Universität Stuttgart

INSTITUT FÜR
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Architectures for Optical Burst Transport Networks - A View Beyond QoS -

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HHI-Kolloquium
Berlin, 4. April 2006

e-Photon ONe

Trends and Motivation

Internet emerged as the global platform for communication

- **Sustained traffic growth due to fixed/mobile broadband access**
  ➔ Migration towards optical metro and core networks
- **Highly dynamic and asymmetric traffic profiles**
  ➔ Flexible packet transport
- **Next generation networks demand quality of service QoS**
  ➔ Support from transport networks

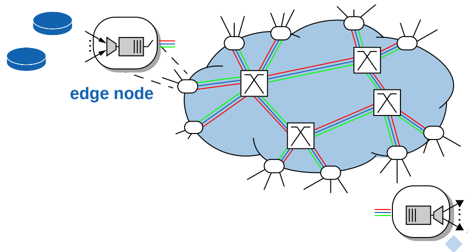
OBS proposed as long-term IP-over-WDM solution

- **Scientific work centers around QoS of OBS-only scenarios**
- **Few realization and scalability evaluations**
  ➔ How to find optimal architectures combining QoS and realization arguments?
- **Missing evolution link to existing wavelength-switched networks**
  ➔ How to build burst-switched networks on wavelength-switched networks?

Outline

- **Optical burst switching architecture**
  - Introduction and functional components
  - Contention resolution for high QoS
  - Integrated evaluation including realization and scalability
- **OBS meets wavelength-switching**
  - Motivations for virtual topology
  - Key trade-offs and realizations
- **Optical Burst Transport Network (OBTN)**
  - Network and node architecture
  - Performance evaluation

Optical Burst Switching



- **Burst assembly in edge node: IP packets ➔ optical bursts**
- **One-way signaling**

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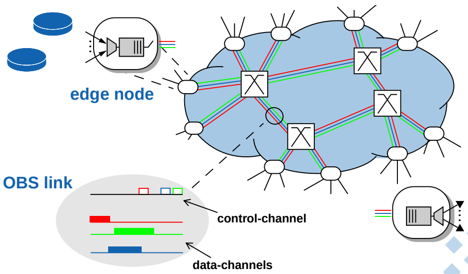

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- **Separation of control and data**

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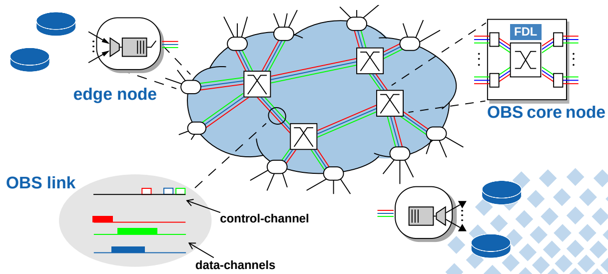
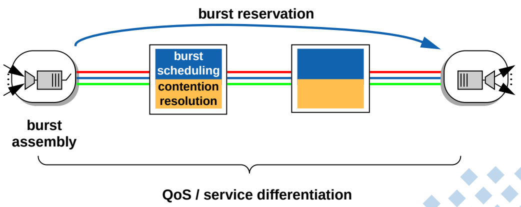


- **Burst assembly in edge node: IP packets ➔ optical bursts**
- **One-way signaling**
- **Separation of control and data**
- ***Fast* optical burst switch with fiber delay line buffer (FDL)**

OBS Functional Components

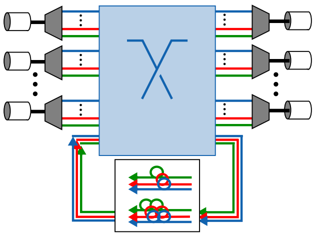


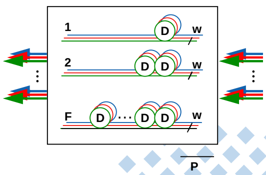
Burst assembly	assembly of client layer data into bursts
Burst reservation	**end-to-end** burst transmission scheme
Burst scheduling	assignment of resources in **individual** nodes
Contention resolution	reaction in case of burst scheduling conflict

Contention Resolution

- **Wavelength domain – wavelength conversion**
  - very effective as all WDM channels shared among all bursts
  - but: low burst loss probabilities only for $\geq 100\lambda$s
  - ➔ **additional schemes necessary**
- **Time domain – buffering**
  - simple fiber delay lines (FDLs) in nodes
  - no random access functionality
  - FDL operated in WDM
  - prioritized reservation of buffered bursts with JET possible
- **Space domain – deflection/alternative routing**
  - uses entire network as resource for contention resolution
  - additional network load due to detours ➔ positive feedback

OBS Node with FDL buffer





degenerate buffer: $T_i = i*D$, i = 1, ..., F

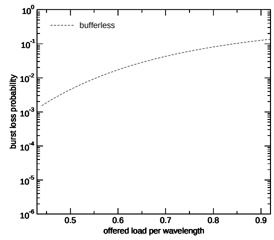
Recirculation buffer

- **Shared per node**
- **Coordinated scheduling**

Degenerate Buffer

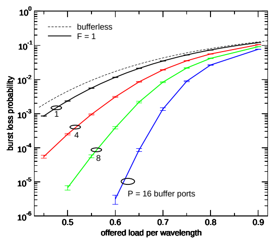
- **FDLs in buffer** F
- **wavelengths per FDL** w
- **total number of ports** P = F*w
- **delay granularity** D

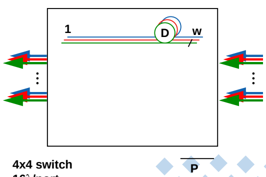
FDL Buffer Performance



4x4 switch
16λ/port

FDL Buffer Performance

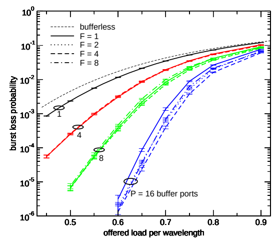


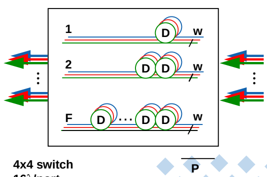


4x4 switch
16λ/port
D = 4h = 40 µs

- **Increasing the number of wavelengths improves QoS**

FDL Buffer Performance

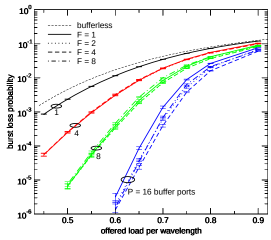


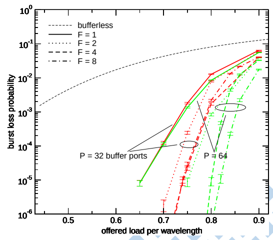


4x4 switch
16λ/port
D = 4h = 40 µs
F = 1, 2, 4, 8

- **Different buffer configurations with same P yield comparable performance**
  ➔ select the configuration based on realization arguments

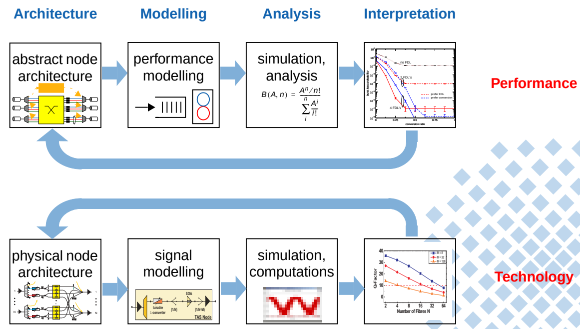
FDL Buffer Performance



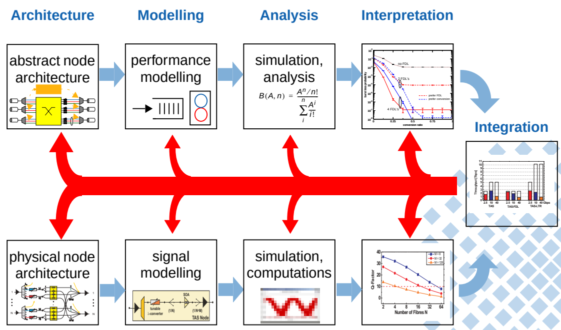


- **Few ports: different buffer configurations with same P yield comparable QoS**
  ➔ select the configuration based on realization arguments
- **Many ports: QoS depends on buffer configuration**
  ➔ further evaluate QoS and realization trade-off

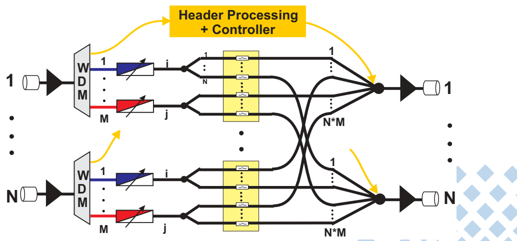
Integrated Evaluation



Integrated Evaluation



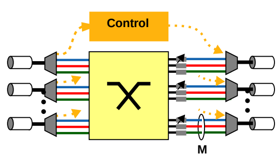
Tune-and-Select Architecture (TAS)

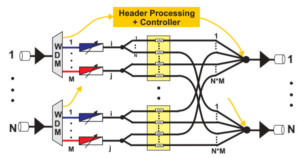


proposed by H. Buchta, E. Patzak, J. Saniter, HHI
ITG 2002, ECOC 2002

- **Single-stage switching matrix**
- **Non-blocking**
- **Full wavelength conversion**

Node Parameters

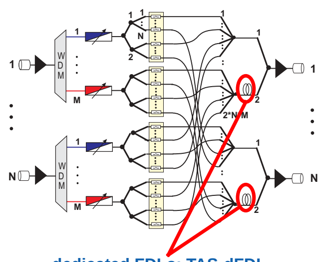




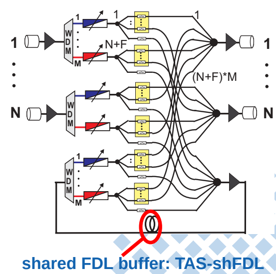
Impact on performance
- **Number of fibers N**
- **Number of wavelengths per fiber M**
- **Contention resolution scheme**

Impact on signal
- **Splitting loss: 1/N, 1/NM**
- **Noise of SOA and EDFAs**
- **Crosstalk**
- **Power loss**

TAS with FDL Buffers



dedicated FDLs: TAS-dFDL



shared FDL buffer: TAS-shFDL

➔ Performance Improvement
- due to buffering
- TAS-shFDL: multiple FDLs

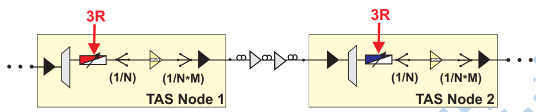
➔ Signal Degradation
- due to increased splitting loss
- due to loss in FDL

Evaluation Methodology

1. **Analysis of signal degradation between two regeneration points**
   - TAS-shFDL: node-to-node path is critical signal path

   ➔ maximum number of wavelengths per fiber M_{max}

   ➔ maximum throughput

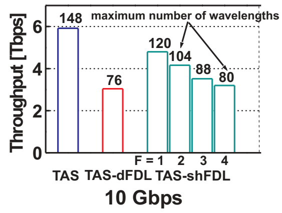


2. **Simulation of OBS node using M_{max}**

   ➔ utilization for a given tolerable burst loss probability P_{loss}

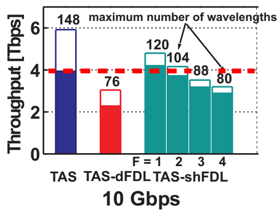
   ➔ effective throughput

Maximum Throughput



- **Maximum throughput always between 2 and 6 Tbps**
- **Greatest for TAS and smallest for TAS-dFDL**
- **More FDLs in TAS-shFDL yield smaller nodes**

Effective Throughput



- **Effective throughput between 1.5 and 4 Tbps**
- **FDL buffers improve utilization**
- **More FDLs lead to better utilization but also to smaller nodes**

  ➔ some TAS-shFDL yield lower effective throughput than TAS

Outline

- **Optical burst switching architecture**
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  - Contention resolution for high QoS
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- **OBS meets wavelength-switching**
  - Motivations for virtual topology
  - Key trade-offs and realizations
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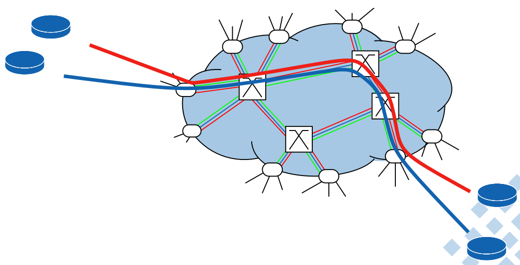
Wavelength Switching



- **Transports packets in lightpaths**
- **Two-way signaling based on ASON, GMPLS, "lambda grid"**

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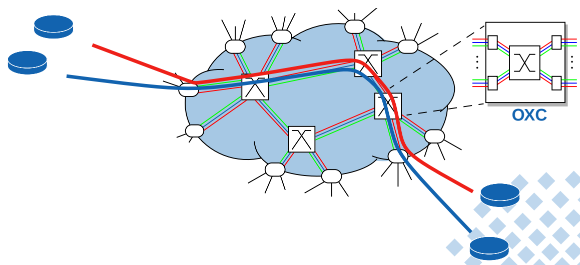
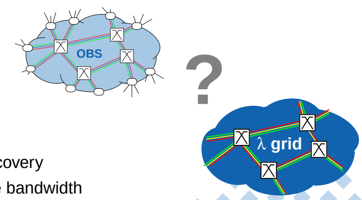


- **Transports packets in lightpaths**
- **Two-way signaling based on ASTN, GMPLS, "lambda grid"**
- ***Slow* optical cross-connect**

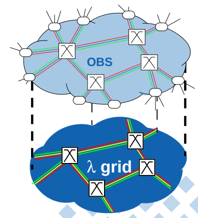
  ➥ **Used to provide virtual topology**

OBS meets Wavelength Switching



- **Optical burst switching (OBS)**
  - Fine-grain statistical multiplexing
- **Wavelength switching**
  - Coarse-grain provisioning and recovery
  - Mature technology ➔ inexpensive bandwidth
- **OBS is often proposed to replace wavelength-switched core networks**
  - But: lambda grids are well-suited for core transport networks
  - But: high aggregation does not require fine-granular statistical multiplexing

OBS meets Wavelength Switching



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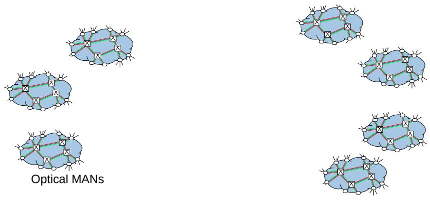
➥ **Intelligent combination instead of rapid replacement**

Motivations for Virtual Topology



- **First introduction of burst techniques more likely in MANs**

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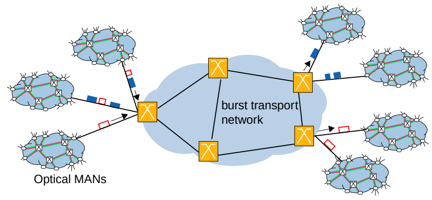

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➥ **Need for efficient burst transport across core network**

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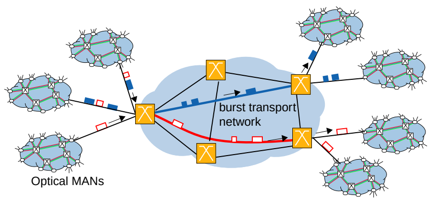


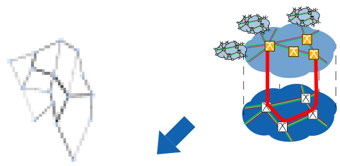
- **First introduction of burst techniques more likely in MANs**

➥ **Efficient burst transport across core network**

- **Cost of switching dominates cost of transport**
- **Reduction of node size becomes a primary concern**

➥ **Bypass intermediate nodes to reduce transit traffic**

Virtual Topology Trade-offs

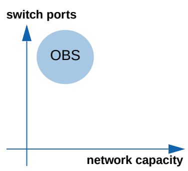


Sparsely meshed

e.g. virtual = physical topology

- **high stat. mux gain**
  ➔ high link utilization
- **high transit traffic**

➥ **OBS**



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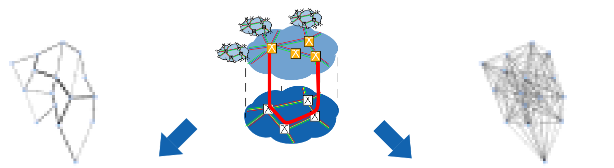

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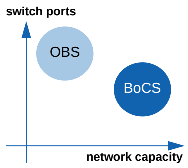


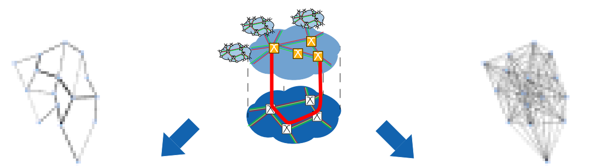
Densely meshed

e.g. virtual topology = full mesh

- **low stat. mux gain**
  ➔ low link utilization
- **no/few transit traffic**

➥ **Burst-over-Circuit Switching (BoCS)**

Virtual Topology Trade-offs



Sparsely meshed

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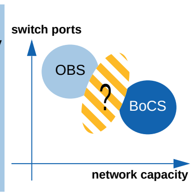

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➥ **Burst-over-Circuit Switching (BoCS)**

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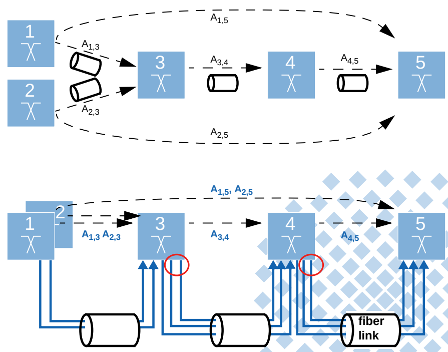
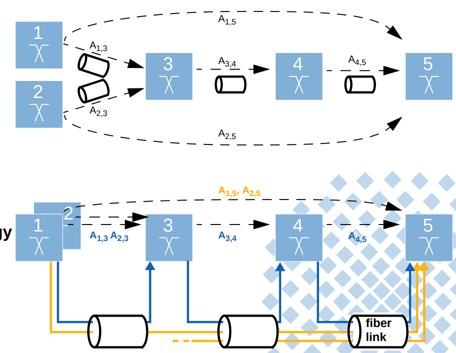
Optical Burst Transport Network (OBTN)

- **Traffic demands**
- **Physical topology**
- **OBS virtual topology**

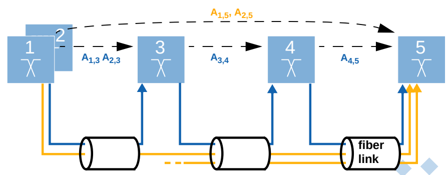


Optical Burst Transport Network (OBTN)

- **Traffic demands**
- **Physical topology**
- **BoCS virtual topology**

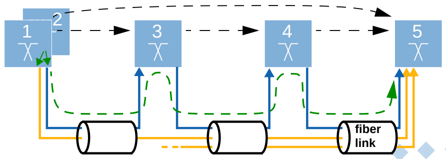


Optical Burst Transport Network (OBTN)



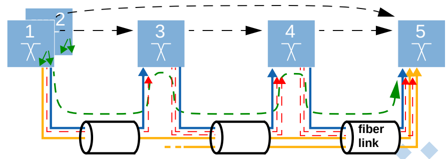
1. **Direct lightpaths as virtual links**
   ➔ Minimizes transit traffic

Optical Burst Transport Network (OBTN)



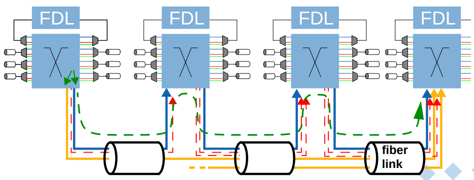
1. **Direct lightpaths as virtual links**
2. **Constrained alternate routing along fiber links of primary route**
   ➔ Resolves contention without route length variation

Optical Burst Transport Network (OBTN)



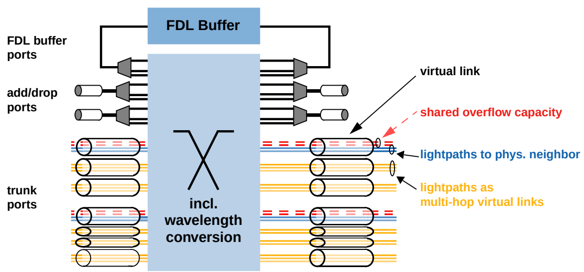
1. **Lightpaths as multi-hop virtual links**
2. **Constrained alternate routing along fiber links of primary route**
3. **Shared overflow capacity compensates for traffic on alternate routes**
   ➔ Improves statistical multiplexing as aggregated on few single-hop virtual links

Optical Burst Transport Network (OBTN)



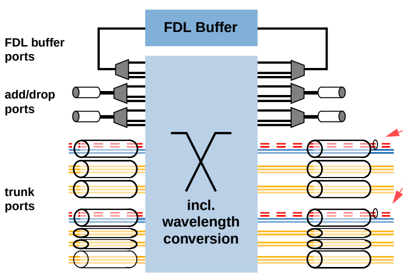
1. **Lightpaths as multi-hop virtual links**
2. **Constrained alternate routing along fiber links of primary route**
3. **Shared overflow capacity compensates for traffic on alternate routes**
4. **Effective contention resolution**
   ➔ Achieves high QoS and utilization

OBTN Node View



- **OBTN node realized like OBS node (e.g. TAS, BAS, AWG, ...)**

Unified Modeling of Architectures



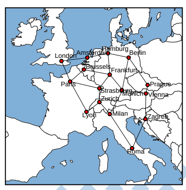
β = relative amount of shared overflow capacity

- **BoCS** $\beta=0$
- **OBTN** $0<\beta<1$
- **OBS** $\beta=1$

Resource metrics

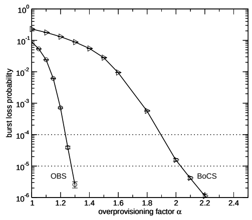
- **Number of ports in burst-switched nodes**
- **Number of fiber hops in physical network**

Performance Evaluation



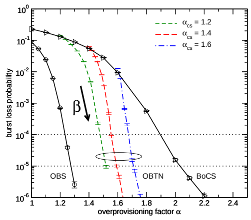
- **European reference topology as core network**
  - 16 nodes
  - 23 links in physical topology
- **Optical MANs abstracted as traffic sources**
- **Traffic**
  - Population-based demand model, approx. 10 Tbps
  - Poisson arrivals
  - Exponential burst transmission time, mean h = 10µs
- **FDL buffer**
  - Single FDL using WDM with 32 wavelengths
  - Delay of 4 mean burst transmission times

QoS Comparison



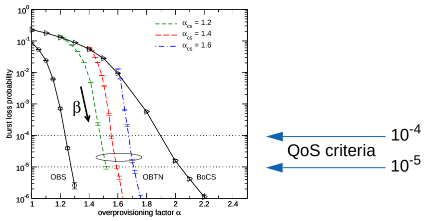
- **BoCS requires much higher overprovisioning than OBS**

QoS Comparison



- **BoCS requires much higher overprovisioning than OBS**
- **OBTN in between BoCS and OBS**
  - β: shared overflow capacity allocation is very effective

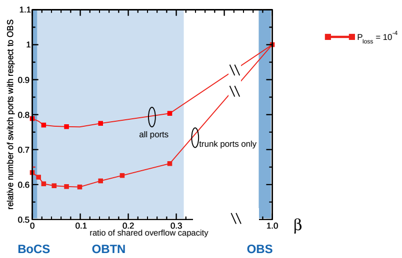
QoS Comparison



- **BoCS requires much higher overprovisioning than OBS**
- **OBTN in between BoCS and OBS**
  - β: shared overflow capacity allocation is very effective

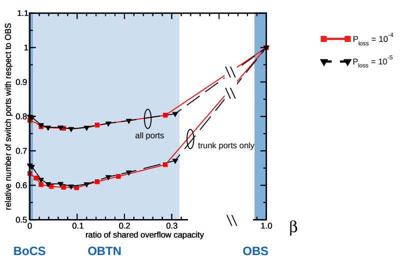
➥ **Further resource studies for defined QoS criteria**

Number of Switch Ports



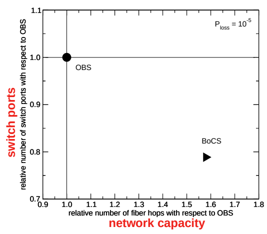
- **OBTN requires fewest number of ports – trunk and overall**
- **Small β already effective ➔ few shared overflow capacity**

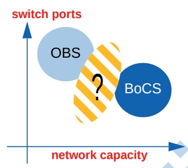
Number of Switch Ports



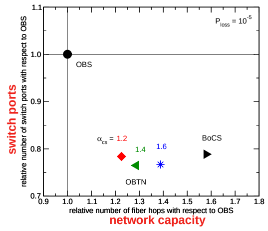
- **OBTN requires fewest number of ports – trunk and overall**
- **Small β already effective ➔ few shared overflow capacity**
- **Robust regarding QoS criterion: 10^{-4} ➔ 10^{-5}**

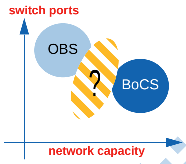
Node and Network Resources





Node and Network Resources



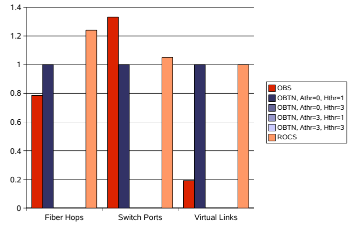


OBTN achieves

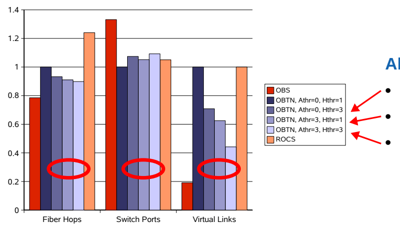
- **Reduced number of burst-switched ports regarding OBS and BoCS**
- **Penalty in number of wavelength hops compared to regular OBS**

➥ **Overall cost reduction honoring cost structure**

Alternative OBTN Virtual Topologies



Alternative OBTN Virtual Topologies



Alternative virtual topology desig

- **Path length-based**
- **Demand-based**
- **Combined**

➥ **Less densely-meshed virtual topologies in OBTN feasible**

- slightly less fiber hops
- slightly more switch ports

Conclusions

- **FDL buffers effectively resolve contention**
  ➔ Low burst loss probability at high channel utilization
- **Additional ports to be considered in integrated evaluation of scalability**
  ➔ Buffer has significant impact regarding signal degradation
  ➔ Few or no improvement regarding the maximum effective throughput

- **Motivations and key trade-offs for burst transport with virtual topology**
- **Optical Burst Transport Network (OBTN) architecture introduced**
- **Unified resource modeling of OBS, BoCS, and OBTN**

- **Performance and resource evaluation for OBTN**
  ➔ Yields overall high quality of service
  ➔ Reduces switch ports with limited penalty in network capacity compared to OBS

➥ **Overall reduction of resource requirements**

Outlook

Integrated performance and technology analysis

- **Broader application in projects**
- **Provide simplified models for non-experts**

Further OBTN modeling and evaluation

- Optimal virtual topology design
- Extend resource studies to technological scalability analyses
- Control plane issues
- Migration scenarios for OBS: performance, technology, control, business …

Research on photonic networks and systems: We should …

- **… narrow the gap between technology, systems, networks, and applications**
- **… also build the stuff, lots of activities in Asia**
- **… watch the research networks community**

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Architectures for Optical Burst Transport Networks - A View Beyond QoS -

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HHI-Kolloquium
Berlin, 4. April 2006