

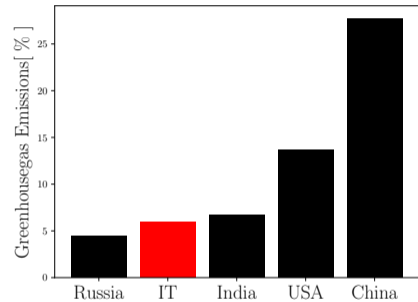
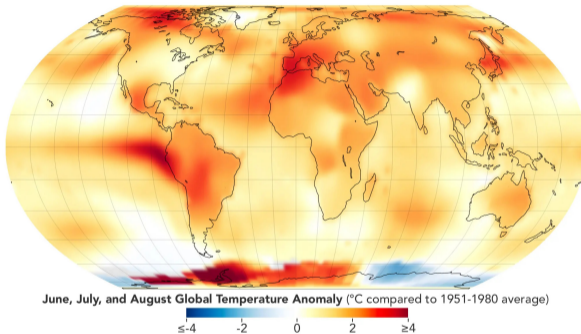


# Green Segment Routing

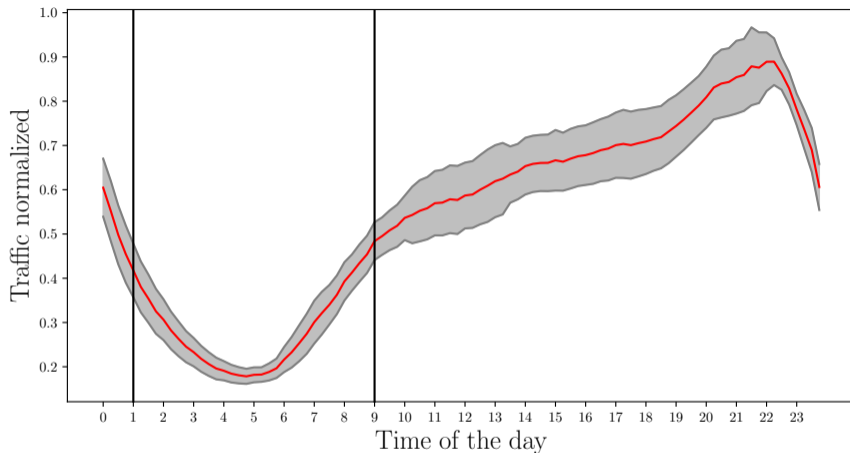
## Enhancing Energy Efficiency in Backbone Networks

Daniel Otten

Ripe Meeting  
10.2024



<https://climate.nasa.gov/news/3282/> <https://theshiftproject.org/en/article/lean-ict-our-new-report/>



- The maximum is four times higher than the minimum.
- Parts of the infrastructure are not always needed.

## Power consumption of an ASR-9912 router

Component	Power Consumption
A9K-MOD400-TR	524 W
A99-8X100GE-TR	810 W
A99-8X100GE-TR	813 W
A99-8X100GE-TR	812 W
<b>Linecards Overall</b>	<b>2959W</b>
A9K-RSP5-SE	263 W
A9K-RSP5-SE	258 W
RSPs Overall	521 W
Fans and Chassis	935 W
<b>Total Power Consumption</b>	<b>4415W</b>



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[www.cisco.com/c/en/us/products/collateral/routers/asr-9000-series-aggregation-services-routers/datasheet-c78-737393.html](http://www.cisco.com/c/en/us/products/collateral/routers/asr-9000-series-aggregation-services-routers/datasheet-c78-737393.html)



## Turning routers off



## Turning ports off



## Turning linecards off



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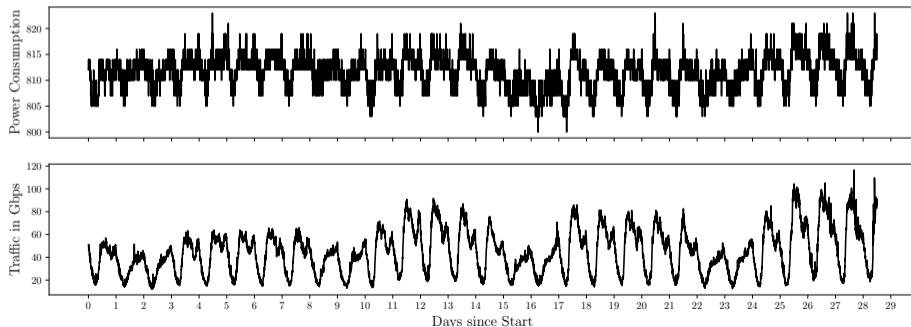


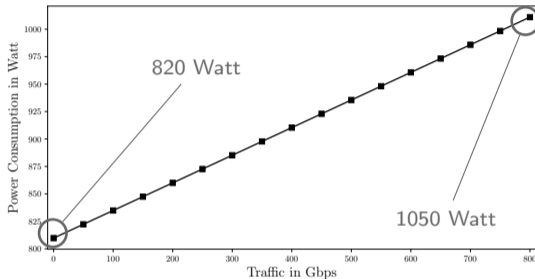
## Turning a router off

- The routers take about 30 minutes to reboot.
- Hardware defects can occur.
- Peering with customer networks.

## Method

- Measuring Power consumption via Cronjob
- Measuring the amount of Traffic via Prometheus
- Runtime: four weeks
- Linecard 0: A9K-MOD400-TR
- Linecard 1-3: A99-8X100GE-TR





- Power consumption varies by just 200 Watt.
- To reduce power consumption, parts must be switched off.

## Measurement ASR9904

- Measurement using Traffic Generator
- Power Consumption in different scenarios



## 50 G per Port or 100 G on 16 Ports?

- Processing 32 X 50 Gbps Traffic: 915 Watt
- Processing 16 X 100 Gbps Traffic, 16 Ports on: 912 Watt
- Processing 16 X 100 Gbps Traffic, 16 Ports off: 875 Watt

## Freeing half of the NPUs or 2 Ports per NPU

- Processing 16 X 100 Gbps Traffic, 16 Ports on: 906 Watt
- Processing 16 X 100 Gbps Traffic, 16 Ports off: 872 Watt

## Turning routers off



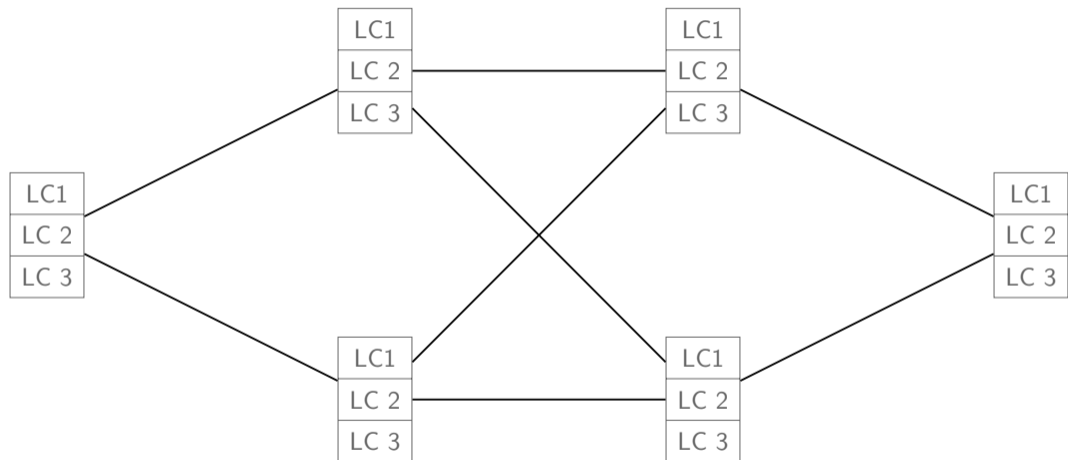
## Turning ports off



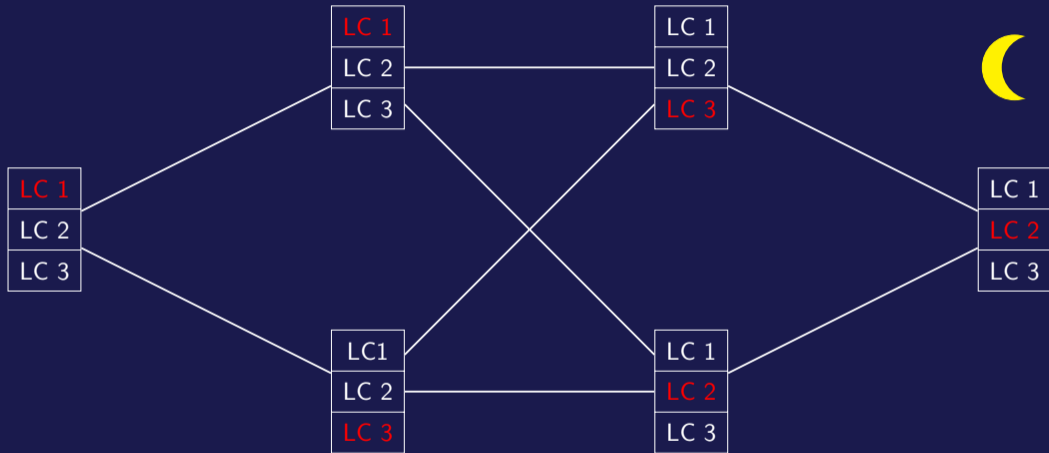
## Turning linecards off



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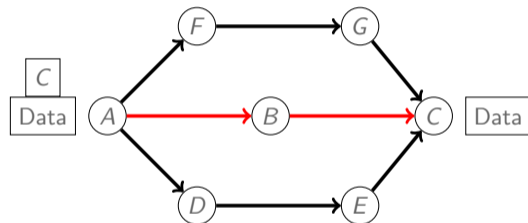






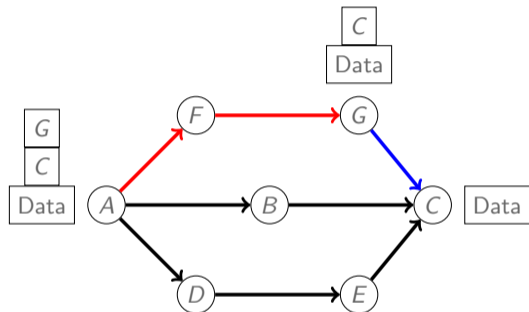
## Segment Routing

- Source Routing Architecture.
- Define interim destinations.
- Using the IGP to reach waypoints.
- Reducing algorithmic complexity.
- Already implemented.



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- Source Routing Architecture.
- Define interim destinations.
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Source	Destination	Traffic
Node1	Node5	42
Node3	Node4	5
...	...	...

$$\begin{aligned}
 \min & \sum_{i \in N} \sum_{j \in N} |x_{ij}| \\
 \text{s.t.} & \sum_{j \in N} x_{ij} = 1 \\
 & x_{ij} \geq 0 \\
 & \sum_{i \in N} \sum_{j \in N} x_{ij} \leq \sum_{i \in N} \sum_{j \in N} c_{ij} \\
 & \sum_{i \in N} x_{ij} = \sum_{k \in N} x_{ki} \\
 & x_{ij} \in \{0,1\}
 \end{aligned}$$

$$\begin{aligned}
 W_{i,j} & \in S^1 & (i) \\
 W_{i,j} & \in S^1 & (ii) \\
 W & \in A & (iii) \\
 W_{i,j} & \in A & (iv) \\
 W & \in \bigcup_{i \in N} P(i) & (v)
 \end{aligned}$$

Output:

- Routing Policy
- Reduced Topology

## MCF-LC

- Target Function: Minimize the number of active linecards
- Every Path is allowed
- Upper bound for the link utilization: 70 %
- Theoretical upper bound

## 2SR-LC

- Target Function: Minimize the number of active linecards
- Paths are limited to all 2-SR Paths
- Upper bound for the link utilization: 70 %

## Repetita Instances [2]

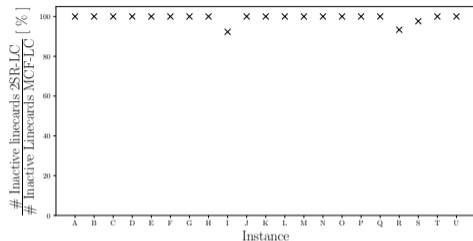
- 21 Random Instances.
- Reduced the traffic by 50 %.
- Usage of the A99-8X100GE-TR linecard is assumed.

## Repetita Instances [2]

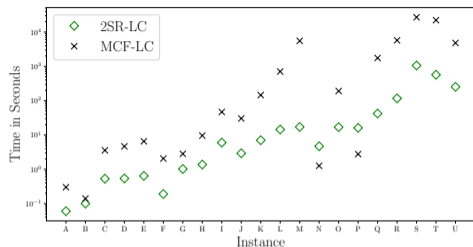
- 21 Random Instances.
- Reduced the traffic by 50 %.
- Usage of the A99-8X100GE-TR linecard is assumed.

## Real-World Instances

- Includes traffic and topology.
- One Snapshot from every month of 2020 and 2022.
- All snapshots were taken at 1:00 a.m.
- Usage of the A99-8X100GE-TR linecard is assumed.



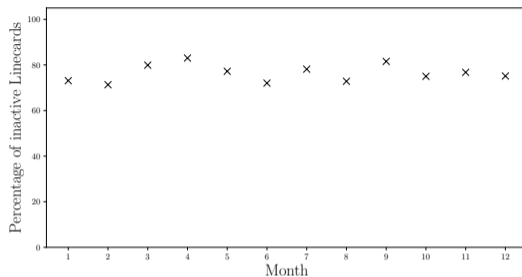
(a) Solution of 2SR-LC compared with MCF-LC



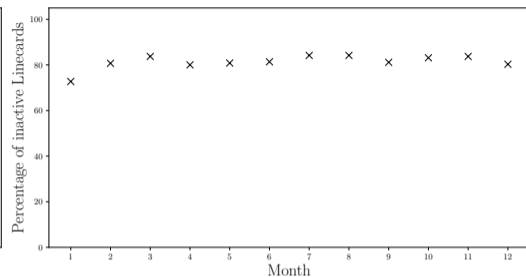
(b) Run time of 2SR-LC compared with MCF-LC

- Nearly optimal results
- Significantly reduced computation time



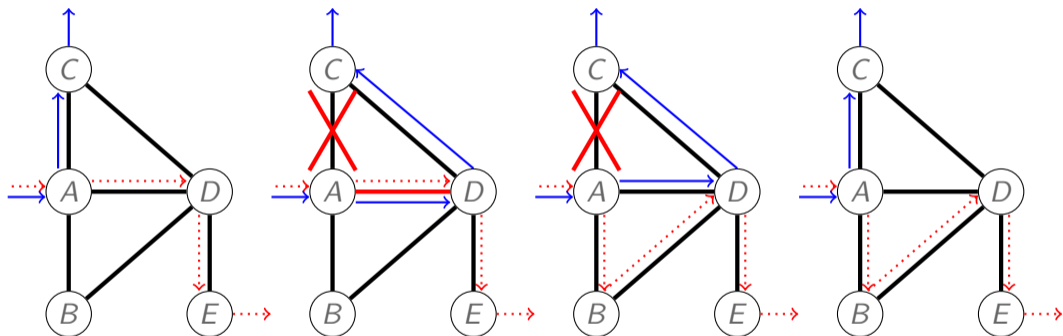


(a) Evaluation of 2020



(b) Evaluation of 2022

- Overall Energy Consumption (theoretically) reduced by 50 %
- Heuristic works on bigger instances





Source	Destination	Traffic
Node1	Node5	42
Node3	Node4	5
...	...	...

$$\begin{aligned}
 \min & \sum_{e \in E} |x_e| \\
 \text{s.t.} & \sum_{e \in E} x_e = 1 & W_{u,v} \in \mathbb{R}^+ & (1) \\
 & x_e \leq 0.5 & W_{u,v} \in \mathbb{R}^+ & (2) \\
 & \sum_{u,v \in V} \sum_{e \in E} x_e W_{u,v} \leq f & f \in \mathbb{R}^+ & (3) \\
 & \sum_{u,v \in V} x_e = \sum_{u,v \in V} f_e & & (4) \\
 & x_e \in \{0,1\} & & (5)
 \end{aligned}$$

Output:

- Routing Policy
- $MLU \leq 0.5$
- Reduced Topology
- no link turned off completely



Result Step 1

### Make the solution failure resilient

- Check all error cases
- If a Link is overloaded add corresponding constraint
- Solve the ILP
- Repeat until done

Source	Destination	Traffic
Node1	Node5	42
Node3	Node4	5
...	...	...

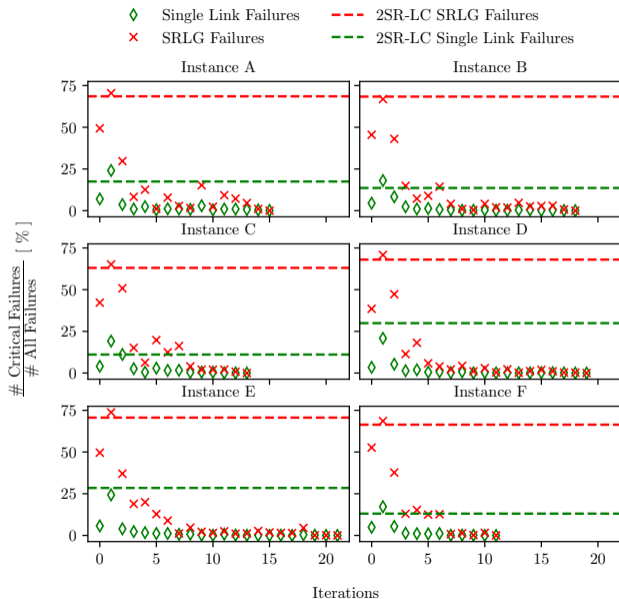
## Real-World Instances

- Includes traffic and topology.
- One snapshot from six months of 2022.
- All snapshots were taken at 1:00 a.m.
- Usage of the A99-8X100GE-TR linecard is assumed.

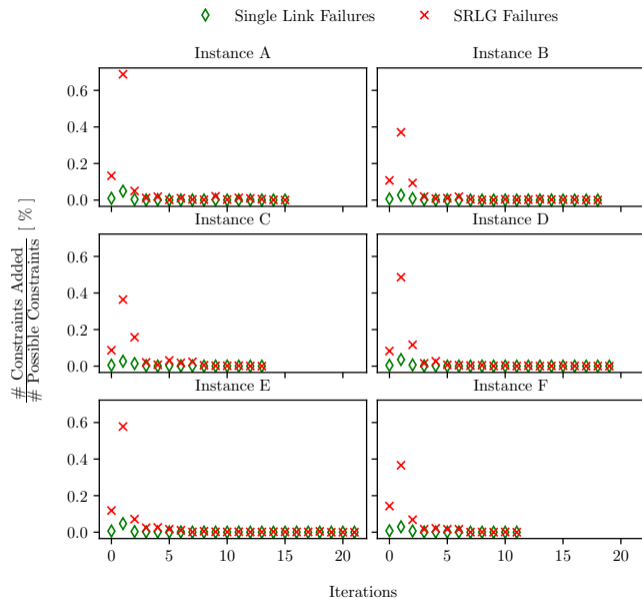
## Failure Scenarios

- All Single Link Failures.
- Shared Risk Link Group (SRLG) Failures.

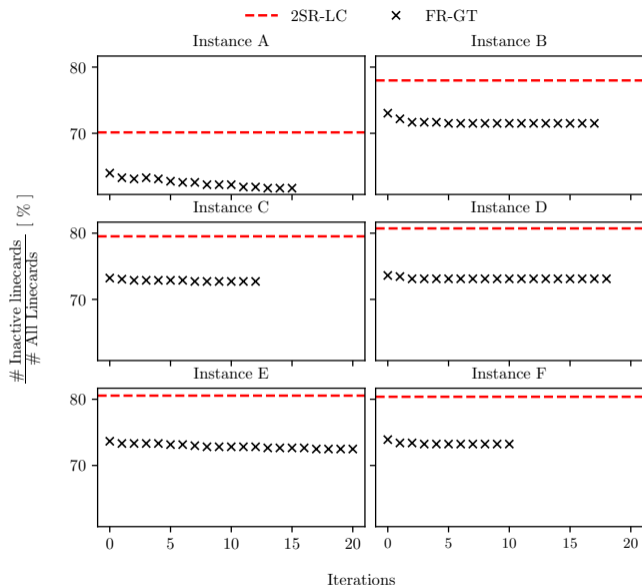
- More than 50 % of all errors are critical
- At most 21 Iterations are needed



- Only a small fraction of all possible constraints added per iteration.
- Effective reduction of computational overhead.



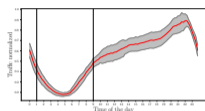
- Initial decrease in deactivated linecards during the process
- Only a small extra amount of linecards is needed to solve all errors





- [1] Daniel Otten et al. “On Modelling the Power Consumption of a Backbone Network”. In: *Proc. of the IEEE International Conference on Communications Workshops (ICC Workshops)*. 2023.
- [2] S. Gay et al. “REPETITA: Repeatable Experiments for Performance Evaluation of Traffic-Engineering Algorithms”. In: *ArXiv e-prints (2017)*. arXiv: 1710.08665.
- [3] Daniel Otten et al. “Green Traffic Engineering by Line Card Minimization”. In: *Proc. of LCN*. 2023. DOI: 10.1109/LCN58197.2023.10223344.
- [4] Daniel Otten and Nils Aschenbruck. “Failure Resilient Green Traffic Engineering”. In: *Accepted for the LCN*. 2024.

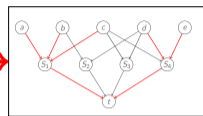
## Contributions and Findings:



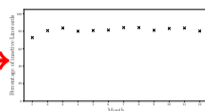
Traffic-Analysis



Measurement



Complexity-Analysis

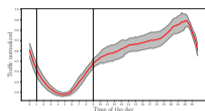


Evaluation

## Future Work:

- Reducing the number of policies
- Considering additional constraints

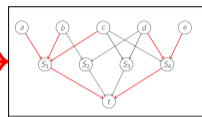
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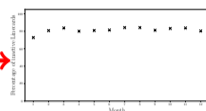
Traffic-Analysis



Measurement



Complexity-Analysis



Evaluation

## Future Work:

- Reducing the number of policies
- Considering additional constraints

Time's up? Find me at  
<https://sys.cs.uos.de/otten/>  
or contact me directly:  
[daotten@uos.de](mailto:daotten@uos.de)