Traffic Grooming (Multiplexing) and Inverse Multiplexing Problems in Telecom Networks

(Data/Ethernet over SDH/SONET over WDM)

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Part I:

Network Maps, etc.

Part II:

Traffic Grooming (Multiplexing) Problems in Telecom Networks

Why Traffic Grooming?

- Capacity of a wavelength channel
  - Today: OC-192 (10Gbps)
  - Tomorrow: OC-768 (40Gbps)
- Bandwidth requirement of a single connection
  - Diverse, e.g.,

    STS-1 : STS-3 : STS-12 : STS-48 : STS-192

    = 300 : 20 : 6 : 4 : 1
- Bandwidth mismatch results in the need for traffic grooming
  - Efficiently mux/demux low-speed connections onto/from high-capacity channel
  - Intelligently switch traffic at intermediate nodes

Outline of Part II

- Grooming node architectures
- Grooming policies
- A novel generic graph model
- Survivable traffic grooming
- Hierarchical grooming
- Source-node grooming

Traffic Grooming: Ring and Mesh

- SONET/WDM ring networks
  - Architecture: OADM and S-ADM
- Evolution of topologies of backbone networks
  - From interconnected rings to arbitrary, irregular mesh topologies
- WDM mesh networks
  - Grooming optical cross-connect (OXC)

Traffic Models

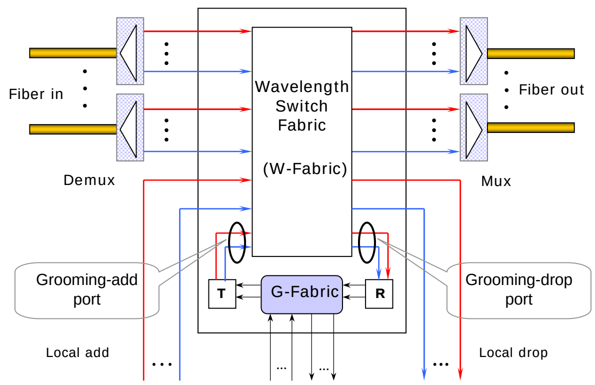
- **Static traffic**
  - Maximize throughput (using limited resources)
  - Minimize cost (while satisfying all requests)
  - Can be part of network design problem
- **Dynamic traffic**
  - Minimize blocking probability
  - Traffic-engineering problem

Grooming Node Architecture

- **Single-hop grooming OXC**
  - Switch at wavelength granularity
  - Low-data-rate ports for local add/drop
- **Multi-hop partial-grooming OXC**
  - Only a few wavelength channels can be switched at sub-wavelength granularity
- **Multi-hop full-grooming OXC**
  - All wavelength channels can be switched at sub-wavelength granularity

See IEEE JSAC, Sept. 2003

Multi-hop Partial-Grooming OXC



Grooming Policies

- For a given traffic demand, four operations can be used to carry traffic without altering existing lightpaths
  - *Operation 1*: Route the traffic onto an existing lightpath directly connecting the source and the destination
  - *Operation 2*: Route the traffic through multiple existing lightpaths
  - *Operation 3*: Set up a new lightpath directly between the source and the destination, and route the traffic onto this lightpath
  - *Operation 4*: Set up one or more lightpaths that do not directly connect the source and the destination, and route the traffic onto these lightpaths and/or some existing lightpaths
- Grooming policies determines which operation should be employed under which situation
  - An adaptive grooming policy can be used for dynamic traffic

Challenges

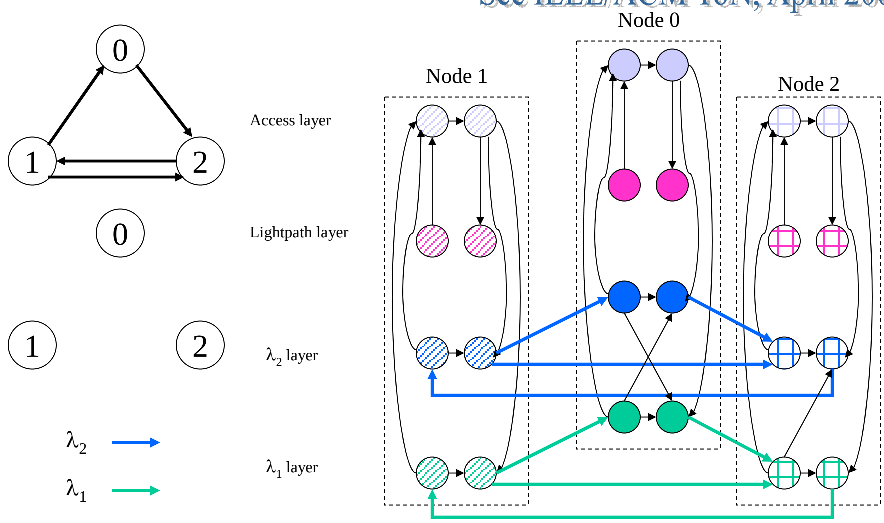
- Four correlated sub-problems:
  - Determine virtual topology (setup lightpaths)
  - Route the lightpaths over physical topology
  - Assign wavelengths to the lightpaths
  - Route the low-speed connection requests over the virtual topology
- Heterogeneity in mesh networks
  - Irregular topology
  - Arbitrary traffic pattern
  - Different node architecture
    - Sparse and partial wavelength conversion
    - Sparse and partial grooming capability
  - Various grooming policies

A Novel Generic Graph Model

- Construct an "auxiliary" graph to represent the node architectures and network states
- Advantages
  - Takes into account heterogeneity of networks
    - Can represent different node architectures
    - Easy to achieve various grooming policies
    - Suitable for static and dynamic traffic
  - Simple and uniform model
    - Employs shortest-path computations

Graph Model: An Example

See IEEE/ACM ToN, April 2003



Survivable Traffic Grooming

- Survivability is an important property
- **Grooming with shared protection**
  - Traffic assumption
    - Low-speed connections outnumber high-speed connections
  - Node architecture: multi-hop partial-grooming OXC
  - Two types of resource constraints
    - Wavelength-links
    - Grooming capacity (# of grooming ports)
- Approaches
  - **Protection-at-Lightpath (PAL) level**
  - **Protection-at-Connection (PAC) level**
    - MPAC: working and backup paths mixed together
    - SPAC: working and backup paths separated

See IEEE JSAC, Nov. 2003

Survivable Traffic Grooming

	PAL	MPAC	SPAC
End-2-End Protection	Lightpath	Connection	Connection
W & B Traffic	Separate	Mixed	Separate
Backup Sharing	Fixed routing	Fixed routing &λ	Fixed routing
Complexity	Low	High	High

Survivable Traffic Grooming

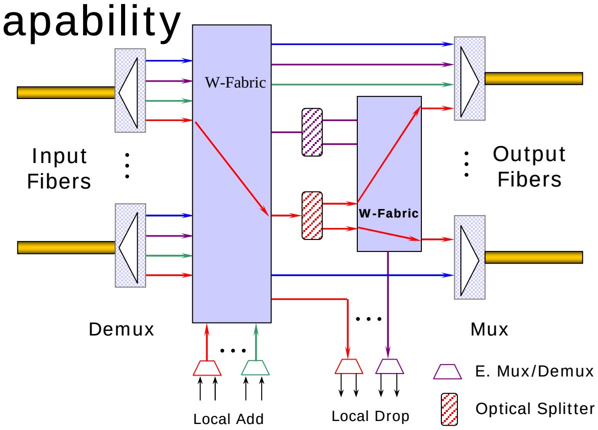
- Some research results
  - Beneficial to groom working paths and backup paths separately
  - When grooming capacity is sufficient, beneficial to protect each connection individually
  - When grooming capacity is moderate or low, beneficial to protect each lightpath

Hierarchical Grooming

- Traffic grooming in networks with hierarchical node architecture
  - Waveband path
  - Possible different switching granularities
    - Waveband switches
    - Grooming switches
  - Can be handled by the graph model

Source-Node Grooming

- Node architecture with multicast capability



See IEEE Comm. Mag., Feb. 1999

Source-Node Grooming

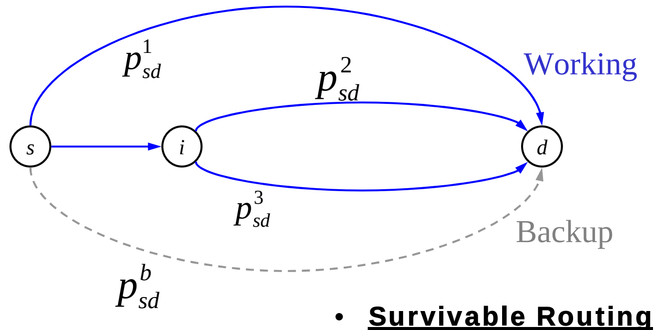
- Utilize property of “**light-tree**”
  - Information sent from the source will reach all the destinations
- Multicast-and-select approach
  - Source node packs several low-speed connections onto light-tree
  - Destination nodes pick up the traffic destined to them

Part III:

Inverse Multiplexing Problems in Telecom Networks

(Data/Ethernet over SDH/SONET over WDM)

Technical Overview

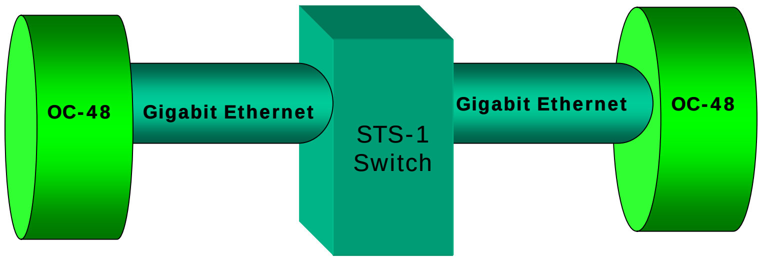


- **Multi-path routing**
  - How many paths?
  - State-dependent path capacities
  - Virtual concatenation (VC) ("traffic grooming")
- **Survivable Routing**
  - Primary + backup path(s)
  - Precomputed backup (?)
  - Shared backup (?)
  - Need reliable path (five-9's)
    - Component/link availability
  - Need fast recovery

State of the Art -- WAN: SDH/SONET

- Characteristics
  - TDM-based Digital Hierarchy
  - Ring-based network topology
  - OAM&P supports
  - Fast failure recovery
- Current SDH/SONET
  - Dominant transport network infrastructure
  - Multi-service platform
  - Revenue source

Ethernet over Legacy SONET/SDH



- Legacy SONET/SDH
  - Stringent hierarchy: inefficiency
  - Rigorous concatenation: resource fragmentation
  - Fixed b/w allocation: inefficiency in handling bursty traffic

SONET/SDH Limitations

- Stringent hierarchy causes efficiency problem

Optical Level	Electrical Level	Line Rate (Mbps)	Payload Rate (Mbps)	Overhead Rate (Mbps)	SDH Equivalent
OC-1	STS-1	51.84	50.112	1.728	-
OC-3	STS-3	155.52	150.336	5.184	STM-1
OC-9	STS-9	466.56	451.008	15.552	STM-3
OC-12	STS-12	622.08	601.344	20.736	STM-4
OC-18	STS-18	933.12	902.016	31.104	STM-6
OC-24	STS-24	1244.16	1202.688	41.472	STM-8
OC-36	STS-36	1866.24	1804.032	62.208	STM-13
OC-48	STS-48	2488.32	2405.376	82.944	STM-16
OC-96	STS-96	4976.64	4810.752	165.888	STM-32
OC-192	STS-192	9953.28	9621.504	331.776	STM-64

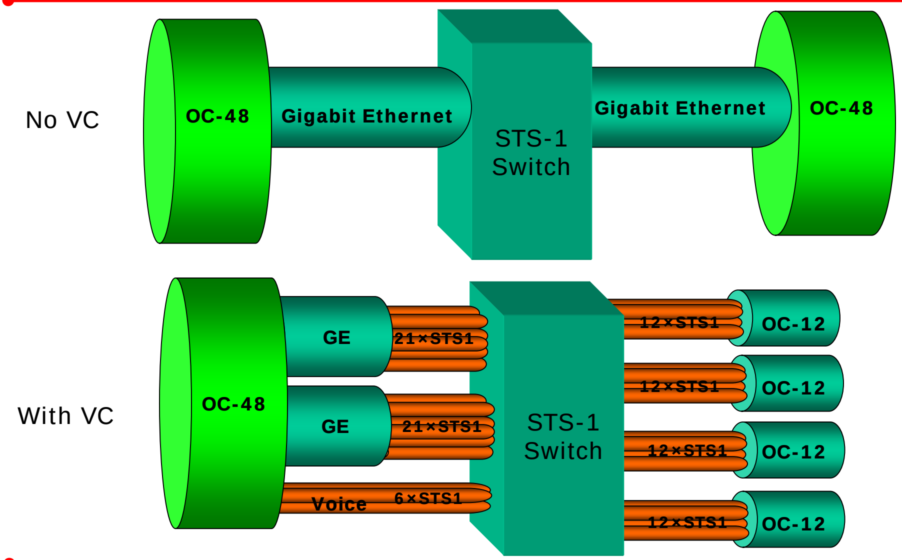
Next-Generation SONET / SDH

- Motivation, needs, and driving factors
  - Higher efficiency and flexibility in supporting data services
  - Private Leased Line, GigE, SAN
- Virtual Concatenation (VC)
- Link-Capacity-Adjustment Scheme (LCAS)
  - Dynamically adjusts bandwidth on the fly
  - ITU-T Rec. G.7042, Oct. 2001
- Generic Framing Procedure (GFP)
  - Maps client signal to an octet-synchronous signal

Virtual Concatenation (VC)

- What is VC?
  - Provides flexible and effective use of SDH/SONET payload
  - "Virtually" concatenates several payloads to provide an aggregated payload with flexible bandwidth
  - Different payload components could be sent over diverse routes through the network
  - Possibility to bifurcate traffic
    - to balance network load, and
    - to provide "survivability" – degraded service vs. no service
  - Typical devices support differential delay of up to 50 ms (+/– 25 ms) with external RAM... equivalent to 10,000 km difference in route lengths

VC Benefits – A Local Node's View



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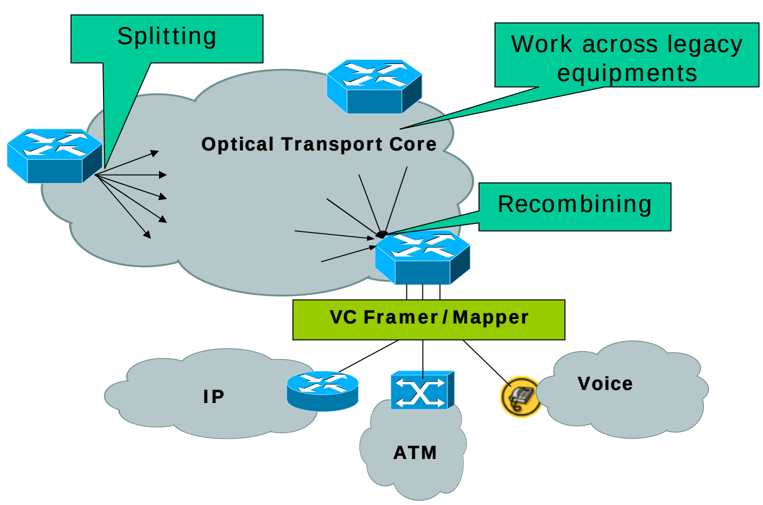
VC Benefits – Network View



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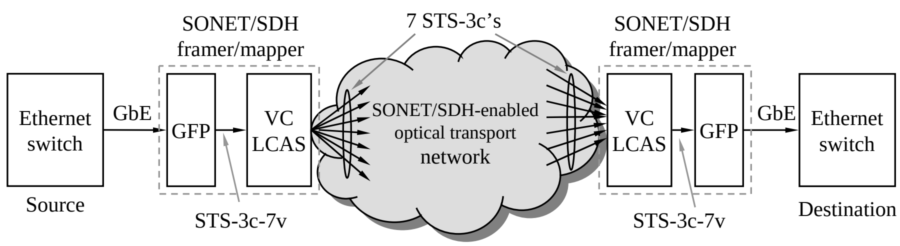
Benefits of Next-Gen SONET/SDH



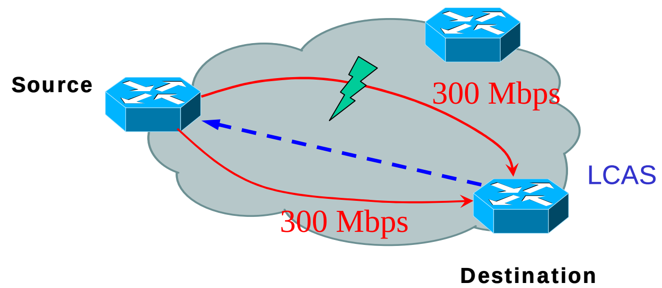
- Network wise
  - Inverse multiplexing
- Node wise
  - Relaxing time-slot contiguity/alignment

Problem Statement

- **Given:**
  - Network topology G (V, E, C(e, w))
  - Basic time-slot component, e.g., VT1.5, STS-1, STM-1, etc.
  - A high-speed request R with bandwidth requirement B.
  - An inverse-multiplexing control parameter K for maximal allowed path number.
- **Find:**
  - k distinct paths, where $1 \leq k \leq K$,
    such that the aggregated capacity they offer $\geq$ B.

Implication to Service Resilience

- Route splitting enables *degraded services*
  - Ethernet service: peak rate 600 Mbps, guaranteed rate 300 Mbps (against single network-element failure)
  - Need LCAS



Why Survivable VC?

- Why not SONET/SDH APS?
  - 100%+ protection bandwidth (ring operation)
  - Not all customers need 50-ms protection
- Why not data-network restoration?
  - Slow for mission-critical services

Challenges: Route Computation

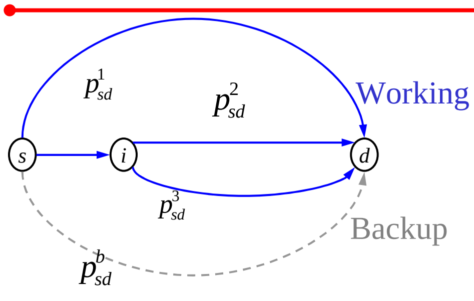
? Compute a *flow* instead of a *path*

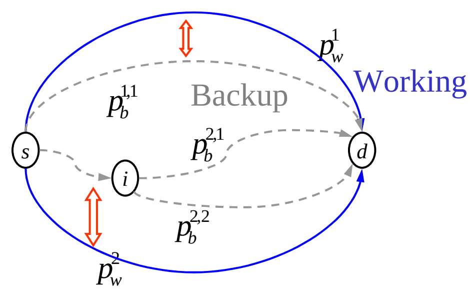
? Take advantage of route splitting

? Limit number of routes

? Control differential delay of multiple paths

Which Method?





- **PREV: Provisioning fast REstorable VCG**
  - One backup path per node pair
- **PIVM: Protecting Individual VCG Member**
  - One working VCG per connection
  - One backup VCG per working VCG member