

Horizontal and Vertical Integration for Automation Systems – Virtual Automation Networks

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Abstract

Current situation in industry is characterised by a strong trend towards distributed automation systems based on intelligent devices and intelligent decision making. This affects on the one hand the hardware components and on the other hand the approaches of software development and processing. In addition to this, Ethernet technologies are penetrating more and more the field device level applying more and more IT standards well-known from the office world which have to be adapted to meet industrial requirements. This paper – based on the European IST NMP Integrated Project VAN – presents research activities to overcome the gap between these office technologies and automation technology and also to provide a communication infrastructure with appropriate security and safety mechanisms to interact in heterogeneous communication environments resulting in Virtual Automation Networks – VAN. Based on this architecture a methodology is presented.

1. VAN Vision

To strengthen European leadership in industrial communication and automation the vision of VAN is an open universal, seamless multivendor networking solution which is able to link worldwide components in process and factory automation from the single sensor in one factory plant to remote machinery in de-centralized enterprises/sites. VAN's interoperable communication can be realized via fieldbuses, office networks and even the public communication infrastructure - wired or wireless.

Core of this approach is PROFINET, enlarged by web-services and other IT based technologies to enable

VAN's all-embracing communication approach. By means of a common engineering model the user may not see the single building blocks of the underlying communication infrastructure and regards the whole network as a homogeneous system [5]. To realize this totally new concept, the VAN solution provides scalable real-time, safety and security strategies, needed to meet QoS requirements over the whole Virtual Automation Network, necessary in automation-science and –practice.

2. VAN Architecture

The VAN project provides innovative solutions, extensions and standards dedicated to industrial environments to fill the existing gap between office technologies and industrial automation technology, focused on a new dimension of uniform networking of production and manufacturing processes and defining the base of international industry plant management, advanced control and service concepts. As a target scenario an “Industrial System Environment” which could be called Virtual Automation Network (VAN) is shown in Figure 1.

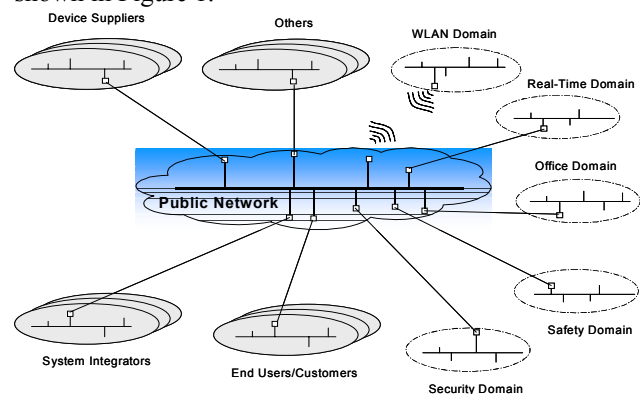


Figure 1: Virtual Automation Network

The complete supply chain within VAN ranges from Device Suppliers over System Integrators (each in different levels) to the End Users, Customers and Others. All actors are connected within a heterogeneous network including different domains with different requirements regarding their applications. The interactions between these domains within the network will be achieved by a merging of existing and emerging IT and automation standards covering embedded architectures, fieldbus technologies, Ethernet, Internet technologies, real-time technologies, wireless LAN technologies, security and safety concepts. To cover all different domains and to be very flexible and generic, the overall architecture of VAN is based on an open automation platform and system architecture. Hereby, an optimal model of the Open Platform and System Architecture will be specified and developed. This model will combine existing industrial network protocols with new generation of IT and telecommunication protocols and works out the optimal interfaces, service and protocol boundaries to integrate the new VAN extensions to introduce a new quality of automation networks [4].

3. VAN Methodology

The top-level workflow (Figure 2) is a generic representation of a stepwise approach to realize a complex holistic VAN engineering process for a complete automation system. In order to provide a clear overview and to emphasize the main activities of the overall engineering process, the representation of the top-level workflow is simplified.

On the one hand the transitions to preceding activities are not shown. Although only the top-down workflow is represented there are also transitions from each activity of the top-level workflow to all of its preceding activities.

On the other hand not all of the individual databases involved during the engineering process are shown, but only a representative for all the databases inside each specific workflow phase [2].

3.1. Modelling

The first initial step for an engineering process is to create a formal or informal model of the customer's requirements. The aim of modelling is to reduce complex systems in a simple mental model to get a system scope of the customer requirements and its environment. So engineering tools are used to build easy to understand formal models (e.g. in UML), that can be verified with the customer. Formal models help to assure that the future planning phase is built upon a valid model that meets all customers' requirements. Commercial tools for modelling are available. For VAN the general functional behaviour of a networked VAN System is described by a functional model. The benefit of a functional view is the separation between the functional

design and the device implementation. A system scope improves the modelling of functional behaviour.

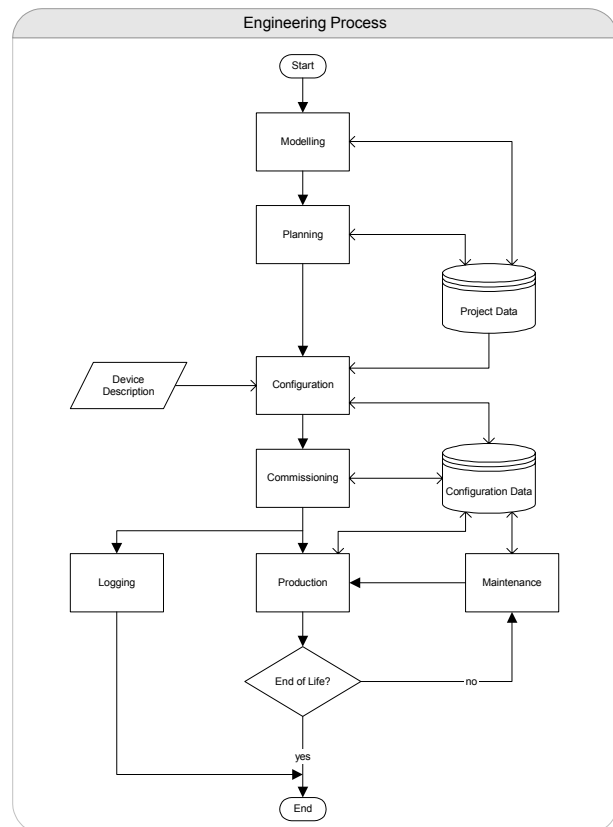


Figure 2: Engineering process

In VAN engineering the functional model divides the entire system into function components and describes interactions of these function components. The scope of this functional model in VAN is the view of data exchange and data transmission between the function components. The modelling phase is prerequisite for the planning phase, which allocates a physical process for realising the modelled function components. For this the modelling has to break down the functions to a level that allows the allocation of physical processes to the functions. To guarantee this allocation three classes of function components are defined in a hierarchical manner as shown in Figure 3. On the top level the Main Function Component is defined as a result from the structured decomposition of an entire function, respectively system, into a reasonable set of mainly distinguishable functions. By this, each Main Function Component must have one or more defined interfaces for the connection to the other Main Function Components of the system. The next detailing step is named Function Group.

A Function Group is defined as a part of a Main Function Component. Function Groups further logically divides a Main Function Component into several function components. These function components can be again Function Groups or Function Basic Elements the

last of the three defined classes. Such a Function Basic Element can not be further decomposed usefully - in the sense of the application. That means a Function Basic Element can not be further decomposed into other Function Basic Elements. With this background the following approach is useful to design a functional model.

- Define a VAN project for complete automation system
- Describe the Main Function Components of the application
- Provide graph based model for the Main Function Components as description of their functional dependences. These functional dependences are the basis for fixing the communication in later activities of engineering.
- Describe interfaces that interconnect the Main Function Components (the process of such an interconnection can be described with UML Sequence diagrams).
- Decompose the Main Function Components into Function Groups (a composition of further dividable functions) and Function Basic Elements (functions which can not be further divided)
- Allocate Function Groups and Function Basic Elements to the according VAN subdomains.
- Describe the Function Groups and Function Basic Elements
- Describe interfaces that interconnect the Function Groups and/or Function Basic Elements

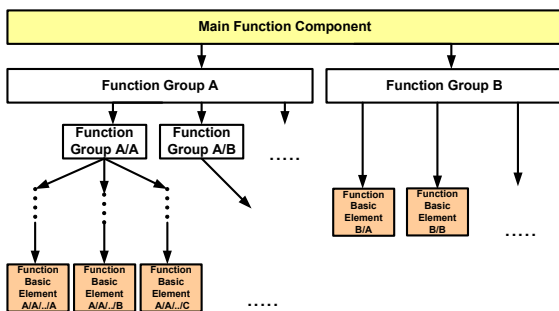


Figure 3: Hierarchy of Functional Components

After realization of all these activities within this approach the result is a formal hierarchical model of real world processes with preparation and definition of Main Function Components/Function Groups/Function Basic Elements from the Main Function Components and their allocation to VAN subdomains. Furthermore a formal description of the needed function components with all requirements and a description of the relations between the function components are also results.

This functional coherency should be considered for the specification of the rules for the consistent combinations of VAN communication devices [1],[2].

3.2. Planning

In the planning phase the devices and network technologies of the automation system are chosen. Engineering tools are used to describe the network topology and to define the network technologies as well as devices to be used in the automation system. In this step data exchange between the engineering tool and external CAD tools may be required. Prerequisites for planning phase are the results of the activity modelling and a catalogue containing VAN automation device as well as network devices.

The different function component classes represent the requirements while the automation components are representing the devices for the implementation.

The defined function components have to be combined to VAN domains or VAN subdomains. This assignment is based on their task to perform together an application. All classes have to be assigned and the engineer has to check additionally, if the defined VAN domains/VAN subdomains are appropriate. This step is essential for the whole engineering process.

If a network segment is predefined depending on customer requirements devices have to be assigned to function components. It implicits an allocation to the right VAN domain/subdomain. The devices have to be assigned only to the right segment.

If no requirements are defined identification of connections between components must be started first. Thereby the crossing of borders between different technologies must also be considered. After this the selection of devices and the assignment to VAN domains /Van subdomains and to the right segment is the next task of planning phase. Finally, all assignments must be stored in a project data base. It is necessary to combine selected data to a special view of the VAN system for example functional view, device view and a network view [3]. Additionally it can be necessary to provide specific combination of information of objects of different views such as segment information (MAC address, IP address), VAN-AP information, names and functional component interface variables.

The results of a planning phase are the assignment of defined function components to automation components. Thereby the network topology for the plant, the hierarchy of VAN domains/subdomains is also defined. Additional following issues must be defined within planning phase:

- communication relations between function components (source, destination, data type, cyclic, acyclic, ...) and the resulting relations between VAN automation devices
- selected communication technologies (e.g. fieldbus type) and properties (e.g. baud rate)

- list of all devices (type of specific vendor)
- VAN domain names for all devices
- assignment of VAN-services to devices (e.g. PnP-Manager)
- PLC-program for components
- IP address ranges for DHCP server of routers
- QoS: speed , safety, security
- requirements for permissions (access control) for VAN domains/subdomains, devices, VAN-ECs

VAN planning is based on a strict separation of functional design and device implementation of the functions. This allows a top-down-approach [1],[2].

3.3. Configuration

In this phase the network settings are made and the devices are configured and/or programmed. The engineering tools can be used for configuration in offline mode based on the information provided by the device description.

During examination and refinement of the workflow descriptions it turned out that programs for devices (esp. PLCs) have to be available in the planning activity already, although these programs can be adjusted and revised during configuration and commissioning phase.

Based on the project data filled by modelling and planning step automation components can be selected and configured in parallel by different engineers with different engineering tools. This allows a distributed engineering a further benefit of the VAN engineering client (VAN EC) defined as an entity of VAN network capabilities and a local or distributed set of engineering functions in order to engineer VAN relevant functions of VAN devices.

If the automation component has been configured before and this configuration has to be adapted or extended then the VAN-engineering client for automation devices (VAN ECD) (a part of the VAN EC,) for the devices of this automation component has to be used in order to read the old configuration from the corresponding project file.

If the automation component is configured the first time for this automation system then the component type description has to be retrieved from the component catalogue of the project data.

During the planning activities a device catalogue was used, which only provides information on the functionality and on the external parameters of a device. In contrast the device description includes the full information set, which is necessary for configuration of all internal and external parameters of a device. If the device description for a device of the selected automation component is not already available in the configuration data, then the file with the correct device description has to be located. Once the device description file is available it is stored in the

configuration data. The Benefit is the later reuse when either the same device is reconfigured or when the same device type is used in another automation component.

After completion of the configuration for each device the corresponding VAN-ECD has to store the new or updated information in the configuration data. The configuration data is not saved in a central database but each VAN-ECD can use an independent repository. If the repository is controlled by a version management tool then the selected component should be checked-in again during this activity.

The Results of Configuration are stored in configuration data containing all the information, necessary to make the settings for each device in the automation system. This includes the device description, the VAN name for identification of the device, parameter names according to the device description and values for the parameters.

Configuration of the fieldbuses and communication networks is defined by corresponding parameters of the devices, which are controlling the network segment and which are connected to the network segment. Also services, like DHCP or PnP manager, are configured by corresponding parameters of the devices hosting these services [1],[2].

3.4. Commissioning

The commissioning leads the system from the configuration phase to the production phase. A bottom-up approach is used, starting from the commissioning of devices and automation components. To install the complete system all pre-configured and pre-assembled devices and subsystems are combined stepwise. The engineering tools are used in online mode, i.e. they are connected to the automation system. For each composition adjustment of the configuration parameters may be necessary. The diagnostic features of the engineering tools are used to identify and solve problems. The engineering tools are connected to the devices through the system's network and/or via a direct link.

From the top-level view of the automation system a domain/subdomain is selected and the commissioning work will start on that part of the automation system. Next step is to get the configuration data for all automation components and devices in the subdomain under consideration. This also includes the VAN names for all the devices in the subdomain selected. Then the assignment of a unique identifier or name to the device is an important step. This operation can be performed in different ways, by direct physical connection to the device or by connecting the VAN-ECD to the network segment and starting a discovery of the devices connected to them. After checking if the subdomain under configuration is VAN enabled or VAN independent two approaches are possible. For VAN enabled subdomains connect only to the device hosting

the PnP manager and for VAN independent subdomains a connection to each device has to be established. The PnP manager contains all the configuration data for the devices under its control. In case of a faulty device replacement the PnP manager provides the configuration of the replaced device. The swap of a faulty device is only possible in case of VAN aware devices which can be reconfigured directly from the PnP manager. For a VAN independent device no swap functionality for a faulty device is provided.

In both cases a connection to the device has to be established and the corresponding configuration data is downloaded to the device itself. The physically connection of all devices within the subdomain and the setting of all parameters correlated to the communication between the individual devices are the next logical step. After the positive result of the testing phase it is necessary to join this subdomain with all the subdomains previously commissioned. After evaluation and commissioning of the selected domain is finished, it is necessary to interconnect this domain with all the domains previously commissioned.

The output of commissioning is the final automation system ready for the production phase. After the commissioning phase all the adjustments on the configuration data required to make the system operative are made, and the testing of every single part of the overall system is done. There isn't a specific data output but a refinement of the existing configuration data.

According to the VAN system architecture the VAN naming conventions must be addressed. During the commissioning phase the VAN-ECDs assign a unique VAN name to the VAN devices which compose the VAN automation system.

Another important characteristic of the new VAN architecture is the introduction of the described PnP manager inside the automation system. This new element requires a specific configuration and at the same time it changes the classical workflow for the download of the configuration. Instead of downloading this information directly to the VAN devices, the complete configuration information is downloaded to the PnP manager, which in turn distributes this information to the corresponding VAN devices.

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3.5. Production

When production phase starts the engineering process is basically finished. Further use of engineering tools takes place under consideration of the following two aspects. First is repairing and restoring. In production phase engineering tools may be used in online mode for

monitoring and diagnostic purpose. During production process a component will be connected cyclic, sporadic or continual to backtrack and to control the whole process. Detected problems may be fixed online without disturbing the production process.

The second aspect is adaptation and reengineering. The lifetime of a complex automation system may be years or even decades; it is very unlikely that the original configuration of such a system keeps unchanged during this period. There may be adaptations necessary to fit changing requirements in the production process. This implies a partly or complete iteration of the overall engineering process. Although this is normally performed during a scheduled maintenance period it may happen also during this activity.

For this purpose engineering tool are used mainly for monitoring of the active state within a VAN domain. If a device requires a test/adaptation the device can be selected online and within a Van domain this can be done also across heterogeneous networks. In case of testing the project data will not be changed. In case of adaptations the results of all previous activities of the overall engineering process may be modified. Engineering tools are used in online mode to test and verify the functionality of the device. If functionality is not ok corrective measure must be initiated in order to restore the functionality.

Concerning the engineering process project and configuration data may be modified during application of the previously described activities.

In a VAN domain a service engineer will be able to connect to any appropriate device across heterogeneous networks by the use of engineering tools if the configuration of the access rights allows this. Additionally a VAN device itself will have internal diagnostic functions. This combined with a network wide logging system will help the service engineer to localize and analyse any upcoming or already existing problem within the VAN context [2].

3.6. Maintenance

During this activity devices are checked, reconfigured or modified. Engineering tools are used in online mode through the VAN network or via a direct connection. Tests can be performed manually or automatically with the support of simulations. In contrast to production phase more detailed tests and more extensive modifications will be worked out. This activity can be subdivided into three sub phases. The interesting phase is the adaptation/modification of devices for example firmware upgrades. These upgrades can be carried out in online mode with help of engineering tools or automatically done by the introduced PnP Manager. This VAN management function will support all runtime activities while capturing, identifying and configuring changed devices nearly automatically. Additionally a

developed VAN update service will clearly reduce manual effort needed in preventive maintenance [2].

3.7. Logging

In contrast to all other activities in the engineering process the logging activity is not self-reliant but in parallel operation to other phases, mainly production and maintenance. Logging functions can be subdivided into two core operations:

- logging of information about system or application process e.g. connection status
- logging of user action

Logging functions may not be running continuously but are activated due to existing problems.

Logging functions may provide different levels of logging information.

Logging functionality is just a subset of the overall VAN functionality. Thus all descriptions and definitions made so far concerning the overall engineering process will be valid. The logging strategy for a single device, a VAN segment or the whole VAN domain has to be planned, configured and commissioned as any other VAN relevant features/functions. Logging information will be stored local on the device or decentral depending on the configuration of the VAN management function set which may be implemented in a VAN server device. The log files can be remote accessed by engineering tools [2].

4. Synopsis

Analysis of the today's workflow showed that it can basically be subdivided into the phases modelling, planning, configuration, commissioning, production and maintenance. The existing tools are well advanced with respect to the phases configuration, commissioning, production and maintenance. But there is a lack of methods to systematically derive a formal model of the automation system from customer requirements and continuously refine this model for the planning of the automation system. Moreover an analysis of available engineering tools on the market shows that existing tools provide only limited support during the modelling and planning phases of complex and distributed systems.

Based on these considerations the VAN project has to elaborate on the following topics.

On the one hand the methods for modelling and planning have to be improved. For that purpose a UML based information model is developed. Different views representing different views of the automation system. The functional view represents the results of the modelling phase. The network view represents the hierarchical structure of VAN domains and subdomains as well as their relation to network segments. The device view represents the structure respective the type of a VAN device can be configured. A profile view shows the classes which directly generalize the VAN object.

The VAN object is represented in common classes view [3]. This view shows classes which are commonly used by all other classes of the entire information model. This information model already incorporates the defined architecture of the VAN network and the VAN devices.

The benefit of using different views is the clear structure during the whole runtime of the engineering process. Changes in each activity are visible for all other activities because of the dependencies and relations of classes within each view.

On the other hand integration of different tools has to be addressed. For this, a common workflow was specified as a reference for engineering tools to be integrated in the VAN platform. For each phase of the workflow descriptions of the VAN specifics are made

These descriptions facilitate to identify necessary enhancements for existing tools and integration of them in the VAN platform. Additionally a common database for the representation of the complete automation system allows exchange of data between different tools. Furthermore the results of this engineering approach will contribute to a better integration by the specification of a device description and tool interfaces.

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