Evaluation of a Centralized Solution Method for One-Step Multi-Layer Network Reconfiguration

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Outline

Motivation

Load-Dependent Core Network Operation

- resource adaptation assumptions
- multi-layer network reconfiguration

Periodic One-Step Network Reconfiguration

- constraints and resulting reconfiguration procedure
- optimization problem
- optimization-heuristic solution method

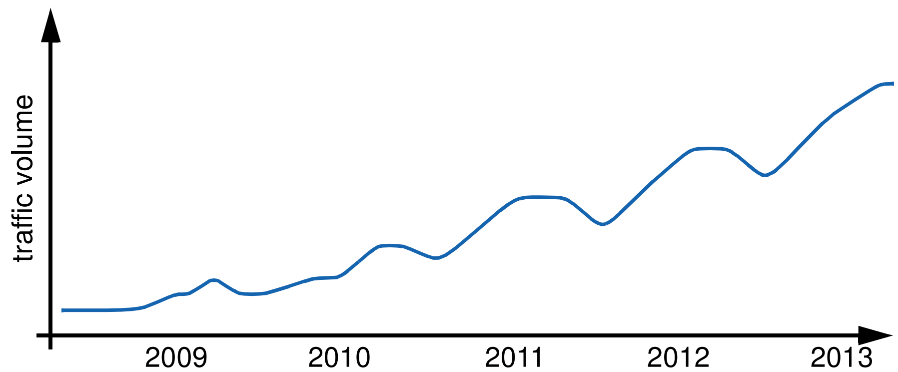
Evaluation

Conclusion

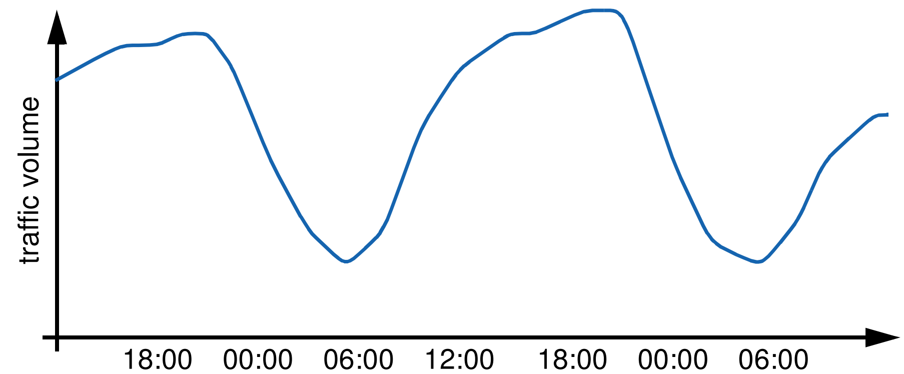
Motivation: Trends in Transport Networks

Traffic Evolution

exponential growth of traffic volume



significant diurnal traffic variations

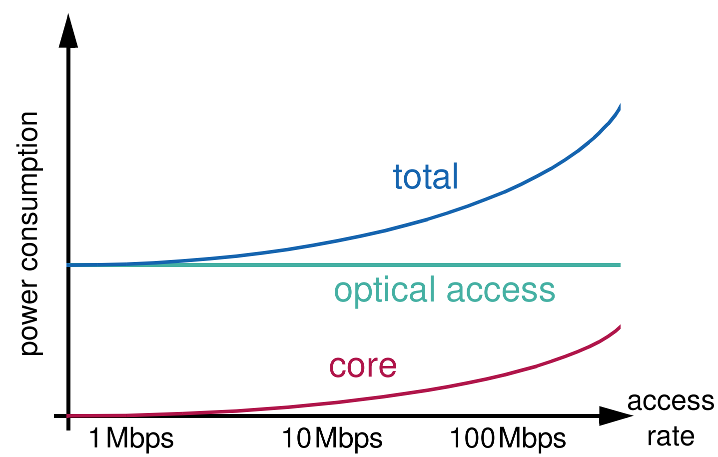


cf. eg.: DE-CIX traffic statistics

Access Technology Evolution

energy-efficient optical access technologies

→ power consumption in the core gains importance

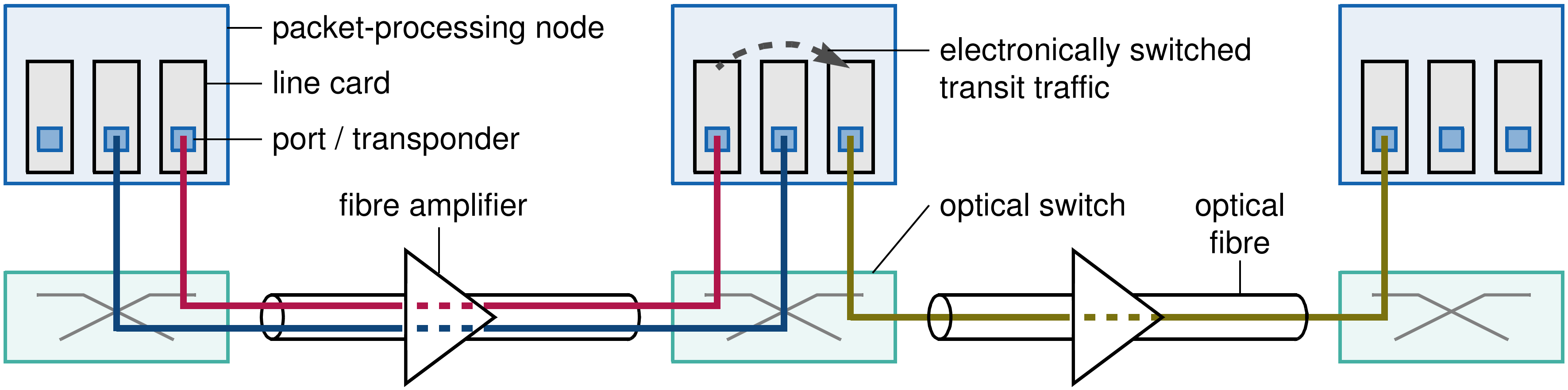


cf. e.g.: Hinton, Baliga, Feng, Ayre, Tucker, "Power consumption and energy efficiency in the Internet," IEEE Network, vol. 25, 2011.

→ 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

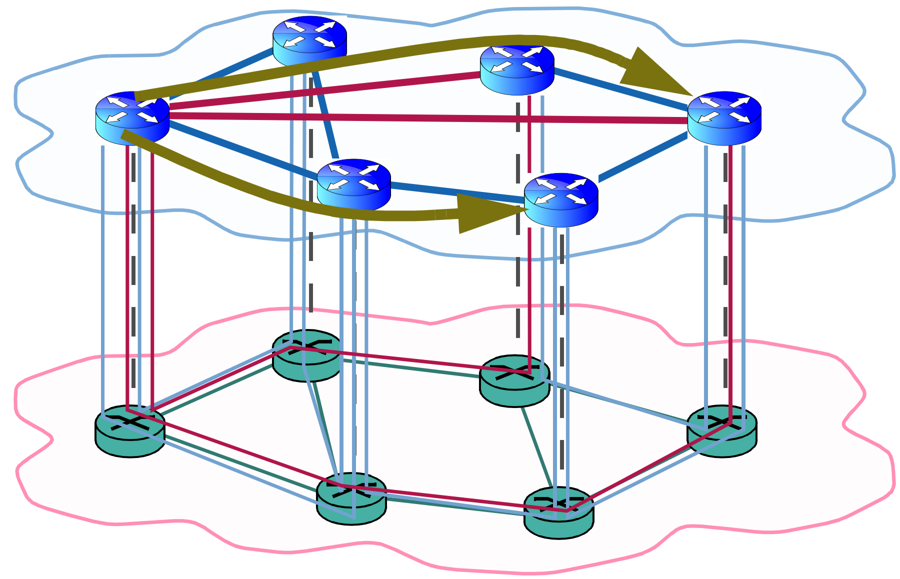
- activation / deactivation of **optical circuits**
  - along with **line cards and transponders** consuming largest share of energy
  - switching times in the **order of minutes** due to interaction with fibre amplifiers
- power scaling in **packet processors**

  enabled by sleep modes for parallel structures and frequency scaling

  → energy consumption scales closely with traffic load

→ energy savings by adapting network configuration to load

Multi-Layer Network Reconfiguration



Configuration Dimensions

Upper layer

- **virtual topology**
  - realized by **optical circuits**
  - independent of physical topology
- **demand routing** in **virtual topology**

Lower layer

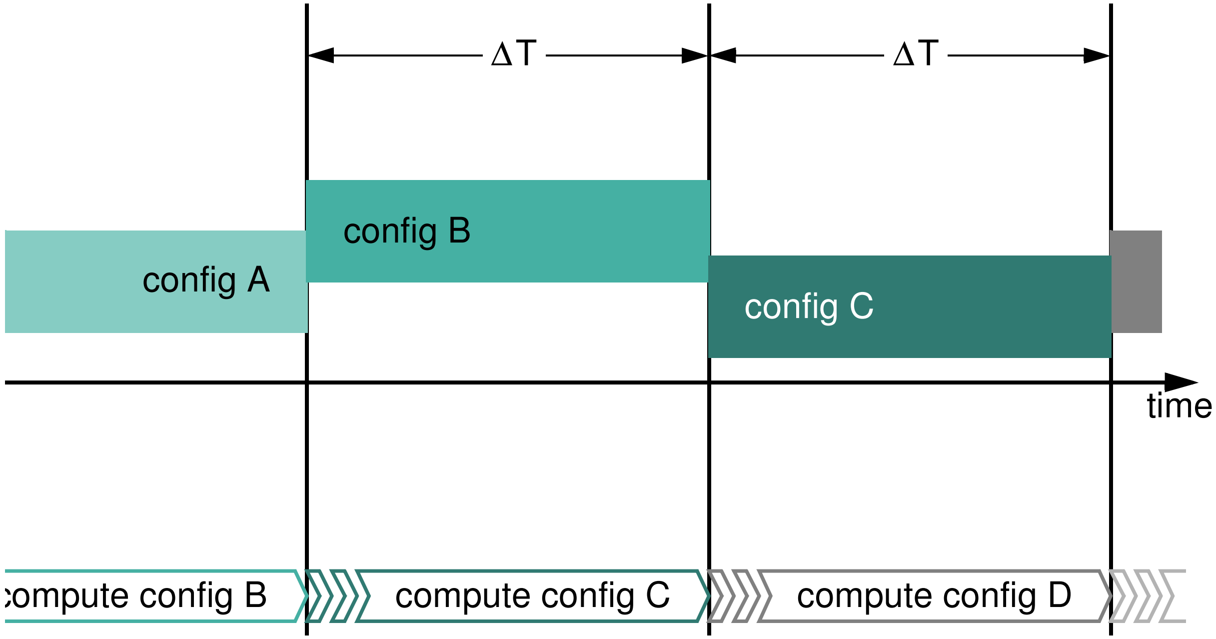
- routing of optical circuits
- wavelength assignment

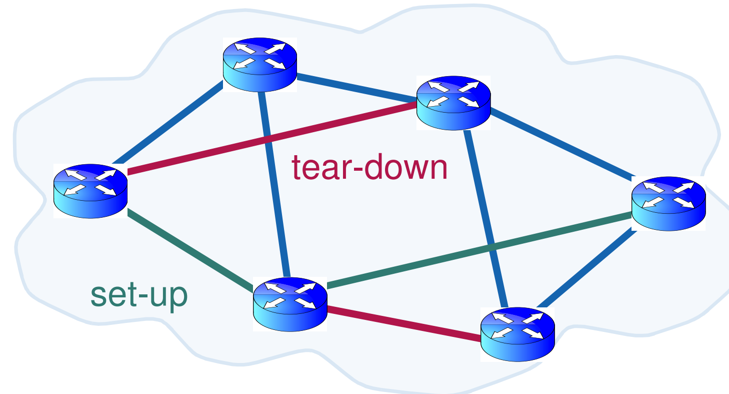
Reconfiguration Objective

Energy consumption – defined by upper layer

→ focus on upper layer

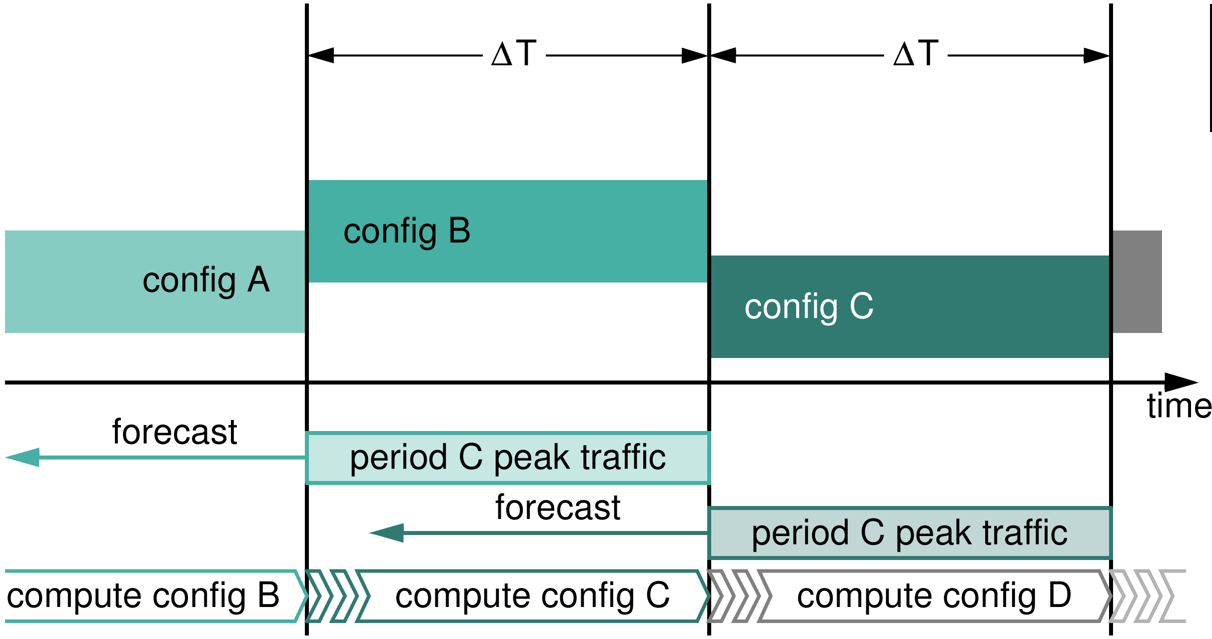
Periodic One-Step Network Reconfiguration

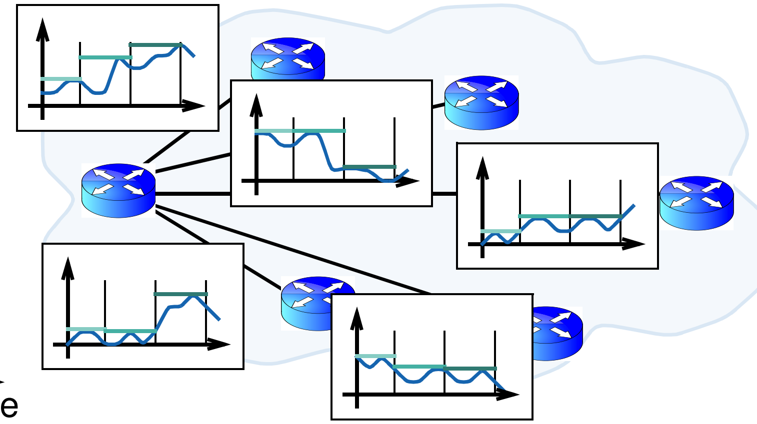




- time-triggered computation of low-energy network configuration for forthcoming traffic

Periodic One-Step Network Reconfiguration





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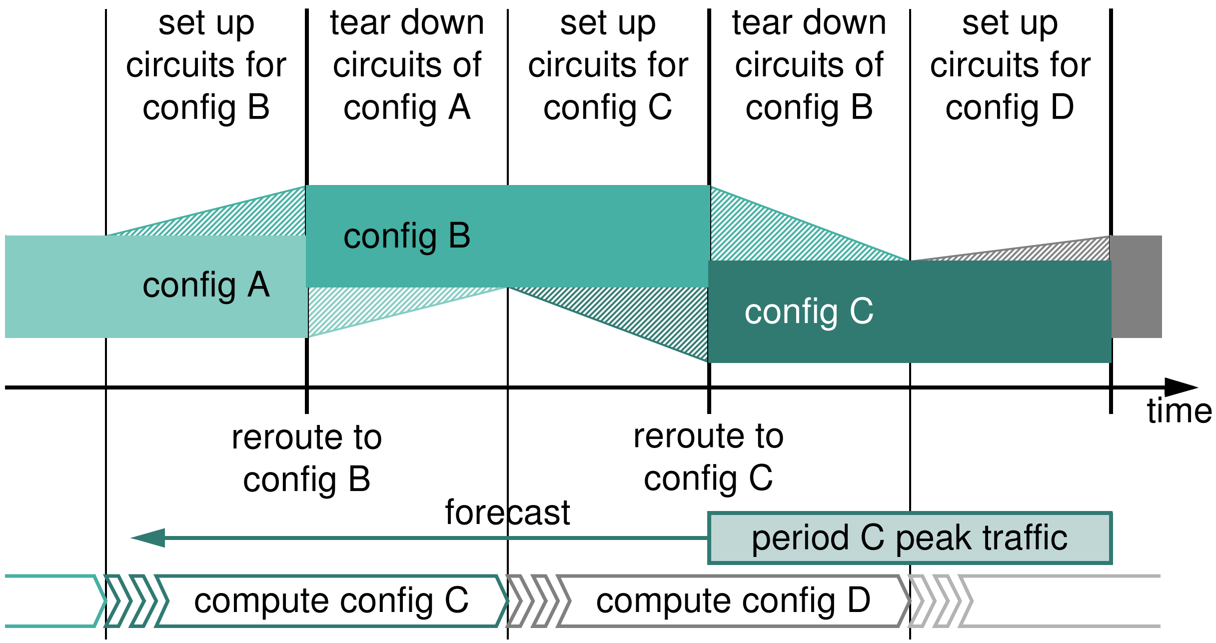

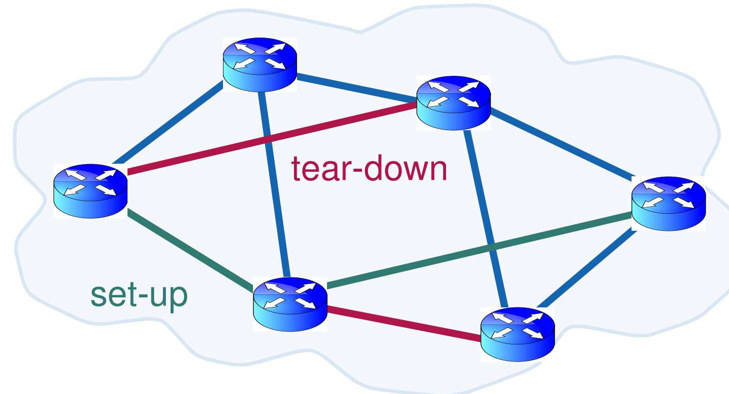

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  amplifier transients require slow circuit setup and teardown

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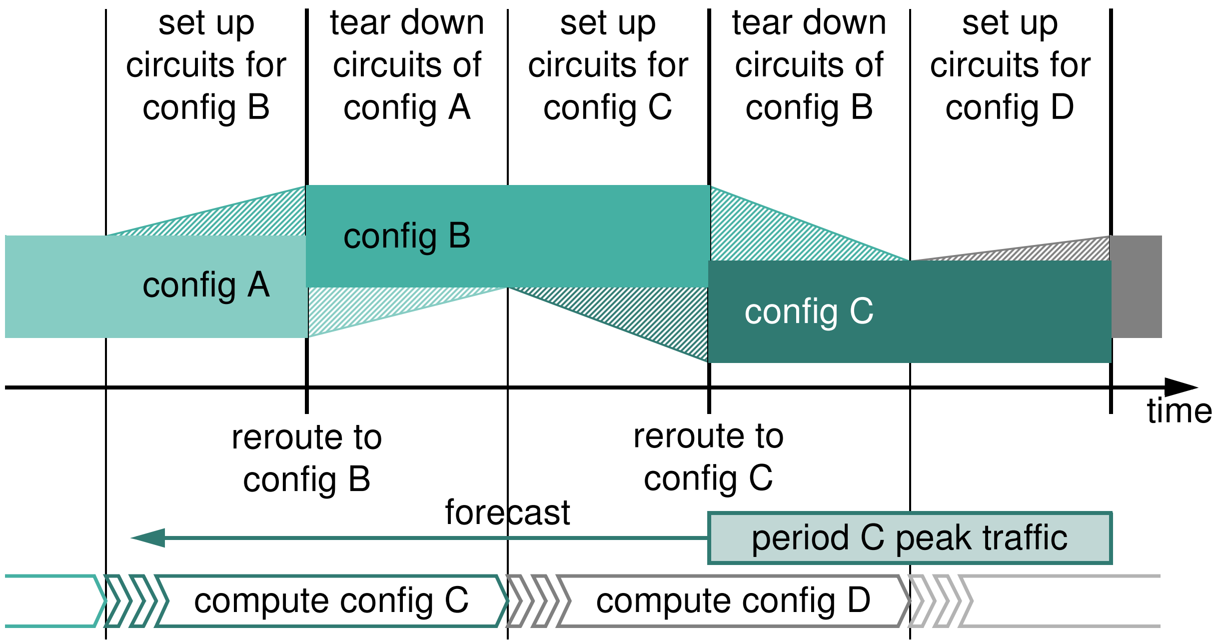

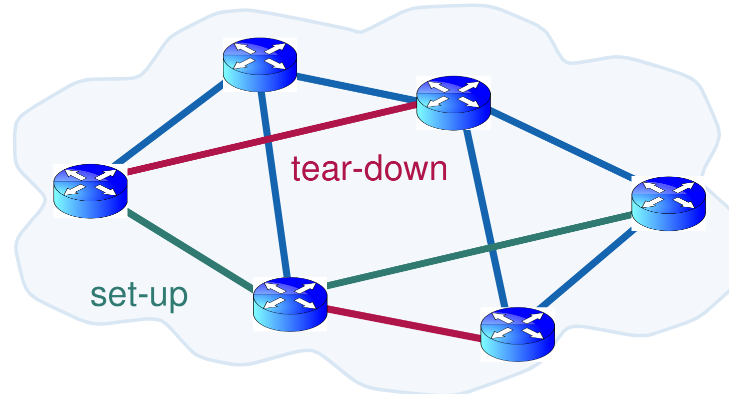

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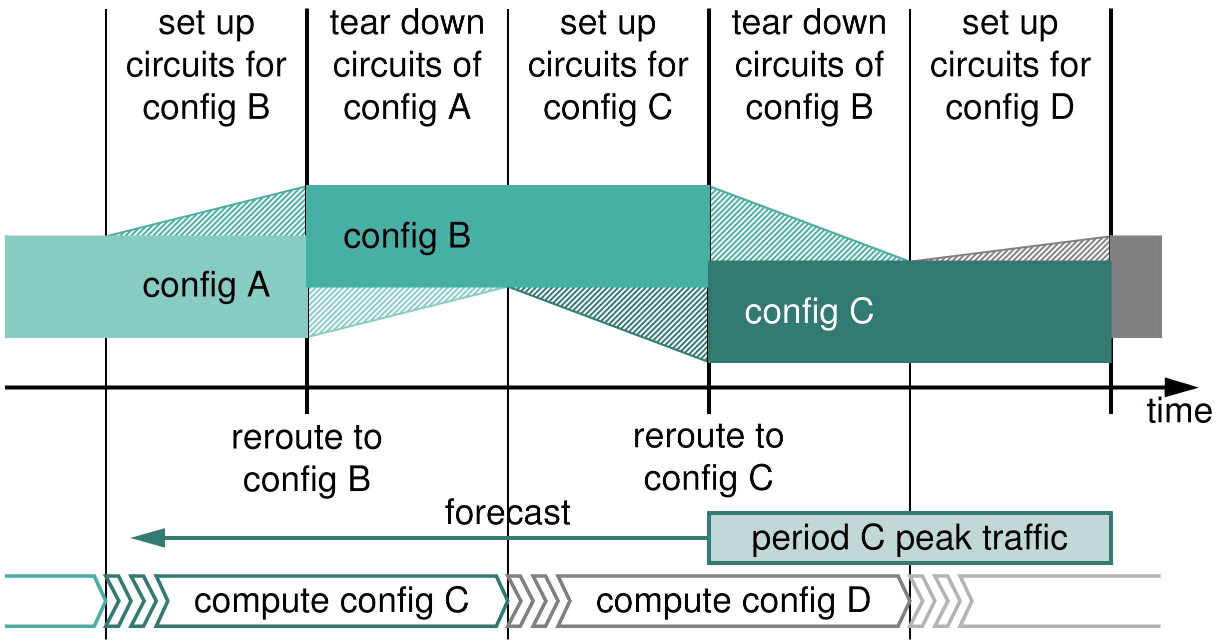

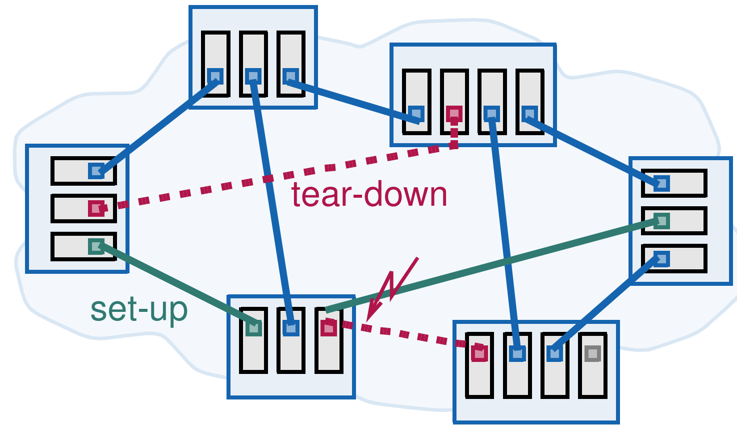

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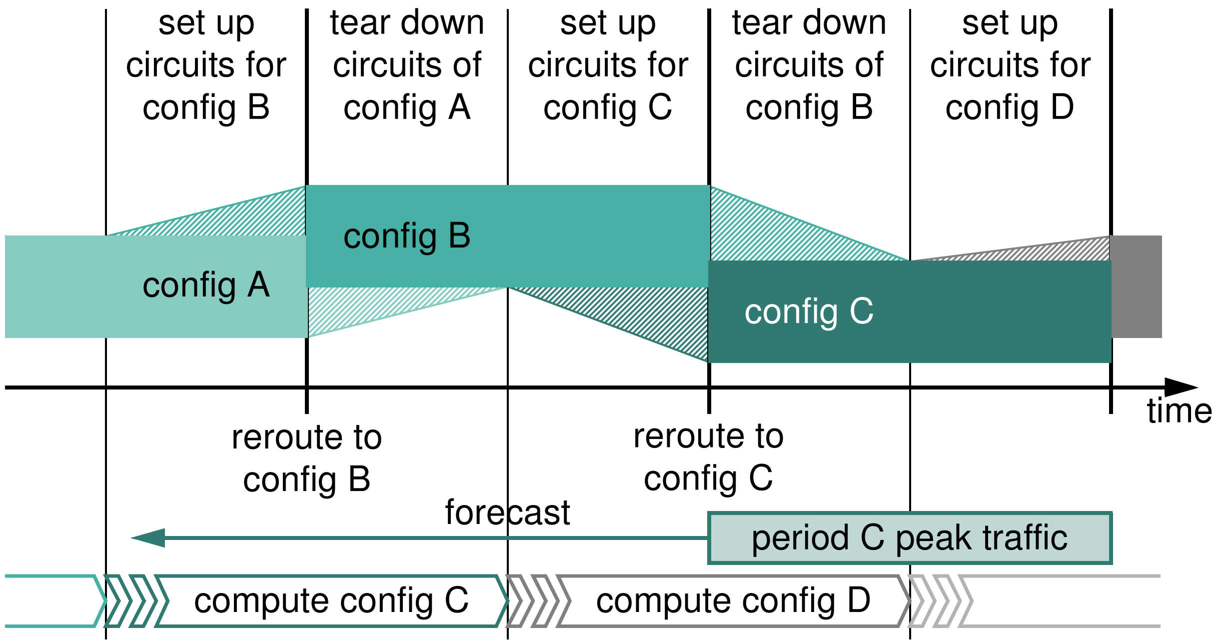

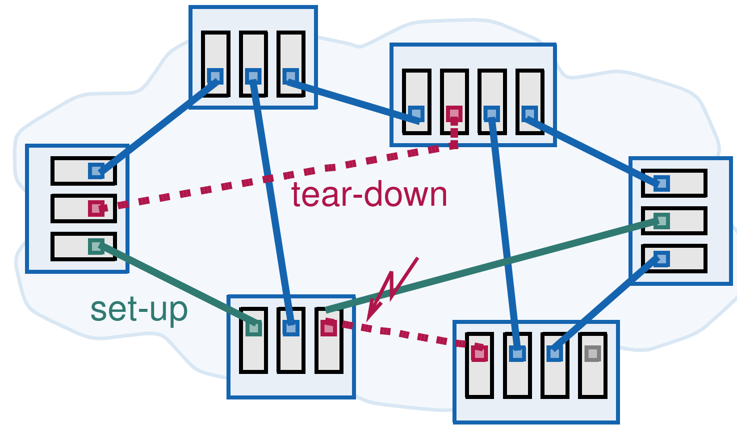

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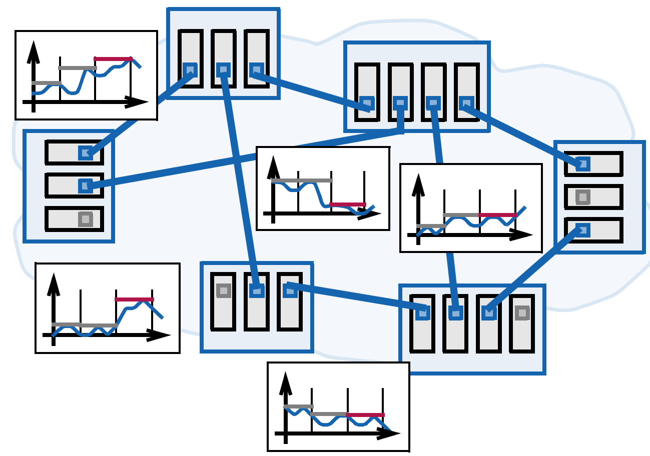
  → new circuits may only use resources not occupied in the previous configuration

→ specific optimization problem – to be solved in less than the reconfiguration interval

One-Step Reconfiguration Problem

Finding a Network Configuration in terms of

- **set of optical circuits** including the resources they occupy
- **routing of demands** in resulting virtual topology



Constraints

- traffic demands (between all node pairs) to be satisfied
- installed resources (line card ports and fibre capacity)
- resource occupation in previous configuration

Objective

Simultaneously minimize

- energy consumption
- changes to configuration
- traffic blocking

Cost Function

cf =

= α × *# active optical circuits*

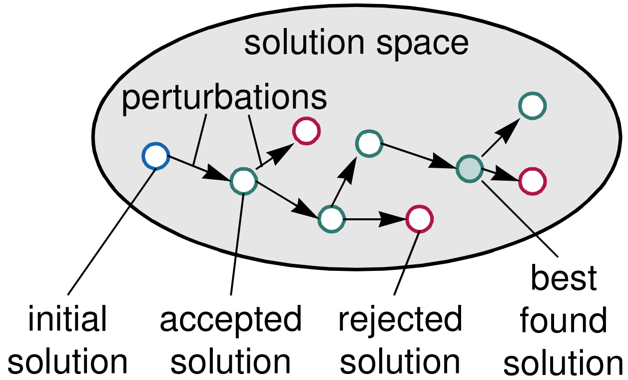
+ β × *electronically switched transit traffic volume*

+ δ × *# newly established or torn-down circuits*

+ μ × *# virtual links with insufficient capacity*

+ ν × *blocked traffic volume*

Virtual Topology Centric Reconfiguration (VTCR)



Simulated-Annealing Based Solution Method

Heuristic optimization: randomized search of solution space

Optimization Procedure (Loop)

- **perturbation** of **virtual topology**

  randomly add or remove one virtual link
- cost computation
  - **deterministically route demands** on shortest path in virtual topology
  - determine required circuits from traffic on each virtual link
    - set up according circuits if feasible
    - count blocking if insufficient resources
  - evaluate cost function

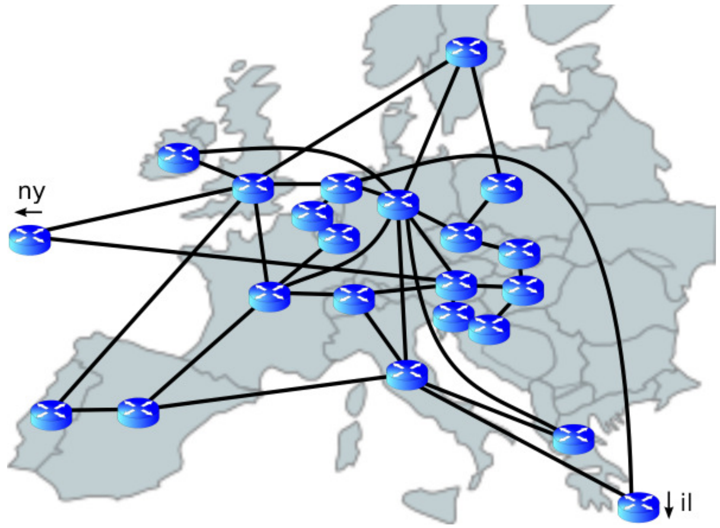
Post-Processing

Drawbacks of deterministic demand routing

1. blocking on shortest-path links while spare resources on alternative paths available
2. lowly utilized circuits while traffic could be accommodated by existing circuits on other path

→ greedy traffic rerouting heuristic to resolve such situations

Evaluation by Simulation



Scenario

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

  22 nodes, 36 links, 462 traffic demands
- 14 days out of measurement-based demand trace; scaled to vary average load
- reconfiguration every 15 minutes
- network resources dimensioned for peak of all demands

Baseline Case

resource scaling (RS)

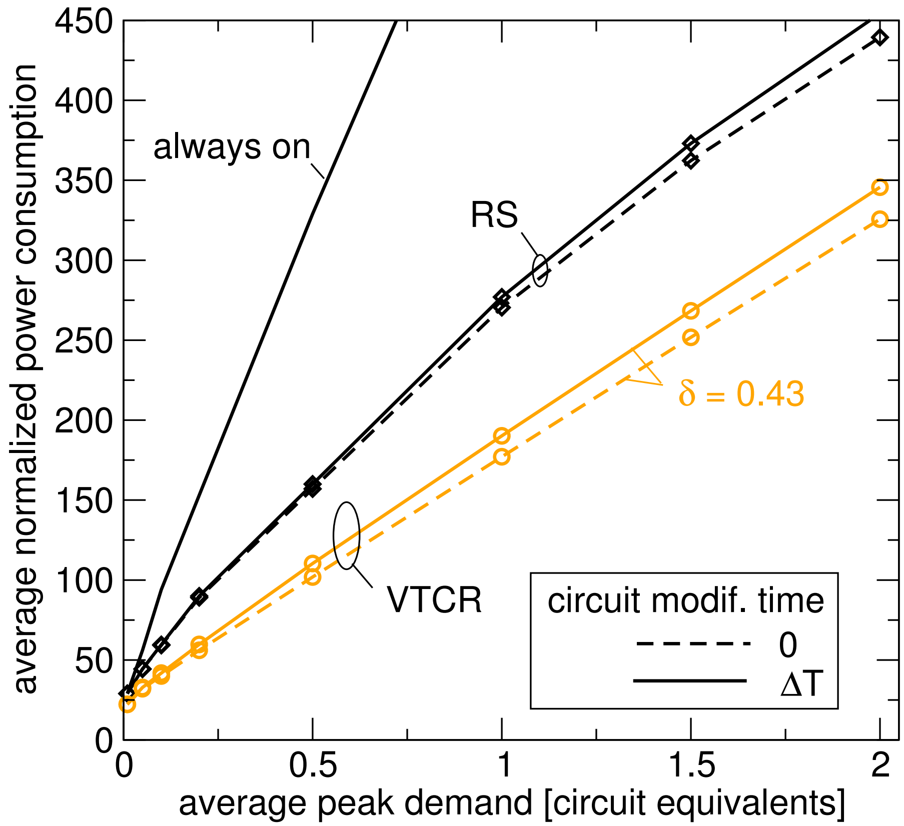
- fixed virtual topology and fixed traffic routes (optimized for peak demands)
- load-dependent resource operation

Cost Parameters

- energy – per circuit: $\alpha = 1$; per circuit equivalent of switched traffic: $\beta = 4.3 \cdot 10^{-5}$
- circuit modification: $\delta \in \{0; 0.43\}$
- traffic blocking: $\mu = \nu = 17$

Evaluation Results

Energy Consumption



- VTCR reduces energy consumption by 25% to 35% over resource scaling

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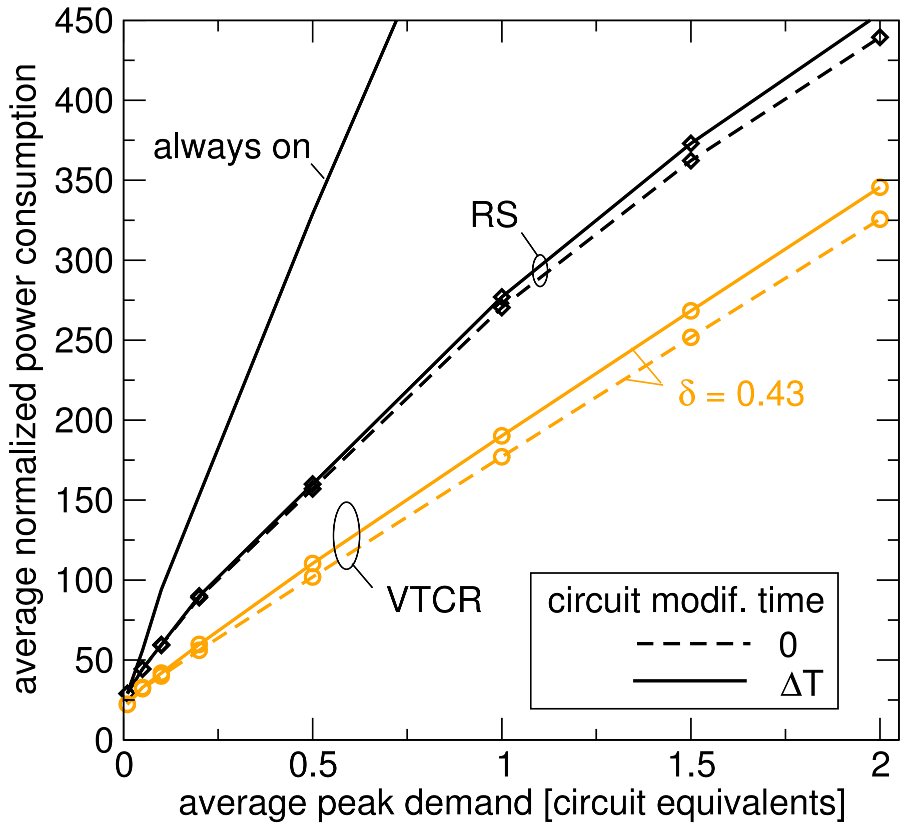
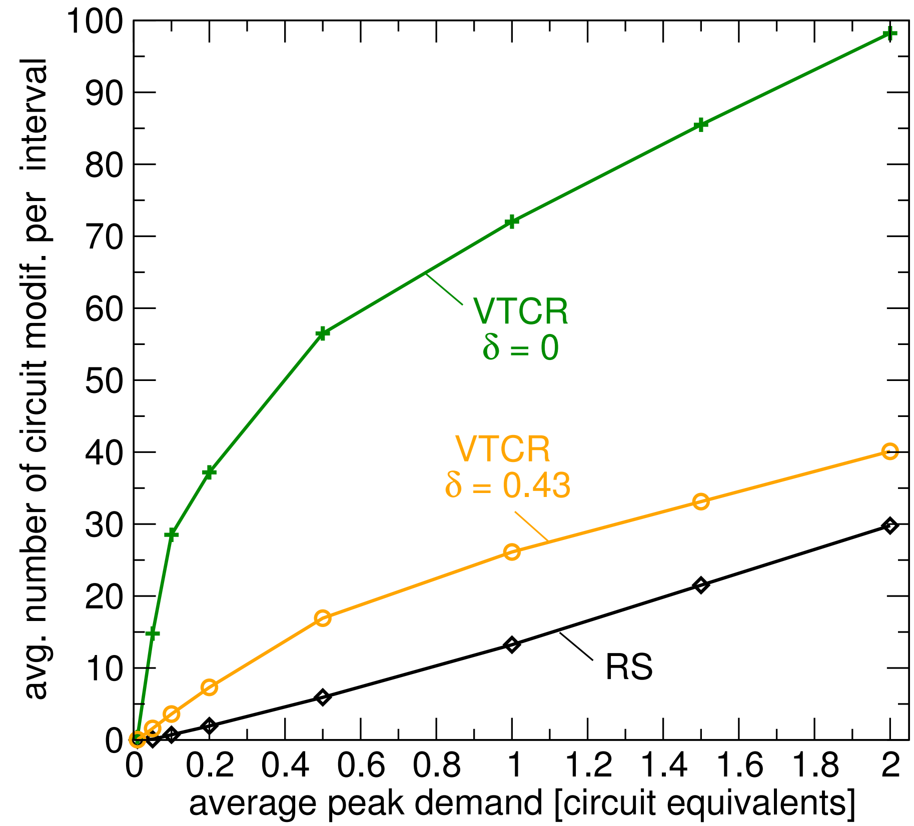


Configuration Changes



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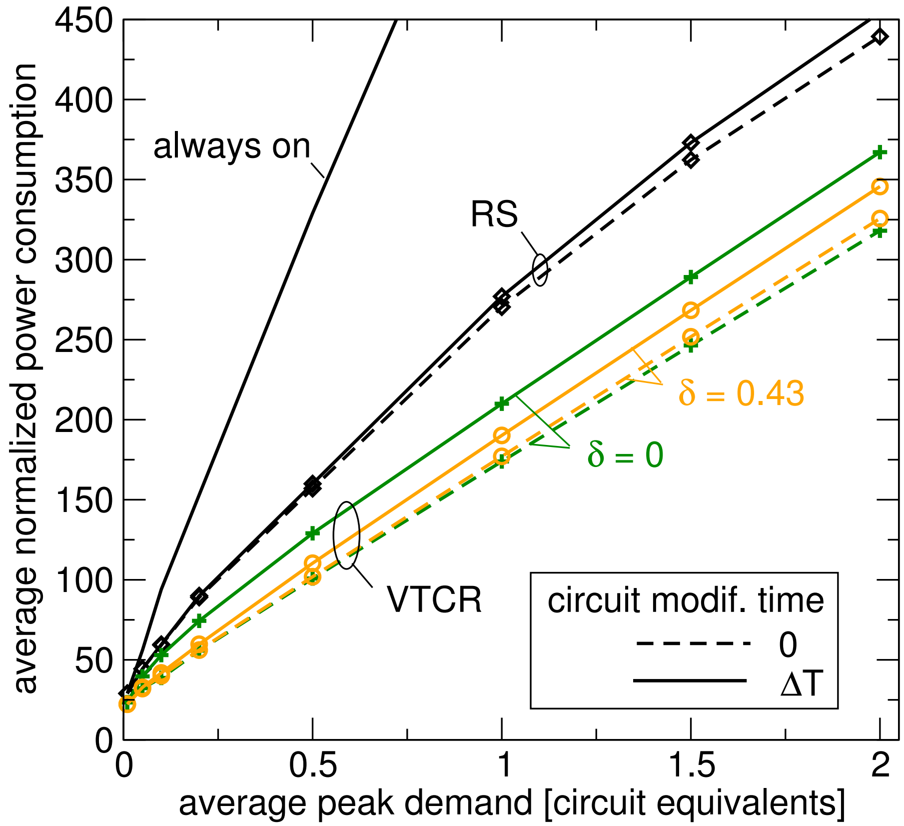

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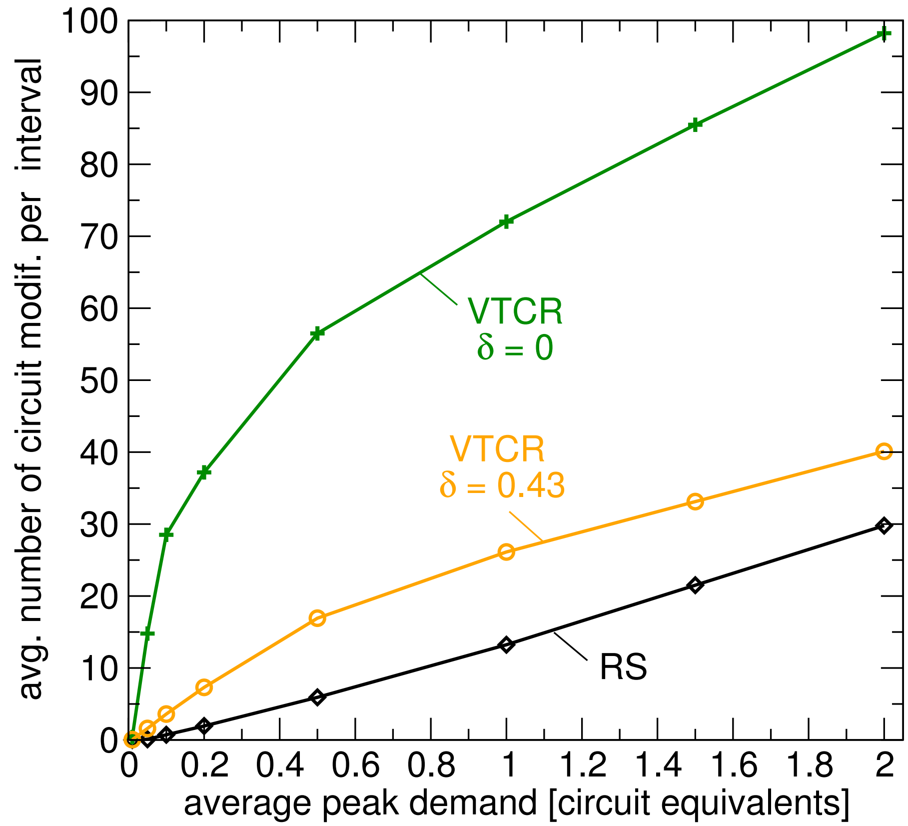

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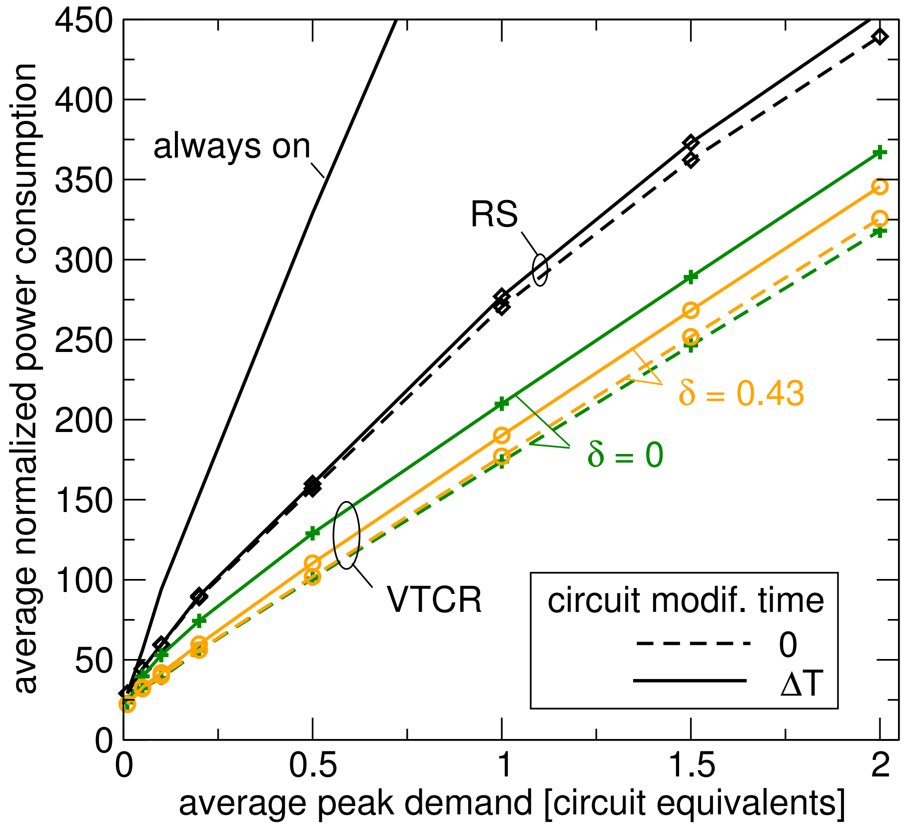

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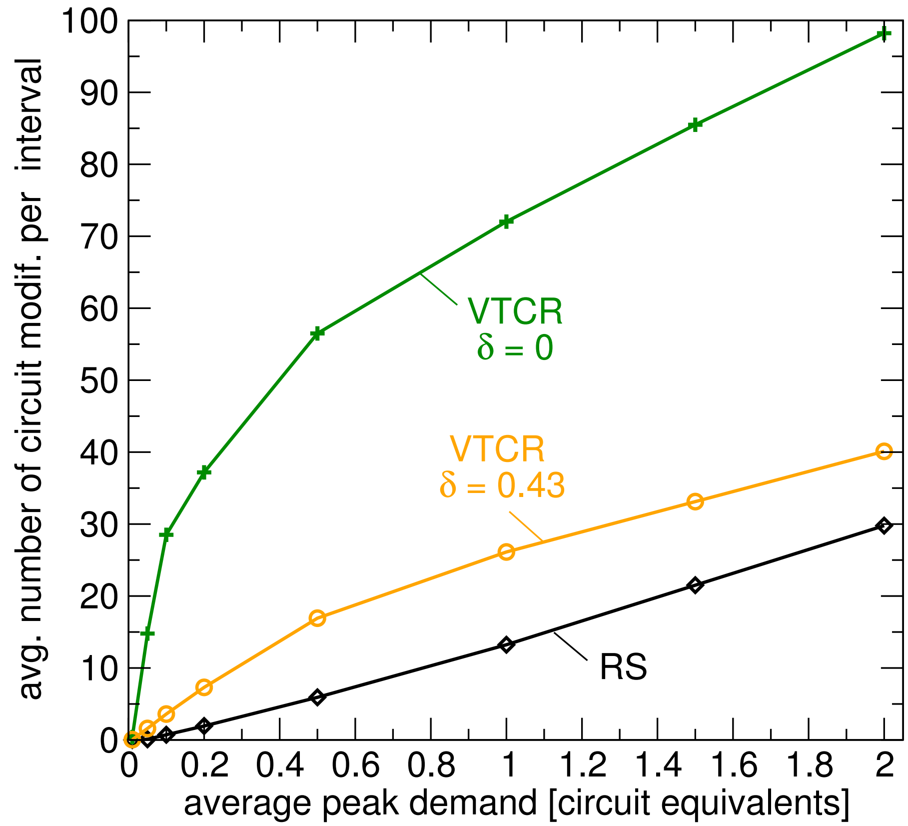

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- positive reconfiguration penalty δ significantly reduces circuit changes
  → increased energy efficiency if consumption of transient circuits considered
- traffic blocking in 8 / 21,504 settings due to sparse resources or suboptimal solutions

Conclusion

Periodic One-Step Multi-Layer Network Reconfiguration

- reconfiguration procedure implied by technological and operational time constraints
  $\rightarrow$ optimization problem with resource pre-occupation constraints
- VTCR: an optimization-heuristic solution method for this problem
  - optimization of virtual topology
  - deterministic demand routing (shortest path & greedy heuristic)
- evaluation results
  - VTCR reduces load-dependent energy consumption by 25% to 35% compared to dynamic resource operation with static virtual topology and fixed traffic routing
  - reconfiguration penalty significantly reduces number of circuits established and torn down
  - traffic blocking is rare and resolvable by improved heuristic in practically relevant cases

Future Work

- accounting for resource hierarchy for power consumption (port – line card – rack)
- evaluation in further scenarios (e.g. different network size, resource dimensioning)
- MILP formulation and exact reference solution for small problem instances
- comparison with other network reconfiguration schemes

References

- K. Hinton, J. Baliga, M. Feng, R. Ayre, R. S.Tucker, "Power consumption and energy efficiency in the Internet," IEEE Network, vol. 25, 2011.
- A. Bononi, L. Rusch, "Doped-fiber amplifier dynamics: a system perspective," Journal of Lightwave Technology, vol. 16, 1998.
- P. N. Tran, U. Killat, "Dynamic reconfiguration of logical topology for WDM networks under traffic changes," IEEE Network Operations and Management Symposium (NOMS), 2008.
- F. Idzikowski, S. Orlowski, C. Raack, H. Woesner, A. Wolisz, "Dynamic routing at different layers in IP-over-WDM networks – maximizing energy savings," Optical Switching and Networking, vol. 8, no. 3, 2011.
- E. Bonetto, L. Chiaraviglio, F. Idzikowski, E. L. Rouzic, "Algorithms for the multi-period power-aware logical topology design with reconfiguration costs," Journal on Optical Communications Netw., vol. 5, no. 5, May 2013.
- S. Orlowski, M. Pióro, A. Tomaszewski, R. Wessäly, "SNDlib 1.0 – Survivable Network Design Library," Networks, vol. 55, no. 3, 2010, http://sndlib.zib.de.
- S. Uhlig, B. Quoitin, J. Lepropre, S. Balon, "Providing public intradomain traffic matrices to the research community," SIGCOMM Computer Communication Review, vol. 36, Jan. 2006.