

ABSTRACT

The Laboratory of Telecommunications Technology is active in Research in the areas of networking technology and teletraffic theory. Currently the focus of our research is on enhancing the Internet technology with capabilities that are needed for it become the all services networking technology. These capabilities include Quality of Service mechanisms, a set of new protocols, improved security and interoperability solutions with legacy networks. We give graduate and post-graduate courses in data communications including the Internet technology, in circuit switched networking, in switching, in teletraffic theory and in protocol and service development. In year 2000, Laboratory staff published three journal papers and 27 papers in conferences. In 2000, two Licentiate degrees and 33 M.Sc degrees were awarded to the students of our Laboratory.

Helsinki University of Technology
Department of Electrical and Communications Engineering
Laboratory of Telecommunications Technology
Address info

Professor Raimo Kantola Tel +358 9 451 2471, fax +358 9 451 2474 e-mail: raimo.kantola@hut.fi	Secretary Arja Hänninen Tel +358 9 451 2461, fax +358 9 451 2474, email: arja.hanninen@hut.fi
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1 INTRODUCTION

This is the last Annual Report of the Laboratory of Telecommunications Technology. In reaction to the convergence in the networking technology, at the end of year 2000 we decided to change our name to *Networking Laboratory* (Tietoverkkolaboratorio, Laboratoriet för Nätteknik). We believe that this new name better reflects the real content of our research and also our courses. We also renamed a lot of our graduate and postgraduate courses to reflect the changed priorities and current real situation in our teaching and research.

A new professor, Jorma Jormakka Ph.D, joined the Laboratory on 1st of January, 2000. He gave his inauguration lecture on March 7. The area of the new chair is telecommunications, in particular software, services and protocols.

Operationally, the year was dominated by increased maturity of our research groups – we now have three professors who are active in a well interlinked set of research areas contributing towards mutually beneficial research seminars and discussions. We have three researchers with a doctoral degree and a number of advanced Ph.D students in our research groups. After a rather long dry period in the broad area of networking technology, our post-graduate students have started to submit Licentiate theses and in the year 2000 two of them were awarded the Licentiate degree. What is even more delightful, the trend seems to continue.

The internationalization of the laboratory proceeded. Our sister laboratory at KTH, headed by Gunnar Karlsson, visited us and we had a fruitful joint seminar with them in November. The Master's Programme in Telecommunication continued and the second intake of some 60 students were enrolled in this programme in Fall 2000. Our teaching contribution in the programme is increasing. The programme is headed by professor Kantola from our laboratory. In the area of teaching, an important milestone was the introduction of the Communications Engineering degree program in parallel with the Electronics and Electrical Engineering degree program in the Fall 2000. We made a significant contribution towards the definition of the Communications Engineering program and we believe that this will allow our Department to present a much clearer profile of education when competing for new recruits.

A notable event in our teaching was the Telecommunications Forum, organized for the fourth time with an ever increasing success. In the study year 2000 - 2001, two majors Telecommunications Technology and Teletraffic Theory were offered. The total number of courses provided by the laboratory was 28. Three of the courses are new and were developed by professor Jormakka. Also, four (S38.001, S38.145, S38.130, S38.151) of the courses were given in English and for some others the lecture notes were made available also in English.

On May 30th, we had our annual development day in Sjökölla. Professor Ohisalo gave a presentation on the use of Problem Based Learning in teaching exemplified by its use in higher medical education. In June we did a boat trip to the sunny Iso Vasikkasaari. Other extra-curricular activities included several sports events and a pre-christmas celebration in restaurant Shashlik. Part of the celebrations was the presentation of the traditional Finnish tiernapojat by the members of the staff, which we all enjoyed tremendously.

An aspect that limited the possibilities of further development of the laboratory was that a lot of us were staying in a temporary location and we moved twice during the year. Fortunately, the last move was into a renovated wing and the situation is now normalized.

These and other developments in 2000 are described in more detail in this Annual Report.

1.1 Key facts 2000

Masters thesis	33
Lic.Tech. thesis	2
International journal publications	3
Conference presentations	27
Other publications	4

2 PERSONNEL 2000

2.1 Laboratory staff

Jormakka, Jorma	Ph.D., professor
Kantola, Raimo	D.Sc. (Tech.), professor, head of laboratory
Kilkki, Kalevi	D.Sc. (Tech.), docent
Pirinen, Aulis	Ph.D., docent
Rahko, Kauko	D.Sc. (Tech.), professor emeritus
Virtamo, Jorma	D.Sc. (Tech.), professor
Aalto, Samuli	Ph.D., senior researcher
Beijar Nicklas	Research assistant
Costa Requena, Jose	M.Sc., research scientist
Gao, Peng	Research assistant
Erke, Tapio	Laboratory engineer, on leave of absence
Espigares, Inmaculada	M.Sc., research scientist
Fan, Tyh-Dar	Research assistant
Haapala, Juho	Research assistant
Hlinovsky, Jan	Research assistant
Hyytiä, Esa	M.Sc., research scientist
Hänninen, Arja	Department secretary
Ilvesmäki, Mika	M.Sc., senior research scientist
Kaikkonen, Sampo	research assistant
Karvo, Jouni	Lic.Sc. (Tech), research scientist
Kosonen, Vesa	M.Sc., assistant
Kuusela, Pirkko	Ph.D., senior research scientist
Lassila, Pasi	Lic.Sc. (Tech.), research scientist
Lemetyinen, Mirja	Department Secretary
Leppänen, Risto	Summer trainee
Lignell, Laura	Research assistant
Lindfors, Erno	Research assistant
Luoma, Marko	Lic.Sc. (Tech), senior research scientist
Ma, Zhangsong	M.Sc., research scientist
Mäntylä, Harri	M.Sc., research scientist
Nieminen, Klaus	Student adviser
Nupponen, Esko	Senior laboratory supervisor
Nyberg, Eeva	M.Sc., research scientist
Paju, Antti	Research assistant
Pedros Porres, Ramiro	Research assistant
Penttinen, Aleksi	Research assistant
Peuhkuri, Markus	M.Sc., senior research scientist
Pitkäniemi, Kimmo	Research assistant
Ramirez Yebenes, Julio	Research assistant
Renko, Jari	M.Sc., research scientist
Rummukainen, Hannu	Research assistant

Sipilä, Mari	Research assistant
Sirén, Elena	Research assistant
Somerkoski, Pauliina	Research assistant
Susitaival, Riikka	Research assistant
Ventura Agustina, Juan	Research assistant
Voipio, Kirsi	Research assistant
Zhang, Peng	Ph.D., research scientist
Zhen, Xiaoling	Research assistant
Zhou, Wenpeng	Research assistant

2.2 Part-time teachers & assistants

Aarnio, Jaakko	S-38.164	Broadband Switching Technology
Kilkki, Kalevi	S-38.210	Special Course in Telecommunications Technology
Mertanen, Pauli	S-38.191	Corporate Networks
Pietiläinen, Antti	S-38.164	Broadband Switching Technology
Ruutu, Jussi	S-38.164	Broadband Switching Technology
Sainio, Sampo	S-38.147	Simulation of Telecommunication Networks
Tervonen, Ari	S-38.164	Broadband Switching Technology
Tuunainen, Virpi	S-38.191	Corporate Networks

2.3 Guest lecturers

S-38.001 Telecommunications Forum

Pauli Heikkilä	Dr. Tech., Man. Dir.	Digita
Markus Bäckström	Development Man.	Elisa Communications
Jorma Heinonen	Deputy Man. Dir.	Comptel
Valtteri Pukander	Director	LetsBuyItcom
Tom Källström	Director	Finnair
Ukko Lappalainen	General Manager	Nokia Networks
Kari Penttilä	Vice President	IOBOX
Tatu Ylönen	Chief Technology Officer	SSH Communications Security
Petteri Koponen	President	Firsthop
Heikki Nortta	Vice President	Nokia Mobile Phones
Juha Häkämies	Chief Technology Officer	Sonera Zed
Marjo Sjöberg	Director	Done Wireless
Mika Uusitalo	Vice President	Sonera

3 RESEARCH PROJECTS

3.1 Mi²TTA - Models for Integrated Internet and Telecommunication networks Traffic and Architecture

Project leader Jorma Virtamo
Researchers Marko Luoma, Markus Peuhkuri

MI²TTA is part of the Finnish contribution to the European COST 263 Action, in which laboratories and research institutes from 12 countries participate. The research is funded by the Academy of Finland. The project focuses on issues of traffic management and measurements in the Internet, in particular in the QoS aware Internet.

The main milestones during the last year have been:

- A simulation model for the Differentiated Services based Internet environment was completed. This simulator, built on the commercial simulation tool BONEs, is able to simulate Assured Forwarding, Expedited Forwarding and Best Effort traffic classes implemented with Weighted Round Robin, Processor Sharing and Priority scheduling. Comprehensive studies of combining different classes in the same network have been carried out. A licentiate thesis describing DiffServ architecture, the simulator and the simulation studies was completed.
- The measurement system for a long time scale continuous measurement of Internet traffic developed in the previous year was used to make extensive traffic studies. The main interest in the measurements has been the characterization of the impatience of users of http web browsers. The user impatience is an important consideration from the point of view of different congestion management schemes. However, relatively little is known about the users' impatience behaviour; thus the measurements have yielded new information.
- The European COST 263 Action organized the first international workshop on Quality of Future Internet Services, QoFIS'2000, in Berlin, September 25-27, 2000. The members of the laboratory were actively involved in the work of the Technical Program Committee. Three papers from the laboratory were presented at the workshop.

3.2 COST 257

Project leader: Jorma Virtamo
Researchers: Samuli Aalto, Esa Hyytiä, Eeva Nyberg, Riikka Susitaival

COST 257 was a joint project between the Laboratory of Telecommunications Technology at HUT and VTT Information Technology. The project was carried out as the Finnish contribution to the European COST 257 Action, in which laboratories and research institutes from 18 countries participated. The European Action ended in

September 2000 with a final seminar held in Würzburg. The final report of the project, published in the final seminar, consists of a summary booklet and a CD-ROM compilation of 205 working documents, 30 of which were written by the VTT and HUT research groups.

The research of the domestic project was funded by TEKES, Nokia Networks and Sonera. The research focused on models and methods for the performance analysis of telecommunication systems. The following problem areas were addressed in 2000:

- An analytical study of the QoS mechanisms in the Internet was initiated. The work aims at modeling the mechanisms both at the flow and packet levels. Attention has been paid, in particular, on the operation of the SIMA mechanism proposed by K. Kilkki of Nokia Research Center. A model has been developed to calculate the packet losses experienced by different priority classes in a SIMA node. The results are in good agreement with the measurements made at the Tampere University of Technology under similar experimental conditions.
- A new approach for the nearly optimal solution of the routing and wavelength allocation (RWA) problem in WDM networks has been further developed. The method applies policy iteration in the setting of Markov Decision Processes to improve a given heuristic policy used as a starting point. Experiments made with the method have shown that the performance of the heuristic policy can indeed be improved. The improvement is greatest in cases where there are disparities in the values of different calls or the traffic is unevenly distributed in the network, i.e. when there are any kind of peculiarities which are difficult to take into account in heuristic policies.
- Buffering optical packets by a bank of delay lines in optical packet switches was analyzed. Under the assumption of Bernoulli arrivals, a Markov model was developed for the system and the model was solved numerically. The study clarified the factors that differentiate a "good" set of delay lines from "bad" ones. Some rule of thumb resulted for avoiding inefficient delay line combinations. Approximate closed form analysis is being pursued.

3.3 Com² - Computational Methods for the Performance Analysis of Broadband Communication Networks

Project leader: Jorma Virtamo
Researchers: Samuli Aalto, Jan Hlinovsky, Pirkko Kuusela, Pasi Lassila, Aleksi Penttinen, Hannu Rummukainen, Laura Lignell, Elena Siren

The aim of the project is to develop computational methods for the performance analysis of broadband communication networks. A program library of the algorithms resulting from the project is maintained. The project, which is funded by the Academy of Finland, will end in the middle of 2001. Specifically, the milestones in 2000 were:

- The performance of the TCP congestion control mechanism together with RED buffer management was studied. The earlier work where a RED controlled queue was described in terms of the expected values of the instantaneous queue lengths and the exponentially averaged queue length has been extended to include a population of TCP sources working in so called congestion avoidance phase with additive increase multiplicative decrease (AIMD) adaptation algorithm. The behaviour of the whole system is governed by a set of three retarded differential equations which provide the most refined model for the system available today. The model has been used to derive necessary and sufficient conditions for the stability of the system.
- New algorithms have been developed to calculate the end-to-end blocking probabilities in a multicast network, where an originating node sends several transmissions, "programs", via separate dynamic multicast trees, which the users can join and leave. While the earlier exact algorithm is scalable with regards to the network size, it becomes computationally complex for a large number of channels. The new algorithms tackle this problem. In the first phase, an algorithm was developed for the case where all the channels are statistically identical, i.e. chosen by the users with the same probability and having the same holding time distributions. Then the algorithm was extended for the case where the channels can be grouped into several sets such that within each set the channels are statistically indistinguishable. Further extensions include the multilayer coding of the channels.
- The efficient sampling method for the Monte Carlo simulation of multi bit rate networks introduced in the previous year was further developed. A fast implementation of the simulator was programmed in C and made publicly available via the web. An interface through which the program can be run interactively is being finalized. The sampling method was extended for the efficient simulation of multicast networks. Impressive speed-up factors of the same order as in the case of multi bit rate networks were recorded.
- The work on the optimal control of a link carrying multi bitrate traffic was completed. Control of a single link form the basis for optimal routing in a network. New methods for estimating the relative costs of states has been developed based on appropriate analytical representation of the cost function and recursive methods for calculating the matrix elements.

3.4 Quasimodo - Quality of Services Methodologies and solutions within the services framework

Project leader: Jorma Jormakka
Researchers: Ramiro Pedros Porres

The presence of Internet protocol (IP)-based networks and related applications is steadily getting more pronounced. Numerous applications require more than traditionally offered best-effort service, i.e. they ask for Quality of Service (QoS) assurance. Today's networks cannot support different requirements coming from

different applications, since the methodology, mechanisms and their implementations are not yet mature. Some mechanisms assuring service differentiation and QoS support in IP-based networks are available (e.g. Integrated Services (intserv), Differentiated Services (diffserv) by IETF), but it is not clear how to use these in order to deliver the service end-to-end with the quality agreed with a user. Also, it is not clear which parameters to use to express quality at application service level (i.e. the level the user perceives quality). Moreover, mapping these parameters to network performance parameters is not a trivial task. In addition, no services are charged for the quality they are provided with.

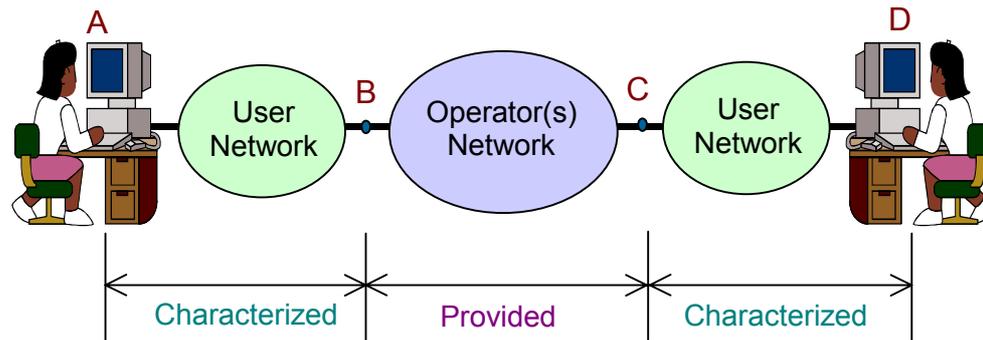


Figure 1. Original QUASI-model physical scenario

The EURESCOM project P906-GI QUASIMODO (Quality of Service Methodologies and solutions within the service framework: Measuring, Managing and Charging QoS) tried to answer some of the above issues. The main idea of offering a "reasonable" set of quality classes to users according to their needs and possibilities (e.g. to pay) was investigated by developing a QUASI-model, implementations and management, and charging schemes and models, as it will be described here. Figure 1 shows the basic idea of the QUASI-model, a provider is offering QoS guarantees in edge routers (B, C). The work in HUT concentrated on defining and implementing QoS measurements and QoS management. We created the QUASI-IntServ variant of the IETF IntServ architecture, where pipes are reserved between edge routers and QoS is monitored. Laboratory tests were made to show that the implemented design works.

3.5 IMELIO - Internet MEchanisms for quaLity and InterOperability

Project leader: Raimo Kantola
 Researchers: Mika Ilvesmäki, Peng Zhang, Zhangsong Ma, Sampo Kaikkonen, Pauliina Somerkoski, Nicklas Beijar, Jose Costa Requena, Julio Ramirez Yebenes, Wenpeng Zhou, Xiaoling Zhen

Internet has continued raising in importance as the future all enveloping networking technology. In September 2000, we started a new project, IMELIO – Internet Mechanisms for quaLity and InterOperability to work on improving the Internet technology and to carry on the work started in IPANA.

Differentiated Services seem to be the most promising way to introduce improved Quality of Service Mechanisms into the Internet. The idea of Differentiated Services has two main implementations: the DiffServ architecture and Multi-Protocol Label Switching with priority bits on the “shim” layer. The architectures allow carrying high quality voice and video among data over the network. DiffServ introduces per hop behaviours (PHBs) - essentially priorities for classes of packets. Based on PHBs the packets are treated differently in the network nodes. This changes the service paradigm of the network and will have wide business implications. Intermediate steps may be needed before DiffServ can be widely deployed.

The Architectures of DiffServ and MPLS are, however, by no means ready. Additional mechanisms for improving quality and network performance need to be studied and introduced. A candidate improvement to the Architecture of quality aware Internet is traffic classification - the idea that all or some of the traffic is classified by the network into background best-effort, interactive and real-time and that each of these classes are assigned different PHBs. This can be seen as a first short step in changing the service paradigm or a basis for assigning traffic to different PHBs per se in the ingress nodes or used as an additional mechanism in a highly loaded DiffServ network to avoid eventual or intermittent quality degradation in the network.

Another candidate improvement is Class or constrained based routing - the idea that each class or some of the classes could be routed differently from others for the purpose of improving service quality and network performance. A particular problem that could be addressed by routing is avoiding starvation of the lower priority classes on highly loaded links while the amount of high priority traffic increases. The new routing could be applied to flows or be introduced as another background process. In any case, this would change the current shortest path internet routing paradigm. We need to understand what are the potential gains under different conditions and how this could be implemented - a particular complication in implementing alternative routing in the Internet is that currently there is no route pin-down mechanism. MPLS (Multi Protocol Label Switching) is now proposed as a means to retain the existing traffic on the original shortest path while additional network load is diverted to an alternative path - i.e. to achieve route pin-down. Alternative route pin-down mechanisms may also be studied.

While Internet grows in importance and starts to carry voice, before it can replace the Switched Circuit Network in a large scale, it has to become a peer network to the Switched Circuit Network. The SCN does not disappear overnight, maybe it never will - we need to be prepared for a long period of coexistence of the two peer networks. This means that we need to identify the interoperability and service management issues in the hybrid network and solve them before they become problems. In IPANA we identified Numbering and number portability as a key interoperability issue in the hybrid network. IPANA has produced a draft solution to this problem based on loosely synchronised reachability information across multiple administrative domains. In IMELIO we intend to refine the solution and study its scalability properties.

Telephony over Internet introduces a new environment for call signaling. New approaches are being introduced, specified and prototyped. At the moment the most important developments are ISUP over IP, Megaco and SIP. We need to follow this development, identify and evaluate the fundamental changes in signalling in as much as they may have an impact in the technology base and the business conditions in the industry.

The main results of the project during its first three months included an M.Sc –thesis on the Performance Cost evaluation of QoS routing and a Journal paper on the Interoperable Routing Information testbed.

3.6 IPANA / IP voice

Project leader: Raimo Kantola
Researcher: Jose Costa Requeña, Juho Haapala, Nicklas Beijar, Julio Ramez Yebenez

Voice over IP studied the transmission, switching and routing of voice in IP networks and service interoperability of such networks with PSTN/ISDN. The project was initiated in April 1997 and completed in September 2000. The project was mainly funded by a TEKES grant, and it had four industrial partners (Nokia Research Center, Nokia Telecommunications, Sonera Oy and Omnitele/Helsinki Telephone Research).

During the third year of the project we continued to develop the Interoperable routing information testbed for IN/IP Telephony. The purpose of the testbed is to study the feasibility of automating service management in the hybrid network and provide seamless number portability as a by-product. The results in this regard include conference papers in IN2000 and IPTel2000 conferences and significant progress on the software development of the testbed itself. In addition we reported our results on Service development in the SIP (session initiation protocol) environment in the IPTel2000 conference.

3.7 IPANA / IP switching

Project leader: Raimo Kantola
Researchers: Mika Ilvesmäki, Peng Zhang, Zhangsong Ma, Sampo Kaikkonen, Pauliina Somerkoski, Juan Ventura Agustina, Peng Gao

The project was initiated in April 1997 and completed in September 2000. The project was mainly funded by a TEKES grant; it has four industrial partners (Nokia Telecommunications, Sonera Oy and Omnitele/Helsinki Telephone Research).

Although viewed as the prototype of the future Information Superhighway, the current Internet technology has a number of drawbacks, including: limited transmission and routing capacity, limited speed, long and variable transmission delays and no support for quality of service. The project was aimed at helping to solve some of these problems by focusing on issues of deployment of ATM to increase the performance of the Internet and to improve the quality of service available to the user.

The most important results in the project during 2000 lay in two areas. First area is traffic classification where we use neural algorithms for classifying Internet traffic and apply the classification results for boosting the network performance and perceived quality of service. In the 2000 our research on Quality of Service Routing started in 1999 started to bear fruit. In this topic, the purpose is to study the feasibility and usefulness of using constrained based or class based routing in an IP switched network built using Multiprotocol Label Switching and Differentiated Services.

The first public version of QRS – a new quality of service routing simulator was completed and released. Results related to the QRS –simulator were reported in three different conferences. A post graduate seminar was organised in this area. The seminar produced a handsome set of student papers and study reports. Some of the postgraduate students also used our QRS simulator as part of their study of routing.

4 TEACHING

4.1 Development of teaching

Professor Jormakka introduced three new courses into our curriculum. These are Service creation and management (S38.151), Security in telecommunications (S38.153) and Protocol design (S38.157). These courses also form the core of a new path within the telecommunications technology major in parallel with the existing data communications and switching technology paths.

Docent Kalevi Kilkki gave a special course on differentiated services in the Internet. A new course called Quality of Service in the Internet was conceived and will be delivered during this year for the first time strengthening our teaching in the area of internetworking technology.

This is the full list of courses in our curriculum:

4.1.1 *Studia generalia*

S-38.001 Telecommunications Forum (Telecommunications Forum)

4.1.2 *Basic courses for all students studying telecommunications*

S-38.105 Principles in Communication Engineering (Tietoliikennetekniikan perusteet)

S-38.118 Principles in Telecommunications Technology (Teletekniikan perusteet)

4.1.3 *Courses concerning communications and networks*

S-38.188 Telecommunication Networks (Tietoliikenneverkot)

S-38.191 Corporate Networks (Televerkot yrityksissä)

4.1.4 *Courses on switching and ATM*

S-38.110 Telecommunication Switching Technology I (Tiedonvälitystekniikka I)

S-38.122 Telecommunication Switching Technology II (Tiedonvälitystekniikka II)

S-38.164 Broadband Switching Technology (Laajakaistainen välitystekniikka)

4.1.5 *Courses on teletraffic theory*

S-38.145 Introduction to Teletraffic Theory (Liikenneteorian perusteet)

S-38.147 Simulation of Telecommunication networks (Televerkkojen simulointi)

4.1.6 *Courses on protocols and services*

S-38.151 Service Creation and Management (Palvelunkehitys ja hallinta)

S-38.153 Security in telecommunications (Tietoliikenteen tietoturva)

S-38.157 Protocol Design (Protokollasuunnittelu)

4.1.7 Seminars, laboratory works, special assignments

- S-38.117 Seminar on Telecommunications Technology (Teletekniikan seminaari)
- S-38.123 Telecommunications Technology, laboratory course I
(Teletekniikan laboratoriotyöt I)
- S-38.124 Telecommunications Technology, laboratory course II (Teletekniikan laboratoriotyöt II)
- S-38.128 Telecommunications Technology, special assignment
(Teletekniikan erikoistyö)
- S-38.202 Telecommunications Engineering Project (Teletekniikan projektityö)
- S-38.300 Thesis Seminar on Telecommunications Technology
(Teletekniikan diplomityöseminaari)

4.1.8 Postgraduate courses

- S-38.130 Postgraduate Course in Telecommunications (Teletekniikan lisensiaattikurssi)
- S-38.141 Teletraffic Theory (Teleliikenneteoria)
- S-38.143 Queueing Theory (Jonoteoria)
- S-38.149 Postgraduate Course in Teletraffic Theory (Teleliikenneteorian lisensiaattikurssi)
- S-38.200 Individual Course in Telecommunications (Teletekniikan yksilöllinen opintojakso)
- S-38.210 Special course in Telecommunications Technology (Teletekniikan erikoiskurssi)
- S-38.350 Research Seminar on Telecommunications Technology
(Teletekniikan tutkijaseminaari)

4.2 Degrees

4.2.1 Licentiate of Technology

Esa Salminen: The utilisation of satellites in Finnish Defence Forces

The use of space is strongly growing. Especially major space powers invest large amounts of money in developing different space-based activities today. Also small European countries like Finland have good opportunities to join the space activities within the European Space Agency (ESA) and the European Union.

The thesis defines, for the first time from a national point of view, how the Finnish Defence Forces can utilise satellite communications, satellite navigation/orientation and remote sensing. The multiple criteria method known as analytic hierarchy process used in the research proved to be an effective semi-hard method for a technical study.

Marko Luoma: Simulation studies of Differentiated Services Networks

The thesis serves as an introduction to the service problems of QoS networking in the Internet. It presents Best Effort, Integrated Services and Differentiated Services architectures, and tries to pinpoint their strengths and weaknesses. Simulations of DiffServ provide some insight to the problems of mixed implementations of service. In addition, difficulties of service provisioning become apparent from the results.

4.2.2 Masters of Science in Telecommunication technology

Ahvonen, K.	IP telephony signalling in a UMTS All IP network	Nokia
Aittola, M.	Analyzing performance of telecommunications software in an emulator environment	Nokia
Alutoin, M.	Interworking functions in a V5.2 controlled access node	Nokia
Andelin, M.	Impacts of GPRS on service systems of a mobile portal, In Finnish (GPRS:n vaikutukset matkaviestinportaalin palvelu-järjestelmiin)	SON
Frosterus, T.	Business and technology networks in the Internet portal industry	Nokia
Haapalainen, J.	Windows 2000- käyttöjärjestelmän käyttöönotto suur-yrityksessä	UPM
Hakala, T.	Comparison of IP based virtual private network architectures	-
Hapuoja, V.	Operator interfaces to the GPRS roaming network, in Finnish (Operaattorirajapinnat GPRS-yhdysliikenneverkkoon)	SON
Huhtio, S.	Interworking between GPRS and IP networks, In Finnish (GPRS:n ja IP-pohjaisten verkkojen yhteistoiminta)	SIE
Immonen, J.	3G Messaging-Analysis of markets and solutions	TEC
Immonen, M.	Estimation of Software Release Criteria and Testing Effort Using Software Reliability Analysis	TL
Järvinen, V.	Transforming value added short message services into WAP services, In Finnish (Lyhytsanomalisäarvopalveluiden muuntaminen WAP-palveluksi)	Elisa
Kohila, T.	Location Services on Wap over GPRS	Nokia
Koivu, K.	Data Service Development In Mobile Networks	OT
Kokkonen, J.	Feasibility of Differentiated Services and MPLS in UMTS LPS Interface, In Finnish (Eriytettyjen palveluiden ja leima-kytkennän soveltuvuus UMTS:n radio- ja verkkojärjestelmien yhdistämisessä)	Nokia
Laine, J.	Utilizing a signalling network management system in network operator's services, in Finnish (Merkinanto-hallintajärjestelmän hyödyntäminen verkko-operaattorin tuotteissa)	SON
Laine, J-E	Productiozation and development of a tailored public sector telephone service network, In Finnish (Palveluliittymän tuotteistus ja kehitys)	Elisa
Ma, Z.	Performance and Cost Analysis of QoS Routing in an Intranet	Lab
Malmström, J.	Security in initiating a Fixed Network call from the Internet, In Finnish (Internetistä muodostetun kiinteän verkon puhelun tietoturva)	SIE
Nieminen, J-P	Virtual Private Network over Digital Subscriber Line	TL
Nieminen, P.	Implementation and economics of voice transmission in a corporate IP network, In Finnish (Puheensiirron toteuttaminen ja taloudellisuus yrityksen IP-pohjaisessa verkossa)	Elisa
Ollila, H.	Mobile data in multilayer GSM network, In Finnish (Pakettidataliikenne monikerroksisessa GSM-verkossa)	SON
Partanen, A.	Security in mobile corporate applications	SON
Poikselkä, M.	Number portability in third generation mobile networks	Nokia
Relander, R.	Gateway between the switched network and voice over IP in TETRA networks, In Finnish (Piirikytkeytyn puheen ja IP-puheen yhdyskäytävä TETRA-järjestelmässä)	Nokia
Rummukainen, H.	On Approximative Markov Control of Multiservice	Lab

Telecommunication Links

Saarnio, J.	Managing Multinational Research Projects	NRC
Tiainen, J.	Simulation of Dual Band Base Station Capacity, In Finnish (Kaksitaajuustukiaseman kapasiteetin simulointi)	Nokia
Valtonen, T-P	Quality of Service In The 3 rd Generation Transmission Network And The Internet	Nokia
Vanhala, M.	Service differentiation in an xDSL access network	SIE
Villikka, J.	The signalling traffic load of the fixed network in a mobile exchange, In Finnish (Kiinteän puhelinverkon merkinantoliikenteen kuorma matkapuhelinkeskuksessa)	SIE
Yang, M.	Managing a Mobile Network Dynamically	NRC
Ylipieti, M.	Parley Service Architecture in Third Generation Mobile Networks	Nokia

Elisa	Elisa Communications Oyj
Lab	HUT / Laboratory of Telecommunications Technology
NRC	Nokia Research Center
Nokia	Nokia Corporation
SIE	Siemens Oy
SON	Sonera
OT	Omnitele Oy
TEC	Tecnomen
TL	Tellabs Oy
UPM	UPM-Kymmene

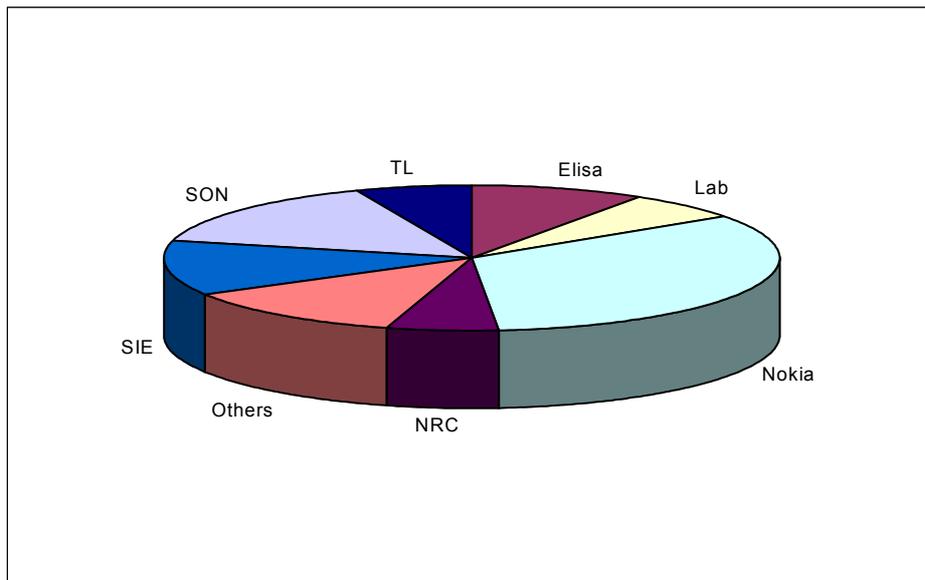


Figure 2. Employers of Masters students.

5 ACTIVITIES

5.1 International conferences and meetings

- COST257 Management Committee meeting, January 20-21, Barcelona, Spain (Virtamo)
- Fifth INFORMS Telecommunications Conference (Boca2000), March 5-8, 2000, Boca Raton Florida USA (Aalto)
- IWT-panel meeting, March 9-10, 2000, Bryssels, Belgium (Kantola)
- IEEE Infocom-2000 conference, March 26-30, 2000, Tel Aviv, Israel (Virtamo)
- The 1st IP-Telephony Workshop, April 12-13, 2000, Berlin, Germany (Kantola, Reguena)
- IEEE Intelligent Network Workshop - IN 2000, May 7-11, 2000, Cape Town, South-Africa (Bejar, Kantola)
- Dagstuhl Workshop on IP Quality of Service, May 8-12, 2000, Dagstuhl, Germany (Jormakka)
- Networking 2000 Conference, May 14-19, 2000, Paris, France (Nyberg, Virtamo)
- COST-257 Management Committee Meeting, May 18-19, 2000, Kjeller, Norway (Aalto)
- Sixteenth UK Teletraffic Symposium (UKTS), May 22-24, 2000, Harlow, UK (Peng)
- 2000 Symposium on Performance Evaluation of Computer and Telecommunication Systems, June 16-20, 2000, Vancouver, B.C. Canada (Peng)
- The Fifth IEEE Symposium on Computers and Communications, July 3-7, 2000, France (Hyytiä)
- IFIP ATM & IP 2000 Workshop, July 17-19, 2000, Ilkeley Yorkshire, UK (Ilvesmäki)
- NIT 15th Nordic Teletraffic Seminar, August 22-24, 2000, Lund, Sweden (Aalto, Jormakka, Kuusela, Lassila, Virtamo)
- Quality of Future Internet Services Conference (QofIS'2000), September 23-26, 2000, Berlin, Germany (Jormakka, Kantola, Lassila, Peng, Virtamo)
- COST257 final seminar, September 26-29, 2000, Wuerzburg, Germany (Aalto, Lassila, Virtamo)
- TINA2000 Conference, September 13-15, 2000, Paris, France (Kantola)
- Interworking 2000 Conference, October 3-6, 2000, Bergen, Norway (Peng)
- REMIN2000 Conference, October 4-8, 2000, Pisa, Italy (Karvo)
- IWT-panel meeting, November 23-24, 2000, Bryssels, Belgium (Kantola)

- Eurescom meeting, November 23-24, 2000, Berlin, Germany (Jormakka)
- QoS of Next General Networking, November 27-30, 2000, Nagoya, Japan (Hyytiä)
- COST263 meeting, November 29-December 1, 2000, Budapest, Hungary (Peuhkuri)

5.2 Foreign visitors in 2000

The following persons have visited the Laboratory of Telecommunications Technology during the year 2000:

Professor Udo Krieger, J. W. Goethe-Universität, Germany

Professor Gunnar Karlsson, researchers Lena Wosinska, Robert Rönngren, Fredrik Orava, Henrik Lundqvist, Evgueni Ossipov, Ignacio Mas Ivars, Ian Marsh from Sweden, Royal Institute of Technology (KTH)

Professor Shiduan Cheng, Beijing University of Posts and Telecommunications, China

Dr. Tech. Jian Ma, Nokia China R&D Center, China

Professor Valey I Chrissanov, St. Petersburg State University of Telecommunications, Russia

Professor Ding Daogi, National Power Telecommunications Center, China

Philip K McKinley, Michigan State University, USA

Professor Condalo Arce, University of Delaware, USA

6 PARTICIPATION IN BOARDS AND COMMITTEES

6.1 University boards and committees

- **Raimo Kantola**

- Director of the Master's Programme in Telecommunications
- Member of Council of Degree Programme

- **Jorma Virtamo**

- Vice chairman of the Committee for the International Affairs (until July 2000)
- Chairman of the Committee for the nomination proposal for the appointment of the professorship in Telecommunications Engineering (Virantäyttötoimikunta)

- **Markus Peuhkuri**

- Member of Committee of Post Graduate School at Department of Electrical and Communications Engineering (Tohtorikoulutoimikunta)

- **Kirsi Voipio**

- Member of Committee for Qualitative Development of teaching at Department of Electrical and Communications Engineering (Opetuksen laatutoimikunta)

6.2 Other boards and committees

- **Jorma Jormakka**

- Member of the teaching council of the National Defense Collage
- Member of the scientific council of the National Defense Collage
- Member of Technical Committee of 1st International Workshop on Quality of Future Internet Services, QofIS, Berlin, Germany, September 15-16, 2000
- Member of the Program Management Committee of EURESCOM QUASIMODO-project

- **Raimo Kantola**

- Member of the Supervisory Council in Sonera Oyj

- **Jorma Virtamo**

- Vice Chairman of the action COST 257 “Impacts of new services on the architecture and performance of broadband networks”
- Session chairman at the Final Seminar of the action COST 257, Würzburg, September 27-29, 2000
- Member of IFIP Working Group 6.3, Performance of Communication Systems
- Member of the Technical Committee of and session chairman at the Conference Networking 2000 (IFIP-TC6), Paris, France, May 14-19, 2000
- Member of the Technical Committee of ITC Specialist Seminar on Mobile Systems and Mobility, Lillehammer, Norway, March 22-24, 2000
- Session chairman at the Fifteenth Nordic Teletraffic Seminar, NTS-15, Lund, August 22-24, 2000
- Member of the Technical Committee of and session chairman at the First International Workshop on Quality of Future Internet Services, QofIS’2000, Berlin, Germany, September 15-16, 2000
- Member of the Scientific Committee of the Eight IFIP Workshop on Performance Modelling and Evaluation of ATM & IP Networks, Ilkley, U.K., July 17-19, 2000
- Member of the Program Committee of the Ninth IFIP Working Conference on Performance Modelling and Evaluation of ATM & IP Networks, Budapest, June 27-29, 2001
- Member of the Technical Program Committee of the Seventeenth International Teletraffic Congress, ITC-17, Salvador da Bahia, Brazil, September 27-29, 2001
- Member of Technical Program Committee of the Internet Performance Symposium, IPS 2001, associated with Globecom 2001, San Antonio, Texas, November 25-29, 2001
- Member of the Board of the Research Foundation of Helsinki Telephone Company

6.3 Referee activities

- **Jorma Jormakka**

- Reviewer for the following scientific journal: IEEE Transactions on Vehicular Technology
- Reviewer for the following conference: QofIS’2000
- Reviewer for Finnish Academy of Science

- **Jorma Virtamo**

- Reviewer for the following scientific journals: IEEE Journal on Selected Areas in Communications, IEEE/ACM Transactions on Networking, Performance Evaluation, Applied Stochastic Models in Business and Industry
- Reviewer for the following conferences: Infocom 2000, ITC Specialist Seminar on Mobile Systems and Mobility, Networking 2000, First International Workshop on Quality of Future Internet Services (QofIS'2000), 25th Annual IEEE Conference on Local Computer Networks, 2001, IEEE-EURASIP Workshop on Nonlinear Signal and Image Processing
- Member of the external examination committee at the Ph.D. dissertation of Ulf Ahlfors, October 20, 2000, Department of Communications Systems, Lund Institute of Technology

7 Publications

1. Aalto, S. Optimal control of batch service queues with finite service capacity and linear holding costs. *Mathematical Methods of Operations Research*, 2000. Vol. 51, nro 2, pp. 263-285.
2. Aalto, S. & Scheinhardt, W.R.W. Tandem fluid queues fed by homogeneous on-off sources. *Operations Research Letters*, 2000. Vol. 27, nro 2, pp. 73-82.
3. Aalto, S. & Virtamo, J.T. Combinatorial algorithm for calculating blocking probabilities in multicast networks. *Fifteenth Nordic Teletraffic Seminar*, Lund, August 22-24, 2000. pp. 23-34.
4. Aalto, S. & Virtamo, J.T. Practical algorithm for calculating blocking probabilities in multicast networks. Espoo: 2000. 16 s. (COST257 TD(00)29).
5. Costa Requena, J., Espigares, I. & Kantola, R. New Tools for Programming IP Telephony Services. 1 st IP-Telephony Workshop (IPTel 2000), Berlin Germany, April 12-13 2000. Berlin 2000, pp. 167-177.
6. Hyytiä, E. & Virtamo, J.T. Dynamic Routing and Wavelength Assignment Using First Policy Iteration. Espoo: 2000. 13 s. (COST257 TD(00)08).
7. Hyytiä, E. & Virtamo, J.T. Dynamic Routing and Wavelength Assignment Using First Policy Iteration. *Computers Communications ISCC 2000*, Antibes-Juan Les Pins France 3-6 July 2000. pp.146-151.
8. Hyytiä, E. & Virtamo, J.T. Dynamic Routing and Wavelength Assignment Using First Policy Iteration, Inhomogeneous Traffic Case. *International Conference on the Performance and QoS of Next General Networking P&QNet2000*, Nagoya Japan, November 2000. pp. 301-316.
9. Hänninen, A. Annual report 1999. Espoo: TKK / Teletekniikan laboratorio, 2000. 36 s. (Teletekniikan laboratorion raporttisarja).
10. Ilvesmäki, M. & Karvo, J. On the behavior of the candidate table of the per-flow packet count flow classifier. *IFIP Working Conference ATM & IP 2000*, Ilkley West Yorkshire, UK 17-19 July, 2000. pp. 36/1-11.
11. Jormakka, J. Changing Priority of IP Packets and Splitting Traffic. *Fifteenth Nordic Teletraffic Seminar*, Lund, August 22-24, 2000 . pp. 305-317.
12. Jormakka, J. Experimental evaluation of QoS measurement and management. Heidelberg, Saksa: EURESCOM deliverable, 2000. 53 s. (EURESCOM deliverable).
13. Jormakka, J. Methodologies and tools for QoS measurement and management. Heidelberg, Saksa: EURESCOM, 2000. 49 s. (EURESCOM deliverable).
14. Jormakka, J. QUASI-model implementation. Heidelberg, Saksa: EURESCOM, 2000. 56 s. (EURESCOM deliverable).
15. Jormakka, J. Reducing Jitter by Changing Priority Queuing . *Dagstuhl Workshop on IP Quality of Service*, Dagstuhl, 8.-12.5.2000. s.10.

16. Jormakka, J. Survey of existing methodologies and tools for QoS measurement and management. Heidelberg, Saksa: EURESCOM, 2000. 63 s. (EURESCOM deliverable).
17. Jormakka, J. & Heikkinen, K. QoS/GOS Parameter Definitions and Measurement in IP/ATM Networks. Quality of Future Internet Services (QofIS 2000), Berlin Germany September 23-26, 2000. Berlin, Germany 2000, Springer; Lecture Notes in Computer Science 1922, pp. 182-193.
18. Jormakka, J., Tiihonen, P. & Hiirsalmi, P. SRM related problems in mobile multicast. 9th Summer school on Telecommunications, Workshop on future network topologies. s. 66-75.
19. Kantola, R., Costa Requena, J. & Beijar, N. A Common Numbering Infrastructure for IN and IP Telephony. IEEE Intelligent Network Workshop-IN 2000, Cape Town, South-Africa, 7-11 May 2000. Cape Town, South Africa 2000,
20. Kantola, R., Costa Requena, J. & Beijar, N. An Architecture for an SCN/IP Telephony Routing Testbed. 1 st IP-Telephony Workshop (IPTel 2000), Berlin Germany, April 12-13 2000. Berlin 2000, pp. 203-216.
21. Kantola, R., Costa Requena, J. & Beijar, N. Interoperable routing for IN and IP Telephony. Computer Networks, 2000.
22. Kuusela, P. & Virtamo, J.T. Modeling RED with Two Traffic Classes. Fifteenth Nordic Teletraffic Seminar, Lund, August 22-24, 2000 . pp. 271-282.
23. Lassila, P., Karvo, J. & Virtamo, J.T. Efficient Importance Sampling for Monte Carlo Simulation of Multicast Networks. Third Workshop on Rare Event Simulation, RESIM2000, Pisa Italy October 5-6. 2000 . Elektroninen julkaisu (CD-ROM)
24. Lassila, P. & Virtamo, J.T. Inverse Convolution Approach to Importance Sampling in Monte Carlo Simulation of Loss Systems. Fifteenth Nordic Teletraffic Seminar, Lund, August 22-24, 2000. pp. 161-172.
25. Lassila, P. & Virtamo, J.T. Modeling the Dynamics of the RED Algorithm. Quality of Future Internet Services (QofIS 2000), Berlin Germany September 23-26, 2000. Berlin, Germany 2000, Springer; Lecture Notes in Computer Science 1922, 28-42.
26. Lassila, P. & Virtamo, J.T. Nearly Optimal Importance Sampling for Monte Carlo Simulation of Loss Systems. Espoo: 2000. 19 s. (COST257 TD(00)20).
27. Nyberg, E., Virtamo, J.T. & Aalto, S. An Exact Algorithm for Calculating Blocking Probabilities in Multicast Networks. Networking 2000, Paris France, May 14-19, 2000. 2000, Springer, pp. 275-286.
28. Renko, J. MPLS-multi protocol label switching. Espoo: Teknillinen korkeakoulu, Teletekniikan laboratorio, 2000. 57 s. (Teletekniikan laboratorion raporttisarja 1/2000).
29. Rummukainen, H. On Approximative Markov Control of Multiservice Telecommunication Links. Espoo: Teknillinen korkeakoulu, Teletekniikan laboratorio, 2000. 89 s. (Teletekniikan laboratorion raporttisarja 2/2000).

30. Virtamo, J.T. & Vidacs, A. Parameter estimation of geometrically sampled fractional Brownian traffic. IEEE Infocom 2000, Tel Aviv, Israel, 26-27 March 2000. Israel 2000, pp. 1791-1796.
31. Zhang, P. Routing algorithms in the diffserv MPLS networks. Espoo: Teknillinen korkeakoulu, Teletekniikan laboratorio, 2000. 72 s. (Teknillinen korkeakoulu, Teletekniikan laboratorion raporttisarja 3/2000).
32. Zhang, P. & Kantola, R. Building MPLS VPNs with QoS Routing Capability. 5th IFIP TC6 International Symposium, INTERWORKING 2000, Bergen Norway, 3-6 October 2000. 2000, Springer; Lecture Notes in Computer Science 1938, pp. 292-301.
33. Zhang, P. & Kantola, R. Mechanisms for Inter-domain QoS Routing in Differentiated Service Networks. Quality of Future Internet Services (QofIS 2000), Berlin, Germany, September 23-26, 2000. 2000, Springer; Lecture Notes in Computer Science 1922, pp. 153-166.
34. Zhang, P., Kantola, R. & Ma, Z. Design and Implementation of a New Routing Simulator. 2000 Symposium on Performance Evaluation of Computer and Telecommunication Systems, Vancouver, British Columbia, 16-20 July, 2000. pp. 229-232.

