HYBRID OPTICAL SWITCHING AND POWER CONSUMPTION IN OPTICAL NETWORKS

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Table of contents

Hybrid Optical Switching (1/2)

Wavelength Division Multiplexing (WDM):

- *Reference technology for optical backbone networks*
- *Divides the available bandwidth in multiple high-speed independent channels*

Switching schemes in WDM networks:

Optical Circuit Switching (OCS):

✔ High reliability and low cost

✗ Low bandwidth utilization

Optical Burst Switching (OBS):

✔ Good bandwidth utilization and contained cost

✗ High losses at the intermediate nodes

Hybrid Optical Switching (2/2)

Optical Packet Switching (OPS):

✔ Very high bandwidth utilization

✗ High cost of implementation and maintenance

Hybrid Optical Switching (HOS):

- Integration of OCS/OBS/OPS on the same network
- Long flows are carried over circuits or long bursts
- Short flows are carried over packets or short bursts

HOS nodes:

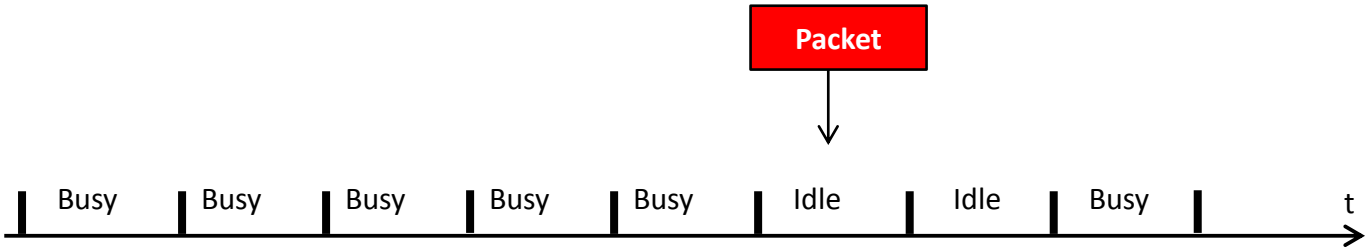
Edge nodes: Link the HOS network to legacy networks

Core nodes: Route traffic from ingress to egress edge nodes

Control Plane (1/3)

Data Format:

1. Time division multiplexed (TDM) circuits



Possibility for core nodes to insert optical packets in unused TDM slots of circuits.

✔ Circuit utilization is raised.

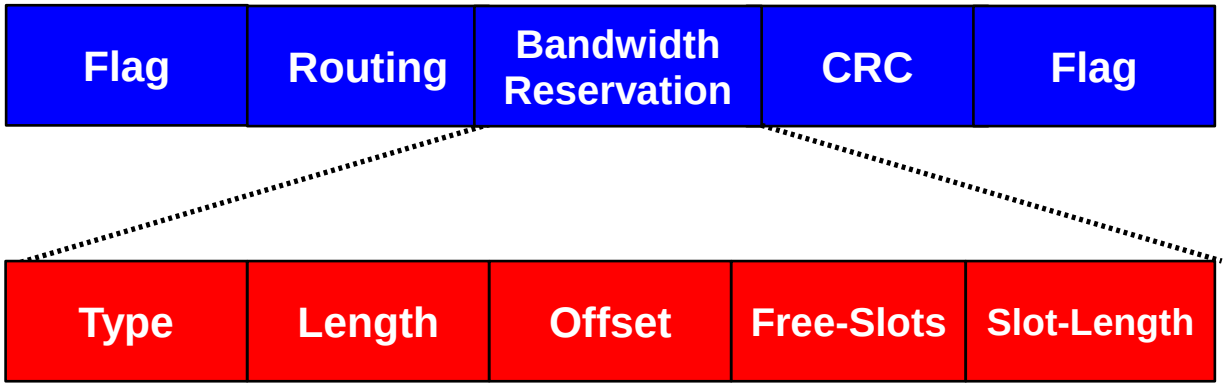
✔ More space is left available for other traffic flows.

2. Just Enough Time reservation mechanism for bursts

✔ Resources are reserved only for the duration of the burst.

Control Plane (2/3)

Control packet format:

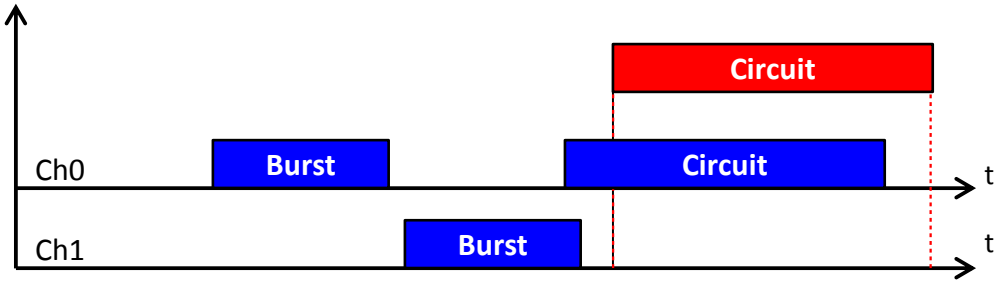


Type: distinguish between circuits, bursts and packets.
Length: data length in kBytes.
Offset: offset duration in microseconds.
Free-Slots: position and number of free slots in a circuit.
Slot-Length: TDM slot duration in microseconds.

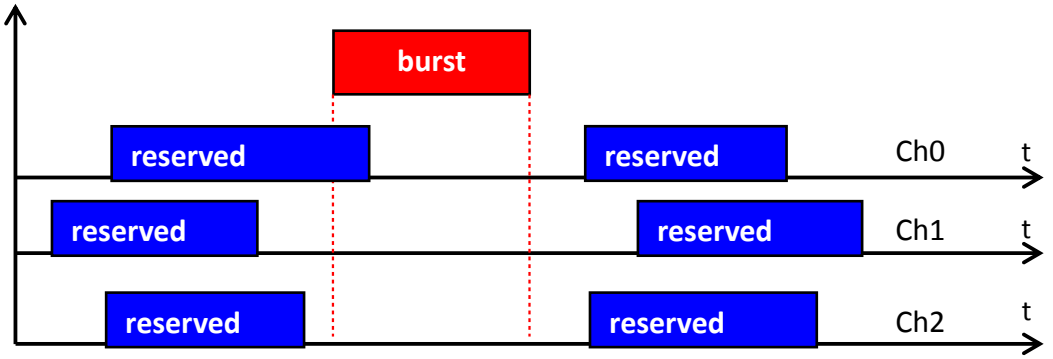
Control Plane (3/3)

Scheduling Algorithms:

1. Circuits scheduling:
Definition of circuit-offset
Circuit-offset > RTT
Circuit-offset > MaxOffsetBurst + MaxLengthBurst

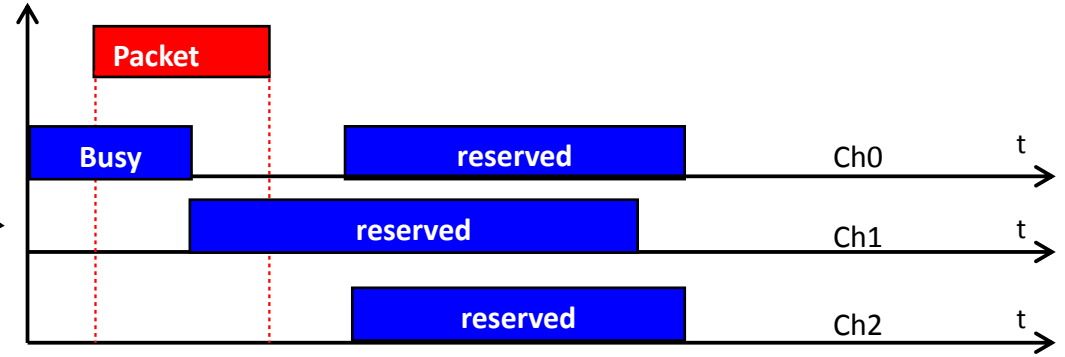


2. Burst scheduling:
First-Fit Unscheduled Channel with Void Filling (FFUC-VF) algorithm.



3. Packet scheduling:

- Check if there is an available circuit
- Else fast packet scheduling



Node Architectures (1/4)

Three different node architecture have been considered to be managed by the proposed control plane:

1) All-optical hybrid architecture

2) Optical/electronic hybrid architecture

3) All electronic architecture

All architectures are composed of an electronic control unit and a switching fabric.

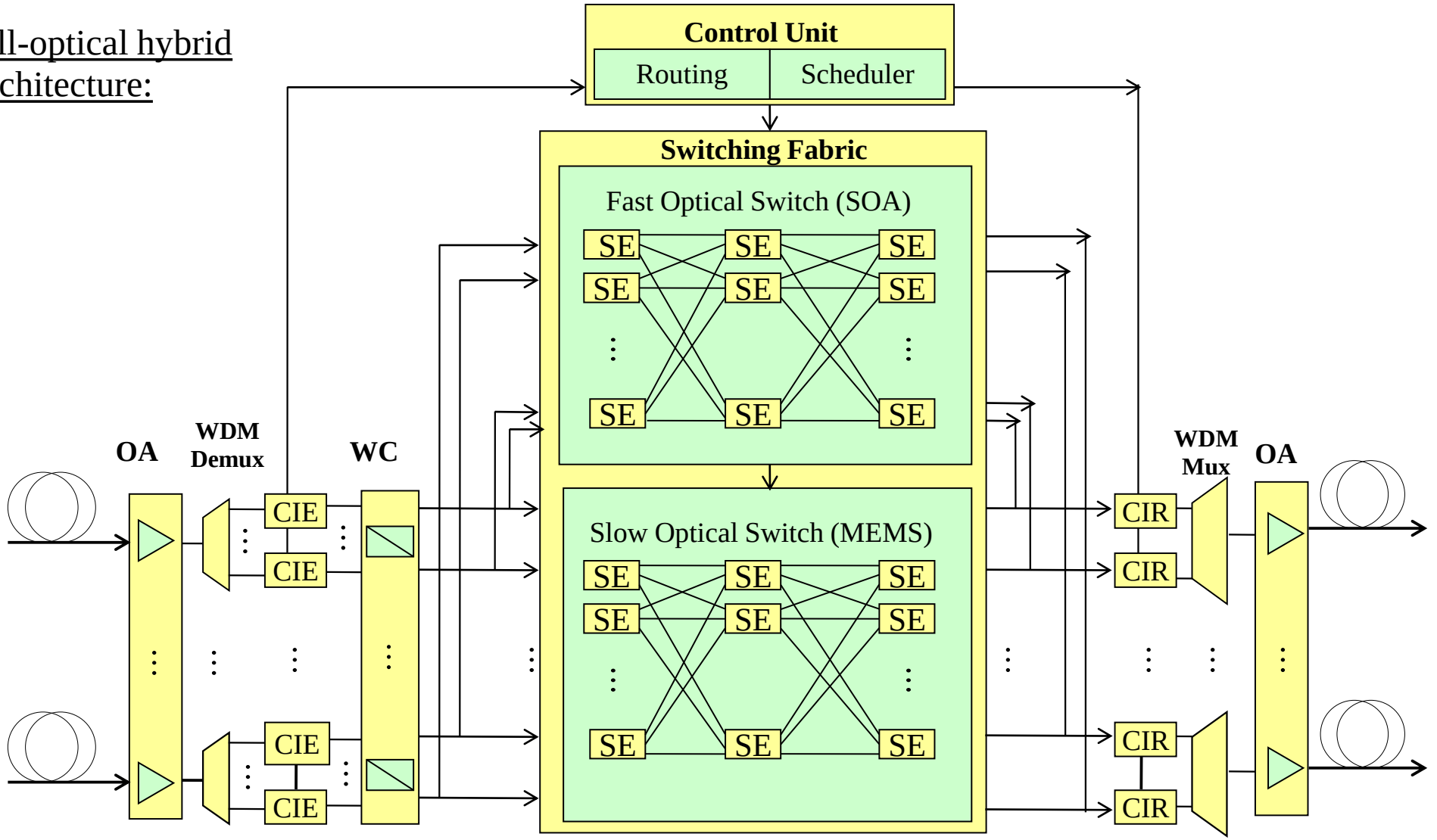
In hybrid architectures the switching fabric is divided in two switches:

1) Fast switch: *composed of switching elements whose switching time is in the order of nanoseconds and it is used to forward packets and short bursts*

2) Slow switch: *composed of switching elements whose switching time is in the order of microsecond and it is used to forward circuits and long bursts.*

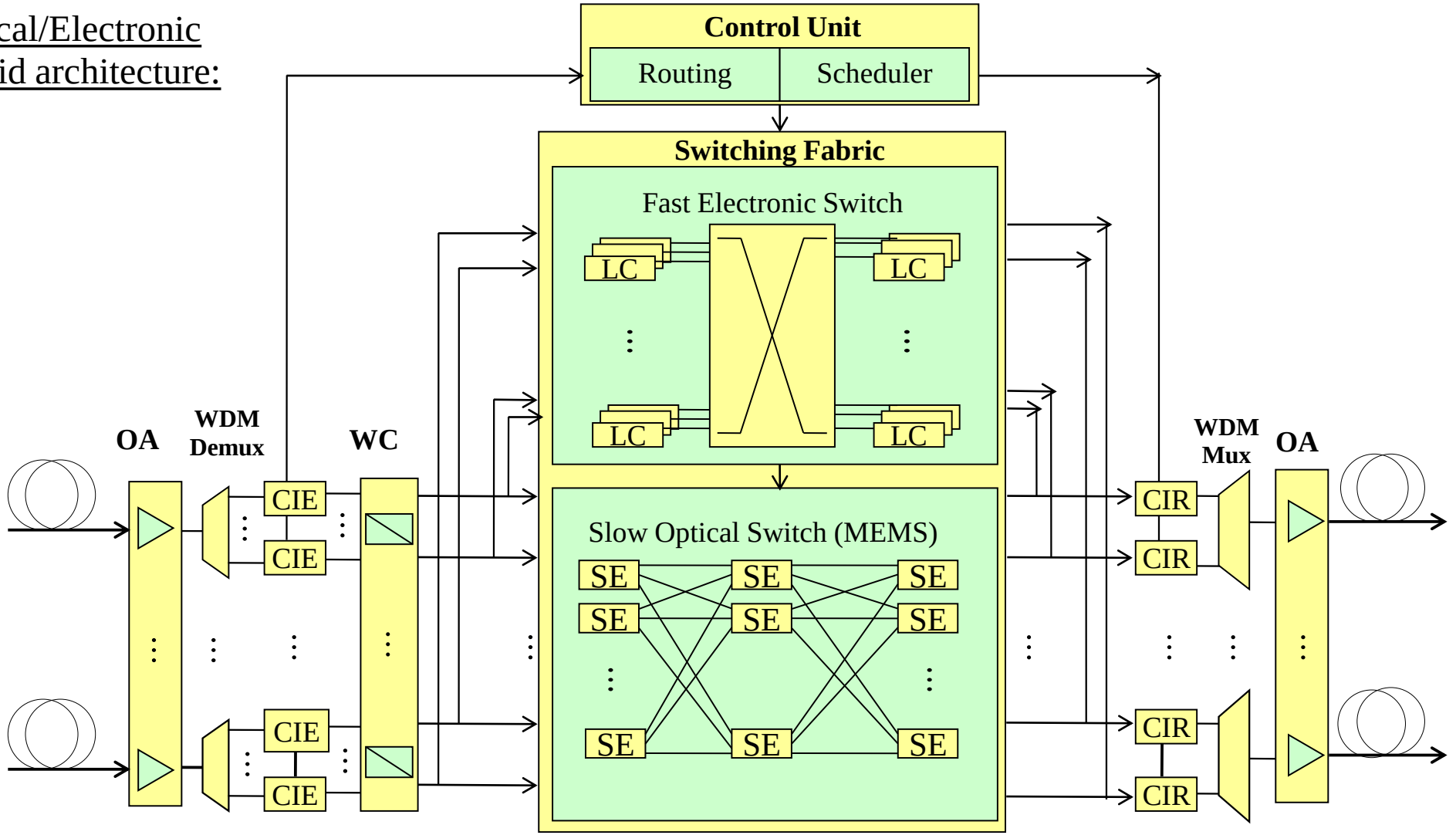
Node Architectures (2/4)

All-optical hybrid architecture:



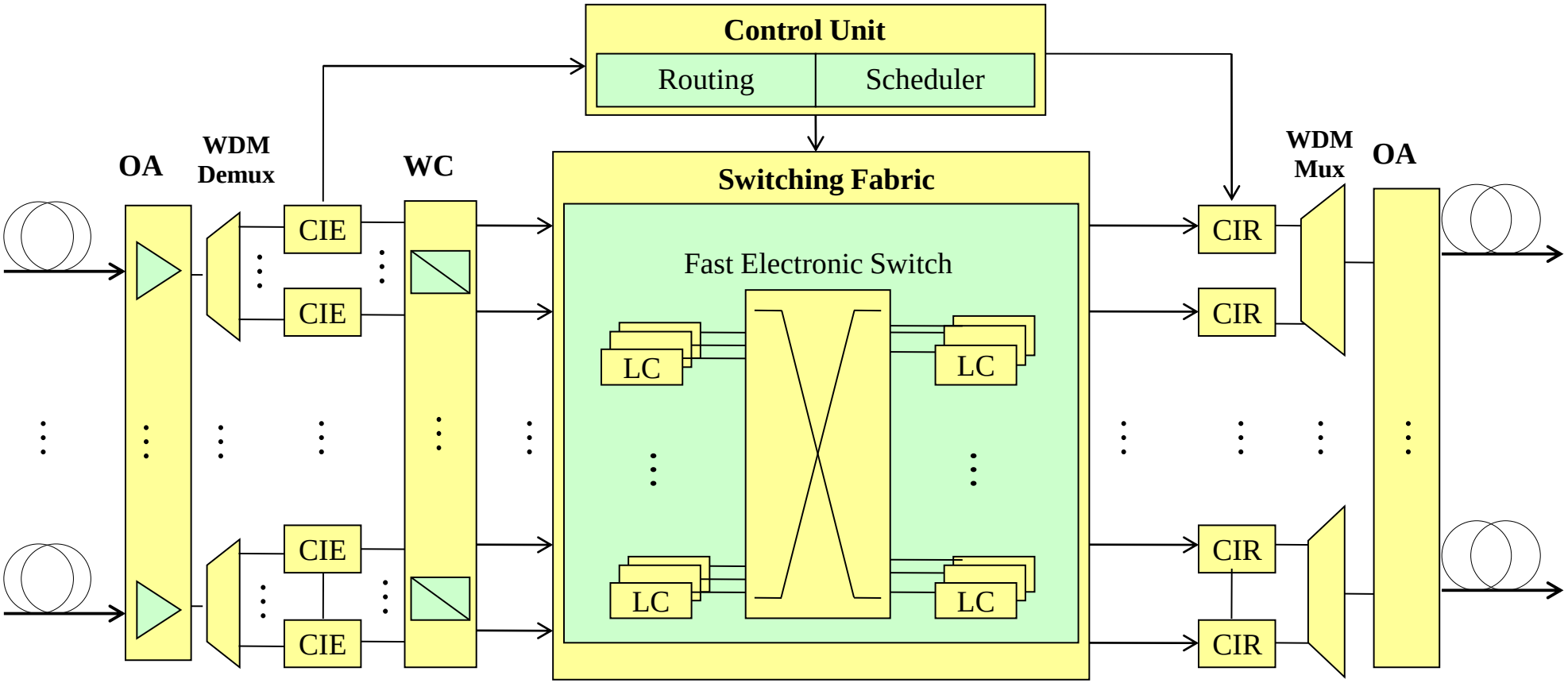
Node Architectures (3/4)

Optical/Electronic hybrid architecture:



Node Architectures (4/4)

All-electronic architecture:



Power Consumption (1/3)

- Let N be the number of input/output fibers and W be the number of wavelengths per fiber.

- Total node power consumption:

$$P_{TOT} = P_{SF} + P_{OAC}$$

- Power consumption of other active components (P_{OAC}):

$$P_{OAC} = P_{CP} + P_{RP} + P_{SC} + N \cdot W \cdot P_{CIE/R} + 2N \cdot P_{OA} + N_{TWC} P_{TWC}$$

P_{CP} = Power consumption of the control plane.
P_{RP} = Power consumption of the route processor.
P_{SC} = Power consumption of the switch control unit.
$P_{CIE/R}$ = Power consumption of the control information extractor/reinsertor.
P_{OA} = Power consumption of optical amplifiers.
P_{TWC} = Power consumption of tunable wavelength converters.
N_{TWC} = Number of active tunable wavelength converters.

Power Consumption (2/3)

- Power consumption of the switching fabric (P_{SF}):

$$P_{SF} = P_{Switch\_Port} \cdot N_{AP}$$

P_{Switch_Port} = Power consumption per switch port.
N_{AP} = Number of active ports of the switching fabric.

- Power consumption per switch port of the SOA based switch:

$$P_{Switch\_Port} = N_{SOAxPort}P_{SOA} + N_{TECxPort}P_{TEC} + N_{3RxPort}P_{3R}$$

TEC: Temperature stabilization circuit.
3R: 3R regenerator.

In a switch with a total capacity of 76.8 Tbps with 24 input/output fibers P_{Switch_Port} is ***19W***.

Power Consumption (3/3)

- Power per switch port of the MEMS based switch:

$$P_{Switch\_Port} = P_{3D\_MEMS}$$

The power consumption per switch port of a MEMS based switch is ***0.1W***.

- Power per switch port of the Electronic switch:

$$P_{Switch\_Port} = P_{LC} + P_{SE}$$

P_{LC} = Power consumption of an electronic line card.
P_{SE} = Power consumption of electronic switching elements.

Considering unidirectional electronic line cards at *40 Gbps*, the power consumption per switch port of a MEMS based switch is ***306.8W***.

Increase in Power Efficiency

- Let NT be the normalized throughput and AC be the aggregate node capacity.
- Achievable throughput: $AT = NT \cdot AC$
- Power efficiency: $P_{EFF} = \frac{AT}{P_{TOT}}$
- Increase in power efficiency between all-optical hybrid and optical/electronic hybrid:

$$IE_{O,O/E} = \frac{P_{EFF}\big|_{All\text{-}optical} - P_{EFF}\big|_{Optical/electronic}}{P_{EFF}\big|_{Optical/electronic}}$$

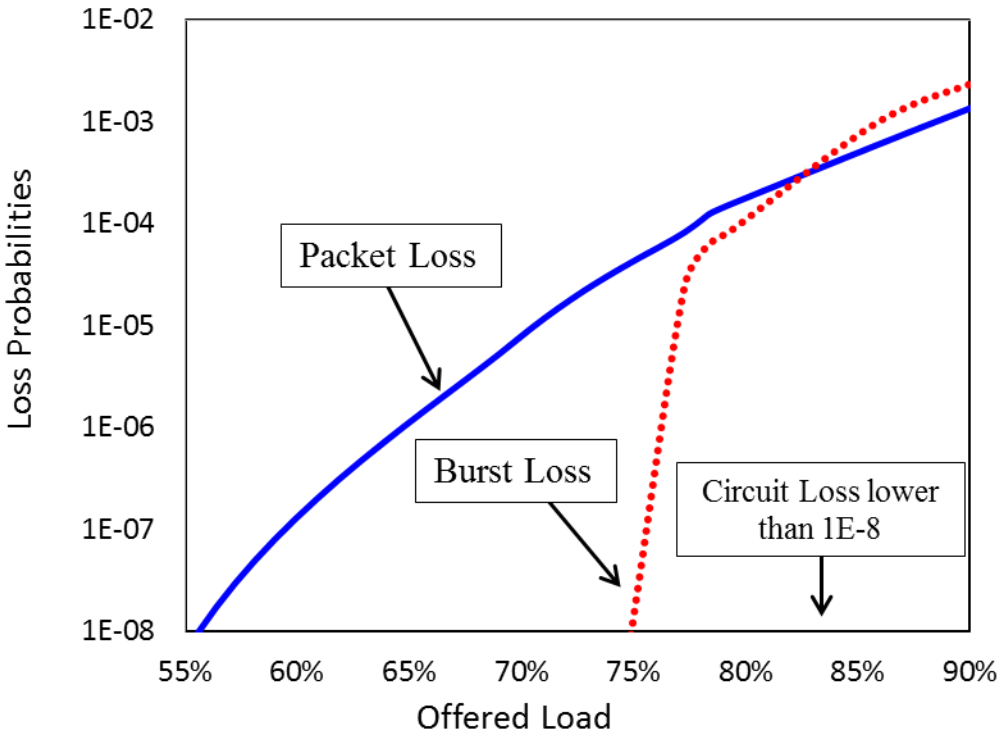
- Increase in power efficiency between optical/electronic hybrid and all-electronic:

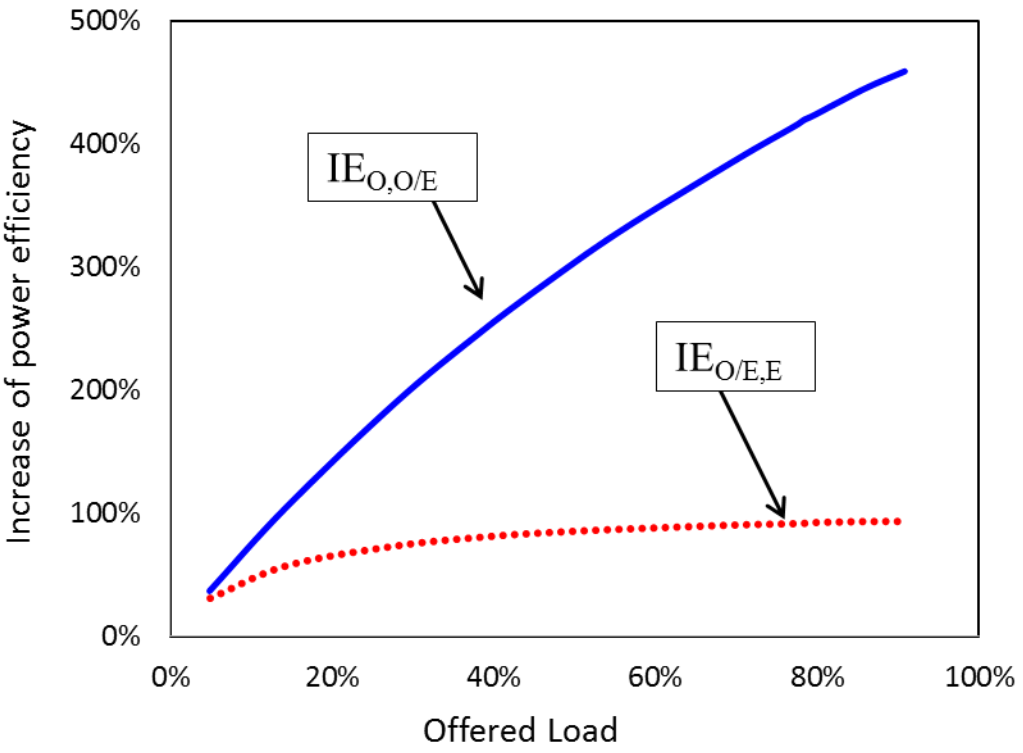
$$IE_{O,O/E} = \frac{P_{EFF}\big|_{Optical/electronic} - P_{EFF}\big|_{All\text{-}electronic}}{P_{EFF}\big|_{All\text{-}electronic}}$$

Numerical Results (1/4)

Impact of input load:

Capacity: 76.8Tbps with 24 input/output fibers.
Traffic pattern: 40% circuit, 30% burst, 30% packet.

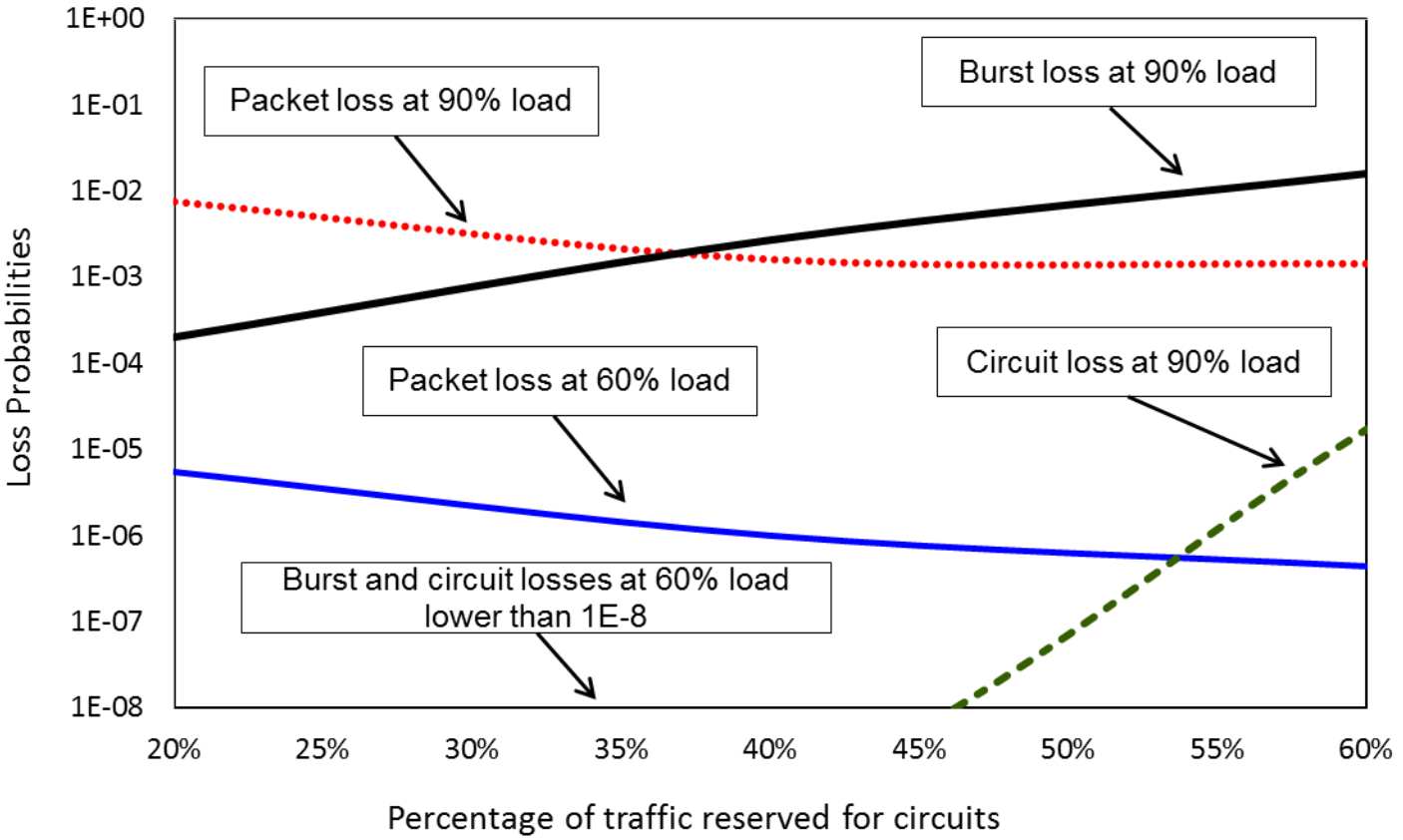




Numerical Results (2/4)

Impact of traffic pattern on data losses:

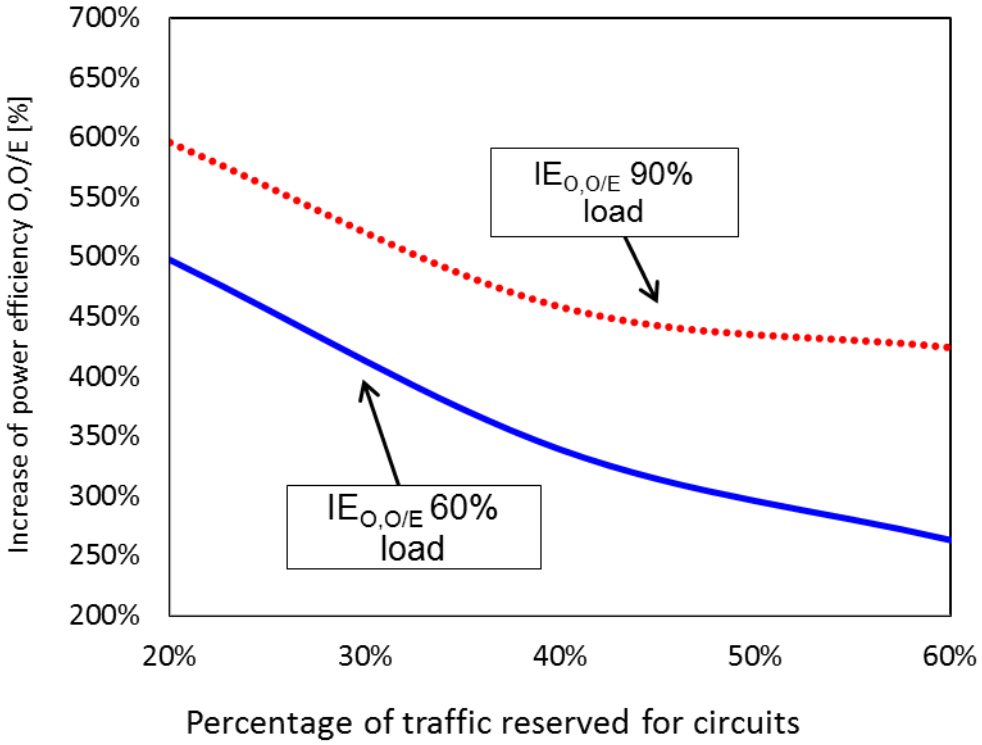
Capacity: 76.8Tbps with 24 input/output fibers.
Input load: 60% and 90%.

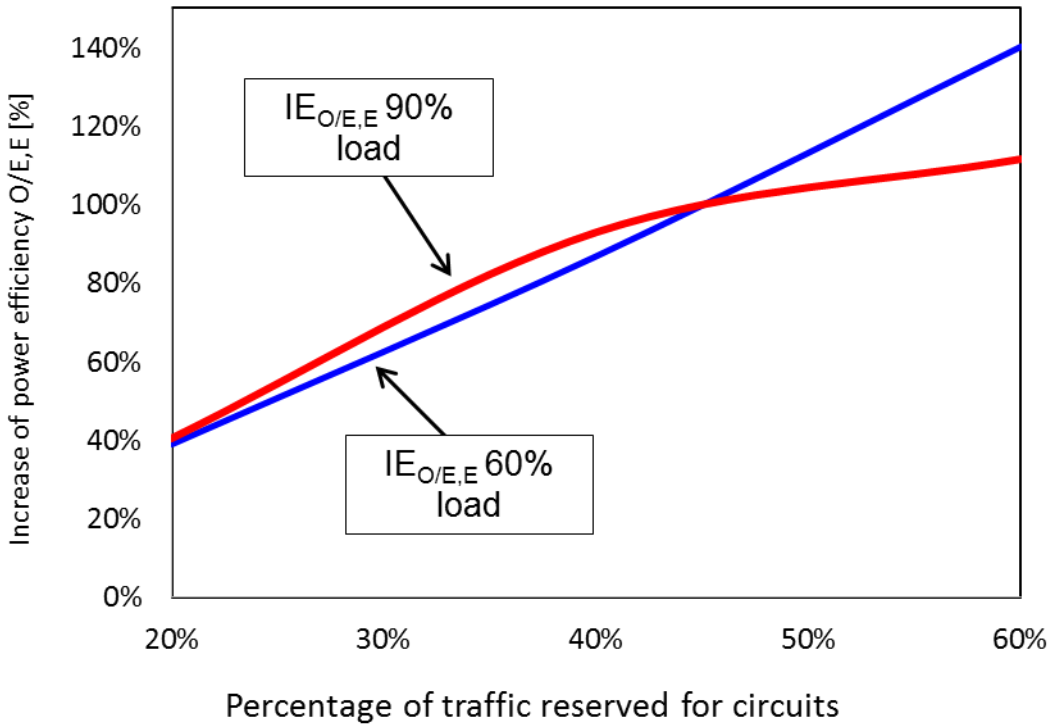


Numerical Results (3/4)

Impact of traffic pattern on node power consumption:

Capacity: 76.8Tbps with 24 input/output fibers.
Input load: 60% and 90%.





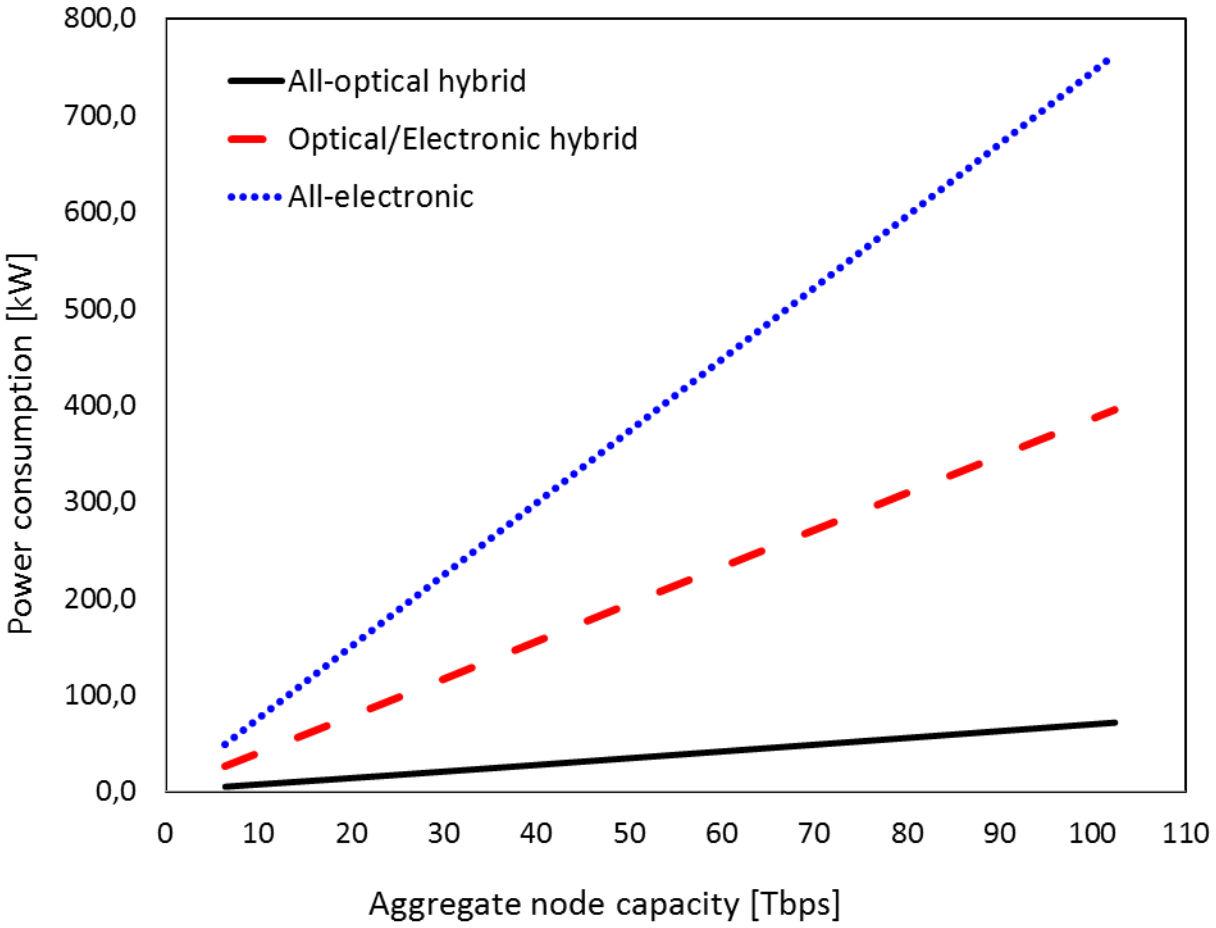
Numerical Results (4/4)

Power Consumption:

All-electronic:
- Advanced data processing
- High power consumption (760 kW at 102.4 Mbps)

Optical/electronic hybrid:
- Advanced data processing on fast traffic
- Contained power consumption (395 kW at 102.4 Mbps)

All-optical hybrid:
- No advanced data processing
- Low power consumption (70 kW at 102.4 Mbps)



Conclusions

- Performance and power consumption characterization of a hybrid optical core node.

- Numerical results show that:

1) Hybrid optical switching is a promising technique for next generation WDM networks because it combines the advantages of OCS/OBS/OPS

2) An integrated control plane employing a proper scheduling algorithm for each data type leads to high bandwidth utilization and low data losses.

3) Hybrid architectures employing a switching fabrics composed of a slow optical switch and a fast switch allow to reduce the power consumption of current electronic router.

- Future works aim at the evaluation of performance and power consumption in a HOS network based on the proposed control plane.

- For further study:

M. Fiorani, M. Casoni, S. Aleksic, "Performance and Power Consumption Analysis of a Hybrid Optical Core Node", OSA/IEEE Journal of Optical Communications and Networking, Vol.3 , Issue 6, pp. 502-513, June 2011.

THANK YOU

Questions?