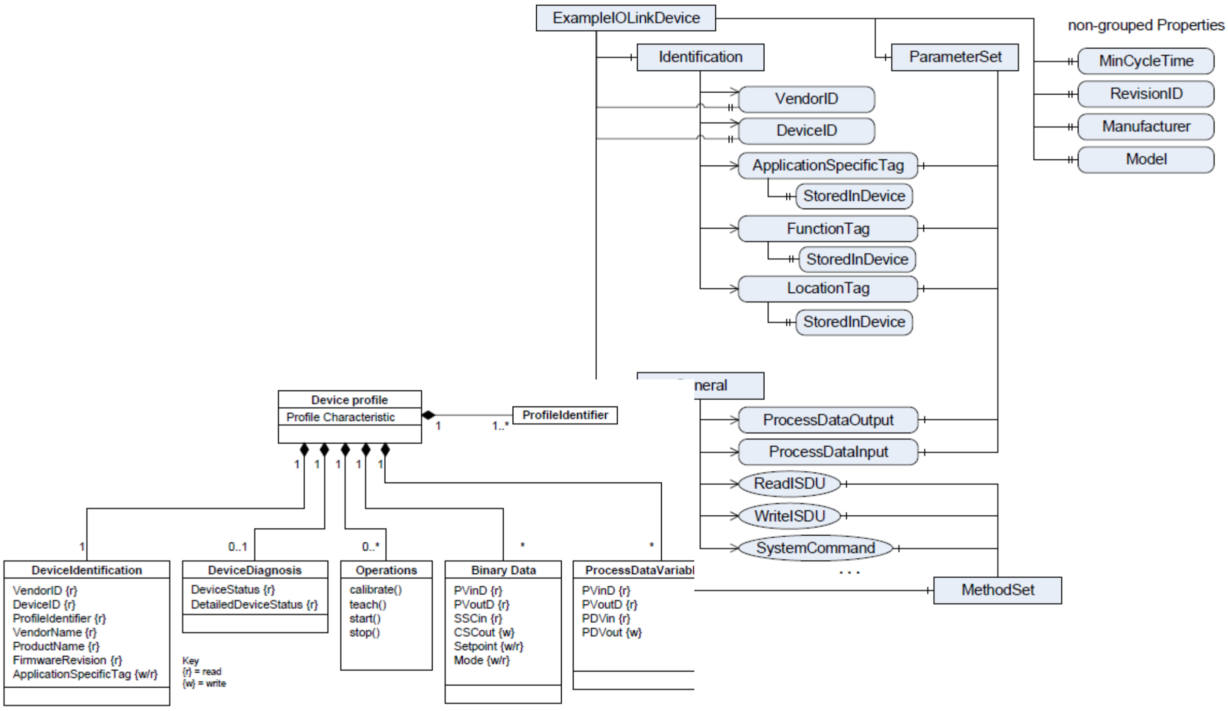


Figure 39: Basic structure of the IO-Link Common Profile and its mapping in the OPC UA Companion Specification

The Smart Sensor Profile provides the following status and diagnostic information:

- Device Status and Detailed Device Status
  - NORMAL, MAINTENANCE_REQUIRED, OFF_SPEC, CHECK_FUNCTION, FAILURE
- Manufacturer-specific diagnostic messages (described in the IODD (IO-Link Device Description) file)

6.4.6 Remote IO – IO for PA and IO for FA

The profiles of Remote IO for PA and Remote IO for FA are designed for coupling these devices to controllers. The data specifications refer mainly to the syntax of the measuring and control signals, which are mostly standard signals (Figure 40 – (1) and (2)). In addition, the I&M objects are defined, as well as special diagnostic information.

Typical **use case**:

- Acceptance and setting of the analog and binary sensor and actuator values of the devices connected to the remote IO from the controller

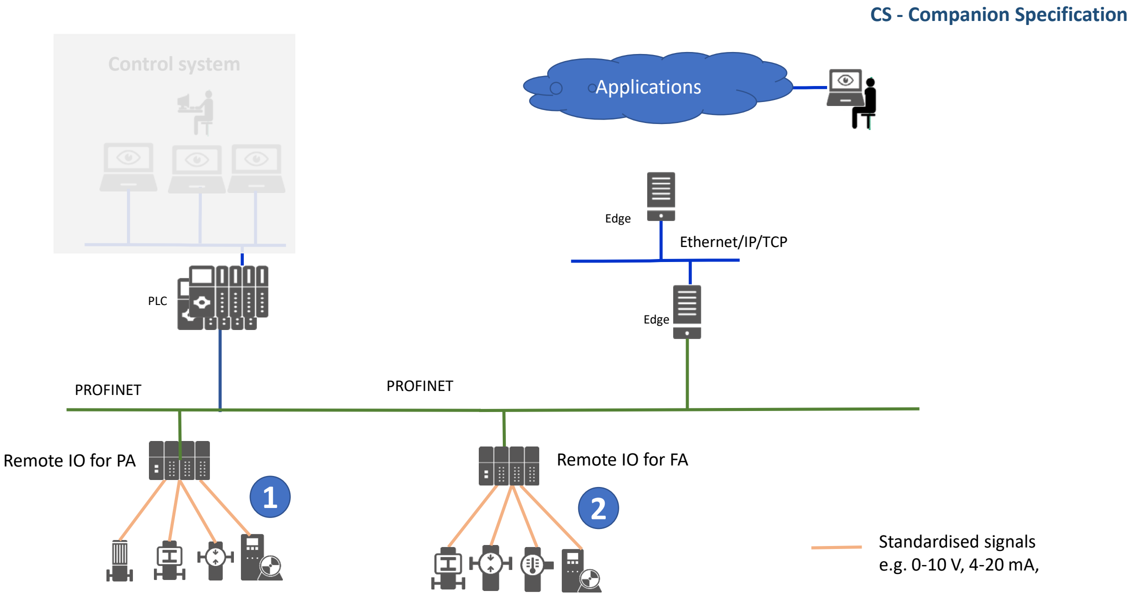


Figure 40: Classification of Remote IO for FA and PA

The Remote IO profile provides the following status and diagnostic information:

- Line break
- Line short circuit
- Overvoltage
- Overheating

For these two Remote IO profiles, the corresponding OPC UA Companion Specifications are already in progress. For an overview, see Figure 41 and Figure 42.

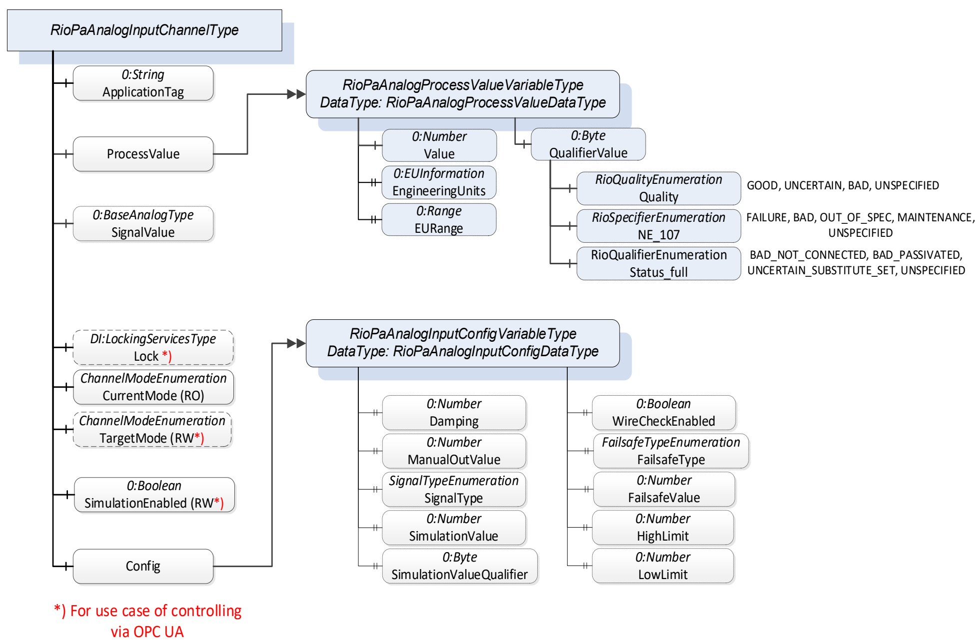


Figure 41: RIO for PA analog input channel

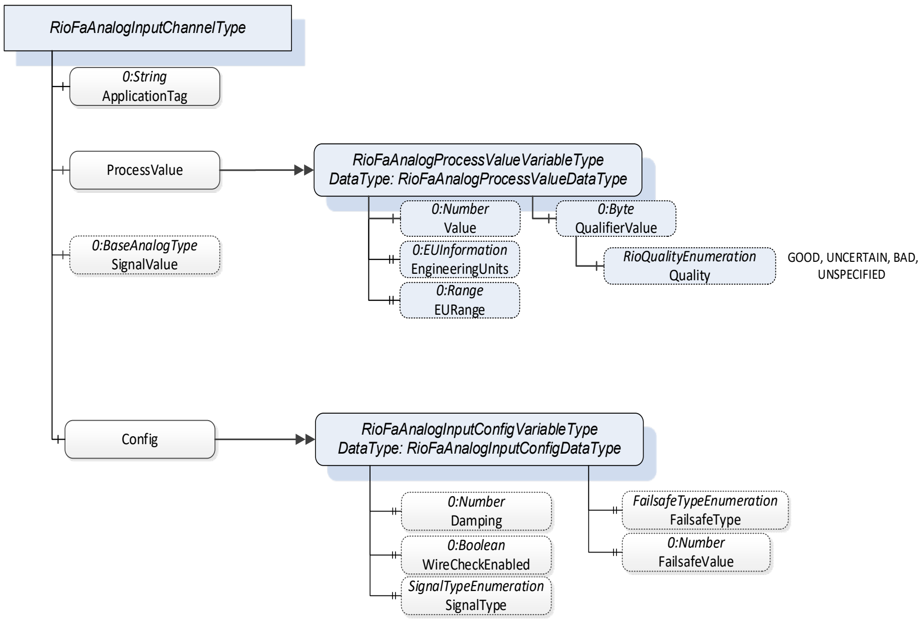


Figure 42: RIO for FA analog input channel

7 Use of the facets in the system view

A wide range of data is available to the user who wants to gain added value from the data in their plants (Figure 43). The asset facet allows the identification of automation devices and partly also of the components to which the devices have been attached (i.e. nameplate); the PROFINET facet shows the access paths to and from the device; the network facet allows the location of the devices in the communication network (i.e. topology detection); and the functional facet provides both the measured and actuating values of the systems and the required parameterization of the devices (i.e. device functionality). All facets are accompanied with diagnostic and status information that provides details on the health of the plant, as well as the automation and communication system.

The tasks of the automation devices, even of the same type, are different. Positioning devices can indicate that something is open or closed, up or down, or right or left. Measured values for pressure or temperature at different points of the system, have different meaning because they refer to an inlet, outlet or the inside of a container.

The location of an automation device within a communication network and the measurement and control values must still be supplemented by the task of the devices in the system. The latter is performed by the system description, which is provided, e.g., in the form of the P&I flow diagrams in process engineering or with AutomationML in other industries. The design and implementation of the application's use cases must therefore bring all the information together.

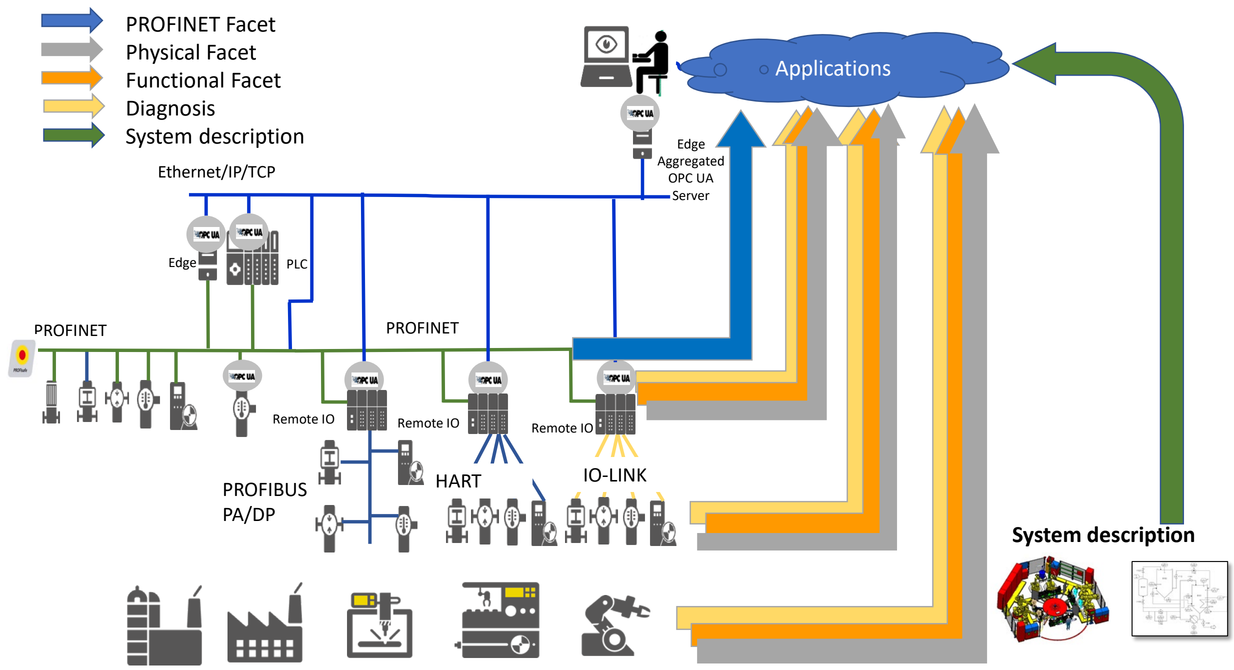


Figure 43: Use cases of applications using facet data and the system description

For the design of applications, the relationships between the elements of different information models must be clearly known. These relationships are defined at the level of the information model representation, here by means of the OPC UA information model. Such a relationship definition is shown in Figure 44 as an example. The four vertical sub-models each represent a different facet: (from left)

- The component hardware structure[3] – derived from the system description
- The integration of the devices and components into the PROFINET network (e.g., network interface and port[4]) – physical facet, here the communication controller of the device is meant
- The device-related structuring from the point of view of PROFINET into modules and submodules – PROFINET facet
- The functional structuring of the devices – functional facet

The individual functions are implemented within the modules and submodules of the automation devices. Therefore, “isRepresentedBy” from the partial function (subfunction) refers to the corresponding submodule. The submodules each have a port address in the communication controller of the device, which makes the modules and submodules addressable by the application (reference “refersTo”). The communication controller is assigned to a device or component which is connected by the reference “hostedBy”.

These relationship types (“refersTo”, “hostedBy”, etc.) must also be provided in a standardized way so that applications can read them by machine. This standardization is currently being carried out as part of the harmonization activities of the OPC Foundation. These relationships are brought into an OPC UA server by a standalone configuration step that brings together the various OPC UA servers in a system. If interpretable system descriptions are available, e.g., P&I flow diagrams according to IEC 62424 or other descriptions, this work step can be supported by software tools.

If the application knows the desired function or partial function, or the subordinate parameters or commands as well, all required information can be explored via these references. The time-consuming search for these configuration details, which are absolutely required to access the signal path, can be read from the information model by the application.

3 The component view is currently still in specification in the OPC Foundation

4 The structural integration of the interfaces into the devices was not yet included in the first version of OPC UA 10000-22; i.e., the assignment of the interface to the chassis is only preliminary.

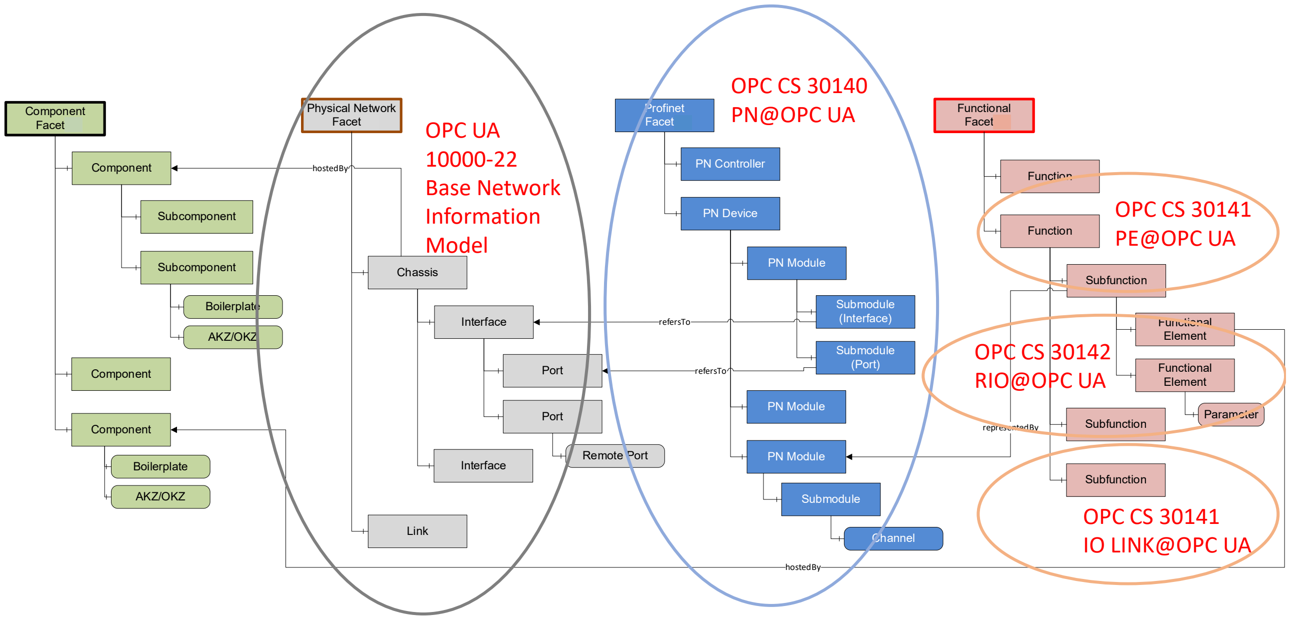


Figure 44: Interrelationships of elements of the information models

Supplementary to Figure 44, Figure 45 represents the relationship of the elements of the PA-DIM Companion Specification together with a dictionary. This Companion Specification is currently the only one that has already contributed its elements to a dictionary.

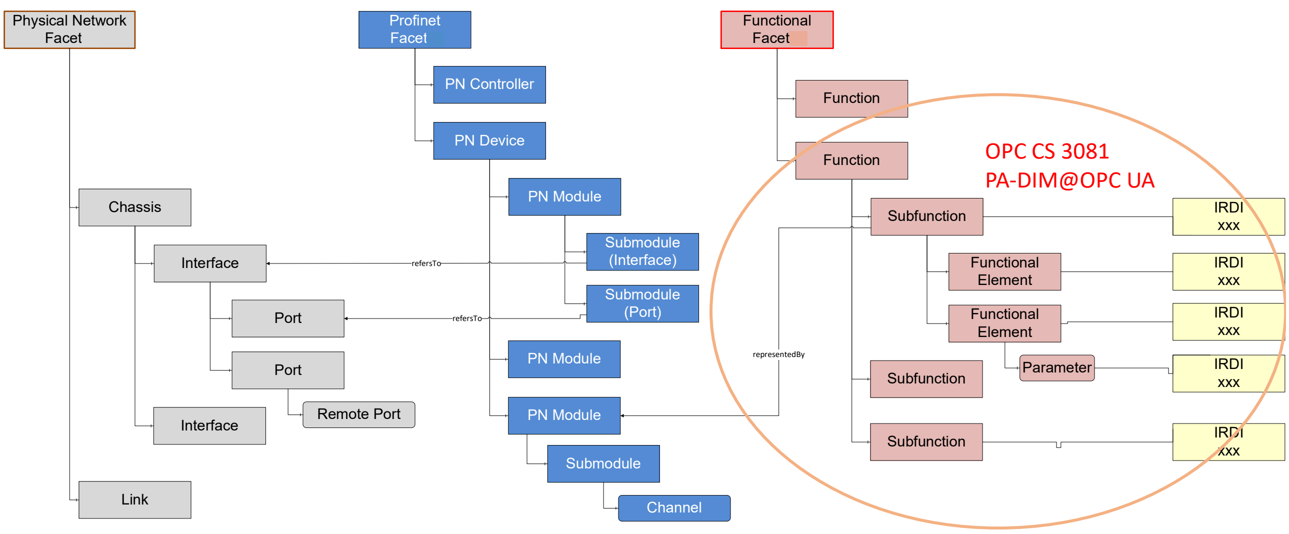


Figure 45: Characteristic integration with IRDI in the PA-DIM information model

8 Next steps

The basic framework consisting of the concept and some information models in OPC UA is in place. Step by step, further field device functionalities are transferred to the OPC UA Companion Specification. This also applies to network components and the communication-related parts of the automation devices in order to cover the entire communication paths for data transport. The goal is to embed all profiles and components of all technologies combined in PI into an OPC UA-based Companion Specification.
In particular, the next steps are:

- Transfer of PROFIdrive and encoder profiles to the OPC UA Companion Specification.
- Participate in the harmonization work of the OPC Foundation to integrate the system descriptions and standardize the relationship types between the individual facets and system descriptions.

- Incorporate the elements of the PI-related Companion Specifications into dictionaries, e.g., ECLASS and IEC CDD.
- Include OPC UA-based controller-controller communication (data exchange between controllers) in the PI technology canon.

9 Summary and outlook

The classic communication landscape consists of cyclic data exchange between controllers and field devices, as well as data exchange for parameterization, monitoring and diagnostics of field devices. This will be supplemented by an additional communication path for data-driven “Advanced Asset Management” and “Data Analytics”. This extension is also called vertical communication. This vertical communication requires an additional access point to the devices and a machine-readable description of the data. PI has selected OPC UA as the appropriate technology for this purpose. The protection of the access to the data and information models is handled by the security mechanisms of OPC UA or PROFINET.

Advanced Asset Management and Data Analytics look at different aspects of the machines, components and systems, of which the focus here is on automation devices and communication. PI looks at the data from the physical, functional and network-oriented view of the devices, which are referred to as the physical facet, functional facet and PROFINET facet, respectively. The corresponding diagnostic data is embedded in all facets. These facets are supplemented by information models / Companion Specifications of the OPC Foundation such as “Physical Network Facet”.

All data is supplemented by its description (so-called metadata, e.g., data type, unit of measurement) and therefore becomes facet-specific information models. The profiles available for PROFIBUS, PROFINET and IO-Link can be used, which already have their information stored in PDF documents. These profiles, as well as information-oriented parts of the PROFINET specification, are transferred to OPC UA Companion Specifications and therefore form the access point for vertical communication. It should be emphasized here that the variables and parameters are included step by step with references to dictionaries (e.g., ECLASS), in which the descriptions are stored in a technology-independent manner, i.e., valid even outside of PI technologies. Knowing these references, applications can process data from different data sources without having to consider the specific characteristics of the underlying communication system.

Machines and plants have several facets that are included in different OPC UA information models. For higher-level applications, such as advanced asset management and data analytics, a complete picture emerges from the various facets, akin to the compound eye of an insect. To connect individual facets in a suitable form, relationships between the information models are included in the definitions of the OPC UA information models. An application can automatically resolve these relationships to provide a consistent representation even with other information models (e.g., P&I flow diagram).

Industrie 4.0 picks up on the opportunities offered by digitalization and creates new value-adding applications, especially through vertical communication. Information models are an essential building block for this. PI is currently focusing on modeling using OPC UA and ECLASS. This white paper focuses on operations. Industrie 4.0 concepts explicitly provide for the entire life cycle of devices, components, machines and systems, from planning and commissioning to operational use and maintenance. In addition to OPC UA as the technological basis for implementing the information models, this very broad scope of consideration also requires other implementation options, such as in files, using HTTP/REST or MQTT interfaces with an information model. Examples of use include machine-readable product information from catalogs, manuals and technical specifications, the interaction between manufacturer repositories and planning tools or engineering or logistics systems and maintenance tools. Digital twins are envisaged for this purpose as one of the central concepts of Industrie 4.0. The administration shell is the solution of the Industrie 4.0 Plattform, which is in the process of standardization and is introduced and accompanied on the market by the “Industrial Digital Twin Association – IDTA”. PI is one of the founding members of this organization. With the multitude of activities described in this white paper, PI is consistently pursuing the path to vertical communication and is thus optimally equipped for the future in the interest of the user.

10 Abbreviations and glossary

10.1 Abbreviations

AI	Analogue Input
AO	Analogue Output
AR	Application Relationship
C2C	Controller-to-controller communication
CDD	Common data dictionary
CS	Companion specification:
DI	Digital Input
DO	Digital Output
ECLASS	Data standard for the classification of products and services using standardized ISO-compliant characteristics
FA	Factory automation
HTTP	Hyper Text Transfer Protocol
I&M	Identification and maintenance
ID	Identification
IDTA	Industrial Digital Twin Association
IEC	International Electrotechnical Commission
IO	Input/output
IODD	Input Output Device Description
IP	Internet Protocol
ISO	International Organization for Standardization
ISO	International Organization for Standardization
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
LLDP	Link Layer Discovery Protocol
MQTT	Message Queuing Telemetry Transport
OPC UA	Open platform communication unified architecture

OSI	Open System Interconnection
PA	Process Automation
PA-DIM	Process Automation – Device Information Model
PB	PROFIBUS
PI	PROFIBUS&PROFINET International
PLC	Programmable Logic Controller
PN	PROFINET
PNO	PROFIBUS Nutzerorganisation e. V.
PV	Process Value
RDF	Resource Description Format
PLC	Programmable logic controller
TCP	Transmission Control Protocol
XML	Extensible Markup Language

10.2 Glossary

Asset	Entity that has a perceived or actual value to an organization and is owned or individually managed by the organization.
AutomationML	AutomationML is a comprehensive XML-based object-oriented data modeling language. It enables the modeling, storage and exchange of engineering models covering a wide range of relevant aspects of engineering.
Characteristic	A characteristic is a qualitatively or quantitatively clearly determinable property. Notes: The term “characteristic” is often used in the industrial environment for product characteristics that say something about the usability of the products
Data	(Numerical) values obtained through observations, measurements, statistical surveys, etc Note 1: Plural of data item Note 2: Data is information encoded in digital form Data is the plural of data item and refers to facts, points in time, or calendar time data. As a plural (though used with the singular verb form), it refers in common language to numerical values obtained by observation, measurement, and the like and to information or formulable findings based on these values.

	Entities of signs or continuous functions that represent information based on known or assumed arrangements, primarily for the purpose of processing and as its result.
Data type	Summary of data on which the same operations can be performed. Note: The mathematical operations +, -, * and / can be performed on floating point values. Formally, a data type in computer science refers to a collection of sets of objects with operations defined on them. Here, the data type of the data set using a so-called signature exclusively specifies the names of these object and operation sets. A data type specified in this way does not yet have semantics. The far more frequently used, but more special meaning of the term “data type” comes from the environment of programming languages and designates the summary of concrete value ranges and operations defined on it to a unit. Examples can be integers or commas, strings or more complex types like date/time or objects. To distinguish these data types, the term “concrete data type” is also used in the literature. For a discussion of how programming languages handle data types, see “Typing”.
Date	Single digit data
Dictionary	A dictionary is a reference work that lists words or other linguistic units, usually in alphabetical order, and assigns explanatory information or linguistic equivalents to each entry (lemma). A dictionary in the narrower sense is used to look up linguistic information while, in the broader sense, the term also includes other reference works organized by keyword and containing primarily factual information, as well as mixed forms of both types.
ECLASS	ECLASS (old spelling eCl@ss) is a data standard for the classification of products and services using standardized ISO-compliant characteristics. The ECLASS standard enables the digital exchange of product master data across industries, countries, languages or organizations. Especially in ERP systems, the use as a standardized basis for a material group structure or with product-describing characteristics of master data is widespread.
Encoder	An encoder is a technical element. In this context, the term can appear both in communications engineering and in drive engineering and can have different meanings. In communications engineering, an encoder is generally understood to be the first converter or transducer for digital or analog signals. It forms a logical unit or a functional chain with possible further converters or a decoding unit, also called a decoder. Encoders for signal formation from movements operate optically, magnetically or mechanically with contacts. They are transducers or input devices that detect the current position of a shaft or a drive unit and output it as an electrical signal. Two types of encoders are distinguished: Rotary and linear encoders. Rotary encoders are mounted on rotating components, for example, on a motor shaft. Linear encoders are typically mounted on components with straight movements.

Energy manage-ment	Energy management is the combination of all measures that ensure minimum energy use for a required output. It refers to structures, processes, and systems, as well as human behaviors and changes.
Facet	A partial aspect; figuratively one of the many “faces” of a person, thing or object - here a specialized information model Note 1: An information model tailored from the point of view of a device, machine, system or network Note 2: OPC UA uses the term “facet” to name partial aspects of the OPC UA server and client implementation. This is mainly used for the selection of test cases. These “facets” are not meant here.
Facet model	Information model that can be combined from facets for diverse use cases
Industrie 4.0	Industrie 4.0 is the name given to a future project for the comprehensive digitization of industrial production in order to better equip it for the future. The term goes back to the German government's Research Union and a project of the same name in the German government's high-tech strategy; it also refers to a research platform. Industrial production is to be interlinked with modern information and communications technology. The technical basis for this is intelligent and digitally networked systems. With their help, largely self-organized production should become possible: People, machines, plants, logistics and products communicate and cooperate directly with each other in Industrie 4.0. Networking should make it possible to optimize not just one production step, but an entire value chain. The network should also include all phases of the product's life cycle – from the idea of a product through development, manufacturing, use and maintenance to recycling.
Information	Notification about a specific matter Note: This notification is sent from at least one transmitter to at least one receiver In information theory, information is the knowledge that a transmitter conveys to a receiver through an information channel. The information can take the form of signals or code. The information channel in many cases is a medium. For the receiver, the information leads to an increase in knowledge. Information can be transmitted consciously as a message from a transmitter to a receiver, or it can be transported unconsciously and become noticeable through the perception of the form and property of an object. Information receives its value from the interpretation of the overall event at different levels by the receiver of the information. Transmitters or receivers can be not only persons/humans, but also (more highly developed) animals or artificial systems (such as machines or computers/computer programs).
Information model	Set of data object types with their attributes and their dependencies and relationships among them. The data object types describe objects to be viewed in the desired application In information technology, an information model is an abstract representation of objects with their properties and relationships. The information model supplements the data model with contextual information that allows a person to interpret and use data in a consistent manner. It provides the structures that make explicit the knowledge needed by a person or a group of people in a specific situation. In everyday language, often no clear

	distinction is made between information and data models, and the terms are used synonymously.
Life cycle	Periodic sequence of the existence of something. In the context of automation, often used in connection with an automation system or the product.
Position	Mathematics: a function is a relationship (relation) between two sets that assigns to each element of one set x (function argument, independent variable) exactly one element of the other set y (function value, dependent variable y-value). Computer science: Program construct that has pass variables and provides a return variable value In computer science and in various higher programming languages, a function is the name of a program construct that can be used to structure the program source code so that parts of the program's functionality can be reused. Mathematics: A function is used to describe relationships between several different factors.
Profile	Agreement on the use case-specific use of options of a specification. Note: In the field of industrial communication, the term is used to agree on binding rules for mapping application functions and variables to the capabilities of specific communication systems. Characteristic appearance Entirety of distinct properties
Property	Property denotes something that is assigned to an object of observation Note 1: Observation objects can be real things, e.g., a device or conceptual things, e.g., an object, a relation or an event Note 2: “Property” and “characteristic” are often used as synonyms, but the property statements often remain fuzzy in contrast to a characteristic, which is more clearly determined.
Protocol	In computer science and telecommunications, a communication protocol is an agreement according to which data transmission takes place between two or more parties. In its simplest form, a protocol can be defined as a set of rules that determine the syntax, semantics, and synchronization of communication. Protocols can be implemented by hardware, software, or a combination of both. At the lowest level, a protocol defines the behavior of the connection hardware. If the communication is in a computer network, it is called a network protocol.
Semantics	Relationship between words and their meaning Semantics, also called semantics, is the theory or science of the meaning of signs. Characters can be any symbols, but in particular also sentences, parts of sentences, words or parts of words.

	Insofar as semantics deals with signs of all kinds, it is a subfield of semiotics. Insofar as it deals solely with linguistic signs, it is a subdiscipline of linguistics.
Use Case	A use case describes the externally visible interactions of actors with the system under consideration. Note: A use case does not describe the order in which the interactions are to be performed.
View	A view of a system is a user-related compilation of elements of the system, each with a selection of their properties.

11 List of references

[ECLASS] Referenz-Datenstandard für die Klassifizierung und eindeutige Beschreibung von Produkten und Dienstleistungen. https://www.eclass.eu/

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