9:00 – 10:00, Plenary session

Welcome address
Ilse Lievens, Piet Demeester, Ghent University-IMEC-IBBT, Belgium
Ioannis Tomkos, AIT, Greece

Opening speech
Optical Networking: Its Inter-Disciplinary Nature and New Research Challenges (Invited)
Prof. Biswanath Mukherjee, University of California, Davis, USA

10:20 – 12:00, Session 1 – Issues in Next-Generation Optical Networks

Session chair: Mike J O' Mahony

Novel Network Architectures for Next-Generation Optical Networks (Invited)
Monika Jaeger, T-Systems International GmbH, Germany

Techno-economic Concepts and Techniques used for Strategic Planning of Optical Telecommunication Networks (Invited)
Sofie Verbrugge, Ghent University-IMEC-IBBT, Belgium

A New Method for Considering Physical Impairments in Multilayer Routing
Szilard Zsigmond, Akos Szodenyi, Balazs Megyer and Tibor Cinkler, BUTE, Hungary, and Anna Tzanakaki, Ioannis Tomkos, AIT, Greece

Hybrid Optical Switching for Data-Intensive Media Grid Applications
Jurgen Baert, Marc De Leenheer, Bruno Volckaert, Tim Wauters, Pieter Thysebaert, Filip De Turck, Bart Dhoedt, Piet Demeester, Ghent University-IMEC-IBBT, Belgium

12:40 – 14:10, Session 2 – Physical Aspects in Next-Generation Optical Networks

Session chair: Marian Marciniak

Impacts of Physical Constraints on Dynamic Lightpath Routing (Invited)
Dominic Schupke, Siemens, Germany

Electrical Equalization for Duobinary and Phase Shift Keyed Modulation Formats
Chunmin Xia and Werner Rosenkranz, University of Kiel, Germany

Parametric Amplification and Multiple Wavelength Conversion in HNLF: Experimentation and Modelling
Kaňka J. Karasek M., Institute of Radio Engineering and Electronics, Czech Republic

Performance Evaluation of 2R Regenerator based on Self-Phase Modulation in Fiber
Ch. Kouloumentas, A. Barlas, A. Tzanakaki, and I. Tomkos, AIT, Greece

14:30 – 16:10, Session 3 – Novel Node Architectures for Next-Generation Optical Networks

Session chair: Benny Van Houdt

Novel Node Architectures for Next-Generation Optical Networks (Invited)
Mike J O' Mahony, University of Essex, UK

Contention Resolution in Next-Generation Optical Node Architectures (Invited)
Joris Walraevens, Ghent University, Belgium

Packet Loss due to Bit Errors in All-Optical Networks
Andreas Kimsås, Harald Øverby, Steinar Bjørnstad and Vegard L. Tuft, NTNU, Norway

Contention Resolution in Multi-Fibre Optical Packet Switches
Giovanni Muretto, Carla Raffaelli, University of Bologna, Italy

16:30 – 18:00, Session 4 – Next-Generation Optical Networks and their Survivability
Session chair: Mario Pickavet

All-Optical Label Swapping in Novel Optical Network Architectures: a Network Recovery Perspective (invited)
Ruth Van Caenegem, Ghent University-IMEC-IBBT, Belgium

On-line and Dynamic Multi-Layer Routing with Protection
Anna Urra, Eusebi Calle, Jose L. Marzo, University of Girona, Spain

End-to-End Recovery in Multidomain IP-over-OTN Networks
D. Staessens, L. Depré, D. Colle, I. Lievens, M. Pickavet, P. Demeester, Ghent University-IMEC-IBBT, Belgium

Sensitivity Analysis of Transmission Network with Optical Packet Switching
Marko Lackovic, Ericsson Nikola Tesla R&D Centre, Croatia; Robert Inkret, UoZagreb, Croatia; Cristian Bungarzeanu, EPFL-STI-ITOP-TCOM, Switserland

Optical Networking: Its Inter-Disciplinary Nature and New Research Challenges (Invited)
Prof. Biswanath Mukherjee, University of California, Davis, USA
Abstract
Optical fiber is the medium of choice for building high-capacity networks: from broadband access networks to regional metro networks to long-haul backbone networks. After the telecom bubble burst in 2000, the optical networking (ON) industry went into a consolidation phase. But, in 2004, ON equipment manufacturers started reporting profits again, and this $5-Billion industry is poised to double in size over the next 4-5 years.
Successful growth of ON, however, will occur only if researchers from multiple disciplines (physics, optics, communications, networking, computer algorithms, operations research, and business school) are able to work together in identifying, understanding (one another's jargons), and effectively solving the important and exciting inter-disciplinary problems in the field. A sampling of these inter-disciplinary opportunities and new research challenges will be outlined in this talk.
Biswanath Mukherjee received the B.Tech. (Hons) degree from Indian Institute of Technology, Kharagpur (India) in 1980 and the Ph.D. degree from University of Washington, Seattle, in June 1987. At Washington, he held a GTE Teaching Fellowship and a General Electric Foundation Fellowship.
In July 1987, he joined the University of California, Davis, where he has been Professor of Computer Science since July 1995, and served as Chairman of Computer Science during September 1997 to June 2000. He is a winner of the 2004 Distinguished Graduate Mentoring Award at UC Davis. Two PhD Dissertations (by Dr. Laxman Sahasrabuddhe and Dr. Keyao Zhu), which were supervised by Professor Mukherjee, were winners of the 2000 and 2004 UC Davis College of Engineering Distinguished Dissertation Awards.
He is co-winner of paper awards presented at the 1991 and the 1994 National Computer Security Conferences. He serves or has served on the editorial boards of the IEEE/ACM Transactions on Networking, IEEE Network, ACM/Baltzer Wireless Information Networks (WINET), Journal of High-Speed Networks, Photonic Network Communications, Optical Network Magazine, and Optical Switching and Networking journal. He also served as Editor-at-Large for optical networking and communications for the IEEE Communications Society. He served as the Technical Program Chair of the IEEE INFOCOM '96 conference. He also serves as Chairman of the IEEE Communication Society's Optical Networking Technical Committee (ONTC). He is Editor of Springer's Optical Networks Book Series.
Mukherjee is author of the textbooks "Optical WDM Networks" (to be published by Springer in 2005) and "Optical Communication Networks" (published by McGraw-Hill in 1997). He is a Member of the Board of Directors of IPLocks, Inc., Silicon Valley startup company founded in March 2002. He has

consulted for and served on the Technical Advisory Board (TAB) of a number of startup companies in optical networking. His current TAB appointments include: Teknovus, Intelligent Fiber Optic Systems, and LookAhead Decisions Inc.

Novel Network Architectures for Next-Generation Optical Networks (Invited)
Monika Jaeger, T-Systems International GmbH, Germany
Abstract
Today, the ubiquitous deployment of residential broadband access and the roll-out of fiber-to-the-home (FTTH) are the main drivers for metro and core network architecture evolution. Integrated offers of voice, internet, and video services, so-called "Triple-Play" are expected to be delivered using the same access platform and will lead not only to a higher demand for bandwidth but also to a completely new user behavior. This poses new requirements to the metro and core network architecture. The metro and region areas need to efficiently aggregate multiple traffic streams and have to provide differentiated Quality of Service, whereas the core area will provide high throughput at very low cost. The core network architecture is based on scalable optical technology, and needs to be open for growth. The future access network architecture has to support multiple public and private IP and VPN services on different layers. The suitability of the network architecture highly depends on the types of services to be supported and the share of different traffic types (e.g. IP, Ethernet, SDH). A provider who supports a wholesale approach has other network requirements and preferences than an ISP only. A key question of tomorrow's network architecture design will be the role of Layer 2 services and switching technology. A considerable part of CAPEX and OPEX is related to the operation-supporting systems. Today's networks are configured quasi-statically with very long preparatory times. Cost intensive pre-planned dedicated protection mechanisms are used. In the past years research, development, and standardization activities led to the definition and implementation of ASON/GMPLS Control Plane functions for use in future multilayer IP/optical metro and core network architectures. The main functions of the Control plane such as signaling, routing, and automatic discovery allow the automation of network operation processes and provisioning services.
This presentation will highlight trends and drivers for access, metro and core network evolution and will discuss network architecture optimization options.
Monika Jaeger (monika.jaeger@t-systems.com) is a senior research engineer and project leader in the department "Network Architecture" at T-Systems International GmbH, Technologiezentrum in Berlin, Germany since 1998. She held previous positions with the Fraunhofer Institute for Open Communication Systems (FOKUS), and DeTeWe in Berlin. In 1992, Monika Jaeger graduated in Electrical Engineering from Technische Universität München, Germany. Her current research interests are in the area of optical transport network design. She is involved in the European IST project NOBEL.

Techno-economic Concepts and Techniques used for Strategic Planning of Optical Telecommunication Networks (Invited)
Sofie Verbrugge, Ghent University-IMEC-IBBT, Belgium
Abstract
This presentation will discuss results obtained Strategic Planning in the GBOU-project Optical Networks and Node Architectures.
The network planning problem is situated in a constantly changing environment. Nearly all important inputs for the network planning process vary over time. Changes are observed in the number of customers as well as in the type of the offered services. Data traffic has for instance known a tremendous growth and this greediness is not expected to stop. However, future traffic demands are not known in advance, therefore predictions have to be used. No expert can produce exact predictions and no methodology can completely eliminate the uncertainty. The traffic volume is expected to keep growing, but the growing rate is unknown. Apart from future demand, also future equipment cost is unknown. Strategic planning focuses on helping the network operator to expand his network in an economical way in this dynamic and uncertain environment.
Several parts of the strategic network planning problem have been studied in the project and will be discussed in this presentation. Different techniques to assess the uncertain situation and take this into account during planning calculations were described. The concept of anticipated network planning to take into account long-term evolutions is described. A lot of attention is also given to the use of economic investment decision techniques for the network planning problem. Network expansion can be considered as a long-term investment problem involving import cash flows for the network operator. Among those cash flows, revenues and costs can be distinguished. Costs for the operator include

capital as well as operational costs. Special attention was given to the development of an OpEx cost model for a network operator. To describe long-term network expansion, the use of classical investment decision techniques like Net Present Value is compared to the recent approach of Real Options Valuation. All research topics were studied concerning realistic network planning examples.
Finally, the presentation will also cover recent research results, obtained during the last phase of the project. In the light of the ongoing traffic growth in backbone networks, both the use of grooming and the introduction of Optical Cross-Connects (OXCs) are interesting solutions for a network operator to transport this traffic in an economical way. Grooming means optimizing the resource usage in a multi-layer transport network e.g. by efficiently packing low-capacity traffic streams into high-capacity optical channels in an IP-over-Optical network. The introduction of OXCs in backbone nodes allows to send transit traffic in the nodes directly on the optical layer, without going back to the IP layer in intermediate nodes, saving capacity on the IP layer. Since OXCs are still very expensive today, it is important for the operator to find the optimal introduction time. Starting from the trade-off between link-by-link and end-to-end grooming, we have studied the gradual migration from a network without OXCs (using link-by-link grooming) towards the introduction of OXCs in some nodes (and the use of end-to-end grooming). A migration path introducing OXCs in so-called end-to-end grooming islands is proposed. The impact of OXC introduction on the logical network layer, as well as some practical implications, is described. A case study for a pan-European network with growing traffic demand over the time interval of 10 years illustrates the practical application of the suggested migration technique. It is shown that OXCs get introduced gradually. To be able to spread the expenses and gradually adapt to the growing traffic demand, the island based grooming approach is a straightforward and effective approach. Starting from an entirely link-by-link grooming network in 2004, nearly all core nodes are equipped with OXCs by 2014. Simulations have shown that this island based grooming approach can lead to important savings in capital expenditures. Sensitivity analysis revealed that the main cost driver in case of link-by-link grooming is the SDH line card cost. A lower line card cost favours the use of link-by-link grooming, whereas a higher cost favours the introduction of OXCs and the use of end-to-end grooming.

Sofie Verbrugge received a M.Sc. degree in computer science engineering from Ghent University (Ghent, Belgium) in 2001. She is currently working toward the Ph.D. degree in the IBCN-group of the Department of Information Technology, at the same university, as a researcher for the Institute for the Promotion of Science and Technology in Flanders (IWT-Vlaanderen), in the field of long-term planning of optical networks. Her main research interests include techno-economic aspects of telecom network planning, such as migration scenarios, investment decision techniques and cost modelling. During the summer of 2004, she was a visiting scientist at the Technologiezentrum of T-Systems (Deutsche Telekom, Berlin, Germany) where she mainly worked on the development of an operational cost model. She has been involved in the European IST-LION project as well as in the ITEA-TBONES project and is currently active in the IST-NOBEL.

Impacts of Physical Constraints on Dynamic Lightpath Routing

Dominic A. Schupke, Siemens, Germany

Abstract

Future transparent WDM networks handle more and more dynamic lightpath demands, requiring an adaptive routing that fulfils physical constraints. After summarising the context between network planning and operation processes, we classify different approaches to connection setup. The involved algorithms, that compute the constrained routing and wavelength assignment (RWA), are subject to the trade-off between computational complexity (thus, run-time) and the model accuracy of the physical aspects (thus, network performance).
We investigate an iterative RWA algorithm that is able to incorporate physical constraints by a simple constraints model. Besides low computational complexity, the model aims at minimising administrative and operational effort. To assess the network performance, we simulate the blocking probability of this approach, comparing with unconstrained RWA.
This talk includes results of the work and the discussions within Work Package 5 of NOBEL, an EU 6th Framework project.

Dominic A. Schupke received his Dipl.-Ing. degree from RWTH Aachen in 1998 and his Dr.-Ing. degree (with distinction) from Munich University of Technology (TUM) in 2004. From 1998 to 2004 he was research and teaching staff member of the Institute of Communication Networks at TUM. In 2004 he joined the research and development department of Siemens, Corporate Technology, in Munich, Germany. There, he is Senior Research Scientist and Competence Field Manager of the Network Configuration and Planning Group in the Optical Networks and Transmission Department.

His research interests include network architectures and protocols, routing and wavelength assignment, recovery methods, availability analysis, network optimization, and network planning.
Dominic has been as technical program committee member for the conferences DRCN, Globecom, ICC, and ONDM. He is member of IEEE, ITG/VDE, and VDI.

Novel Node Architectures for Next-Generation Optical Networks (Invited)
Mike J O' Mahony, University of Essex, UK
Abstract
Current transport networks are voice-optimised and connection oriented, however the amount of data traffic is rapidly increasing, resulting in a continuous increase of average traffic through major exchanges exceeding 30% per annum (in Europe). Roadmaps of future network generations point to a number of options for the future with a timeline from (a) the current fairly static circuit switched scenario to (b) dynamic path reconfiguration using optical cross-connects capable of routing continuous data at 10 or 40 Gb/s over wavelength paths to (c) optical burst switching where bursts are assembled at the network edge and routed through OXC nodes in a cut-through manner, and finally to (d) optical packet switching, where optical packets (formed at the network edge) and routed in a store and forward manner. In recent times switching approaches based on optical code division multiplexing have appeared, which point the way towards future networks using increased levels of optical processing and can be used in conjunction with techniques such as optical packet switching. Each stage of evolution adds its own challenges at both a network and technology level., but there is a clear objective behind these evolution trends which is to develop a network which has, ideally, low capital cost and low operating costs. Key features looked for in switching equipment, in the face of large throughput requirements, are small footprint and low power consumption, and it is felt that optical technologies offer great benefits in these respects.
This presentation will look at switching approaches based on optical packet switching and optical code division multiplexing with a view to understand the issues concerning these approaches. Optical packet switching designs, which offer flexible and efficient transport, have been established to support ultra high speed transmission (eg up to 160 Gb/s demonstrated); and high speed transmission is also amenable to optical processing. Optical code division multiplexing (OCDM), a technique very appropriate to future networks which have end –to-end fibre channels, is now a topic of great interest. Encoding and decoding techniques prove relatively easy to implement in optical technology and the narrow pulse widths associated with this technique are again interesting from an optical processing viewpoint. OCDM can be used in conjunction with OPS to provide another labelling approach, or in its own right as a wavelength path transport and switching technique. Technologies being considered for packet switching, such as optically controlled delay, will also have a major impact on OCDM networks.
Mike J O' Mahony received his Ph.D degree in 1977, from the University of Essex, for research into digital transmission systems. He then joined BT Laboratories reaching the position of Head of Inland Systems Section, responsible for research into long haul optical systems and networks. In 1991 he joined the Department of Electronic Systems Engineering at the University of Essex as Professor of Telecommunication Networks and is Head of the Photonic Networks Laboratory. He is the author of over 250 papers relating to optical communications.

Contention Resolution in Next-Generation Optical Node Architectures (Invited)
Joris Walraevens, Ghent University, Belgium
Abstract
As advances in Dense Wavelength Division Multiplexing (DWDM) push fibre transmission capacities well beyond the Tbit/s, electronic switches and routers are becoming the bottlenecks of the backbone network. All-optical packet switching (OPS) could alleviate the problem, but the technology is expected to be still a few years away. As intermediate solution, optical burst switching (OBS) has been proposed. Both solutions, however, confront switch designers with several major challenges, of which the lack of optical RAM is but one. This presentation touches upon a number of distinct approaches to resolve the inevitable output port contention and gives a limited overview of the work done in this area. The emphasis will lie on studies that approach this problem via analytical techniques, as opposed to simulation driven solutions.
In the first part of the talk, we focus on the following conflict resolution strategies: deflection routing, (limited) wavelength conversion and optical buffering. When deflection routing is applied, some of the packets involved in the conflict are simply forwarded through a different output port, hoping that these packets will eventually reach their intended destination. Such a solution is probably mostly feasible for

low load scenarios. For higher loads, wavelength conversion and optical buffering seem more appropriate. Wavelength conversion allows packets to switch wavelengths on an output port, which partially alleviates the contention. An important issue is the determination of the required number of converters. To press expenses, some researches have proposed the use of limited wavelength conversion, meaning that only a limited range of wavelengths can be realised during the conversion. The trade-off between these solutions is not obvious and requires careful study. Even with full wavelength conversion, there might still be a need to have some optical buffering capabilities; however, optical RAM is presently lacking. An often proposed solution is to make use of fibre delay lines (fdl's), which aim at delaying packets to resolve the output port conflict. A brief literature overview of analytical approaches that try to shed light on these issues will be presented.

The second part of the presentation will mainly focus on the work done in this area as a part of the GBOU ONNA (Optical Networks and Node Architectures) Project. In this project, we have analyzed the performance of optical packet switches with fdl's used as contention resolution approach. Therefore, we have extended traditional queueing models (used to analyze switches with electronic RAM) to cope with the specific characteristics of fdl's. The most important difference with traditional models is that packets are delayed for a certain amount of time, corresponding with the length of the fibre. That packet thus has to be transmitted through the output port (or delayed again) after precisely that time (not earlier nor later). This influences the performance of the packet switch considerably. In this part of the presentation, we focus on output queueing feed-forward systems, i.e., packets are routed to their output ports where they are delayed for a certain amount of time before leaving the system or being dropped. The 'fdl system' consists of a number of fdl's of different lengths. The influence of different designer choices on the packet loss rate is investigated. A number of such design choices are: the number of fdl's, the lengths of the fdl's (equidistant structure or not?), the scheduling mechanism of packets into the fdl's, possible drop mechanisms, synchrone or asynchrone transmission, etc.

Joris Walraevens (jw@telin.UGent.be) was born in Zottegem, Belgium, in 1974. He received the M.S. degree in Electrical Engineering and the Ph.D. degree in Engineering in 1997 and 2004 respectively, all from Ghent University, Belgium. In September 1997, he joined the SMACS Research Group, Department for Telecommunications and Information Processing, at the same university. His main research interests include discrete-time queueing models and performance analysis of communication networks. His publication list can be found on his webpage http://telin.UGent.be/~jw.

All-Optical Label Swapping in Novel Optical Network Architectures: a Network Recovery Perspective (Invited)

Ruth Van Caenegem, Ghent University-IMEC-IBBT, Belgium

Abstract

One of the goals of the GBOU "Optical networking and node architectures" (ONNA) project is to study next-generation optical network architectures. Technological advances such as WDM and fast optical switches as well as protocol standardization have given us flexible high-bandwidth transport networks. This high-bandwidth also introduces the need to study the resilience aspects of such networks. The project both examines automatic circuit-switched optical networks and the longer term solution of optical packet-switched networks. Optical circuits established through optical switching are used in providing on-demand coarse granularity connectivity services. This connectivity is offered between nodes of higher network layers. For example, an IP over optical multi-layer network uses these fast-switching optical networks as a transport layer for carrying data traffic, though the large discrepancy between IP layer traffic flow granularity and optical layer granularity (e.g. wavelength channels) may prove a challenge. Optical packet-switching (OPS) can offer a flexible and bandwidth efficient architecture. Compared to circuit-switched approaches, it provides smaller granularity to the optical layer (on a packet-by-packet basis), while still allowing for optical bypassing of transit nodes (without E/O conversions) for traffic traversing multiple hops. This smaller switching granularity also gives promising opportunities to apply differentiation in recovery techniques. Ideally, we envisage transparent optical networking, where the optical packet can contain an arbitrary client layer protocol. In spite of this, optical packet-switching is still a challenge because of the high bitrates that forces optical technology to switch very fast. To make routing decisions faster and more efficient the Multi Protocol Label Switching (MPLS) routing protocol makes use of local labels. Even though MPLS forms a good solution it yet doesn't cross the chasm between the router's switching speed (i.e. table look-up procedures are time consuming) and the fibre's data speed. In an attempt to overcome this, research starts to focus on all-optical packet-switching by way of All-Optical Label Swapping (AOLS).

AOLS implements the packet-by-packet routing and forwarding functions of MPLS directly at the optical domain. By using optical labels, the IP packets are directed through the optical network without passing them through electronics whenever a forwarding decision is necessary. Ideally this approach has the ability to route packets/bursts independently of bit rate, packet format and packet length. Still AOLS encounters new troubles. The lack of all-optical memory makes the AOLS nodes very complex and resource consuming. Whereas the electronically implemented look-up table was easy to adapt to changing routing demands (i.e. LSPs are set-up, broken down at all possible moments in the network), a big number of optical components need be installed to perform the same functions all-optically. How many components and how they are designed relate directly to the router's ability to accept more or fewer LSPs. This is of great importance when providing the all-optical network with resilience. The ONNA project focused on different protection/restoration schemes (real-time or in advance, local or end-to-end) that could be used in combination with all-optical packet-switching networks. It investigated how the presence of back-up facilities in the network affect the label length and number of labels needed throughout the network (i.e., the router's dimensions).

Ruth Van Caenegem received the M.Sc. degree in electrical engineering, specialized in micro- and opto-electronics from Ghent University, Gent, Belgium, in 2003. From August 2003 on, she has been working on all-optical networks in the Department of Information Technology (INTEC), at the same university. She is involved in the European project IST LASAGNE and the national inter-university project IWT GBOU ONNA.