

Hints on capacity planning (and other approaches)

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Capacity (re)planning

- Design from scratch (or modify) network topology, link capacity, routing, to
 - efficiently use resources
 - satisfy user requirements
- In circuit switching networks more standard approaches
- In packet switched networks mostly done by trial and error approaches
- Steps
 - Define node position and estimate (or measure) user traffic (during busy hour?)
 - to derive traffic matrix
 - Define logical topology
 - Includes logical link capacity assignment
 - (Map to a physical topology)

Traffic models as a key to enable capacity assignment

- Traffic model: how users and aggregation of users behave
- Examples
 - How long a user uses an ADSL modem
 - Average size of a file transfer
- Models change with network usage (and applications)
 - Guess about the future
- Models are based on
 - Measurements
 - Estimates (... Guesses ☺ ...)

Telephone traffic models

- Call dynamics?
 - Call arrival model
 - Shown that call inter-arrival time to be well approximated by an exponential distribution
 - Call arrival process follows a Poisson distribution
 - Memoryless: the fact that a certain amount of time has passed since last call gives no information of time to next call
- Call duration?
 - Also modelled as an exponential distribution
 - Some measurements show it is heavy tailed
 - A non negligible number of calls last for a very long time
 - Normally neglected
- Poisson models are easy to manage and well accepted

Internet traffic models

- More difficult
 - Many different applications (although all rely on file transfer over UDP and TCP)
 - Few applications account for most of the traffic
 - But this changes over time
 - Web, P2P
 - Difficult to model destination distribution
- Two main features
 - LAN connections are different from WAN connections
 - Higher bandwidth and longer holding times
 - Many parameters are heavy tailed
 - #bytes in a call
 - Call duration
 - Few calls are responsible for most of the traffic
 - Means that even large aggregate of traffic are not smooth (law of large numbers)

Telephone network capacity planning

- How to size a link to obtain a blocking probability smaller than a target value
- Erlang-B formula gives blocking probability as a function of
 - Avg number of calls (in erlangs) on a link
 - Avg call arrival rate r
 - Avg call holding time h
 - Call load $E = r h$
 - Trunk capacity m
 - Infinite number of sources
 - $m=5, E=3$, blocking probability = 0.11
 - For a fixed load, as m increases the call blocking probability decreases exponentially

$$P_b = B(E, m) = \frac{\frac{E^m}{m!}}{\sum_{i=0}^m \frac{E^i}{i!}}$$

Telephone network capacity planning

- Blocking probability along a path
- Assume traffic on links is independent
 - Blocking probability is the product of the probability on each link
- Routing table and traffic matrix determine the load on a link
- Assign capacity to each link given the load and target blocking probability
 - Or add new link
 - And/or change routing table

Packet switching (?) capacity planning

- Very complex
 - often relies on trial and error procedures
- Planning problem often divided in two problems
 - Logical Topology Design
 - Routing (and Wavelength) Assignment
- May be formalized as an optimization problem
 - Joint optimization
 - Unfeasible for complexity and organizational reasons
 - Heuristics
 - Two step formulation
 - Each step may independently be formalized as an optimization problem
 - Often heuristics needed for the two separate problems
 - See class “Operations research: theory and applications to networking” for LTD and RWA examples

Measure or estimate traffic to create traffic matrix

- Build for the worst case (?)
 - Pick the busiest hour (over which time-scale?)
- Add some safety margin to allow for
 - Measurement or estimate errors
 - Future traffic growth
 - Provisioning against failures?
- Traffic matrix definition assumes that current pattern predicts future
- Time scale critical (traffic over shorter time scale may be heavier)
- When adding endpoints traffic matrix become obsolete
- Not always possible to measure all traffic on all links
 - Privacy issues
- Routing policies interact with link load measurements
- Not always easy to rebuild flow infos from packet info

Define topology and assign capacity

- Logical topology definition
 - Define network connectivity (may include alternative paths for robustness to failures)
 - Geographical/cost considerations
 - Some links may be easier to be obtained
 - Available capacity may impose some constraints (see later)
- Capacity assignments
 - Enough capacity to carry traffic defined in the traffic matrix
 - Actual paths depend on routing
 - May define optimal paths dynamically (look at link load?)
 - Risk of reaction (higher capacity, become more attractive for routing, requires more capacity, etc etc)
 - Easier to assign capacity for static routing

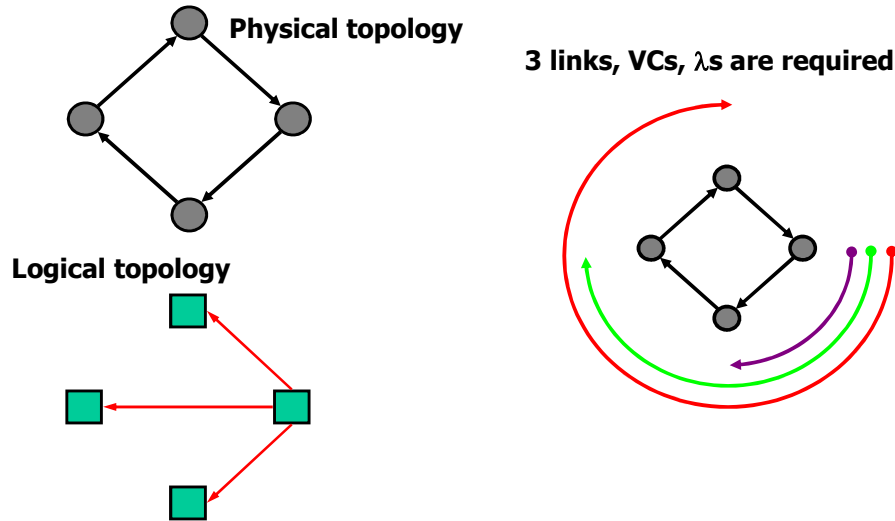
Logical Topology Design

- Input
 - Traffic matrix
 - Costs (e.g. number and speed of links I can pay for, price, performance)
- Output
 - Logical topology that “best” suits the traffic matrix with the cost constraints
- “Extreme” solutions if costs is the number of links
 - No cost constraint
 - Full mesh
 - Single-hop approach
 - Each node process only generated/received traffic
 - Circuit switching like solution
 - Minimize costs
 - Tree/ring/star topologies
 - Multi-hop approach
 - Nodes must process also in-transit traffic
 - Permits grooming to “match” traffic load to channel capacity
 - Packet switching like solution

Routing (and wavelenght) assignment

- Need to map to a physical topology the defined logical topology
 - Create physical links, or virtual circuits, or lightpaths
 - Any difference? Lightpath, if transparent, imply no processing of local traffic
- Often done by the organization/provider that owns the physical infrastructure
 - Often different from the one that has defined the logical topology
- Physical topologies may impose constraints on logical topologies feasibility due to lack of resources
- Once established, the logical topology, owners “do not see” the physical topology
 - Performance depend on the logical topology layout only
- Besides selecting routes on the physical topology, in WR networks, also wavelenghts should be assigned

Trivial example



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Examples

- Start with a traditional first-generation telephone network (which has only point-to-point optical links and electronic switching)
 - Typical current solutions consider a SONET/SDH ring topology, in which OC48-STM16 (2.5 Gb/s) links are used
 - Add-drop multiplexers (ADM) and digital cross-connects (DCX) are used
- Then we extend it to a ring that exploit WDM as a transmission technology
- Finally, we examine the possibility of moving to a WR solution

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First example

- The following (normalized) traffic matrix must be carried:

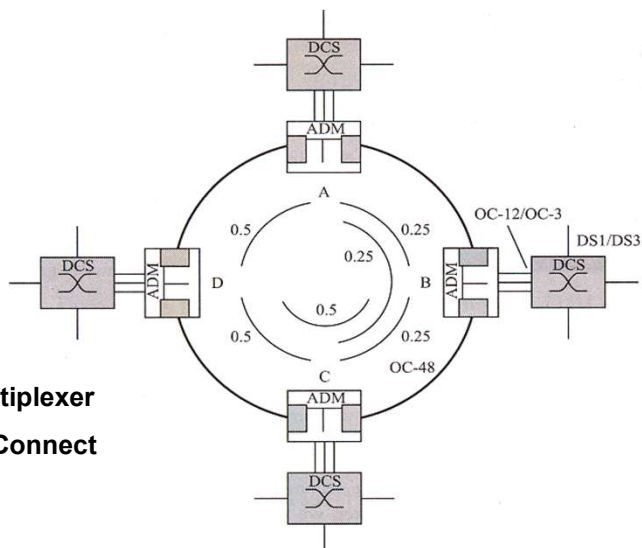
	A	B	C	D	TOT
A	-	0.25	0.25	0.5	1
B	0.25	-	0.25	0.5	1
C	0.25	0.25	-	0.5	1
D	0.5	0.5	0.5	-	1.5
TOT	1	1	1	1.5	

- If traffic grows, a capacity increase must be introduced

	A	B	C	D	TOT
A	-	1	2	1	4
B	1	-	1	0.5	2.5
C	2	1	-	1	4
D	1	0.5	1	-	2.5
TOT	4	2.5	4	2.5	

- a WDM upgrade may be an alternative

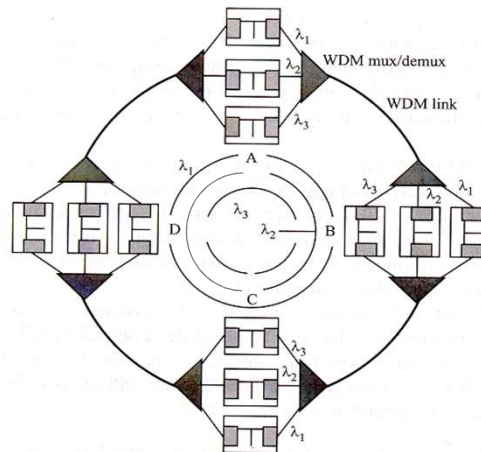
Traditional SONET ring



ADM = Add-Drop Multiplexer

DCS = Digital Cross-Connect

WDM ring: WDM on links



WDM ring

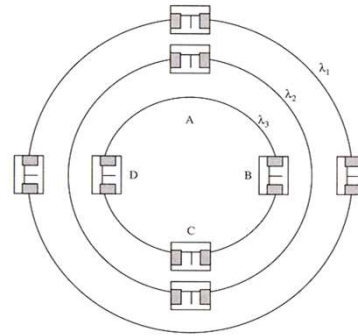
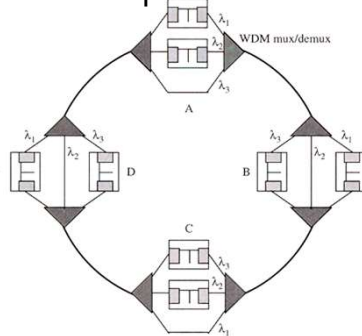
- Traffic routing becomes:

flow	wavelength	# OC-48
AB	λ_1	1
BD	λ_1	1
AD	λ_1	1
AC	λ_2	2
BC	λ_3	1
BD	λ_3	1
CD	λ_3	1

- 3 wavelengths are needed

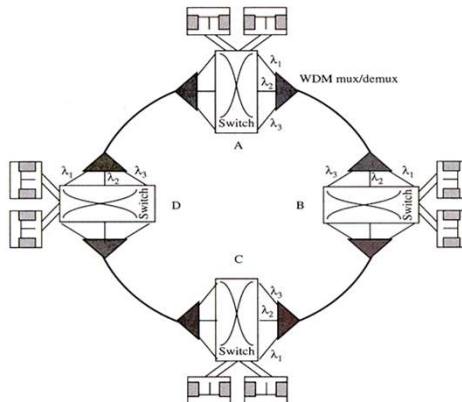
WR ring

- By using WR, we build a logical topology, in which links are optical lightpaths, on top of the physical topology, in which point-to-point connections on a ring are available
- No need to process in-transit traffic

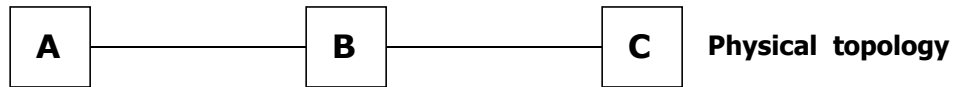


WR ring

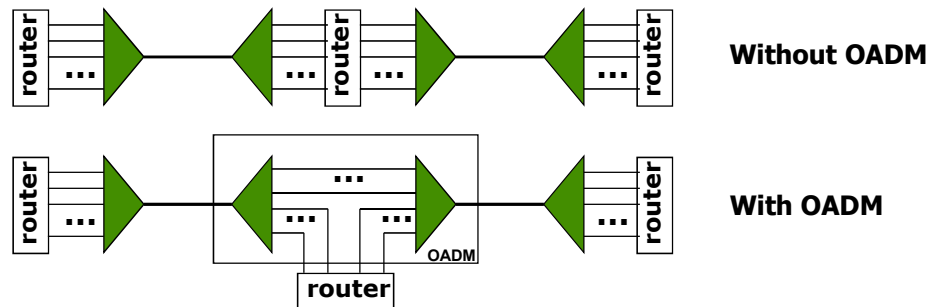
- Optical switches may be used to add flexibility: in case of traffic changes, or to manage faults, the logical topology may change



Second example



Three IP routers, A, B e C, with 10 Gb/s interfaces
50 Gb/s of traffic for each router pair

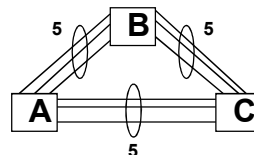
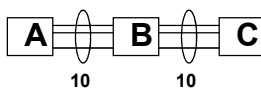


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Second example

- 10 wavelengths are required in both fibers
- Without OADMs, the physical topology and the logical topology are the same, being a bus topology in both cases; router B has 20 interfaces
- With OADMs, the logical topology is a ring; router B has only 10 interfaces
- The cheapest solution depends on the relative cost of components (OADMs vs. router ports)



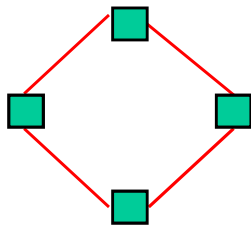
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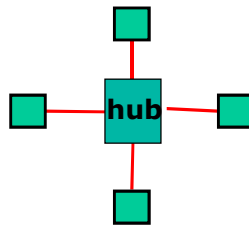
Third example

- Three different logical topologies overlaid on the same bidirectional ring physical topology. Compare them considering:
 - the number of interfaces at routers
 - the number of wavelengths
 - the distance (number of hops) in the logical topology
- Traffic is uniform, so that each router transmits $t\%$ of the capacity of a WDM channel to all other routers ($t/(N-1)$ from router to router)

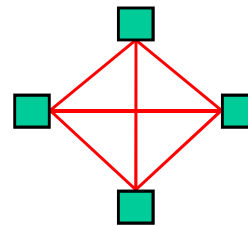
WDM point-to-point
(PWDM)



hub
(single hub)



full-mesh
(fully optical)



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(an additional hub is added)

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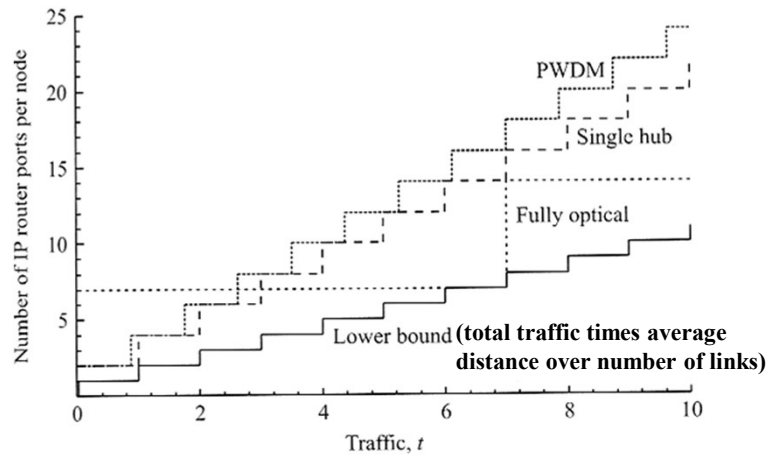
Third example

	PWDM	Hub	Full-mesh
Number of router ports (Q)	$Q = 2W$	$Q = \lceil t \rceil$	$Q = (N-1) \lceil t/(N-1) \rceil$
Number of wavelengths (W)	$W = \lceil t/8 (N+1+1/(N-1)) \rceil$	$W = \lceil t \rceil N/2$	$W = \lceil t / N-1 \rceil (N^2/8+N/4)$
Distance (number of hops)	$N/2$	2	1

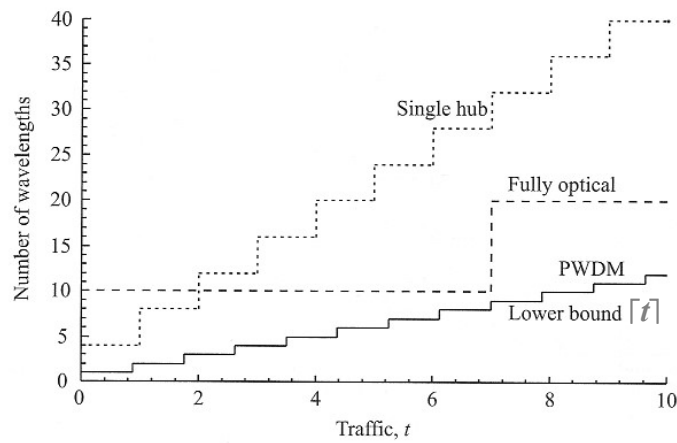
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Third example: # of ports



Third example: # of λ 's



Third example

- Previous plots refer to the case $N=8$, for different values of t
- In the design of an optical network, it is likely better to minimize the number of ports (transceivers) rather than optimizing bandwidth usage
- Fully-optical solution
 - Limited grooming (multiplexing of traffic flows in a single wavelength)
 - For small t , lightpaths are underutilized
 - Coarse quantization in the plots