TransiNet - Innovative Transport Networks for the Broadband Internet

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Abstract

The project TransiNet focuses on new approaches and system concepts for IP over optical and radio networks. The goals and activities of the five participating research institutes are described. In addition, their technical approaches and first results are presented.

Introduction

The research project "Innovative Transport Networks for the Broadband Internet (TransiNet)" focuses on new approaches and system concepts for IP over optical and radio networks. The three-year project started June 2000 and is supported by the German Federal Ministry of Education and Research (BMBF). The five project participants Heinrich-Hertz-Institut Berlin, Munich University of Technology, Technical University of Berlin, T-Nova and University of Stuttgart cooperate in working groups based on the focal points depicted in **Fig 1.1**.

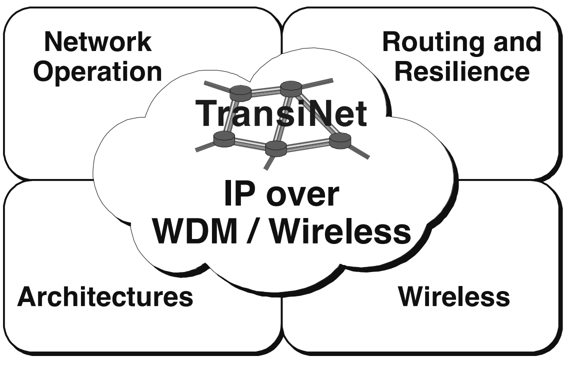

Fig 1.1 Focal points in TransiNet

The technical goals and activities of the project participants are described in the next sections. Based on these technical considerations the project also aims to provide for the exchange with industry and to supplement the education in this field. The participating institutes are encouraged to spin off start-up companies and to contribute to international standardization.
The following five sections contain the descriptions of the partners. Finally we give a conclusion.

Heinrich-Hertz-Institut Berlin

The two departments „Optical Networks“ (ON) and „Broadband Mobile Communication Networks“ (BM) of the Heinrich-Hertz-Institut für Nachrichtentechnik Berlin GmbH (HHI) are contributing to the joint research project.

In this project the main research areas of the department ON for the next-generation Internet are new concepts for network and node architectures, the corresponding protocols, enabling technologies and error detection in the optical domain for protection and restoration. Advanced optical subsystems are being investigated, including WDM transmission, add-drop multiplexers, optical cross-connects and wavelength router/switches, together with their interworking with higher-layer protocols. In the department BM the research is aimed at the development of new signal processing algorithms for the transmission of several applications over mobile channels. Furthermore methods for traffic engineering for design and evaluation of mobile radio systems are developed.

Ongoing Work

The emergence of dynamic wavelength provisioning, the reduction in provisioning timescales (**Fig. 2.1**) and the paradigm shift from circuit switched to packet switched optical networks is creating new technical requirements for optical components and subsystems.

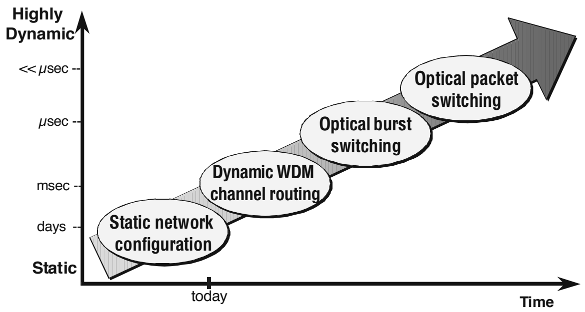

Fig. 2.1 Dynamic network configuration

These requirements will be investigated at the beginning of the project by the HHI.

Optical Switches for Bursts and Packets

For optical burst switching, data packets with a length in the order of 40 μs are discussed (this corresponds to 50,000 Bytes at 10 Gbit/s). The switching time of now available Optical Micro-Electro-Mechanical Switches (MEMS) is a few milliseconds. Integrated optical switches have switching times of less than one nanosecond, but they suffer from high insertion loss and crosstalk (**Fig. 2.2**). Therefore concepts for burst/packet switching must be developed that either allow slow switches by aggregation of bursts or tolerate the non ideal performance of the fast switches.

Material	**$LiNbO_3$**	**Semicond. (InP)**	**Silica/Si**	**Polymer**
Physical Effect	el.-optic	el.-optic	thermal	thermal
Switching time	< ns	< ns	> ms	ms
Optical losses	4 dB	> 5 dB	0.5 dB	2.5 dB
Crosstalk	-20 dB	-20 dB	-22 dB	-30 dB
Power dissipat.	-	-	400 mW	80 mW

Fig. 2.2 Integrated optical switches

Optical Fiber Amplifiers

For optical burst or packet transmission the optical channels are no longer operated continuously. This has some implications for the optical amplifiers and receivers. Optical fiber amplifiers (EDFAs) are driven into saturation and have nearly constant output power but no constant gain, when the input power changes (e.g. during gaps in input signals, the gain of the EDFA rises). This leads to a transient variation of the output signal power of the other WDM-channels. This can decrease the BER performance of the affected channels. **Fig. 2.3** shows the measured results of an experiment with two channel transmitted over a cascade of four amplifiers. At t=0 channel 1 was switched off and the power of channel 2 was measured.

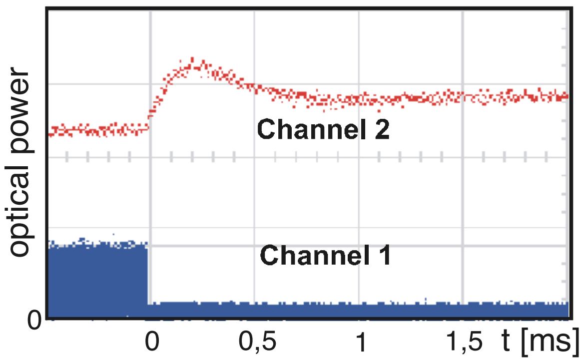

Fig. 2.3: Measured transient gain variation

The same configuration was simulated, using the program PTDS by Virtual Photonics Inc. (**Fig. 2.4**).

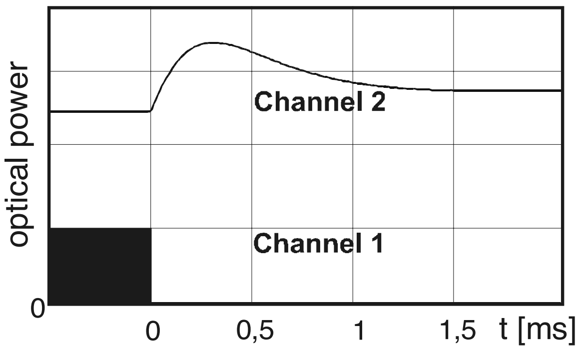

Fig. 2.4: Simulated transient gain variation

The results from the simulation are in good accordance with the measurement, proving that the parameters for the simulation were selected properly. In a next step, multi channel burst systems will be measured and simulated.

These first results are indicating that for burst transmission it is necessary to control the power of each output channel. We will examine what the requirements for burst transmission are and how they can be fulfilled. One possibility might be a fast gain control of the amplifiers, another is the transmission of additional optical channels used for compensating the power variations of the data channels.

Optical Burst Receivers

A receiver of bursts through optical switches must synchronize its circuitry very fast to the arriving data stream, at both the bit clock level and the burst power level. Standard SDH-receivers need several milliseconds for synchronization, so they can't be used for burst reception. **Fig. 2.4** gives an overview about optical high speed burst receivers. The 10 Gbit/s from NTT is the only one that exists as a prototype [1]. This receiver needs 64 bits or 6.4 ns at 10 Gbit/s. Many developments are necessary until burst receivers will be commercially available.

Gbit/s	who	Principal of Operation	Synctime
0,622	AT&T	Start-Stop Oscillator + power control	few bits
0,622	ETH Zürich	Selection from 7-phase clock	few bits
10	NTT	Start-Stop Oscillator + differential receiver	64 Bits
10	NEC	Selection from 4-phase clock	9 Bit

Fig. 2.4: Optical high speed burst receivers

Allocation of Resources for CDMA Systems

For wireless networks some families of spreading sequences for separation of the mobile terminals have already been developed [2]. For this resource allocation several quality criteria for generation of the spreading sequences were refined and analyzed. This family builds the basis for the suitable allocation of resources applicable to the SMPT procedure, which was submitted by the Technical University of Berlin. For the time being the allocation is controlled on the basis of important momentary channel parameters (**Fig. 2.5**).

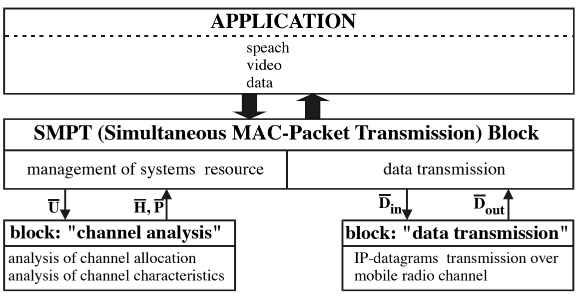

Fig. 2.5: Interface between physical and data link control layers

The first approaches for mobility models were submitted and implemented. The main results will be taken to enhance the channel modeling.

Outlook

For optical IP-networks work will be continued on network elements, node architectures and protocols. Based on the results of simulations and experiments concepts for Optical Label Switching (OLS), Optical Burst Switching (OBS) and new network concepts will be investigated.
Additionally the focus will be on supervision concepts for optical WDM networks. Optical burst transmission will require totally new concepts for error detection and localization in the optical domain and the protection and restoration mechanism.
For wireless networks spreading sequences will be constructed for the common channel scenarios. The next important step is the prediction of the channel impulse response and utilization of it for the allocation of resources. The proposed algorithms will be evaluated on the basis of data transmission by real datagrams (for example by video sequences).

Munich University of Technology

The Institute of Communication Networks (LKN) belongs to the department of Electrical Engineering and Information Technology of Munich University of Technology. Besides the head, Univ.-Prof. Dr.-Ing. J. Eberspächer, the institute comprises 20 researchers. Current research fields include multimedia services and applications, mobile communications, network planning, architectures and fault tolerance.
Among the institutions participating in TransiNet, LKN is particularly committed to resilience issues in future IP and optical networks [3-5].

Mission

Along with the research community, we anticipate new challenges by the use of IP as a primary platform which enables multiplication of services. To accept the dare, a systematic assessment of operator requirements at our institute will elaborate the characteristics of these services and investigate future traffic demands.
Furthermore, network concepts and architectures with focus on resilience will be considered. In doing so, a special aspect will be the support of multipoint and asymmetric traffic. Another improvement in network resilience can be realized by allowing redundancy within network node architectures.
In novel IP over optical networks, scalability issues require routing functionality partially be shifted from the network layer to lower layers. Irrespective of the fact whether existing or adapted routing protocols will be run on the corresponding layers, advanced

techniques for integrated routing need to be developed, because network operation and resilience would be substantially affected without any coordination of the routing instances involved.

Progress

Our assessment of operator requirements asserts that conventional assumptions are still applicable when being enriched by aspects from novel Internet applications. Among such aspects, let us name diverse routing on administrative domains or network operator levels when routing is done physically disjoint. Other facets are the deployment of protocols and network elements which were implemented independently by different manufacturers but are otherwise identical.

Availability requirements increasingly became an integral part of service level agreements (SLAs). In this context, the definition of suitable metrics for the agreed availability guarantees is vital. The different aspects of availability requirements were examined by the LKN in compliance with current standardization.

Traffic matrices hold information on the relations among the nodes of a network. They are required whenever it comes to optimization of existing networks or planning of new ones. While measurement of traffic flows is at least theoretically feasible in the former case and relations between the nodes may be set up subsequently, the latter case enforces a different kind of derivation. We developed a systematic method which alleviates the traffic matrix setup. Based upon the examination of typical ISP networks, an abstract architecture with a limited number of node types (corresponding to matrix entries) has been defined by means of which various methods for approximation of traffic flows can be studied.

Our current work on network architectures comprises different switching techniques in optical networks, namely multiprotocol lambda switching (MPλS), synchronous optical time-division multiplexing (OTDM), optical burst switching and optical packet switching (using multiprotocol packet switching, MPLS). Optical burst switching presently emerges as a promising technique, and initial work towards simulative examination has been done.

The support of asymmetric traffic has been elaborated on both optical and IP layer [6]. On the optical layer, a disproportionate wavelength or bitrate assignment in the two directions of a connection (link asymmetry) can yield a significant reduction of cost in laser sources and regenerators. A similar result may be achieved in the case of unidirectional lightpaths (**Fig. 3.1**). This requires, however, an additional emulation of the bidirectional links on the IP layer (so-called unidirectional link routing, UDLR).

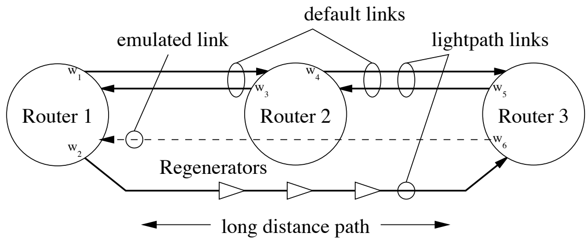

Fig 3.1 A unidirectional link with a tunnel

An adjustment of IP routing weights by the network management system is necessary with this kind of asymmetry, too. Path asymmetry (the unidirectional components of a bidirectional connection follow different paths) improves usage of network resources, yet it complicates the administrative burden considerably. Currently, link und path asymmetry are checked for efficiency by simulation.

In terms of redundant node architectures, we presently compile a survey on promising node concepts which substantially enhance availability by local provisioning of redundant resources like extra modules and boards. The underlying functional features and principles are of particular interest. Moreover, it is clarified to which extent node redundancy can be provided by existing protocols on the IP layer, like routing and router redundancy protocols.

Technical University of Berlin

The telecommunication networks group (TKN) at the Technical University Berlin (TUB) concentrates on wireless and wired networks and their interconnection. This leads to our main areas of research in the context of the „TransiNet“ project that will be described in the following sections.

Wireless Section

CDMA was chosen by the ETSI for the 3rd generation mobile communications systems. In contrast to TDMA or FDMA, which are limited in their capacity by the number of time or frequency slices, respectively, CDMA is interference limited. Therefore a hard limit in the number of users does not exist (soft capacity). But each active wireless terminal will degrade the performance of other terminals.

A key feature of DS-CDMA is power control. The power control entity controls the transmitter power of each wireless terminal in such a way that the received power of all wireless terminals is the same. The channel condition for each wireless terminal differs

depending on the mobiles' location and is time variant.
One goal within the TransiNet project is to decrease the interference within the wireless cell considering information of higher protocol layers at the data link layer. E.g. we consider MPEG-4 video streams, where each video segment has its own delay constraint. In case the delay constraints are violated the segment should be skipped from the transmission queue. From the other subscribers' point of view this will lead to a decreased multiple access interference. A key-feature of MPEG streams is the subdivision into different frame types. While "P" and "B" frames are less important and the impact of their loss on the application layer is small, a lost "I" frame has a significant influence. Therefore we invented mechanisms based on Multi—Code CDMA , which are able to recover from gaps caused by bursty errors using parallel channels for a very short time. While the usage of parallel channels will lead to a performance degradation of other mobiles, this mechanism will be used only for "I" frames. Different mechanisms how to use parallel channels were already investigated [7]. The mechanisms work distributed and autarkic. Thus a minimum of signaling is necessary. Because the performance of the mechanism is correlated on the design of the spreading sequences, we want to investigate how such sequences can be obtained and which performance gain can be achieved.

Optical Section

Work in the area of optical communication will focus on IP over WDM networks. Our understanding of IP networking over fiber is that of optical packet switching (OPS) as the logical successor of what is being developed today as MPλS and OBS (Optical Burst Switching).
Optical signal generation, transport and processing has its pros and cons compared to the electrical domain. While the bandwidth of a single fiber is essentially unlimited, optical signal, i.e. header processing is still in its infancy. Thus, the traditional way of doing packet switching has to be thought over.
The approach that is being followed at TKN is passive routing in the optical domain. By using passive routers like Arrayed Waveguide Grating (AWG) most of the routing decision is being transferred to the edge of the network.
Two basic models of AWG-based network are evolving here: A single-hop and a multihop network. Both will be explained here in short.

Single Hop Network

In any single hop WDM network, some kind of pre-transmission coordination has to be done. This can be accomplished via a dedicated control channel, carrier sensing (in a circular search protocol like in the RAINBOW-I testbed) or distributed scheduling mechanisms. To establish a single hop network, wavelength tunable transmitters and/or receivers are needed. In the case of optical packet switching, tuning times have to be in the order of nanoseconds. At present, only electrooptical filters can perform such a fast switching, but they only tune over a small range of wavelengths. This is where an AWG comes into play. Due to its passive routing of wavelengths it provides full connectivity between all N inputs and outputs using N wavelengths in contrast to N^2 for a passive (broadcast-and-select) star architecture.
The architecture of the network is depicted in **Fig. 4.1**. The network is based on a DxD AWG. At each AWG input and ouput port a wavelength insensitive Sx1 combiner and splitter, respectively, is attached. The transmitter of a node is connected to the combiner, whereas the receiving part of the node is attached to the splitter. The whole network consists of N=DxS nodes that are equipped with a LD (laser diode) and a PD (photo diode) each. These are used for data transmission, and an additional LED (light emitting diode) per node is used for the transmission of control packets. The broadband signal from the LED is spectrally sliced such that all receivers are able to receive the control information. The control information is spreaded before modulating the LED. Thus, despreading the signal at the receiver side makes it possible to distinguish between control and data information. For details about the MAC protocol and a performance evaluation please refer to [8].

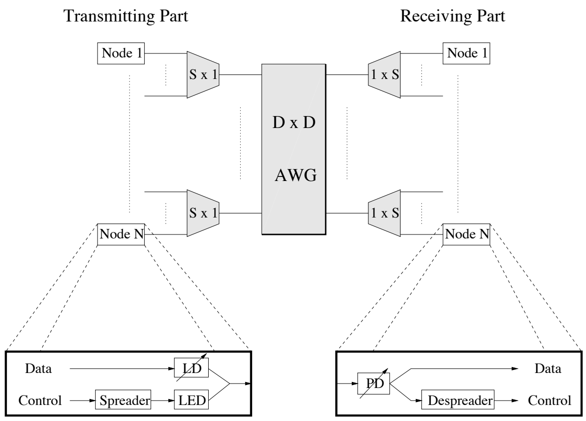

Fig 4.1 Architecture of a single hop network based on an Arrayed Waveguide Grating

Multihop Network

In multihop networks, as it can be guessed from the name, packets travel from source to destination via intermediate nodes. The nodes are usually equipped with a small number of fixed transmitter/receiver pairs. This makes multihop networks potentially more effective for packet switching than single hop networks that require a tuning in between packet transmissions. On the other hand, some sort of routing decision has to be made inside the nodes. As described before, this can be accomplished using CDMA coding for the control information that overlaps the data in spectrum and time.
Using an AWG as the central node for a multihop network can lead to different virtual topologies. The approach that is followed here results in virtual ring strucures on every wavelength employed. As can be seen in **Fig. 4.2**, using a DxD AWG, (D-1) rings with a different ordering of the stations appear. In order to achieve full connectivity on every wavelength, the number D has to be prime. The advantage of such a system of nested rings is that full connectivity can be gained with only a single fixed transmitter/receiver pair per station. Additional capacity can be installed in a modular fashion, thereby increasing the total network capacity with more than the square of the number of wavelengths. For details of this approach please refer to [9].

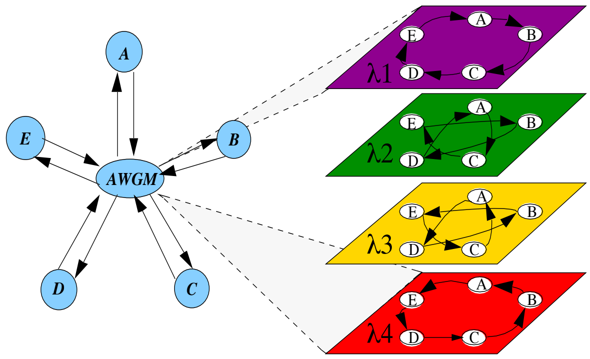

Fig. 4.2 Architecture of a multihop network based on an Arrayed Waveguide Grating

Interconnection of wireless and wired Networks

The idea of "bridging the gap" between the optical backbone and the wireless broadband transmission over the last few meters to the end user is the third goal in our project work. We will investigate several approaches to this. Some basic considerations lay the foundations of our work here:
Broadband wireless systems will very likely be situated in the 60 GHz band. Cell sizes of only a few meters will be common. This results in a small number of users per cell and a high number of base stations. Consequently, the wireless broadband communication in this sense will simply replace the wiring of the desktop. Base stations of such a wireless network will have to be much less expensive to make this commercially attractive. One idea to off-load base stations is the so-called optical microwave generation, where basically a microwave signal is transmitted on the fiber and sent out without any signal processing in the base station. This of course results in the concentration of all the functionality in a central control station. This might even be advantageous for mobility management, but the cost of installing a fiber to each base station seems to outweigh that. The next step would be to introduce WDM in the local network to connect more than one base station to a single fiber. But now, when considering WDM in the local network, passive routing using AWGs might after all become an issue again.
Thus, there are a number of alternatives that will be studied inside the project.

T-Nova

T-Nova is Deutsche Telekom’s research and development company, which is creating, developing, testing and introducing innovative products, services and network techniques in the area of telecommunications and information technology. The Technologiezentrum, an organizational unit within T-Nova concentrates on research and development for all kinds of network related services. It has about 1000 employees mainly working in various projects for the different divisions and subsidiaries of the Deutsche Telekom group.
The Technologiezentrum sees itself as an industrial research and development institute, but also as a connecting link between other research institutions in Germany and the Deutsche Telekom as the major German network provider.
The department ”Network Architecture and System Concepts” of the Technologiezentrum is located in Berlin and has many experiences in the field of management of optical networks like functional architectures of optical networks, basic principles of handling the analogue character of optical networks and planning and design rules of optical networks. The department's expertise in optical internetworking has been used in recent research projects for theoretical analysis and practical evaluation of various IP over WDM network architectures. The department is an active member of the Optical Internetworking Forum.
The participation of T-Nova in the TransiNet project helps the consortium to get a better understanding of

the challenges a network provider has to face today, to keep pace with increasing traffic demands, new applications and new network technologies. One project goal is to analyze how newly evolving optical networking technologies may be used to migrate actual transport networks to highly dynamic and IP optimized future transport networks.
In the beginning of the project T-Nova concentrated on the definition and classification of services and traffic aspects. Based on this classification, the characterization and modeling of IP traffic will be an ongoing activity during the whole project .
A key issue will be the different routing, signaling and resilience aspects in a dynamically configurable optical network to support and improve transport network services. A promising way to optimize future transport networks and to meet future demands, different concepts for a control plane for implementing configuration- and fault management functions will be investigated.
The development of innovative network architectures will take into account existing concepts from the IP world, like MPLS, but also new approaches like optical label switching or optical burst switching. Finally, T-Nova will help to transfer the achieved research results into the ongoing standardization processes, like within ITU-T or OIF.

University of Stuttgart

The Institute of Communication Networks and Computer Engineering (IND) is part of the department of Electrical Engineering and Information Technology of the University of Stuttgart. Prof. Dr.-Ing. Dr. h.c. mult. P. J. Kühn and his currently 21 researchers concentrate their activities around communication networks and distributed systems covering architectures, protocols, design methods as well as teletraffic theory and engineering.

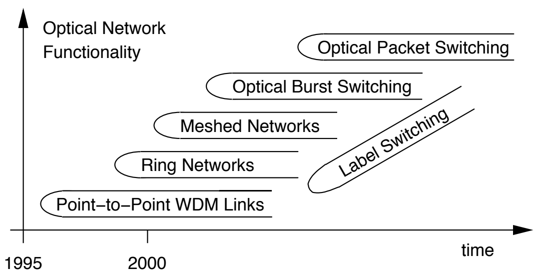

Fig. 6.1 Evolution of photonic transport networks

From the IND point of view, TransiNet is structured in three main blocks that are highly interrelated. The first part is concerned with definition and classification of services and traffic aspects. This includes measurements and modeling with special focus on traffic aggregation. The second part focuses on the evaluation and further development of architectures for optical networks such as optical burst, label and packet switching and MPLS. Evolution scenarios for these architectures are of special interest (**Fig. 6.1**). Finally, IP and WDM routing is considered. Existing protocols are evaluated and compared, first separately later in an integrated way. The common ground of all three IND parts is the architecture for photonic IP networks.

Project Objectives

The basis for design and evaluation of optical networks is a picture of service requirements to be supported, as well as assumptions on traffic characteristics and paths in such networks. This working area is defined in close cooperation with the other partners. The focus of the IND is on definition and classification of service classes that are supported by the network and the mapping of existing and upcoming applications onto these service classes.
In order to get an idea of future traffic characteristics that have to be expected in such networks, traffic measurements will be carried out in the student dormitory network on the university campus. This network provides users with broadband access and therefore a variety of new (QoS-demanding) applications are carried by this network.
The link between the supported service classes and the traffic profile is (traffic) aggregation. For the core network, strategies are developed and evaluated that best support the mapping of expected traffic onto supported service classes with respect to bandwidth needs and QoS-parameters such as loss probability and delay.
Finding an appropriate architecture for a future photonic transport network is a key objective. In addition to attributes like high throughput, reliability and scalability, an IP-centered network architecture should support dynamic IP traffic efficiently, satisfy Quality of Service (QoS) constraints of elastic and real-time applications and take best advantage of available technology, e.g. WDM or fast optical switching. **Fig. 6.1** shows a possible evolution scenario for photonic transport networks.
The work of IND comprises Optical Label Switching (OLS) and Optical Burst Switching (OBS) architectures, their critical design issues and performance. In a later phase of this project Optical Packet Switching (OPS) will also be focused on and new alternative architectures are to be investigated.
Independent of the network architecture of choice, there is a need for management protocols which are able to support the demanded high quality standards.

Multiprotocol Label Switching (MPLS) is a promising approach for a control plane integrating various network architectures. As MPLS allows for routing based on labels it lends itself ideally to traffic management. MPLS, Generalized MPLS (GMPLS) as well as Multiprotocol Lambda Switching (MPλS) will be evaluated based on their performance as well as suitability for future photonic networks. MPLS and its supporting standards like Label-Distribution-Protocol (LDP) and Resource Reservation Protocol (RSVP) must be well understood, and then adapted to key requirements.
In photonic networks, the notion of routing in multiple layers significantly increases the level of complexity inherent to routing. WDM Routing has been a research topic in the IND for some time [13]. Different protocols and strategies already described for single layers will be investigated and extended to be used with multiple layers either in an integrated way or concurrently. Finally we will evaluate their efficiency within that project's framework.

Ongoing Work

Currently, a first proposal of the IND for a service classification with respect to the used underlying transport protocol as well as the real-time requirements is discussed by the consortium. In this context, we suggest to support following classes of service in a future network: A *premium class*, mainly for interactive applications like audio and video and applications with stringent requirements on answering times like (network) games, a *better treatment class* for streaming traffic, commercial database applications and high quality Internet and finally the well-known non-critical *best effort class*. Measurement equipment has been set up and test measurements regarding functionality and performance have been carried out.
The OBS architecture has been studied, key issues have been identified, proposed mechanisms have been classified and performance evaluation on reservation mechanisms and service differentiation has been conducted. Results are presented in [10] and at this conference [11]. Performance evaluation employs our OBS simulation tool based on the IND Simulation Library (INDSimLib) [12] as well as queueing theory analysis.
A working document containing a summarization of the latest drafts and sources on the steadily evolving MPLS protocol family and their adoption to new photonic networks has been compiled. This forms the basis for a ranking of the described ideas and extensions for later deployment within the project. To understand how MPLS exactly behaves in different environments we will set up a laboratory experiment based on existing MPLS implementations for Linux. This may lead to a framework of an „virtual photonic network“.
Starting from our work on lightpath routing strategies and performance evaluation of routing protocols (PNNI, BGP and OSPF), we have started to fill the gap that exists in between the IP/ATM and the optics layer. This work considers the aspects of future photonic network architectures as well as carriers' requirements for QoS and resilience. In order to obtain integrated routing, we are looking at extensions to routing protocols proposed within the IETF for photonics and its characteristics. We also plan on evaluating these routing strategies in systems which are not lightpath switched.

Conclusion

In this paper the partners of the project TransiNet described their pursued goals and activities including their technical approach and first results.
To stimulate the know-how exchange with industry, workshops are planned in which recent results are presented and which provide a platform for discussion.
Further information can be found on the project home page `http://www.transinet.de/`.

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