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

Access Technology Evolution

energy-efficient optical access technologies

→ power consumption in the core gains importance

→ 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
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- prediction of peak traffic demands for future periods assumed to be available
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- interruption-free transition between configurations (→ make-before-break)
  amplifier transients require slow circuit setup and teardown
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  - amplifier transients require slow circuit setup and teardown
  - traffic forecast horizon is limited (presumably) $\rightarrow$ one-step reconfig (no transition path)
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  - traffic forecast horizon is limited (presumably) → **one-step reconfig** (no transition path)
  - 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
\[
 cf = \\
 = \alpha \times \text{# active optical circuits} \\
+ \beta \times \text{electronically switched transit traffic volume} \\
+ \delta \times \text{# newly established or torn-down circuits} \\
+ \mu \times \text{# virtual links with insufficient capacity} \\
+ \nu \times \text{blocked traffic volume}
\]
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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- Positive reconfiguration penalty $\delta$ significantly reduces circuit changes.

**Configuration Changes**
Evaluation Results

Energy Consumption

- VTCR reduces energy consumption by 25% to 35% over resource scaling.
- Positive reconfiguration penalty $\delta$ significantly reduces circuit changes.
  - $\delta = 0.43$ increases energy efficiency if consumption of transient circuits considered.

Configuration Changes
Evaluation Results

Energy Consumption

- VTCR reduces energy consumption by 25% to 35% over resource scaling
- positive reconfiguration penalty $\delta$ significantly reduces circuit changes
  $\rightarrow$ 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
  → 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


