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Analysis of the Impact of Network Performance Measurement Design Choices

Faculty of Electronics, Communications and Automation

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ABSTRACT OF THE MASTER'S THESIS

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Network performance measurements have an important role in various activities of mobile network operators: They can be used, for example, to estimate the user perceived quality of service, to pre-detect potential faults, or to provide valuable input data for network planning and optimization procedures. Therefore, the network's capability of producing comprehensive, detailed, and explicit performance data for the operator is a valuable matter.

However, finding an optimal set of performance measurement capabilities to be implemented for each network element provides a major challenge for the element vendors, especially in an economic sense: Avoiding excess costs, while simultaneously creating true value for the customers (the operators) is anything but straightforward. The purpose of this master's thesis is to assist one network element vendor, Nokia Siemens Networks (NSN), to identify the costs and benefits related to the choices made by its R&D units regarding these measurement capabilities. This information is further utilized to identify the potential issues in the company's current procedures, and to suggest for possible improvements. The research behind this thesis consisted of interviewing several NSN specialists and managers, as well as of a literature survey.

The linkages between the network element measurement capabilities and element vendor costs and benefits were found to be extremely complex and difficult to evaluate financially. However, some guidelines of a high abstraction level were defined for designing the measurement capabilities to satisfy various needs of the customers, as well as to avoid excess costs. Using these guidelines, some areas with potential room for improvement were identified in NSN's current processes, procedures, and policies; and some remedial actions were suggested.

Keywords: Network performance, network management, performance management, performance measurements

AALTO-YLIOPISTO TEKNILLINEN KORKEAKOULU	DIPLOMITYÖN TIIVISTELMÄ

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Verkon suorituskykymittauksilla on merkittävä rooli matkapuhelinverkko-operaattoreiden toiminnassa: Niitä voidaan hyödyntää esimerkiksi loppukäyttäjän kokeman palvelunlaadun arvioinnissa, potentiaalisten vikatilanteiden ennaltahavaitsemisessa, tai verkon suunnittelu- ja optimointiprosesseja tukevan informaation tuottamisessa. Näin ollen verkon kyky tuottaa operaattorille kattavaa, yksityiskohtaista ja täsmällistä suorituskykydataa on arvokas ominaisuus.
Kuhunkin verkkoelementtiin toteutettavien suorituskykymittausominaisuuksien määrittäminen optimaalisiksi, varsinkin taloudellisessa mielessä, tarjoaa kuitenkin suuren haasteen verkkoelementtien valmistajille: Ylimääräisten kulujen välttäminen samalla, kun asiakkaille (operaattoreille) pyritään tuottamaan todellista arvoa, on kaikkea muuta kuin suoraviivaista. Tämän diplomityön tarkoituksena on auttaa yhtä verkkoelementtien valmistajaa, Nokia Siemens Networksia (NSN), tunnistamaan erilaiset kustannukset ja hyödyt, joita sen tuotekehityksen tekemiin, mittausominaisuuksia koskeviin valintoihin liittyy. Näitä tietoja puolestaan käytetään potentiaalisten ongelmien havaitsemiseen yhtiön nykyisistä toimintatavoista, sekä mahdollisten parannusehdotusten laatimiseen. Diplomityöhön liittyvä tutkimustyö sisälsi useiden NSN:n asiantuntijoiden ja johtajien haastatteluja, sekä kirjallisuusselvityksen.
Riippuvuudet verkkoelementtien mittausominaisuuksien ja valmistajan kustannusten sekä hyötyjen välillä osoittautuivat erittäin monimutkaisiksi ja vaikeiksi arvioida rahallisesti. Joitakin korkeahkon abstraktiotason ohjenuoria pystyttiin kuitenkin määrittämään mittausominaisuuksien suunnittelemisesta siten, että erilaiset asiakastarpeet saadaan täytettyä, ja suurimmat ylimääräiset kustannukset vältettyä. Näitä suuntaviivoja hyödyntäen NSN:n nykyisistä toimintatavoista, prosesseista ja käytännöistä löydettiin joitakin puutteellisia osa-alueita, joihin ehdotettiin parannustoimia.

Avainsanat: Verkon suorituskyky, verkonhallinta, suorituskyvynhallinta, suorituskykymittaukset

Preface

I would like to express my gratitude to my instructor Kari Loukola and supervisor Jörg Ott, both of who always managed to find some time from their busy schedules to offer me some valuable guidance.

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Also, big thanks to my parents for their continuous support during the whole time of my studies, and to my girlfriend for her patience during my intense writing process.

Espoo, 10.5.2010

Jarno Lääveri

Contents

Abbreviations

2G	Second Generation (Mobile System)
3G	Third Generation (Mobile System)
3GPP	3rd Generation Partnership Project
3GPP2	3rd Generation Partnership Project 2
AM	Accounting Management
AND	Access Network Domain
ARPU	Average Revenue Per User
AS	Access Stratum
ATM	Asynchronous Transfer Mode
BML	Business Management Layer
BSC	Base Station Controller
BSS	Base Station Subsytem
BSS	Business Support Systems
BTS	Base Transceiver Station
CAPEX	Capital Expenditure
CC	Cumulative Counter
CM	Configuration Management
CN	Core Network
CND	Core Network Domain
CS	Circuit Switched
CSP	Communications Service Provider
DER	Discrete Event Registration
EDGE	Enhanced Data rates for GSM Evolution
EM	Element Management
EML	Element Management Layer
EMS	Element Management System
FCAPS	Fault, Configuration, Accounting, Performance, and Security (management)
FM	Fault Management
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio Service
GSM	Global System for Mobile communications
HLR	Home Location Register
HW	Hardware
IMT–2000	International Mobile Telecommunications–2000
IS–95	Interim Standard 95
ISO	International Organization for Standardization
ITU	International Telecommunication Union
ITU-T	International Telecommunication Union – Telecommunication
KPI	Key Performance Indicator
KQI	Key Quality Indicator
ME	Mobile Equipment
MMS	Multimedia Messaging Service
MSC	Mobile Switching Center

NAS	Non-Access Stratum
NBI	Northbound Interface
NE	Network Element
NM	Network Management
NM	Network Management
NML	Network Management Layer
NMS	Network Management System
NSN	Nokia Siemens Networks
NW	Network
O&M	Operations & Maintenance
OAM	Operations And Maintenance
OBS	Operations and Business Software
OPEX	Operating Expenditure
OSS	Operation Support Systems
PS	Packet Switched
PSTN	Public Switched Telephone Network
QoE	Quality of Experience
QoS	Quality of Service
R&D	Research & Development
RAB	Radio Access Bearer
RAN	Radio Access Network
RNC	Radio Network Controller
RNS	Radio Network Subsystem
RoI	Return on Investment
SAP	Service Access Point
SBI	Southbound Interface
SDU	Session Data Unit
SGSN	Serving GPRS Support Node
SIM	Subscriber Identity Muodule
SLA	Service Level Agreement
SM	Security Management
SML	Service Management Layer
SMS	Short Message Service
SRNC	Serving Radio Network Controller
SW	Software
TCO	Total Cost of Ownership
TE	Terminal Equipment
TMF	TeleManagement Forum
TMN	Telecommunications Management Network
UE	User Equipment
UED	User Equipment Domain
UMTS	Universal Mobile Telecommunications System
USIM	User Services Identity Module
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visitor Location Register

1 Introduction

In today's world of telecommunications business, where competition is fierce, margins are low, and all the participants are forced to constantly evolve, innovate, and at the same time cut costs wherever possible, it is increasingly important to properly identify the sources of expenditure and income in the first place. One area of telecommunications in which this kind of research has proven to be especially challenging is the area of network management: Network equipment vendors, operators, and service providers have only recently gained awareness of the scale of impact of network management related matters on their costs and revenues. The inefficiencies and drawbacks of the network management processes and systems are still often left unnoticed.

Even when a corporations understands that a problem exists, it might be difficult to identify its sources, and even more difficult to find a solution that would satisfy all the involved parties. This thesis is based on a research work conducted around one such issue: The overwhelmingly large and almost exponentially increasing number of performance management counters that are implemented to Nokia Siemens Networks' (NSN's) network elements. This problem was identified by NSN's Operations Support Systems (OSS) business line, which initiated this research.

This introductory chapter discusses the motivations behind the study, defines the goals and describes the structure of the thesis, and explains the research methods that were applied.

1.1 Motivation

NSN is one of the largest telecommunications hardware, software and services companies in the world [22]. The company provides end-to-end solutions to its customers: It assists the customer in the process of designing a network, supplies and installs all the required equipment and software, and also provides training of the customer staff.

As a large global organization that designs and produces a wide range of products and services of different nature, it is necessary for the company to be divided in several business units and departments. Although each of these sub-organizations has a carefully determined role, own business targets, and own management, the decisions made by one entity often affect wide range of other entities as well, which potentially leads to problems in some situations. One such problem is the effect of performance management functionality choices (made by network element R&D) on the workload of OSS business line which is responsible for the development of network management software.

The total number of network management attributes in NSN's network elements (including the performance management counters that are the subject of this research) already reached 460,000 in year 2008 (counting the cumulative number of the attributes, including all the versions of each attribute). This number was estimated to reach 800,000 in 2009 and 1.2 million by the end of 2010. It has been studied that each of these attributes required, on average, ten staff hours of work in the OSS business line alone, generating huge annual costs. Quite obviously, the benefits of providing such a large number of attributes to the customers are not perceived to offset these costs.

In addition to being a significant source of expenses, the large network management attribute base is perceived to have other drawbacks as well. Although it is believed that some of the customers would prefer to have extensive capabilities to manage their networks on a very low level — a positive effect of having plenty of attributes — most would probably prefer to have a clear high-level view, which would be less complicated to achieve with fewer attributes. Overall, the true customer preferences regarding this matter are not completely understood.

Based on these studies and perceptions, it seems obvious that significant financial benefits could be achieved by intervening the designing of new network management attributes.

1.2 Goals

The initial goal of this project was to find a concrete solution to the issue described above: The number of network management attributes needed to be reduced considerably, or at least the growth of the number of attributes needed to be halted. To narrow the scale of the study to make it suitable for a master's thesis work, one subset of the attributes, Performance Management counters, was chosen to be the primary target of research. The perception of the OSS Product & Solution Management is that most of these counters were basically duplicates of each other, and hence plenty of redundant work was done in designing, implementing and testing the counters with different names but the same functionality for different network elements. By inventing some sort of process or structure that would prevent the company from designing duplicate counters, considerable cost-savings were believed to be achieved: The target was set to reduce the total counter-related expenditures in OSS business unit by 50%.

However, some further research quickly indicated that the problem was far more complicated and would require much greater effort to solve than what is possible in the scale and scope of a single master's thesis. Duplicate counters, to the extent that they existed, did not appear to be a major issue, and removing them (if even possible) would likely not reduce the OSS workload considerably. Also, the number of different entities being somehow involved in the matter is huge, including all the customers in addition to the different organizations inside NSN, each having different interests and priorities as well as a different perception about the discussed issue and its sources. What was commonly agreed upon was that a problem actually existed: The performance measurement capabilities of NSN network elements were not optimally designed to serve the interests of the customers nor the company itself.

Therefore, the goals of the thesis needed to be redefined. The ultimate goals are listed below:

1. To identify and describe the ways by which implementation of network element performance measurement capabilities affect the vendor's profitability
2. To identify the issues in NSN's current procedures, processes, and policies in the light of the above results
3. To form a basis for future research by indicating where the greatest potential exists for improving the company's profitability.

1.3 Applied Research Methods and Structure of the Thesis

The main research work behind this thesis is an interviewing project conducted in summer 2009. The research consisted of interviewing a large number of NSN employees (from several different units) who are in some way involved with performance management counters or otherwise have some perspective on the studied issue. Also, to better understand the counter utilization in an actual network management environment, some performance management experts at Elisa (a Finnish mobile and broadband communications service provider) were interviewed. The complete list of the interviewees is presented in Appendix A. Besides the interviews, a literature survey was conducted and large amount of NSN internal written material was studied.

The first part of the thesis, consisting of Chapter 2 and Chapter 3, contains the theoretical background required to understand the research environment. Chapter 2 provides a high-level introduction to the third generation mobile telecommunications networks, network management, and telecommunications ecosystem. Chapter 3 concentrates on the core technical subject of the thesis, network performance management.

The second part, comprising of Chapter 4, incorporates the economic aspects to the technical discussion by analyzing the financial consequences that may follow from network element vendor's decisions concerning its elements' measurement capabilities. This part is mainly a result of the literature survey, with certain chapters also using information gathered through interviews as a reference.

The third part, comprising of Chapter 5, describes the identified issues in NSN's procedures, processes, and policies, that potentially lead (from the economic perspective) to less than optimal counter implementation decisions. Conclusions made in the previous part of the thesis are applied to form suggestions for possible improvement actions. This part of the thesis relies heavily on the results of the interview research.

Chapter 6 summarizes the conducted research and analyzes the validity of the results and applied methods.

Figure 1 illustrates the information sources and work phases of the research.

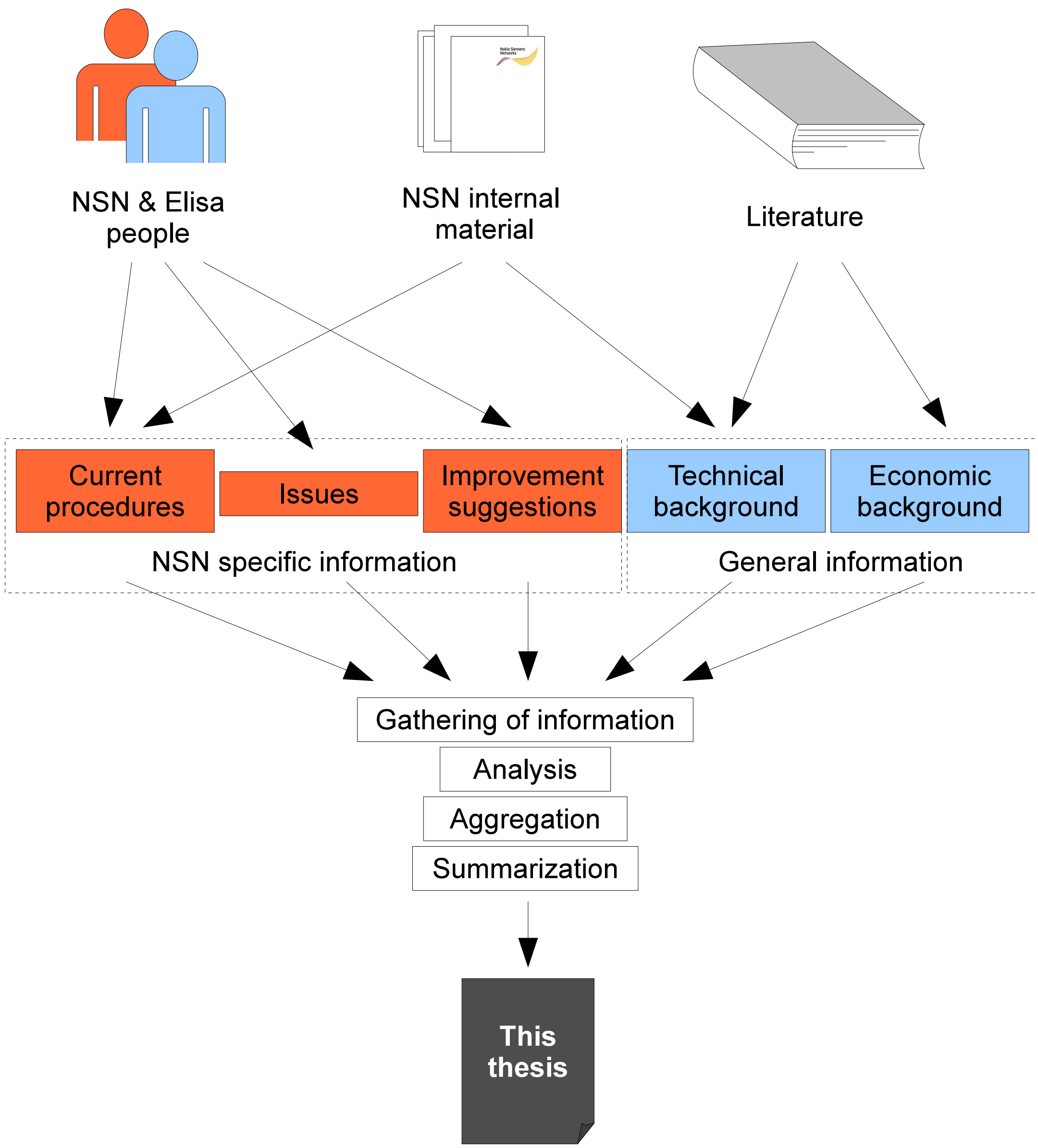

Figure 1: Information sources and work phases of the research.

2 Basics of 3G Mobile Telecommunications

This chapter introduces the technical and economic concepts that are important to be adopted before exploring the research part of the thesis. The following matters will be discussed:

- Evolution and standardization of mobile telecommunications networks
- Basic structure and components of a modern mobile telecommunications network
- Network management concepts, procedures, and systems
- Different roles and business relations in mobile telecommunications ecosystem
- Concepts of quality and performance

2.1 History of 3G Networks and Standardization

Public mobile radio systems have evolved dramatically all over the world during the last couple of decades. However, the different regions of the world, most specifically Europe, United States and Japan, each handled the development of the first two generations of their mobile technologies in a proprietary manner, resulting in a profusion of systems incompatible with each other. [4], [5]

Demand for a different approach to the design of the next generation of mobile telecommunications systems was generated by the mobile users' desire to be able to use the same handsets and access the same services everywhere in the world - as well as the naturally increasing demand for higher data rates and spectrum efficiency, which together would enable more advanced mobile services such as video calls and Internet access.

However, to protect the network operators' large investments in existing telecommunications infrastructure, as well as to provide seamless transition between the generations, it was important that the existing network technology could be used as a basis for the next generation systems. Due to the diversity of second generation (2G) technologies around the world, a whole range of different third generation (3G) systems and migration concepts were defined by the International Telecommunication Union (ITU). Close coordination of the development of these technologies should guarantee terminal equipment compatibility with each. [5]

Performance, compatibility, functional and other requirements of 3G networks were defined in the ITU's family of standards, referred to as International Mobile Telecommunications-2000 (IMT-2000). However, the actual standardization work was delegated to the 3rd Generation Partnership Project (3GPP) which was established to coordinate the efforts of several standardization institutes. Standards of the 3GPP cover radio access and core network infrastructures and system architectures, radio interfaces, network management and also some user equipment functionality. [5], [26]

The 3G system standardized by 3GPP, named Universal Mobile Telecommunications System (UMTS), is based on the European 2G system, Global System for Mobile communication (GSM) and its extensions, General Packet Radio Service (GPRS) and Enhanced Data rate for GSM Evolution (EDGE). Hence, a parallel partnership project was established to develop the specifications of CDMA2000, a 3G system based on IS-95 2G technology used mainly in America. This partnership project was named 3GPP2. [27], [28]

2.2 Network Technology

A basic structure of a mobile telecommunications network is depicted in Figure 2. The user device, equipped with a Subscriber Identity Module (SIM) card, has access to the core network (CN) via a radio access network (RAN). Core network provides the customer a variety of services and connections to other networks, such as the public switched telephone network (PSTN) and Internet. Networks are built of network elements (*"a discrete telecommunications entitiy which can be managed over a specific interface"* [15]) and connections between them. [5]

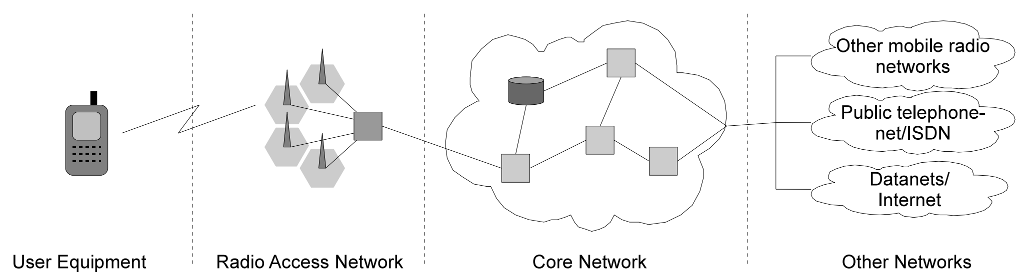

Figure 2: Basic structure of a mobile telecommunications network

This section describes the basic architecture of a UMTS network and functionalities of its main components.

2.2.1 High-level Architecture of UMTS Network

The physical architecture of UMTS can be divided into domains, as shown in Figure 3. Term "domain" here refers to *"the highest-level group of physical entities"* [15]. The User Equipment Domain (UED) is formed by a mobile terminal together with a User Services Identity Module (USIM), which is physically incorporated into a SIM card and contains all the encryption and authentication information of the user. The Access Network Domain (AND) provides the user equipment with access to the network. The Core Network Domain (CND) is an integral platform that consists of different transport networks linked together over network gateways. CND is further divided into three domains: The serving network, which provides the core network functions locally to the user; the home network, which maintains static subscription and security information; and the transit network, which implements the interface to the other network in case the remote party (or home network) is not linked to the serving network. The interfaces between the domains (indicated with dashed lines in Figure 3) are defined by 3GPP to guarantee compatibility between equipment produced by different vendors. [8], [4]

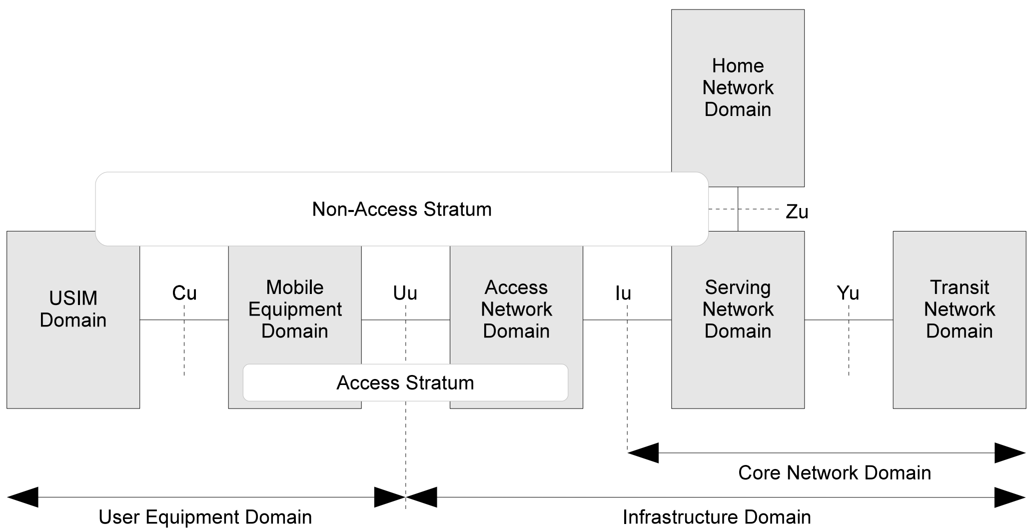

Figure 3: UMTS Architecture: Domains, strata, and interfaces [8], [4]

A UMTS network can also be divided into two strata (also shown in Figure 3): Access Stratum (AS) and Non-Access Stratum (NAS). Stratum refers to *"grouping of protocols related to one aspect of the services provided by one or several domains"* [15]. AS contains the communication protocols used between the user equipment and the access network, and NAS the protocols used between the user equipment and the core network. [8]

2.2.2 Network Elements

Figure 4 shows the basic structure of a UMTS network's access plane. As mentioned in Section 2.1, UMTS is based on GSM and its extensions GPRS and EDGE, and it was designed to reuse the infrastructure of these preceding technologies as extensively as possible. In practice, this means that the same core network elements can be used to provide UMTS services, but new 3G Radio Network Subsystems (RNSs) have to be installed besides the existing 2G Base Station Subsystems (BSSs) to provide the network users with UMTS support.

As can be seen in Figure 4, UMTS Terrestrial Radio Access Network (UTRAN) consists of Radio Network Subsystems (RNSs), each containing one Radio Network Controller (RNC) and one or more 3G base stations (Node Bs). Corresponding

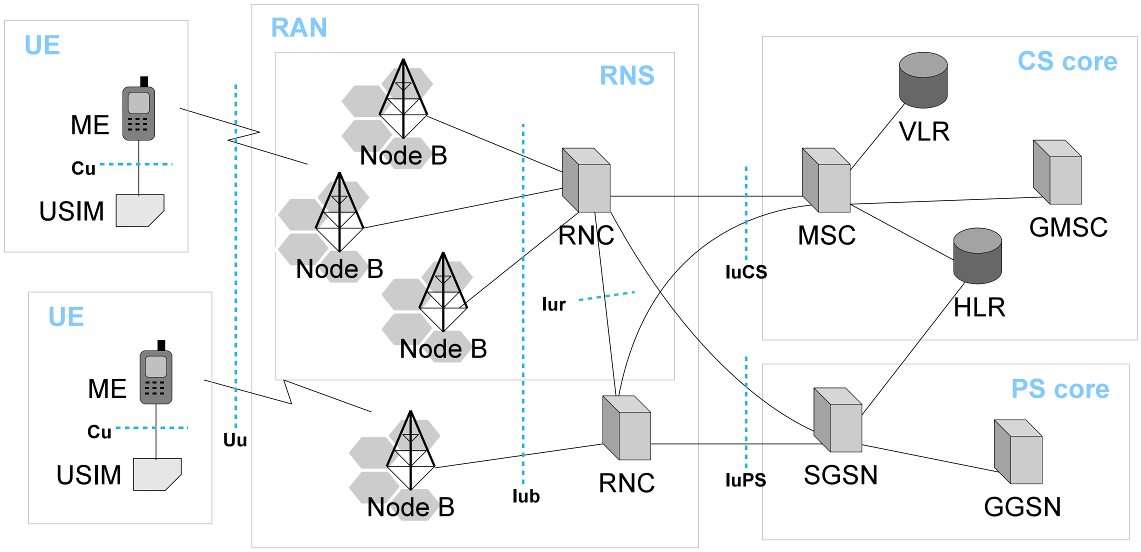

Figure 4: Architecture of the Access Stratum [4], [5]

elements in GSM/GPRS network would be Base Station Controller (BSC) and Base Transceiver Stations (BTSs).

RNC is the central node in RAN, essentially being responsible of the following tasks: Call admission control, radio resource management, radio bearer set-up and release, code allocation, power control, packet scheduling, handover, serving RNS relocation, encryption, protocol conversion, ATM switching, and operation and maintenance. RNC is connected to an MSC over the IuCS interface and to an SGSN over the IuPS interface. [4]

Node B, the base transceiver station in UMTS networks, only has minimum functionality. It is connected to the user equipment over the Uu (air) interface and to the RNC over the Iub interface. Node B converts the radio interface signals into data streams and vice versa. One Node B typically serves three or six cells.

The core network (shared by 2G and 3G) consists of two parts: Circuit Switched (CS) core and Packet Switched (PS) core. The most important elements of the CS core are Mobile Switching Center (MSC), Home Location Register (HLR), and Visitor Location Register (VLR). In the PS core, the main elements are Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN).

MSC is the element responsible of routing circuit switched traffic in 2G and 3G networks, in a similar manner to the traditional telephone exchanges — the main difference being that the MSC also needs to support user mobility, and, therefore, to handle localization and handover procedures. An MSC that provides the mobile network with interfaces to the PSTN and various other networks is referred to as Gateway MSC (GMSC).

HLR and VLR are databases containing all the required authentication, authorization, and service related information (such as the phone number) for each subscriber.

Each subscriber's data, along with a reference to the subscriber's current location, is stored in one associated HLR. VLR, on the other hand, stores a local (temporary) copy of this same data for all the users currently located in its area, to avoid overloading the central database.

SGSN in PS core functionally corresponds to a combined MSC and VLR in CS core, performing packet routing and mobility management tasks as well as containing a local copy of subscriber information. Gateways to the other packet switched networks, such as the Internet, are offered to the mobile network by GGSN. [5]

2.3 Network Management

Communications networks are complicated systems that cannot simply be built, connected and left running without any attention: They also require continuous management. This section defines the concept of network management, and discusses the matters involved in managing a telecommunications network. Network Management Systems and processes are also introduced.

2.3.1 Definition and Principles of Network Management

A. Clemm [1] defines network management with the following sentence:

> *"Network management refers to the activities, methods, procedures, and tools that pertain to the operation, administration, maintenance, and provisioning of networked systems."*

Another good definition is offered by Saydam and Magedanz [13]:

> *"Network management includes the deployment, integration, and coordination of all the hardware, software, and human elements to monitor, test, poll, configure, analyze, evaluate, and control the network and element resources to meet the real-time, operational performance, and Quality of Service requirements at a reasonable cost."*

In simple words, network management consists of all the tools and actions that are required to keep a network up and running. These tools and actions are classified by International Organization for Standardization (ISO) into five different categories: Fault, Configuration, Accounting, Performance and Security. This management reference model is commonly referred to as FCAPS, an acronym formed by the names of the categories. The following subsections describe the concepts, respectively based upon the references given at the end of each section's first paragraph.

Fault Management (FM)

The purpose of fault management is to detect fault conditions in the network and respond to them as quickly and effectively as possible to minimize their impact on the QoS. Fault information is logged and used for fault diagnosis and proactive fault management. [1], [3], [14].

Whenever a network element recognizes an unexpected event with a negative influence, such as a malfunction in any of its components, overheating, communication failure or software outage, it creates an alarm — an unsolicited message sent to the management system. Management system collects, stores and visualizes received alarms. In some cases the fault situation can be effectively isolated and corrected solely using the management tools, but sometimes alerting operating personnel and actual site visits are required.

The number of alarms received by a management system every minute in a nationwide communications network is typically so enormous, that handling each alarm individually would overload management personnel. Hence, the alarms are automatically filtered and correlated by management system, exploiting the fact that several alarms are often caused by a single fault. Filtering removes unimportant and redundant alarms, while correlation aggregates related alarms to provide the managing personnel with a clear picture of the fault condition. (In practice, some manual work is also required in alarm filtration and correlation.)

After the filtration and correlation procedures, each remaining alarm is classified by its severity level and needs to be acknowledged by management personnel. If the problem behind an alarm is severe, in sense that it requires human intervention or would likely affect the operators capability to deliver service, a trouble ticket is created so that the network provider organization can keep track of resolution of the problem. The trouble ticketing procedure also applies to problems not detected by network elements, but instead reported in by customers.

Configuration Management (CM)

The task of Configuration management is to initialize and modify network equipment configurations to match service requirements, keep track of connected devices, upgrade software images of devices when necessary, and maintain backups of configurations. [1], [19].

After the initial configuration process of an installed network, continuous re-configuration of network parameters is required to satisfy both long-term and short-term requirements of the network operator. In a short-term view, re-configuration is required to restore stability of network after some of its equipment or software have been modified. In a long-term view, network needs to be enhanced to meet performance, capacity and QoS requirements of the operator and its customers. New services can be provisioned and old ones can be pruned, traffic can be manually re-routed, new devices can be installed, etc.

Configuration management is an essential part of network management also in sense that the other management functions depend on it: For example, fault and performance management would be of little use were it not possible to re-configure network elements in purpose of minimizing effects of a fault or optimizing performance of network. Also, accurate knowledge about the network's configuration is often required by the other management functions.

Accounting Management and Security Management (AM and SM)

Accounting management consists of gathering usage statistics of services and charging users based on these statistics, controlling user access to the network, and logging of this usage-related data. [1], [20].

The task of security management is to secure the telecommunication service, network and data from various threats, such as hacker attacks, spread of worms and viruses, and malicious intrusion attempts. Also, the network management itself has to be secured from unauthorized access.

Performance Management (PM)

Performance management consists of measuring network performance; logging and processing measured data; and utilizing measured data to improve network's QoS and optimize its resource usage. Since performance management is strictly related to the subject of this thesis, it is analyzed in further detail in a dedicated chapter (Chapter 3).

2.3.2 Operations Support Systems

All the systems (software and hardware) that a CSP uses to manage its network are together referred to as Operations Support Systems (OSS). Figure 5 presents a possible hierarchical structure of the OSS, complying with the Telecommunications Management Network (TMN) model defined by ITU-T (An international telecommunications standardization organization).

On the lowest layer of the structure are the network elements. Elements typically comprise low-level management functionality, such as conducting measurements, generating alarms, and executing configuration changes. Each element can (but does not need to) be assigned to an Element Management System (EMS), which is concerned with managing the functionality of one element. Also several elements of same kind may share a single EMS, but the EMS treats each of these elements as individual. All the EMSs of the network, as well as the elements with no EMS, are connected to the Network Management System (NMS), which handles the network-wide management decisions and thus also takes into account all the connections between the elements. [34]

EMSs and NMS, although functioning at different layers in this hierarchy, are not necessarily different systems. For example, Nokia NetAct can act as an EMS, as an NMS, or as a sub-NMS (managing multiple different elements below the NMS). Each management system can be connected to lower-level management systems

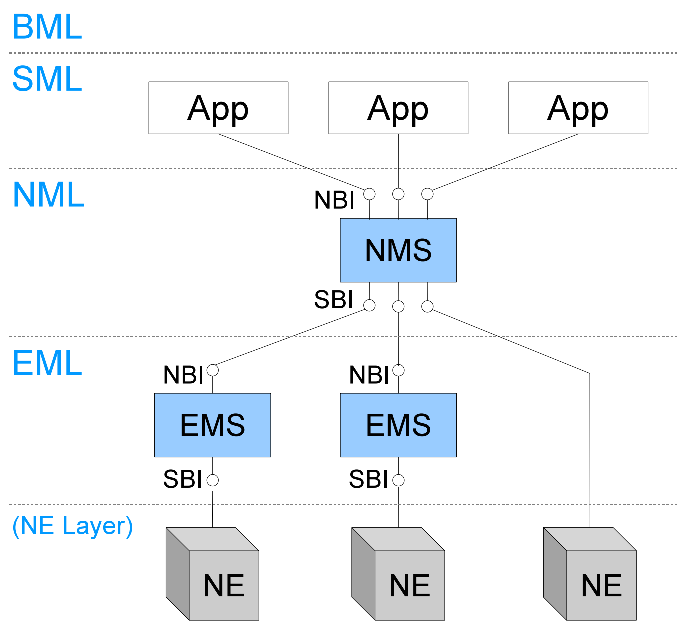

Figure 5: Hierarchy of Operations Support Systems.

(or network elements) through South-Bound Interfaces (SBIs) and to higher-level management systems through North-Bound Interfaces (NBIs).

The Element Management Layer (EML) formed by the EMSs, and Network Management Layer (EML) formed by the NMS, are two of the four layers in the TMN model. Above the NML is the Service Management Layer (SML), which comprises of the systems handling the definition, administration and charging of services. For example, the monitoring, reporting, configuration and optimization applications are part of the SML. Above the SML is the Business Management Layer (BML), which ties the network related aspects to the CSP's business activities. [35]

Systems functioning on the BML, as well as some of the SML and NML components, are typically categorized as Business Support Systems (BSS) instead of Operations Support Systems.

2.4 Different Roles in Mobile Telecommunications Ecosystem

The previous sections of this chapter have described the technology and operations required in providing communications services to end-users. This section adds a business perspective to the discussion by specifying the different roles that entities involved in this process may have as well as the relations between them. All these entities that enable or otherwise affect the existence of the service, together with the service's users and an environment in which it is used, form a communications ecosystem.

Figure 6 is a simplified version of the one presented by Kaleelazhicathu et al. [40]. It depicts the different roles and relationships that exist in communications ecosystem.

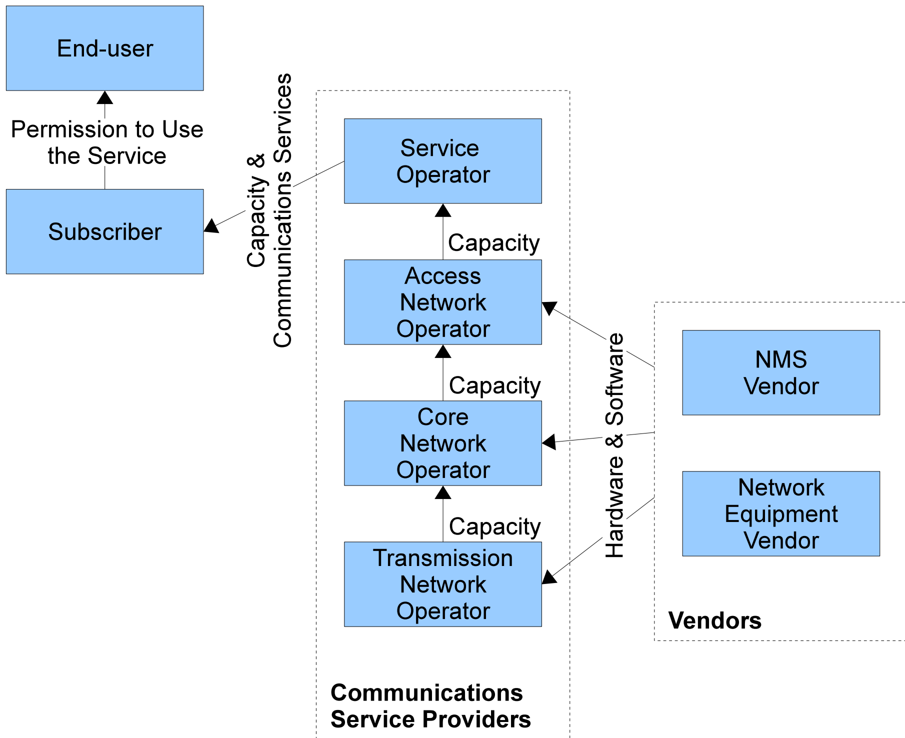

Figure 6: Communications ecosystem roles and relations (only those that are relevant to the subject of this thesis).

The difference between the terms end-user and subscriber is that the end-user is a person who ultimately consumes the service, whereas the subscriber is an entity that pays for the service and usually has the power to choose the service and make the decisions concerning the continuation of service usage. The subscriber may be an individual person (consumer) in which case the same person is often at the same time the end-user who uses the service to satisfy his or her communication needs. The subscriber may also be a company (business subscriber) that typically uses the service as a tool in the process of creating value to its customers. In that case, end-users are usually the employees of the company.

Network operators own and administrate their networks. Transmission network operators provide transmission services to core network operators, which in turn provide capacity to access network operators. Service operators do not own network infrastructure, but purchase capacity from access network operators and use it to offer communications services to subscribers. Service operator also handles subscriber, accounting, and security management.

Companies that produce hardware and software required to construct and maintain networks are referred to as vendors. Network operators are therefore customers of the vendors. [40]

One company may, of course, play multiple roles in this value network: It is common, for example, that an equipment vendor also produces network management software, and that a network operator offers communications services to subscribers, acting as a service operator. Although the number of roles that a single company may absorb is not limited by any means, in practice at least one clear division can be made: Companies that produce network equipment or software, and companies that operate the networks. In this thesis, the former group will be referred to as vendors and the latter as the Communications Service Providers (CSPs). CSP could also be defined here as any company that provides services to either a subscriber (consumer or business) or another service provider by utilizing the network technology and/or software produced by vendors.

2.4.1 Operator Business

This subsection briefly describes the different business related matters in telecommunications ecosystem as well as the financial concepts required to be understood later in the thesis.

The purpose of any company is to create value to it's shareholders, which can generally be achieved through satisfying a specific need or needs of the customers by sufficiently cost-effective means. As the customers pay for a company's goods or services, the company receives revenues (R). To produce the goods or services, the company incurs expenditures (E). The difference between the company's revenues and expenditures determines the company's profits (P):

$$P = R - E \tag{1}$$

The company's expenditures can be classified into two categories: Operating Expenditures (OPEX) and Capital Expenditures (CAPEX). OPEX refers to the cost of producing the good or service; for a CSP, the cost of network management, sales, marketing, billing and customer care; interconnection and roaming fees paid to other CSP's; and the general and administration costs. CAPEX, on the other hand, refers to the cost of investments (typically in fixed assets) by which the company makes it possible to produce the good or service. Typical CSP's CAPEX is mainly formed of the cost of network equipment and their upgrades. [39]

Revenues of the CSP can be expressed as a product of its Average Revenue Per User (ARPU) and the number of its subscribers (which can be further factorized into market share and penetration). Equation 1 can now be expressed as follows:

$$P = n \times ARPU - (CAPEX + OPEX) \tag{2}$$

This formula will be used as basis of CSP profitability discussions in the coming sections.

2.5 Quality and Performance in Telecommunications

Quality and performance are ambiguous terms and they have various definitions and interpretations within different contexts and publications. This subsection discusses these concepts in the context of telecommunications and defines the manner in which they are used in this thesis. Also, the quality related features of UMTS are described.

2.5.1 Network Performance

Network performance describes the ability of a network to provide services to the end-users. It can be determined (for example) with the following three factors: Quality of Service (QoS), capacity, and coverage.

QoS describes the quality of a connection that the network provides. In packet switched data networks, typical QoS attributes are bit error rate (proportion of transferred bits that have altered during the transmission) or packet loss rate, latency (time it takes for a data packet to travel through the network) and jitter (variance of latencies of data packets). For circuit switched voice networks, typical QoS attributes are signal-to-noise ratio, drop call rate, and latency. [9], [10]

Capacity (or throughput) of the network determines how much traffic the network can transfer per time unit. Larger capacity enables higher data transfer speeds with the same number of users, or larger number of users with same data transfer speeds. In circuit switched networks higher capacity enables larger number of simultaneous calls.

Coverage determines the geographical extent to which the network is capable to provide the service; the larger the area in which the service is available, the better the coverage.

It is important to note that these three performance attributes can typically compensate each other, at least in data networks. For example, the reduction in QoS can be compensated with increased capacity (and the other way around): If the bit error rate increases such that the share of bits required for error correction rises from 10% to 25%, a 20% increase in throughput enables the same number of correct bits to be transferred per time unit (since $(1-0.25)x \times (1+0.20) = (1-0.10)x$). In a similar manner, the coverage of the service can usually be extended by improving the capacity, since reaching the edge of coverage becomes apparent as decreased connection quality and throughput. [12]

Different applications have different requirements and preferences regarding the performance attributes: Some are tolerant to relatively high amount of errors but intolerant to latency and jitter, some tolerant to delays but require absolute error-free transmission. Table 1 provides some examples of different applications and their requirements.

Table 1: QoS requirements of some applications

Application	Throughput requirement	Error sensitivity	Delay sensitivity	Jitter sensitivity
Voice call	low	low	high	high
SMS	low	high	low	low
Web browsing	low	high	medium	low
Downloading files	high	high	low	low
Video streaming	high	low	low	high
Interactive gaming	low	high	high	high

2.5.2 Quality of Experience

The increasingly common practice in telecommunications is to distinguishing the user-perceived quality, Quality of Experience (QoE) from the technical quality (QoS). Quality of Experience is the kind of quality that determines end-user satisfaction and therefore directly affects the CSP's revenues, whereas QoS should only be seen as a tool that the CSP uses to provide QoE to its customers. That is not to say, however, that the QoE would only be affected by network QoS. Typical components of the QoE are presented in Figure 7. These include:

- User's current mood and personal expectations regarding the service
- Hardware and software quality of the user's Terminal Equipment
- Performance of the CSP's network (affected by every network element, link, and protocol layer along the transmission path)
- Performance of the (possible) external networks along the transmission path (transmission networks and B-subscriber access network)
- Quality of the B-subscriber's Terminal Equipment hardware and software, or, in the case of content services, quality of the content.

Typical attributes that can be used to evaluate the QoE are usability (how convenient the service is to use), accessibility (how often and how widely the service is available and how long is the setup time), retainability (how often the connection is lost) and integrity (how noticeable are the technical QoS impairments such as delay, jitter and data loss during the data transmission). [10]

Because of its subjective and qualitative nature, QoE is obviously difficult to measure. Besides, due to the complexity of networks (possibly very large number of nodes, links, and protocol layers along connection path), measuring even the network performance contribution to QoE alone is difficult (this problem is discussed

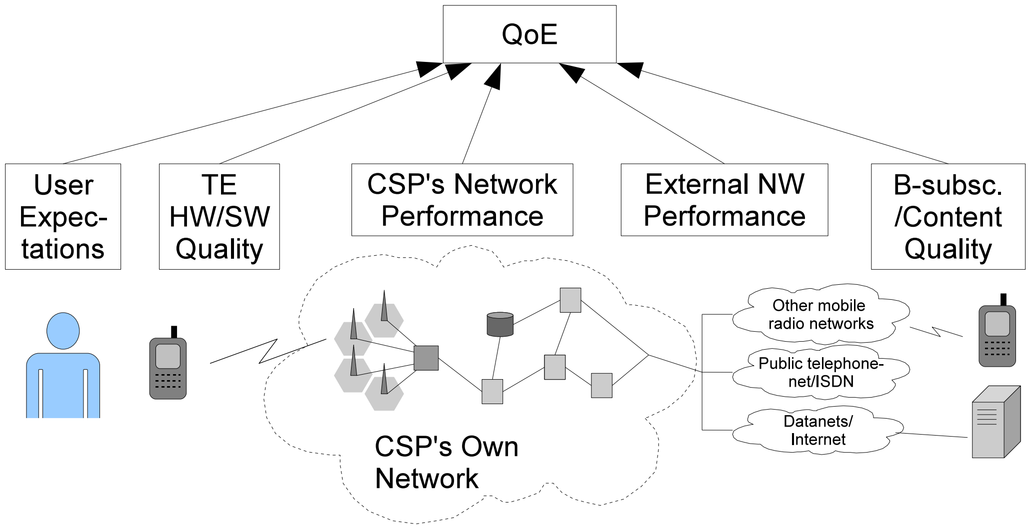

Figure 7: Components of QoE

in detail in Chapter 3). However, it is crucially important for the CSP to be able to measure QoE, as its revenues are highly dependent on it. Chapter 4 further analyzes the importance of quality and quality measurements in the context of CSP and NE vendor profitability.

2.5.3 QoS Provision in UMTS

Unlike the first and second generation mobile communications systems, UMTS is able to take into account the different network performance requirements of different applications, at least to some extent. The traffic can be classified into four different QoS classes, primarily based on its delay sensitivity:

- Conversational class — for the most delay sensitive traffic, such as voice calls
- Streaming class — for traffic that is not as sensitive to delay, but is sensitive to delay variation (jitter); for example video streaming
- Interactive class — for traffic that is not very delay sensitive, but requires low bit error rate; for example web browsing
- Background class — for transferring data that the destination is not expecting within certain time (but typically requires low bit error rate), such as email messages

Besides the traffic class, UMTS bearer service is specified by several other QoS attributes as well. These are Maximum bit rate, Guaranteed bit rate, Delivery order, Maximum SDU size, SDU format information, SDU error ratio, Residual bit error ratio, Delivery of erroneous SDUs, Transfer delay, traffic handling priority, Allocation/Retention priority, Source statistics descriptor, and Signaling indication. (All bearer attributes are not relevant for all QoS classes.)

QoS class and values for other QoS attributes can be requested by terminal equipment (at either end of the connection) within the limits of the QoS Profile in the subscriber's UMTS subscription and capabilities of the network. However, it is important to note that the QoS class and attributes only apply within the UMTS network; possible other networks (such as Internet or GSM network) along the transmission path do not recognize them.

(Quality of Service concept and architecture are specified in 3GPP TS 23.107 [21], which was used as a reference throughout this subsection.)

2.6 Summary

This chapter has discussed the modern mobile telecommunications from both technical and economic aspects. Brief history of the (recent) evolution of the networks was provided, together with a description of the involved standardization procedures. Architecture of a 3G network, functionalities of the different network elements, and network management categories and systems were described. Economic matters related to providing communications services and the concepts of quality and performance were also introduced.

This background information provides a context for the research of the thesis and will used as a basis for the technical and economic discussions of the rest of the chapters.

3 Performance Management

Performance management is the network management category of the FCAPS model that consists of measuring network performance; logging, processing and visualizing measurement data; and utilizing the gathered information to improve user-perceived Quality of Experience and to optimize resource usage in the network.

This chapter describes the different methods of gathering performance data, its properties and classifications, processing and utilizing performance data, as well as the general purpose and goals of performance management.

3.1 Gathering of Performance Data

A number of different methods are available for the CSP to gather data about the performance of its network:

- Using direct customer feedback (QoE issues reported in by customers)
- Active QoE monitoring
- Passive performance monitoring

Although customer feedback provides concrete information about the QoE issues in the service, it cannot be considered as a desirable source of performance data due to its re-active nature: The damage is already done when a user notices the degradation in QoE, and some of the potential revenues might already be lost.

Active QoE monitoring methods imply generating traffic in a controlled manner, and analyzing the involved network elements' performance [10]. This can be done as statistical sampling in a semi-automated manner with the help of probes in network equipment and/or agent software in user devices; or by trials method, which implies actually "going to the field" with measurement equipment.

The active approach for QoE monitoring has several advantages: It is possible to gather service-level, end-to-end information about the QoE; even QoE of the other CSPs' networks can be examined; and the functionality of the network can be tested even when no user-generated traffic exists (for example, due to the early state of the network). However, because the data that is gathered by active monitoring methods is only statistical and does not provide complete picture of network performance, active monitoring should only be concerned as a complementary method to use with passive monitoring. [10], [9]

Passive performance monitoring, as opposed to active QoE monitoring, does not imply generation of traffic to be measured. Instead, performance data is collected from the network in a non-intrusive manner. In fixed networks, CSPs have been able to get an end-to-end view of the QoS by installing monitoring equipment at the customer Service Access Points (SAPs). However, it is not possible with today's technology to implement QoS monitoring in the same extent for mobile terminals.

Therefore, the most significant source of the performance data are the CSP's own network elements. [10], [9]

Although passive performance monitoring enables the generation of extensive amounts of detailed performance data with procedures that can be highly automated, it also has its disadvantages compared to the active methods: The produced data is very technology oriented and each measurement only concerns one component of the network, complicating the measuring of end-to-end performance. This issue is further analyzed in Section 3.4. Also, the extensive amount of performance data may cause various issues, which are discussed in detail in Chapter 4. Nevertheless, passive monitoring of network element performance typically is the CSP's primary method of gathering input data for network operation, planning, and optimization processes.

Optimizing the passive performance measurement functionality of network elements is the core topic of this thesis. Therefore, the concept of performance data under this discussion refers solely to the data collected by passive monitoring from network elements.

3.2 Passive Performance Monitoring

Network performance can be observed from different perspectives. As discussed in Section 2.5, it is often described in terms of capacity, coverage and QoS. These attributes represent the network point of view. The user of a communications service typically evaluates the network performance in terms of accessibility (ability to access the network), retainability (ability to retain connection), quality (how flawlessly the service works) and connection speed (how quickly the service responds and how fast is the data transferred).

Passive performance measurements, however, can only be conducted on network element level, which places some limitations on what kind of traffic attributes can be measured; each element only sees the traffic that passes through it (or is otherwise handled by it), not the entire connections. Task of an individual network element is to obtain performance data from this traffic; aggregation of the data and calculation of the actual performance indicators is conducted on the higher network management levels.

Performance data can be obtained in a number of different forms, of which the *cumulative counter* is distinctly the most common one. Each countable event, such as the reception of a certain signaling message, can be assigned a counter which counts the occurrences of that event. Whenever the network element notices an event to which a counter has been assigned, it triggers the counter (increments the counter's value by one).

Other possible forms (defined by 3GPP) of obtaining measurement data are *status inspections*, which sample the network element internal counters (maintained for resource management purposes) at predetermined rates; *gauges*, which produce low and high tide marks of determined variables that can change in either direction;

and *discrete Event Registrations (DERs)*, which capture data related to particular events [16]. (In this thesis, the cumulative counters are considered as the only form of obtaining measurement data, for simplicity. However, all the same concepts and clauses are applicable to the status inspections, gauges, and DERs as well, although not explicitly mentioned.)

Measuring the network performance is conducted as *measurement jobs*. Measurement jobs can be created, deleted, modified, suspended, and resumed by the element manager. Each measurement job is characterized by a set of one or more *measurement types*, all pertaining to a specified set of *measured resources* and sharing the same *granularity period* and *measurement schedule*. The measurement type defines what exactly is the property being measured. Measured resource is a physical or logical entity such as network element, component of an element, or radio channel, to which the measurement type pertains. The granularity period defines the time interval between the measurements (collections of measurement results), typically in the range of 5 to 60 minutes. The measurement schedule determines the time frames, each consisting of one or more granularity periods, during which the measurement job is active. [16]

After each granularity period of an active measurement job, an actual measurement is conducted: The measurement results (i.e. the performance data) are collected by reading the value of each involved counter (after which the counters are reset). These results are stored into the network element's internal database as a scheduled report. From there, the report can be transmitted to the EM (or NM) either by request; or automatically, according to a predetermined schedule. [16]

Figure 8 presents an abstract example of how the counters work and how measurement data is generated. The measurement job in this example would contain two measuring types: number of occurrences of event x and number of occurrences of event y. The granularity period would be three time units.

Measurement results usually have to be processed and aggregated — either on the EM or NM layer — before they they can be utilized for management purposes. The most important product of this processing and aggregation are Key Performance Indicators (KPIs), which are considered to be *"primary metrics to evaluate process performance as indicators of quantitative management, and to measure progress towards enterprise goals."* [18]. 3GPP has defined several KPIs for UMTS and GSM networks, along with formulas by which they are obtained from performance measurements. Proprietary KPIs may also be defined by CSPs and vendors. An example of the calculation of KPIs from measurement results is presented in Subsection 3.4.2.

3.3 Utilization of Performance Data

The ultimate goal of performance management is to provide the CSP with means to retain customers and prevent customer churn by fulfilling end-user service needs in terms of quality, reliability, responsiveness, availability, and diversity. Two different approaches are actively applied by every network-owning CSP to fulfill these tar-

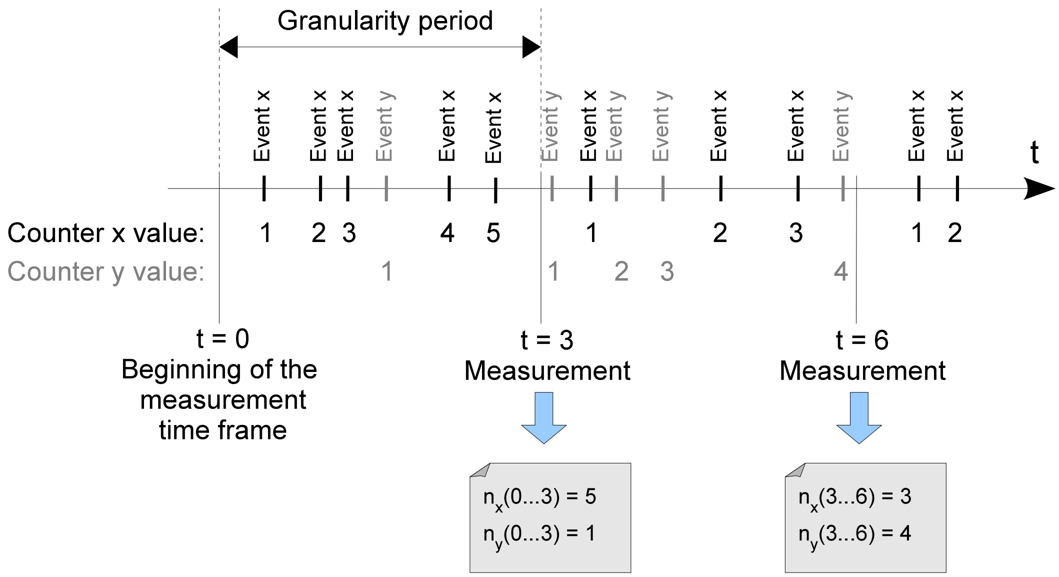

Figure 8: Counting the number of occurrences of each event with a cumulative counter, and collecting measurement data.

gets. These approaches are referred to as network operation and network planning (including optimization). Both are indispensable factors of the CSP's success and require performance data as an input.

The purpose of network operation is to enable the maintenance of at least a sufficient level of network performance (capacity, coverage, and QoS) in short term. This includes the real-time (or almost real-time) monitoring of network performance indicators to identify the possible trouble situations in as early state as possible — preferably before the customer notices an issue in service performance — and taking the corresponding actions. Besides, network operation involves monitoring the SLA compliance (in both directions) by verifying that network performance satisfies the agreed levels.

Network planning and optimization, on the other hand, is responsible of developing the network to match the long-term customer needs in as cost-effective manner as possible. Performance data from existing networks is typically utilized in the planning of new networks or network extensions to dimension the capacity, coverage, and QoS requirements. In network optimization, performance data is utilized to indicate both the bottlenecks and (unintended) redundancies in the network to enable improving the balance of the infrastructure. For example, high congestion levels suggest that further investments in equipment or rerouting of traffic may be required. On the other hand, if the utilization level of a certain component of the network is low, better efficiency could probably be achieved by resource reallocation.

Besides these, performance data can be utilized for various other purposes as well:

- Analyzing the causes of faults that have occurred; investigating the sources of problems (input data for Fault Management).

- Verification of the network configuration and evaluation of the changes that have been conducted (input data for Configuration Management).

- Producing data for accounting, administration, sales, marketing, and product management organizations.

3.4 Measuring the Quality of Experience

As explained in the previous section, CSPs' compulsion to manage network performance inherits from the end-user quality needs. However, the user perception of network performance — as a part of the QoE, as discussed in Subsection 2.5.2 — is typically affected by every protocol layer and network element in the connection path and is often expressed in service-specific, subjective, qualitative terms. On the contrary, performance data produced by a network (as explained in Section 3.2) is quantitative and technology-specific in nature, and typically each measurement only concerns a single network element, connection, or component of an element. Therefore, the relations between network performance characteristics and end-user quality perceptions need to be understood in order to be able to utilize performance data for quality management purposes. [9], [29]

However, mapping of the parameters that users use to express QoE to the parameters that CSPs use to characterize network performance has become one of the major challenges of performance management. It is particularly difficult to determine the correlation between user experience and network measurements in the area of packet switched data services, which are constituting an increasingly large portion of the overall traffic carried in todays telecommunications networks.

For the circuit switched voice services, it is still relatively straightforward to match the issues indicated by performance measurements to those experienced by end users (and vice versa): High bit error rate induces poor voice quality, transmission delay can be noticed as delay in speech, and losing the radio signal to the transceiver station (even temporarily) usually results in a dropped call.

For the packet data services, high protocol stacks as well as effective error correction and retransmission capabilities are required to hide network technology from the users, and to enable the diversity of packet data services to function on the same physical network with maximum QoS. However, they also effectively hide the causes of performance degradation from the end-user. For example, when a mobile Internet user notices deceleration in the speed at which a web page loads, the cause might be a congestion in any of the routers along the connection path, congestion in the radio interface, a weak (or even temporarily lost) signal to the transceiver station, internal hardware or software based issue in the mobile terminal, or something else. Also, the other way around, a performance issue identified from the network perspective may have totally different influences on the user experience depending on the characteristics of the service that is being used. For example, a high packet loss rate may cause serious problems for audio/video streaming, whereas email and Multimedia Messaging Service (MMS) remain virtually unaffected. [9], [10]

One of the most significant contributors to the research of managing user perceived network quality is the TM Forum (in full: TeleManagement Forum), having developed a methodology for identifying service quality measurements or Key Quality Indicators (KQIs) and deriving the related network metrics. The performance indicator hierarchy, presenting relations between measurements, KPIs and KQIs, is depicted in Figure 9. [29].

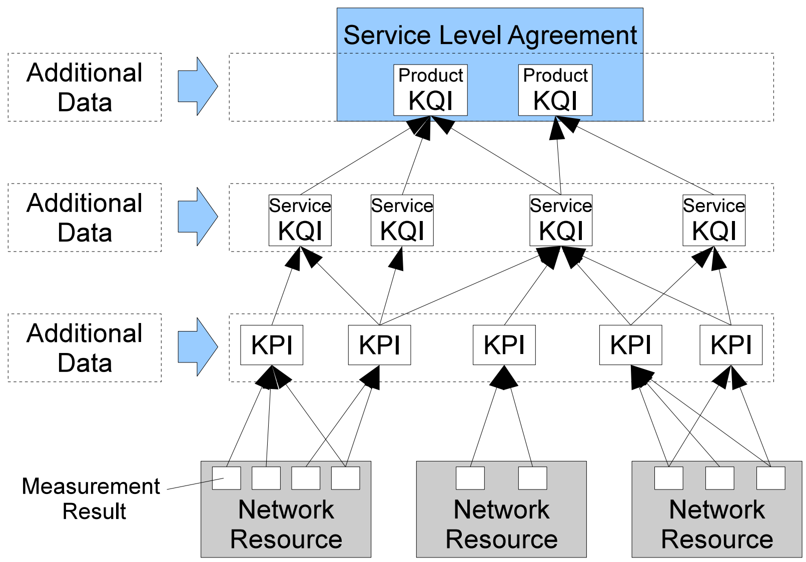

Figure 9: Performance indicator hierarchy

3.4.1 Performance Indicators

When one party provides communications services to another, the level of service quality needs to be negotiated, quantified (to some extent), and formalized as a Service Level Agreement (SLA). SLAs are used not only between consumer and communications service provider, but also between service providers and network operators, or between any two parties in the value chain. SLAs may also be internal, that is, between organizations inside the same company. [29], [9].

Primary input for SLA management are the KQIs. KQIs help service provider to enforce SLA compliance by measuring the performance of *products*, services and service elements. Product, here, refers to a composition of services, processed materials, hardware and software, or any combination of those, that an entity provides to another — in case of CSPs, most often a combination of various services.

Two main categories of KQIs are defined: Product KQIs measure the quality of products and typically support end-user SLAs, whereas Service KQIs produce data for Product KQIs by measuring quality of services (product components), and typically support internal or supplier/partner SLAs. Service KQIs are sometimes composed of several lower level KQIs; Usage of KQI hierarchy levels enables effective reuse of computed data. Some additional data, such as weighting factors, may also be used in calculating KQIs. [29].

However, the primary input for KQIs are the KPIs. Formulas by which KQIs are obtained from KPIs define the relation between network performance and quality of service: While KQIs measure performance of the product and its components from an end-user perspective, KPIs measure performance of service resources, that is, network elements and their components, from a network perspective.

KPIs, as described in Section 3.2, are calculated from performance measurement results and possibly some additional data, such as weighting factors. [29].

3.4.2 Example: RAB Establishment

This example of performance data processing and utilization considers Radio Access Bearer establishment in RNC. The following cumulative counters are defined in 3GPP specifications [17] (For simplicity, some details such as existence of different traffic classes and information about whether queuing has occurred before RAB establishment or not, are ignored here):

- *Attempted RAB establishments for CS domain* (RAB.AttEstabCS). This counter counts the number of received 'RANAP RAB ASSIGNMENT REQUEST' messages for CS domain.
- *Successful RAB establishments for CS domain* (RAB.SuccEstabCS). This counter counts the number of successful RAB establishments from the transmitted 'RANAP RAB ASSIGNMENT RESPONSE' messages for CS domain.
- *Failed RAB establishments for CS domain* (RAB.FailEstabCS). This counter counts the number of failed RAB establishment attempts from the transmitted 'RANAP RAB ASSIGNMENT RESPONSE' messages for CS domain.

The counters listed above are subject to the "*(n-1)* out of *n*" approach. That is to say, if any two of them are implemented, the third one can be calculated in post-processing and therefore needs not to be implemented in the element.

Corresponding counters for the PS domain, RAB.AttEstabPS, RAB.SuccEstabPS and RAB.FailEstabPS have also been defined.

The following KPIs can be obtained from the counters listed above:

- *RAB Establishment Success Rate for CS domain* using formula

$$RabEstabCSSR = \frac{RAB.SuccEastabCS}{RAB.AttEstabCS}$$

- *RAB Establishment Success Rate for PS domain* using formula

$$RabEstabPSSR = \frac{RAB.SuccEastabPS}{RAB.AttEstabPS}$$

- *Percentage of Established RABs, CS Speech* using formula

$$\%RabEstabCSConv = \frac{\sum_{RNC} RAB.SuccEastabCS}{\sum_{RNC} \left\{ \begin{array}{l} RAB.SuccEastabCS+ \\ RAB.SuccEastabPS \end{array} \right\}}$$

- *Percentage of Established RABs, Total PS* using formula

$$\%RabEstabPSConv = \frac{\sum_{RNC} RAB.SuccEastabPS}{\sum_{RNC} \left\{ \begin{array}{l} RAB.SuccEastabCS+ \\ RAB.SuccEastabPS \end{array} \right\}}$$

The first two KPIs can be utilized, for example, in calculation of several KQIs that measure service access and availability. Minimum requirements for these attributes can be defined in an SLA, and the KQIs can thus be used to measure SLA compliance.

The third and fourth KPI can be utilized, for example, in producing information about network usage, and controlling service development and network optimization according to that information.

3.5 Summary

Performance management has an important role in the operator business, providing CSPs with valuable input data for several crucially important network management and administration activities. This chapter described the technical aspects of performance management: What the performance data is, how it is collected from the network, and how it is utilized by CSP's. The following chapter adds the economic aspects to the discussion.

4 Impact of Performance Management

The goal of this chapter is to provide a comprehensive analysis of the different linkages between the following matters:

a) The decisions that are made concerning the implementation of network element performance measurement functionality (e.g. the number and granularity of counters)

b) The element vendor's profits.

This analysis is then used as a basis for the company specific research in the next chapter.

The first two sections of the chapter provide some background to the topic. The first one discusses the overall impact of network management on the CSP's business, and the second one describes the design choices that an element vendor has regarding the measurement functionality of its network elements.

The structure of the rest of the chapter is outlined in Figure 10, which provides a high-level view of possible effects that the above mentioned design choices may have in the value chain.

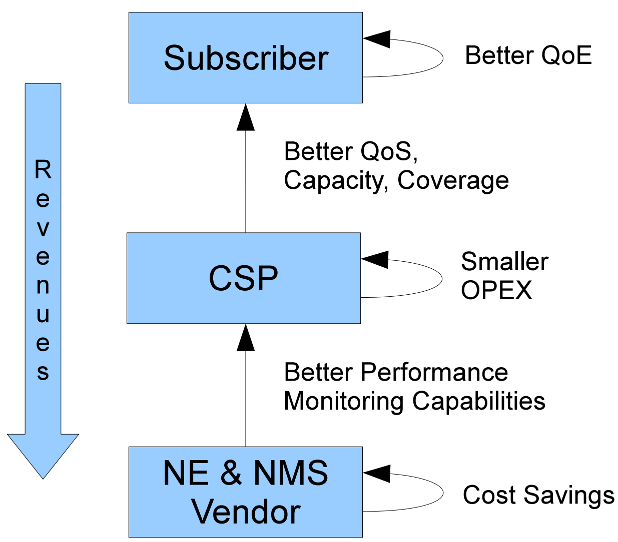

Figure 10: Benefits (depicted by black arrows) to the different parties of a value chain due to well-designed and -implemented network element performance measurement capabilities provided by the element vendor

In Figure 10, the following areas are identified and further discussed in the following sections:

- CSP's improved revenues due to subscriber's better QoE

- CSP's reduced expenditures due to better optimized networks
- NE vendor's improved revenues due to customer (CSP) satisfaction
- NE vendor's internal cost savings

It should be noted that, at this point, the clauses listed above are only assumptions, and their validity as well as their actual (financial) significance is rarely unambiguous or easily resolvable. These concerns are discussed for each of the clauses in respective section.

The final section summarizes the ways by which a vendor can affect its profitability through measurement functionality optimization. (Any profitability calculations are out of the scope of this thesis, due to the complexity of the studied environment, and are thus ignored.)

Sections 4.2, 4.3.2, 4.3.3, 4.4, 4.5 and 4.6 of this chapter are primarily based on the interview research (unless literature reference explicitly indicated). The rest of the sections (excluding the final conclusions) result from a literature survey.

4.1 Value of Network Management in General

In recent years, CSPs have begun to realize the increasingly significant importance of network management for their businesses. Both structural and functional complexity of a typical network are growing, which also places higher requirements on network management systems. A traditional approach of merely controlling and supervising networks under the label of operations and maintenance (O&M or OAM) is no longer sufficient, and has been substituted by sophisticated network management organizations and comprehensive, highly automated OSSs. [2]

However, despite the high level of automation, the cost of managing a modern network still forms a major part of the total cost of ownership (TCO) associated with the network. According to Clemm [1], the cost of operating a piece of network equipment can exceed the cost of amortizing it by a factor of two: In other words, it may be twice as expensive to operate a network device as it is to purchase it. Therefore, the savings in operational expenditure that a CSP can achieve by a relatively small investment in more efficient management systems may provide a major competitive advantage.

In addition to the OPEX savings, investing in better network management systems also provides CSPs some efficient means to differentiate. Successful operators have the ability to provide and maintain high quality and availability of services, quickly repair faults and minimize their impact, rapidly roll-out new services, fully utilize their equipments and quickly respond to changes in their business environment. All these factors are dependent on efficiency of network management. [25], [1]

However, network management should not be seen as an additional benefit or a mere tool for cost savings and differentiation. Since running the network is the core of a CSP's business, the importance of network management as a guarantor of its revenues is critical [1].

4.2 Design Choices for Measurement Functionality

By "measurement functionality" of a network element, this thesis primarily refers to the properties of the element's counter base — the set of counters that are implemented. (Term "counter base" can also be used to refer to any other set of counters, for example the counter base of an entire network.)

The measurement functionality of the CSP's network elements ultimately determines what kind of performance data is available for the CSP to gather, and how much post-processing is required to transform the raw data in to a usable form. The CSP's processes of collecting, processing and utilizing performance data were already described in Section 3.2. The purpose of this section is to describe what kind of design choices an element vendor typically faces concerning the counter bases of its elements. The impact of these choices on the CSP's procedures are discussed in the following sections.

4.2.1 Characteristics of the Counter Base

An element's (or network's) counter base, or any group of counters, can be characterized (for example) in terms of scale, scope and granularity, as illustrated in Figure 11. Scale and scope refer to the extent to which the counters are capable of expressing the value of each measurable attribute, and how extensively the counters cover the element's (or network's) functionality, respectively. In this context, it is typically difficult — besides irrelevant — to unambiguously separate these two concepts from each other, or to evaluate them in any quantitative manner.

Granularity represents the extent to which the measurements are subdivided in to counters; in other words, what is the level of detail of the performance data produced by the network (element). High (or fine) granularity signifies large number of detailed, low-level counters, whereas low (or coarse) granularity signifies small number of high-level counters. Granularity of a counter base is independent of its scale and scope.

Figure 12 shows an example of a countable event, RAB release for CS voice connection, for which a counter set has been implemented at three different levels of granularity. In the lowest level (the most coarse-grained counter set) there is but one counter, counting the total number of RAB releases. On the second level, the counter is subdivided in to two: One that counts the number of normal RAB releases and one that counts the number of system-originated RAB releases (dropped calls). The third and highest level of granularity (the most fine-grained counter set) shows not only if the RAB is released in normal or abnormal manner, but also the cause of the release (normal completion of a session, SRNC relocation, RAB pre-emption, Iu-interface related problem, radio interface synchronization failure, etc.)

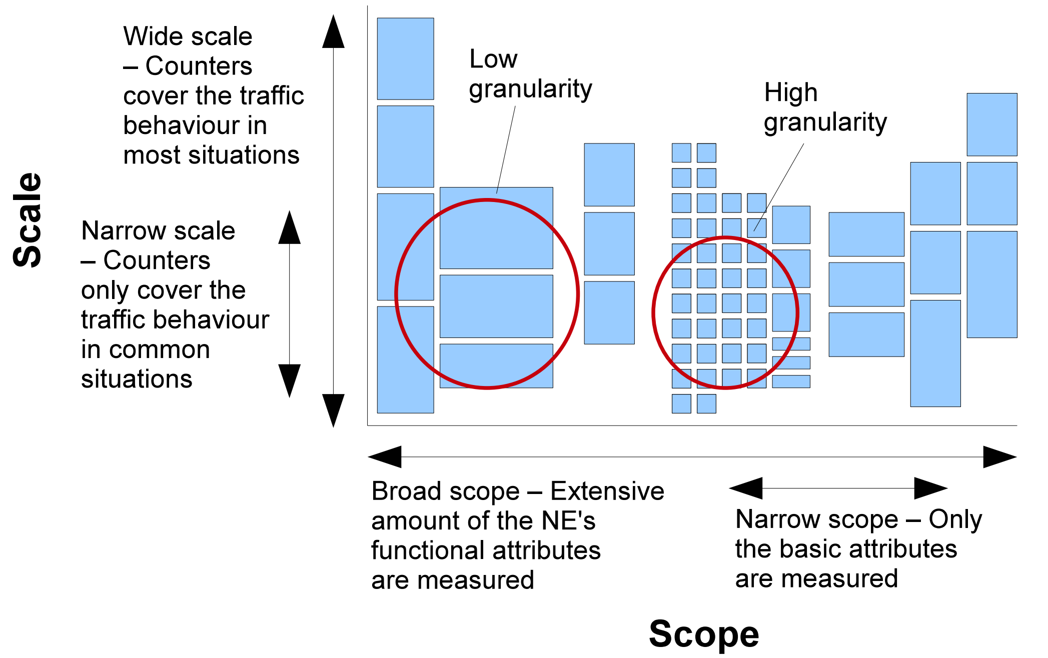

Figure 11: Scale, scope and granularity of a set of counters (the colored rectangles).

Granularity	Subdivision by	RAB Release counters for CS_voice
Low	None	RAB_rel_CS_voice
	Normal/System release	RAB_rel_CS_voice_normal RAB_rel_CS_voice_system
High	Normal/System release + Cause	RAB_rel_CS_voice_normal_comp RAB_rel_CS_voice_normal_p_emp RAB_rel_CS_voice_system_srnc RAB_rel_CS_voice_system_iu RAB_rel_CS_voice_system_radio RAB_rel_CS_voice_system_bts RAB_rel_CS_voice_system_iur RAB_rel_CS_voice_system_rnc RAB_rel_CS_voice_system_ue

Figure 12: An example of three different RNC counter sets counting the number of RAB releases for CS voice with different levels of granularity.

It is important to note that the level of granularity can be altered from higher to lower by post-processing, but not the other way around. Using the counter sets of Figure 12 as an example, if the counters implemented in RNC are RAB_rel_CS_voice_normal and RAB_rel_CS_voice_system, the value of the counter of the lower granularity level, RAB_rel_CS_voice, can easily be calculated by summing the two. However, the counters of the higher granularity level cannot be derived from the implemented counters, since there is no cause information available.

Higher level of granularity has both its advantages and disadvantages. Although it provides the CSP with more accurate, comprehensive performance data, it also requires more of the following resources:

- Network capacity (to transfer the performance data from EMS to NMS)
- Storage capacity (to store, at least temporally, all the performance data)
- Processing power (to transfer the raw data in to a usable form, either on EMS or NMS level)

The problem of determining and achieving the optimum level of granularity is discussed in Chapter 5.

If, again referring to the example presented in Figure 12, coarse-grained counters such as RAB_rel_CS_voice_system provide more commonly required information than their fine-grained components, "sub-counters" (which, in this example, include the cause data), the "*(n-1)* out of *n*" approach [17] that was already mentioned in Subsection 3.4.2, can be exploited to preserve some network, storage, and processing capacity. This implies including to the counter base the counter of lower granularity level, along with *(n-1)* of the *n* sub-counters. Now, the commonly required measurement of lower granularity level can be directly conducted without further processing the performance data, and the value of the one fine-grained sub-counter that was not included, can be calculated from the implemented counters.

The previously explained method also enables discarding of the least useful sub-counters for the purpose of reducing recourse needs, since the important value of the coarse-grained counter can be collected as such.

4.2.2 Factors Influencing the Design Process

Several factors can be identified that influence the designing of measurement functionality. As already mentioned in Chapter 3, standardization organizations such as 3GPP have specified an extensive set of measurements, including the required counters, for different network elements. These specifications give an important basis for the design process, although the standard counters are not being forced to be included in the element's counter base by any entity. Table 2 gives an example of how the measurements are defined in 3GPP specifications.

Several factors should encourage the network element vendors to utilize standard measurement definitions. Most importantly, the compliance with standards enables compatibility with different management systems and network elements from other vendors. Also, the vendor's own R&D expenditures can be reduced by utilizing the ready definitions.

However, the technical diversity of network equipment and the use of proprietary technical solutions often requires a set of vendor-specific counters in addition to the

Table 2: An example of a standard measurement as defined in 3GPP specifications [17]

Name	Attempted RAB modifications for CS domain
Description	This measurement provides the number of requested RABs in modification attempts for CS domain. The measurement is split into subcounters per traffic class.
Collection Method	CC (Cumulative Counter)
Condition	On receipt by the RNC of a RANAP RAB ASSIGNMENT REQUEST message for CS domain, each requested RAB in modification attempts is added to the relevant measurement according to the traffic class requested. See TS 25.413 and TS 23.107. NOTE: The addition is performed with the condition that the RAB has been setup or modified successfully in a previous RANAP RAB ASSIGNMENT RESPONSE or RELOCATION REQUEST ACKNOWLEDGE.
Measurement Result (Measured Value(s), Units)	Four integer values.
Measurement Type	RAB.AttModCS.Conv RAB.AttModCS.Strm RAB.AttModCS.Intact RAB.AttModCS.Bgrd
Measurement Object Class	RncFunction.
Switching Technology	Valid for circuit switched traffic.
Generation	UMTS.
Purpose (optional)	

standard ones. Furthermore, the customer (CSP) requests for new measurement functionality cannot be ignored. Different CSP's may have very different performance measurement needs depending on their established practices, and as the CSPs also pursue differentiation with their services, new requirements arise frequently.

Since the network elements constantly evolve and new functionality is added, also the counter bases of the elements occasionally require amendments and additions. In some cases, due to a new standard, customer request, optimization act, or another reason, a counter or a set of counters has to be replaced with a new counter or a new set of counters. However, it is often a case that the old counters cannot be simply discarded: They have to be further supported in parallel with the new ones for a certain time period to guarantee the element's compatibility (in terms of measurement capability) with the existing network infrastructure.

In Section 5.2, the influencing factors of counter (base) design processes and related issues are discussed in detail for the special case of Nokia Siemens Networks.

4.3 Impact to the CSP's Revenues

In telecommunications market today, it is of crucial importance for a CSP to be capable of measuring its service quality – especially the type of quality that its customers see, that is to say, QoE. As Gómez and Sánchez write in [9]:

> *"The accuracy of the measurement has a key role in telecommunication business, and can be in the position to decide between business success and failure."*

In a similar manner, according to Rosenberg and Kemp in [11]:

> *"Defining quality makes the essential link between good engineering and good business ... With convergence and an increasingly mature, competitive market, implementation of fully defined and measurable QoS is essential to business success."*

Lastly, as stated by Soldani, Li, and Cuny in [10]:

> *"It is very important to measure QoE: Waiting for end-users to vote with their money might turn out to be very expensive for stakeholders."*

The purpose of this section is to discuss the ways by which the measurement functionality of CSP's network elements, and therefore the available performance data, can affect the CSP's revenues. This topic will be broken down in to three clauses for easier analyzation:

a) Better QoE enables higher revenues

b) Better network performance enables better QoE

c) Better performance data enable better performance

The above clauses are illustrated in Figure 13 and will be further analyzed in the following subsections.

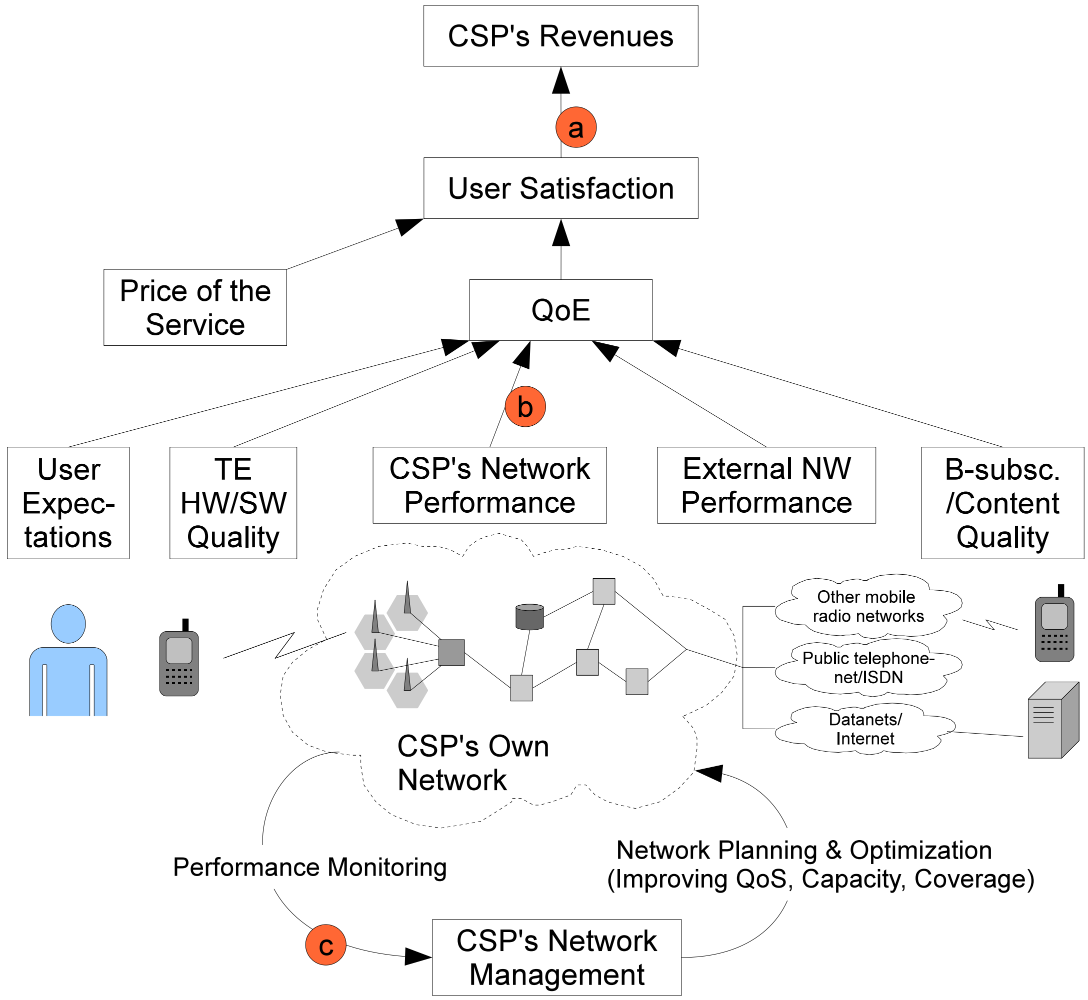

Figure 13: CSP's performance monitoring (c) as an enabler of better QoE (b) and higher revenues (a).

4.3.1 Financial Significance of the QoE

As explained in Subsection 2.4.1, the amount of CSP's total revenues is the product of ARPU and the number of subscribers. Increasing the CSP's revenues, therefore, requires increasing of either the amount of revenues an average subscriber brings to the CSP, or the number of subscribers that the CSP has (or both).

Key to the revenue improvement, in any case, is customer satisfaction, which depends on the Quality of Experience (together with the price of the service). Users that are satisfied with a service that they use tend to use it more (increasing the ARPU if usage-based charging is applied) as well as to recommend it to their friends and relatives (potentially increasing the number of CSP's subscribers). On the other hand, dissatisfied users cause loss of revenues by using the service less, possibly switching provider, and even recommending some potential service adopters to choose another CSP as well. Even the slightest unreliability in service is noticed by several customers — most likely the premium subscribers due to their higher usage levels — and may damage the CSP's revenues.

Therefore, for a CSP to remain competitive and ensure its revenues, it has to attract subscribers with low prices or by offering high QoE. (Note that "CSP" in this thesis refers to a provider of basic communications services only, and the role of value added service provider is distinguished; therefore, differentiation by value added services is not considered here.)

However, since telecommunications markets are already saturated in a large part of the world, a CSP can only enlarge its customer base by taking market share from its competitors [11]. Achieving this by competing solely on price would be difficult in the saturated markets where margins are already low (and decreasing) [37]: Assuming that each CSP provides identical service with the same level of QoS, subscribers only switch provider if the price advantage of the new provider is greater than the switching cost (which might be substantial) [38]. Also, since lowering the price of the service only increases usage in a decreasing manner, the optimal ARPU can likely not be achieved by moving the price point close to the marginal cost of producing the service [36].

Thus, the most important means by which a CSP can increase its revenues is to succeed in providing higher QoE to its subscribers.

Furthermore, weak QoE does not only cause dissatisfaction among the subscribers, but might also hurt them financially. This is especially the case with business subscribers, some of whose revenues depend on communications services. Quality issues might increase their expenditures (e.g. lower working pace of employees due to poor data connections) or decrease their revenues (e.g. failures to receive customer sales orders). Some organizations, such as police, health care and fire department rely heavily on communications services and adequate level of connection quality might be of fundamental importance for them.

It is also possible in today's telecommunications ecosystem that a CSP's customer itself is a service provider of some kind: Another network operator, service operator, mobile virtual network operator or value added service provider. In these cases, the customer's revenues directly depend on the capacity, coverage and QoS provided by the providing CSP, and minimum requirements for these attributes should be strictly defined in SLAs.

It is obvious that in this kind of cases, even the slightest QoE related issues might cause the CSP to lose major customers and suffer significant losses of revenues.

4.3.2 Network Performance as a Component of the QoE

The concept of QoE and its factors were already introduced in Subsection 2.5.2; and the linkage between network performance attributes and QoE attributes was analyzed in Chapter 3 under the discussion of Performance Management. This subsection provides a recap of the most relevant points of those sections and binds the previous discussion to the context of this chapter.

QoE represents the end-to-end quality that a user experiences when using the service. It is affected, as shown in Figure 13, by

- User's expectations (and mood)
- Quality of the terminal equipment (in both ends of the connection)
- Quality of the service application(s)
- CSP's network performance (QoS, capacity and coverage)
- Performance of the possible other networks on the transmission path

The user does not (and is typically not even able to) distinguish the effects of one factor from those of another: The only relevant matter is the end-to-end QoE. However, out of the above listed factors, the CSP is able to affect but the fourth one: Performance of its own network. (Actually, by enforcing SLA compliance with the CSPs that provide it with transfer capacity, the CSP can also affect QoE influences of external networks; however, the topic of SLA management is out of the scope of this thesis.)

This does not, however, imply that the CSP's role as a QoE provider and maintainer would be anything but significant. In terms of accessibility and retainability — properties highly dependent on the radio interface between the base station and terminal equipment — it is usually the access network performance together with user equipment that define the QoE impact; and, when considering the contribution to the QoE of capacity and QoS related attributes such as bit error rate, delay, and jitter, the network typically has far more significant role than the user devices (which, today, often possess great amount of processing power — even the mobile ones).

Network performance has both short-term and long-term impact on the QoE. In short-term, it affects the QoE of individual sessions: The quality of voice or video, data transfer speed, probability of dropping the call or data session, and the temporal availability of the service. In long term, it determines which services the CSP can provide (for example, is the maximum data rate of the connection sufficient for video streaming, and how extensive is the geographical coverage of the service).

It is important to distinguish between the short-term and long-term performance, since the CSP has different methods for managing each. The long-term performance can be considered to impact the QoE more predictably and to affect the subscriber's *expectations* regarding the service; whereas the short-term performance is often unpredictable in nature and affects the user's *satisfaction*. (The long-term satisfaction is determined by the average level of short-term QoE together with its stability — users tend to appreciate stable service quality).

It is, therefore, important for the CSP to manage the performance of its network in both short and long term to achieve and maintain a sufficient level of QoE.

4.3.3 Impact of Measurement Functionality on the Performance

As discussed in the previous subsections, QoE is a fundamental factor of CSP's revenues, and network performance is one of the key factors of QoE. Therefore, one of the CSP's core interests should be maintaining and improving its network performance. Basically two separate processes, already introduced in Section 3.3, are applied by CSP in purpose of ensuring sufficient level of performance:

1. Operation — Endeavoring to maintain the most optimal (or at least a sufficient) short-term performance level.
2. Planning and optimization — Developing the network in the most cost-effective way to best match the long-term service requirements of end-users.

The contents of these processes were discussed in Section 3.3; this subsection, in turn, explains how the implementation of network elements' measurement functionality affects them.

The most fundamental requisite to succeed in operation, planning and optimization processes is the ability to get proper feedback of the network performance and achieved QoE. As discussed in Section 3.1, CSP typically has various methods to gather this kind of feedback, and passive performance monitoring is the most significant one of these methods. Performance monitoring produces performance data, which is used as a primary input for the above mentioned processes. The characteristics of (raw)performance data available to the CSP depend on the network elements' measurement functionality, as explained in Subsection 4.2.1.

However, since the two processes discussed above are very different from each other in nature, the characteristics of the performance data that is required as an input for each also differ considerably. The different consumers of performance data inside the CSP organization may even have contradictory requirements and priorities regarding this matter. From the operation perspective, it is important to have a clear, frequently updated high-level view of the network performance to allow for a quick identification of the possible issues, so that they can be reacted in as early state as possible. Therefore, performance data with low granularity and low overall number of measurements is typically preferred.

For planning and optimization, on the other hand, time is not such a crucial matter. It is more important that enough information with adequate accuracy is available so that the best decisions can be made; thus the higher the scale, scope and granularity of the measurement data available, the better. Changes that are made to the physical network structure are often difficult and expensive to revert, so the CSP has to be sufficiently confident that these changes have positive effect on the QoE. This confidence is highly dependent on the accuracy of available measurement data.

As also mentioned in Subsection 4.2.1, post-processing can be used to change the nature of measurement data to some extent, but certain limitations exist. First, the granularity of the data cannot be increased: Therefore, if the data is optimized for operations, it cannot be made better suited for planning and optimization by any post-processing. Second, the post-processing requires time and resources (possibly including some manual work). Thus, if the data is optimized for planning and optimization, it might be too slow or difficult to process it into operation-friendly form.

It is also worth mentioning, that not only do the performance measurements help the CSP to improve its overall performance by providing it with necessary input data for the operation, planning and optimization processes; but they can also provide the CSP with means to identify the most valuable customers and target the performance enhancements towards them to achieve the maximum ARPU increase. [9]

4.3.4 Summary

This section has discussed the following matters:

- QoE as a driver of CSP's revenues (the significance of QoE as a differentiating factor between the CSPs, and the likely subscriber reactions to the changes in QoE).
- Network performance contribution to the QoE (network as a typical performance bottleneck, and the short-term and long-term effect of performance to the QoE).
- The significance of performance data as an input to the performance maintenance and enhancement processes, and how the properties of performance data affect the extent to which it can be utilized for different purposes.

While it is fairly obvious, in light of the previous discussion, that the available performance data does affect CSP's capability to provide QoE and make revenues, the exact financial influence of any counter base optimization act is practically impossible to calculate due to the indirect nature of the described linkage, complexity and unpredictability of subscriber behavior, and quantity of external factors.

4.4 Impact on the CSP's Expenditures

Besides its revenues, the measurement functionality of CSP's network elements also affects its expenditures — both CAPEX and OPEX. As a matter of fact, the same factors that are behind the CSP's increased revenues, typically also generate costs: That is, higher QoE incurs higher expenditures.

The following examples show how the improper performance data optimization, discussed in Subsection 4.3.3, can be perceived as a source of expenditures instead of as a factor of poor QoE:

- Measurement functionality optimized for network operation may lead to poor network planning or optimization decisions (due to insufficient performance data) and excessive capital expenditures are required to achieve the same level of QoE that would be reached with optimal decisions.

- Measurement functionality optimized for network planning and optimization creates need for heavy post-processing, so that the excessive performance data could be utilized in network operation with the same efficiency (to provide the same QoE) as if optimal data was available. This increases the operation workload and personnel costs (OPEX).

However, the overall poor quality of available performance data increases the CSP's expenditures without having positive impact on revenues. For example:

- Complex or difficult-to-interpret measurement results and excess amount of useless or redundant performance data increase the overall workload of the CSP and increase personnel costs.
- High overall amount of performance data (often produced due to poorly optimized counter base and high redundancy) may strain the network when transferred from EMS to NMS, increasing the need for further infrastructure investments.
- Large amount of performance data also requires plenty of storage capacity (from EMS, NMS or both), and might cause the system upgrades to require long offline periods (during which necessary backups are performed).
- Reduced QoE due to inadequate network monitoring capabilities (see the previous section) leads to higher customer dissatisfaction and increased need for customer care resources.
- Additionally, the CSP may be bound (by an SLA) to pay monetary penalties if unable to provide sufficient level of QoS with sufficient degree of availability ("sufficient" levels are defined in SLAs). [29]

Besides the operation, planning and optimization, CSP utilizes performance data for various other purposes as well, as mentioned in Section 3.3. Sales and marketing, administration, and other performance data consumers all have their own preferences considering the characteristics of performance data, and additional expenditures arise whenever there is a difference between these preferences and the actual characteristics of the data.

4.5 Impact on the Vendor's Revenues

Given the CSP's financial benefits that it can achieve with better network element measurement functionality, it is natural to assume that the element vendor who manages to provide the CSP with optimal measurement functionality would also benefit. Products that better fulfill customer needs enable higher asking prices, and larger number of satisfied customers lead to higher revenues.

Section 4.1 discussed the major OPEX savings that CSP could achieve by investing in more efficient network management, and sections 4.3 – 4.4 provided an example of a potential source of these savings: Better optimized network element measurement functionality. In light of these discussions, network equipment vendors should have high incentives to produce equipment with better management capabilities — such as measurement functionality — than in the products of their competitors. If operational costs comprise x percent of the CSP's total cost of ownership of a network element, the potential price premium an equipment vendor can charge the CSP for y percent more efficient management capabilities for that element would be

$$\frac{x \times y}{100 - x} \quad percent.$$

If, for example, the operational cost is twice as large as the amortizing cost (which, as stated in Section 4.1, is a realistic situation), i.e. $x = 2 \times (100 - x)$, thus $x = 67$, then a vendor whose product has 25% more efficient operational capabilities could charge 50% higher price [1].

However, as previously mentioned, it is often difficult to quantify the cost savings achieved by optimizing network management and therefore also to determine the return on investment (RoI) on the management systems. According to a study conducted in 2006 by Comptel, 36 percent of the network operators did not measure the Return on Investment (RoI) for OSS projects [24]. The operators have only recently begun to consider also the management capabilities of network elements in their purchase decisions. They have also become increasingly aware of the influence of the equipment's operational costs. [1]

Nevertheless, the difficulty and complexity of calculating the exact impact of network element measurement functionality on the CSP's revenues and expenditures (especially when considering a single element as a part of the network) also greatly diminishes the vendor's opportunities of yielding profits with investments in measurement functionality design processes. A higher price point of a network element is often difficult (in practice) to justify with the element's management capabilities.

4.6 Measurement Functionality Related Vendor Expenditures

Designing and implementing network element measurement functionality generates various costs for the element vendor, depending on the scale and scope of the vendor's product (and service) range. This section briefly discusses the costs that typically arise; Chapter 5 further describes the counter related expenses for Nokia Siemens Networks.

Vendor's counter related costs can be classified into direct and indirect costs. Direct costs, that are part of the actual counter "production", incur

- Designing and defining the functionality of the counters (what is measured), required research work, and business case analysis (are the proposed counters profitable to implement; that is, are the customers actually willing to pay for them)
- Technical R&D concerning the implementation of the required hardware and/or software components
- Increased network element production costs due to additional measurement hardware required

Indirect counter related costs are typically borne by vendor's supporting business units. It is common that a network element vendor provides more or less end-to-end solutions instead of mere equipment. These solutions may include, for example, network planning and installation, customer technical training and support, network (and business) management software, and even temporal operation of a customer's network. Some of these processes are affected by design choices concerning network element measurement functionality, and thus generate indirect counter related costs. For example:

- Provision of OSS support: Making the vendor's management software compatible with each of the counters and measurements
- Technical support costs (amount of required knowledge and complexity of remedial actions are affected by measurement functionality)
- Customer (and own staff) technical training costs

The characteristics of the counter base determine the magnitude of the related costs, both direct and indirect. In some cases, typically regarding the indirect costs, the relationship between the costs and total number of different counters (the size of the counter base) is close to linear: For example, the adaptation specification work required to provide basic OSS support for a single counter is typically fairly constant. However, when it comes to direct costs, technical complexity of the counter has the most significant effect.

Technically complex counters (that provide information on higher abstraction [or lower granularity] level) are typically far more expensive to implement than an equivalent set of simple counters that only utilize the basic arithmetics (addition and subtraction), due to the complexity of required hardware components. Amount of design work required to specify several simple counters instead of few complex ones might also be smaller. However, providing software support for a large set of low-level (fine-grained) counters requires remarkable amount of work, since the high-level (coarse-grained) data that is often required by CSP has to be made available through post-processing applications of the management system.

Besides, the costs that incur from actual research work that is conducted to determine the consequences and profitability of counter base related choices cannot be disregarded. Due to the complexity of interrelations between the influencing factors, benefits achievable through this kind of research do not necessarily suffice to cover the cost of the research itself. In such cases, the most profitable option — for the vendor, that is — is to settle for solutions that are technically less than optimal.

Issues related to the above discussed matters in the special case of Nokia Siemens Networks are examined in the following chapter.

4.7 Conclusions

The purpose of this chapter was to bring up the possible linkages between the network element vendor profits and measurement functionality related choices that the vendor makes. Figure 14 summarizes the most important factors of the ones that were introduced, together with their interrelations.

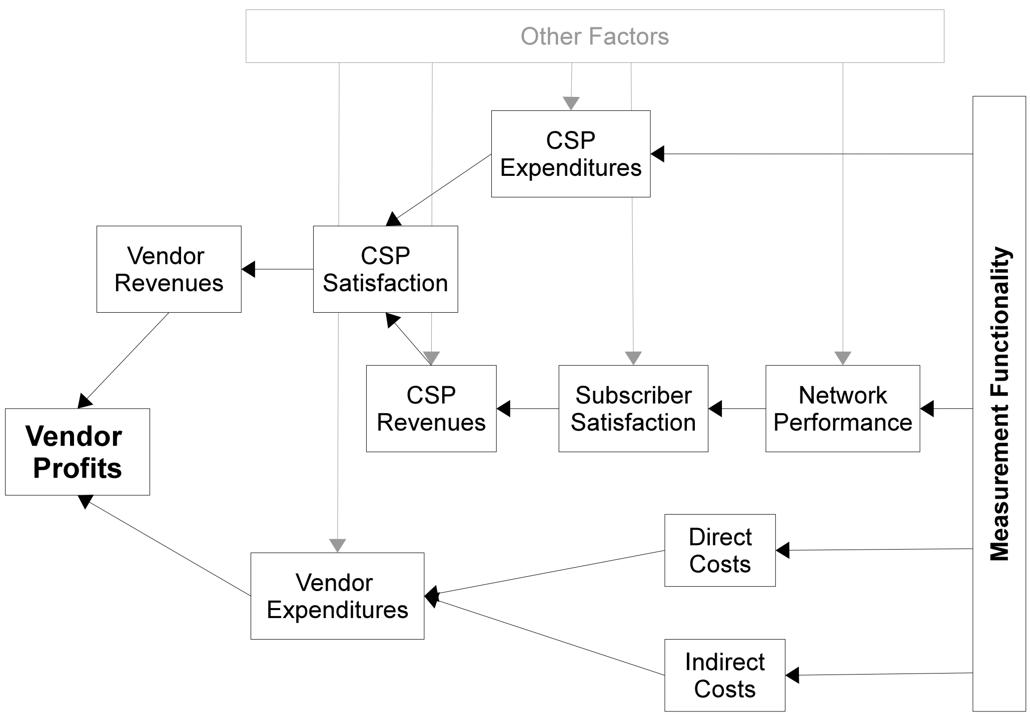

Figure 14: Role of the NE measurement functionality as a factor of vendor profits.

The following formula can be expressed for the effect of measurement functionality related decisions to the vendor's profits, based on the discussions of this chapter:

$$\begin{aligned}\Delta P_v &= -\Delta C_v + \Delta R_v \\ &= -\Delta(n \times (\overline{C_d} + \overline{C_i})) - C_r + k \times (\Delta R_{CSP} - \Delta C_{CSP}),\end{aligned} \quad (3)$$

where P_v, C_v, and R_v denote the profits, costs and revenues of the vendor, respectively (delta indicates the effect of counter base design choices to each variable); n is the number of counters; $\overline{C_d}$ and $\overline{C_i}$ are, respectively, the average direct and indirect costs related to a counter; C_r denotes the cost of the research work that is conducted to study the financial influence of counter base design choices; k is the factor which indicates the CSP's willingness to pay for the counter related benefits; and C_{CSP} and R_{CSP} denote the costs and revenues of the CSP, respectively.

Due to the many complex interrelations between the different factors, as well as the numerous external factors that are present, it is impossible to define an unambiguous formula to maximize the vendor's profitability by counter base optimization. However, to summarize the discussions of this chapter utilizing the notation of Equation 3, the following separate means for improving the vendor's profitability can be identified:

- Minimize $n \times (\overline{C_d} + \overline{C_i})$: Counter-related vendor expenditures can be reduced by decreasing the value of either n or $(\overline{C_d} + \overline{C_i})$. What makes this intricate is the fact that the value of $\overline{C_d}$ is typically strongly dependent on the value of n — in an inversely proportional manner.

- Maximize R_{CSP}: Design the counter base so that it best supports CSPs' network operation, planning, and optimization activities.

- Minimize C_{CSP}: Design the counter base so that it minimizes the CSPs' measurement related expenditures.

- Optimize k: If $(\Delta R_{CSP} - \Delta C_{CSP})$ is large, try to maximize k by making CSPs aware of the benefits provided by better measurement capabilities. The smaller the value of $(\Delta R_{CSP} - \Delta C_{CSP})$, the less effort it is worth to increase the value of k.

The most interesting variable in Equation 3 is C_r, which denotes the cost of all the research work that a vendor conducts to find out the optimal balance between the utilization of the above listed means. If this cost is higher than the (estimation of) achieved benefits — that is, if

$$C_r > E[-\Delta(n \times (\overline{C_d} + \overline{C_i})) + k \times (\Delta R_{CSP} - \Delta C_{CSP})], \tag{4}$$

then the research is not worth conducting.

5 Company Specific Issues Related to Measurement Functionality

This chapter forms the core research part of the thesis. Goal of the research, as explained in the introductory chapter, is to identify the reason(s) behind the enormous, exponentially growing number of performance management counters in Nokia Siemens Networks' network elements, and provide suggestions about the potential remedial actions.

The research conducted for this chapter consists of the following three parts:

1. Study the current processes, procedures, and policies involved in planning, implementation, management and processing of the counters in NSN.

2. Identify the issues concerning the above mentioned processes, procedures and policies that potentially decrease NSN's profitability, by applying the theory presented in the previous chapter.

3. Analyze the identified flaws from different aspects, and suggest for improvements or topics for future research based on the guidelines of the previous chapter.

The research was conducted by interviewing more than 30 NSN (vendor) and three Elisa (CSP) employees from different positions and business units, and by reviewing NSN's internal literary material such as documents, presentations and specifications, as well as measurement metadata. List of the interviewed persons is presented in Appendix A.

The following three sections each correspond to one part of the research. The next chapter — the final one of this thesis — summarizes the results and reviews the research methods.

5.1 Introduction of NSN Organization, Roles, and Procedures

Nokia Siemens Networks is the second largest telecommunications infrastructure vendor in the world with its 21% market share (according to research by Dell'Oro, Feb 2010 [33]). It employs more than 60,000 people in over 150 countries, and serves 600 customers around the world [22].

The company offers its customers a wide range of solutions, services, and products, including

- Broadband connectivity equipment

- Converged core equipment

- Radio access equipment
- Network and business management software
- Energy solutions
- Network management services
- Consulting and training services
- Different levels of technical support and customer care
- Network planning and implementation (end-to-end)
- Delivery operations
- Customized products and services

The company is divided into several business units, which are further divided into smaller organizations on several levels, each one having its individual role as well as own business goals and management. Organizational changes may be executed in a relatively frequent manner, so it is important to emphasize that in this thesis, NSN's organizational structure is considered as it was in August 2009 (unless stated otherwise). It would, however, be irrelevant to explain the complex organizational structure in detail, so only the entities that are essential from the aspect of this topic are considered. Also, some simplifications are made.

Figure 15 presents a high-level view of the relations (regarding the subject of network performance measurement functionality) between

- The organizations inside NSN that develop network elements (NE R&D)
- The organization inside NSN that develops operations support systems (OSS R&D, belonging to the Operations and Business Software (OBS) business unit)
- Customers (typically CSPs).

The most important note to make on Figure 15 is that network element R&D and Operations Support Systems R&D are handled strictly separately in organizations that only share common management and administration on a very high level.

Also, each different type of network element (RNC, NodeB, SGSN, HLR, etc.), or a small group of network elements, is developed distinctively in its own NE R&D unit. Naturally, these units are also responsible of developing each element's performance measurement functionality, as a part of the element's feature management. Each unit has its own established procedures and processes related to planning, defining and implementation of counters. Procedures of different NE R&D units may vary greatly (after all, the elements themselves are technically quite different), which further complicates this research. Figure 16 composes the identified factors that influence counter base implementation, together with some of the common phases of

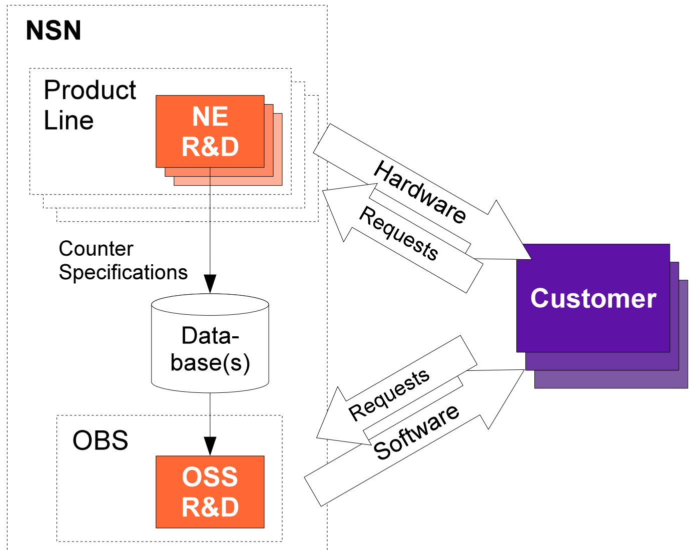

Figure 15: High level view of the entities and relations relevant to the subject.

the related processes. Figure 16 can be considered as a basis of this study and it will be further analyzed in coming sections to indicate the flaws that potentially transpire as an excess amount of counters. In Section 5.3, the figure will be accomplished with development and improvement suggestions.

Detailed specification is created for each (to-be) implemented counter and stored in a common database, as previously illustrated by Figure FIG:NSNorg. OSS R&D accesses the database to collect specifications of new (or modified) counters and produces the necessary metadata and software components to guarantee the network management systems to be able to properly interpret, process, and represent each measurement result. This work requires several phases, such as understanding the semantics of, testing, developing, transforming, and defining each counter. (Note: When this thesis work was conducted, new tools were in course of preparation that were to allow increased automation and therefore to decrease the OSS workload.)

A few other sub-organizations are also in some way involved with the counters in such way that their work loads partially depend on the counter planning decisions, but this research mainly considers the indirect costs from the OSS R&D perspective.

5.2 Potential Issues in the Current Procedures

This section further analyzes the procedures, processes, policies and organizational structure of NSN, and applies the theory introduced in the previous chapter to point out the potential issues. (For confidentiality reasons, no quantitative figures concerning financial matters will be disclosed in this thesis.)

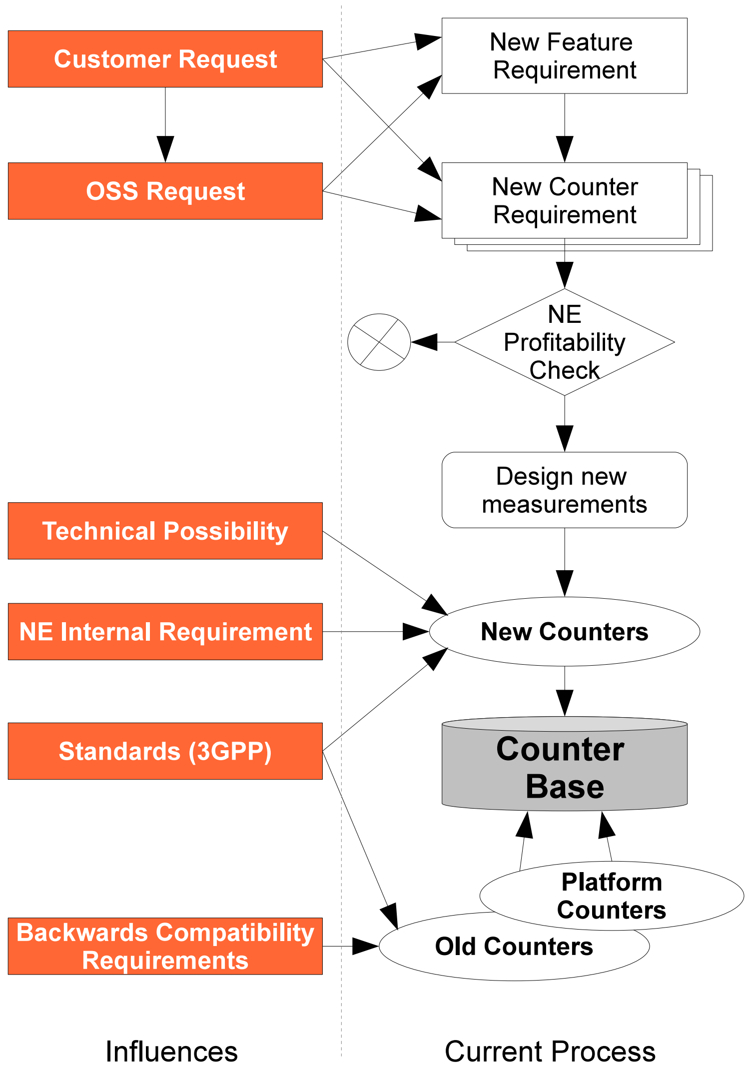

Figure 16: Generalization of counter base design procedures in NSN.

5.2.1 Planning of the Counters

Figure 16 in the previous section illustrated the processes related to producing new counters. Colored boxes on the left side of the figure represent the typical factors that NE R&D uses (or can use) as an input for the process, and the right side of the figure illustrates the actual work phases that are (or can be) performed. These are explained in more detail in the following clauses. (Note that, as mentioned in the previous section, considerable differences may exist between the procedures of different NE R&D units):

a) Customer requests may concern either hardware or (network management) software features. In the former case the requests are typically expressed directly to the NE R&D, and in the latter case to the OSS R&D. OSS R&D

determines the required hardware features based on its software requirements (that might be either customer-originated or internal) and expresses them to the NE R&D.

b) New counter requirements are determined based on the feature requests expressed by customers and OSS R&D. Implementation of single counters may have also been requested.

c) Profitability of implementing the set of counters (or the feature) that has been requested, is evaluated: How much would the implementation cost, and what is the estimated return on investment — how would the implementation of the counters affect the sales of the element, or otherwise benefit the vendor?

d) Requested counter sets and features that pass the profitability check will be implemented, whereas the rest will be discarded.

e) In some cases, it may appear that implementing a certain counter would generate virtually no additional costs, for example, if no new hardware components are required and existing NE software would need only minor adjustments. In such situation, a counter may be implemented "just in case" even though it has not been requested nor is it certain that any of the customers would ever utilize it.

f) Sometimes it is worthwhile for the NE R&D to implement counters solely for internal purposes, e.g. to test the functioning of the element.

g) Standardization organizations (in this case, primarily, the 3GPP), are an important source of counter definitions, as discussed in Subsection 4.2.2. Standard counters should be included to guarantee compatibility of NSN network elements with products of the other vendors. Standard counter sets are not static; instead, new counters are defined by 3GPP in relatively frequent manner.

h) Each network element is based on certain platform (such as Nokia DX200), and each platform has its own set of counters. This set can be considered as a part of each element's counter base.

i) Typically, all the counters from the previous release(s) of the network element are automatically supported in the new release as well. To guarantee backwards compatibility, e.g. with older network management systems or customer-specific solutions, it is often undesirable to discard an old version of the counter even if it has been upgraded or replaced (as also mentioned in Subsection 4.2.2).

Issues

The danger of the following potential issues can be associated with the above listed clauses, considering the theory of the previous chapter:

- In (a): Customers requests may be accepted without enough criticism; this issue is discussed in detail in the next subsection.

- In (b): It is often perceived to cost too much (to be profitable) to determine the optimal characteristics — from any other than technical implementation point of view — of the counter base, e.g. what is the granularity level best suited for customers' purposes. Hence, the designed counters might not fulfill the customer needs well even if they would concern the right performance attributes.

- Also in (b): New counters may sometimes be implemented, even though existing ones could be utilized in implementing the requested feature(s).

- In (c) and (d): When profitability of implementing a set of requested counters (or the feature) is evaluated, certain issues in the organizational structure might give NE organization incentives to only consider its own costs and benefits (sales of the NE), even though implementation of counter base may strongly affect the workload of other NSN sub-organizations as well. NE organizations do not likely even possess all the information about the company wide effects of their decisions so that they could be considered. These organizational structure related issues are discussed in the following subsection.

- In (e): Again, NE organization has no incentives to study the impact of the implemented counters on the other involved entities, and this impact is not likely even outright understood.

- In (f): While it is justifiable to implement temporary counters for testing purposes, they cause redundant workload for other involved entities if not discarded from the final (released) version.

- In (g): If complying with standards is neglected at some point, it may cause trouble later. Even though a standardization organization's version of a counter or a measurement would be perceived to be inferior to its proprietary substitute, it may be required in future as a basis of some other features. Later implementing the standard counterparts besides proprietary counters to provide support for the new features is something that easily leads to duplicacy.

- In (i): Counters that are no longer used for any purpose are estimated to constitute a significant part of the overall counter base. This issue is also further discussed in the next subsection.

The bottom line is, that plenty of research work would be required to design the counter base in such way that it would maximize the whole company's benefits. At least from an NE organization's perspective, it may be difficult to see the value in this kind of research work, unless proper incentives are set from outside. This issue is further discussed in the following subsection.

5.2.2 Concerning Customer Requests

Customer requests are one of the most important inputs of counter planning process for a vendor, since satisfying the needs of customers is a key success factor in any business (linkage between CSP satisfaction and vendor revenues was discussed in Section 4.5). However, several matters should be concerned when customers request new features and counters from network element vendors.

CSPs typically request new features or new counters for the following reasons:

- Desire to improve the Performance Management efficiency or effectiveness
- Previously used vendor's corresponding element has the counter, so it is also required from the new vendor
- Vendor has discarded an old counter and a replacing one is required so that the old KPIs and reports work

Customer requests for new features or counters should not be accepted without any criticism. Making the requests does not itself cost anything to the CSP — but the research work required to investigate the actual benefits of the requested features does have a cost. Therefore, the CSP basically has incentives to request all the features and counters it can think of, without extensively deliberating how useful they would be. Furthermore, it is even more difficult for the customer to estimate the true cost of the feature than it is for the vendor. If these costs are not resolved by vendor and communicated to the customer, the profitability analysis (clause (c) in the previous subsection) does not get sufficient input information.

Also, the other way around, if the vendor implements new features which are not based on customer requests, it might be difficult to use these features as selling points because their provided benefits may be unclear to the customer.

Another issue related to customer preferences is the support of old counters. Even though in some cases it is necessary to continue the support, the number of counters that are not actually utilized in any way by any customer is commonly estimated to be huge. Conducting a survey to find out whether any of the customers are still utilizing each presumably redundant counter for any measurement activity would be laborious and is not perceived to be an economically viable solution. Besides, customers would anyway have little incentives to respond negatively to that kind of survey; it is always better to have too many than too few features — at least from the management's point of view.

Furthermore, the customer itself is likely not fully aware of the true usefulness of each low-level counter that its elements contain, as it is common that all the available performance data is collected from the network and automatically post-processed before utilization. Complex KQI and KPI formulas effectively hide the low level (measurement level) details from consumers of performance data, so it might not be easy to resolve what kind of effect removing a certain counter would have (if any) — in which case, again, the CSP naturally prefers to keep rather than discard.

On the contrary, some counters may appear to be of little use for the customer, but should still not be removed: This is the case when the counter is needed in a special situation, such as in resolving the cause of a malfunction. CSP may not realize the importance of the counter if it cannot be utilized in network operation or planning and optimization — especially in case that the trouble solving in CSP's network is outsourced to another party (possibly to the vendor of the network element).

If these matters are ignored in the counter planning process, it is likely that the implemented counter base is not optimal in sense that it would maximize the vendor's revenues. However, the other side of the situation is, that all the research work that is conducted by the vendor to study the usefulness of counters not only generates costs, but also lengthens the lead time of the product, which might cause more harm to the customer than what less optimal measurement functionality would.

Finding the optimum between the amount of conducted research, cost, and time is certainly challenging, and forms one identified area in which there is room for improvement in NSN.

5.2.3 Organizational Structure, Management, and Procedures

Organizational structure determines how the company can be administered and how the different functional units can be managed at different levels. Due to the scope of its business and scale of its portfolio, NSN is a complex organization to manage. As described in Section 5.1, NSN's organizational structure embodies relatively high level of isolation between the sub-organizations that are responsible for each product. Giving these sub-organizations plenty of power to make their own decisions concerning their products, i.e. applying the "bottom-up approach" in which the decisions made on the low organizational levels are aggregated on higher levels, eventually determining the overall direction the company takes, may cause various issues.

The following clauses describe the identified issues that are related to the organizational matters.

Strategic Influence of the NE R&D Decisions

As can be concluded from Chapter 4's discussions, the vendor's decisions regarding its counter base affect the customers' perception of its value proposition, and can thus be considered strategic decisions. NE R&D units should not, however, be considered qualified to make strategic decisions, due to the following reasons:

- They belong to a low organizational level and operate in highly independent manner with few common policies or processes
- They do likely not possess the kind of information (e.g. regarding the financial significance of each customer) that strategic decisions require
- They may not even realize the strategic impact of their decisions

Strategic decisions should first be made at the highest organizational level and then be subdivided into lower levels ("top-down approach"), so that the overall strategy of the company could be coordinated according to what is best for the company in whole, taking into account all the relevant facts. If this procedure is not adhered, the company's profitability will likely suffer.

Shortcomings in Coordination

Higher level of common coordination of the counter planning would be advantageous for the following purposes:

- To guarantee that the company-level profitability of the decisions will be considered, including the costs and benefits to all involved sub-organizations.
- To enable the alignment of measurement functionality related decisions with the company's high-level strategy.
- To guarantee a sufficient level of consistency in the product range and to prevent compatibility issues.
- To prevent redundant work from being conducted in NE units and other sub-organizations, thus reducing costs.

However, managing the optimization of network element counter base is anything but straightforward. One of the major problems is the enormous amount of information about various products, from different aspects, that would need to be taken into account in the process. This amount of information would likely be too much for any single person to adopt. Furthermore, the information is not readily available anywhere nor is it easy to gather. Instead, the required knowledge about different areas is shattered around the organization: Each NE unit possesses the best technical knowledge about its product(s), the OSS business line has the knowledge about network management and software related matters, customer teams know the individual preferences of each CSP, and the top management is best aware of the business strategies that, when correctly implemented, would lead to the best financial results. All of this knowledge would be required for decision making, and thus none of these entities alone could make the optimal decisions.

Therefore, even though the lack of clear high-level coordination of counter planning processes is itself one source of issues, establishing a new unit with the responsibility of coordinating them would have its own challenges as well. The unit would have to be small enough to be effective but still possess enough expertise, without being biased.

Business Goals and Rewarding System

In a large multi-level corporation, as already mentioned, the high-level goals (set by the top management) need to be split into several sub-goals on each level of the organization, so that each individual unit has its own, clearly defined targets and each employee can understand the influence of his or her work effort to the organization's benefits without having to first understand the operational details of the entire organization. Also, the rewarding system, the purpose of which is to motivate the employees to endeavor achieving these goals, needs to be carefully defined on each level.

However, for a company such as NSN that has multiple product lines, each product developed independently but commonly sold as a package together with several other products, and with strong interdependencies between the properties of different products, the maximal profitability of the company as a whole might not be achieved by maximizing the profitability of each product or product line. This is also the case here: If the goals of the NE R&D units are set to maximize the profitability of each network element — which might call for implementation of a large number of counters — then it is highly likely that other sub-organizations of NSN, such as OSS — whose costs are partially proportional to the number of counters — will suffer.

In NSN, the rewarding system mainly considers, as an input, the financial results of each sub-organization. Therefore, the most profitable approach for the NE organizations might be not to invest too much resources in counter planning, but to simply make sure that as many of each element's properties as possible can be measured, and let the upper layers (OSS and application developers) produce the software that can transfer the raw measurement data into a usable form.

However, a rewarding system that would be based on anything else than financial figures — in an ideal case, to the value that each sub-organization produces to the company — would be difficult to implement, since one of the key properties of a rewarding system is that its input values are quantitative and unambiguously measurable. As can be concluded from the previous chapter's discussions, the effect of an NE organization's decisions to the other sub-organizations' operation cannot be expressed in terms that fulfill either of these criteria.

5.2.4 Technical issues

The original (primary) goal that was set for this thesis work was to find technical means to decrease the size of, or at least to decelerate the growth of the counter base. Even though the conclusion was later made that the issues of other than purely technical nature had greater contribution to the amount of redundancy in the counter base, it is worthwhile to also discuss the technical issues that were identified.

Due to the increased complexity in services that the modern telecommunications networks enable, and especially due to the emergent transition to the packet data services, some growth in the number of required counters is obviously inevitable. However, it is equally obvious that a large part of the counters implemented in NSN's network elements are redundant in some of the following ways (note that these are not exclusive to each other):

- Not utilized by any customer
- Implemented in unnecessarily high level of granularity
- Duplicate in sense that the same event is counted by another element
- Duplicate in sense that the same event is counted by another counter in same element

The first issue — the counters that are not useful to customers — was already discussed in the previous sections. The second one, unnecessarily high level of granularity, may be caused by misinterpretation of customer needs or strive for technical simplicity in counter implementations, and is thus also strongly related to the previous discussions. The last two issues, concerning the number of duplicate counters, were concluded to be relatively insignificant in terms of volume. However, since the number of duplicates was originally assumed to be the biggest cause of measurement base growth, the issue of duplicacy is briefly explained here.

A typical case of a duplicate counter in another element would be the counter of number of certain requests sent to (or received from) that element; it is common that the number of same requests are counted in both ends of the connection. This does not, however, mean that the duplicate counter would always be redundant: CSPs often use elements from several vendors, so it cannot be assumed that the element in the other end of the connection is always an NSN element that contains all the same counters. Besides, in a case of malfunction, it might prove to be useful that each element can measure certain attributes. Therefore, some level of duplicacy between the elements is justifiable.

Duplicate counters inside the same element were estimated to be rare. This kind of duplicates would typically refer to cases in which a replaced counter is not removed to guarantee backwards compatibility (already mentioned in Subsection 5.2.1), resulting in two counters basically counting the same event, with slightly different names.

Term “duplicate counter” may also be used to refer to a counter that has the same functionality as another counter in another network element, but somewhat different specification. For example, several elements measure bit error rate, so that could be considered as a duplicate measurement, likely based on duplicate counters. The only difference between this kind of duplicates may be the counter’s name, which typically has a context specific prefix of suffix. Obviously, this kind of duplicacy alone would not make any counter redundant, but it was assumed by OSS R&D that some reduction in adaptation and testing costs could be achieved if the specifications of the similar counters from different elements could be somehow equalized. However, such possibility was not discovered.

Besides these issues, adjusting to the increased amount of measuring requirements may itself cause trouble. For example, increased scale of one measurable property (or, merely, an increased amount of traffic) may create need to implement another counter to indicate the overflow of the first one. While this is obviously not the optimal solution, it might well be the fastest and easiest one from the NE R&D point of view.

5.2.5 Information Models and Tools

One source of efficiency (or inefficiency) in the vendor's counter R&D processes is the quality of the set of tools, databases and information models that are available. Some major refinements in this area were in course of preparation at NSN at the time this research was conducted, which is why these matters are only narrowly covered in this thesis.

The importance of common tools and information models is emphasized in organizations such as NSN's, where different parts of the work (related to counter planning) are done in relatively isolated units. As can be seen in Figure 15, the main linkage between the NE and OSS R&D units is the database in which the counter specifications are stored. NE R&D creates the counters and specifications for them, and OSS R&D then uses these specifications to make the necessary OSS adaptations.

Thus, the counter adaptation related workload in OSS greatly depends on the information models applied in the database and tools that are available to process the data: In the ideal case, the specifications could be used as such or at least be automatically converted into a usable form.

Deficiencies in information models or tools increase the amount of manual work that is required to make the network management software compatible with the designed hardware and reduce the end-to-end visibility of the influences of counter related decisions. Even a small amount of manual work that has to be done for each counter, multiplied with the number of counters, may become a major source of expenses.

5.3 Development Suggestions

This section summarizes the above identified issues and makes some suggestions for remedial actions. Due to the relatively limited scope of the study, the group of presented suggestions should not be seen as a concrete list of actions that, if performed, would fix all the issues; but rather as a basis for future research.

5.3.1 Procedure Updates

Subsection 5.2.1 described, using Figure 16, the typical procedures applied to counter base planning in NE R&D units. Several potential issues were identified in these procedures. Figure 17 presents the same diagram with some suggested additions, the effect of whose should be further researched.

The following additions to the discussed procedures are suggested in Figure 16:

- When customers request new features, further research would be needed to

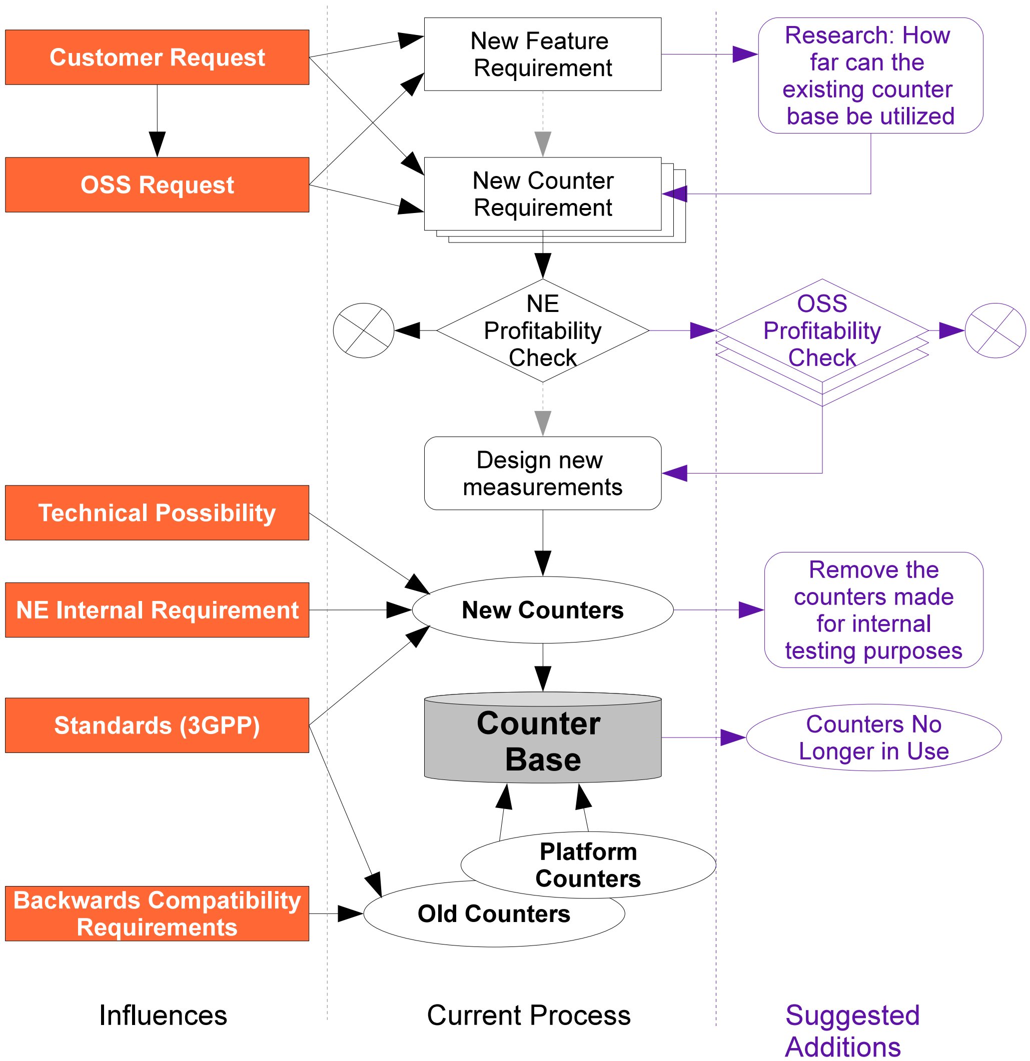

Figure 17: Generalization of counter base design procedures in NSN, with suggested additions.

ensure that the existing counters are utilized as far as possible, before implementing any new ones.

- Profitability of each counter (or set of counters) should be evaluated from the perspective of each sub-organization whose operation is affected by counters.
- Counters that have been implemented for NE R&D's internal purposes should be discarded when no longer needed, because they likely cause unnecessary workload for other entities.
- Counters that are no longer utilized by any customer for any purpose, should be removed from the counter base.

Issues directly related to customer requests and organizational structure are discussed in the next two subsections, and are thus omitted in the figure above.

5.3.2 Considering Customer Needs

One of the main issues identified in this research was the lack of understanding of the true customer needs. The true customer needs, in this context, are those needs that the customer is willing to pay for to get satisfied. If these needs are not recognized by the vendor, it is impossible to calculate the RoI regarding each feature, and some unprofitable investments are inevitably made. However, investigating the customer needs, especially when it comes to performance measurements, is itself an expensive and complex task, so it is not obviously profitable to conduct in full extent for every feature.

One possible solution would be the method of *licensing*, in which the vendor identifies (for each network element) the counters that are likely not utilized by most of the customers, organizes them in to feature sets, and asks for an additional price for activating each feature. Only the access to the basic set of counters, including the commonly used ones as well as those that have significant roles in problem-solving cases (even though customer would not directly see value in them) would be offered free of additional charge.

Licensing method has several advantages:

- Customers have incentives to more carefully evaluate which counters they truly need, and choose only those counters.
- By adjusting the prices, vendor would directly see which counters customers are willing to pay for and how much, without conducting expensive researches.
- Counters not purchased by any customer could “safely” be discarded.

Disadvantages of the licensing method are the difficulty of determining the feature sets (due to the large number of counters) and their asking prices, as well as the possible negative customer response due to charging for features that have previously belonged to the elements as standard. Because of the cost (now borne by customer) of resolving the value of each feature, the outcome could be a situation in which the customer either purchases the element with all additional features, or chooses another vendor.

Whereas licensing would help the vendor to adjust its counter offerings to match the customer needs, an alternative approach would be to try to adjust the customer needs to match the implemented counters. This could be achieved by improved the marketing efforts: The customer should be made aware of the overall advantages of having extensive performance measurement capabilities (large number of detailed counters), as well as of each of the measurement related features that the competitors are lacking. Naturally, the cost of this marketing effort should be carefully considered and achievable benefits estimated.

5.3.3 Organizational Improvements

Another considerable source of counter related issues recognized in the research was the organizational structure of the company. Bottom-up approach to the counter planning (decisions made on low organizational levels and then aggregated on higher levels) and lack of clear company wide coordination of the planning processes, together with business goals and rewarding systems that do not encourage taking into account the benefits of the company in whole, create an environment in which it is obviously difficult to avoid excess costs or maximize the revenues.

It is always difficult to introduce any major changes in organizational structure, procedures, or policies in a large, global organization. However, several potential ways to improve the situation should be further investigated, for example:

- Establishing a new business entity that would drive the cooperation between all the sub-organizations the work of which is to some extent affected by counter related decisions. This entity would coordinate the counter planning process taking into account the costs and benefits of each party, and provide consultancy in all phases of the process.
- As a lighter alternative to the previous suggestion; defining communication policies between each of the sub-organizations to guarantee that each party's opinions are heard in the planning process.
- Renewal of the rewarding system to take into account not only the financial success of each product, but also the costs and benefits the product causes for other sub-organizations

5.3.4 Technical Improvements

As a recap, the main issues regarding the NSN's overall network element counter base properties were identified to be the large number of counters that are not utilized by any customer, counters implemented in unnecessarily high level of granularity, and (to lesser extent) the counters that are in some way duplicates of each other. Whereas most of these issues are more process and policy related, some can also be approached from a purely technical perspective.

One possible technical improvement worth further research would be the better utilization of "*(n-1)* out of *n*" approach for each set of counters, as explained in Subsection 4.2.1. For example, in several cases, implementing the summary counter along with (only) the most useful sub-counters would enable the reduction of both the number of counters and the need for post-processing of performance data, without significantly increasing the cost of NE R&D or reducing the level of detail of the data available to the CSP's network planning and optimization departments.

6 Final Conclusions

Three goals were defined for this thesis in Chapter 1. The first goal was to identify and describe the ways by which implementation of network element performance measurement capabilities affect the vendor's profitability. To achieve this goal, the problem was first divided into smaller parts. Literature survey was conducted to gather existing knowledge and research results regarding each of the parts and linkages between the parts. Also the results of the interview research were utilized. The results of this study were discussed in Chapter 4.

The second goal was to identify the issues in NSN's current procedures in the light of the previous results. To achieve this goal, the first task was to study the procedures themselves as well as the research environment; organizational structure, processes, and policies of the company. The second task was to search for the issues in these matters, by using conclusions made before about the linkages between measurement functionality choices and vendor's profits.

The third goal of the thesis was to indicate the areas where the greatest potential for improving the company's profitability exists, by analyzing the identified issues. A large number of people from different parts of the organization were interviewed and their perceptions regarding the issues and potential improvement methods were gathered and analyzed. A few suggestions for topics of future research were presented based on the results. Chapter 5 describes the identified issues and improvement suggestions.

Several difficulties were experienced during the research process. The original goals proved to be excessively ambitious and they needed to be redefined several times; for example, the financial calculations needed to be omitted. However, further delimiting the topic would have been difficult without considerably decreasing its value as a research.

Although the first goal was achieved on a high abstraction level, that is to say, the linkages between the vendor's profitability and implementation of the elements' measurement functionality were sufficiently covered, the actual RoI calculations had to be omitted due to the excessive scope and complexity of the research environment. Therefore, the identification and analysis of the company specific procedures and issues also needed to be conducted on a rather high abstraction level, leaving the actual profitability calculations as a subject of future research.

Consequently, interviews of specialists and managers were used as a primary source of information for the research of the company specific procedures and issues. This naturally leaves some room for ambivalence, since the interviews always reflect the interviewee's personal opinions and perceptions, to some extent. Having concrete, quantitative figures as a baseline would have considerably increased the value of the study. However, the approach that was taken clearly was the only one practicable under the circumstances.

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Appendix A

A list of the persons who have been interviewed or who have otherwise contributed to the research behind this thesis:

M. Amaral De Figueiredo	Software Developer (Ext.), OSS
Kashyap Bhatt	OSS PM Architect
Christian Cosimetti	Product Specialist, Radio Access /PM
Jussi Erjanti	Senior Product Specialist, OSS
Erik Hiltunen	Manager, R&D Department, OSS
Jörg Huth	Operability & Performance Management R&D Line Manager, Radio Access
Risto Häkkinen	Senior Specialist, System Architecture, OSS
Jari Juntunen	Core Product Manager, OSS
Anssi Juppi	NE Solution Architect, Core
Raimo Kangas	Manager, R&D Team, OSS
Helinä Keski-Petäjä	Radio/3G Product Line Manager, OSS
Hannu Kokko	Manager, R&D Department, OSS
Riku Kylmäkoski	Manager, Q&P
Minna Laanti	Specialist, Integration/Verification, OSS
Reijo Lahti	Manager, R&D Team, OSS
Jari Liimatainen	NSN Operability Manager, OSS
Kari Loukola	Head of Product and Solution Management, OSS
Esa Malm	NE Solution Architect, Core
Juhani Neva	NOP Concept/Service Manager, Content Management Coordinator
Kai Oelert	Manager, PM Applications, OSS
Teija Olkkonen	Specialist, Systems Engineering, OSS
Michael Port	Manager, OSS NE Integrations
Jaakko Riihinen	Head of OSS R&D
Juha Riissanen	Quality Manager, OBS Business Excellence
Juha Rikkilä	Manager, Business Excellence
Janne Rissanen	Senior Specialist, Specification, OSS
Rauno Roppo	Senior Specialist, Specification, OSS
Kari Rossi	Principal, Interoperability & Customer Technologies
Vilho Räisänen	Senior Specialist, RTP RT NOA Management
Sami Sailo	Business Development Manager
Marko Siiskonen	Senior O&M System Specialist
Martti Tuulos	Manager, R&D Department, OSS
Rami Mattila	Elisa
Antti Maarela	Elisa
Marko Salmi	Elisa
Heikki Leppänen	Elisa