Node architectures for optical packet and burst switching

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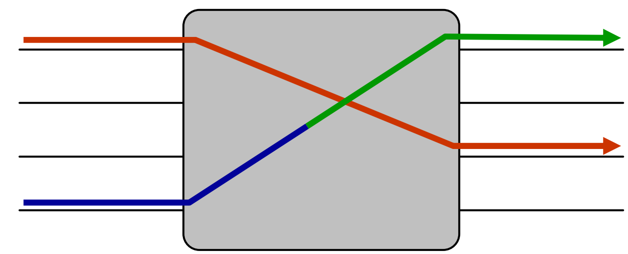
Outline

- Introduction
  - OPS and OBS concepts
  - packet & header format
- Node architecture
  - functionality
  - optics and/or electronics
- Switch matrix
  - alternatives
  - scalability
- Contention resolution
  - problem & solution
  - buffer architectures

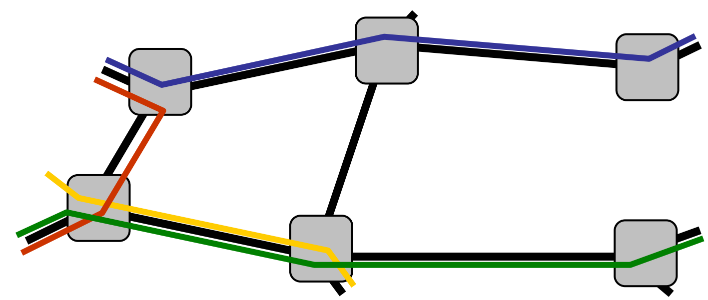
Introduction

Optical switches

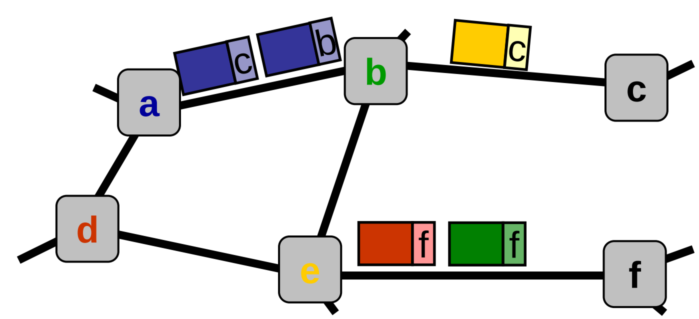
- Optical switching:
  - direct light from an input port to an output port
  - possibly wavelength conversion



- circuit-switching:
  - continuous bit-stream
  - pre-established light-paths
  - set-up: “manually” or dynamic



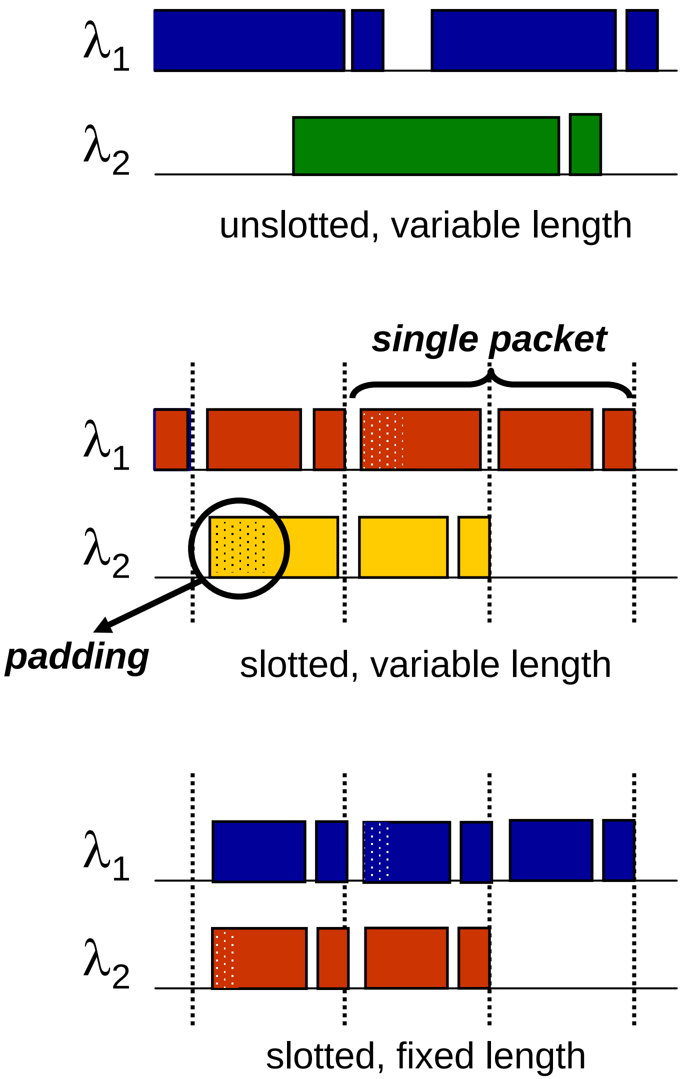
- packet/burst switching
  - chunks of bits, encapsulated in packets
  - packet header determines forwarding
  - e.g. label switching, GMPLS based



Packet format

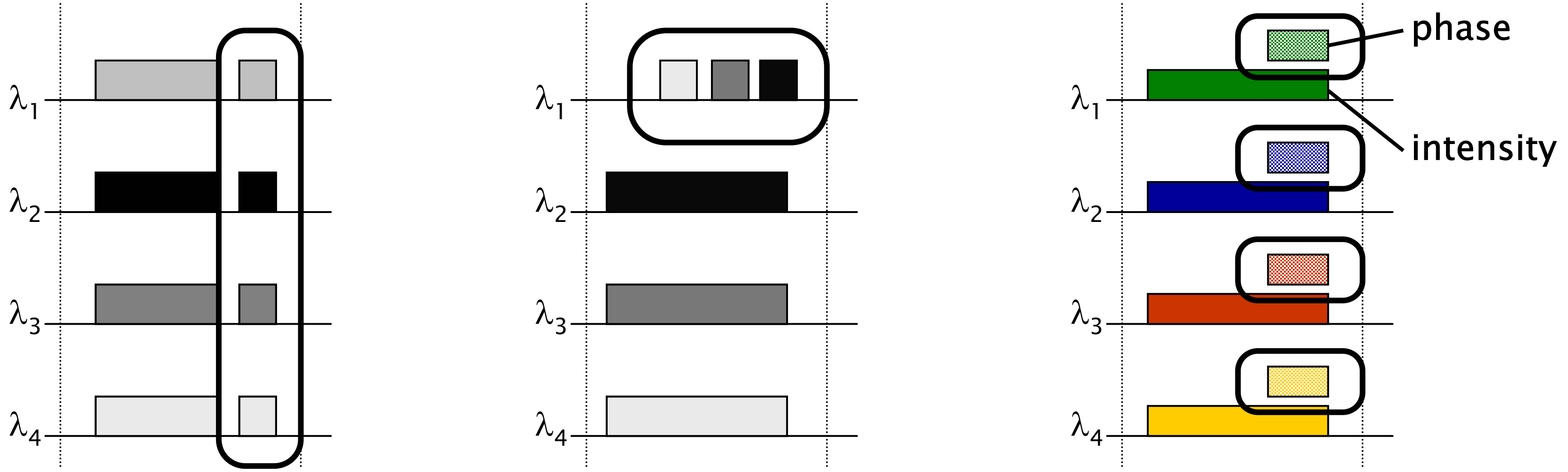
- fixed/variable duration:
  - pro variable = no fragmentation/ reassembly, no padding, less header overhead
  - contra = long packets can block many short ones
- slotted/unslotted operation:
  - pro slotted = easier packet scheduling (synchronous switching)
  - contra = cost of synchronisation components

- OPS = fixed, slotted packets
- OBS = variable, unslotted packets



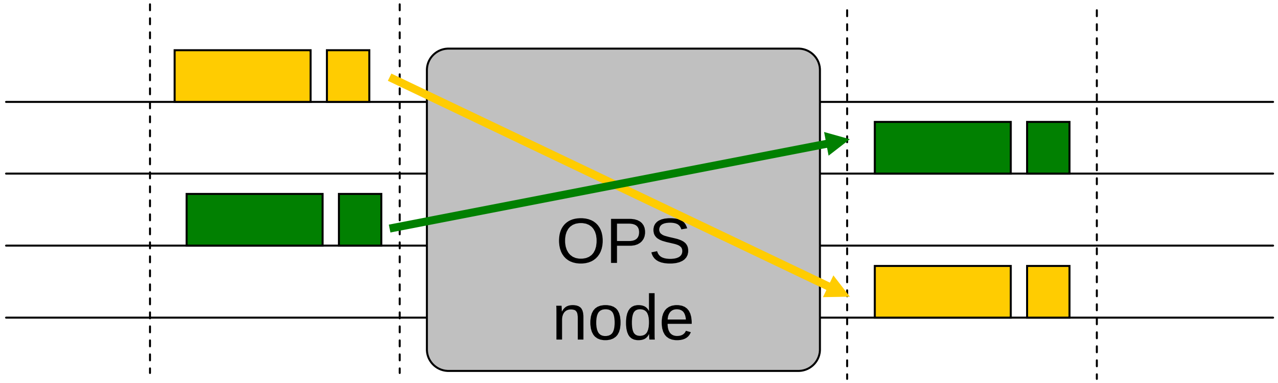
Header format

- position of header:
  - in band: header and payload are sent sequentially, separated in time
  - out of band: dedicated wavelength; also multi-wavelength headers have been proposed (see e.g. PS.TuC1)
  - out of band: orthogonal channel (e.g. DPSK)



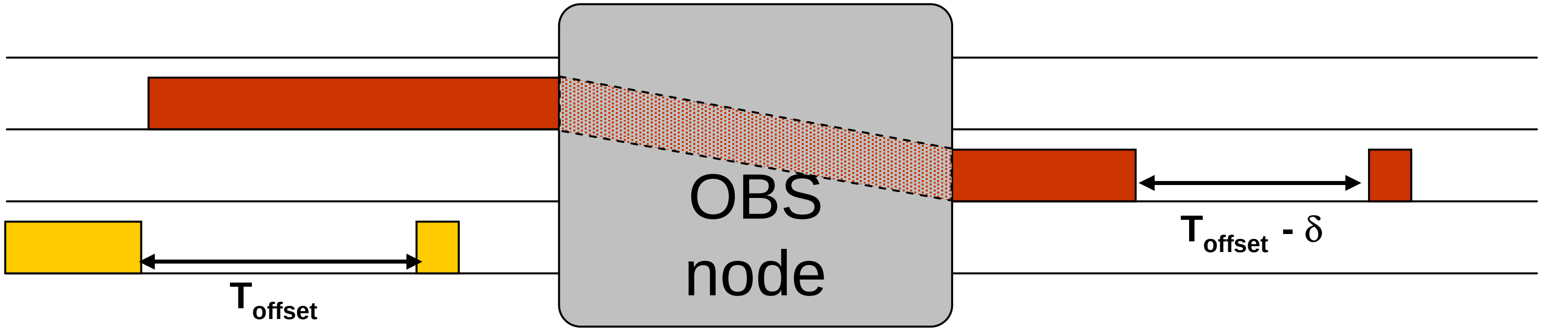
Operation of OPS

- <u>fixed-length</u> packets, <u>slotted</u> operation
- header accompanies payload
    - contains necessary information to make forwarding decision
- each timeslot:
    - inspect packets at input ports
    - decide which packets can be forwarded without collisions
- switch is “memory-less”
    - no knowledge of packets scheduled in past is necessary



Operation of OBS (1)

- variable packet lengths, unslotted operation
- header is sent T_{offset} before payload
  - contains necessary information to make forwarding decision
  - functions as one-way reservation (allows timely config. of switch fabric)
  - offset decreases by header processing time per hop
- on arrival of header:
  - decide whether burst can be forwarded without collisions
  - make necessary resource reservations if burst is accepted
- switch needs “memory”:
  - keep track of reservations made in past



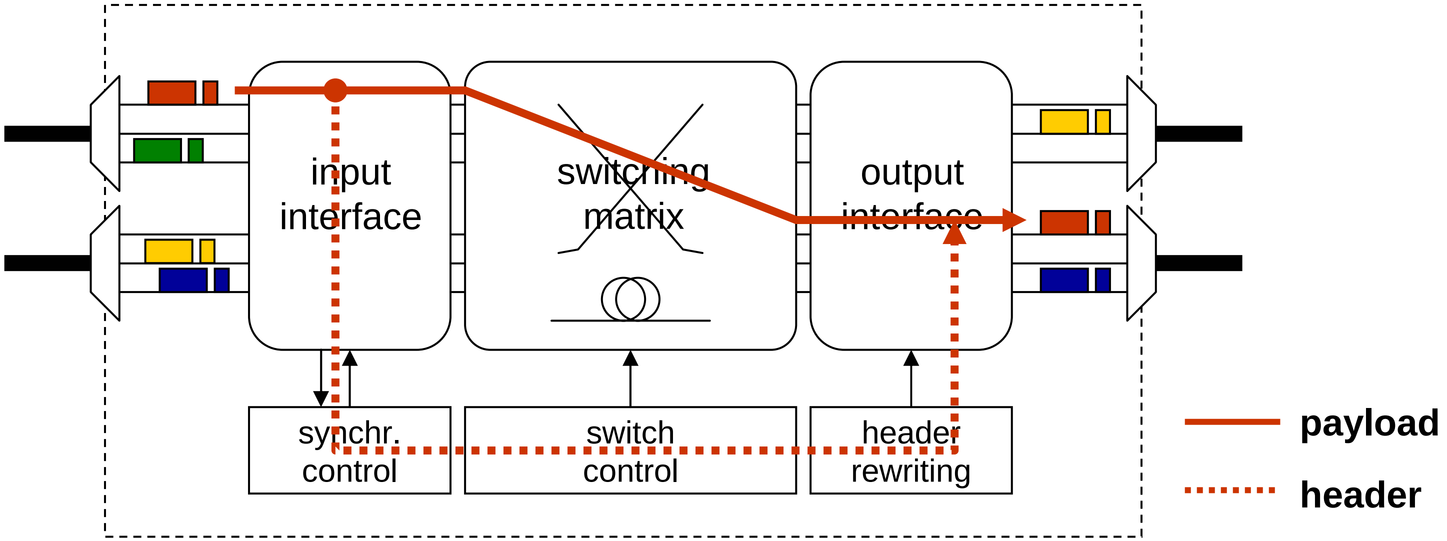
Operation of OBS (2)

- Note: WR-OBS = wavelength-routed OBS
  - two-way reservation
    - “header” is sent from source to destination within OBS network
    - if all goes well, acknowledgement is sent back to source
  - this is more like wavelength switching at very short timescales
  - proposed by P. Bayvel et al. (Univ. College London, UK)

Node architectures

Functionality of an OPS / OBS node

- input interface:
  - header extraction (straightforward if out-of-band)
  - synchronisation: detect beginning of packet/burst
  - in OPS: align packets
- switching matrix (see further)
- output interface
  - e.g. regeneration of optical signal; header re-writing…

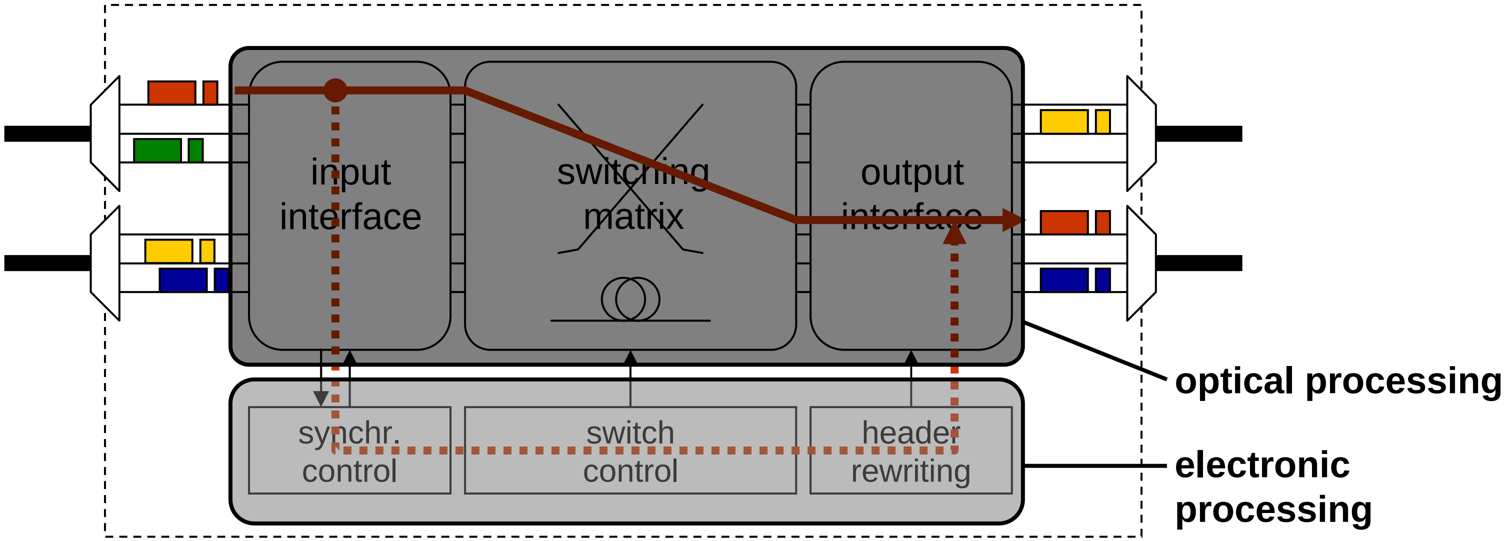


Combine the best of electronics and Optics

- optical packet switching “today”:
  - header is processed electronically
  - payload is switched optically

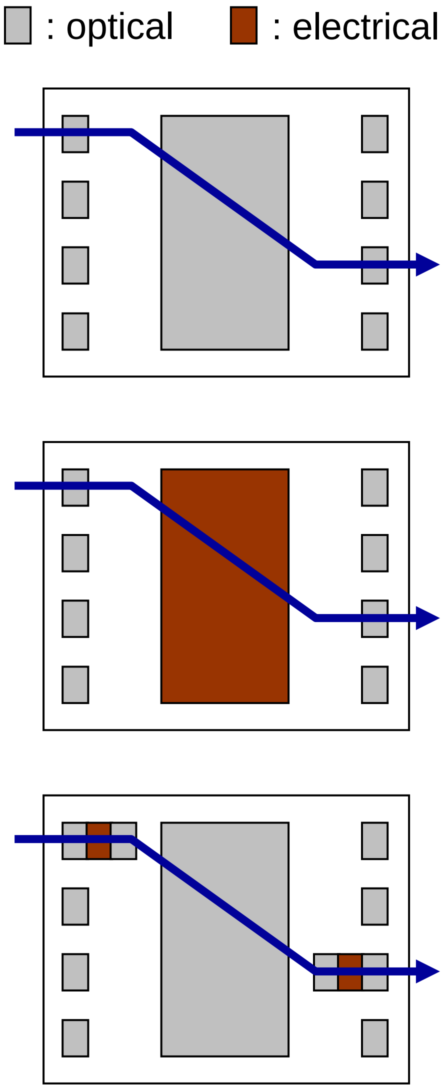
  ⇒ <u>optics</u> for capacity & switching,
  <u>electronics</u> for routing & forwarding

- note:
  - all-optical header processing is “under study” (e.g. PS2001, PThD5)



Oh-oh-oh*

- O-O-O:
  - optical input interface, optical switch fabric, optical output interface
  - payload is switched transparently, without leaving optical domain
  - **pro** = bitrate-transparent
  - **con** = still emerging technologies, BER can not be monitored
- O-E-O:
  - optical inputs, converted to el. for switching, back to optics at outputs
  - "opaque": no more all-optical;   but straightforward grooming
  - **pro** = well established techno, 3R regen. "for free"
  - **con** = no bit-rate transparency, scalability ~ Moore's law
- OEO-O-OEO
  - (some) inputs and outputs: electronic 3R regen.
  - **pro** = scalability of optical switch fabric with 3R regen.
  - **con** = bit more complex than O-O-O

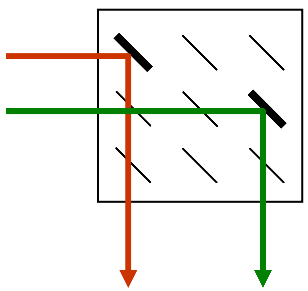


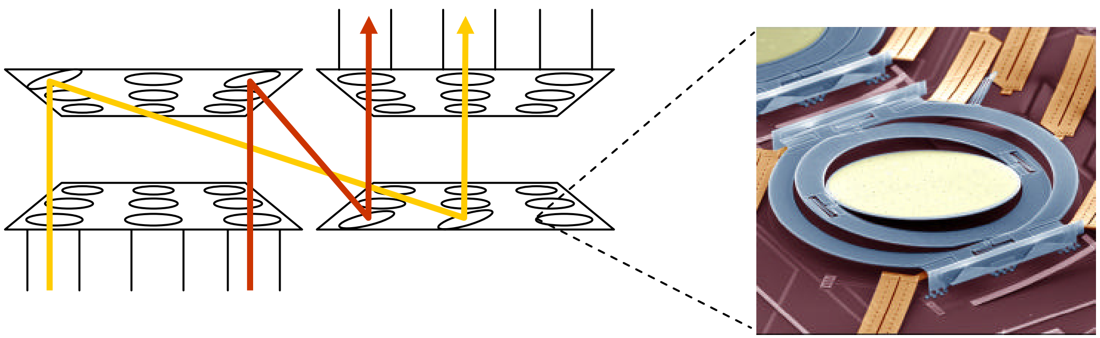
*: G.Bennet, at www.lightreading.com

Switch fabric

Overview of dominant architectures

- dominant approaches to optical switch fabrics:
  - MEMS (=micro-electro-mechanical systems)
  - broadcast-and-select (e.g. SOA-based)
  - AWG and tuneable lasers
- MEMS:
  - principle:





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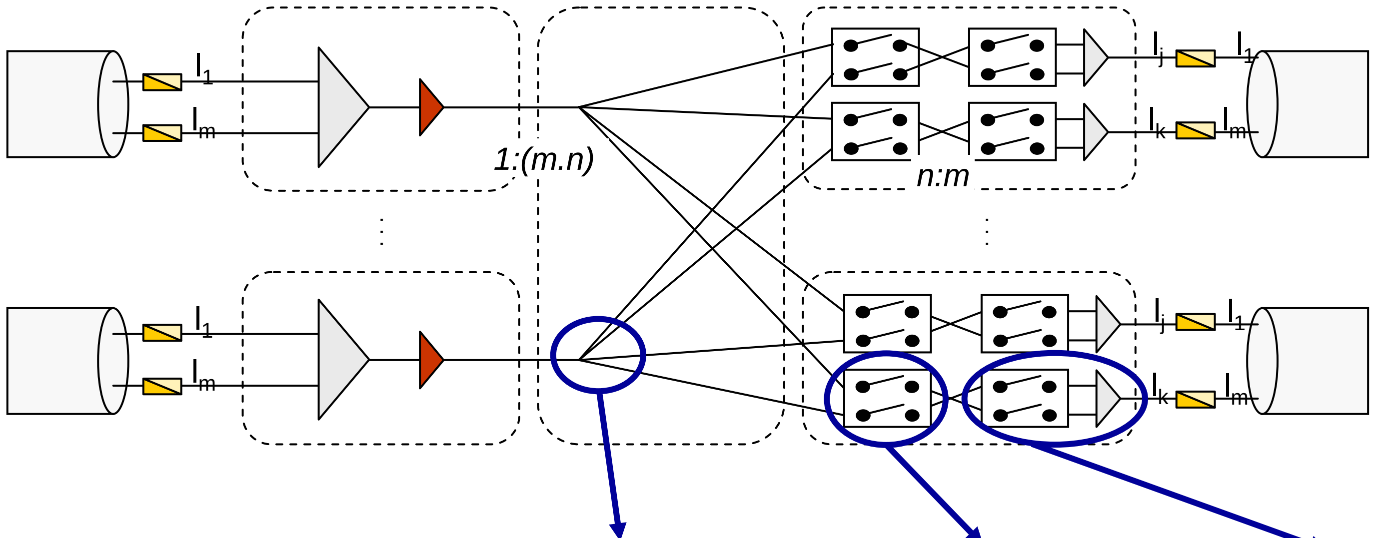
  - main components:
    - tiny mirrors (2D pop-up, or 3D tilting)
  - characteristics
    - low loss, good scalability (=high port counts)
    - but… too slow for packet switching (ns timescale not feasible)

Broadcast-and-select switch

- principle: (e.g. David, http://david.com.dtu.dk; ECOC'01)



- main components:
  - splitters
  - selectors
- characteristics:
  - split losses: calls for regeneration
  - inherent multicast capability

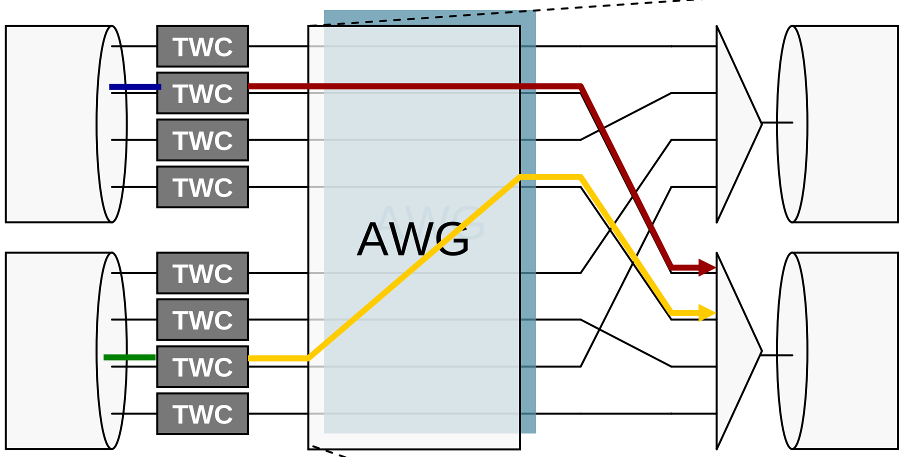
complete fibre is broadcast to all output ports

first array of SOAs selects 1 input fibre

second array of SOAs is used to select 1 wavelength

AWG based switch

- principle: (e.g. Stolas, http://www.ist-stolas.org)

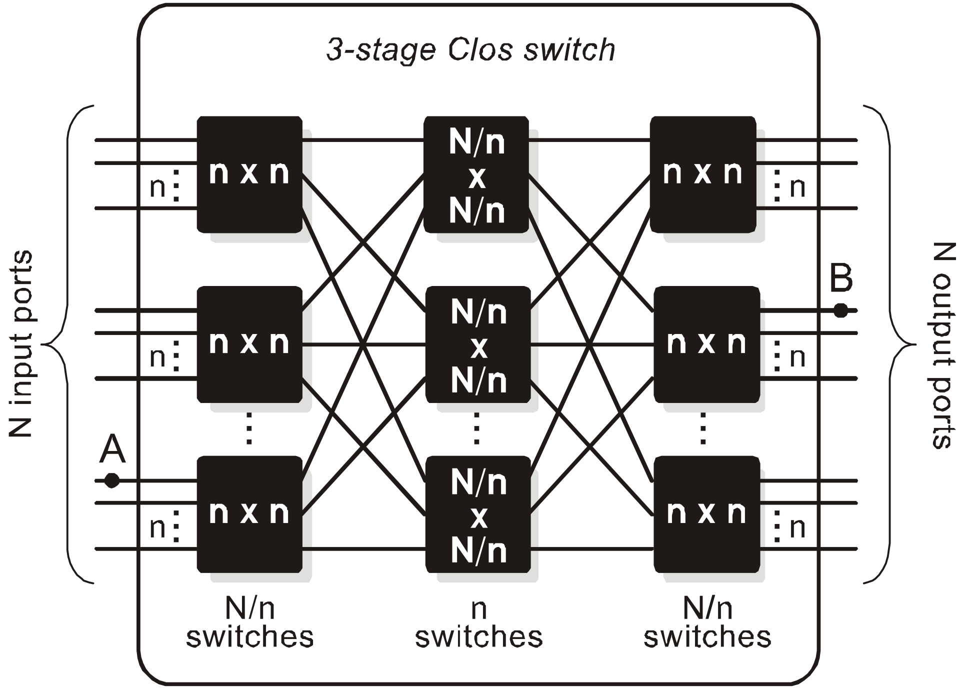


out-port \ in-port	1	2	3	4	5	6	7	8
1	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7	λ_8
2	λ_8	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7
3	λ_7	λ_8	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6
4	λ_6	λ_7	λ_8	λ_1	λ_2	λ_3	λ_4	λ_5
5	λ_5	λ_6	λ_7	λ_8	λ_1	λ_2	λ_3	λ_4
6	λ_4	λ_5	λ_6	λ_7	λ_8	λ_1	λ_2	λ_3
7	λ_3	λ_4	λ_5	λ_6	λ_7	λ_8	λ_1	λ_2
8	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7	λ_8	λ_1

- main components:
  - tuneable wavelength converters
  - AWG
- characteristics:
  - passive component, no split losses
  - multicast quite complex

Scalability

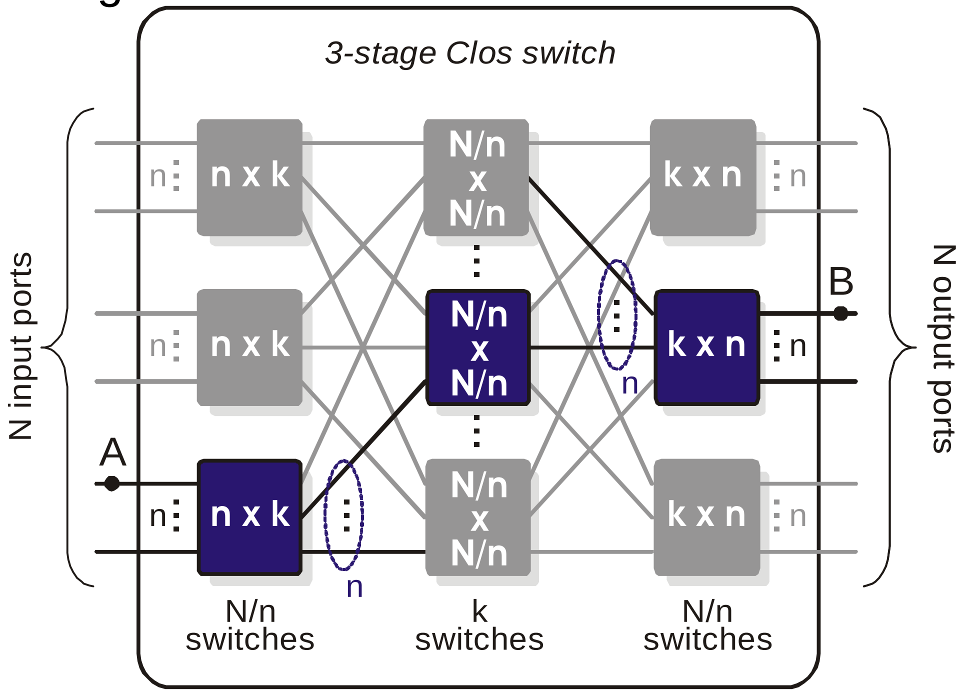
- switch dimensions limited by
  - B&S: split losses
  - AWG: tuneability range of TWCs
- Possible solution:
  - multi-stage switches, e.g. Clos-networks



A three-stage Clos-network (1)

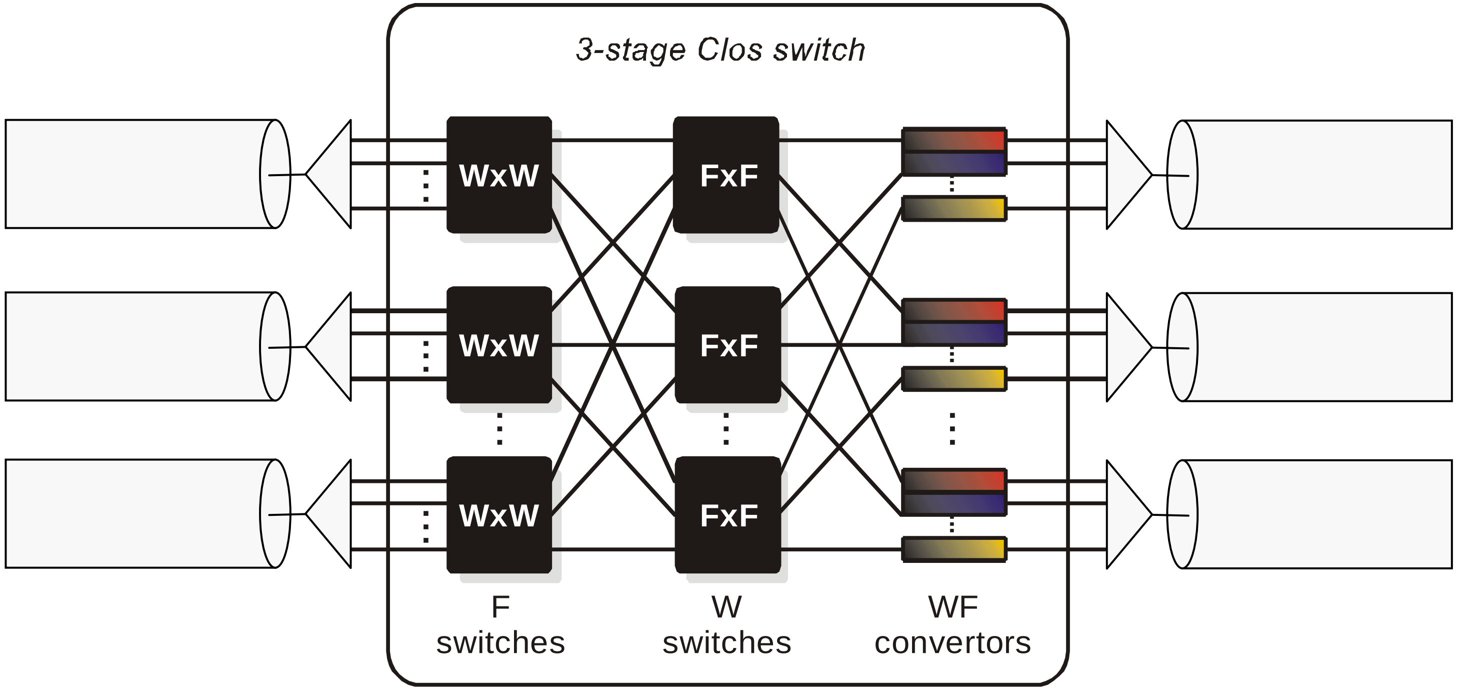
- slotted OPS
  - re-arrangeable non-blocking
  - second-stage switches: k ≥ n
- unslotted OBS
  - fully non-blocking
  - second-stage switches: k ≥ 2n-1

⇒ slotted OPS needs only half as much second stage switches



A three-stage Clos-network (2)

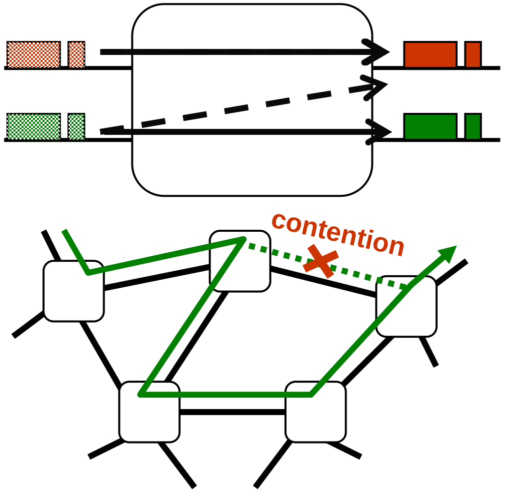
- <u>note</u>: if wavelength conversion is allowed, third switching stage can be eliminated
- e.g. slotted OPS:
  - F fibres, W wavelengths per fibre
  - make 1st and 3rd stage per input/output fibre

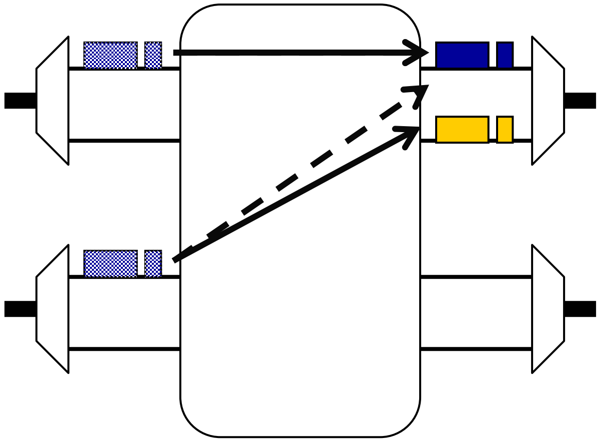


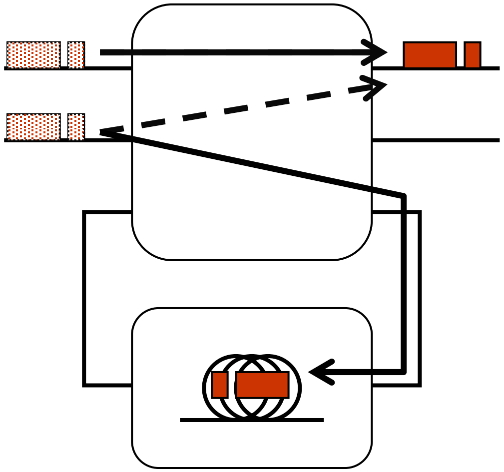
Contention resolution

Problem and possible solutions

- Problem:
  - two or more packets contend for same resource: destined for same outgoing port at the same time
- Solutions:
  - deflection routing
  - wavelength conversion
  - buffering: optical buffer = Fibre Delay Lines (FDLs)





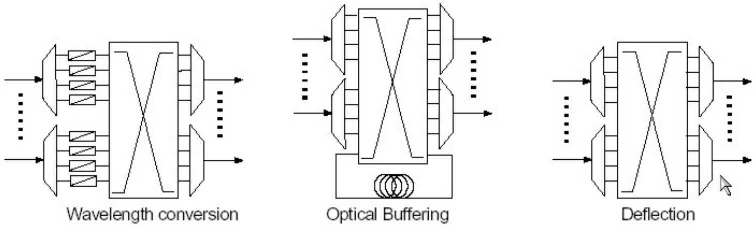


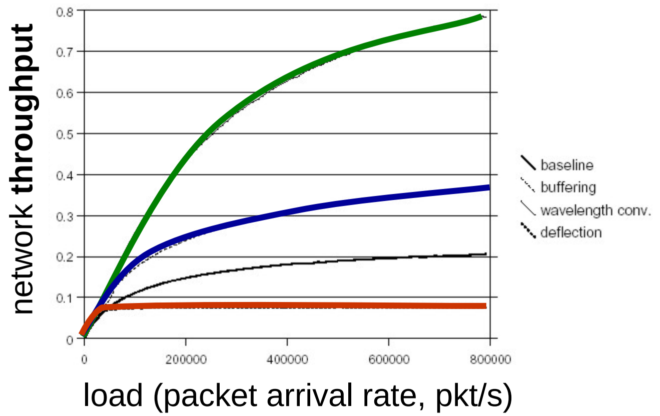
What solution to choose?

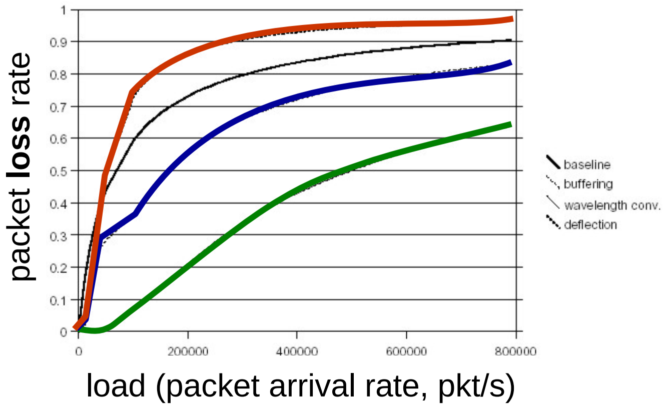
figures © Yao et al., Opticomm'00

- **Deflection:**
  - packets are "stored" in network:
  - increases load, increases delay
  - only works for low loads
- **Wavelength conversion:**
  - no packet storage
  - allows high network throughput, no increased delay
- **Buffering:**
  - local packet storage at nodes
  - small delay penalty

⇒ **Use combination of wavelength conversion and buffers**



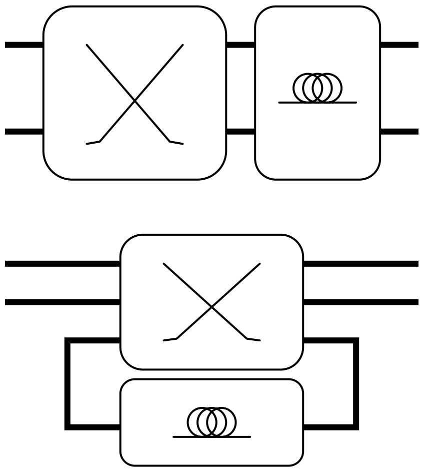




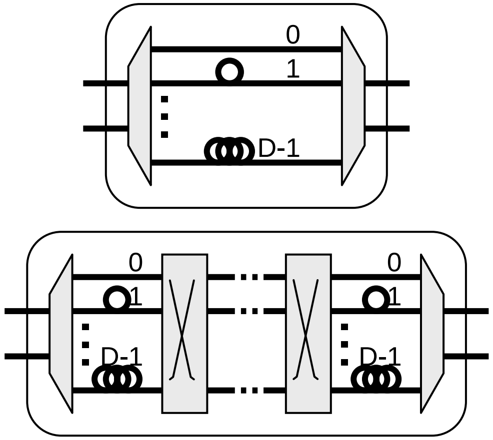
Buffer architectures

- feed-forward vs feed-back
  - feed-forward: input or output buffering
  - feed-back: shared, recirculating FDLs
- single stage vs multiple stage
  - multiple stages separated by switching elements
  - e.g.: each stage different delay resolution (“units”, “tens”, “hundreds”…)
- choice of FDL lengths
  - multiple FDLs: multiples of “unit”, resolution D
  - uniform/non-uniform (D,2D,3D or something else)

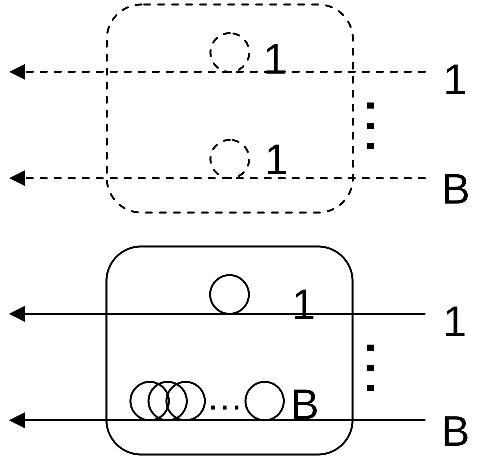
feed-forward vs feed-back



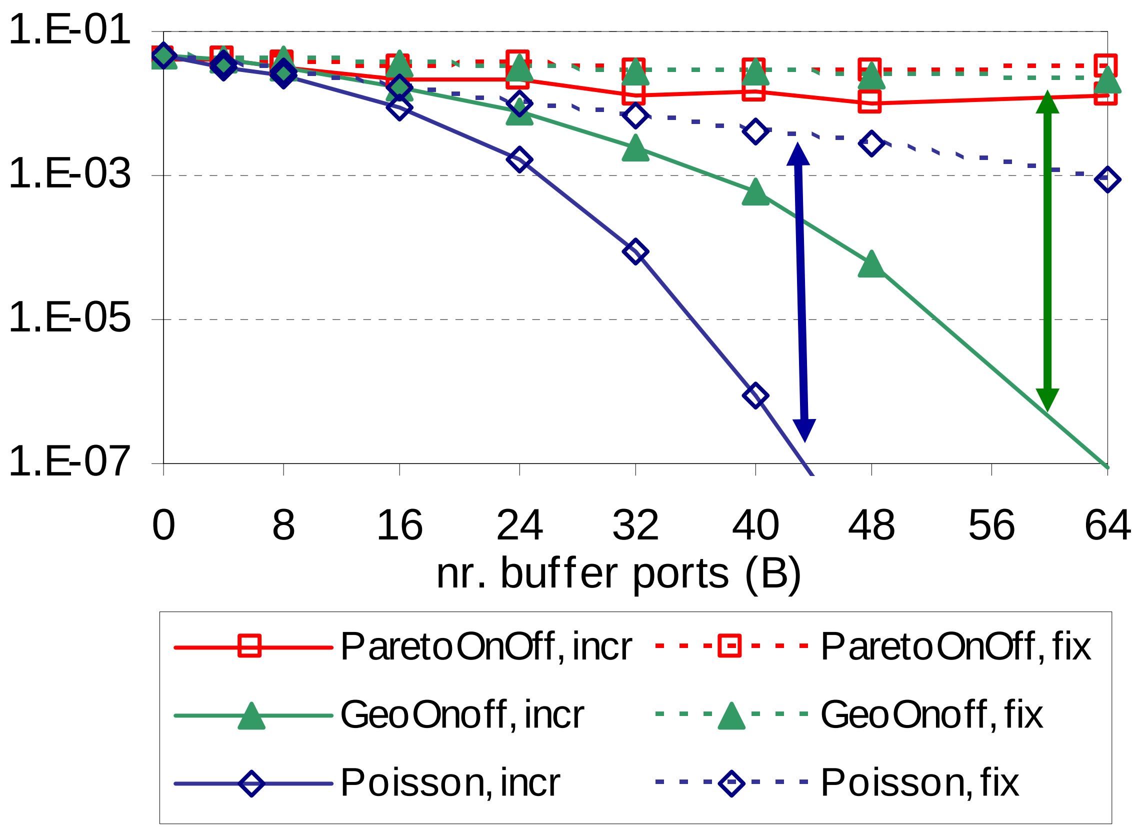
single vs multiple stages



OPS / OBS: fixed vs increasing FDLs



- sample results for fixed-length, slotted OPS
- **Increasing** FDL lengths give far lower PLRs (order of magnitude or more)
- “penalty”: reordering of packets, higher delays



see COIN.TuD1 for details

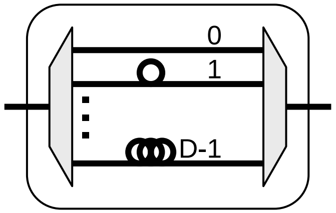
OBS: choice of granularity

- Optimal granularity D:

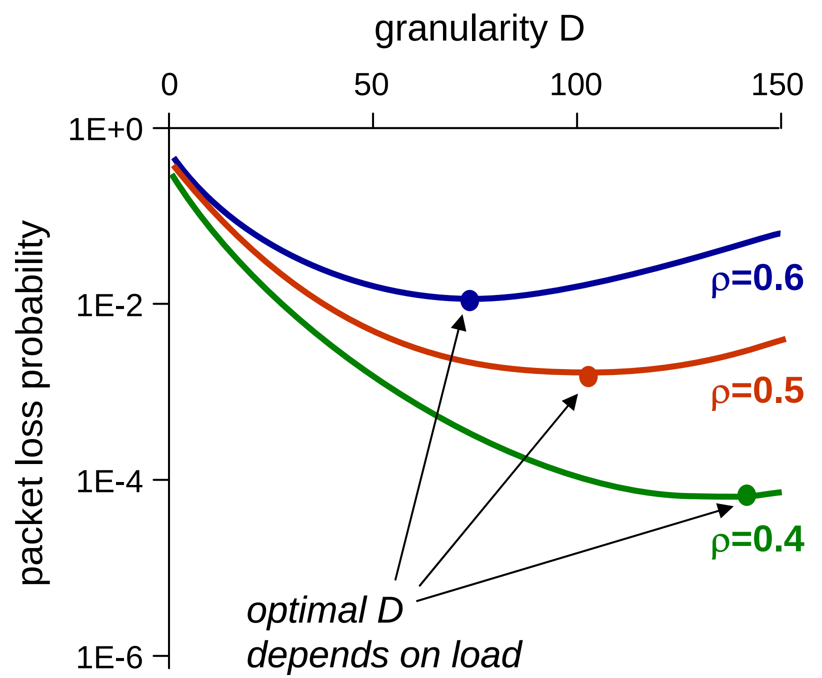
⇒ Non-trivial choice!

- Tradeoff between resolution and buffering capacity
  - small D: small gaps, but limited buffer depth
  - large D: large buffer depth, but large gaps between packets

- Function of
  - load
  - traffic profile (packet size distribution, burstiness…)



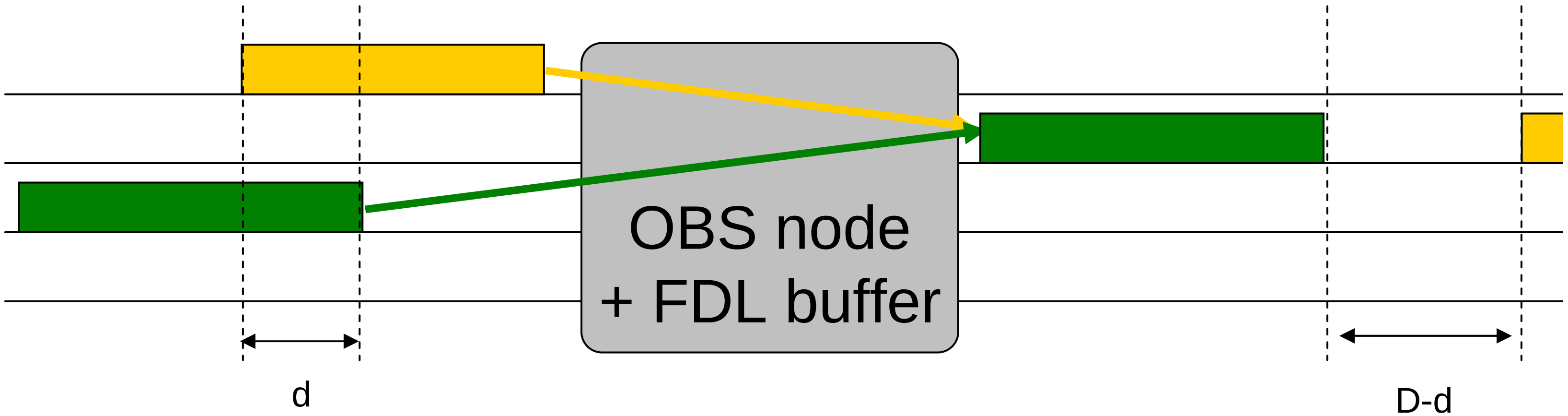
sample results for slotted switch with output buffering, single wavelength per fibre, geometric distr. packet lengths, bernouilli arrivals, 20 FDL lengths



OBS: void filling

- Void creation in case of variable packet-lengths (OBS):
  - FDL buffer offers discrete set of delays (in contrast to e.g. electronic RAM)
  - gaps between successive packets: “voids”

$\Rightarrow$ Need for intelligent buffer scheduling if we want to improve link throughput (i.e. void filling)



example: we need delay d, but FDL only offers D $\Rightarrow$ gap of D-d is created; void filling will attempt to insert packet in this gap

Contention resolution

- wavelength conversion greatly reduces need for buffering
- feed-back architecture allows sharing of FDL resources among all output ports
- when using different delay lengths, this calls for more intelligent buffer scheduling; for variable-length packets (OBS) the issue of void creation arises
- OBS: choice of delay lengths, i.e. the FDL granularity, is non-trivial issue

Conclusions

Summary

- reviewed OPS/OBS concepts
  - OBS as possible 1st step
  - OPS: fully exploit fast switching technologies
- switch architectures:
  - MEMS: too slow for OPS
  - broadcast & select: allows multicast, but splitting losses
  - AWG: passive core component, but no multicast
  - multi-stage architecture to increase scalability (OPS fewer switching elements than OBS)
- buffering:
  - push buffers to network edges
  - use FDLs to lower PLR in core
  - non-trivial choice of FDL granularity for OBS
  - quite complex scheduling for OBS

That’s all, folks!

… thanks for your attention