Evaluation of Centralized Solution Methods for the Dynamic Optical Bypassing Problem

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Outline

Motivation

Load-Dependent Resource Operation in Core Networks

Centralized Dynamic Optical Bypassing

- reconfiguration scheme
- optimization problem
- solution methods

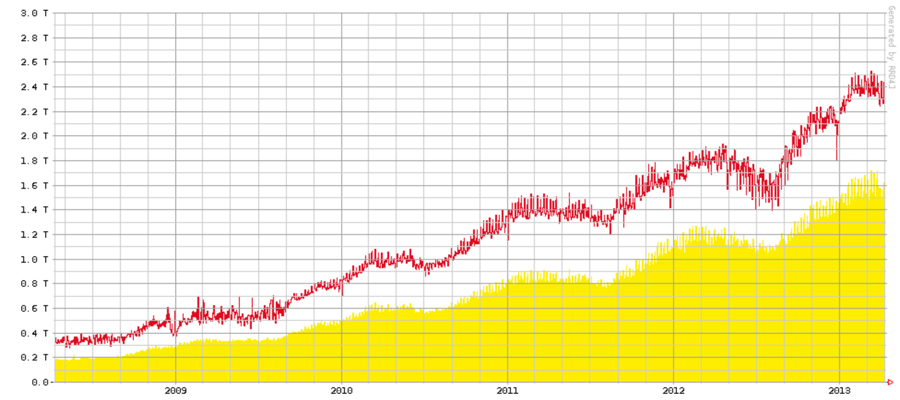
Evaluation

Conclusion

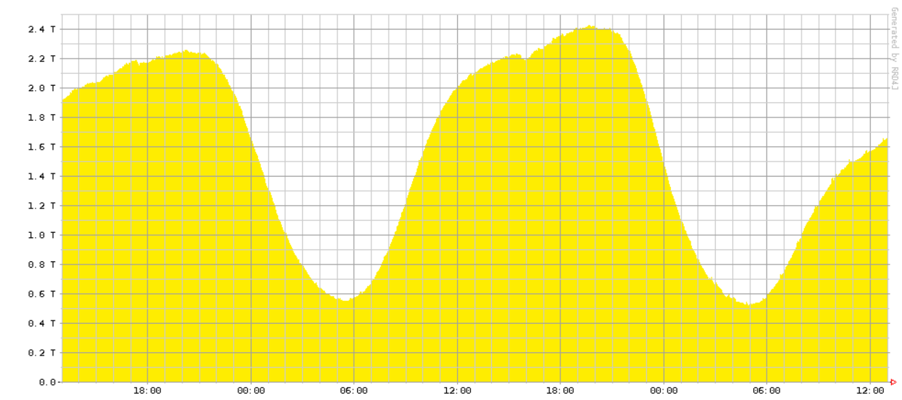
Motivation: Trends in Transport Networks

Traffic Evolution

exponential growth of traffic volume



significant diurnal traffic variations

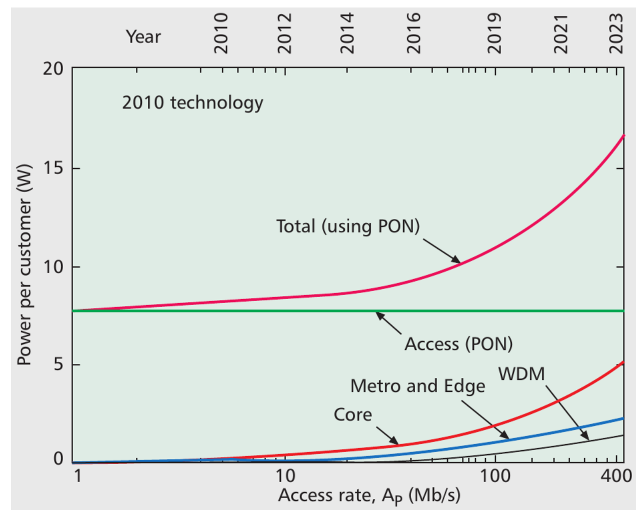


source:
DE-CIX traffic statistics

Access Technology Evolution

energy-efficient optical access technologies

→ power consumption in the core gains importance

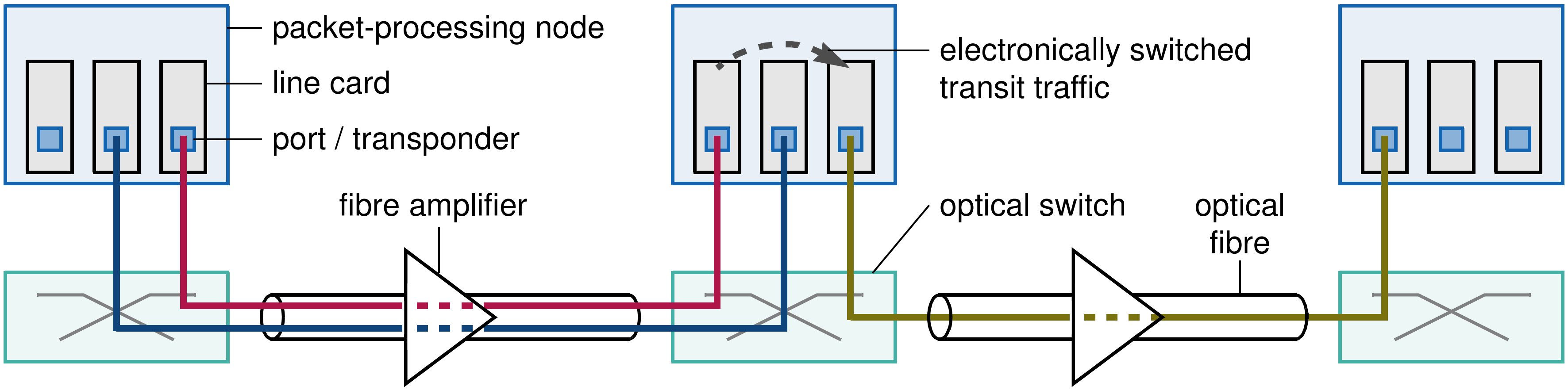


source:
Hinton, Baliga, Feng, Ayre, . Tucker, “Power consumption and energy efficiency in the Internet,” IEEE Network, vol. 25, 2011.

→ energy savings in the core by dynamic resource operation desired

Load-Dependent Core Network Resource Operation

Scenario: Multilayer Network (e.g. IP/MPLS over WSON)



Dynamic Resource Operation

- activation / deactivation of **optical circuits**
  - along with **line cards and transponders** consuming largest share of energy
  - switching times in the **order of minutes** due to interaction with fibre amplifiers
- power scaling in **packet processors**

  enabled by sleep modes for parallel structures and frequency scaling

  → energy consumption scales closely with traffic load

→ **network reconfiguration to realize energy savings**

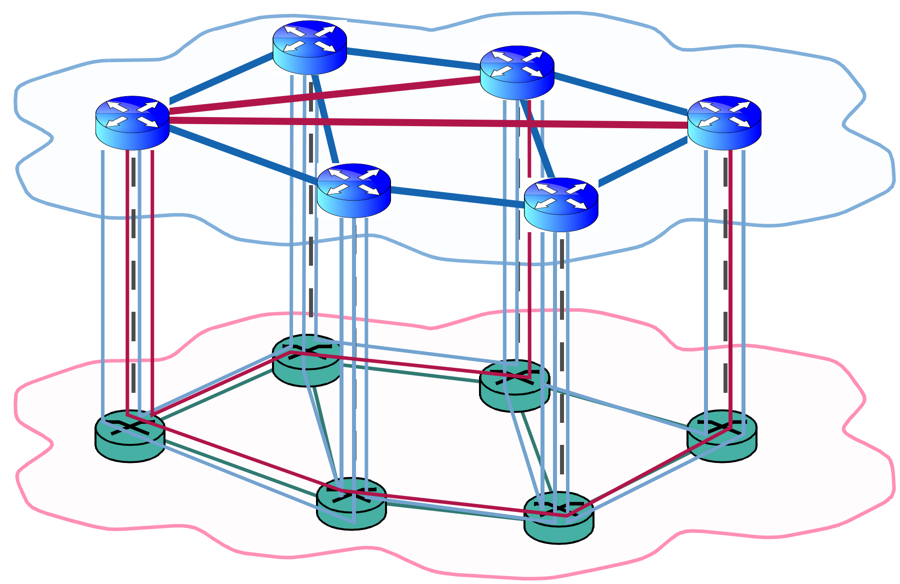
Dynamic Optical Bypassing

Inspiration

Distributed reconfiguration scheme

- start with circuits according to physical topology
- offload transit traffic to bypass circuits

  → additional links in virtual topology



Centralized Approach

- focus on **virtual topology**

  → define **bypass link** configuration
- traffic routing adheres to idea of *offloading*

  → use shortcuts along given path

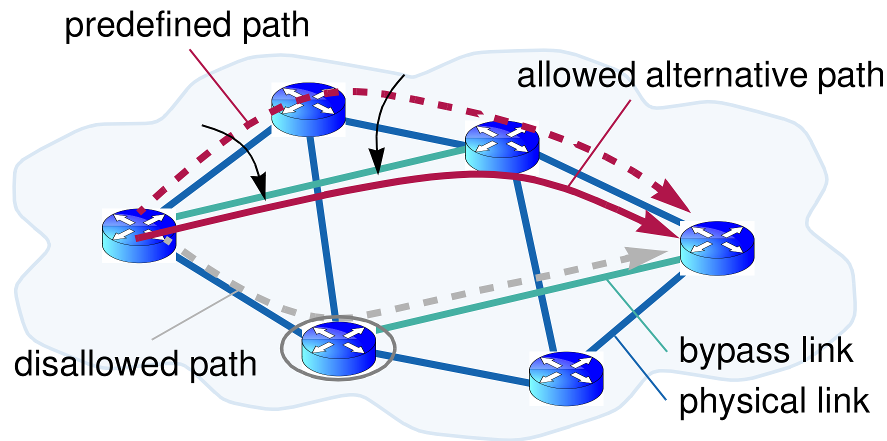
Centralized Dynamic Optical Bypassing Problem

Optimization Problem

find the best virtual topology

... while routing traffic only over nodes on a predefined path

... such that the total energy consumption is minimal



Additional objective for reconfiguration

limited number of circuit modifications

$\rightarrow$ factored into cost function

Cost Function

$\alpha \times$ number of active optical circuits

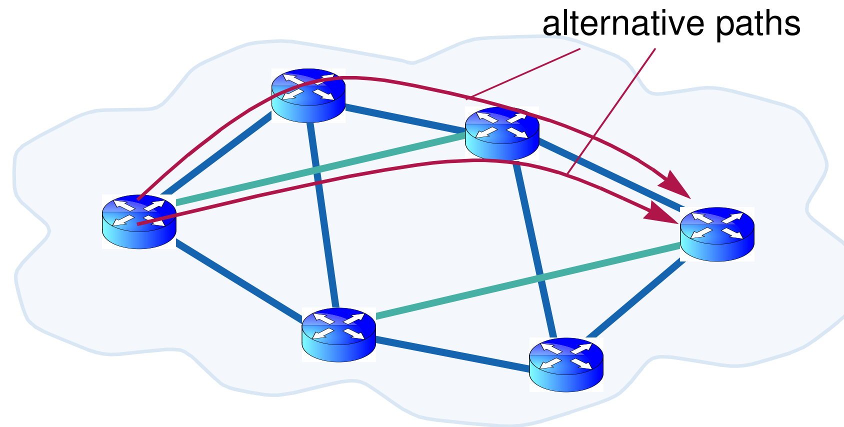
$+ \; \beta \times$ amount of electronically switched transit traffic

$+ \; \gamma \times$ number of newly established or torn-down circuits

Solution Methods

Mixed Integer Linear Program

- multi-commodity flow problem formulation
- optimizes
  - circuit configuration
  - traffic splitting and routing
    onto alternative bypass combinations



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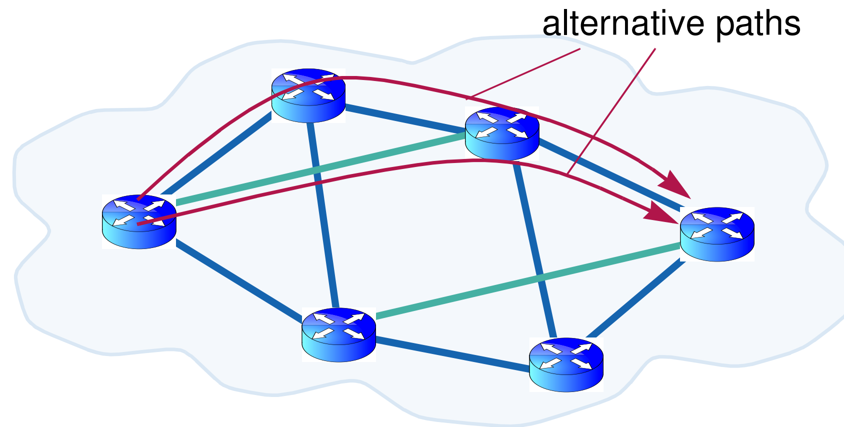

Optimization Meta-Heuristic (Simulated Annealing)

- optimizes virtual topology
- routes traffic onto shortest path (combination of admissible virtual links) without splitting

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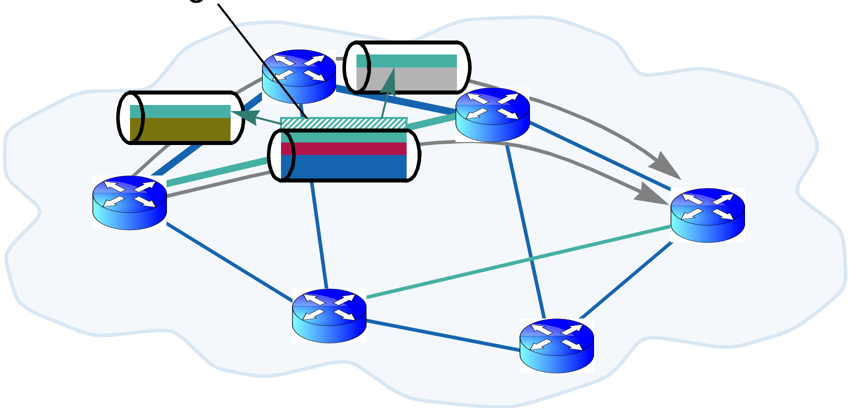

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- optional post-processing step to re-route traffic in order to avoid lowly utilized circuits

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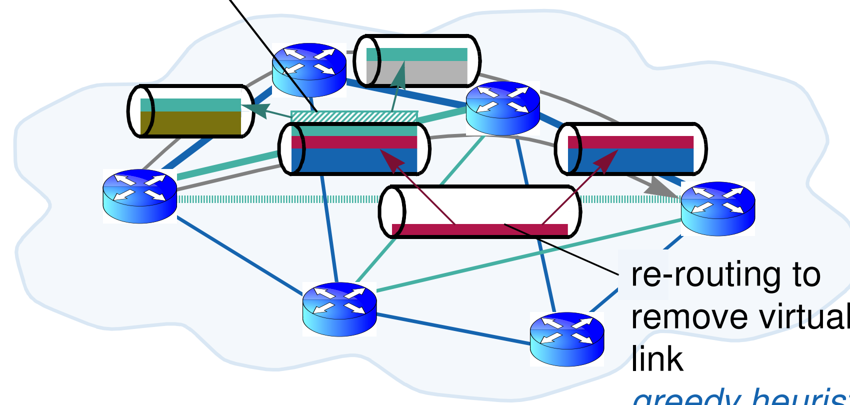

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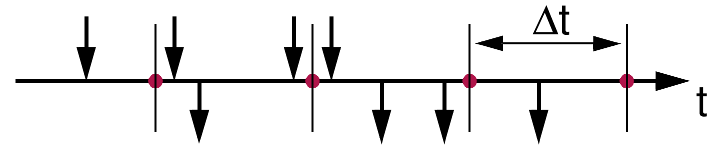
Greedy Heuristic

- starts from full-mesh virtual topology and one-hop traffic routing
- iterates over all bypass links to re-route traffic if more energy-efficient

Evaluation by Simulation

Assumptions

- maximum traffic demands in next interval are known
- reconfiguration every 15 minutes
- no resource limitations

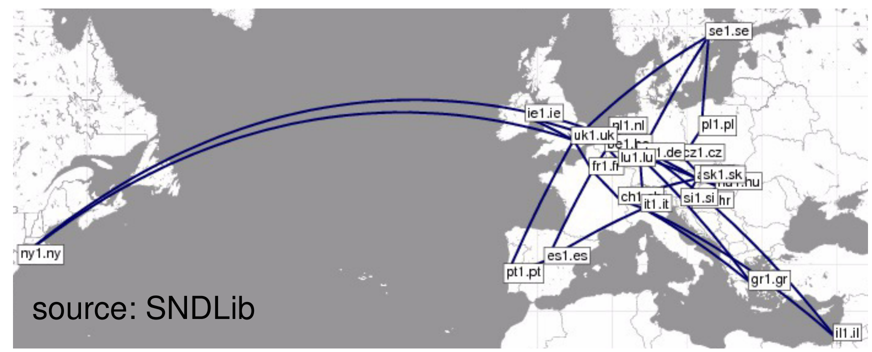


Scenario

- Géant reference network topology from SNDLib (http://sndlib.zib.de)

  22 nodes, 36 links, 462 traffic demands

- 10 working days out of measurement-based demand trace



Baseline Case

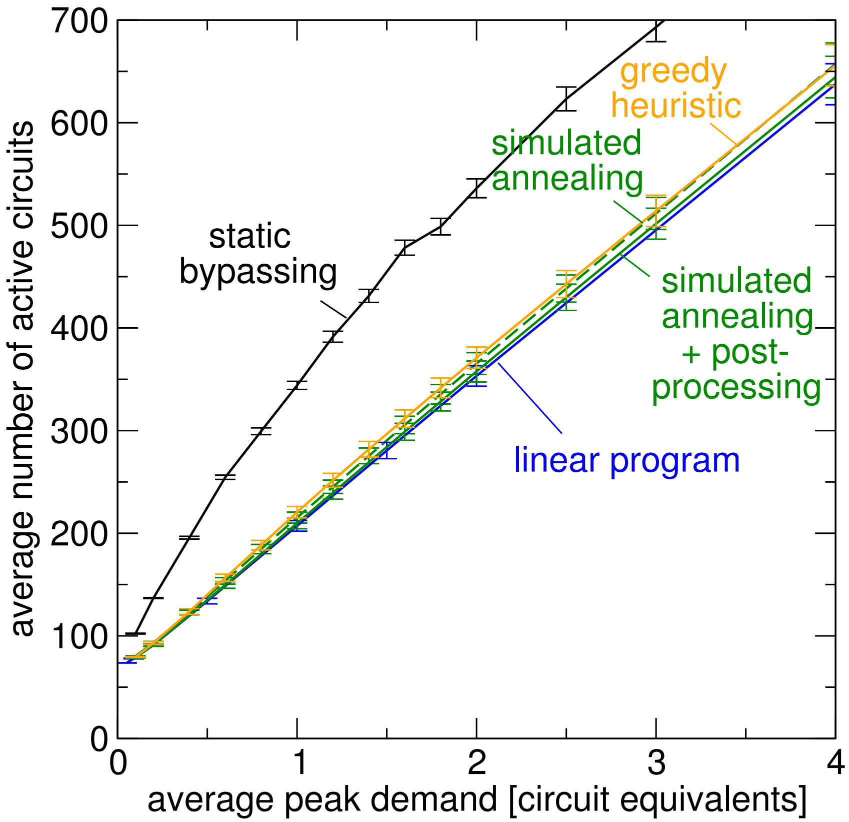
static bypassing

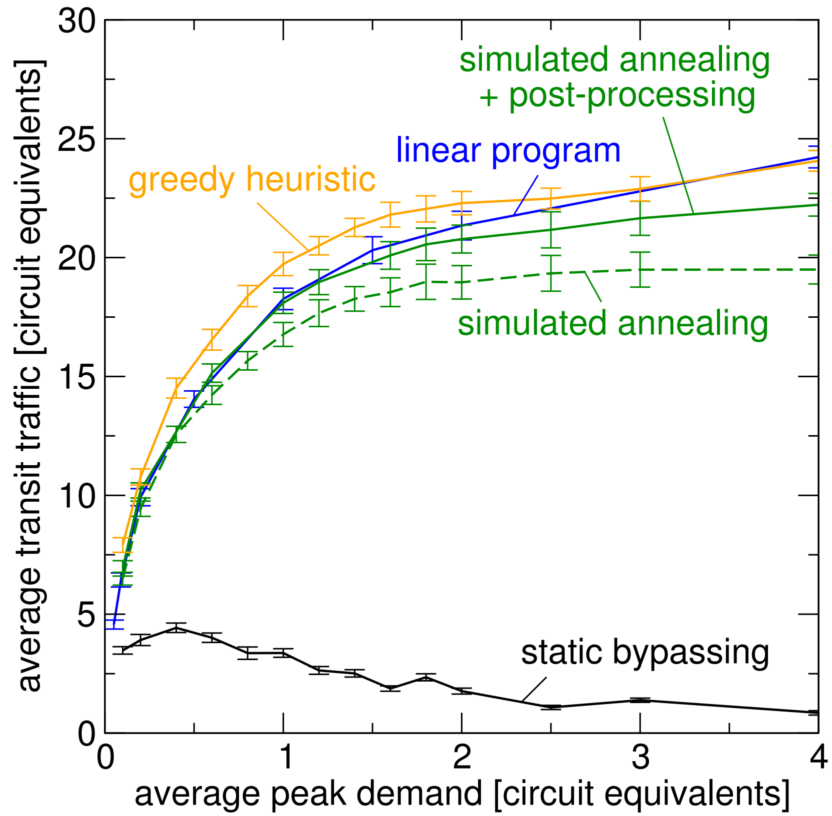
- fixed virtual topology and fixed traffic routes
- load-dependent resource operation

Evaluation Results

α = 1.0
β = 1.0
γ = 0.5

Energy Consumption Metrics





- energetic cost of switching transit traffic is small compared to operation of circuits
- all dynamic optical bypassing solution methods perform similarly
- dynamic bypassing reduces energy consumption by 20% to 35% over static bypassing

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α = 1.0
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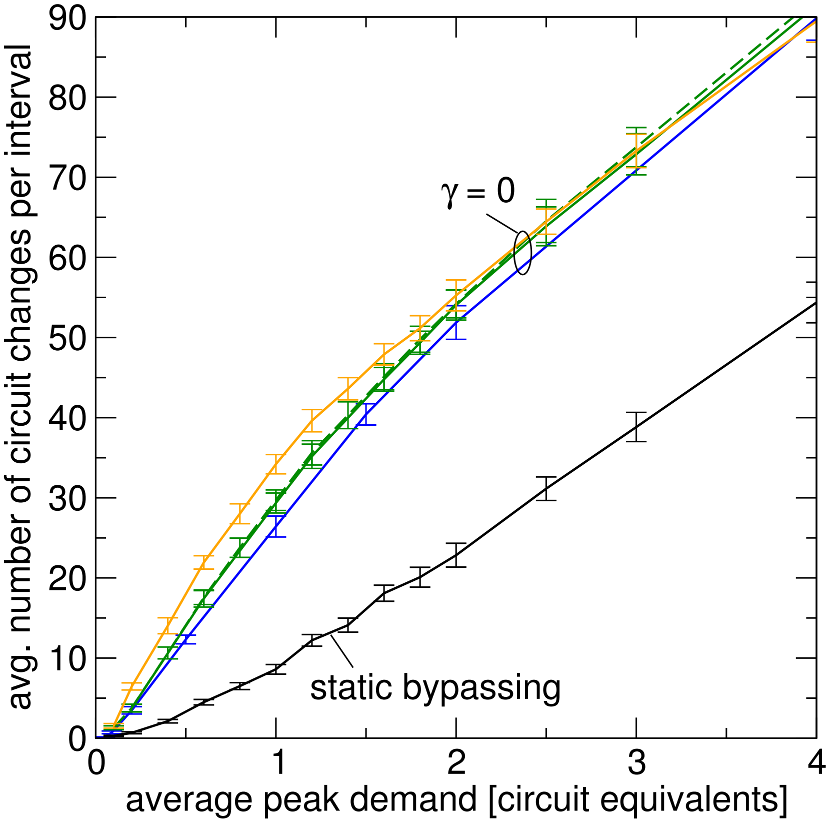
γ = 0..0.5

Reconfiguration Metric



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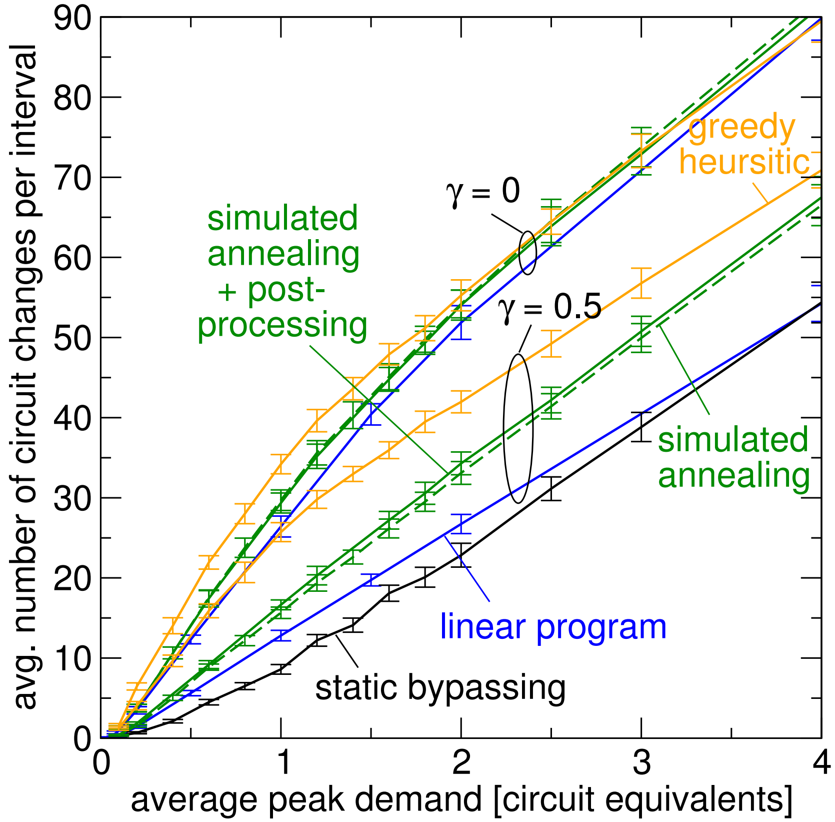

- for $\gamma = 0$, similar result for all dynamic optical bypassing solution methods
- positive reconfiguration penalty ($\gamma > 0$) reduces circuit changes (by 25% to 50%)
  - effect differs between the solution methods
  - level of static bypassing (with dynamic circuit operation) is achievable

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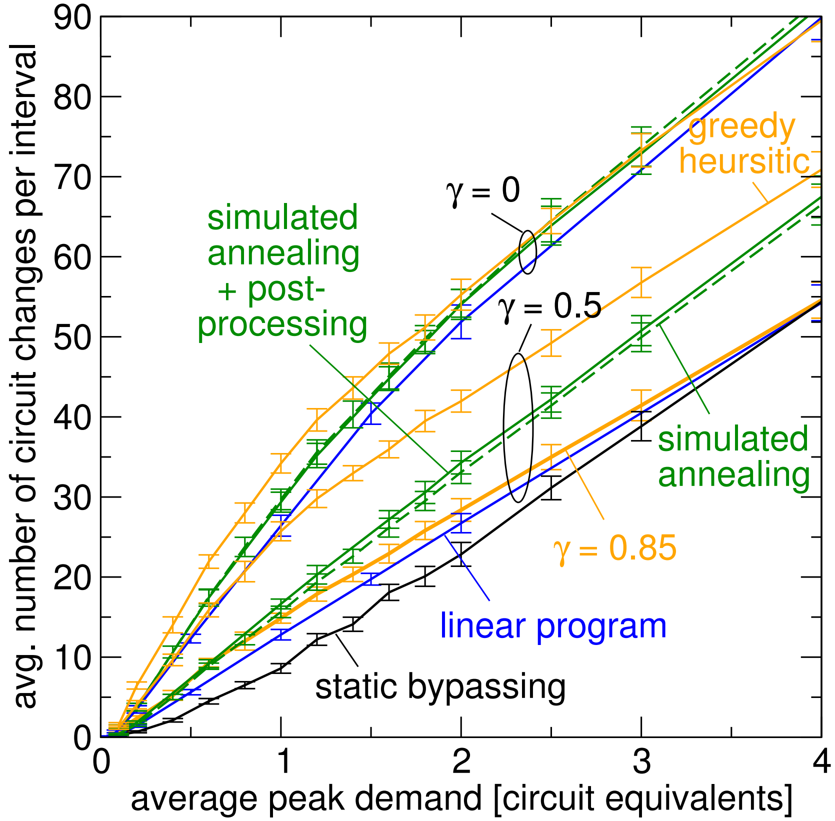

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Conclusion

Centralized Dynamic Optical Bypassing

- a multi-layer network reconfiguration problem
  - adapting virtual topology and circuit configuration to varying traffic load
  - restricting traffic routing to nodes of a predefined path
- three solution methods investigated
- evaluation results
  - all methods provide solutions of similar quality
  - reconfiguration penalty significantly reduces number of circuits established and torn down without significant effect on energy consumption
  - dynamic bypassing reduces load-dependent energy consumption by 20% to 35% compared to dynamic resource operation with static virtual topology and fixed traffic routing

Future Work

- extension of dynamic optical bypassing problem and solution methods
  - include light-path routing for circuit realization
  - consider resource constraints in dimensioned network
- refinement of dynamic resource operation and energy consumption model
- comparison with different network reconfiguration schemes