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Public Network and Telecontrol Concepts in Virtual Automation Networks

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Abstract: This paper describes the aspects for the needed integration of public networks (Wide Area Networks) into Virtual Automation Networks as investigated in the respective work package of the equally named EU-funded project VAN. The main aspects when using public network services within automation applications are the following: (1) Real-time capabilities of public networks related to automation tasks; (2) Telecontrol requirements; (3) Provider Contracts (Service Level Agreements); (4) QoS capabilities and network monitoring from automation side. Currently available communication solutions and Service Level Agreements do not support the required capabilities for real-time applications as discrete manufacturing applications. On the one hand nowadays available fieldbus standards are primarily based on cyclic transfer of IO data and do not support distributed applications across subnet boundaries. On the other hand a variety of proprietary and standardised protocols designed to communicate across public networks in telematic systems do exist. Thus fieldbus technologies and telecontrol systems today base on different technologies and protocols. In VAN a common open platform and common means for classical fieldbus tasks and telecontrol tasks are defined to be able to realise Virtual Automation Networks that combine both fielbus and telecontrol related aspects. The activities focus on a seamless integration of real-time and telecontrol functionalities into the common open VAN platform. So the paper focuses on the network related - and not the applicational - aspects and is thus not about networked control.

1. INTRODUCTION

The communication of different industrial domains via a heterogeneous infrastructure is an important goal of VAN. Currently implemented manufacturing automation plants are mostly based on local area networks (LANs). Here, communication technologies such as IEC61158 type 10 (IEC61158) are used for the transport of real-time automation data. Special telecontrol systems and remote maintenance access are based on wide area networks. The general demand on further networking within and among companies also leads to the interconnection of the locally distributed (sub-)plants by use of the combination with wide area networks (WANs). The communication must be possible without any or only with less impact. The conjunction of both domains leads to the need of fundamental architectural definitions as realised within the VAN-Architecture (VAN consortium, 2006a, b). This implies the description of an appropriate integration concept associated with the definition of specific application service elements (ASE).

During the status and analysis phase of the project it was diagnosed that currently available communication solutions and service level agreements (SLAs – the contract with a provider) do not support the required capabilities for real-time applications as found in discrete manufacturing applications (VAN consortium, 2006e). Nowadays available fieldbus standards are primarily based on cyclic transfer of IO data and do not support distributed applications across subnet boundaries. On the other hand a variety of proprietary and standardised protocols designed to communicate across public networks in telematic systems do exist. Thus fieldbus technologies and telecontrol systems today base on completely different technologies and protocols. In VAN a common open platform and common means for classical fieldbus tasks and telecontrol tasks are defined to be able to realise Virtual Automation Networks that combine both fielbus and telecontrol related aspects. Thus common open technologies (including protocol stacks) have to be used and if necessary adapted. Therefore the work package decided to focus its activities on how to seamlessly integrate real-time and telecontrol functionalities into an overall VAN platform. The approach is to integrate telecontrol functionalities into the international fieldbus standard IEC61158 type 10 (VAN consortium, 2007).

Concerning wide area networks (WANs) and especially public WANs the detailed infrastructure composition and therefore the exact communication path can not be described in end-to-end detail (see Fig 1.), the communication path is also subject to temporally changes and is often even not known by the service provider himself. Usually the service provider does not provide any online QoS data of the provided line. In this case reliable quality characteristics for the end user can not be taken from the underlying communication technology, there is only the contractual way between user and provider by using service level agreements to define QoS attributes. From the automation point of view this leads to the need for an own online analysis of the current performance of the provided line to check the defined and guaranteed attributes and also as a diagnostic service that can be used to detect and handle service level violations.

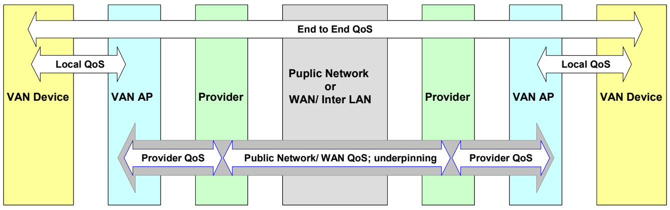

Fig. 1. End-to-End QoS consideration for Virtual Automation Network communication

If the current quality state of an established connection does not fulfill the required parameters it can be necessary to switch from the current line dynamically to another line. This will be considered by the VAN Switching.

There are a large number of internet service providers and WAN access technologies where different types of service levels combined with different cost models are available and can be chosen from. E.g. a low-cost connection is not the best choice in case of need for high bandwidth and high reliability, but for a low price transmission of buffered data. Concerning this an important aspect is the description and classification of automation specific service level agreements (SLA) that can be contracted between operators of plants and the service provider. In this context, IP-based QoS must be analysed and appropriate requirements must be defined in order to have the right basis for the SLA definition. Again, the monitoring of such QoS parameters is needed to get information about the current state of the communication path. It enables the generation of events e.g. for switching between providers or lines. Furthermore, combined with a logging functionality it is an instrument for the observation of the service quality which the provider delivers.

2. REAL-TIME ASPECTS

Real-time can only be defined in close link to application requirements (VAN consortium, 2006c). A system - related to a special application - is real-time capable if it can fulfil the (timely) requirements of that application. Even if this provides a common understanding of real-time, the time constraints of applications can be totally different from each other. Determinism describes whether the behaviour of a network can be predicted (calculated in advance) and thus whether the results are repeatable. Future automation networks have to be able to transmit data in both ways: cyclically and event driven. The cyclic transmission of data (as also realised for voice over IP, video on demand and IPTV) has real-time characteristics and must be predictable to fulfil future requirements. For sure the class of demand will always clearly differ from those in motion control - the predictability in public networks is restricted and can only be given in a certain extent - therefore an important aspect is the monitoring of public network behaviour to be able to react respectively.

In a broad spectrum of applications using WANs it is not necessary to have real-time cycles in the lower ms range (VAN consortium, 2006d), much more important is to have the certainty that the information arrives within a defined time frame. According to the Real-Time workpackage definitions (VAN consortium, 2006c, d) the isochronous real-time communication is out of scope in Inter-LAN as well as WAN or public network constellations. However, real-time communication is required for the whole virtual automation network. During runtime phase, network downtimes are not allowed in any closed loop control applications. The network availability is highly demanded. The behaviour of the currently available infrastructure and quality measures often supported by a provider have to be considered. This infrastructure is mostly non exclusive and the whole path can not be described in detail.

2.1 QoS – Quality of Service

To achieve a more deterministic behaviour when interconnecting VAN domains an approach using priority assignments was defined. This approach is based on QoS classifications of the packets to be transferred as well as the application of appropriate service level attribute definitions used for the service level agreement contracted with a network provider. It was decided to focus only on standard and future technologies. Therefore only IP relevant mechanisms are considered.

There are numerous automation specific communication services which have different timing requirements. As an example the services of IEC61158 type 10 fieldbus system were classified in order to define a categorisation and to map these levels to different QoS. The QoS-aware IP-based infrastructure with DSCP marking in IPv4 as well as in IPv6 is the basis for the differentiation of such prioritised flows. This categorisation has to be considered by the VAN communication stack. That means the different communication services have to be combined with the appropriate QoS sign. In this case the provider is able to distinguish these several services and can transport these streams with respect to the SLA definitions.

2.2 Provider Contracts – Service Level Agreement (SLA)

A Service Level Agreement (SLA) is a formal written agreement in the case of VAN made between two parties: The infrastructure provider and the client, usually responsible for an automation task via public networks. Generally, a SLA contains clauses that define a specified level of service, support options, sometimes incentive awards for service levels exceeded and usually penalty provisions for services not provided.

In order to completely cover the topic of service levels technical and organisational attributes of the service have to be taken into consideration.

The technical aspects describe physical and administrative conditions of a connection with packet loss, latency and similar attributes in a quantitative manner. The organisational part covers service hours, reaction times on problems, responsibilities and escalation scenarios. When investigating on existing service level portfolios it became obvious that nearly no public network service covers the availability demands expressed by the automation industry. The times to fix connectivity problems in all cases where in the range of hours and either the expensive increase of the availability by the service provider or a completely independent provision by another service provider have to be considered in most cases.

Existing SLAs were analysed in order to get the important attributes and typical predefinitions and classifications. As result an automation specific SLA was defined which contains special traffic classes as well es their appropriate DSCP mappings. This SLA can be used as a template and is helpful during the negotiation of the special contract between the provider and the plant operator or system integrator.

One very common practical approach to provide services at a given location is to rent leased lines for the last mile or to span geographical distances with the help of another service provider. This process is known as underpinning. Here the service level definitions of the underlying provider are the minimal values and additional communication overhead has to be taken into account. A service above an underpinning contract can only have better attributes by adding redundancy.

2.3 QoS monitoring

The monitoring shall enable to evaluate the status of the transmission path (see Fig 2.) to be able to derive the proper measures and decisions, including provider switching events. On one hand this means to provide online (run-time) performance analysis, on the other hand also includes offline (non-run-time) measurements for acceptance respectively quality determination tests, optimisation or repeated measuring in case of failures.

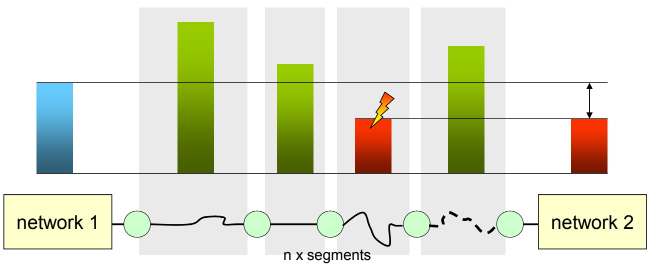

Fig. 2. End-to-End path capabilities in a chain of segments

The monitoring covers the following aspects:

- the measuring of current parameter values between defined measure points,
- the logging and processing of the history of parameter values,
- if possible the integration of measurements provided by the involved public network provider (online or statistical data).

In general for the monitoring two fields can be separately considered: the private part of the network and the public part of the network. The private part can be controlled by well-established internal access and means and is not the critical part of the considerations. The public part is controlled by an external party – the provider (VAN consortium 2007). Usually the QoS requirements for the public part are defined in the Service Level Agreement (SLA), but for automation it might be important to monitor, whether the provider network meets at all the agreed limits contracted in the SLA. Furthermore a network provider can not guarantee a network availability of 100%, a usual contract value is 98%, and this means the network can be not available several days per year. 99,5% are possible but at the moment this is to expensive for a broad use in respective automation applications. After all the network availability of a public network is clearly lower than of a private network, thus the non availability of the public network and also the violation of the contracted attributes has to be technically considered. For automation it is important to be prepared for such a breakdown. The main point is to detect it to be able to initiate appropriate, predefined measures.

To have this ability to react on QoS failure scenarios and to have verification against the SLA an online monitoring of the current network capability is addressed. Because of the above mentioned facts this monitoring is currently regarded as sufficient if restricted to the public network part. The main approach focuses on an active measurement by generating an additional data stream directly between the involved VAN Access Points as the entrance points to the public network part of a connection. The data stream will be produced and analysed by a special application distributed on the producing and receiving VAN-AP. This means the entire public network path is considered according the black box principle.

Since the focus is on evaluating the VAN Object Runtime Tunnel (VAN consortium, 2006a, b), it is useful to generate an adequate stream. For the tunnelling a UDP based openVPN tunnel is used, therefore the generated stream for monitoring should also be a UDP stream.

The behaviour and status of the tunnel has to be investigated according the single defined QoS classes, therefore the monitoring traffic also has to be generated and analysed for the single priority classes. A tunnel with different prioritised QoS channels with pre-allocated bandwidth within one tunnel (realised as different queues in the network routers) is pictured in Fig 3.

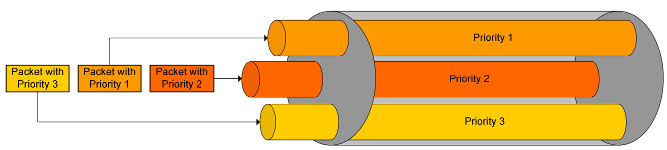

Fig. 3. Different prioritised QoS channels

The monitoring can be used to measure the current network load and to identify if the provider network meets the agreed limits contracted in the SLA. There are two monitoring modes defined: the *stand alone* mode is for testing the link-quality between the endpoints without real automation traffic. So the test traffic transferred along the path is issued and controlled by the measurement process only. In the *parallel in runtime* mode the measurement traffic runs in parallel with the runtime automation traffic (see Fig. 4), thus it has to be assured that the measurement does not impact the runtime automation traffic.

For future research the monitoring can be extended to a condition monitoring that will even allow deriving forecasts of the behaviour of a transmission path from its current and preceding status.

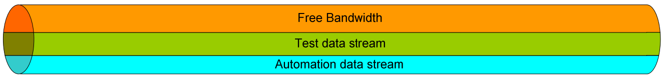

Fig. 4. Bandwidth sharing within a QoS (priority) class

An important trend in that context is covered by the headline "efficient Ethernet converged networks". This describes measures (from the provider side) and technologies for the coexistence of transmission of real-time voice, data and video traffic over existing Ethernet networks – as currently getting important for commercial IT applications (VAN consortium, 2006e).

3. TELECONTROL INTEGRATION

An open-loop controller, also called a non-feedback controller, is a type of controller which computes its input into a system using only the current state and its mathematical model of the system.

A characteristic of the open-loop controller is that it does not use feedback to determine if its input has achieved the desired goal. This means that the system does not observe the output of the processes that it is controlling.

Fig 5 shows the operation principle of a VAN telecontrol object. It realises the behaviour described below.

Telecontrol takes advantage of the fact that there is no direct feedback from inputs to outputs. The transfer from the data provider to the data consumer is decoupled. The major reasons for the application of telecontrol are: minimization of communication costs, minimization of communication volume, delays caused by network transfers and tolerance to a network being temporarily unavailable.

In order to reach the minimisation of the data volume different mechanisms are used: mechanism to generate a transfer object, mechanism to buffer transfer objects, mechanism to initiate a data transfer.

A minimised amount of data is the precondition in order to keep a small network load and to minimise the transmission costs.

The generation of the data and its transfer occur at different times. This kind of communication is called event driven communication.

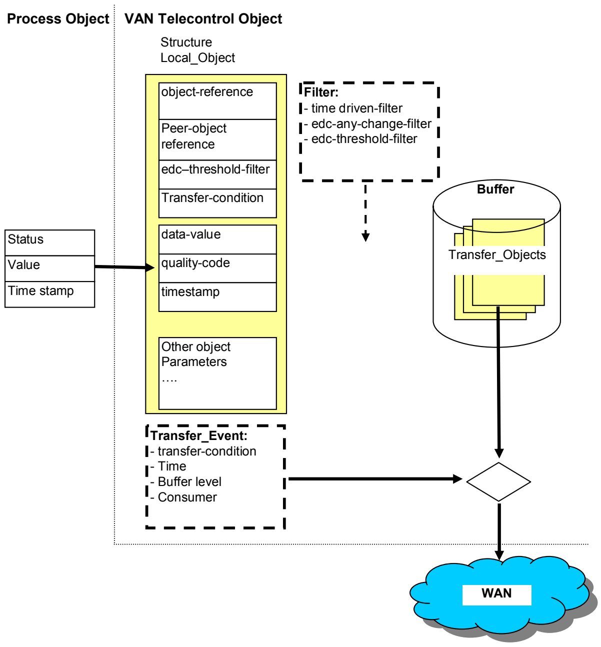

Fig. 5. VAN telecontrol object principle

There are different adjustable filters which control whether the input data is copied into a transfer object and stored in the transfer buffer or not. Criteria are: event-oriented at each value / information change, event-oriented dependent on threshold settings (different strategies), spontaneous (user-controlled, user may be provider or consumer), cyclic (time driven).

These mechanisms guarantee a minimum quantity of transfer objects to be generated and triggering of a data transfer, when the transfer condition is unconditional/immediately, that means an alarm is identified.

The transfer buffer supports two tasks: (1) The objects to be transferred are buffered during communication fault/error. Therefore no data is lost. (2) The amount of data to be transferred and therefore also the communication costs can be further reduced.

The data transfer mechanisms are aligned to the meaning of the data and the reduction of communication costs: *Spontaneously* - Data is transmitted immediately (unconditional). The decision for immediate or later transmission is only relevant for dial-up networks. In other networks with permanent connectivity, data is transferred immediately, even if the transfer-condition is set to conditionally. Alarms are always transmitted immediately. *Conditionally* - Data is transmitted when the send buffer is filled or an alarm (unconditional data) occurs. Time-driven means, that data is transmitted periodically or at given times.

The telecontrol functionality will be realised as a profile, independent from the underlying fieldbus. Fig. 6 shows this telecontrol add-on put on the IEC61158 type 10 fieldbus (IEC61158) stack architecture as it will be implemented for the VAN demonstrator.

The profile uses the functions provided by the communication stack. In order to enable communication relations via a temporarily unavailable network path, extensions within the communication stack may be necessary.

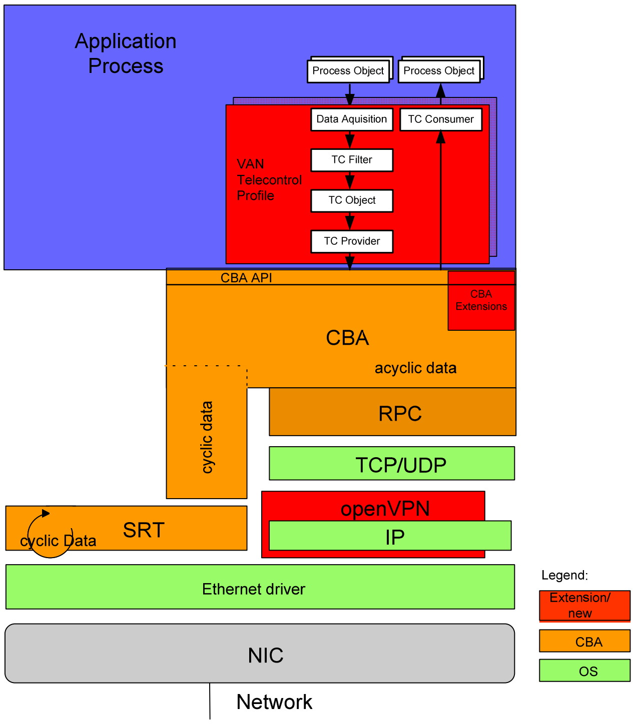

Fig. 6. VAN Telecontrol Profile approach

4. APPLICATION EXAMPLE

Within the VAN research project the developed concepts will be evaluated on industrial experimental setups. One industrial experimental setup is a distributed biotechnological system consisting of several single local plant stations on different, geographically widely distributed locations which are networked via public networks. As shown in Fig. 7 one station contains various sub processes: (1) a bioreactor that operates to transform and degrade biogenic waste material and produces gas and ethanol, (2) a gas cleaning and storage plant and (3) a combined heat and power station for the production of heat and electric power.

For a cost-efficient operation of the local systems the process has to be optimised in a manner that e.g. the foam development during the fermentation is minimised. Therefor a special licensed control is needed. It is too expensive to have such a control at each location. So this functionality is provided on a central server remotely connected with several local systems of the same operator (see Fig. 7). So the know-how of one operator can be used in parallel for the control of a great number of plants and the costs of the centralized control system can be divided to the number of decentralised technological plants. The benefit when using the optimisation compared to not using it is estimated by the Waste-to-Engergy industry with approx. 30% raise of the output, which makes such systems at all profitable.

Since the fermentation process itself is quite slow the needed data update time is quite low and has soft-realtime characteristics, e.g. for the optimisation and stabilisation of the bioreactors 10sec. are sufficient, for the optimisation and stabilisation of the combined heat & power units 5sec. are sufficient, for the tanks stabilization even 100sec. data update time is sufficient.

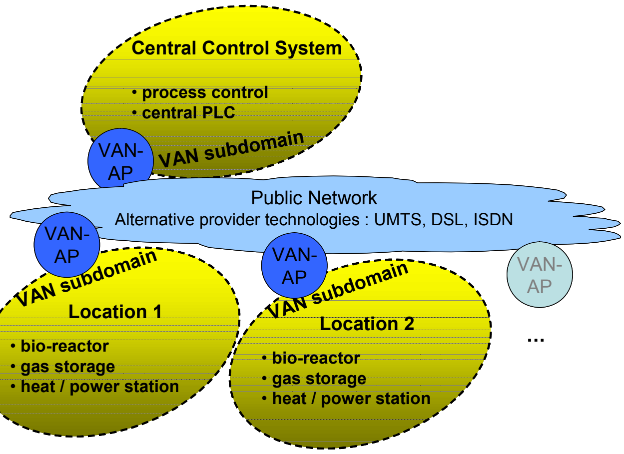

Fig. 7. Distributed biotechnological plant system as VAN application example

5. CONCLUSION

The work presented here provides generic concepts and models for the aspect of seamless public network and telecontrol integration into automation systems that are future oriented as well as covering current conditions. Further development of the infrastructures and involved devices can be expected. Therefore it can be expected that current automation requirements for local networks will be approached in future increasingly by larger network structures.

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