

# Evolution towards an all-optically switched packet network: the LASAGNE viewpoint

(Invited)

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All-optical packet-switching networks form a logical step in the evolution of packet-switched networks. Nevertheless, research now focuses on the migration path towards these all-optical packet-switching networks. This paper paints a picture of different migration strategies from the viewpoint of disaster recovery and from business point of view.

## 1. Introduction

The IST-LASAGNE project [1], investigates all-optical label swapping employing optical logic gates in network nodes: in other words, the intention is not only to switch the payload of a burst or packet optically, but also to process the accompanying header in the optical domain. All-optical packet-switching forms in that way the logical evolution of optical packet-switched (OPS) networks. It overcomes the speed limitations that are posed by costly and difficult optical/electronic/optical conversions of the packet's header and payload. Notwithstanding the research efforts that are done in the fields of all-optical networking and the progress that is made towards a feasible design of an all-optical label swapping router, truly all-optical networks are still considered to be a distant future. The main focus now lies with the design of a migration path from current networking technologies towards (all-optical) packet switching networks. Which migration strategy to follow and how the future networks will look like, depends on the requirements posed by different drivers as business, disaster recovery, user-services...

This paper categorizes different migration scenarios and identifies their special requirements. Section 2 describes the migration strategies in more detail. Section 3 and 4 give the viewpoint of disaster recovery and business operators (two important stakeholders in network design) on the scenarios. Section 5 concludes this paper.

## 2. Migration strategies

This section explains in more detail the migration paths under study.

## 2.1 Node per node

Migration from an existing network to an (all-) optical packet-switched network, following this approach, implies a gradual replacement of the original nodes by the new (all-) optical packet-switching nodes. Both nodes coexist and the intermediate network forms as such a parallel multi-technology hybrid optical network. In this strategy, two scenarios can be distinguished:

- **OPS nodes are introduced in an OCS network, Figure 1 (circuit to packet migration):** this scenario consists of an optical circuit-switched (OCS) network with optical cross-connects (OXC) in which some OPS nodes are introduced dispersed through the network. To permit the migration, OPS nodes should have the capability of OXC underlying.
- **LASAGNE nodes are introduced in an existing OPS network, Figure 1 (packet to packet migration):** this scenario consists of an optical packet-switched network with electronic header processing and LASAGNE nodes with all-optical header processing are introduced.

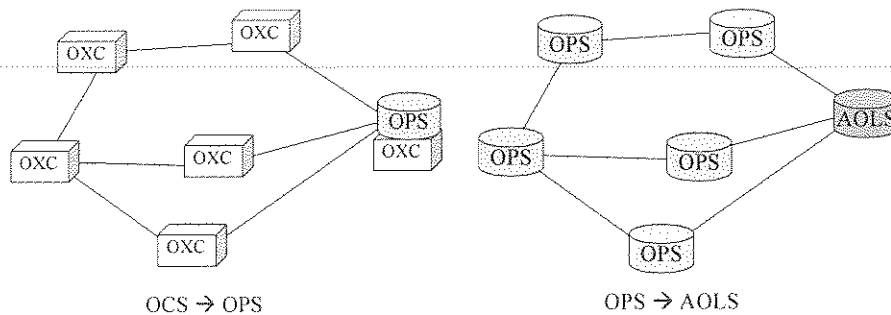


Figure 1 Node per node migration

## 2.2 Island based

This scenario is an extension of the previous migration strategy. In this case, multiple nodes, which form a sub-network, are introduced in the existing network architecture. Also in this migration strategy, two scenarios can be distinguished:

- **Island based introduction of OPS nodes, Figure 2 (circuit to packet migration):** this scenario consists of an OCS network with OXC and in which an island of OPS nodes is introduced. To guarantee the migration to packet-switched networks, additional hardware should be added in the edge OPS nodes to form the correct interface to the OCS network.
- **Island based on LASAGNE nodes, Figure 2 (packet to packet migration):** this scenario consists of an optical packet-switched network in which an island of LASAGNE nodes is introduced. The main difference between the existing OPS nodes and the LASAGNE nodes is the processing of the header.

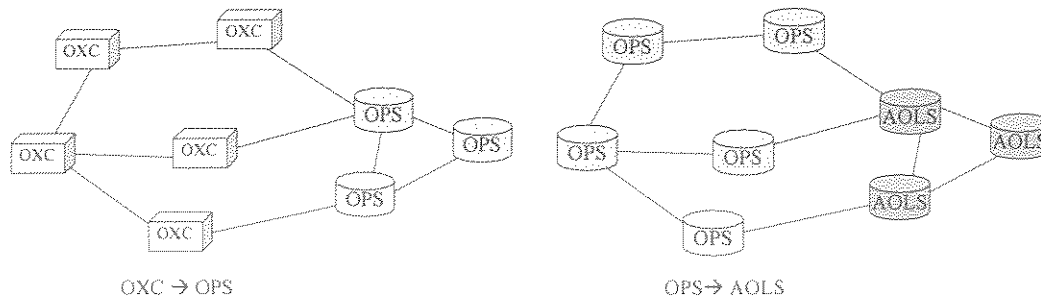


Figure 2 Island based migration

## 2.3 Mixed network: OCS + OPS/AOLS

This migration scenario, Figure 3, is based on two network layers, and forms as such a client server hybrid optical network. The original optical circuit layer still exists but the network architecture is extended with an optical packet layer. Optical packet-switched nodes are then connected using optical Wavelength Division Multiplexed (WDM) circuits provided by the circuit layer. Even if the OPS/AOLS network is supposed to carry every type of client traffic, the connection of client equipment to OPS/AOLS edge routers would need certain time to evolve and the definition of a migration policy. In this transient phase, some clients may use the OPS network, while others are still connected through a circuit based backbone.

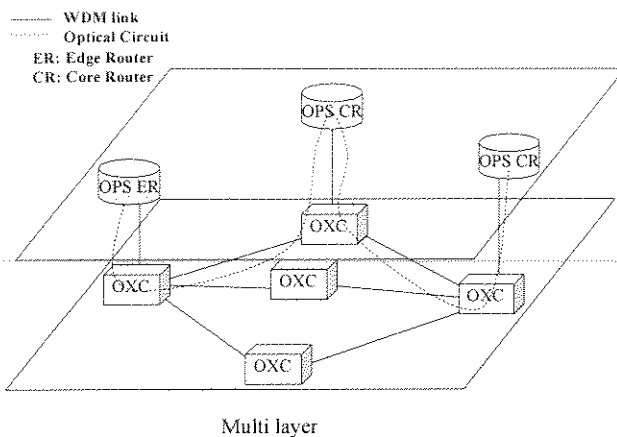


Figure 3 Mixed network scenario

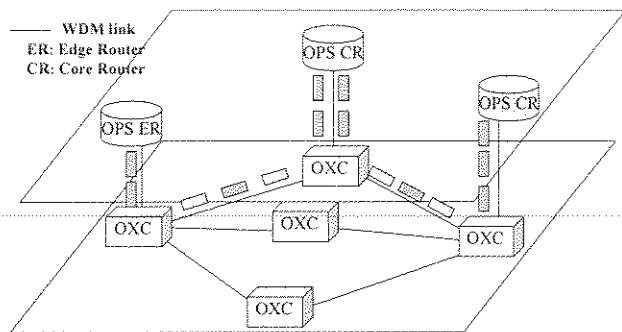


Figure 4 ORION

## 2.4 ORION

The last migration strategy to be studied in the LASAGNE project is the concept of "Overspill Routing In Optical Networks", ORION, [2], Figure 4. The ORION concept makes use of the idle periods on optical WDM circuits to insert optical packets. This is an example of integrated multi technology optical networks in which multiple technologies, e.g., OPS and OCS make use of the same wavelengths.

## 3. Protection/restoration issues

### 3.1 Introduction

Communications networks are subject to a wide variety of unintentional failures that may cause a large amount of data loss. Therefore, the survivability of network is a critical issue and it is thus imperative to provide a high level of network availability by means of recovery schemes.

The network recovery mechanisms are classified in several ways: on a local or end-to-end basis, by protection or restoration and pre-planned or in real time [3].

### 3.2 Resilience in optical circuit-switched networks

Until recently, protection was the only realistic choice for a network operator to make a meshed Optical Transport Network (OTN) resilience against failures. With protection, back-up paths are calculated before the failure occurs and cross-connects on the back-up route are switched beforehand. Applying a protection scheme requires much more installed capacity (wavelength) in the network than applying restoration, where back-up routes are calculated the moment of failure. In fact, typically more than 50% of the capacity installed in the network with a

dedicated protection scheme is spare wavelength capacity, [3]. This is because in almost all cases the back-up path is longer than the working path, and thus uses more wavelengths. Regarding link or path recovery, the former requires typically more capacity because path recovery has a larger view on the network allowing more opportunities to optimize the spare capacity needed in the network.

Concluding, the protection suffers from capacity inefficiency and shows little flexibility in dealing with unexpected failures. Also, path recovery is preferred over link recovery. Therefore, path restoration is the preferable recovery scheme in OTN.

### 3.3 Resilience in optical label swapping networks

Which resilience scheme to choose in all-optical networks depends highly on the effect they have on the dimensions of the all-optical nodes, [4]. Because the protection scheme uses pre-defined paths, the infrastructure needed must be available and configured as if all LSPs were to pass through the back-up link at the same time. Due to this the total number of correlators needed in the back-up node is the sum over all correlators needed for individual failures. On the other hand, the restoration scheme sets up back-up paths at the time the failure occurs. Figure 5 depicts that restoration needs less capacity on the back-up link because it re-uses the same components (i.e. correlators, incoming ODL, outgoing ODL) for different LSPs in the case of different link failures. In terms of AOLS node dimensions, Figure 6 depicts that the protection scheme is worse than the restoration scheme and link recovery needs more capacity than path recovery. As the flexibility of an all-optical network is defined by the components available in the node, restoration - with the re-use of components - is not as flexible as it is in the case of packet-switching networks with electronic header processing. Therefore, the most suitable recovery scheme for all-optical label swapping is thus path protection.

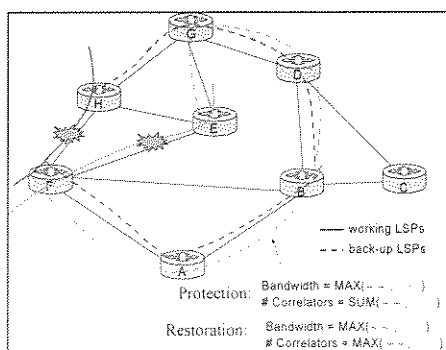


Figure 5 Calculation of the resources needed for protection and restoration in all-optical networks

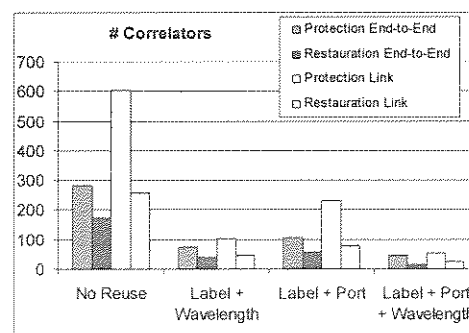


Figure 6 Number of correlators per link for different recovery schemes in the case of a single link failure

### 3.4 Resilience in migration scenarios

As there will be a long time of co-existence of current and future networks, it is important to study the migration scenarios regarding disaster recovery strategies.

#### Node per node

- **OPS node based:** the network consists of different nodes, OXC and OPS nodes with OXC capability underlying. Therefore, an interface that sends packets to OPS node and the non-packets to the OXC is needed. The resilience mechanisms are the same as the circuit-switched networks (section 3.2).
- **LASAGNE node based:** in a packet-switched network, protection increases the recovery speed whereas restoration optimizes the flexibility and lowers the

required amount of spare capacity. The introduction of all-optical nodes increases the throughput of the network. But, in all-optical packet-switched networks, the flexibility is related to the dimensions of back-up nodes. Due to this, restoration is not as flexible and thus protection is preferred. On the other hand, link recovery needs more capacity than path recovery. Therefore, the choice for the appropriate recovery scheme, path protection/path restoration, is a trade-off between the dimensions of the nodes and the throughput.

#### *Island based*

- **Island of OPS nodes in OCS network:** as for the node per node strategy, additional hardware is needed in OPS nodes. In the edge nodes of the packet sub-network, the data traffic should be accommodated in the payload of optical packets. Therefore a mapping procedure should be defined. The incoming wavelength thus should be mapped onto a label. Recovery schemes depend on the part of the network where the failure occurs and which elements are affected.
- **Island of LASAGNE nodes in an OPS network:** in this environment, two cases can be distinguished:
  - The link failure only affects LSPs inside one network, leaving the other intact. From the point of view of resilience, the two networks can be managed independently and the most appropriate scheme can be applied in each network. Thus, path protection for LASAGNE and path restoration for OPS.
  - The link failure affects LSPs in both networks. Then, back-up LSPs can pass through two different nodes (OPS/LASAGNE). As all-optical networks are the critical factor in terms of flexibility, to obtain a more flexible solution, path protection can be chosen as recovery scheme.

#### *Mixed network: OCS + OPS*

In this scenario the connections are established in the circuit layer. Therefore, the recovery schemes typical for OCS networks are applied (section 3.2).

#### *ORION*

The integration of different network technologies into a multilayer network creates challenges with respect to network survivability. In different network layers, recovery mechanisms that are active can be exploited jointly, but interworking is also indispensable in order to overcome the failures that can occur. There are three approaches in multilayer scenario: single-layer recovery, static multilayer recovery and dynamic multilayer recovery [5].

## **4. Evolution towards AOPS from an operator's point of view**

After the rather general considerations of the previous sections, this paper now focuses on a more concrete, very specific example, i.e., the Telecom Italia optical packet backbone network. It is an example of trying to forecast a practical way of introducing an OPS network on an existing situation.

### **4.1 Present network - the TelecomItalia example**

A topological / geographical representation of the Italian IP/MPLS network is shown in Figure 7. It consists of a core section surrounded by access segments. The inner links are equipped with DWDM line systems carrying SDH high capacity frames for the transport of encapsulated layer 3 IP packets. Both optical and SDH layers are

terminated at any edge node, where IP packets are separately switched by electronic matrixes, according to their destinations.

The topology of the core network is organised around four hubs, with a few tens of core PoPs (Point of Presence) connected to them in dual homing, distributed around the country to serve different access areas. The hubs are interconnected via STM-64 links, which form with them the *inner core* of the IP/MPLS network (Figure 9). Since STM-64 containers carry IP packets encapsulated, all the SDH links involved are terminated with Packet over SDH interfaces. The inner core has thus a ring topology, whose shortest sides contain also separated 10GBE links, carrying IP packets. Their main function is to guarantee a correct balancing of the overall traffic between the longest sides of the inner core. The traffic distribution is dimensioned all over the optical packet backbone in such a way that a 50% maximum capacity is effectively used per link, assuring a 1 + 1 protection against a single link failure. To give an estimate of the core PoPs throughputs in the IP/MPLS backbone of Telecom Italia, it can be recalled that the whole core network is based on the Cisco technology of the series 12000 routers with switching capacities comprised between 80 and 320 Gbit/s.

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#### 4.2 Present node structure

From the viewpoint of node architectures, the most important feature is that resource duplication for inner core protection at the link level is further doubled at the hub level. There, each of the four PoPs consists of a small, meshed network of four routers. Two of them (CS nodes on Figure 9) are respectively connected to a four-sided ring. This obviously depends on the choice of extending the 1 + 1 protection. The introduction of two additional routers (E routers on Figure 9) per PoP originates from separating the paths of the transit traffic and the traffic related to the IP access side over the double ring core. Again this is for resilience purposes. Hub duplication (dual homing), besides ensuring protection against single link faults, provides disaster recovery for each hub.

In analogy to the inner core, also the architecture of the outer core PoPs in the above model of IP/MPLS network is characterised by a little meshed network. The meshed network interconnects four routers; two (directly connected to the four hubs via STM-16 links) are called core routers, while the remaining two on the access side are edge routers. These node architectures that are characterised by the use of 4 (6 in some cases) routers in each core PoP, are motivated by resilience requirements. This has obviously economic disadvantages: more operation resources, more fibre plant, more footprint space and more power are needed to maintain these sub-networks of routers within IP/MPLS core networks.

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#### 4.3 Future OPS network and future node structure

It is commonly agreed that future networks will have a meshed topology. There are clear advantages in this configuration: a shortest mean length of the links; resilience to multiple link failures; a better redistribution of the traffic load, etc. On the other hand, a meshed structure is more expensive, due to the higher number of interfaces that are necessary per node. Even before the deployment of an all-optically switched packet network, however, it is likely that the network will evolve towards a meshed topology, with switching capabilities implemented also at the wavelength level by means of OXC.

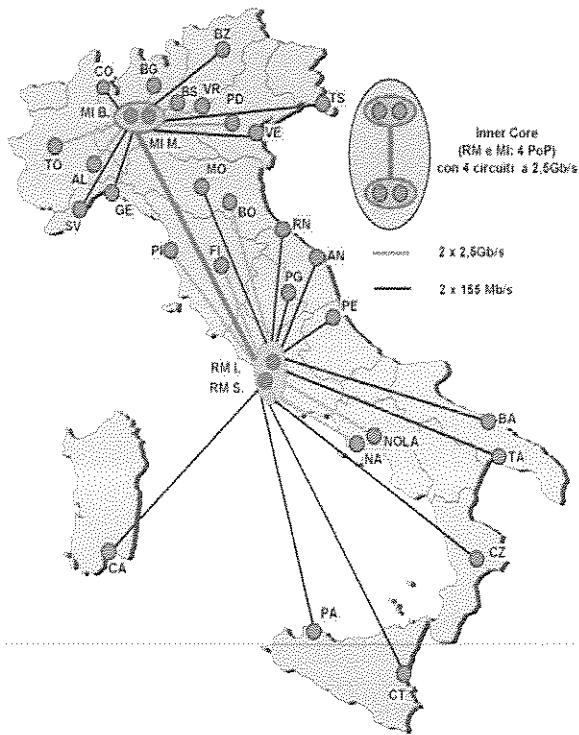


Figure 7 Present Italian Optical Packet Backbone network

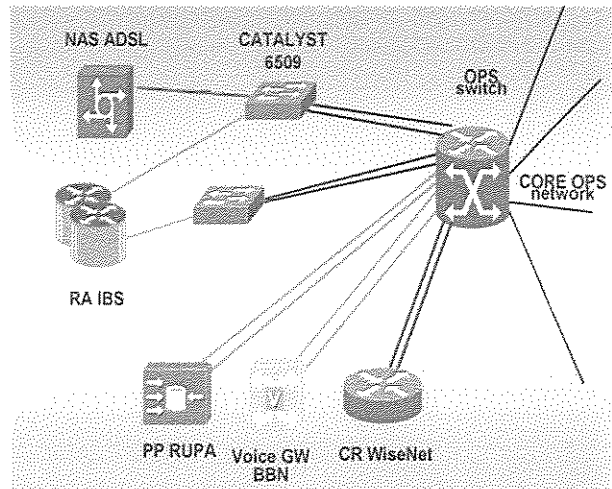


Figure 8: future node structure

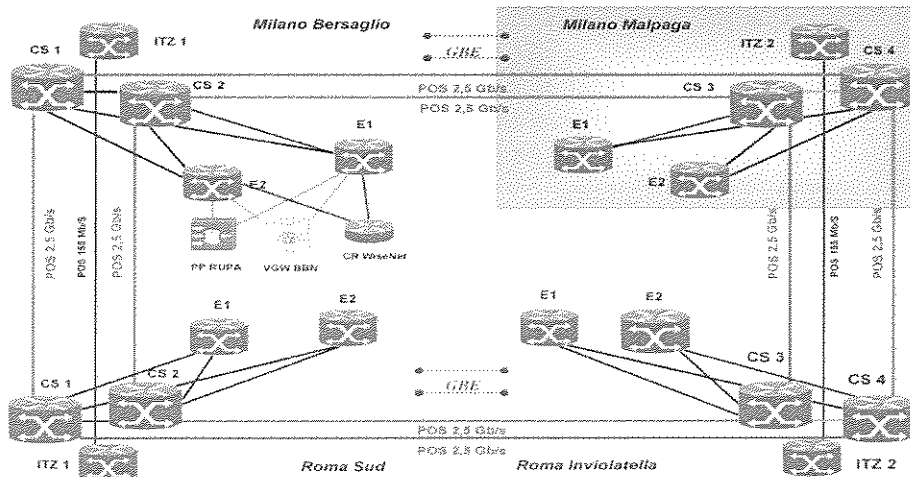


Figure 9 Inner core structure

Although previous forecasts of the IP traffic constantly doubling every year have been somewhat reduced, the ongoing growth of the Internet remains the first driver for the evolution of PoPs' schemes. Especially for the components related to the most demanding services, voice and video streaming. Until now, the majority of service providers and operators have increased the number of routers in their IP/MPLS network to cope with the increased traffic volume. This simple solution, however, is becoming more and more critical for economic reasons. Actually, the installation of a new router in an (almost) fully meshed sub-network, like that interconnecting the routers of core PoPs, makes architectural complexity and capital costs for additional resources needed (e.g., interfaces to be added on old routers, fibre links, etc.) to increase very rapidly. A continuous increase at the same rate as recently experienced would lead to a saturation of presently installed routers. This, in its turn would require a drastic PoPs' architecture simplification with respect to

present models. This need is being taken into serious consideration by routers constructors, who are moving towards unified structures like the one shown in Figure 8.

#### 4.4 Possible migration strategy

As far as a migration strategy towards OPS is concerned, the LASAGNE viewpoint is essentially in agreement with the views expressed in the IST project NOBEL [6]. A smooth migration of services and/or traffic to the new network could be realized, for instance, by first deploying a small network of interconnected OPS nodes in some of the geographical locations where present PoPs of the outer core are installed. Since the lion's share of traffic in the present network is routed through the inner core, it would be preferable to locate the first nodes of the new network not far from inner core nodes. Also some gateways for interworking between the old and the new network are necessary. They are clearly best located at the inner core PoPs of the old network. Their main functionality would be to assemble LASAGNE packets starting from IP packets (and other client data) that were previously embedded in SDH frames. The LASAGNE packets would then be routed through the OPS network up to an edge node. There they are de-assembled into client data and sent to the final client equipment or to another interface gateway were they are again embedded in an SDH stream (not necessarily being first de-assembled into IP packets).

## 5. Conclusion

This paper presented different migration scenarios and addresses rather generally how resilience can be provided to them. It showed that depending on the migration path chosen, other disaster recovery schemes must be deployed. The paper also addressed the business operator's point of view concerning migration for a very concrete situation, the Telecom Italia network. It proves the need for reliable and optimized migration paths.

## Acknowledgements

This work has been supported by the European Commission through the IST-project LASAGNE and the Flemish government through the IWT-project ONNA. R. Van Caenegem thanks the IWT for its financial support through her Ph.D. grant.

## References

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- [2] Erik Van Breusegem, Jan Cheyns, Davy De Winter, Didier Colle, Mario Pickavet, Piet Demeester, Joris Moreau, "A Broad view on overspill routing in optical networks: a real synthesis of packet and circuit switching ?", *Optical Switching and Networking (invited paper)*, Vol.1, No.1, pp. 51-64
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- [4] R. Van Caenegem, D. Colle, M. Pickavet, P. Demeester, "All Optical Label Swapping: a challenge for node dimensioning", *Invited Paper, ICTON 2005, Barcelona 3-7 July 2005*
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# NOC & OC&I

10<sup>th</sup> – 13<sup>th</sup> July, 2006

Fraunhofer-Institute for Telecommunications,  
Heinrich-Hertz-Institut (FhG-HHI), Berlin, Germany

## Programme

Please register now.

### Overview

Monday, 10th July, OC&I

	Track 1 (Lecture Hall)	Track 2 (Seminar Room)
Afternoon (14:00-17:15)	<ul style="list-style-type: none"> <li>• New Fibre Technologies (OC&amp;I)</li> <li>• Progress on Optical Standard (OC&amp;I)</li> </ul>	

Tuesday, 11th July, NOC and OC&I

	Track 1 (Lecture Hall)	Track 2 (Seminar Room)
Morning (09:00-12:15)		<ul style="list-style-type: none"> <li>• Cable and Connectivity Solutic (OC&amp;I)</li> <li>• Installation Experience and Technologies (OC&amp;I)</li> </ul>
Afternoon (14:00-16:05)	<ul style="list-style-type: none"> <li>• Plenary NOC and OCI</li> </ul>	
Afternoon (16:35-17:35)	<ul style="list-style-type: none"> <li>• POF and MMF Systems</li> </ul>	<ul style="list-style-type: none"> <li>• Network Architecture</li> </ul>
	<ul style="list-style-type: none"> <li>• Get together at Fraunhofer HHI Foyer</li> </ul>	

Wednesday, 12th July, NOC

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	Track 1 (Lecture Hall)	Track 2 (Seminar Room)
<b>Morning</b> (09:00-12:50)	<ul style="list-style-type: none"> <li>• Optical Access (MUSE Part1)</li> <li>• P2P Access, TDM-PON, DBA</li> </ul>	<ul style="list-style-type: none"> <li>• Photonic Devices and Applicat 1)</li> <li>• Photonic Devices and Applicat 2)</li> </ul>
<b>Afternoon</b> (14:30-18:10)	<ul style="list-style-type: none"> <li>• WDM-PON (Part 1)</li> <li>• WDM-PON (Part 2)</li> </ul>	<ul style="list-style-type: none"> <li>• Photonic Network Elements an Processing</li> <li>• Evaluation of Novel Photonic I Architectues</li> </ul>

#### Thursday, 13th July, NOC

	Track 1 (Lecture Hall)	Track 2 (Seminar Room)
<b>Morning</b> (09:00-12:30)	<ul style="list-style-type: none"> <li>• Access Roadmap</li> <li>• Radio over Fibre</li> </ul>	<ul style="list-style-type: none"> <li>• LASAGNE Workshop: Photor Network Migration (Part 1)</li> <li>• LASAGNE Workshop: Photor Network Migration (Part 2)</li> </ul>
<b>Afternoon</b> (14:00-17:30)	<ul style="list-style-type: none"> <li>• Access Platforms and QoS (MUSE Part 2)</li> <li>• Prospects of FTTH</li> </ul>	<ul style="list-style-type: none"> <li>• WDM Routing and Protection</li> <li>• Network Quality Management Provisioning</li> </ul>

#### Friday, 14th July, MUSE summer school

	MUSE summer school (Seminar Room)
<b>Morning</b> (08:45-12:00)	<ul style="list-style-type: none"> <li>• Overview of the MUSE Architecture</li> <li>• QoS Framework for access networks</li> </ul>
<b>Afternoon</b> (13:00-16:15)	<ul style="list-style-type: none"> <li>• QoS mechanisms in access multiplexers and PONs</li> <li>• A simple Calculator for network QoS parameters</li> </ul>

## Detailed Programme

### Monday, 10<sup>th</sup> July (Lecture Hall)

#### OC&I Workshop

14:00      **Welcome address**  
 Hans-Joachim Grallert, Managing Director FhG-HHI  
 Rosamund Neat, Chair OC&I

#### New Fibre Technologies

Chair: Bertil Arvidsson

- 14:05      **Characteristics of Holey Fibre and its application to flexible wiring and ultra broadband optical communication**  
K. Nakajima, K. Ieda, T. Matsui, K. Kurokawa, K. Tajima, K. Hiramatsu, T. Kurashima, S. Tomita, I. Sankawa
- 14:35      **New fibre families for optical telecommunications**  
D. Cuomo
- 15:05      **PMD-induced pulse broadening in linear and nonlinear optical transmission systems**  
M. Ferreira and M. Facão
- 15:25      **Temperature dependence of PMD in tight buffered G.652 and G.655 single-mode fibers**  
K. Borzycki, M. Jaworski, M. Marciniak
- 15:45      **Coffee break**

### ***Progress on Optical Standard***

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Chair: Stuart Walker

- 16:15      **A guideline to building of FTTX fibre optic networks**  
B. Arvidsson
- 16:45      **Latest IEC/ Cenelec standards in development**  
R. Neat
- 17:15      **End of OC&I Session 2**

**Tuesday, 11<sup>th</sup> July (Lecture Hall)**

### ***OC&I Workshop***

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#### ***Cable and Connectivity Solutions***

Chair: Daniele Cuomo

- 09:00      **Microduct cabling developments for in-building use**  
R. Neat
- 09:30      **Infrastructure installation solutions for FTTx – Technologies for successful projects**  
T. Ahi
- 09:50      **Smart connectivity in FTTP projects**  
J. D. Jackson and J. Reinhardt
- 10:10      **Coffee break**

***Installation Experience and Technologies***

Chair: Willem Griffioen

- 10:40      **Cable blowing, cable floating: which method to adopt?**  
P. Lépine, M. van Moppes, G. Plumettaz
- 11:10      **Results of BT'S FTTP trial**  
C. Strong
- 11:40      **Network architecture/ broadband access**  
P. Barker and P. Hale
- 12:10      **Strolling lunch**

**Tuesday, 11<sup>th</sup> July (Lecture Hall)*****Joint NOC and OC&I 2006***

- 14:00      **Welcome address**  
Hans-Joachim Grallert, Managing Director FhG-HHI

***Plenary NOC and OC&I***

Chair: Dave Faulkner

- 14:05      **Development roadmap towards 100 G photodetectors and receivers  
and beyond**  
H.-G. Bach, A. Beling, G. G. Mekonnen
- 14:35      **Nonlinear diffusion bandwidth and equivalent single-span model:  
Simple tools for the optimization of dispersion maps**  
J. K. Fischer, C.-A. Bunge, K. Jamshidi, H. Louchet, K. Petermann
- 15:05      **Terabit transmission on a single wavelength channel**  
C. Schubert, C. Schmidt-Langhorst, R. Ludwig, S. Ferber, B. Hüttli, H.-G.  
Weber
- 15:35      **Evolution of next-generation broadband networks in Europe**  
A. Houghton
- 16.05      **Coffee break**

***POF and MMF Systems***

Chair: Alan Harmer

- 16:35 **1.25 Gb/s transmission over 25 m of 1 mm standard step-index PMMA polymer optical fiber for Gigabit Ethernet**  
S.C.J. Lee, H.P.A. van den Boom, R.L. Duijn, P.K. van Bennekom, J. Zeng, S. Randel, B. Spinnler and A.M.J. Koonen
- 16:55 **WDM over POF – a chance for low cost optical Ethernet**  
U. H.P. Fischer, M. Haupt, J.-U. Just
- 17:15 **1.25 Gb/s subcarrier modulated transmission over 4.4 km 50 µm multimode fibre**  
J. Zeng, H. P. A. van den Boom, A. M. J. Koonen
- 17:35 **Get together at FhG-HHI Foyer**

## Tuesday, 11<sup>th</sup> July (Seminar Room)

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### *Network Architecture*

Chair: Ignacio de Miguel

- 16:35 **Comparative analysis of optical solutions for fixed & mobile convergent metro-core networks**
- 16:55 **100 Gbit/s Ethernet for True End-to-End Carrier-Grade Ethernet networks**  
J. F. Lobo, J. P. Fernández-Palacios, A. Ferreiro, I. Mayans, F. J. Martín
- 17:15 **Implementation of high performance schedulers for decoupled electro-optical packet switches**  
R. H. Derksen, A. Kirstädter, G. Lehmann
- 17:35 **Get together at FhG-HHI Foyer**  
F. J. González-Castaño, C. López-Bravo, M. Rodelgo-Lacruz, J. García-Haro, P. Pavón-Mariño, J. Veiga-Gontán, E. Soto-Campos, J. J. Rodríguez-Andina, E. Lago
- 

## Wednesday, 12<sup>th</sup> July (Lecture Hall)

### *Optical Access (MUSE Part 1)*

Chair: Peter Vetter

- 09:00 **Broadband access solutions on a common CWDM platform**

- K. Habel, K.-D. Langer, G.-J. Rijckenberg, A. Ng'oma, J. Lepley, T. Koonen, S. Walker
- 09:30 **QoS-aware traffic protection for access rings**  
S. Chennu, K. Habel, K.-D. Langer
- 09:50 **Compact central office solution for point-to-point fibre access, including novel dual bi-directional fibre optical transceiver**  
G. Arvidsson, S. Junique, K. Å. Persson, E. Sundberg
- 10:10 **An asymmetric passive optical network: a combined point-to-point and Passive-Optical-Network**  
R.C.J. Smets, W. Hellenthal, J.G.L. Jennen, G. van Ooijen, J. S. Wellen
- 10:30 **Burst-Mode Receiver Designs for Next Generation Long-Reach Passive Optical Networks**  
J.J. Lepley and S.D. Walker
- 10:50 **Coffee break**

### ***P2P Access, TDM-PON, DBA***

Chair: J. M. Senior

- 
- 11:20 **10 Gigabit Ethernet: recent developments and a potential new physical layer for EPON**  
D. Cunningham
- 11:50 **Two-stage dynamic bandwidth allocation algorithm for EPONs with heterogeneous traffic load**  
N. Merayo, R. J. Durán, P. Fernández, I. de Miguel, J. C. Aguado, R. M. Lorenzo, E. J. Abril
- 12:10 **GPON dynamic bandwidth assignment protocol for multiple services**  
J. Jiang, M. R. Handley, J. M. Senior
- 12:30 **Service Level Agreement-based Dynamic Bandwidth Allocation for GPONs**  
C.-H. Chang, P Kourtessis, J. M. Senior
- 12:50 **Strolling lunch**

### **Wednesday, 12<sup>th</sup> July (Lecture Hall)**

#### ***WDM-PON (Part 1)***

Chair: David Smith

- 14:30 **Application of semiconductor optical amplifiers in a WDM-PON**  
A. Borghesani, P. Cannard, C. Ford, L. Johnston, T. Kerr, P. Kingham, I. Lealman, R. Moore, A. Poustie, L. Rivers, D. Smith, R. Wyatt
- 15:00 **WDM/TDM access networks: advantages and prospects for the future**  
C. Bock, J. Prat, S. Walker

- 15:30 **10 Gbps hybrid WDM-TDM long reach PONs**  
P. Townsend, G. Talli, C. Wai Chow, E. MacHale
- 16:00 **Coffee break**

### ***WDM-PON (Part 2)***

Chair: David Smith

- 16:30 **Progress in PON research in PIEMAN and MUSE**  
R.P. Davey
- 17:00 **Splitters and arrayed-waveguide gratings for optical access: what's the difference?**  
M.C. Parker, S.D. Walker
- 17:30 **Burst mode penalty evaluation in the presence of interchannel crosstalk**  
A. J. Phillips
- 17:50 **Multi-PON access/ metro network using a coarse-WDM AWG router**  
Y Shachaf, P Kourtessis, J. M Senior
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- 18:10 **End of session**
- 19:00 **Conference Dinner/ Social event**

## **Wednesday, 12<sup>th</sup> July (Seminar Room)**

### ***Photonic Devices and Applications (Part 1)***

Chair: Michael Parker

- 09:00 **Development of optical frequency standards in NICT**  
H. Ito, S. Nagano, Y. Li, K. Matsubara, M. Hosokawa
- 09:30 **Novel Variable Optical-Packet-Buffering Architecture**  
E. Hugues Salas, G. Zarris, M.J. O'Mahony, D. Simeonidou
- 
- 09:50 **Polymers as integration platform for low-cost devices in future optical networks**  
N. Keil
- 10:10 **DPSK signal regeneration with a nonlinear amplifying loop mirror**  
K. Sponsel, K. Cvecek, G. Onishchukov, B. Schmauss, G. Leuchs
- 10:30 **Coffee break**

### ***Photonic Devices and Applications (Part 2)***

Chair: Stuart Walker

- 11:00 **Supercontinuum generation based photonic processing applied to multiplexing format conversions**  
H. Sotobayashi
- 11:30 **Balanced optical phase-locked loop based on four-wave mixing in semiconductor optical amplifiers**  
S. Aleksic and G. Ribnicsek
- 11:50 **Multi-gigabit pseudo-random binary sequence generator and tester**  
L. Pavlovic, M. Vidmar
- 12.10 **Strolling lunch**

### Wednesday, 12<sup>th</sup> July (Seminar Room)

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#### *Photonic Network Elements and Processing*

Chair: Michael Parker

- 14:30 **All-optical packet router based on multi-wavelength PPM header processing**  
H. Le Minh, Z. Ghassemlooy, W. Pang Ng
- 14:50 **Architecture, design and modeling of an optically-controlled recirculating buffer for 40 Gb/s label-switched routers**  
K. Vysokinos, L. Stampoulidis, E. Kehayas, H. Avramopoulos
- 15:10 **Simultaneous one-to-four multi-wavelength conversion using a single SOA-MZI**  
N. Yan, H. Do Jung, I. Tafur Monroy, T. Koonen
- 15:30 **Efficient simulation of Raman amplifiers propagation equations and spectral gain with optimization techniques**  
P. André, B. Neto, S. Junior, A. Teixeira
- 15:50 **Coffee break**

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#### *Evaluation of Novel Photonic Network Architectures*

Chair: Hideyuki Sotobayashi

- 16:30 **Traffic performance study of all-optical label swapping isolated and full network topologies**  
J. M. Delgado Mendinueta, I. Tafur Monroy, J. J. Vegas Olmos, N. Yan, Y. Dimitriadis, I. de Miguel Jimenez, A. M. J. Koonen
- 16:50 **MUPBED: A multi-domain ASON/GMPLS test network**  
C. Gerlach, S. Szuppa, A. Weber, H.-M. Foisel
- 17:10 **Comparison of IP/WDM transport network architectures for dynamic**



- data traffic**  
M. Köhn, S. Bodamer, C.M. Gauger, S. Gunreben, G. Hu, D. Sass
- 17:40 **End of session**
- 19:00 **Conference Dinner/ Social event**

## Thursday, 13<sup>th</sup> July (Lecture Hall)

### *Access Roadmap*

Chair: Klaus Petermann

- 09:00 **Meeting the challenges of FTTP – an R&D perspective**  
D. Faulkner, R. Scarbrough, A. Mayhew, D. Collings, A. Readhead, I. Boyd
- 09:30 t.b.d.
- 10:00 **Coherent WDM**  
F. Gunning, A. Ellis, T. Healy
- 10:30 **Coffee break**

### *Radio over Fibre*

Chair: Izzat Darwazeh

- 11:00 **Switched video-over-fibre networks using semiconductor optical amplifier gates**  
R. Penty and I. White
- 11:30 **Design challenges for broadband access systems**  
H. Louchet, A. Richter, I. Koltchanov, J. Farina
- 11:50 **Stable-matching-based subcarrier assignment method for multimode PON using a multicarrier variant of subcarrier multiplexing**  
R.O. Taniman, B. Sikkes, A.C. van Bochove, P. T. de Boer
- 12:10 **Strolling lunch**

## Thursday, 13<sup>th</sup> July (Lecture Hall)

### *Access Platforms and QoS (MUSE Part 2)*

Chair: Klaus-Dieter Langer

- 14:00      **Trends in Multi Service Access**  
P. Vetter, B. De Vos, E. Gilon, F. Fredrickx, K. Gustafsson, H. Mickelsson,  
J. Wellen, R. Grabenhorst, C. Alter, L. Humphrey, A. De Smedt, R. Van  
den Brink
- 14:30      **Strategies for expediting inter-provider QoS support in access  
networks**  
G. Rajan, A. Elizondo, N. Leligou, H.C. Leligou, K. Kanonakis, J. D.  
Angelopoulos
- 14:50      **Demonstration of a future multi-service access network**  
B. Nagel, F. Geilhardt, T. Monath, E. Gilon, K. Oberle, S. Danton, S.  
Dumet, C. Peña
- 15:10      **A QoS solution exploiting the MUSE QoS concept**  
A. Foglar
- 15:30      **Revolutionary IPv6 optimized access solution**  
C. Lukovszki, L. Kovács, G. Kovács, A. Foglar, E. Areizaga, Z.  
Ghebretensae
- 
- 15:50      **Coffee break**

### ***Prospects for FTTH***

Chair: Nikolaus Gieschen

- 16:20      **Optical access in Asia, present and future, and the impact on the  
international market**  
L. D. Lamb and G. Kramer
- 16:50      **Fiber to the home in Europe – Architecture and technology**  
W. Fischer
- 17:10      **Fibre access provider (FAP) for metro networks**  
Tim Braulke
- 17:30      **End of session**

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## **Thursday, 13<sup>th</sup> July (Seminar Room)**

### ***LASAGNE Workshop: Photonic Network Migration (Part 1)***

Chair: Didier Colle

- 09:00      **Meeting the challenges of future transport networks**  
M. Dueser

- 09:30      **Architectures and Technologies for Service-Oriented Optical Networks**
- D. Simeonidou, G. Zervas, R. Nejabati
- 10:00      **MUPBED point of view on application driven optical transport network**
- H. Wessing
- 10:30      **Coffee break**

***LASAGNE Workshop: Photonic Network Migration (Part 2)***

Chair: Idelfonso Tafur Monroy

- 11:00      **Hybrid solutions for advanced burst/ packet switching networks**
- E. Patzak
- 11:30      **Evolution towards an all-optically switched packet network: the LASAGNE viewpoint**
- R. van Caenegem, D. Roccatto, R. Vilar, D. Colle, M. Pickavet, P. Demeester
- 12:00      **A novel all-optical core architecture employing contiguous bursts created under reservation-based control inside clusters of nodes**
- K. Kanonakis, G. Koukouvakis, H. C. Leligou, I. Pountourakis, A. Stavdas, J. Angelopoulos
- 12:30      **Strolling lunch**

**Thursday, 13<sup>th</sup> July (Seminar Room)**

***WDM Routing and Protection***

Chair: Godehard Walf

- 14:00      **Efficient design and control of wavelength-routed optical networks by means of genetic algorithms**
- I. de Miguel, R. J. Durán, N. Merayo, D. Bisbal, P. Fernández, J. C. Aguado, F. González, R. M. Lorenzo, E. J. Abril
- 14:30      **Comparative study of QoS mechanisms in OBS networks**
- M. Klinkowski, D. Careglio, M. Marciniak, J. Solé-Pareta
- 14:50      **The shared packet recovery 1+1 path protection scheme**
- H. Øverby
- 15:10      **A combined study on 1+1 path protection and shared packet redundancy in optical packet switched networks**
- H. Øverby
- 15:30      **Coffee break**

## **Network Quality Management and Provisioning**

Chair: Dave Faulkner

- 16:00      **Network quality management for video distribution in IP network**  
M. Iwashita and C. Morioka
- 16:30      **Triggering approaches for the consolidation of provisioning oriented optical networks**  
T. Kárász, T. Jakab, B. Kárász, P. Wilcsinszky
- 16:50      **End of session**

**Friday, 14<sup>th</sup> July (Seminar Room)**



### **“Quality of service in packet-based broadband access ne**

Organized by Fraunhofer Institute for Telecommunications, HHI

and National Technical University Athens, NTUA

Slides now available!

#### **Overview of the MUSE Architecture (Tutor: P. Vetter) (8.45-10.15) slides**

- i. Ethernet based access architecture as a true multi-service network
- ii. Issues and solutions for secure connectivity via the access network
- iii. Business model - the roles of different players
- iv. Possible forwarding models based on Ethernet or IP
- v. Autoconfiguration and multicasting in the access
- vi. A survey of related activities in MUSE and international standardisation

#### **QoS Framework for access networks (Tutor: Govinda Rajan) (10.30- 12.00) slides**

- i. QoS with resource based admission control
- ii. Tight & loose QoS models
- iii. QoS in carrier & application network models
- iv. Distribution and adaptation of QoS policies
- v. Performance monitoring for QoS
- vi. Comparison of MUSE QoS principles to other QoS proposals

#### **QoS mechanisms in access multiplexers and PONs (Tutor: J. Angelopou**

[slides1](#) [slides2](#)

- i. How the temporal properties of flows affect QoS
- ii. The role of multiplexing strategy in providing QoS to flows
- iii. Scheduling policy comparisons (GPS approximations versus strict priorities)
- iv. Implementing QoS-capable multiplexers
- v. GPON operating principles according to ITU G.984
- vi. The GPON as a QoS-enabled distributed multiplexer-The impact of MAC on traffic profiles

**A simple Calculator for network QoS parameters (Tutor: G. Stassinopoulos) (14.45-16**

- i. Basic calculus: Convex, concave and mixed flows, Operators and Systems Bounds
- ii. Basic calculus in the primal and dual space
- iii. Modeling Concepts: Traditional Arrival curves, Leaky Buckets, Service Curves, Concatenation
- iv. Modeling Concepts – Alternatives
- v. Modeling through buffer sequences, Input-Output characterizations
- vi. Applications Simple examples exercises - (student participation) 1-2 more elaborate example:

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