On Slotted WDM Switching in All-Optical Bufferless Networks

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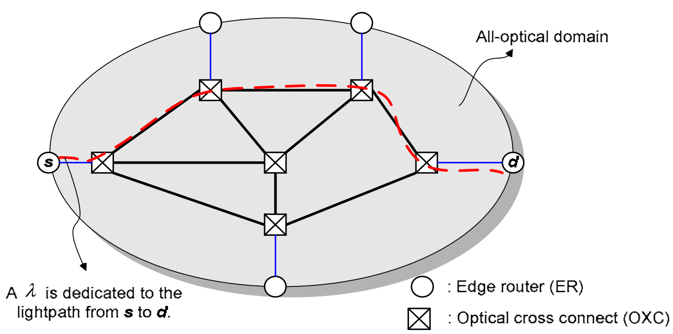
Outline

- All-optical-network Paradigms
  - Optical wavelength switching (OWS)
  - Optical packet switching (OPS)
  - Optical burst switching (OBS)
  - Slotted WDM (sWDM)
- Time Slot Alignment Problem
- Round-Trip Integer Network
- Performance Study for sWDM
- Conclusions

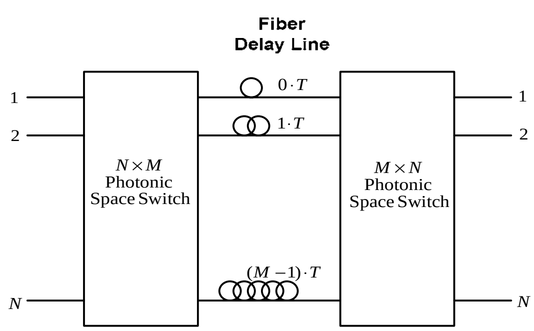
Optical Wavelength Switching (OWS)

- Connection set up before data transmission
- Full λ-bandwidth assigned to each connection
- No optical buffering, no loss
- Bandwidth granularity is coarse → utilization is low



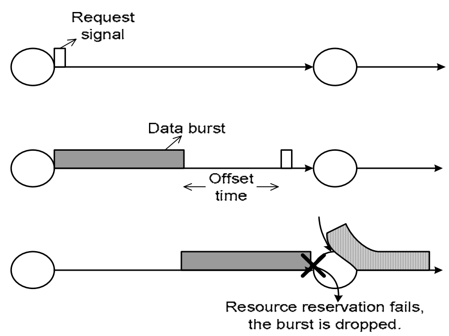
Optical Packet Switching (OPS)

- High switching flexibility
- Optical delay line (FDL) is used to resolve contention
- Sophisticated FDL assignment algorithms



Optical Burst Switch (OBS)

- Request signal setting up connection
- Offset time to compensate for the reconfiguration time
- Burst is dropped if resource reservation fails
- Loss rate is high at high traffic load



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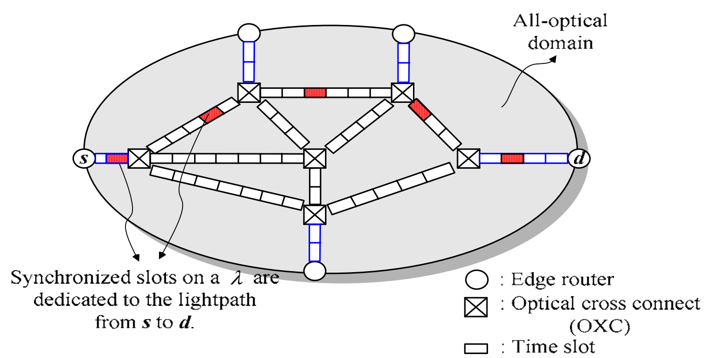
Slotted WDM (sWDM)

- Time is slotted and framed for each λ
- Each circuit connection is assigned a λ and a slot
- No optical buffering, no loss, fine granularity



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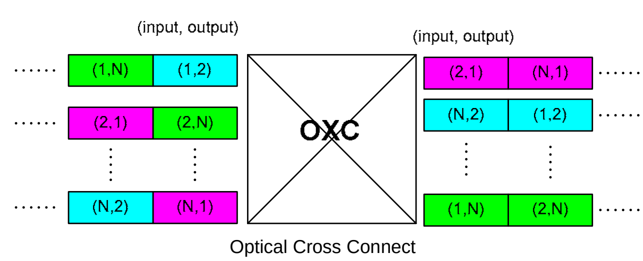
Comparison of Optical Switching Paradigms

Optical Switching Paradigms	Bandwidth reservation	Loss rate	Optical buffer	Wavelength conversion	Challenging issue
OPS	optional	moderat e	required	optional	optical memory
OBS	link-by-link	high	not required	necessary	high loss rate
OWS (circuit)	end-to-end	nil	not required	not necessary	coarse bandwidth
sWDM (circuit)	end-to-end	nil	not required	not necessary	slot alignment

Time Slot Alignment

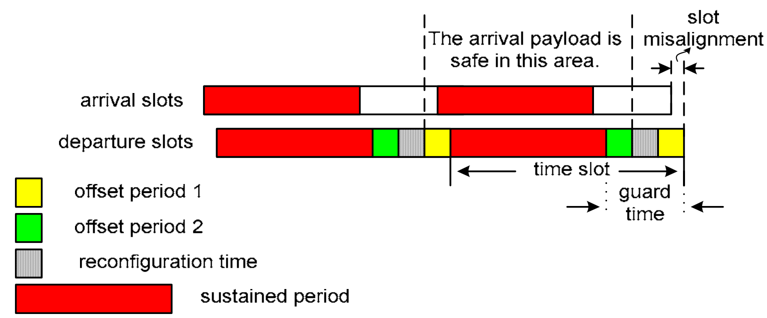


How to handle slot alignment without using optical synchronizer?

Guard Time Overhead

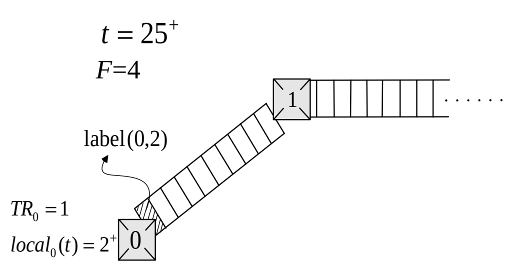
- To accommodate:
  - Slot misalignment
  - Reconfiguration time
  - Fiber variation
  - .....

Example:
- λ-bandwidth: 10 Gbps
- Frame size: 1000 time slots
- Bandwidth granularity: 10Gbps/1000 = 10Mbps
- Slot time: 10 μs
- Guard time: 1μs
- Guard time overhead: 10%



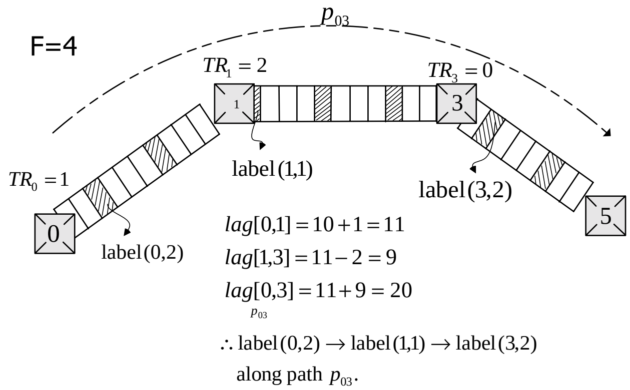
Time Slot Labeling

- Each node maintains its own local time $local_i(t)$ with reference to a time reference (TR)
- The local time is periodic with a frame, analogous to 24-hour system that is periodic with a day, $local_i(t)=(t + TR_i) \bmod F$
- At node i, the switching state is allowed to change only when $local_i(t)$ is an integer
- We label the slots departing from node i on any outgoing links at time t as (i, x), where $x=\lfloor local_i(t) \rfloor$



Time Slot Mapping

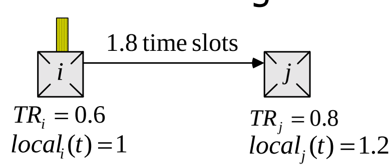
- Time reference difference: $diff[i,j]=TR_j\text{-}TR_i$
- Propagation time: $fly[i,j]$
- Slot lag: $lag[i,j]=diff[i,j]+fly[i,j]$
- label(i,x) → label(j,y), where $y=(x+ lag[i,j]) \bmod F$



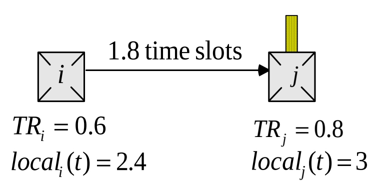
Integer Slot Lag

- With careful assignment of TR, non-integer flying time can be offset such that the lag is an integer → just in-time switching

(a) At t = 0.4, *locali*(t) is an integer and a slot departs from i to j

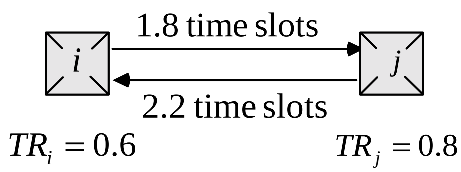


(b) At t = 2.2, the slot arrives at node j just at the moment when *localj*(t) is an integer



Round Trip Integer Network

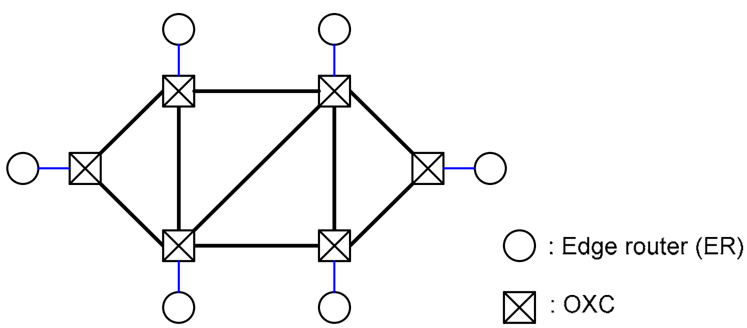
Theorem:
Given an optical network, there exists a time reference (TR) assignment for all nodes such that all lags are integers iff every round-trip link delay is an integer



$$lag[i, j] = fly[i, j] + [TR_j - TR_i] = 1.8 + 0.8 - 0.6 = 2$$
$$lag[j, i] = 2.2 + 0.6 - 0.8 = 2$$

Performance Study

- ρ : load = *arrival rate* x *mean service time*
- W : number of wavelengths per link
- F : number of calls that can be carried on a wavelength
- For sWDM, F is also the number of time slots in a frame
- Use the shortest path and first fit
- Simulation model:



Routing, Wavelength, Slot Assignment Algorithm (RWSA)

- Determine a route from source *s* to destination *d*.
- Let

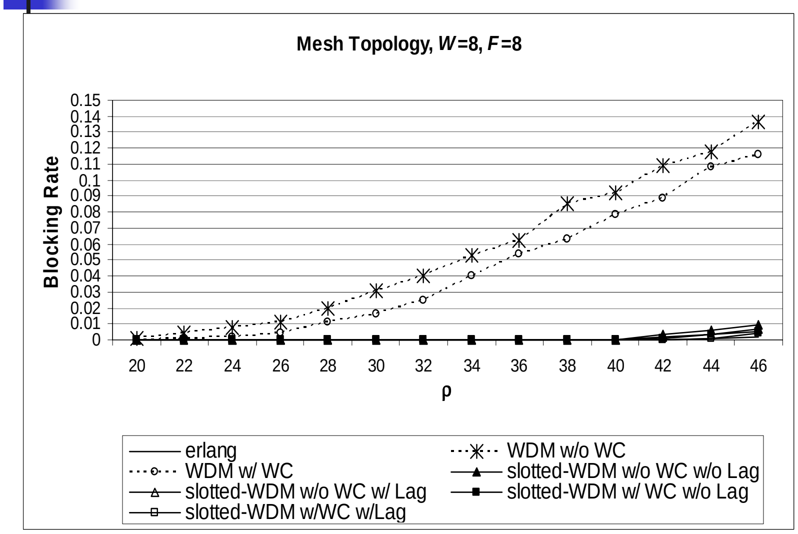
$$V[i,j,\lambda,x]=\begin{cases}0, & \text{if slot } (i,x) \text{ of wavelength } \lambda \text{ on link } (i,j) \text{ is available;}\\ 1, & \text{otherwise.}\end{cases}$$

- Find a set of λ and *x* in such a way that

$$\sum_{link\,(i,j)\in p_{sd}} V[i,j,\lambda,y_i]=0, \text{ where } y_i=\left(x+\underset{p_{si}\subset p_{sd}}{lag[s,i]}\right) \bmod F$$

- If such a set of λ and *x* does not exist, then try another route or block the call
- If more than one set is available, arbitrarily select one

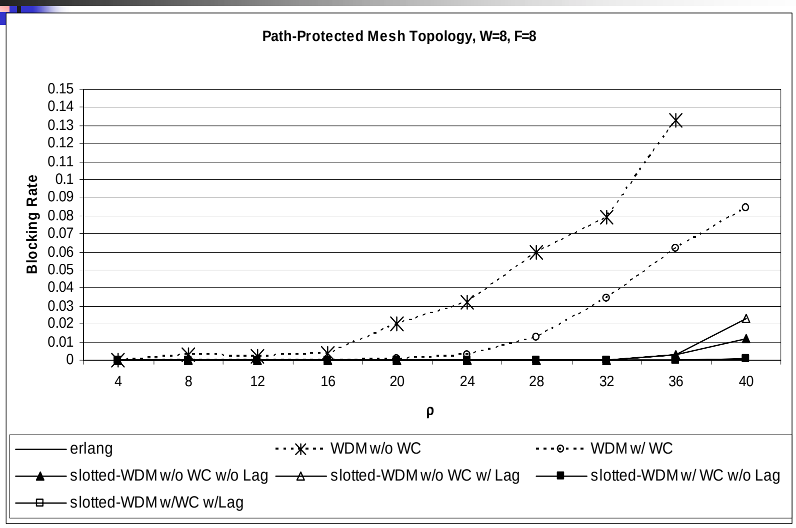
Performance Study



Network Resiliency (Path-Protection)

- Each call is assigned a primary path and a backup path
- A primary path must have a disjoint backup path (no overlapped links)
- A set of λ (wavelength label) and x (slot label) on a link can be assigned to a primary path in an unshared manner
- Alternatively, it can be allocated in a shared manner to multiple backup paths
- All backup paths that share the same set of λ and x on each link must have disjoint primary paths

Network Resiliency (Path-Protection)



Conclusions

- sWDM breaks λ-bandwidth into smaller base bandwidth (finer granularity)
- No optical buffering, no loss, time is slotted and framed for each λ
- Each circuit connection is assigned a λ and a slot according to the slot lag on each link
- A clock signaling can be arbitrarily distributed from a network node to determine the reference time of each node
- Performance study shows sWDM has much higher network utilization than WDM switching