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 assignement

- 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 that 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

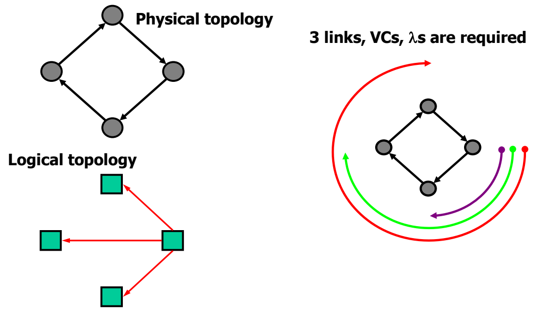
Logical Topology Design

- 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 wavelengths should be assigned

Trivial example



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

First example

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

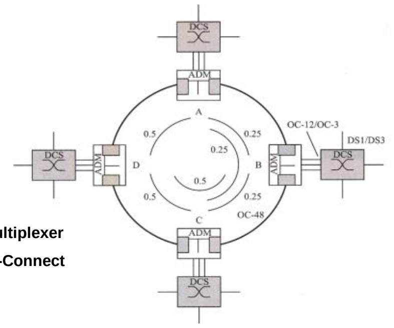
	A	B	C	D	TOT
A	-	0.25	0.25	0.5	1
B	0.25	-	0.25	0.5	1
C	0.25	0.25	-	0.5	1
D	0.5	0.5	0.5	-	1.5
TOT	1	1	1	1.5	

- 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

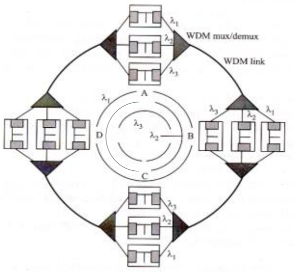
Traditional SONET ring



ADM = Add-Drop Multiplexer

DCS = Digital Cross-Connect

WDM ring: WDM on links



WDM ring

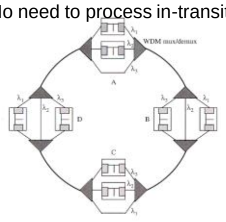
- Traffic routing becomes:

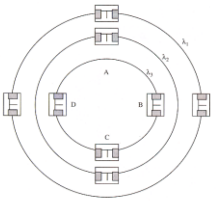
flow	wavelength	# OC-48
AB	$\lambda 1$	1
BD	$\lambda 1$	1
AD	$\lambda 1$	1
AC	$\lambda 2$	2
BC	$\lambda 3$	1
BD	$\lambda 3$	1
CD	$\lambda 3$	1

- 3 wavelengths are needed

WR ring

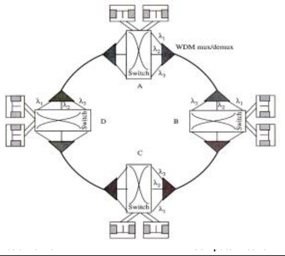
- By using WR, we build a logical topology, in which links are optical lightpaths, on top of the physical topology, in which point-to-point connections on a ring are available
- No need to process in-transit traffic





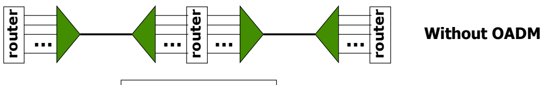
WR ring

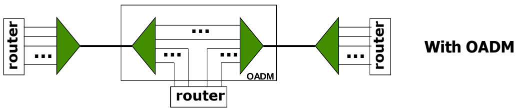
- Optical switches may be used to add flexibility: in case of traffic changes, or to manage faults, the logical topology may change



Second example

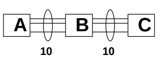
Three IP routers, A, B e C, with 10 Gb/s interfaces
50 Gb/s of traffic for each router pair

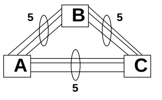




Second example

- 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)

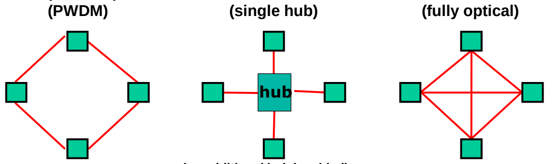




Third example

- 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)**

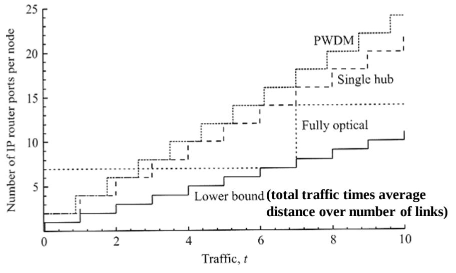


(an additional hub is added)

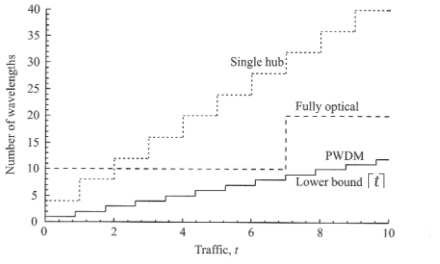
Third example

	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

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