Quality of Service Measurement in Virtual Automation Networks

Lorenz Hundt[1], Martin Hoffmann[1], Christian Schwab[2], Jan Beran [3]
[1] Univ. of Magdeburg, Center Distributed Systems – CVS@IAF
Universitaetsplatz 2, 39106 Magdeburg / Germany
{lorenz.hundt, martin.hoffmann}@ovgu.de
[2] Siemens AG, A&D SC IC SP, Industrial Communication
Gleiwitzer Str. 555, 90475 Nürnberg / Germany
christian.schwab@siemens.com
[3] Brno University of Technology, Dept. of Control & Instrumentation
Faculty of Electrical Engineering & Communication
Kolejni 2906/4, 612 00 Brno
beranj@feec.vutbr.cz

Abstract

Within this work in progress paper, the concept for Quality of Service (QoS) measurements within different network topologies, ranging from Local Area Networks (LANs) to Wide Area Networks (WANs) will be presented. These investigated networks are the basic infrastructure for Distributed Control Systems (DCSs) in "Virtual Automation Networks" (VANs). The main concepts of integration all incorporating kinds of network technologies, the addressing scheme and main infrastructure devices ranging from automation devices to access points in such heterogeneous communication networks will be introduced.

1. Introduction

One of the leading trends in industrial communication is its penetration by IT technologies. Due to their origin in the office world, indeed, these technologies have to be extended to meet industrial requirements. The communication infrastructure, both in office and industrial domains becomes more and more heterogeneous, ranging from LANs to WANs with specific transition technologies to connect different communication domains and techniques.

Within the European funded research project VAN (Virtual Automation Networks) solutions for the usage of LANs and WANs – public and private, wired and wireless – forming Virtual Automation Networks (VANs), for application in industrial domains will be investigated and developed. The concept of Virtual Automation Networks is to provide a reliable and secure end-to-end industrial communication connection which is similar to Virtual Private Networks known from the office world. In VAN, existing IT technologies will be extended and adapted to meet specific industrial requirements such as Real-Time, Safety and Security as scalable features. To engineer the communication relations in such wide area DCS it is necessary to have a well known understanding of the performance of each communication channel and the communication network respectively.

Hence, the following chapters of this paper present a concept for a test system for QoS measurements in VANs. For this, a definition of the communication concept of VAN will be introduced. Furthermore, a definition of common performance indicators and factors of influences of these indicators in VANs will be done.

Before, a short introduction of the VAN concept and the ideas behind the VAN project will be given.
The vision of VAN is an open universal, seamless multivendor networking solution, which is able to link worldwide components in automation from the single sensor in one factory plant to remote machinery in decentralized plants. VAN's interoperable communication can be realized via fieldbus technologies, office networks and also public communication infrastructure – wired or wireless.

VAN focuses on uniform networking of production and manufacturing processes. Considering the specific requirements of industrial communication, the challenge is to adopt, modify and extend existing IT solutions to automation needs regarding scalable real-time, wireless, security and safety aspects. The necessity is well founded in the vertical integration of IT standards in industrial automation. Partially standardized IT systems respectively IT components coming from the office world are used to fulfil tasks without reaching the mentioned industrial standards but with a maximum of reliability.

The fusion of local and wide area networks between the geographically distributed parts of the automation functions over heterogeneous networks and the use of dedicated standard IT are main objectives of VAN. This task is a significant part of flexible automation manufacturing of prospective, knowledge-based, intelligent, and agile manufacturing enterprises. [1]

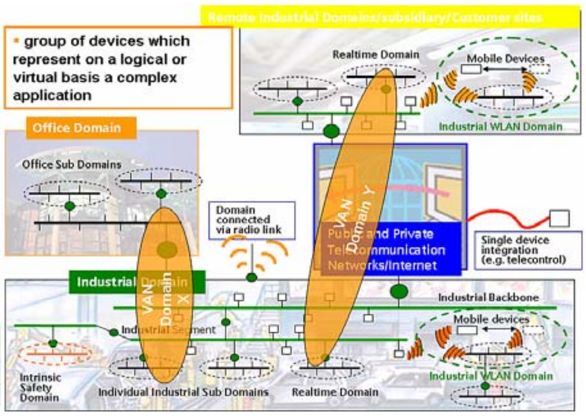

Figure 1: Virtual Automation Network

A scenario of a Virtual Automation Network is shown in Figure 1. It depicts the definition of different VAN domains which contain both an office network and an industrial network. This connection can be realized via a public communication environment which can be wired and wireless.

2. The VAN Concept

VAN Topology

The VAN topology is described by a VAN domain; defined as an entity, within an automation and communication environment. The defined VAN domain covers all engineered devices, needed to fulfil automation tasks. Therefore, the type of network and the location of the devices shall be covered by an overall application. However, all devices that exchange information within the scope must be VAN devices. Components without VAN capabilities can be represented by proxy devices. This allows a mixture of VAN and non VAN networks.

In this way, a VAN domain represents one virtual automation network. The devices within belong to a well defined set of VAN device types. Each device type contains specific characteristics and a set of functions, e.g. a VAN automation device to fulfil an automation function or a VAN access point to connect different domains over a heterogeneous network.

To fulfil its functions, a common architecture of a VAN device was developed also to obtain the integration into a Virtual Automation Network.

Each VAN device realizes mainly two functions. First is its functionality within the automation process, which is provided by one or more application processes. Second is the connection to a VAN network. Furthermore, a VAN device comprises three major layers; the VAN network technology layer, the VAN communication stack, and the application layer.

All layers combine standard technologies and VAN specific technology, as shown in Figure 2. [2],[3]

For the VAN architecture, the runtime object model of PROFINET [4] is used as a common object definition. If other object models are based on the VAN communication stack they could also be used. So, all devices with the same object model can interact by using the VAN infrastructure. Devices with non VAN communication technologies can be integrated into a VAN domain by using a VAN Proxy Device.

An important VAN architecture characteristic trait is the defined set of object-oriented Application Service Elements (ASEs) [2]. The main function of the ASE, contained in all devices, is to act as a container for configuration and diagnosis data. To access the ASE objects, web services are used as a common access and communication technology.

The web service technology is a state of the art approach for communication in heterogeneous network environments, to connect objects implemented on different platforms [5].

Within the VAN environment, the web service technology is used for device configuration (e.g. configuration, diagnosis, connection establishment), for tunnelling of data and within a PnP (Plug-and-Play) application process [6].

VAN Device Classes

A VAN network consists of well defined VAN device types. The defined classes are:

- *VAN Access Point (VAN-AP)*

A VAN device which belongs to a class of VAN-APs, containing the VAN services and protocol implementation. The function of VAN-AP within the VAN network is to connect VAN network segment/domains. They do not have an automation function or an automation application process.

- *VAN Automation Device (VAN-AD)*

VAN-ADs are the devices which provide the (automation) functionality in the VAN context. For this purpose, each VAN-AD contains at least one automation function or application process.

- *VAN Proxy Device (VAN-PD)*

A VAN-PD contains the VAN capability to “speak” VAN and to also to speak the VAN Proxy Application. It is a proxy for automation devices in a VAN application context which can be accessed within the VAN domain.

- *VAN Virtual Device (VAN-VD)*

Devices which have no VAN network capabilities but automation function within the VAN context. VAN-VDs can be integrated by using a VAN-PD.

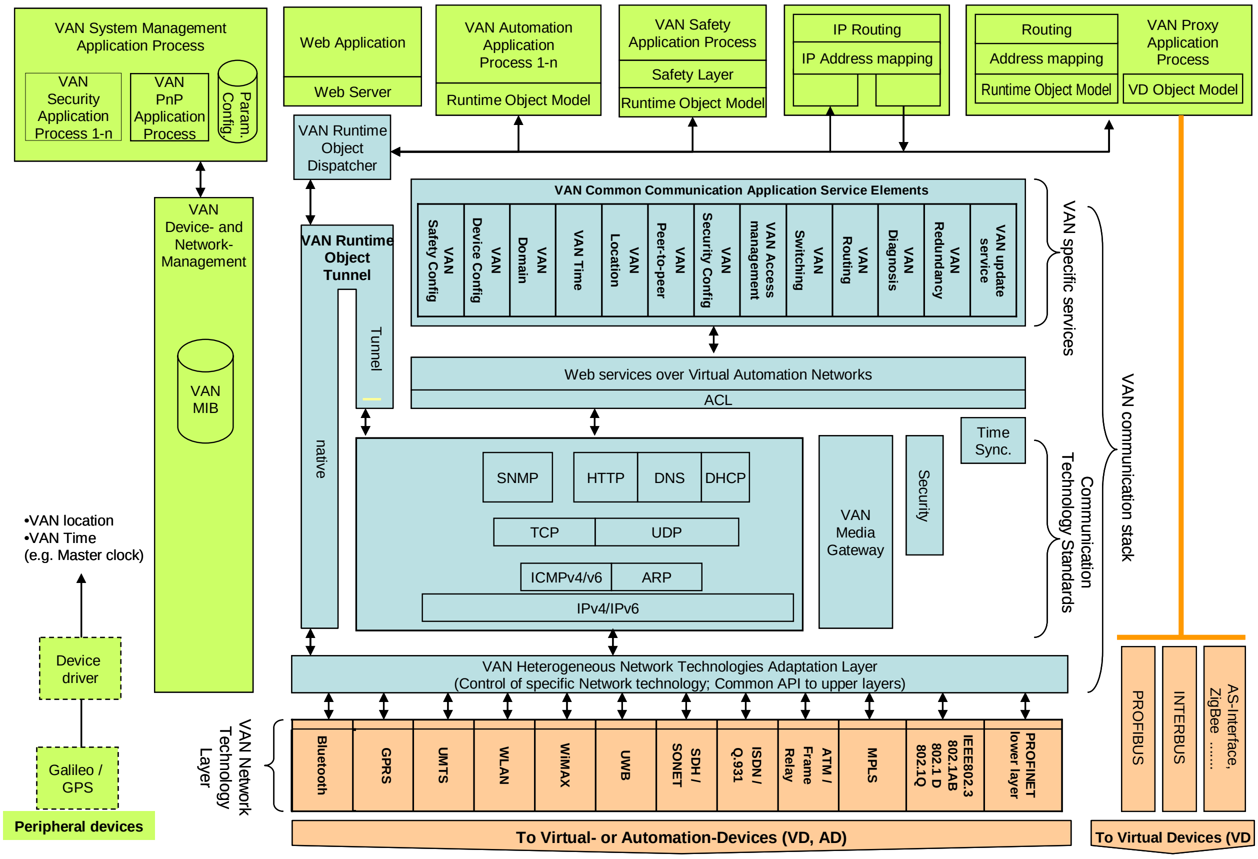

Figure 2. VAN Architecture

Addressing within a VAN

All VAN devices obtain a VAN-Name within their VAN-Domain to guarantee the accessibility to VAN. General aspects within this content are:

- The VAN-Domain is a name based domain. This provides an easier handling instead of IP based addressing for the engineer.
- Each VAN device shall have a unique name according to the defined naming conventions.
- To address VAN devices in a VAN domain, a unique name space is used.
- The naming conventions within a VAN-Domain shall conform to the DNS unique indicator and to PROFINET naming definitions to avoid naming conflicts.
- Address resolving in a VAN with sub domains and communication paths with different IP-subnets is done by DNS service.

The main objective is to assure access via heterogonous communication path to all connected VAN devices. Crossing public communication the subnets are connected via representation by one IP-address. The local IP-address is not directly accessible.

In case of addressing a VAN-VD which is represented by a proxy device (VAN-PD), there can be special types of addresses behind the proxy (e.g. PROFIBUS addresses). They need to be mapped to VAN-VD names.

To solve this addressing bottleneck, the standards and definitions of web services [6] are used in VAN.

3. Communication protocols within VANs

The approach of VAN to achieve a common view of a Virtual Automation Network is to use and integrate different existing and wide spread technologies and network protocols. This includes IT technologies and protocols as well as protocols used and developed for automation. The main challenge of this concept is the integration of all these specific protocols within architecture without modification or corruption of the single protocols.

To realize this task the concept of the VAN Object Dispatcher and in combination with the VAN Runtime Object Tunnel was developed. Within this approach the VAN Object Dispatcher binds virtual device instances to different real or virtual device interfaces. Afterwards it dispatches the data to the corresponding interface. The interfaces are simple device driver interfaces like VPNs or a PROFINET driver. One of the main benefits of this concept is that the existing device applications and stacks will not be touched. The selection which interface has to be used for each communication relation is part of the configuration phase of the tunnel [2]

PROFINET and OpenVPN are the two selected protocols which are used within the VAN Runtime Object tunnel.

Independent of the described communication over the VAN Runtime Object tunnel a second communication method for configuration, parameterisation is part of the VAN concept. For this communication task, SOAP [7] based Web Services are used.

In the following subchapters, an overview about the use of the network protocols PROFINET with Real Time over UDP, Web Service and OpenVPN in VANs will be given.

Web Service

Within the VAN environment the main use for Web Services is restricted for administration requirements (e.g. configuration, diagnosis, connection establishment) and within the PnP application process [2].

PROFINET/RToverUDP

For the VAN Network Technology layer is PROFINET defined as network technology. So it is the network protocol for the native communication through VAN Runtime Object Tunnel. This includes especially the communication within one LAN with no need to be tunnelled though LAN boarders.

OpenVPN

Within the VAN project, OpenVPN is used to build a “transparent” connection between two separated locations. Doing this, devices that can only communicate using local networks are able to establish a connection using wide area networks. The OpenVPN connection is part of the VAN Runtime Object tunnel

4. QoS Measurement in VAN Networks

To set up and engineer a Virtual Automation Network it is required to have a well known understanding of the QoS behaviour of different communication channels used in VAN. To measure this QoS of the communication channels, performance indicators are used which are influenced by different factors.

For realizing VAN QoS measurements performance indicators and factors of influence were analysed, defined and used to specify an easy to use and cheep VAN performance test application.

Performance indicators

To describe the performance of a given communication channel certain parameters are used. These parameters are the performance indicators.

The following list contains a selection of performance indicators which are usable for all kinds of communication channels within a VAN, independent of the type of communication channel like LAN, public network or wireless connection.

A list with useful and important performance indicators is selected by work package 4 of the VAN project. These most important indicators are:

- Transmission delay
- Jitter
- Bandwidth / Capacity
- Packet loss rate
- Packet Duplication
- Wrong packet sequence
- Bit error rate / residual error probability
- Availability
- Costs

To consider further performance indicators is not useful in the context of VAN. This is coursed in concept of VAN which has the aim to integrate different network technologies for communication over LANs, InterLANs and WANs and so a subset of indicators is defined which is common for all used communication channels.

Factors of influence

The performance of a communication channel is affected by different factors. They can be classified into two categories: transport way and transported data.

- Transport way

The transport way is the main influence regarding the performance of a communication channel. In VAN, the transport way usually consists of local and non-local networks. Non-local networks can be public networks but also a dedicated line over a long distance (for example connecting two locations of a company). In all type of networks, the influence of the individual types of infrastructure components has to be regarded.

Local Networks

The performance of local networks is mostly influenced by the network components and the topology of the network.

As infrastructure components of local networks mostly switches are used. A characteristic of switches is that a passing packet is delayed for several microseconds. The delay time is depending on the forwarding mode of a switch (cut-through vs. store-and-forward) and the current network load.

The topology of local networks can be line, star and tree, depending on the used technology. For details see [9]. Depending on the topology, a different numbers of infrastructure components have to be passed by every packet. Delays into local office networks are usually in a range of hundreds of microseconds.

Considering all these facts it has to be mentioned that the influence of local networks on the transmissions is much smaller than the influence of Wide Area Networks.

Public Network / Wide Area Networks

Wide area networks (a well known example is the Internet) do not necessarily have to be public. The characteristics of Wide Area Networks can vary but usually they have the following characteristics in common:

- Connections using wide area networks have often less bandwidth because of restricted connections of the public provider, than local networks. Depending on willingness to pay , higher throughput is often also available for wide area networks.
- The delay of wide area networks is higher in comparison of LANs, because of longer distances and more routers on the way (also with change of the transport medium).
- When using wide area networks there can be several bottlenecks like the connection to the WAN (often DSL, UMTS or still ISDN) or single links within the WAN (which could be too small dimensioned or overloaded).

- Transported data

When analyzing the performance of communication channels, it is also necessary to have a look on the transported data – regarding the packet length, priorities aso. Depending on the transport media, the type of transported data can have a big influence on the performance.

Packet length

From automation point of view, most interesting is the amount of data that should be transferred per cycle. It can vary from a few bits to hundreds of bytes, depending on the application. From network point of view, the size of the resulting packets is the interesting point. That also depends on the transport media. Ethernet for example has a minimum packet size of 64 Bytes. Smaller packets are not allowed and have to be filled with zeros.

Other media supports only very small packets, which leads to big packets being split into multiple smaller ones. When changing the media (for example in routers from local networks to WAN), it could be necessary to split arriving packets or reassemble them (depending on the direction).

Packet size also influences the reachable throughput of a transport media or of infrastructure components.

Amount of data

If more data should be transferred over a network than the bandwidth allows, it has to be queued in routers or other infrastructure components. That causes increasing transmission delay. If the data stream lasts longer than the buffers of infrastructure components can store additional – an overload is the outcome and data packets are thrown away.

In private networks or on dedicated lines, there are several solutions to solve this problem by reducing the amount of transported data. But in public networks, a single user has no influence on the data volume over the network.

To measure the QoS for different communication channels in a VAN with common test tools and equipment would raise high cost. To avoid this, a new concept for such a test system is defined within the project, which fulfils the VAN requirements, see Figure 3.

Test System

For realizing QoS measurements in Industrial Ethernet Network used in VANs a test system is defined. This system consists of two parts.

The first part is a PC based test application which initiates and stores the measurement and is the user interface. The second is part is the test configuration. It contains the logical and physical network topology of the communication connection which is tested.

Test Application

To realize a VAN performance test application a solution, which is running on standard office PC enhanced with two ERTEC EB 200 boards [11], is specified.

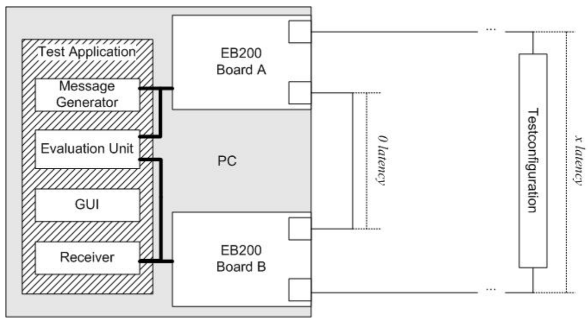

Figure 3: Test System Design

The general functionality of the application can be described as follows:

The application sends Ethernet packets and their derivatives over EB200 board A to EB200 board B over a test network configuration. When the packet is sent on the wire a very precise timestamp is made with help of the EB200 board. At the destination the data packet is passed through to the test application and a second timestamp is taken at board B when the packed arrives at board B. With the help of these two precise timestamps the test application is able to calculate the performance indicators. To optimize the results of this calculation a second message is send in parallel trough a short cut between the two cards. The time which is measured with the second message is used to correct the error caused by passing the protocol stacks. The principle which is used for the measurement is a card2card measurement.

The current architecture of the test application for measurements consists of four functional parts. These are the message generator, the receiver, the evaluation unit and a Graphical User Interface (GUI).

- The *Message generator* which builds the data packages and sends it through the EB 200 board A.
- The *Receiver* for receiving the packets at EB 200 board B.
- The *Evaluation unit* for the calculation of the performance indicators.
- The *GUI* as user interface and for setting the parameters.

This classification describes a logical view on the application and not the implementation of the software.

The test tool provides the following features:

- The application sends Ethernet packets and their derivatives over network
- The length of the packet is scalable and the sending interval will also be scalable
- The application can provide both roundtrip delay measurement and P2P latency measurement. P2P latency can be based on two principles:
- The application affects DSCP bits in IP header
- The application is able to log data and calculate statistics over a subset of measurements

With the described test application an easy to use alternative for QoS measurements is developed, which can be used to measure performance indictors of communication channels in LAN or inter-LAN connections.

Test Configurations

The second part of the test system is the test configuration of the communication channel. This configuration comprises the transported data as well as transport way.

In the VAN test system the setting of the transported data can be set up within the GUI of the test application, e.g. the packet length. The transport way depends, as discussed, on the network topologies. For the investigation within the VAN context three main topologies are identified which have to be used for performance measurements. These are the following topologies:

- *Office Network,* with standard office infrastructure components.
- *Factory floor networks,* which are build up with industrial components.
- and *Company side networks* which includes office components as well as industrial components.

With the investigation of these main topologies, which have to be refined for each test series of the measurement, all communication relations according to [10] within an enterprise network can be analysed.

In the following, for each main topology one example configuration is presented.

Office Network

Figure 4 shows a test configuration to simulate a typical office network. The configuration consist of the PC with the test application, two Cisco 3550 Catalyst layer 3 switches and one Cisco 2612 XM Core Router.

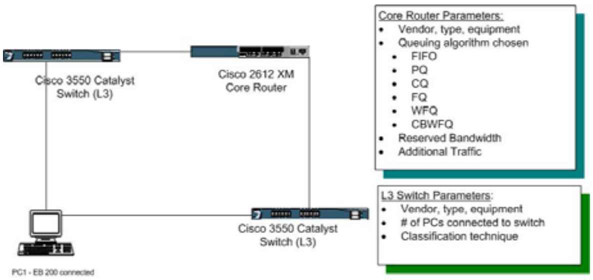

Figure 4: Test Configuration Office Network

This configuration is used for investigate router parameters like the queuing algorithm or the influence of additional traffic one the router. Additionally, the influence of switching parameters can be measured in this topology e.g. classification technique or forwarding mode. Comprising the measurement within an office network provides information for the basic understanding of influence of different technologies to the performance of a network.

Factory floor networks

An example of a topology of a factory floor is shown in figure 5. It contains the test application which can be seen as the two end device which are communicating over a network consisting of two PHOENIX CONTACT FL SWITCH LM 8TX connected in a line topology.

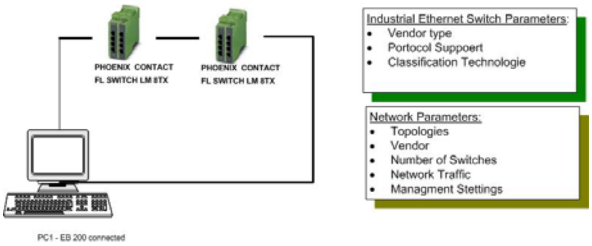

Figure 5: Test Configuration Factory Floor Network

Parameters in this topology are for instance the vendor of the switch, the additional network traffic or the management setting.

The aims of investigation these topologies are:

- To compare the behaviour of industrial components with the behaviour of office components
- To compare the different behaviour of similar products of different vendors.

Company side Network

Figure 6 shows an example topology for a company side network. It includes standard Industrial components (Cisco PIX 525) and industrial components (PHOENIX CONTACT FL SWITCH LM 8TX). Such test configuration can be used for simulate real company side networks with its communication relations.

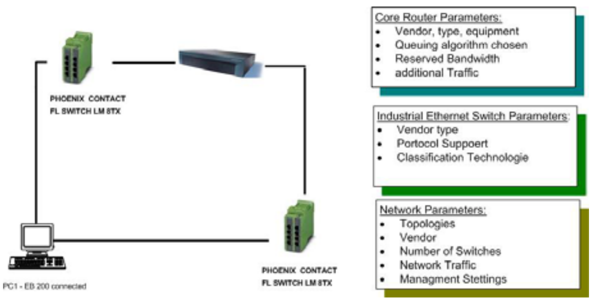

Figure 6: Test Configuration Company Side

Parameters within this topology are the parameters of the switches, the parameters of the router and network parameters, like vendor type, management setting or number of active components.

5. Synopsis

VAN focuses on a uniform networking of production and manufacturing processes. For this it is necessary to integrate different communication concepts to one VAN.

To engineer and set up an industrial automation application such as in VAN a well known understanding of the performances of particular communication line is necessary.

Existing solution to measure performance indicator for such knowledge are either restricted to specific configurations and test scenarios or very complex. Within this paper a solution is presented which has the benefit that it can be used to measure QoS in different kinds of Ethernet based networks in an easy way. .

Based one this solution a further development is planned which enables the measurement over WANs and includes more complex evaluation functions.

During the course of the project this tool will be used to make measurements for different communication channels over LAN, InterLAN and WAN connection.

ACKNOWLEDGMENT

The paper has been supported by the “Virtual Automation Networks” integrated project (FP6/2004/IST/NMP/2 – 016696 VAN) funded by the European Community under the “Information Society Technology” Programme.

The authors want to thank the whole VAN project team.

REFERENCES

[1] VAN project page, *http://www.van-eu.eu*, March 2007

[2] VAN Consortium, Deliverable D02.2-2 of the VAN project *“Specification of the Open Platform for Automation Infrastructure”*, The VAN Consortium, November 2006

[3] VAN Consortium, Deliverable D02.3-1 of the VAN project *“Application specific Architecture for Automation, VAN Profile for Process-Manufacturing-Industry”*, The VAN Consortium, January 2007

[4] International Electrotechnical Commission: IEC 61158 *“Digital data communication for measurement and control – Fieldbus for use in industrial control systems”*, 2003

[5] W3C-Specificationen with German translation and comments; http://www.edition-w3c.de/; March 2007

[6] Schwab, C.; Klostermeyer, A.; Hoffmann, M.; Messerschmidt, R.; Beran, J.: “*Horizontal and vertical integration for automation systems: virtual automation networks*” Methodologies for Emerging Technologies in Automation: international congress 2006, Anipla 2006; Rome

[7] W3C: SOAP Specifications; SOAP Version 1.2; http://www.w3.org/TR/soap, May 2007

[8] VAN Consortium, Deliverable D04.1-1 *“Real Time for Embedded Automation Systems including Status and Analysis and closed loop Real time control.”*, The VAN Consortium, February 2006

[10] Reinelt, D; Lüder, A; *Securing communication in automation networks*, Accepted paper at 5th IEEE International conference on Industrial Informatics- a networked world -, INDIN 2007, Vienna

[11] Siemens AG, Die ASICs der ERTEC Familie http://www.automation.siemens.com/profinet/html_00/produkte/ertec_400.htm, May 2007