Towards Cost-Effective Service Provisioning and Survivability in Ultra High Speed Networks

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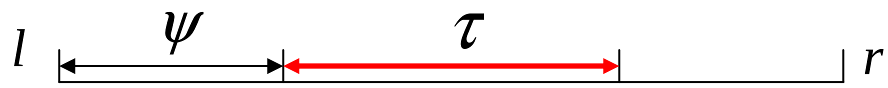
Outline

- Dynamic provisioning of scheduled traffic demands
  - Sliding scheduled traffic model
- Service provisioning of survivable scheduled traffic demands
- Diverse routing in networks with shared risk link groups (SRLGs)
- Traffic grooming

Dynamic Provisioning of Sliding Scheduled Traffic Model

- A demand (s, d, n, ℓ, r, τ)



- *s*: source
- *d*: destination (or a destination set)
- *n*: capacity requirement
- τ: duration, or lasting time
- [ℓ, *r*]: time window during which demand of duration τ must be satisfied
- Example: (*s*, *d*, 1, 10:00, 13:00, 60 minutes)

Time Conflict & Resource Conflicts

- Time conflicts of a set of scheduled demands *M* (temporal conflicts)
  - Demands may overlap in time
  - Demands that are disjoint in time allow resource reuse

- Resource conflicts (spatial conflicts)
  - Routes of demands may overlap
  - If not enough resources are available, conflicts result
  - Some demands may not be schedulable because of lack of resources

Dynamic Provisioning of Scheduled Traffic Demands

- **Problem**: given a sliding scheduled traffic *d*, find a minimal hop route such that the bandwidth and timing requirements of *d* are satisfied

- Given a demand *d*, the actual starting time of the demand is variable relative to the left boundary of its associated time window $[\ell, r]$

- Propose an all hops optimal routing algorithm that iteratively finds all feasible paths of at most h hops at the end of *h*-th iteration

Dynamic Provisioning of Scheduled Traffic Demands

- Remove infeasible links from the network
- Calculate maximum sized feasible intervals on links
  - Bandwidth feasible
  - Timing feasible
- Each node calculates and maintains feasible paths from source to the node in the form of feasible intervals
  - A feasible interval corresponds to a feasible path
- *h*$_{th}$-iteration:
  - (*h-1*)-hop paths maintained on nodes will be tried to be extended to *h*-hop paths by intersecting with feasible intervals on *h*-th link
  - Result paths will be merged and redundant paths will be removed

Dynamic Provisioning of Scheduled Traffic Demands

- The all hops optimal routing algorithm is cycle-free

- The all hops optimal routing algorithm finds all feasible paths of at most *h* hops from the source to all other nodes at the end of *h*-th iteration

Service Provisioning of Survivable Scheduled Traffic Demands

- **Problem**
  - Given a network topology and a set of ***scheduled*** connection requests,
    - find two link disjoint paths for each connection request
      - one working path and one protection path
    - objective is to minimize
      - the total network resources used by working paths and protection paths of all demands
        - » (e.g., number of wavelength-links)
    - while 100% restorability is guaranteed against any single failures

Service Provisioning of Survivable Scheduled Traffic Demands

- Exploit network resource reuse in both ***space*** and ***time***
- Two-step optimization approach (joint approach also studied)
  - Step 1: routing subproblem
    - For each demand, use Eppstein's *k*-shortest path algorithm to pre-compute a set of alternate routes as candidate working paths
    - For each candidate working path of a demand, remove it from the network and use Eppstein's *k*-shortest path algorithm again to pre-compute a set of candidate protection paths
  - Step 2: wavelength assignment subproblem: ILPs
    - Select paths and assign wavelengths

Performance Evaluation

- Weak demand time correlation

			DP	SP	SDP	SSP
Case	Network	I	ILP1	ILP2	ILP3	ILP4
	10-node	1	89	76	28	27
1	$\|\mathcal{D}\| = 8$	2	89	74	28	27
	$\|\mathcal{K}\| = 16$	3	89	73	28	27
	10-node	1	176	148	53	50
2	$\|\mathcal{D}\| = 16$	2	176	136	52	48
	$\|\mathcal{K}\| = 32$	3	176	129	51	47
	14-node	1	176	142	66	65
3	$\|\mathcal{D}\| = 16$	2	176	138	65	62
	$\|\mathcal{K}\| = 32$	3	176	136	64	58
	14-node	1	350	273	71	70
4	$\|\mathcal{D}\| = 32$	2	350	248	70	68
	$\|\mathcal{K}\| = 64$	3	350	233	70	63

Performance Evaluation

- Medium demand time correlation

			DP	SP	SDP	SSP
Case	Network	I	ILP1	ILP2	ILP3	ILP4
1	10-node	1	89	76	44	43
	$\lvert\mathcal{D}\rvert = 8$	2	89	74	44	43
	$\lvert\mathcal{K}\rvert = 16$	3	89	73	44	43
2	10-node	1	176	148	69	67
	$\lvert\mathcal{D}\rvert = 16$	2	176	136	68	61
	$\lvert\mathcal{K}\rvert = 32$	3	176	129	67	60
3	14-node	1	176	142	90	84
	$\lvert\mathcal{D}\rvert = 16$	2	176	138	89	82
	$\lvert\mathcal{K}\rvert = 32$	3	176	136	88	81
4	14-node	1	350	273	120	108
	$\lvert\mathcal{D}\rvert = 32$	2	350	248	119	104
	$\lvert\mathcal{K}\rvert = 64$	3	350	233	118	103

Performance Evaluation

- Strong demand time correlation

Case	Network	I	ILP1 (DP)	ILP2 (SP)	ILP3 (SDP)	ILP4 (SSP)
1	10-node	1	89	76	54	53
	$\lvert\mathcal{D}\rvert = 8$	2	89	74	54	52
	$\lvert\mathcal{K}\rvert = 16$	3	89	73	54	52
2	10-node	1	176	148	114	106
	$\lvert\mathcal{D}\rvert = 16$	2	176	136	113	101
	$\lvert\mathcal{K}\rvert = 32$	3	176	129	112	98
3	14-node	1	176	142	118	103
	$\lvert\mathcal{D}\rvert = 16$	2	176	138	117	100
	$\lvert\mathcal{K}\rvert = 32$	3	176	136	116	98
4	14-node	1	350	273	207	160
	$\lvert\mathcal{D}\rvert = 32$	2	350	248	203	152
	$\lvert\mathcal{K}\rvert = 64$	3	350	233	201	150

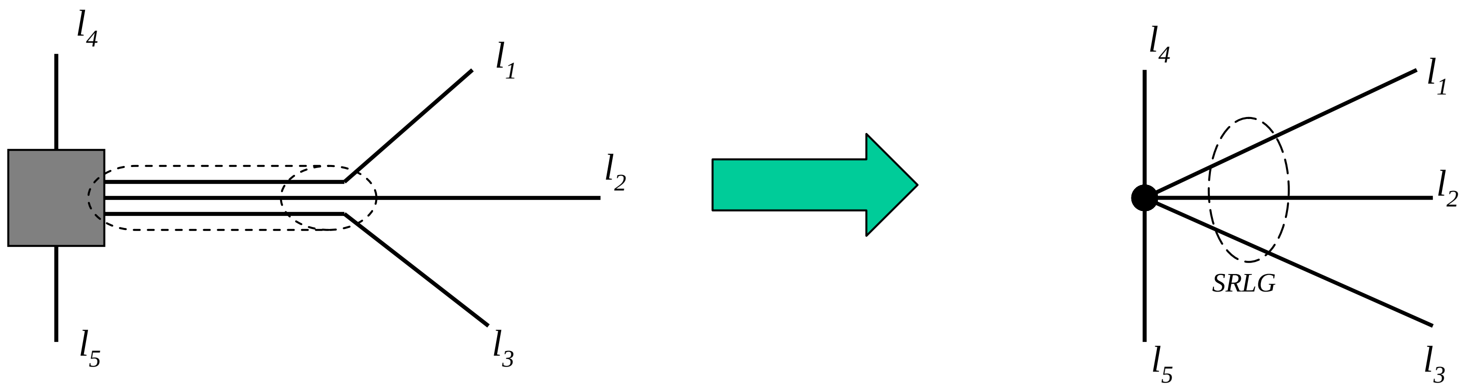
Performance

- *Holding time aware Dedicated Protection* (SDP) and *Holding time aware Shared Protection* (SSP) schemes use much less wavelength-links than DP and SP schemes
- As the demand time correlation gets stronger, the improvement of SSP over SDP increases
- The increase of the number of candidate working paths from 1 to 2 leads to a larger savings in network resources than increasing it from 2 to 3

- The improvement of SDP over DP is more significant than that of SSP over SP
- The improvement of SP over DP appears to be larger than that of SSP over SDP

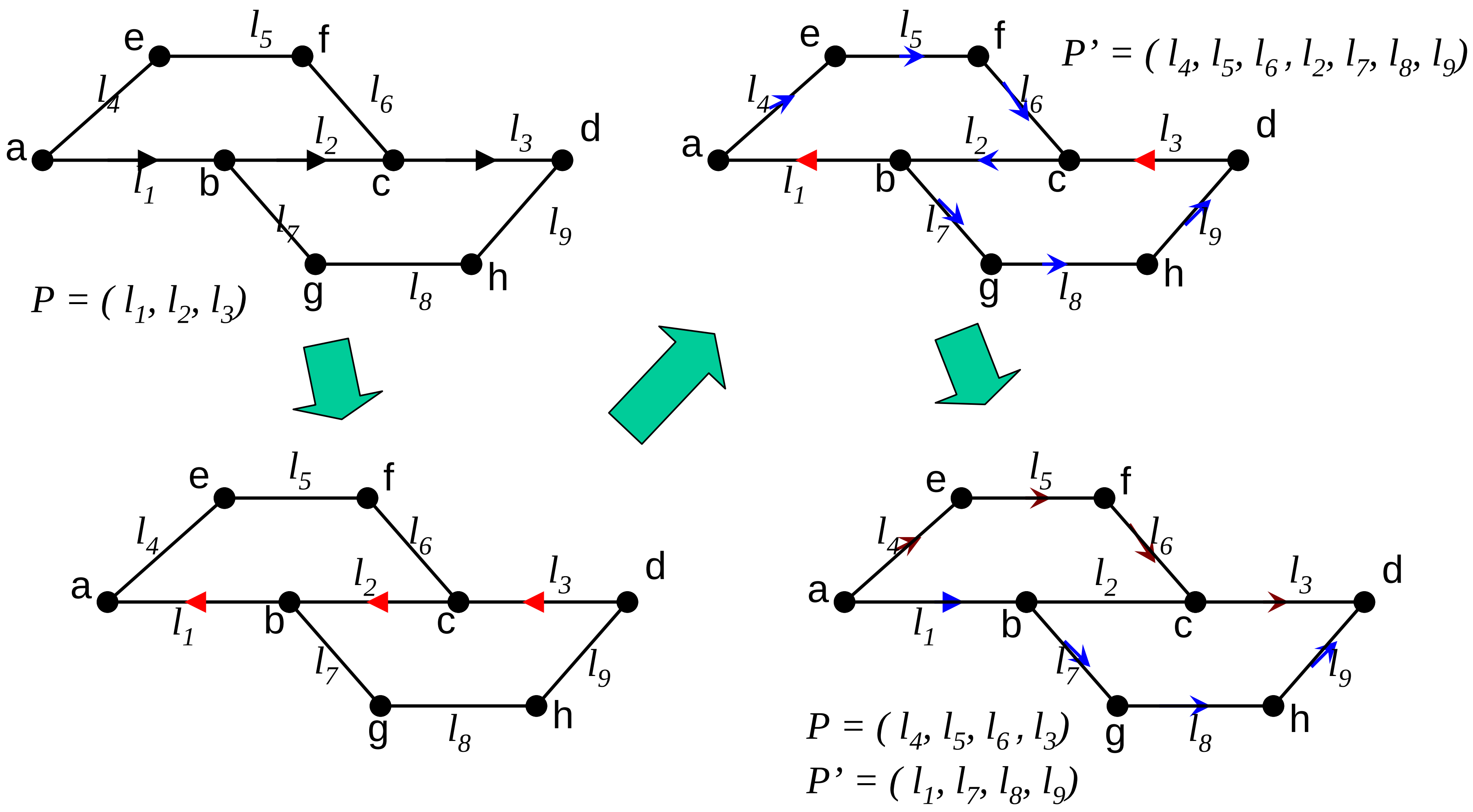
Diverse Routing in Networks with SRLGs

- A network defined as $G = (V, E)$, each link l in E has a cost
- A link can belong to more than one SRLGs
- The links in a SRLG group must share a common endpoint



- Diverse Routing:
  - find a pair of paths between a source and a destination at the optical layer
    - such that they do not share an SRLG and
    - has the least total link cost

Basic Algorithm Steps

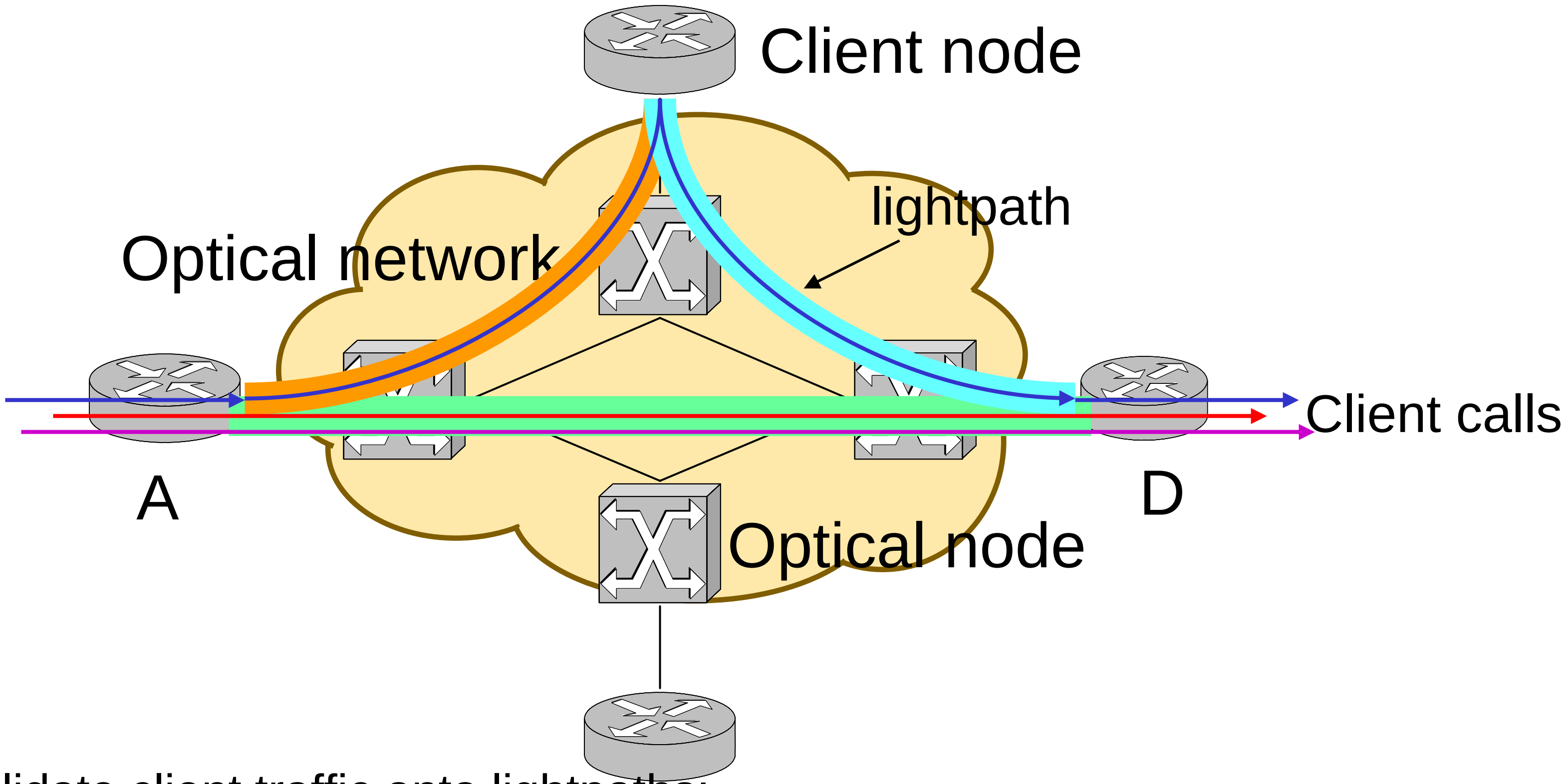


Overview of the Algorithm

1. Route the shortest path P_a
2. Delete links in P_a from the topology, and assign negative weights to the reverse links for each of the link along P_a
3. Apply a Bellman-Ford flavored process to route the second path P_b
4. Do segment deletion and exchange to the common segments between P_a and P_b

Theorem 1: the two paths obtained by the diverse routing algorithm are SRLG-disjoint
Theorem 2: The pair of paths obtained are optimal in terms of total link cost.

Traffic Grooming



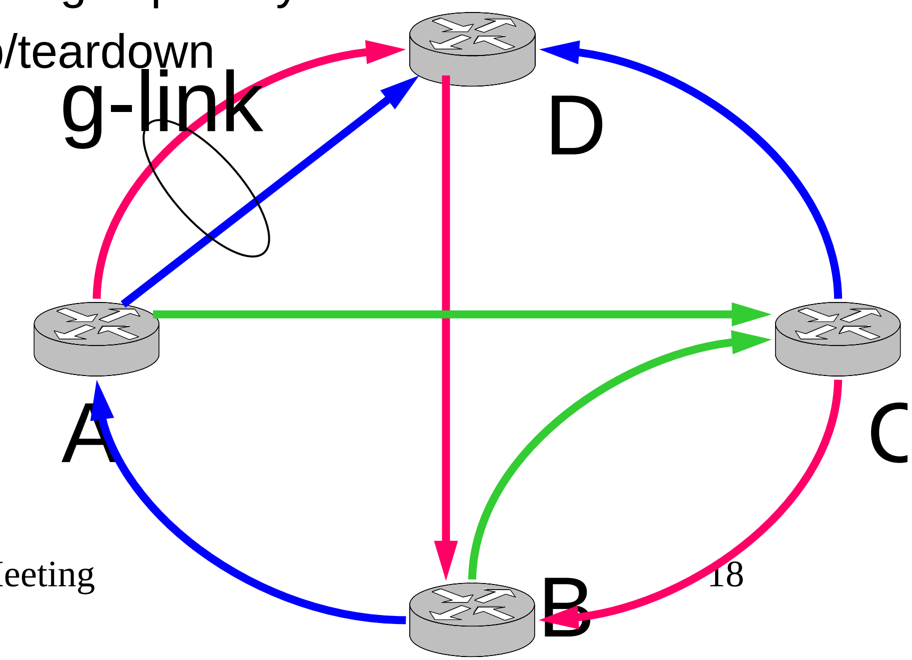
•consolidate client traffic onto lightpaths;

•route client circuit calls over the logical topology;

•achieve efficient utilization of the optical network bandwidths

Design of Logical Topology for Dynamic Traffic Grooming

- Design a logical topology to carry client calls
- Focused on dynamic circuit traffic
- Objective: minimize used network resource while meeting the traffic blocking probability from clients
- Definitions:
  - sd-pair: a source and destination client nodes pair
  - g-link: the bundle of lightpaths between an sd-pair
- Does not need dynamic lightpath provisioning capability
- No overhead for dynamic lightpaths setup/teardown



Lightpath Blocking Model

- The *g*-link blocking probability can be computed by sequentially overflowing multi-service traffic among lightpaths in a *g*-link

- The average blocking probability for all classes of calls is

$$\overline{B}^m(\rho) = \sum_{s \in S} \frac{\rho_s B_s}{\rho}$$

Logical Topology Design for Traffic Grooming

- Given the requirements for the end-to-end traffic blocking probabilities between sd-pairs,
  - Compute the number of lightpaths that are needed by each sd-pair and assign wavelengths to each lightpath,
  - Minimize the used ports (transponders), or wavelengths, while meeting the requirements for traffic blocking probabilities
- Case A: minimize the number of lightpaths (i.e., transponders)
- Case B: minimize the number of wavelengths, without wavelength conversion
- Case C: minimize the number of wavelengths, with full wavelength conversion
- Case D: minimize the number of wavelengths, with sparse wavelength conversion

Logical Topology Design for Traffic Grooming

- Address the average blocking probability for all classes of calls
  - can be extended to address the blocking probability for each class of calls
- Assume single-hop grooming, which completely eliminates intermediate electronic forwarding
- Being extended to logical topology design for multi-hop grooming

Summary

- Dynamic provisioning of scheduled traffic demands
- Service provisioning of survivable scheduled traffic demands
- Diverse routing in networks with shared risk link groups (SRLGs)
- Traffic grooming