QUALITY OF SERVICE IN NETWORK-BASED AUTOMATION

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Abstract: This paper considers quality-of-service (QoS) issues in distributed network-based automation. Recent advances in distributed automation and overall use of modern ICT technologies have raised new kinds of QoS problems. Also the term service is changing due to the overall integration between automation and other information systems. This article gives an outline of the QoS field in automation and discusses its important features and research problems. A GPRS network measurement example is also given. *Copyright © 2005 IFAC*

Keywords: Networks, Automation, Distributed Control, Telecommunication, Quality

1. INTRODUCTION

Service Level Agreements (SLA) and Quality-of-Service (QoS) are conventionally used by teleoperators to manage their networks and services. Same methodology has recently raised interest in other fields, also in automation. This interest can be seen arising from typical trends: the scope of automation is widening and the use of TCP/IP in distributed automation in general but also at low level.

Modern automation systems are or will be in near future integrated with upper level ERP and MES (Kjaer, 2003). EAI (Enterprise Application Integration.) and web services, WSDL, XML etc. are the technical tools used for that. The question "what is automation?" is a difficult one, but if a system theoretical approach and treatment is used for modelling, prediction and control of supply chains (Choi *et al.*, 2001) or even business processes (Aissi *et al.*, 2002), these could clearly be seen as control systems. The actual models and controllers are of course quite different from the conventional ones, but the basic idea of feedback and dynamical behaviour is the same. SLA and QoS seems to be a potentially fruitful framework for performance treatment for these kinds of systems.

More conventional automation and control can be seen from the same perspective. The use of widely distributed automation, like the modern M2M (machine-to-machine) approach is a typical example. Using wireless media, which is by nature sometimes unreliable, is a clear target for quality-of-service type analysis. Telecommunication oriented considerations can easily be applied if the automation specific requirements are known.

The usage of Internet at all levels of automation emphasise this point of view. For example a web server response time has been analyzed and controlled (Henriksson *et al.*, 2004). Similarly, QoS and SLA issues in web service (SOAP, WSDL) context have been studied, c.f. (Menasce, 2002). These techniques form a part of overall integrated automation system but soon they will exist also at lower level, like industrial Ethernet based fieldbuses. New OPC's XML based data access specification is a typical example of this (opc, 2004).

This article tries to formulate and categorize the question "what is QoS in automation?" and give a simple demonstration what this means in practice.

- Can it be defined?
- Can it be measured?
- Can it be maintained and controlled?
- Can design requirements be set i.e. at system design phase?

Easy questions, but answers are harder to give. This is clearly one important research target. One should be able to set those requirements, measure their performance and use this information for system design, management and control.

The rest of the paper is organised as follows. Chapter 2 outlines different automation areas, Chapter 3 introduces and discusses service level management in automation. Chapter 4 introduces the experimental GPRS measurement case study, which is selected to emphasise the automation perspective.

2. AUTOMATION CATEGORIZATION

Application areas in automation are wide. One division could be made between industrial automation and others. One emerging area of latter one is applying M2M technologies to every day life: consumer telematics, home automation, security. Also corresponding industrial level business segments are coming, like remote monitoring, pre-emptive failure diagnosis and homeland security. Typical telematics applications consider fleet management, public transport, logistics and emergency services.

Very few M2M applications require wireless or cellular connectivity, most cases a fixed connection is adequate, if such is available. M2M over cellular (typically SMS based) are so far for low-security and delay tolerant applications. User's minimum service level requirements are guaranteed message latency, guaranteed coverage and cell load.

The adoption of packet transfer networks like GPRS and 3G does not immediately change this, but QoS capable versions will arrive soon and also time-critical and high-reliability applications will to some extent be possible also with cellular access. To what extent, is one interesting research considered in this paper.

High reliability and low latency applications are nowadays typically found in wired digital fieldbus-based industrial applications. Also here can be seen a shift towards TCP/IP and Ethernet. Most demanding automation applications require 100Mbps switched ethernet-level connections: power substation automation, demanding motion control applications, c.f (Lee and Lee, 2002; Skeie *et al*., 2002).

Wireless technologies like WLAN and Bluetooth can applied for local connectivity. Application areas vary from remote diagnostics to wireless control, like (Poplys *et al.*, 2004).

Most demanding network based automation area is real-time control. It requires high reliability and low latency. Recently extensive research considering this has been performed c.f. (Nilsson, 1998; Abdelzaher, 2002; Beldiman, 2000). Various methodologies can be applied to increase the control performance. One could make the control system more robust by applying adaptive technologies or robust design. Also heuristic algorithms for error recovery play an important role when building real applications. More real-time capable networks are one way to achieve better performance. Differentiated Services and MLPS are potential tools for this. The term QoS is naturally inbuilt into these.

3. SERVICE LEVEL MANAGEMENT IN AUTOMATION

As discussed in the previous Chapter, the requirements for transport system features are as diverse as the applications areas itself. What is needed, is some tools to characterize, parameterize, monitor and manage these requirements. One field contains theory and practice defining and measuring the quality of network connections between automation devices in systems. The second area concerns tools and methods for achieving and maintaining the defined quality. It consists mostly of service level agreements and their content and relations between separate parties. The measurement and monitoring methodologies are also an important issue.

The framework of QoS (Quality-of-Service), SLA (Service Level Agreement) and SLM (Service Level Management) seems to be a promising and fruitful way to achieve these goals. The actual meaning of all these terms is rather complex and some clarifying definitions are needed:

Quality-of-Service (QoS):
- Overall required performance of a network, like, availability, accessibility, reachability, latency, jitter, MTBF (mean time between failures), etc.

Service Level Agreement (SLA):
- A formal contract between the customer and the service provider concerning network services. It contains a description of the agreed services in the form of service level objectives (SLOs). A service level agreement also describes what is done when problems arises in the network connection.

Service Level Management (SLM):
- Methodologies, instrumentation and tools used for managing required and agreed on service level. These can be divided into off-line (design) and on-line monitoring areas.

The term "service" is a confusing one. It could mean just bare transport with its delay and reliability characteristics or it could be some upper layer service, like Virtual Private Network, streaming multimedia or web server with guaranteed response time. These services and their QoS features are more or less tightly coupled, they form a layered and chained network of services, c.f. (van Moorsel, 2001). An extensive set of research results considering various QoS and SLA issues is available, c.f (Schonwalder, 2003; Leung and Schormans, 2002; Chen and Hu, 2002; Park, 2001).

The single most important component in Quality of Service in networks is the quality of the connection itself. Traditionally the network connections under study have been intended for human use, and have had thus quite complicated quality issues. The connections consist of three quality components, measured quality, perceived quality and agreed quality, see Fig. 1. The operator's quality control possibilities are also one dividing component.

Measured quality is the quality that the service provider or the customer can measure in any part of the network. It is the quality that is easiest to control. Perceived quality is the most important component for the service provider because it is the quality the user experiences while using the network and thus defines the ultimate performance of the network. True quality lies somewhere between these two.

The monitoring of even simple services is quite demanding as pointed out by (Darst and Ramanathan, 1999) and the difficulties increase when moving to upper level services. For example the HP Lab has performed and extensive research considering monitoring and managements of web services, c.f. (Jin *et al.*, 2002; Sahai *et al.*, 2002).

The SLM framework is typically used by a teleoperator to manage its network infrastructure. The situation is quite different when looking from end-users perspective, as in automation typically is the case. From the automation point of view, the transport network seems like a black box, which some statistically or otherwise characterized features, see Fig. 2. To emphasize this a rather simple experimental GPRS delay and reachability is selected for analysis, see next Chapter.

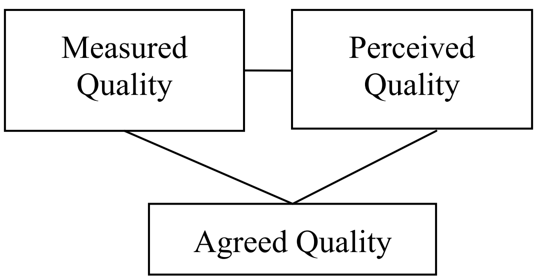

Figure 1 Three types of quality (Hardy 2001).

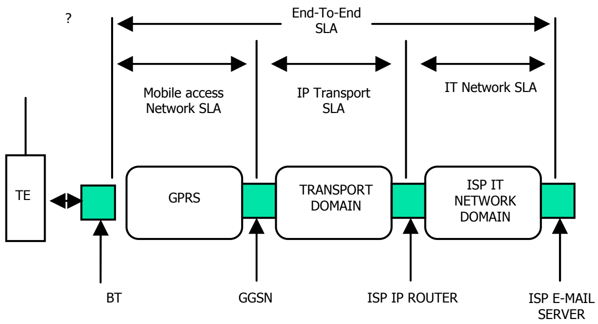

Figure 2. Teleoperators End-to-End SLA point of view in mobile connections. It covers only the wired parts (Artell 2004).

Quality of service in network-based automation is thus somewhat different. The most important factor, as can be seen from the Fig. 2., is that the true end-to-end scope is much bigger than of the teleoperator's. In automation, interacting opponents in the network consists of machines instead of humans, and the concept of perceived quality turns unimportant. In human-to-machine interaction perceived quality is always a combination of facts and subjective properties, like expectations or matters of opinion. In machine-to-machine communication the only measurement of quality is whether the attempted transactions in the system succeed or not.

This new E2E scope explains why we need new tools and methodologies to characterize and parameterize these features in mission critical automation applications. If available, these could be used in on-line monitoring but also in system design phase and in corresponding SLA negotiations with service provider.

4. GPRS NETWORK MEASUREMENT

GPRS performance studies are typically made from a teleoperators' point of view, like simulation studies (Ermel *et al.*, 2002; Lindeman and Thümmler, 2003). Also some experimental studies are available, c.f. (Navarro *et al.*, 2002; Brass and Fuhrmann, 1997; Stuckmann *et al.*, 2002; Jin *et al.* 2002).

The most typically used QoS measures for a network connection are the throughput, delay, packet drop rate and availability. The availability factor (in percents of time) is a very poor measure when predicting the behaviour of a network-based automation system. The availability percent does not however tell anything about service interruption length distribution. Even though the percent would very high, say, 99%, the network might still experience very long disconnections during longer time spans.

This feature is demonstrated within a mobile network in practice by sending 'too' big ping packets in a GPRS-network during one day, and packet loss and

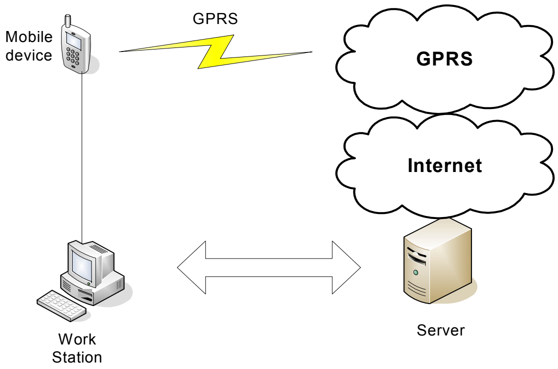

Figure 3 Test setup

latency was measured. The test setup can be seen in Fig. 3.

One way to get around with problems in availability issues is to measure MTBF versus failure length distribution from the network (Hardy 2001). The result of the measure is a graph, which tells how often disconnections of certain length or longer occur in average. When the

maximum possible break in the connection is known, it is very easy to determine from this graph how often the system experiences network conditions which harm the functionality. This is a key feature to be discussed of when making service level agreements.

The system consisted of a work station with a GPRS-connection, a server and a GPRS-network connecting them. The work station generated ICMP packets of size 1600 bytes and the packets were sent one by one to the server. The work station waited up to 15 seconds for the returning packet before sending a new one.

Due to the size of the packets, the packet loss was even as high as 69%. The latency distribution can be seen in Fig. 4. The packets arrived mainly in two different delays. This is probably due to properties of the GPRS connection.

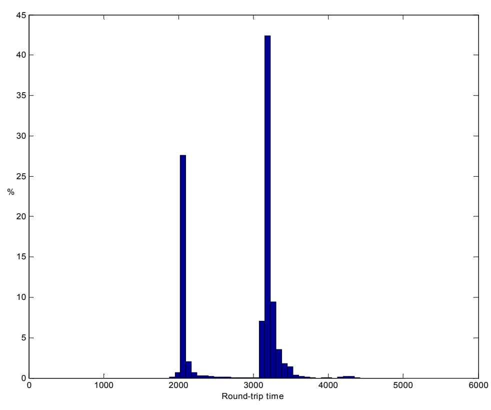

Figure 4 Round-trip time histogram in [ms]

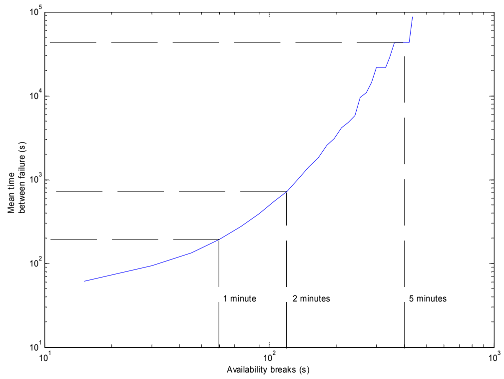

Figure 5 MTBF versus failure length distribution

The MTBF versus failure length distribution graph can be seen in Fig. 5. The graph tells how often a break of certain length *or longer* occurs. For example one minute or longer service interruptions occurred in this network on the average every 200 seconds, which is quite often. Anyhow, this seems to be the correct way to measure the availability instead of just a single number, say, percents of time.

The reader should note that this paper does not try to state anything about a GPRS-connection. The sent packets were chosen to be too big on purpose to more easily achieve bad conditions for rhetorical purposes. With a bit smaller packets the packet loss would have been several orders of magnitude smaller and the critical properties of a connection would have been much harder to reveal.

The availability measurement on a single device is quite easy to do, but to measure availability figures in each communicating device on a bigger network is a huge task, and needs to be split into smaller parts. The first thinkable strategy is to integrate a probe into each device, which then logs the events occurring at the device. The benefit of this approach is that if the probe is intelligent at least to some extent, the network traffic is decreased when the probe sends statistics through the network to the administrator; it only sends summaries instead of raw measurement data. This decreases data exchange in the network.

5. CONCLUSIONS

The widening scope of automation and increased use of TCP/IP in networks brings on new demands for network-based automation. In this paper, the traditionally telecom-oriented terms QoS and SLM were discussed as a quality framework for network based automation. Nowadays, the wireless mobile networks and fixed TCP/IP networks consists mainly of only best-effort type of service, but in the future also the QoS issues will be addressed. Meanwhile, it is up to service providers and system integrators to define and maintain automation specific quality properties in networks in order for the systems to function.

The purpose of this paper was to show, that service level management in automation can and should be done much wider than today is done. Due to huge variety of different automation systems no single requirement for quality can be outlined, but some measures seems to describe QoS in automation better than others. In this paper it was proposed that availability in automation networks should be measured with a MTBF versus failure length distribution and a practical setup was used to demonstrate the use of this tool. In the future these measurements are to be made on true automation systems.

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