Optical Network Design

Robert Sundberg D4
Oskar Svanell D4

Outline
- Introduction
- Optical components
- Lightpaths
- Lightpath topology design and routing wavelength assignment
- Connection management
- SONET/SDH
- Other transport techniques
- Performance & fault management
- Protection in SONET/SDH
- Protection in the Optical Layer
- Network design
- Long-haul & submarine networks
- Photonic packet switching
- Questions?

Introduction
- Historical overview
  - 1858 – First transatlantic telegraph cable
  - 1966 – “Optical wave guide”
  - 1988 – TAT8
  - 2002 – 150 000 km cable produced / year
- Transmission techniques
  - SDM
  - TDM
  - WDM
  - DWDM

Optical Components
- Optical Line Terminal (OLT)
- Optical Add/Drop Multiplexer (OADM)
- Optical Crossconnect (OXC)

Optical Components
- OEO converters
- Optical amplifiers (EDFA)

Lightpaths
- Circuit switched end-to-end channel
- Each lightpath is assigned a wavelength for each section
- The wavelength can be changed along the route
- Makes reuse of wavelengths possible
- Transparent connection
Lightpaths

- Circuit switched end-to-end channel
- Each lightpath is assigned a wavelength for each section
- The wavelength can be changed along the route
- Makes reuse of wavelengths possible
- Transparent connection

Lightpath topology design and Routing wavelength assignment

- Problems:
  1. Design a logical Topology – not covered
  2. Design a Lightpath Topology (i.e. Route Lightpaths)
  3. Assigning Wavelengths to routes

Example

LTD and RWA (cont.)

Definitions:

- $s_d$: Arrival rate for packets for s-d pair
- $a_{ij}^{sd}$: Fraction of traffic between s and d carried over link i-j
- $T_{ij}^{sd}$: Total traffic over link i-j
- Congestion is $C_{ij} = \max\{T_{ij}^{sd} - b_{ij}^{sd}\}$
- $\beta_{ij}$: maximum number of ports per router
- $n^r$: number of lightpaths in the network

Problem stated as a mathematical program:

Objective function: $\min \sum_{sd} C_{ij}^{sd}$
Flow conservation: $\sum_j a_{ij}^{sd} = \sum_i a_{ij}^{sd}$ for all $i,j,s,d$
Total flow on a logical link:
- $T_{ij}^{sd} = \sum_{sd} a_{ij}^{sd}$ for all $i,j,s,d$
Degree constraints:
- $\sum_j T_{ij}^{sd} \leq \beta_{ij}$ for all $i,j,s,d$
Nonnegativity and integer constraint:
- $T_{ij}^{sd}, \gamma_{ij}^{sd} \geq 0$ for all $i,j,s,d$; $b_{ij}^{sd} \in \{0,1\}$

Solving the mathematical problem:

- If the Objective function and the constraints are linear functions of the variables, then the problem is a Linear Program
- LTD is a Mixed Integer Linear Program
- LP-relaxation
- Feasible solutions
- Rounding

Routing Wavelength Assignment:
- Assigning wavelengths to lightpaths
- Can be seen as a graph coloring problem

Example
Connection management

- Long lightpath deployment time
- Connection remains active for a long time
- Goals:
  - Rapid connection setup
  - Dial-up bandwidth
  - Easy bandwidth trading

Connection management

- Distributed connection control:
  - Topology management
  - Route computation
  - Signaling protocol
  - Signaling network
  - Wavelength Routing Protocol (WaRP)
    - Cisco proprietary

SONET/SDH

- TDM streams
- Replaced nonsynchronous standards
- Physical Layer - Fiber and Coaxial(!)
- Transmission Rates
- Framing structure
- Multiplexing - Mapping
- Different Topologies:
  - Point-to-Point
  - Point-to-Multipoint
  - Hub network
  - Ring Network
- Distance terminology

Other transport techniques

- TDM mapped GbE, achieves ~ 10Gbit/s
- IP-GbE-Fiber can give short restoration
- CWDM - Coarse Wavelength Division Multiplexing
  - Larger spacing between wavelengths
- Metro DWDM
  - Each wavelength can transport 2.5Gbit/s or 10Gbit/s
  - Can transport SONET/SDH, ESCON, ATM, GbE etc
  - Number of wavelengths > 32 (Cisco equipment)

Performance & fault management

- Performance management
  - Monitor performance parameters
  - Ensure that performance goals are met

- Fault management
  - Detect problems in the network
  - Restore service in case of failures

Performance & fault management (cont.)

- Impact of transparency:
  - Fully transparent – flexible
  - Nontransparent – easy to engineer and manage

- Bit Error Rate (BER):
  - Parity Check
    - SONET/SDH overhead bytes
    - Digital wrapper overhead for the optical layer
    - Optical signal power / signal-to-noise ratio?
Performance & fault management (cont.)

Alarm management:
- Defect condition
- Forward defect indicator (FDI)
- Backward defect indicator (BDI)

LOL = Loss Of Light

Performance & fault management (cont.)

Alarm management:
- Defect condition
- Forward defect indicator (FDI)
- Backward defect indicator (BDI)
Protection in SONET/SDH

- Extensive management capabilities
- Different switching types
  - Path
  - Span
  - Ring
- Point-to-Point Protection
- Protection in Ring Networks
- UPSR, BLSR/4, BLSR/2

Protection in Ring Networks

- UPSR, BLSR/4, BLSR/2

Protection in the Optical Layer

- Can handle some failures without client layers involved
- Good for WDM networks
- Protects lightpaths
- Protection schemes:
  - 1+1 OMS Protection
  - 1:1 OMS Protection
  - OMS-DPRing
  - OMS-SPRing
  - 1:N Transponder Protection
  - 1+1 OCh Dedicated Protection
  - OCh-SPRing
  - OCh-Mesh Protection
- Best for today’s networks: Mesh Protection

Network design

- Technology considerations
  - SDM / TDM / WDM
  - Unidirectional vs Bidirectional WDM
- Equipment considerations
  - Arrayed vs separate components
  - Wavelength-specific vs wavelength tunable cards
  - All-optical vs O/E/O conversion
  - Different vendors

Network design (cont.)

- Topology design
  - PtP vs Ring vs Mesh
- Adaptation of client signals
  - Compliant wavelength
  - Non-compliant wavelength
  - Subrate Multiplexing

Long-haul & submarine networks

- Long-Haul (LH)
  - More wavelengths
  - Cheaper amplifiers and transponders
- Ultra Long-Haul (ULH)
  - Larger regenerator spacing

Regenerator spacing:
- Metro network: 50-75 km
- LH: 400-600 km
- ULH: 2500-4000 km
Long-haul & submarine networks

Submarine networks:
- Transcontinental ultra-long-haul link
- Repeaterless direct link
- Trunk-and-branch
  - Collapsed ring
- Festoon

Photonic Packet Switching

- Lightpaths, WaRIP – circuit switched
- IP, ATM – packet switched
- PPS – photonic packet switching
  - Difficult to realize
  - Very bulky
  - Very expensive

PPS, (cont.)

Why???
- Potential for higher capacities
- Improved optical bandwidth utilization
- Lower power consumption

IP over PPS:ed optical layer?
- Depends on statistical traffic properties

PPS (cont.)

Router functions:
- Routing
- Forwarding
- Switching
- Buffering
- Multiplexing
- Synchronization

PPS (cont.)

- Electrical buffering
  - registers, RAM
  - effective, cheap, flexible
- Optical buffering
  - 200 m fiber => 1 µs delay => 10 packets (1000b packets at 10 Gb/s)
  - very small buffers
  - fixed buffering time

Questions?