Position paper on Optical Networking Research: Decline or Resurgence?

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First the news

- I do not believe the research will decline
  - It would definitely be different though
- Will it resurge and go beyond where it is?
  - May be, but depends on what else
  - "Devil or good" is in details

Governing Principles

- High granularity traffic can be managed efficiently
- Dynamic traffic need to be handled using approaches suitable for static traffic
  - Dynamics needs to be managed separately
  - Access, multipoint, etc. handled using the same
- Use of forecasting to overcome set-up times needed
- Broadcasting is easier than multicasting
- KISS (Keep it simple stupid) – applies for control
  - Only then success can be guaranteed
  - Bandwidth optimization is not a "big" requirement

WDM Optical Networks: Issues

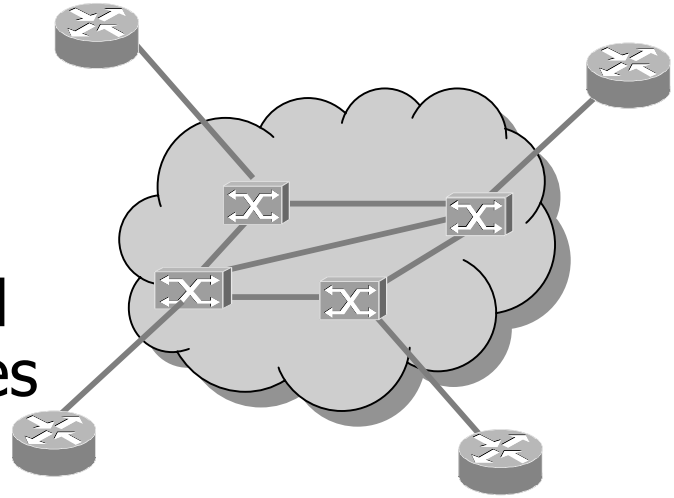
- Wavelength Division Multiplexing is best suited to utilize huge bandwidth
  - WDM channel capacity is increasing to up to 40Gbps
- With increasing channel capacity two main issues
- Channel utilization
  - Request sizes are smaller than channel capacity
  - Traffic grooming for "these" smaller request
- Survivability
  - Fiber optic cables are prone to failures
  - Service disruption due to failure is catastrophe
  - Multiple failure tolerance: CORONET 3-fail tolerant

Network Use: Issues

- Access – Most work needed here
- Integration of wireless and optics
  - Architectures/Protocols for seamless operation
- Use of bandwidth without dynamic switching
  - Must not prohibit dynamic reconfiguration for users
  - PON and light trail kind of architecture
  - There are several implementation technical challenges though

IP over Optical (Electronic Grooming) Networks

- The concept will dominate
- Peer Models:
  - Stochastic, ILP-, Auxiliary graph-, Network flow-, and Clustering based-techniques
- Overlay Models:
  - Grooming heuristic, Dedicated and shared protection, MILP formulation
- Augmented Model
- Problem with electronic routing
  - Router speed scalability issues



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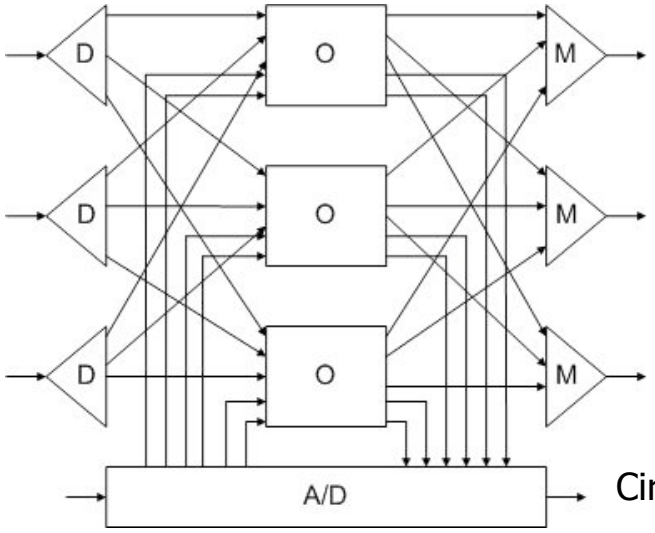
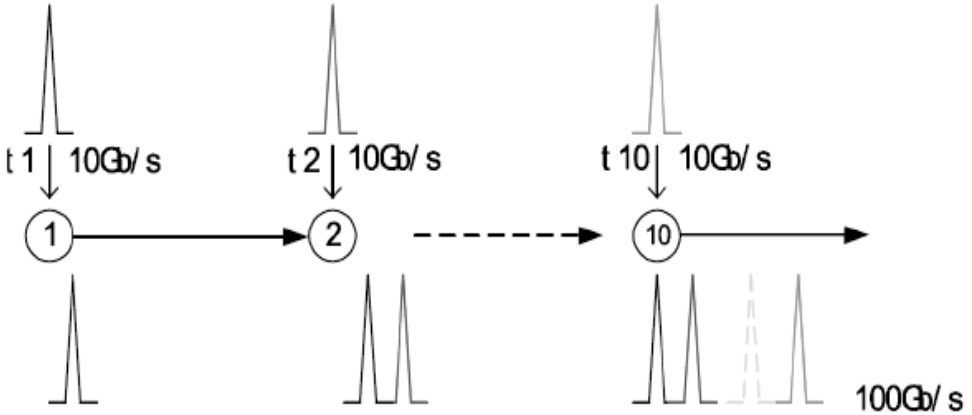
Optical Grooming Architectures

- Optical Circuit Switching – P2P along a path
  - Waveband Switching (does not drop all lambdas)
  - Drop and Continue – P2MP along a path
  - Light Trails – MP2MP along a path
  - Light Trees – P2MP along a tree
  - Clustered Light Trails – MP2MP along a tree
- WDM/TDM – Use TDM over a wavelength channel
  - Optical Time Division Multiplexing – TDM in optics
  - Optical Burst Switching – Set path as needed
  - Optical Packet Switching – Route packet optically
- Optical Code Division Multiplexing
- OTDM + OLT

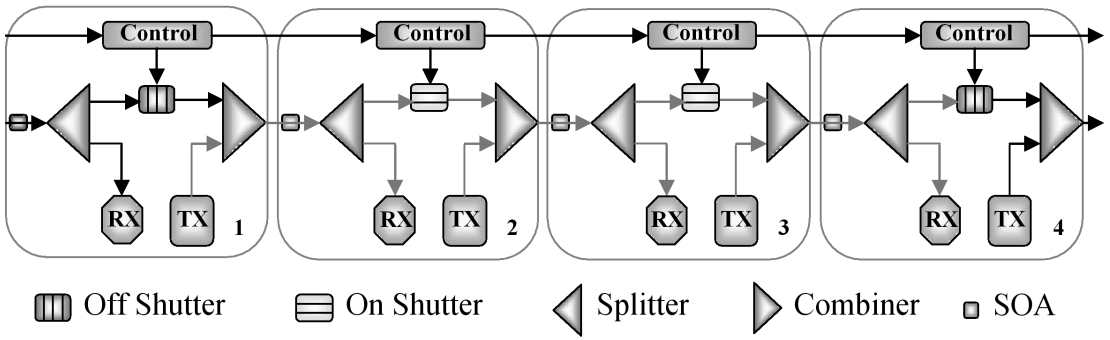
Some Concepts



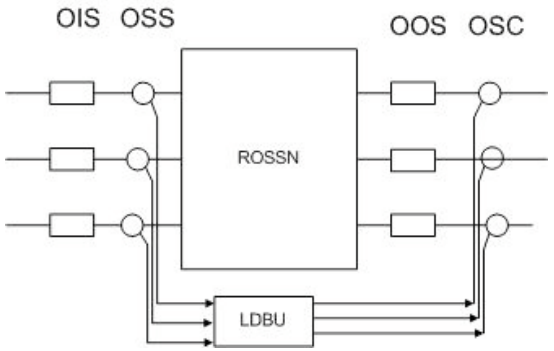
Circuit Switching



OTDM/OLT



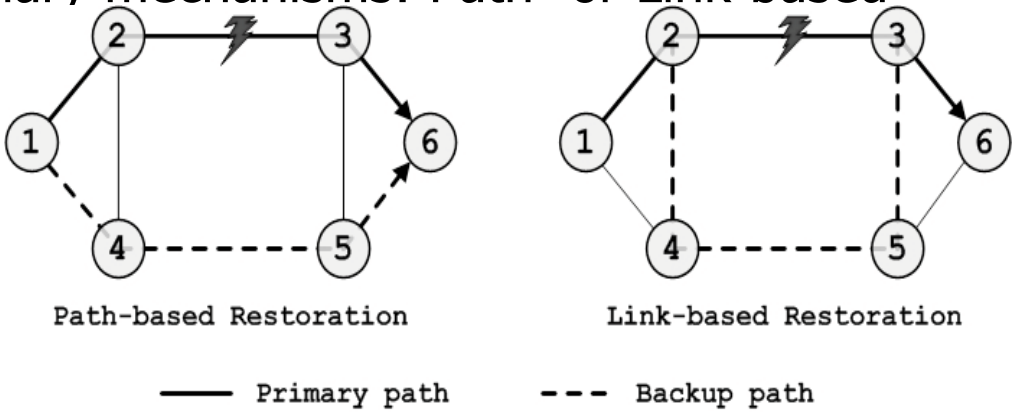
Drop and Continue: Light trail is one example



WDM/TDM

Survivability

- Three primary methods
  - Protection: A pro-active redundancy-based scheme
    - Backup paths are established and provisioned
  - Restoration: A partial pro-active redundancy scheme
    - Backup paths are identified but established upon failure
  - Recovery: A reactive approach
    - Backup paths are identified and established upon failure
- Two primary mechanisms: Path- or Link-based



Survivability Approaches

- Two Alternate Paths (1:1)
  - Two link disjoint unique paths for each request
- Backup Multiplexing
  - Multiplexing of backup connections
  - Primaries paths are link disjoint
- Primary-Backup Multiplexing
  - Multiplexing of some primary connection with backup
  - In case backup is required, primary is preempted
- P-Cycle Approach
  - A systematic ring-based approach to organize backup
- Failure dependent survivability
  - Network may need reconfiguration upon a failure

Technology Trends

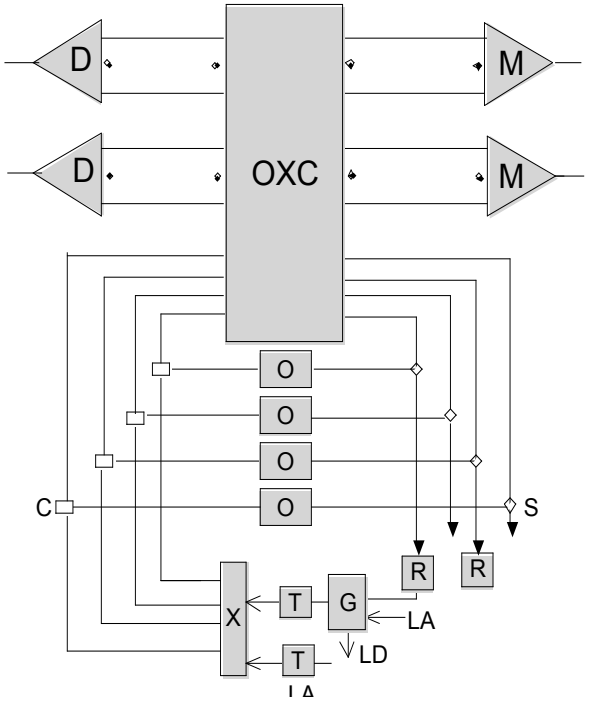
- Increasing access speed
  - FTTH has taken off to support a variety of traffic
  - PONs are commercially available
- WXCs are deployed
- Migration towards mesh topologies (Ring are there)
- Tunable lasers are becoming cost effective
- Wavelength converters have limited use
- Application Centric and Net Centric Architectures
- Architectures specific networks can be planned
- OEO probably cannot be avoided for some time

Technology Challenges & Successes

- Never say never but…..
- Handling of transmission impairments are challenging at higher speed
  - Dedicated protection easy to deploy
  - Standardization needed for other protections
- Sub-micro second switching is expensive
- Optical switching, sophistication header processing, and OCDMA are still and likely to remain challenging
- Successes
  - SONET/FTTH/Optical Ethernet
  - WDM point to point links
  - All optical WDM ring networks using ROADMs/tunable lasers
  - All optical WDM mesh networks using WXCs/tunable lasers

Traffic Grooming with Statistical Sharing of Wavelengths in ONs

- Architecture supporting statistical sharing is final dream
- A node allows sharing n wavelengths of which k are groomable
- m-n wavelengths bypass the node
- If # of wideband transceivers = k, it is a full grooming switch
- At that point most of the research performed until now will be useful



Conclusions

- There are still a large number research topic open
- Focused on traffic grooming and survivability
  - Efficient sharing mechanisms needed
  - Sharing without dynamic switching will lead to very efficient utilization and implementations
- Dedicated survivability architecture are easy to implement, but resource hungry
  - Need efficient survivability implementation standards for other type of protections
- Survivability, with sharing, will need more research
- Investigation of wavelength sharing in topologies of different connectivity