Architecting Efficient Optical Burst Switching Networks

Christoph Gauger
gauger@ikr.uni-stuttgart.de

- **Photonic research integration**
- **Network performance of contention resolution**
- **Integrated node scalability analysis**

COST 279 Final Seminar,
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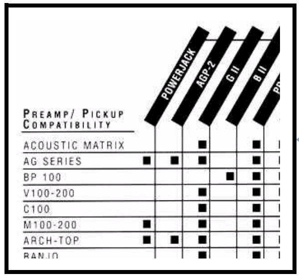
COST

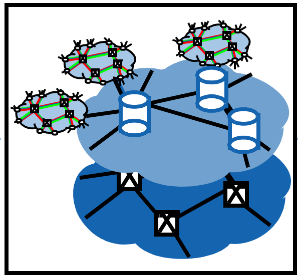
e-Photon ONe

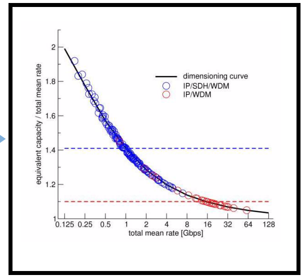
Photonic Research Integration

	Requirements Analysis	Architecture Design	Modeling Evaluation

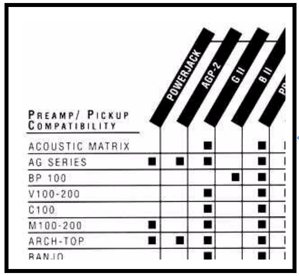
Client Layer Networking and Services

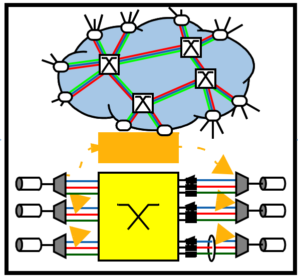


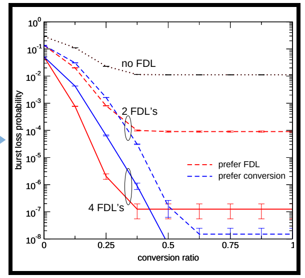




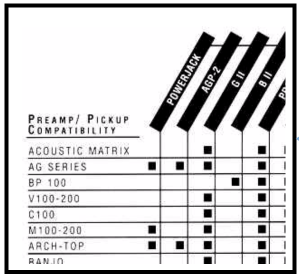
Optical Networking

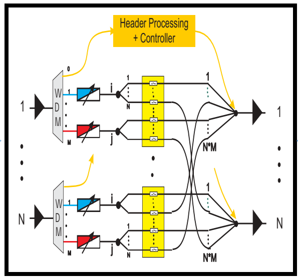


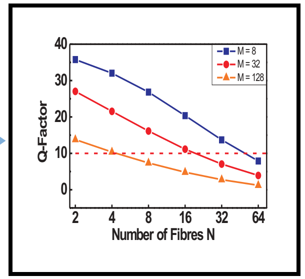




Optical Systems and Technology







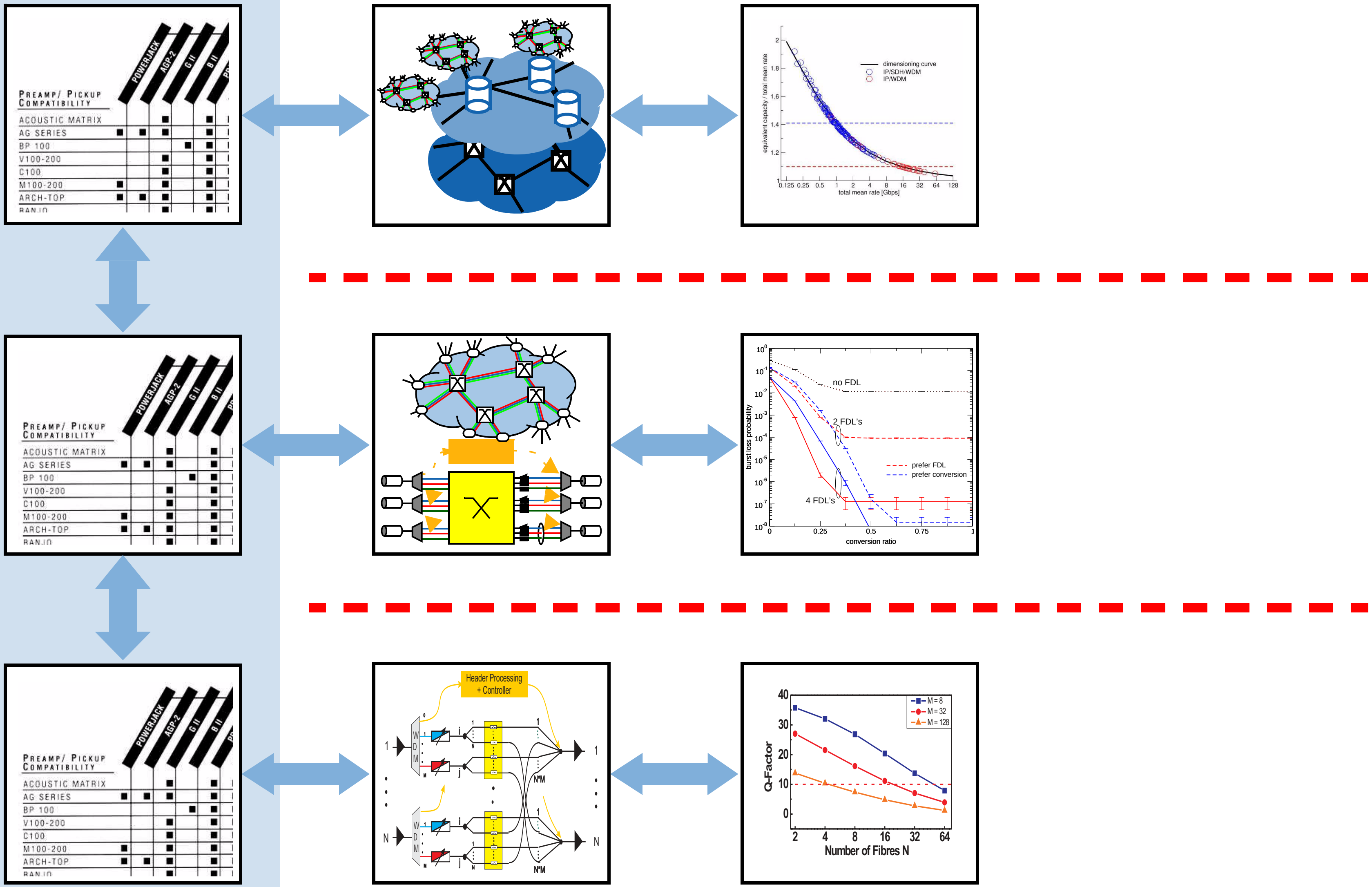
Photonic Research Integration

	Requirements Analysis	Architecture Design	Modeling Evaluation

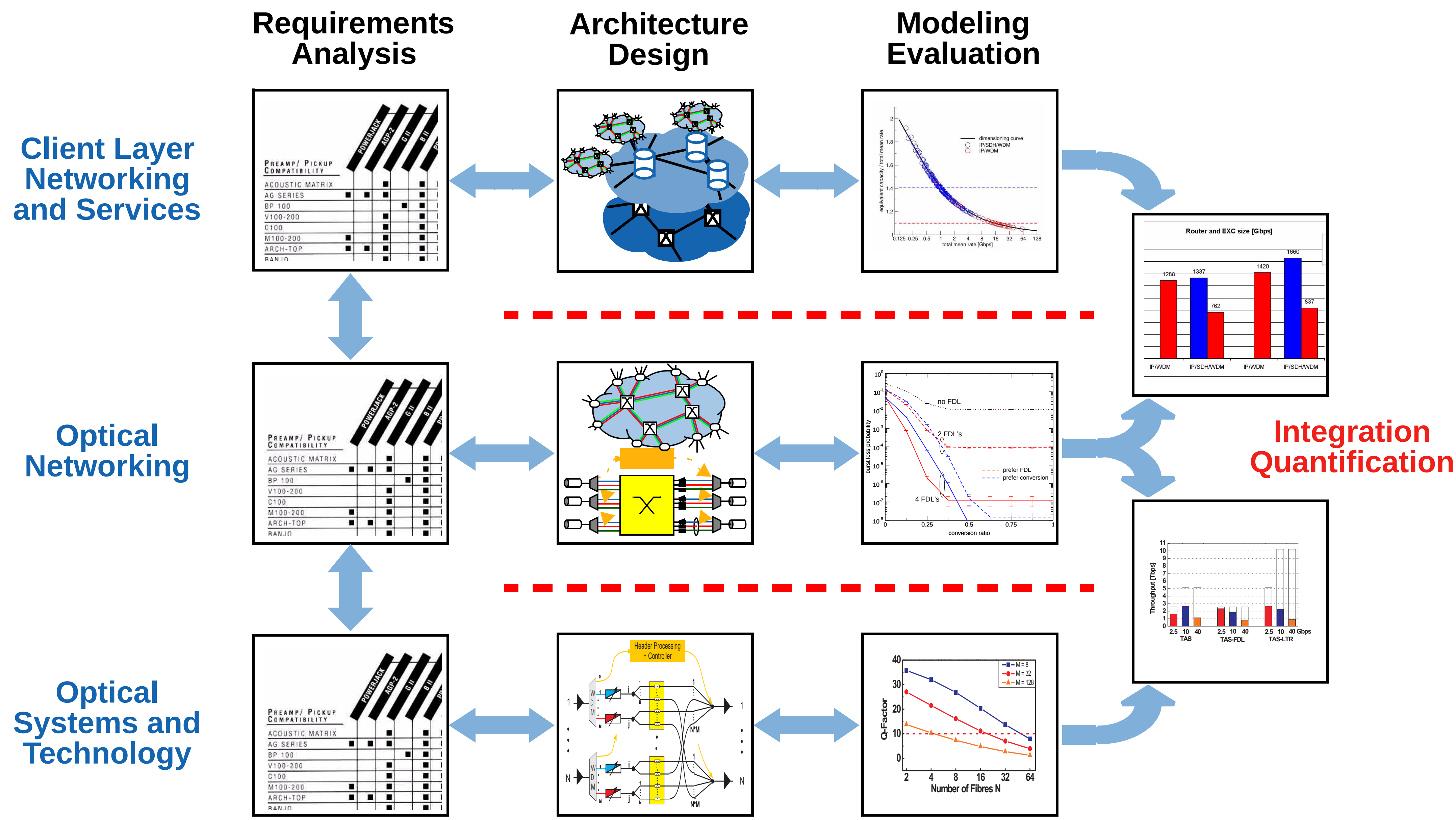
Client Layer Networking and Services

Optical Networking

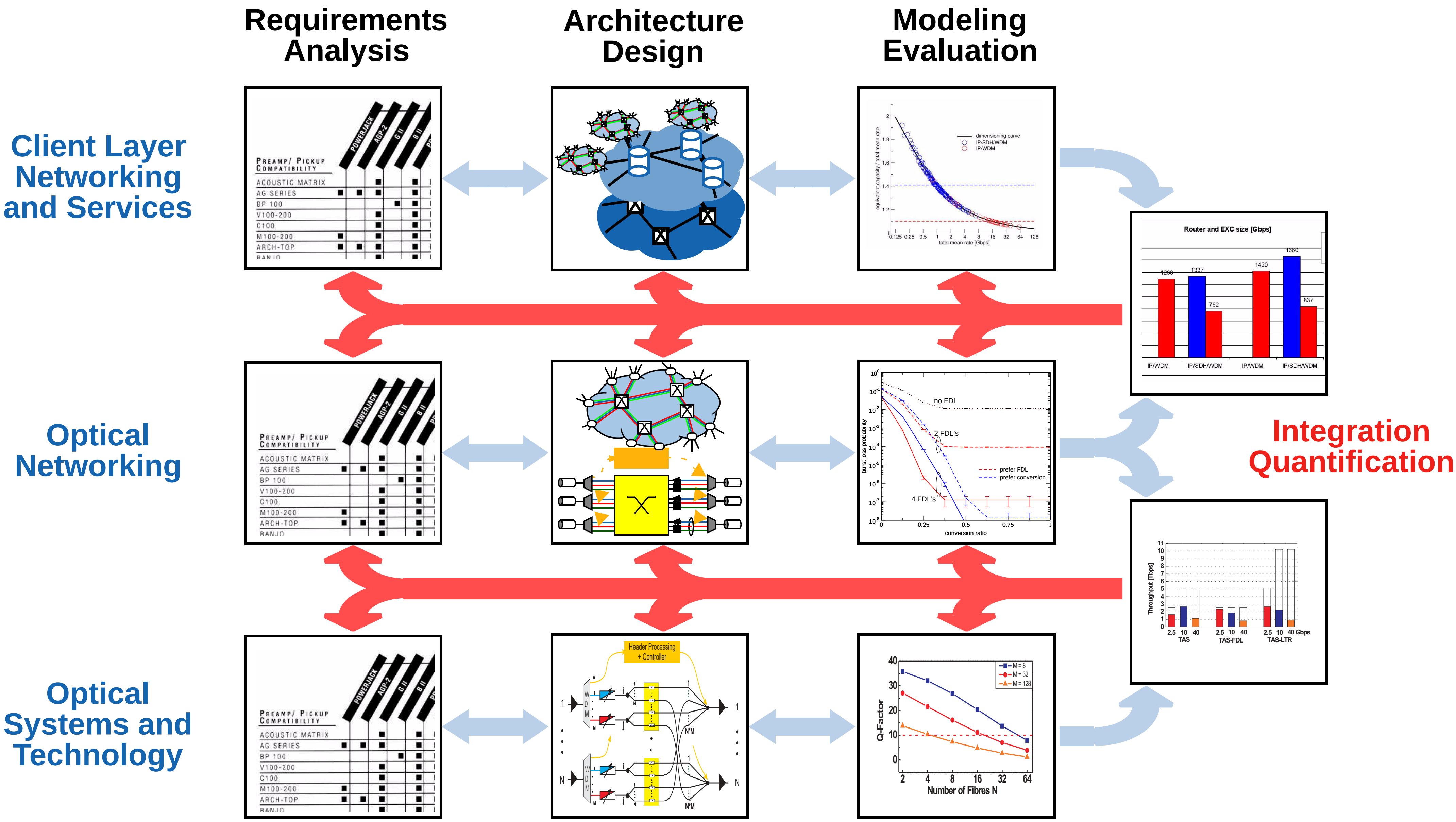
Optical Systems and Technology



Photonic Research Integration

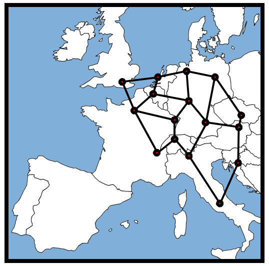


Photonic Research Integration

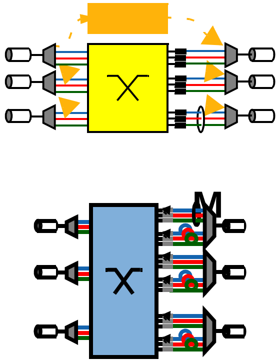


Outline

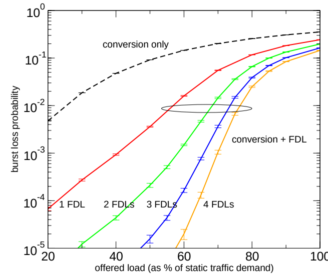
Network QoS analysis



given dimensioning

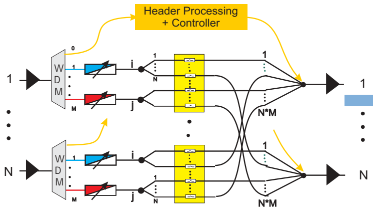


contention resolution schemes



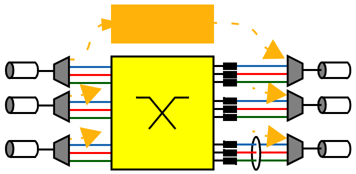
QoS performance

Node scalability and throughput analysis



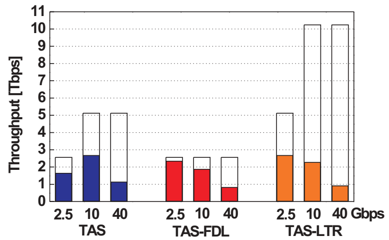
node design with different functionalities

signal analysis



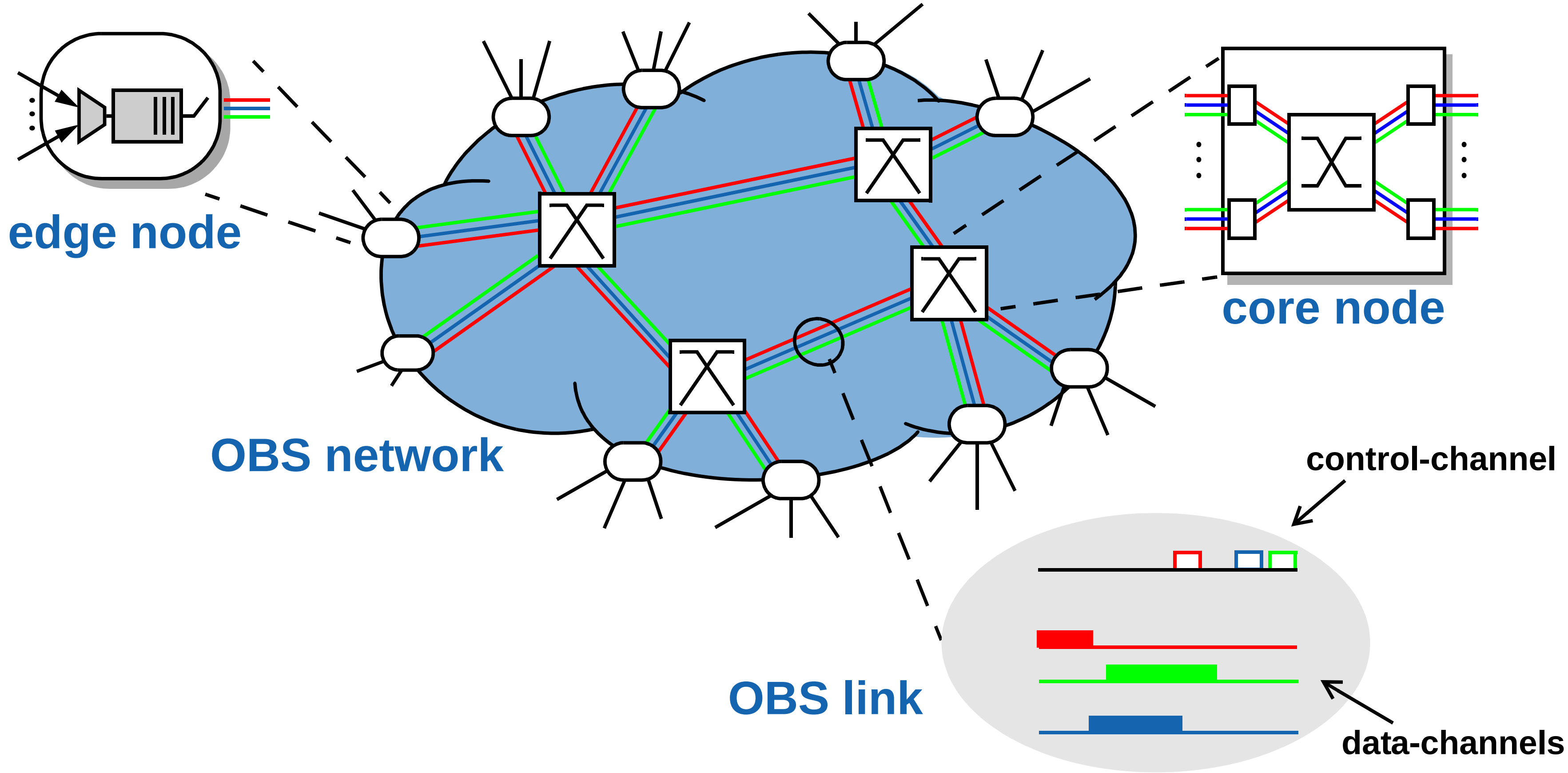
maximum node size

QoS performance



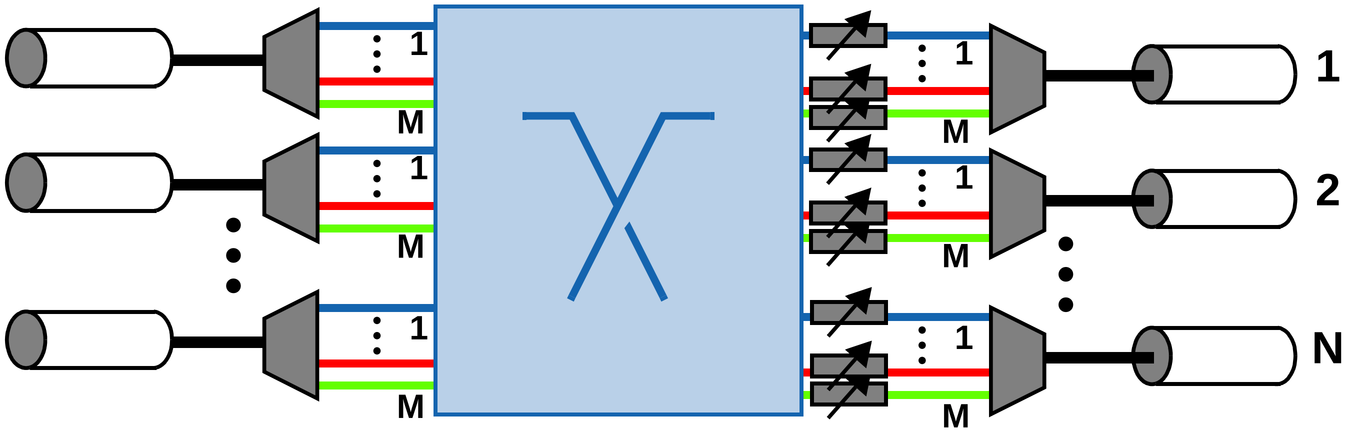
maximum/effective throughput

OBS Scenario



- Burst assembly in edge node, variable length bursts
- Out-of-band burst headers
- Tell-and-go transmission
- Bursts stay in optics
- Headers electr. processed
- Just-enough time (JET) reservation scheme

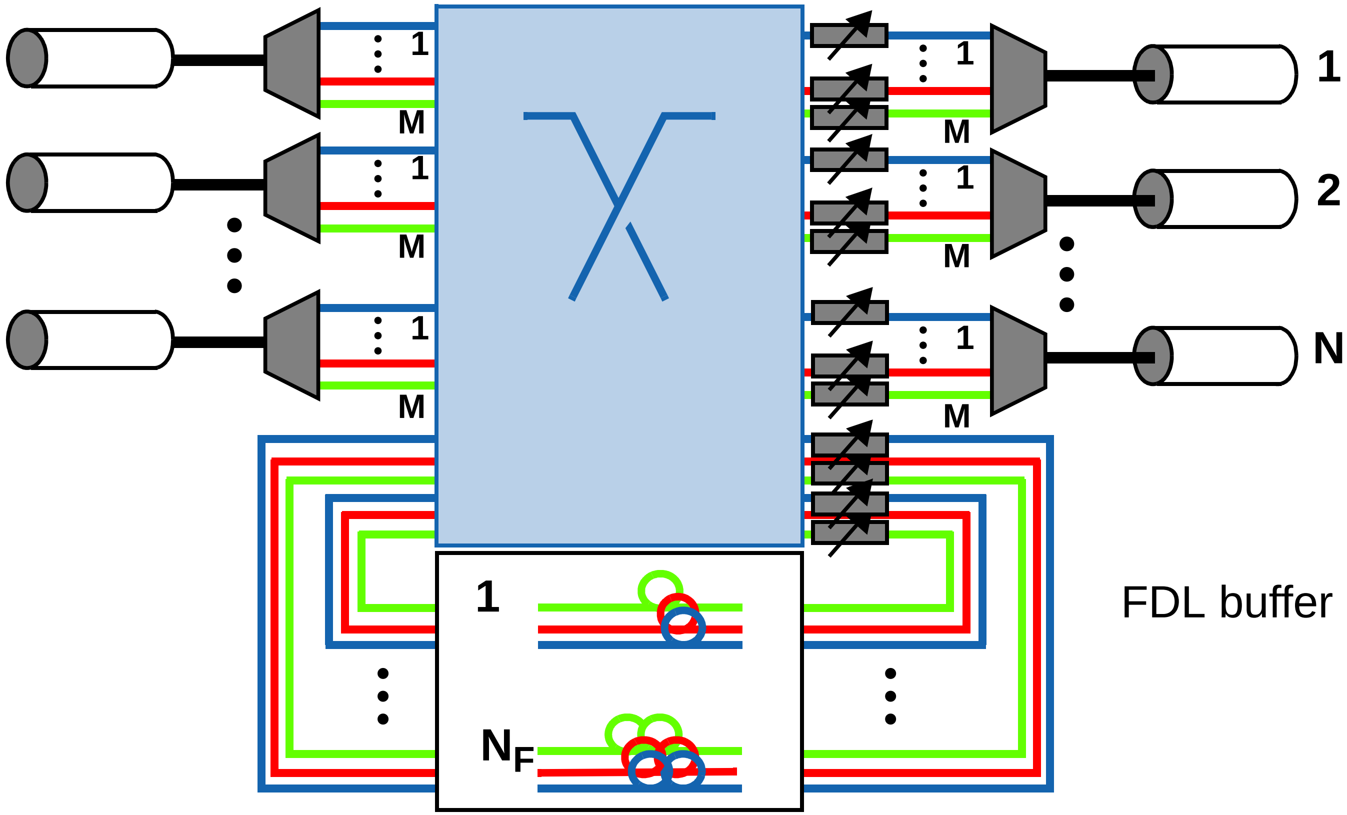
Contention Resolution



- **Wavelength domain – wavelength converters**
  - all WDM channels on a fiber shared among all bursts
  - low burst loss probabilities only for many λs

  ➔ **additional mechanism necessary**

Contention Resolution



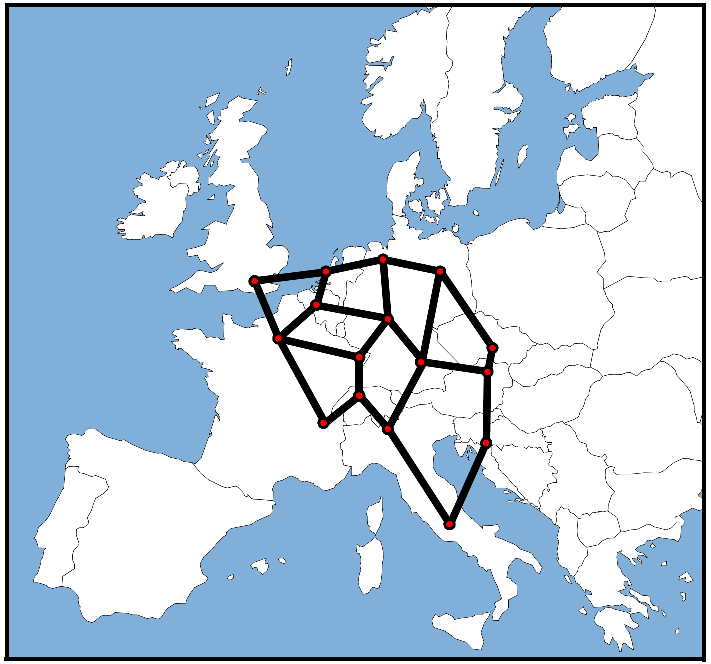
- **Wavelength domain – wavelength converters**
- **Time domain – FDL buffers**
  - simple fiber delay lines (FDLs) in nodes
  - only discrete delays and no random access functionality
  - FDL operated in WDM

Evaluation Model

- **Network dimensioning**
  - demands from population model
  - 10 Gbps line-rate per λ
  - tight based on Erlang model

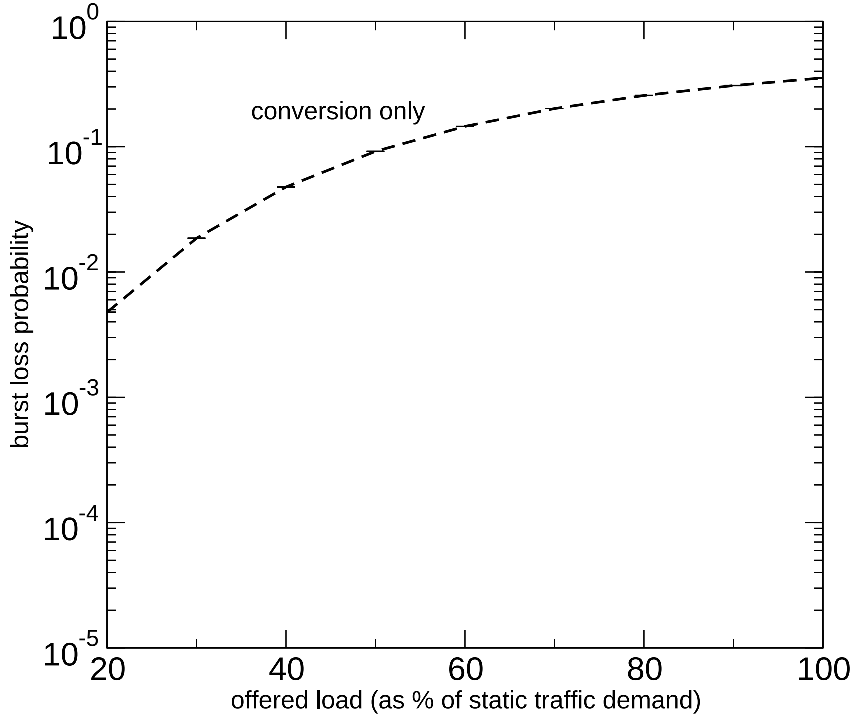
- **Burst traffic characteristics**
  - Poisson arrivals
  - exp. burst lengths with mean h = 10 μs

- **Full wavelength conversion**
- **FDL buffer**
  - 1, 2, 3, or 4 FDLs
  - each FDL in WDM with 8λ
  - FDL delays multiples of 2h = 20 μs



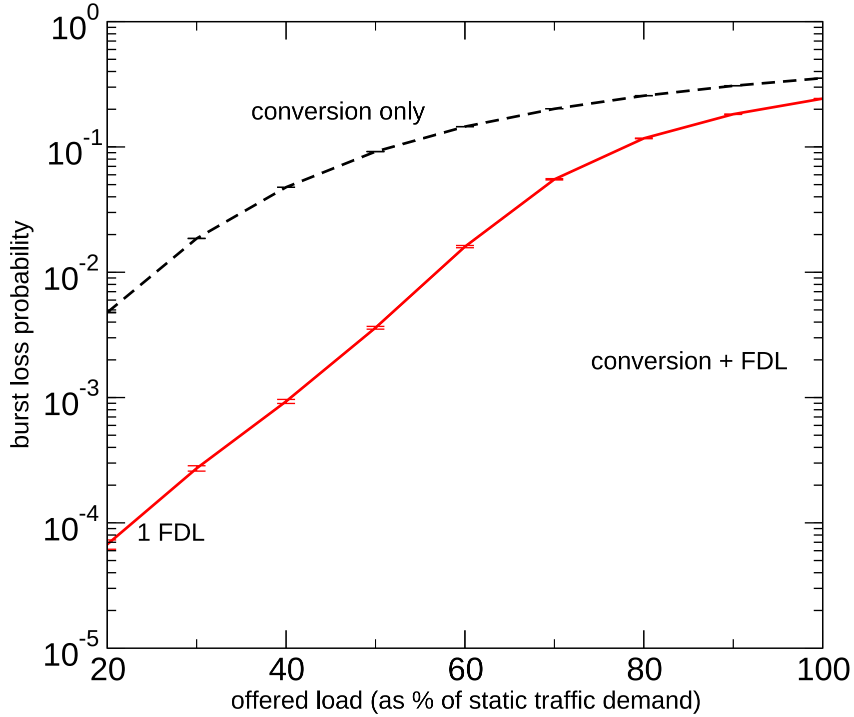
COST266/LION reference n/w CN
traffic matrix for year 2004

Network QoS



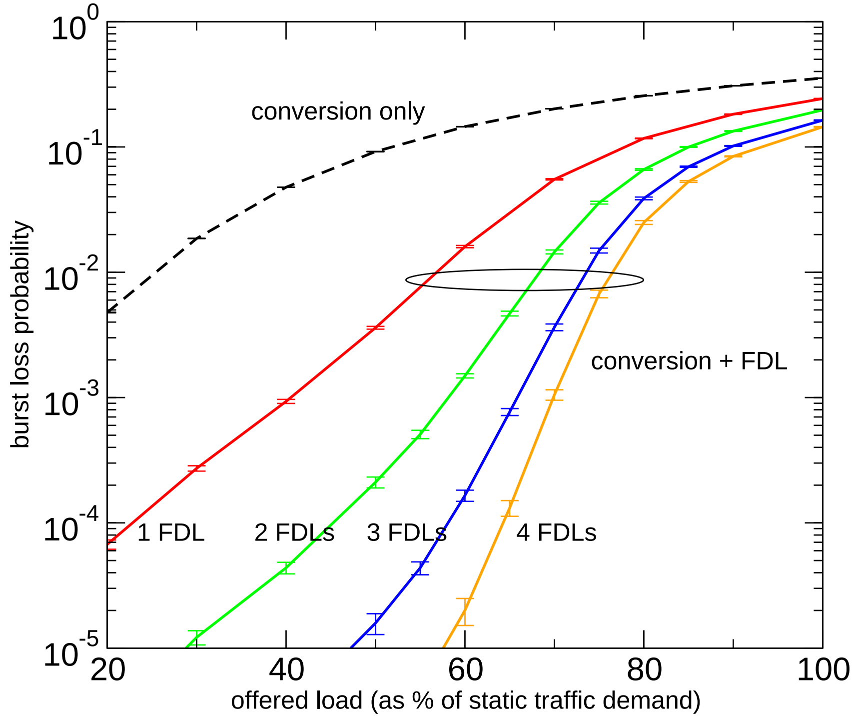
- **Wavelength conversion alone not attractive**

Network QoS



- **Wavelength conversion alone not attractive**
- **Significant improvement with FDLs possible**

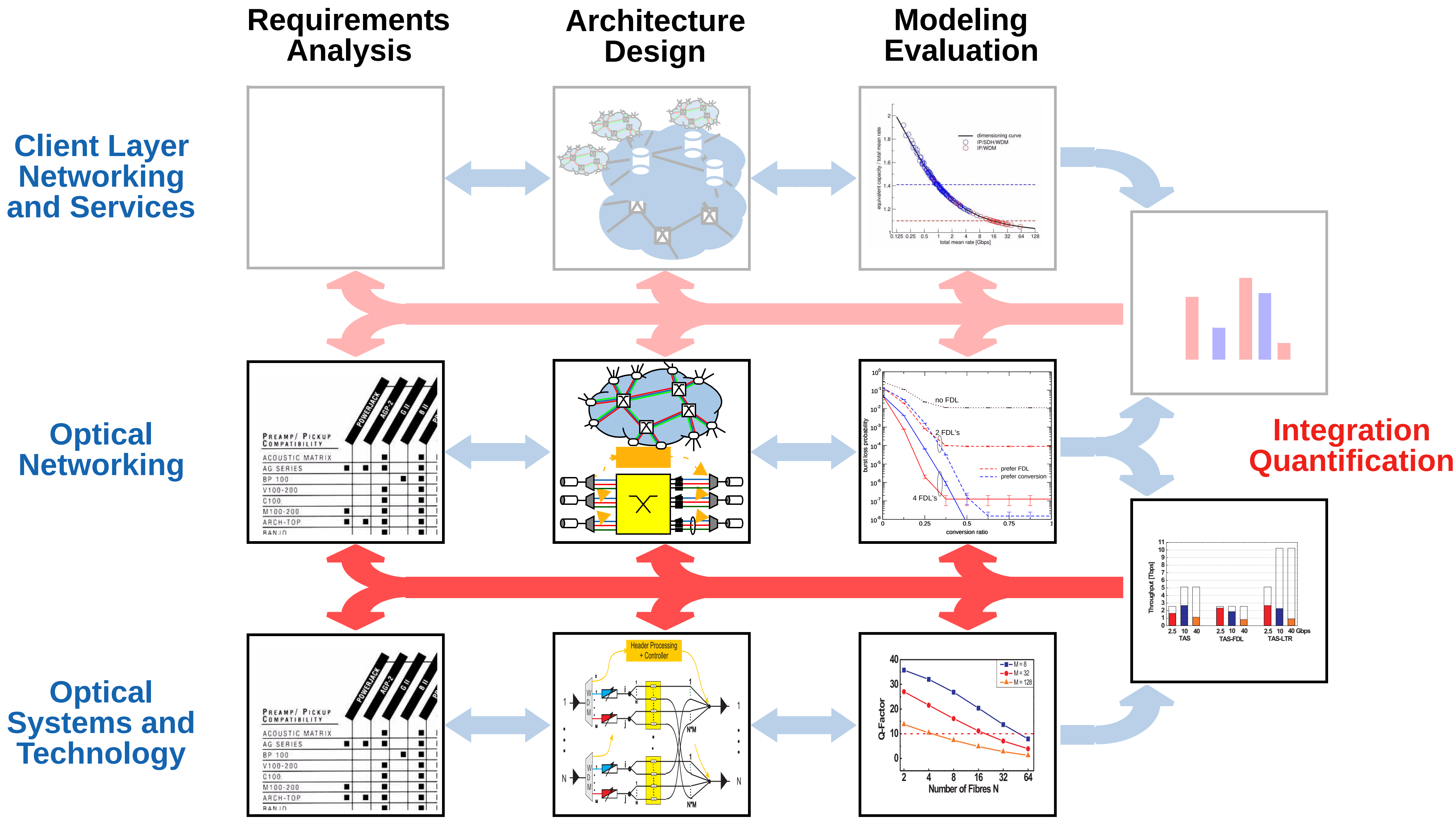
Network QoS



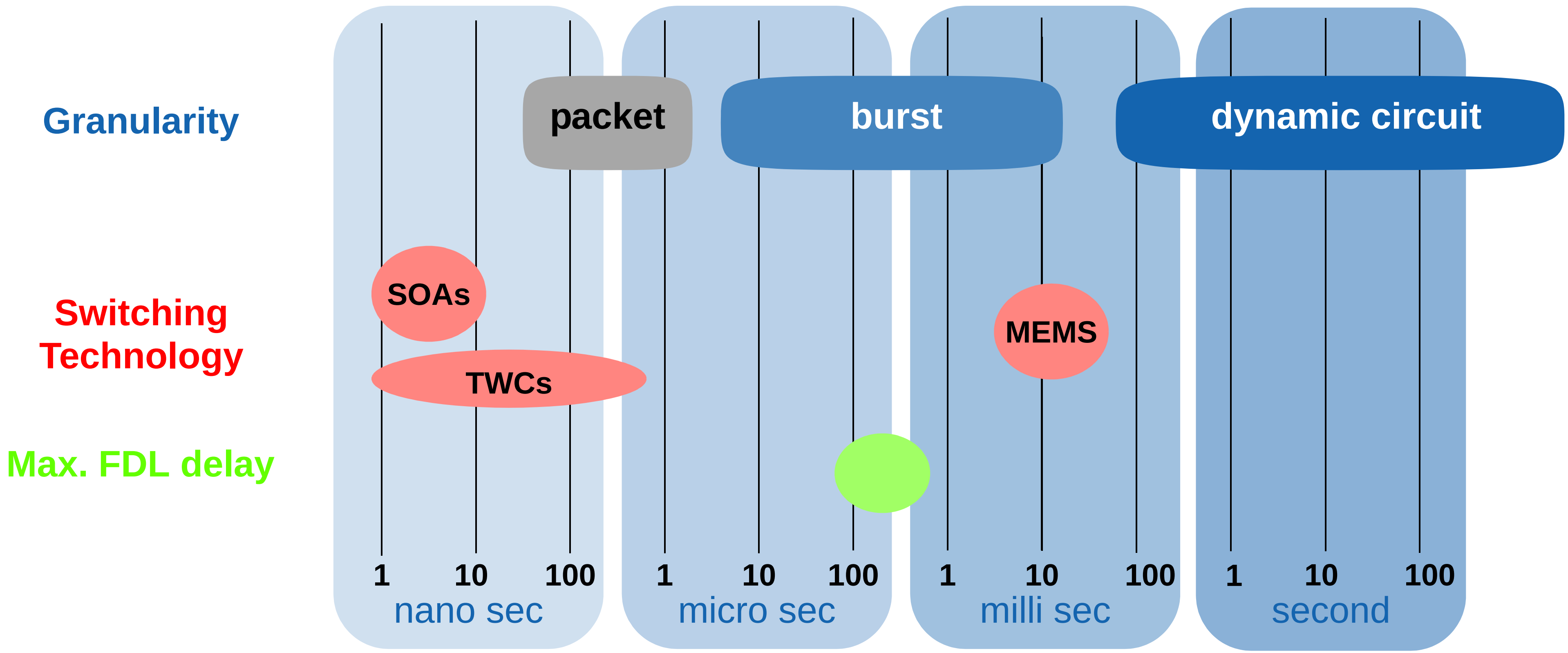
- **Wavelength conversion alone not attractive**
- **Significant improvement with FDLs possible**

➔ **Multiple FDLs: very low loss probabilities up to medium/high loads**

Integrated Evaluation



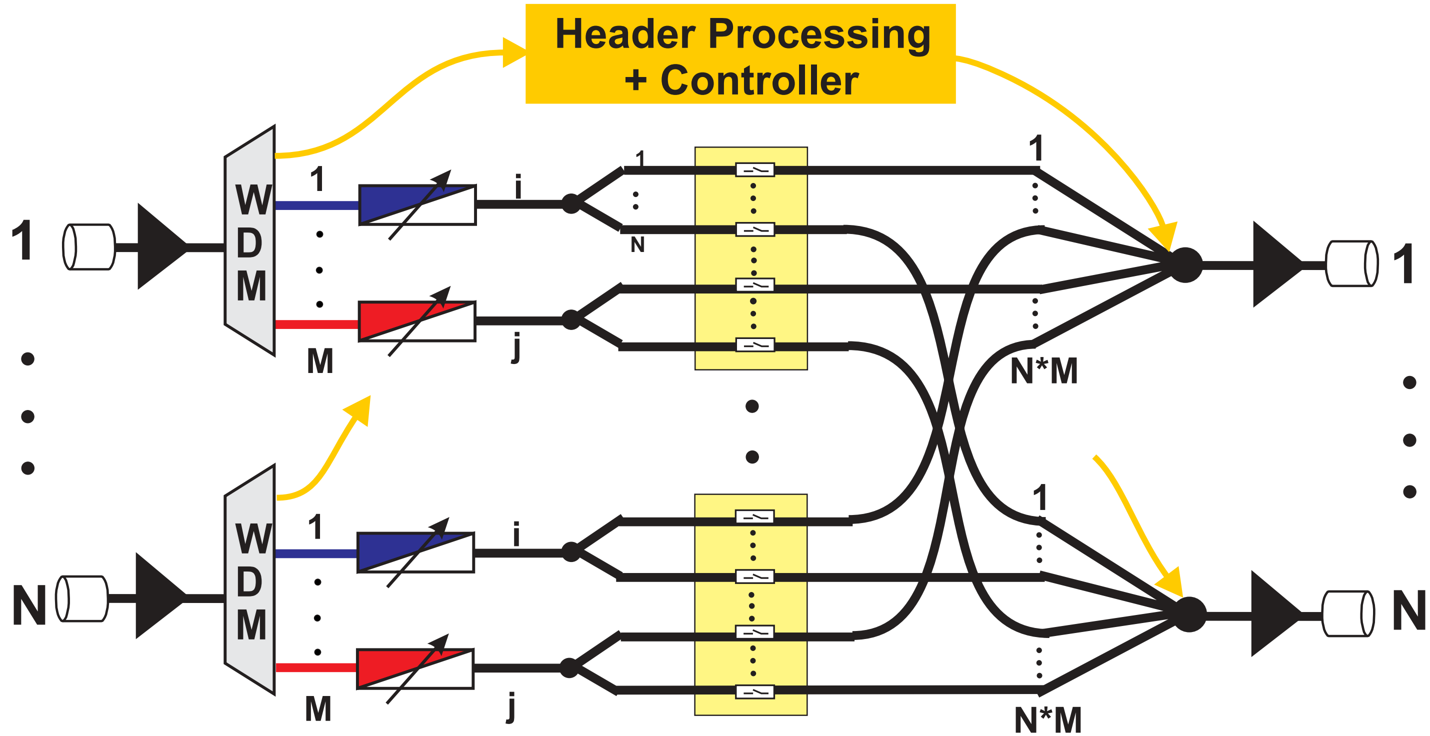
OBS Node Design



- Granularity determines switching technology and vice versa

→ switching time << mean burst duration

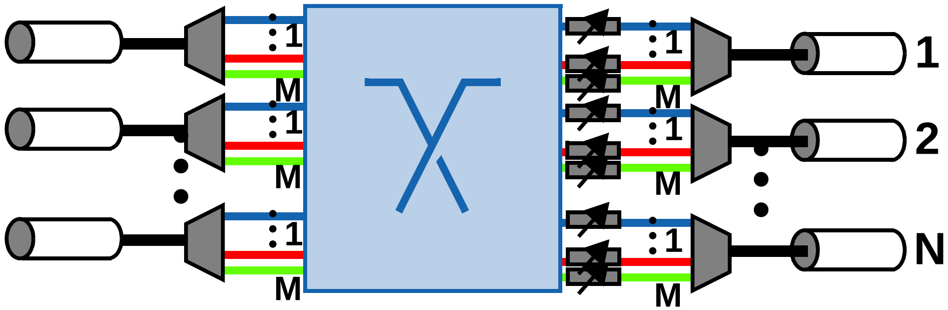
Tune-and-Select Architecture (TAS)

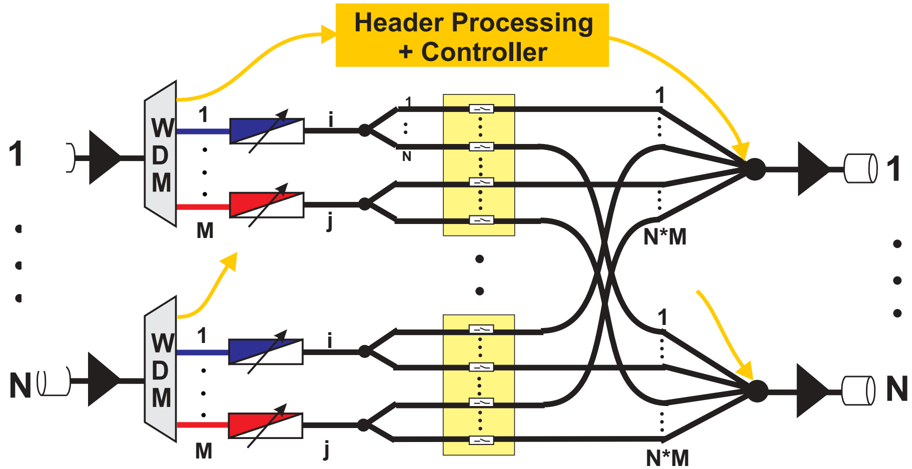


proposed by H. Buchta, E. Patzak, J. Saniter, HHI
ECOC 2002, ITG 2002

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

System Parameters





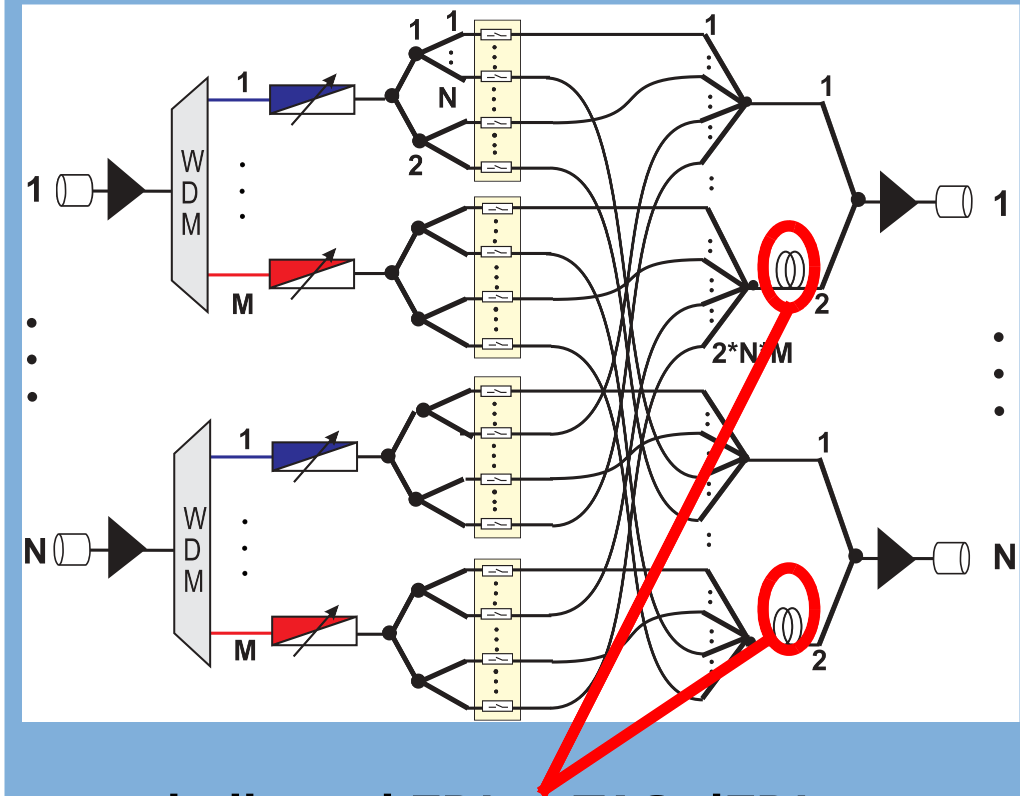
Impact on performance

- Number of fibers N
- Number of wavelengths per fiber M
- Contention resolution scheme

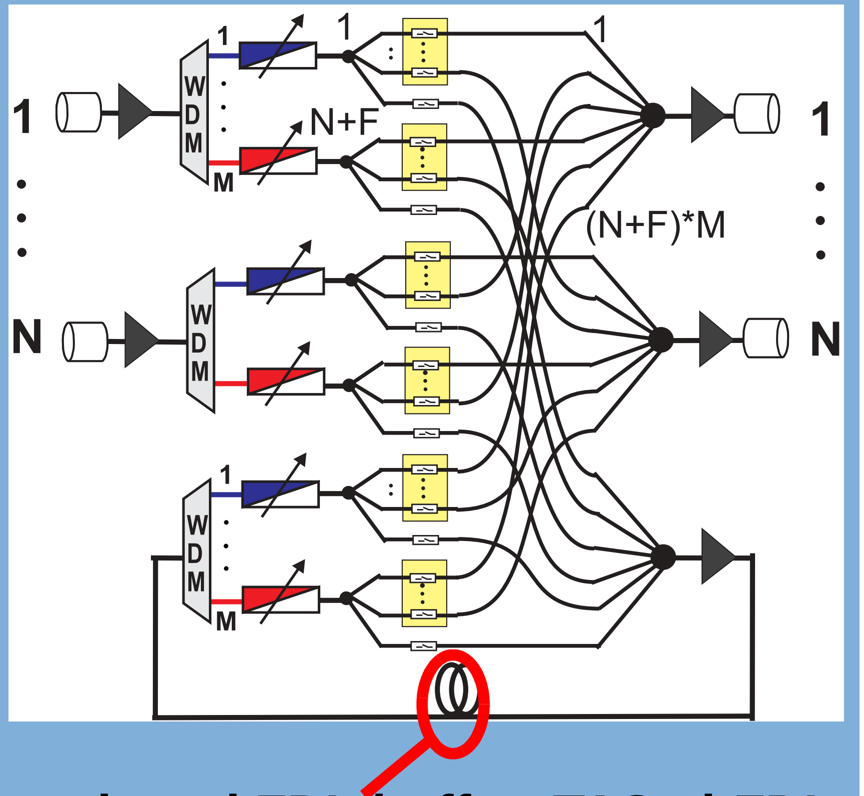
Impact on signal

- 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

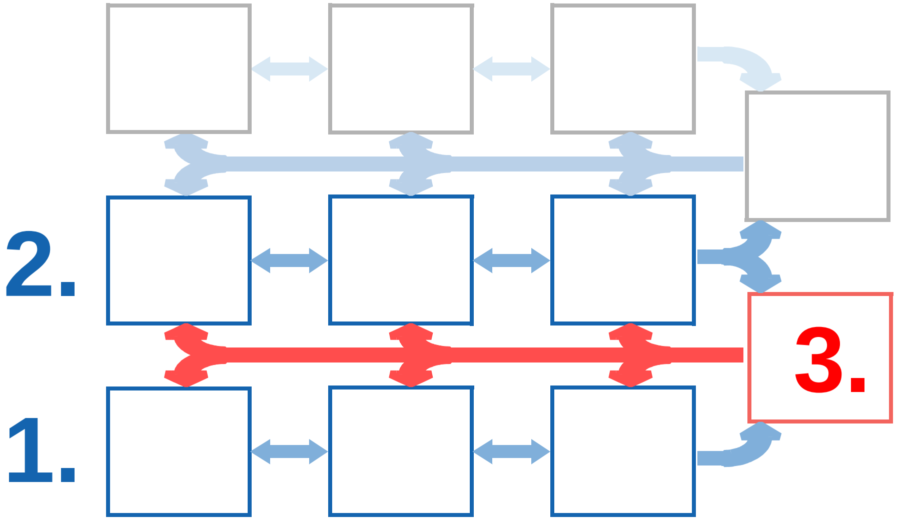
- due to buffering
- TAS-shFDL: multiple FDLs

➔ Signal Degradation

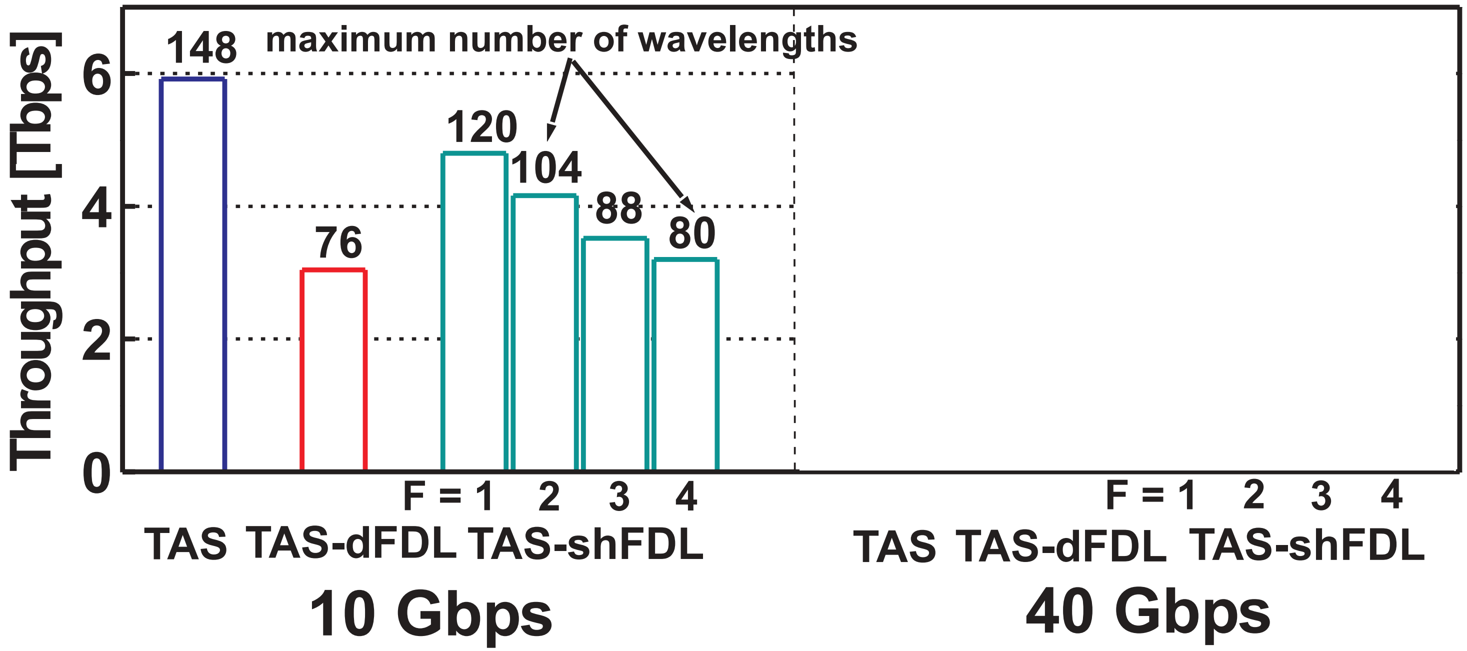
- due to increased splitting loss
- due to loss in FDL

Evaluation Methodology

1. **Analysis of signal degradation between two regeneration points**
   - 4 input/output fibers
   - state-of-the-art component parameters
   - ➔ maximum number of wavelengths per fiber M_{max} for BER 10^{-22}
   - ➔ **maximum throughput**
2. **Simulation/Analysis of QoS using M_{max}**
   - same architecture and functionality
   - ➔ **max. utilization** for tolerable burst loss probability $P_{loss} = 10^{-6}$
3. **Integration**
   - ➔ **effective throughput**

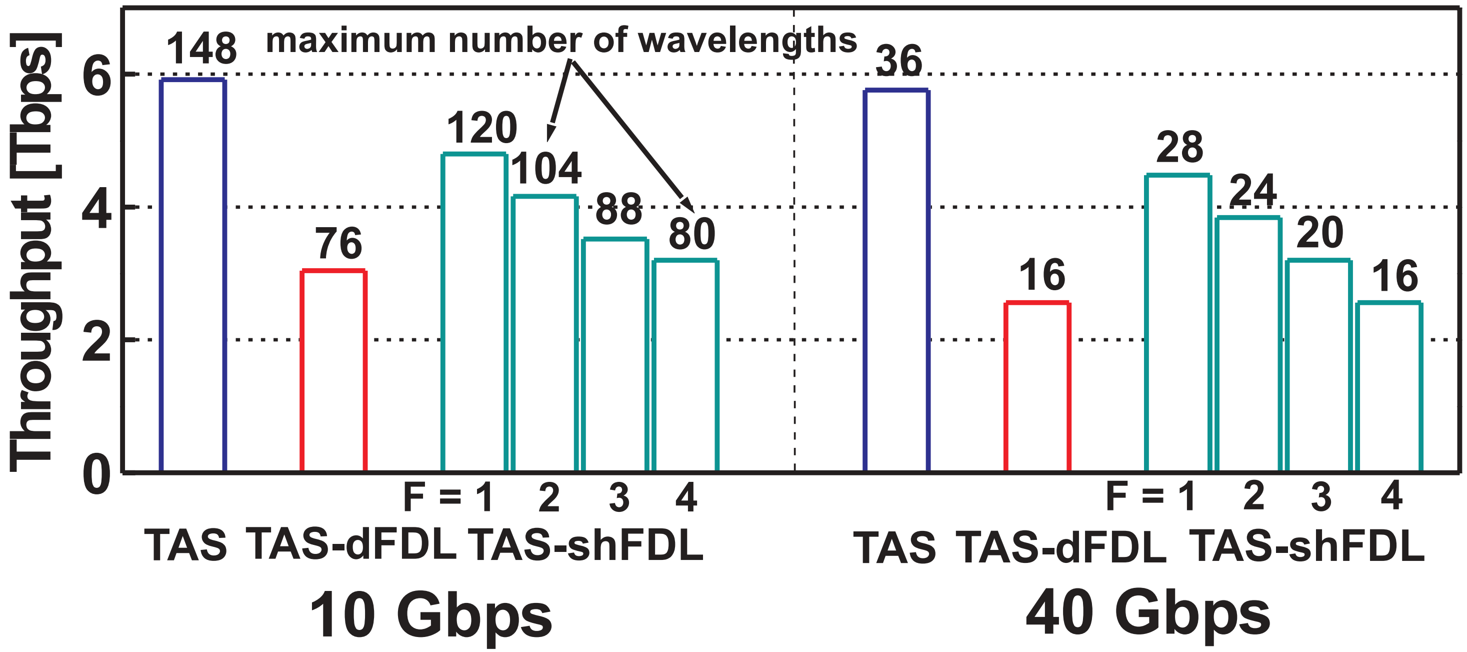


Maximum Throughput



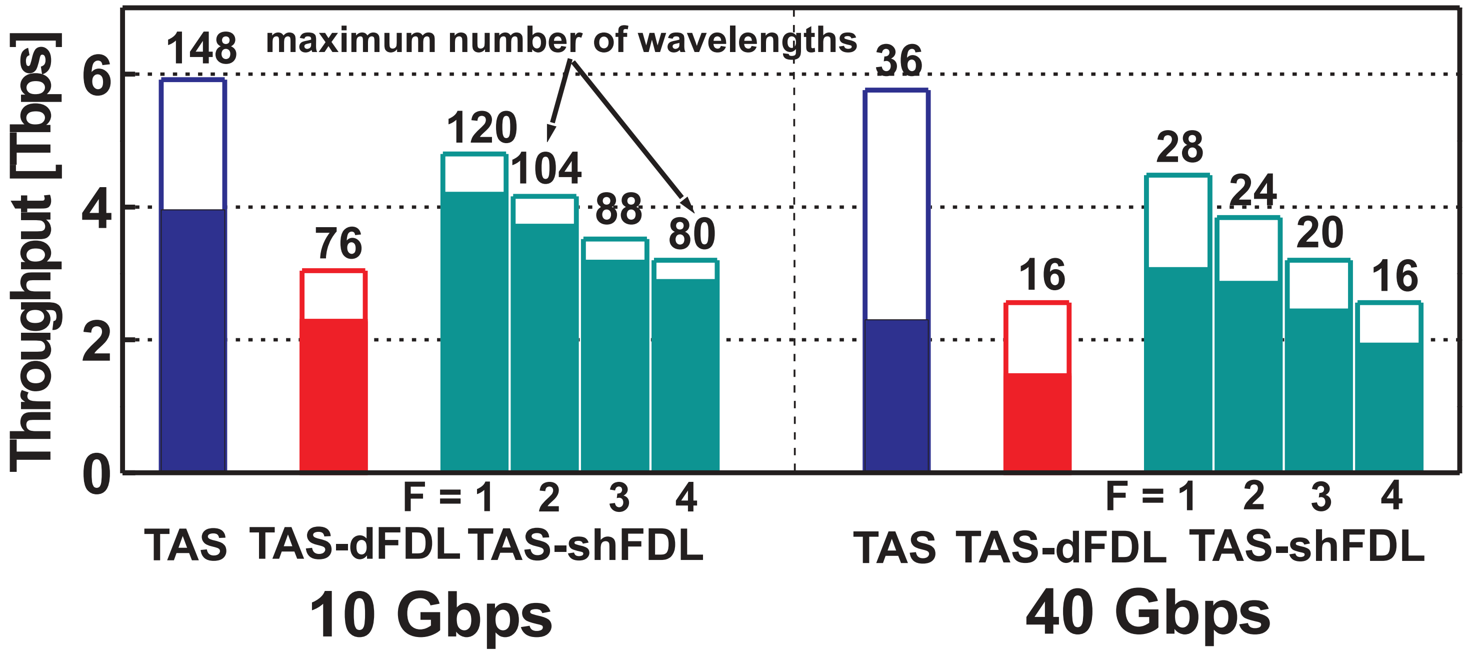
- Maximum throughput in all architectures between 2 and 6 Tbps
- Greatest for TAS and smallest for TAS-dFDL
- More FDLs in TAS-shFDL yield smaller nodes

Maximum Throughput



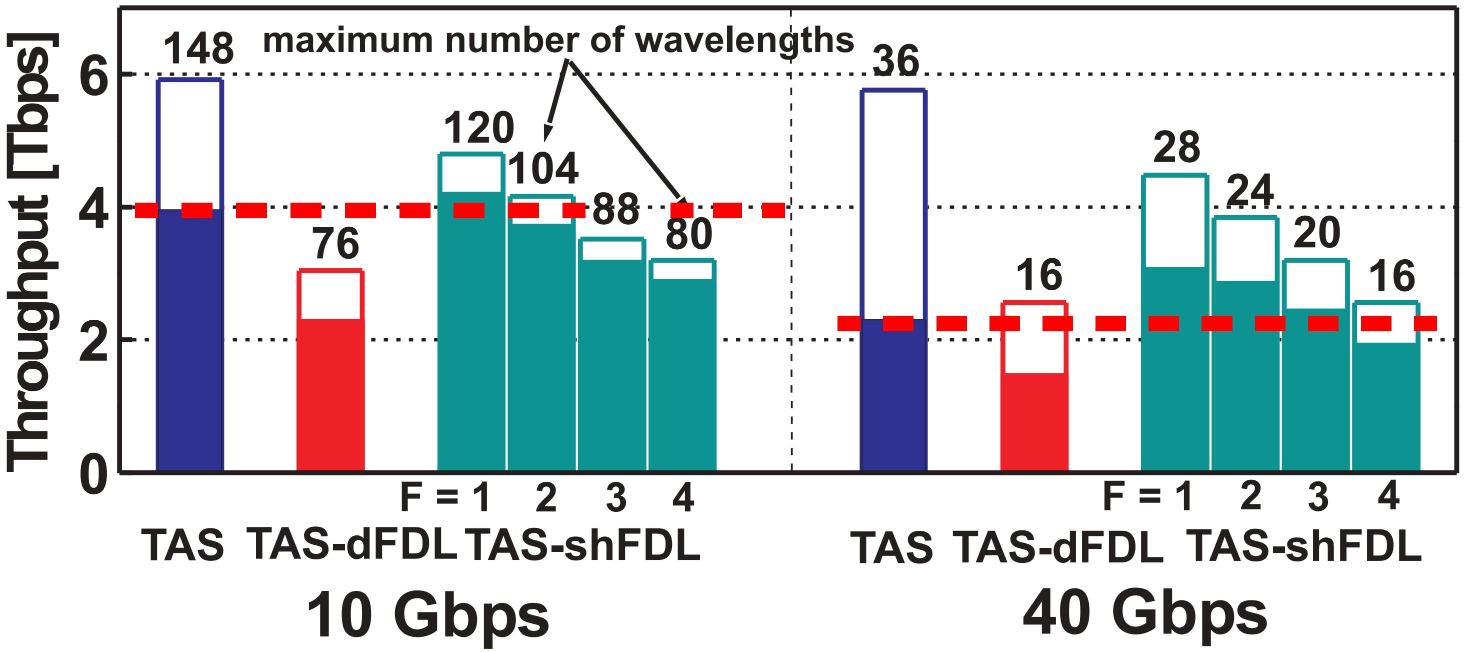
- Maximum throughput in all architectures between 2 and 6 Tbps
- Greatest for TAS and smallest for TAS-dFDL
- More FDLs in TAS-shFDL yield smaller nodes
- Node size exhibits strong dependence on bitrate

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

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
- **TAS-shFDL with 40 Gbps benefits more (due to absolutely fewer λs)**

Summary and Outlook

- **QoS in OBS networks**

  → contention resolution with FDLs improves utilization
- **Node scalability analysis**

  → advanced FDL buffers not necessarily improve achievable throughput

- **Architecting efficient optical networks**

  → optical systems and technology still mostly "analogue"

  → network and node resources and limits have to be considered

- **Different node architectures and technologies**
- **Integarted studies with higher layer studies**
  - overall network structure and aggregation hierarchies
  - impact of/on control plane
- **Abstraction and integration methodology**

Universität Stuttgart
INSTITUT FÜR
KOMMUNIKATIONSNETZE
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Prof. Dr.-Ing. Dr. h. c. mult. P. J. Kühn

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Christoph Gauger
gauger@ikr.uni-stuttgart.de

Acknowledgments
M. Köhn and J. Scharf of UST-IKR
H. Buchta, E. Patzak and J. Saniter of Fraunhofer HHI, Berlin

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Technology Parameters

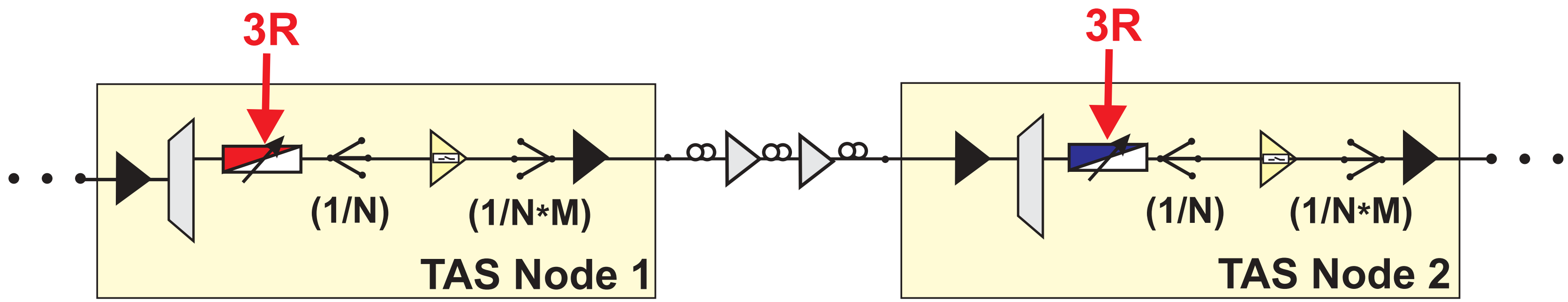
Technology

- **Noise and crosstalk considered**
- **Min. tolerable Q-factor 10 (= BER 10^{-22})**

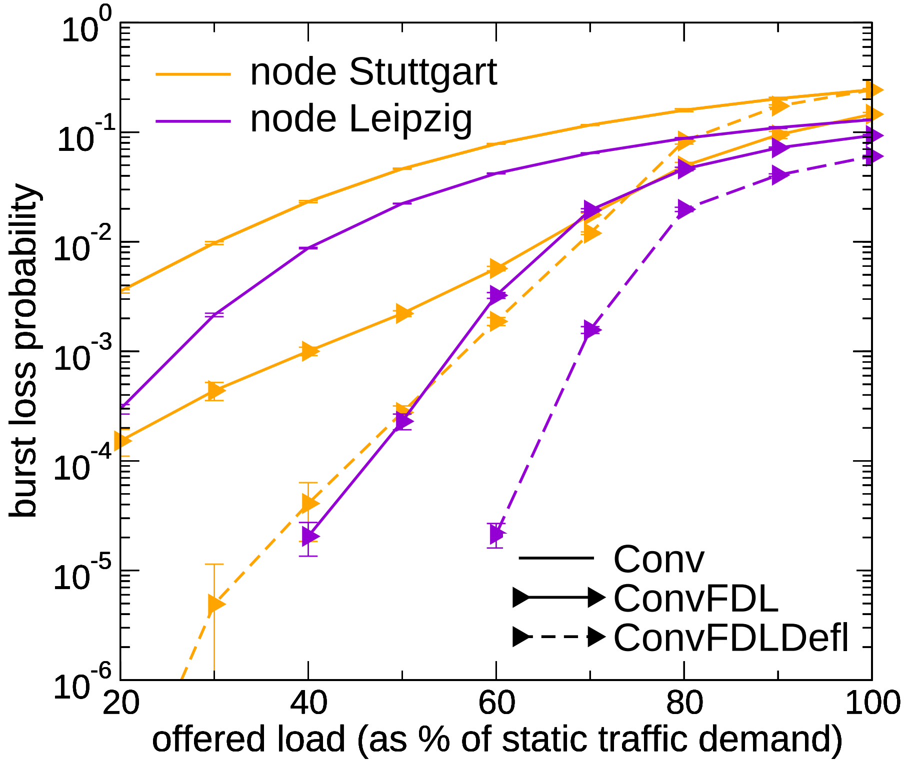
State-of-the-art component parameters

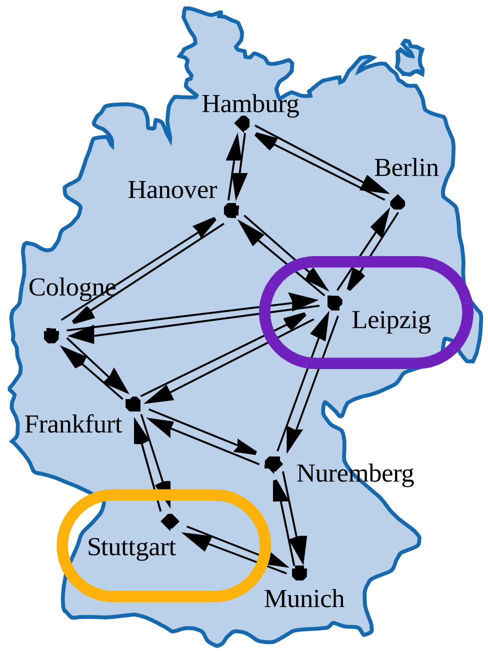
Node	input output	-16 dBm 0 dBm
EDFA	noise figure max. gain max. power	6 dB 30 dB 19 dBm
SOA	noise figure max. gain max power extinction	11 dB 17 dB 11 dBm 50 dB
Splitter/Comb	excess loss	0.3-3 dB
WDM MUX/ DeMUX	excess loss crosstalk	5 dB -30 dB
λ converter	input power output power	-16 dBm 5 dBm
FDL	loss	0.2 dB/km

Methodology



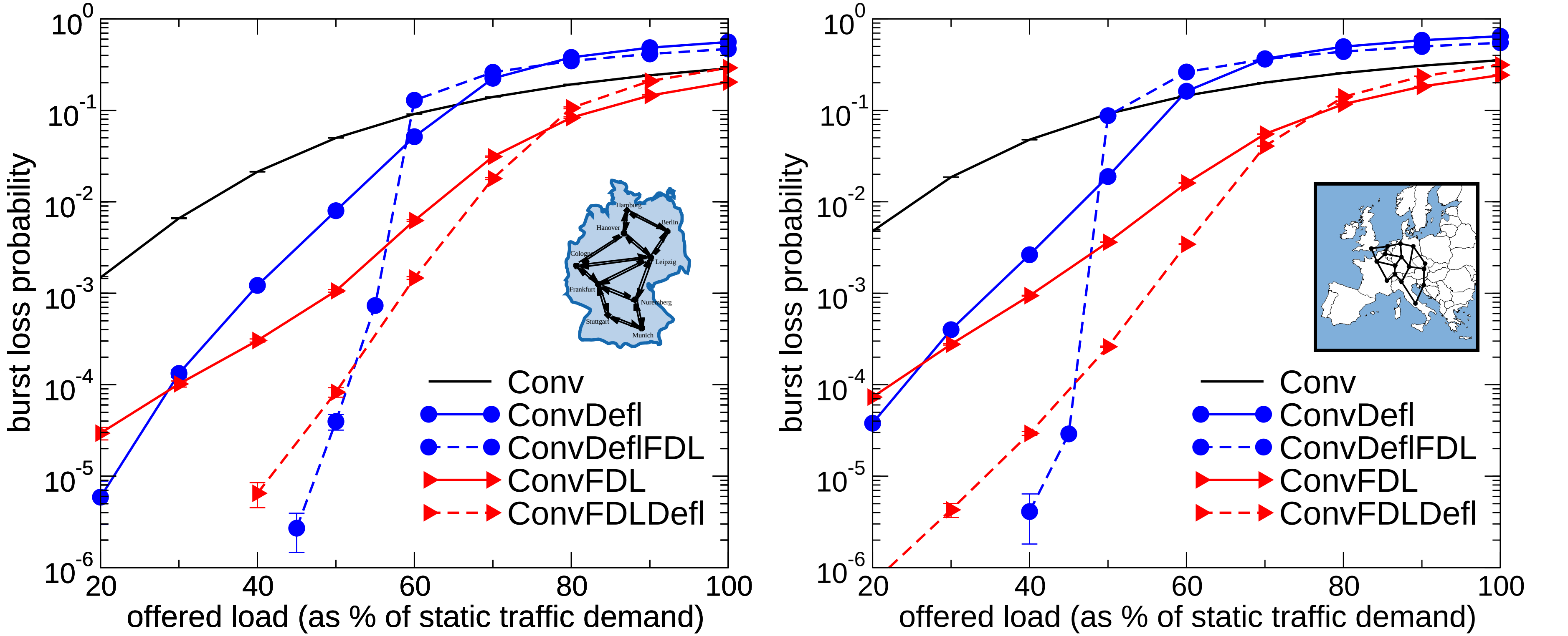
Node Dimensioning and Position





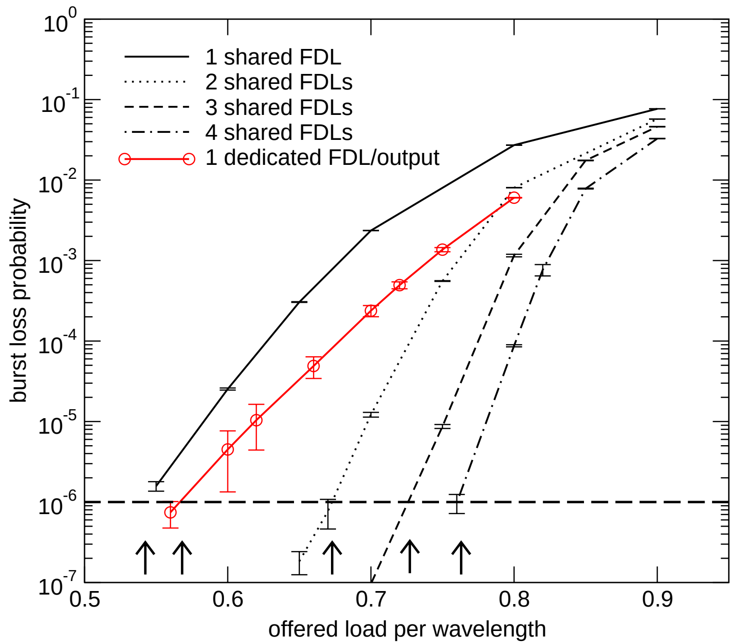
- **Stuttgart with only degree 2 and small link to Munich dominates**
  - local resolution with ConvFDL yields few improvement → Defl needed
- **Leipzig is in core with degree 5, large links to all adjacent cities**
  - local resolution with ConvFDL successful
  - ConvFDLDefl even more efficient due to large number of alternatives

Principal Behavior



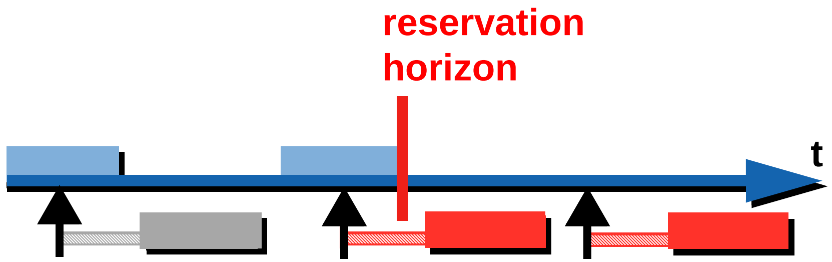
➔ **Principle behavior is the same for both network topologies**

Evaluation Methodology

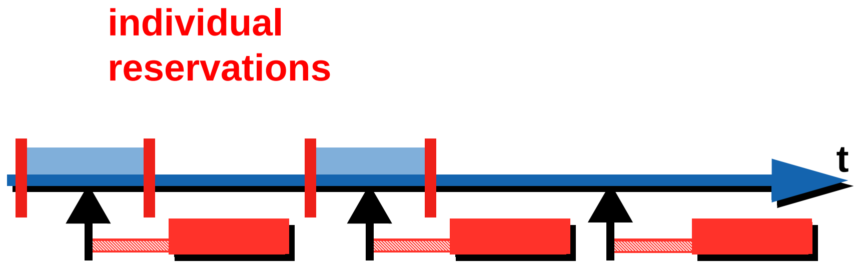


- **Number of fibers, bitrate, min. tolerable Q-factor (left)**
  - → maximum number of wavelengths M_{max}
  - → maximum throughput
- **Number of fibers and wavelengths, bitrate, max. tolerable P_{loss} (right)**
  - → utilization for given P_{loss}
  - → effective throughput

Burst Scheduling



Reserve a Limited Duration
no void filling, e.g. LAUC, Horizon

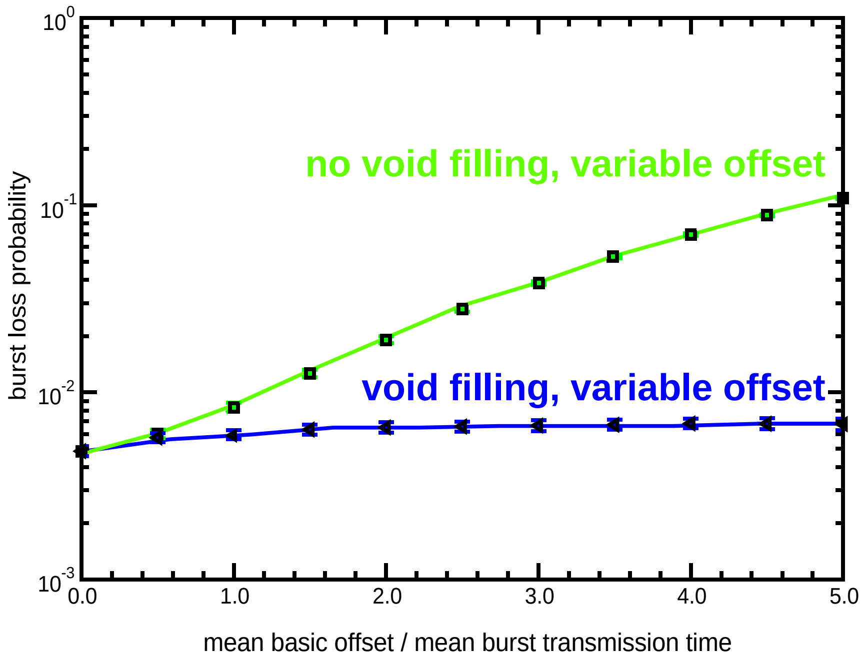


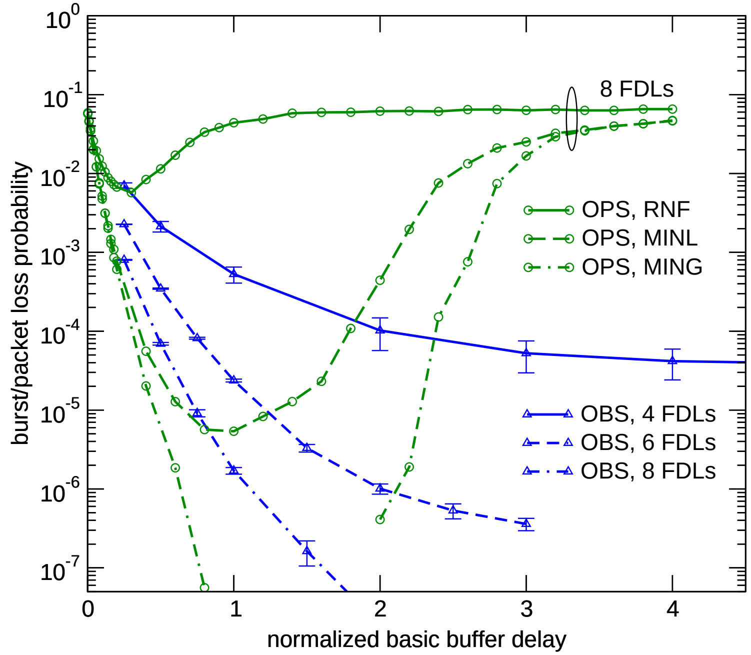
Reserve a Fixed Duration
void filling, e.g. LAUC-VF, JET

- **Huge amount of proposals for optimization**
  - rearrangement of bursts, but: additional signalling needed
  - gap minimization
  - window-based algorithms for blocking switching matrices
- **Two implementations reported for ms and µs bursts**

  → complexity of JET is not prohibitive

Burst Scheduling





joint work with Walter Cerroni, University of Bologna

- **Offsets lead to reservations spread over time → voids**

  → void filling can reduce this negative effects

- **No improvement by void filling for offset == 0 or constant**
- **Significant improvement only for large offset scenarios**

  → offset-based QoS scheme

  → FDL buffer reservation