Link Dimensioning and LSP Optimization for MPLS Networks Supporting DiffServ EF and BE Classes

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Capacity Planning for QoS

- DiffServ + MPLS → QoS in core networks
  - DiffServ provides multiple classes of service (e.g., EF, AF, BE)
  - MPLS provides traffic engineering
- Capacity planning is needed
  - provisioning adequate resources, routing over static LSPs
  - assumes traffic demands predictable in the core network
- Novel aspect: capacity planning for multiple classes of service

Challenges

- Tradeoffs between realistic models and solution complexity
- Some aspects of DiffServ not particularly well-defined or mature
  - e.g., AF not included in this work
- Solution of a nonlinear (convex) integer programming problem
  - nonlinear performance constraint, cost function
  - integer routing variables and link capacities

Problem Inputs

- Network topology
- Set of candidate link types (capacities)
  - cost of a link type a non-linear function of capacity
- EF user demands
  - for each O-D (origin-destination) pair, allow *m* EF demands
  - defined by <*requested bandwidth, average arrival rate*>

Problem Inputs (cont'd)

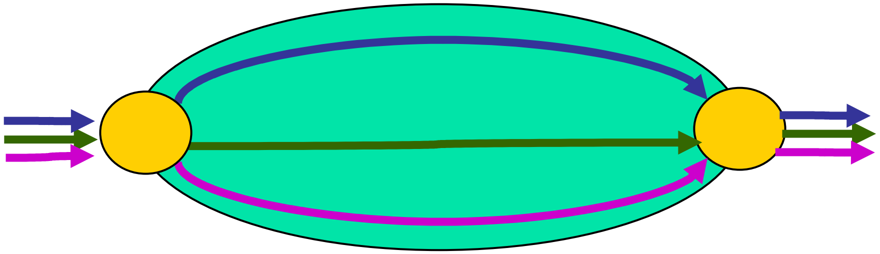
- Best-Effort user demands
  - for each O-D pair, 1 BE demand
  - defined only by <*average arrival rate*>
  - also, define BE "background" traffic demand for each link

Problem Statement

- Objective: minimize the total link cost
- Means:
    - route the EF and O-D based BE user demands
    - choose the candidate link types, capacities
- Major constraint: BE performance requirement
- Routing constraints:
    - each BE demand can be split into multiple paths
    - each EF demand cannot be split (in-order delivery guaranteed)

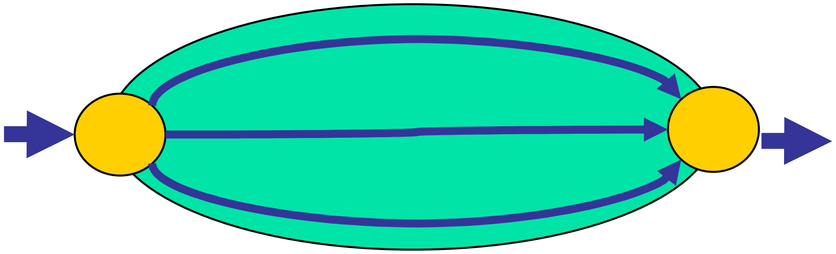
Splitting Traffic

EF user demands



- Multiple EF demands are allowed for the same O-D pair
- Each demand must follow a single LSP

single **BE** user demand



- Only one BE user demand is allowed for the same O-D pair
- Each demand can be split across multiple LSPs

Performance Model

- BE performance requirement is upper bound on average queueing delay per link
  - each link = non-preemptive priority queue, M/G/1
  - Poisson arrivals, arbitrary packet length distribution
  - function is convex in the EF arrival rate to the link
- Upper bound = average packet transmission delay * g_l (a user-defined parameter)
- No explicit EF performance requirement

Problem Formulation (Alt.)

Goal: $\min \sum_{l \in L} \tilde{C}_l$
Subject to:

Total link cost

$$\tilde{\psi}_l \geqslant f(\beta^l_{ef})$$

Performance Constraint

$$x^{ef}_{kmj} = 0/1, \sum_{j \in J_k} x^{ef}_{kmj} = 1$$

$$\sum_{j \in J_k} x^{be}_{kj} = 1$$

Routing Constraint

$$u_{lt} = 0/1, \sum_{t \in T_l} u_{lt} = 1$$

Discrete link capacity Constraint

Solution Method

- Lagrangean relaxation approach
    - has been successfully applied to many link dimensioning and routing problems
- Two sets of discrete variables limit the viable solution method
    - EF routing variables + link sizes
    - relaxing either one of them still results in a difficult non-linear integer programming problem

Solution Details

1. Instead: relax flow aggregation inequalities for both EF and BE traffic

$$\begin{aligned}\beta_l^{ef} &\geqslant \sum_{k\in K}\sum_{m\in M_k}\alpha_{km}^{ef}\sum_{j\in J_k} x_{kmj}^{ef}\delta_j^l \\ \beta_l^{be} &\geqslant \gamma_l + \sum_{k\in K}\alpha_k^{be}\sum_{j\in J_k} x_{kj}^{be}\delta_j^l\end{aligned}$$

2. Results in three independent (separable) subproblems
   - minimize cost per link (solve by gradient projection)
   - solve EF routing (shortest path computation)
   - solve BE routing (shortest path computation

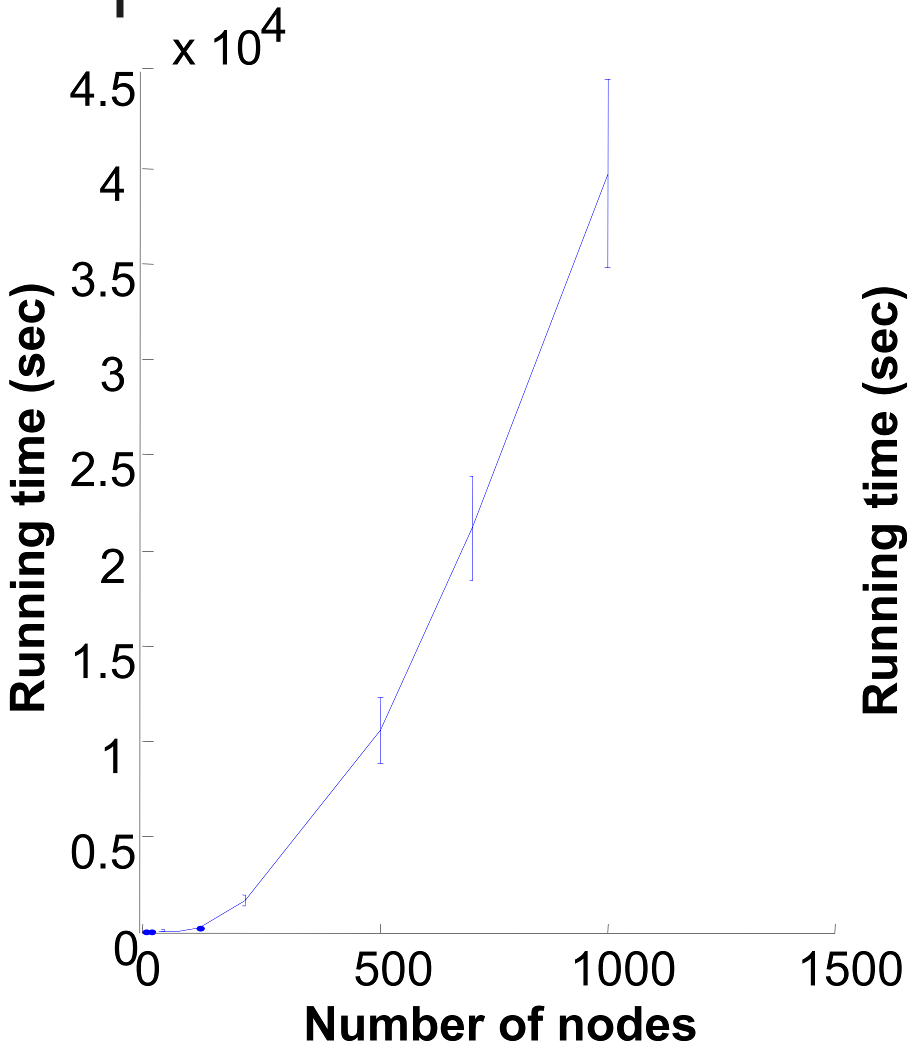
Solution Details (cont'd)

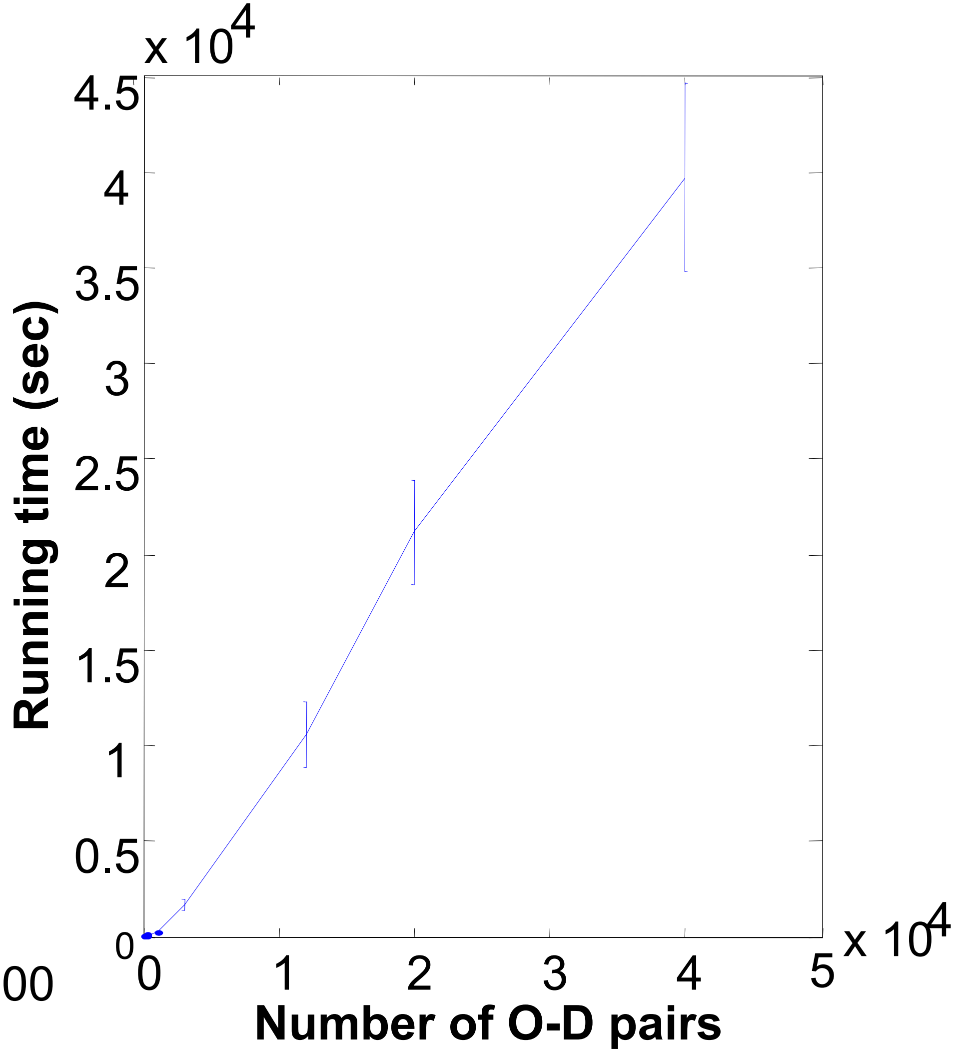
3. Update Lagrangean multipliers by Subgradient method
   - retain the best solution from all iterations for the primary problem
   - maximum of 400 iterations
4. Using best routing solution from dual problem, solve link capacities for primal problem

Computational Results

- Evaluate the algorithm in 8 different sizes of networks
  - up to 1000 nodes and 40000 O-D pairs
  - 30 different topologies for each network size
- Algorithm converges in all 240 test cases
- Measured duality gap $\leq$ 4%
  - upper bound on non-optimality

Computational Results





Contributions

- First capacity planning method for networks using MPLS+DiffServ
- Complex, fairly realistic model
  - BE+EF, priority queueing, O-D and background traffic demands, bifurcated and non-bifurcated routing, discrete set of link types with non-linear costs, ...
- Key solution techniques
  1. convex performance model
  2. novel relaxation

Future Work

1. Incremental (dynamic) solution techniques
2. Include other service classes (AF)
3. Extend to spare capacity planning