

GreenTE:

Power-Aware Traffic Engineering

Beichuan Zhang (University of Arizona)

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  - Driven by exponential growth of data traffic.

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- Limits are being reached:
  - Power delivery to the total system as well as to components.
  - Cooling router components
  - Heat removal from the box and the facility
- Router energy consumption is becoming an important issue for ISPs, IXPs, and Data Centers.
  - System performance, financial, environmental implications.

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- Networks

- Routing affects router's workload, thus its energy consumption.
- *Traffic engineering for better network-wide energy efficiency?*

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# Today's ISP networks

- Built for service availability
  - Overprovision of link capacity
  - Redundant links/paths
  - Load-balancing traffic engineering
  - Lead to low average link utilization.



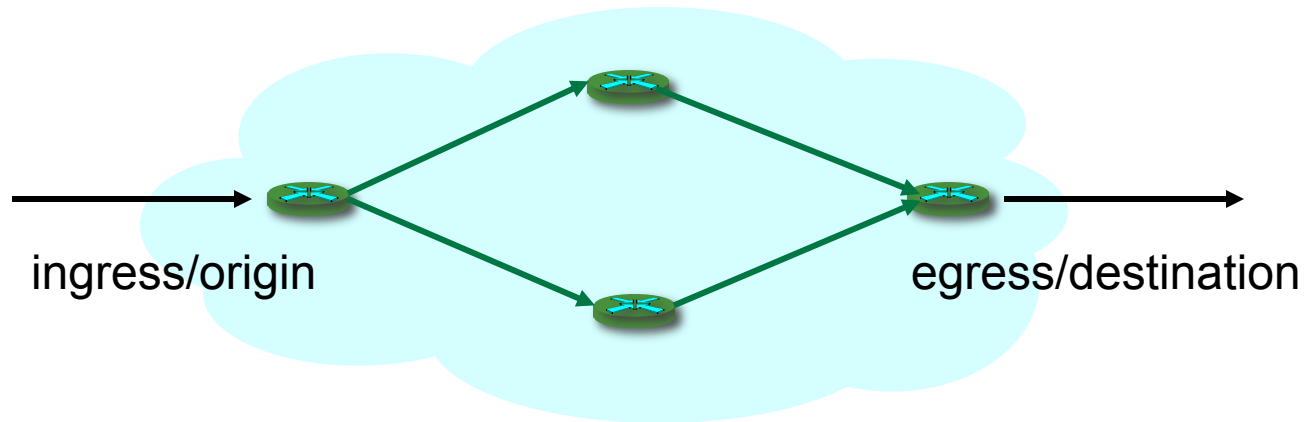
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  - Lead to low average link utilization.
  
- Not very efficient in using energy
  - Routers/links are up 24x7 at full capacity, regardless of workload.
  - Both opportunities and challenges.

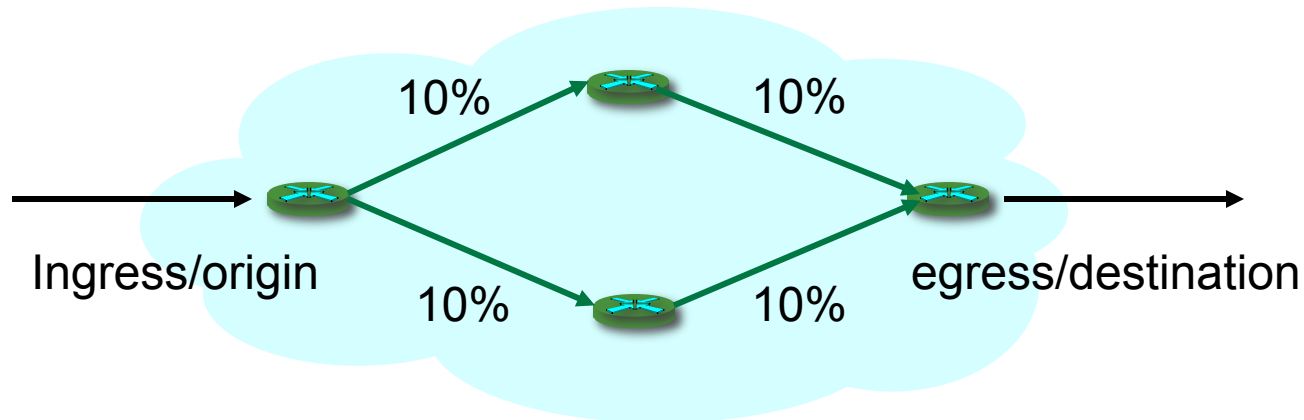
# Opportunities in power-aware TE

- Take advantage of path redundancy and low link utilization.



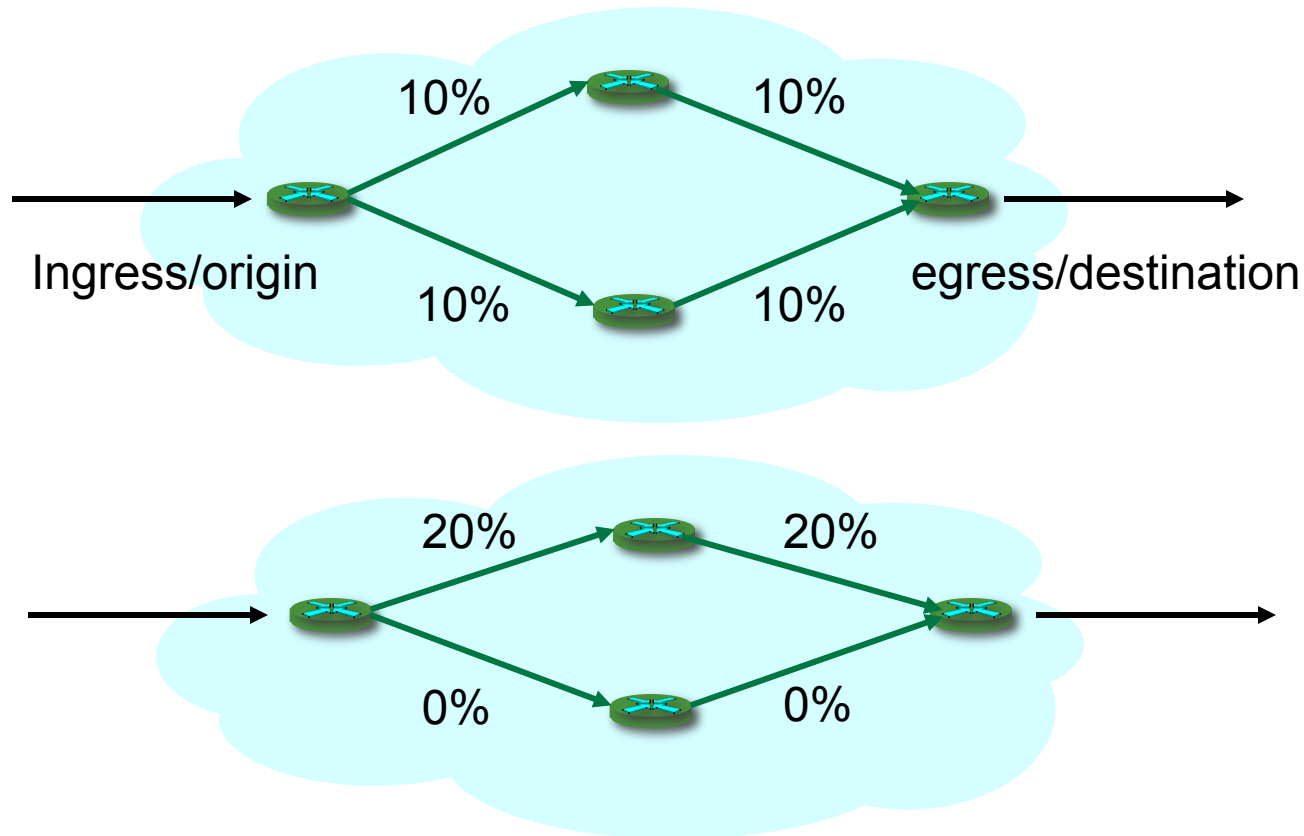
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# Research Questions

- Which links to turn on/off and how much traffic each link should carry?
  - An optimization problem.
- How to maintain performance at the desired level?
  - Link utilization and delay
  - Network reliability
- How to realize the traffic distribution?
  - Traffic engineering mechanisms

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  - Traffic matrix

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  - Maximize total energy saving from turning off line-cards
  - Such that
    - Flow conservation holds
    - Max link utilization (MLU) below a threshold (50%)
    - Delay is bounded (same network diameter or 2x OD delay)
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## A heuristic solution

- Search in a set of pre-computed candidate paths instead of all possible paths.
  - k-shortest paths
  - Apply delay constraints in choosing the candidate paths.
- Take another step to balance link load after knowing which links will be on.

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# Protocol and operation issues

- A server collects input, solves the problem, and distributes the solution.
  - Need to be done periodically to adapt to traffic changes.
- Piggyback on OSPF-TE
  - TE-LSA for input, TE-Metric for result.
  - Take advantage of LSA flooding
- Forwarding is done via both OSPF and MPLS
  - Make changes by changing MPLS tunnels rather than network-wide OSPF convergence.
- Need to handle periodic control messages such as OSPF Hello.

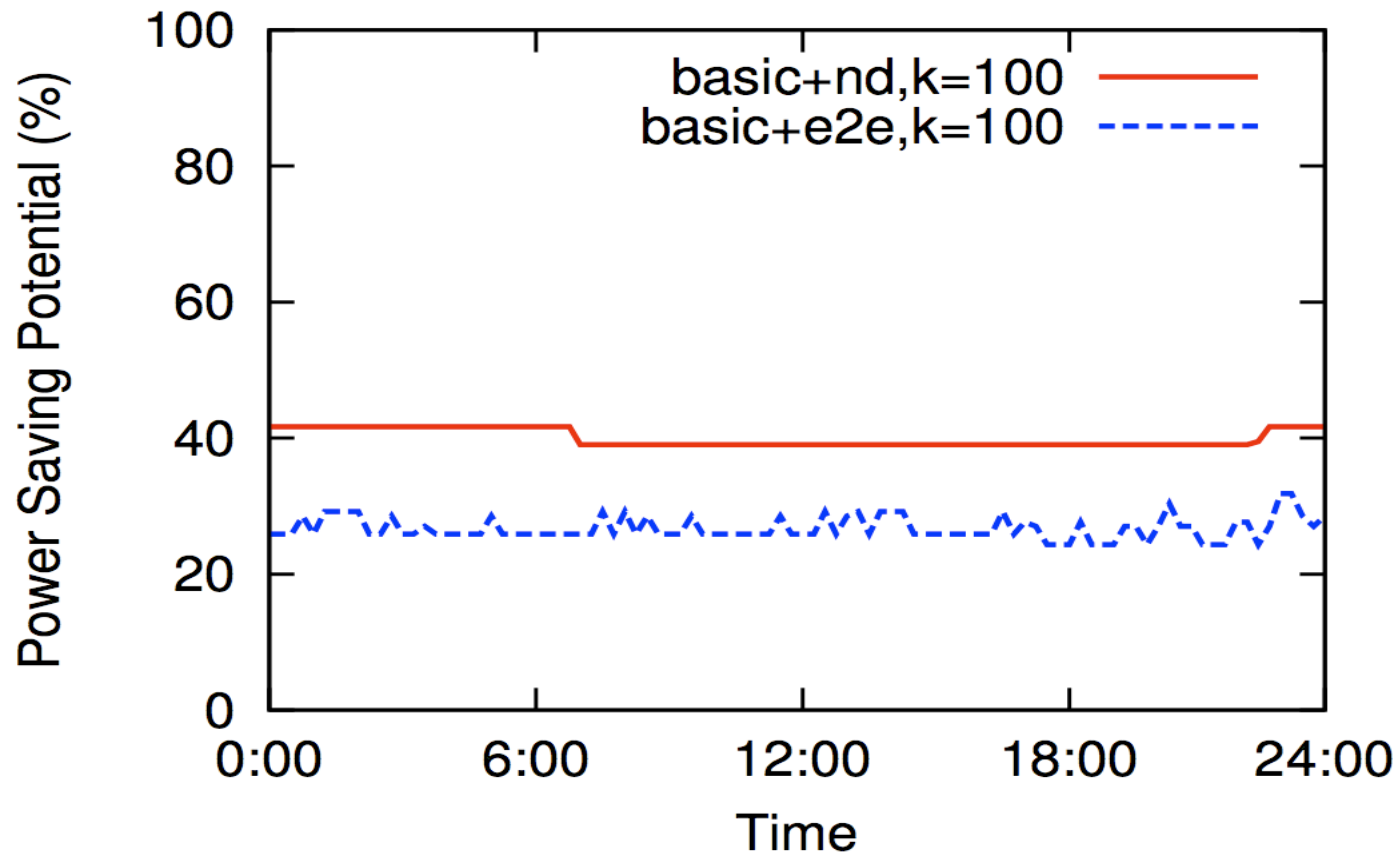
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# Evaluation

- Using data from real networks
  - Real topology and traffic traces for Abilene and GEANT.
  - Measured topology and generated traffic for Sprint and AT&T

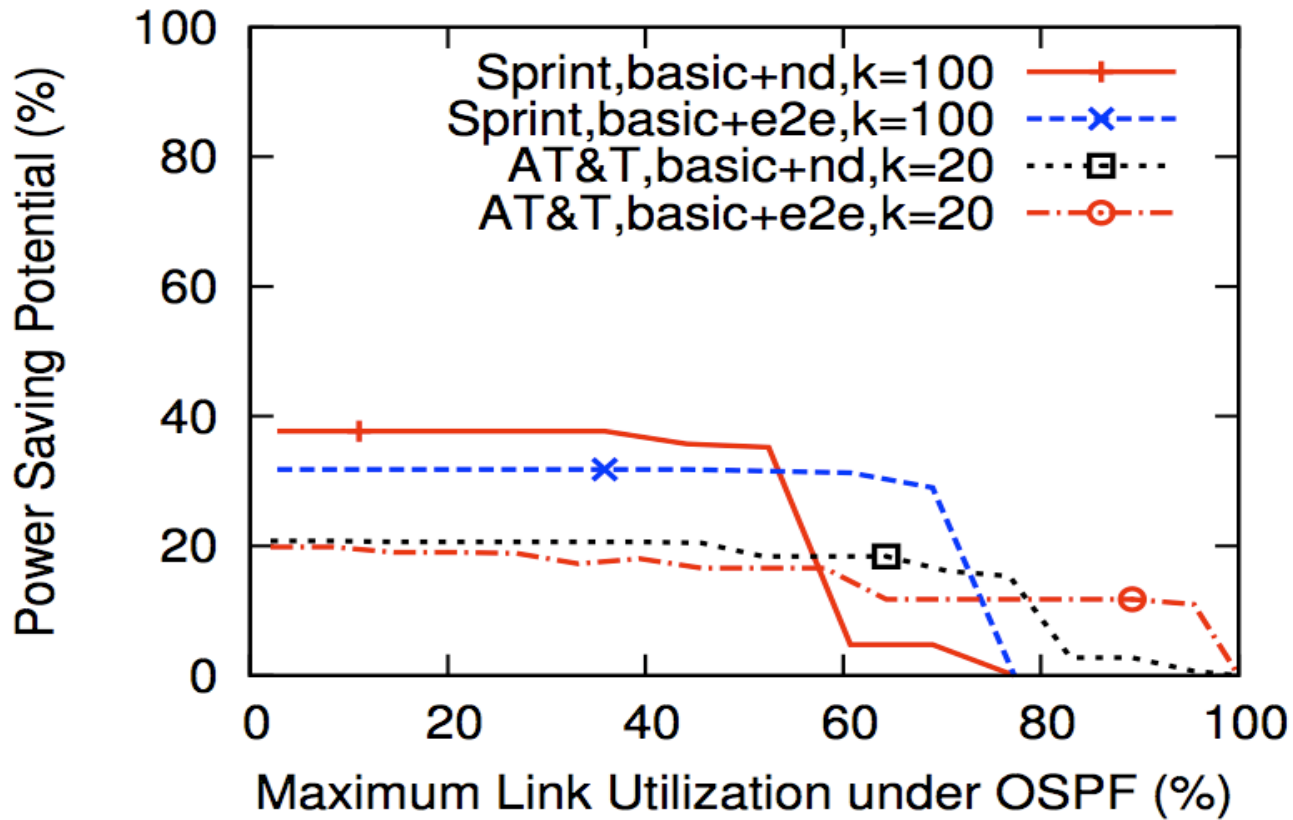
Network	Usage	Location	Nodes	Links
Abilene	Research	US	12	30
GÉANT	Research	Europe	23	74
Sprint	Commercial	US	52	168
AT&T	Commercial	US	115	296

# Power saving



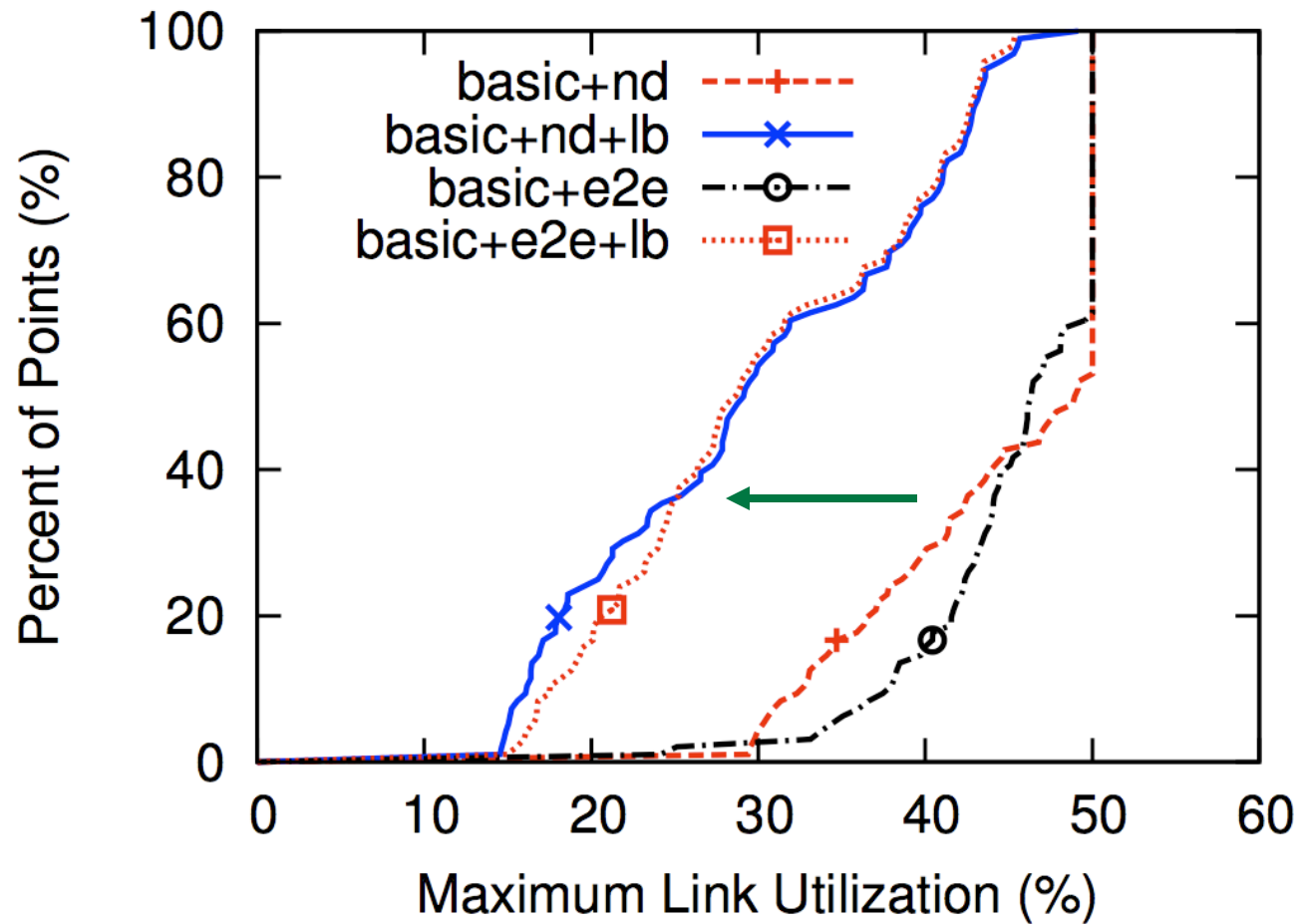
- 27% to 42% of line-card power consumption

# Impact of network load



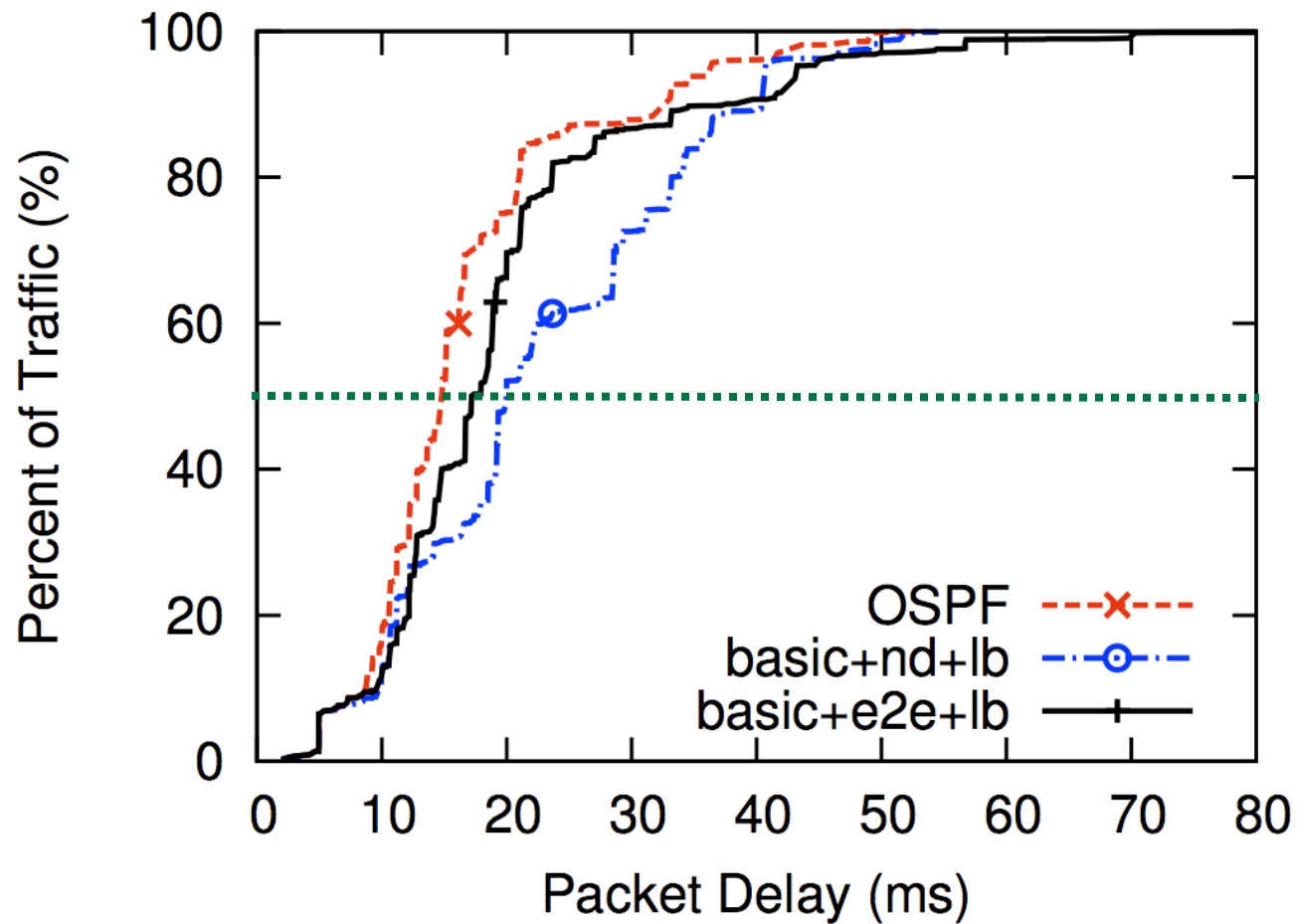
- Links are tuned off under light load, back on under heavy load.

# Load balancing



- Significant improvement after load balancing.

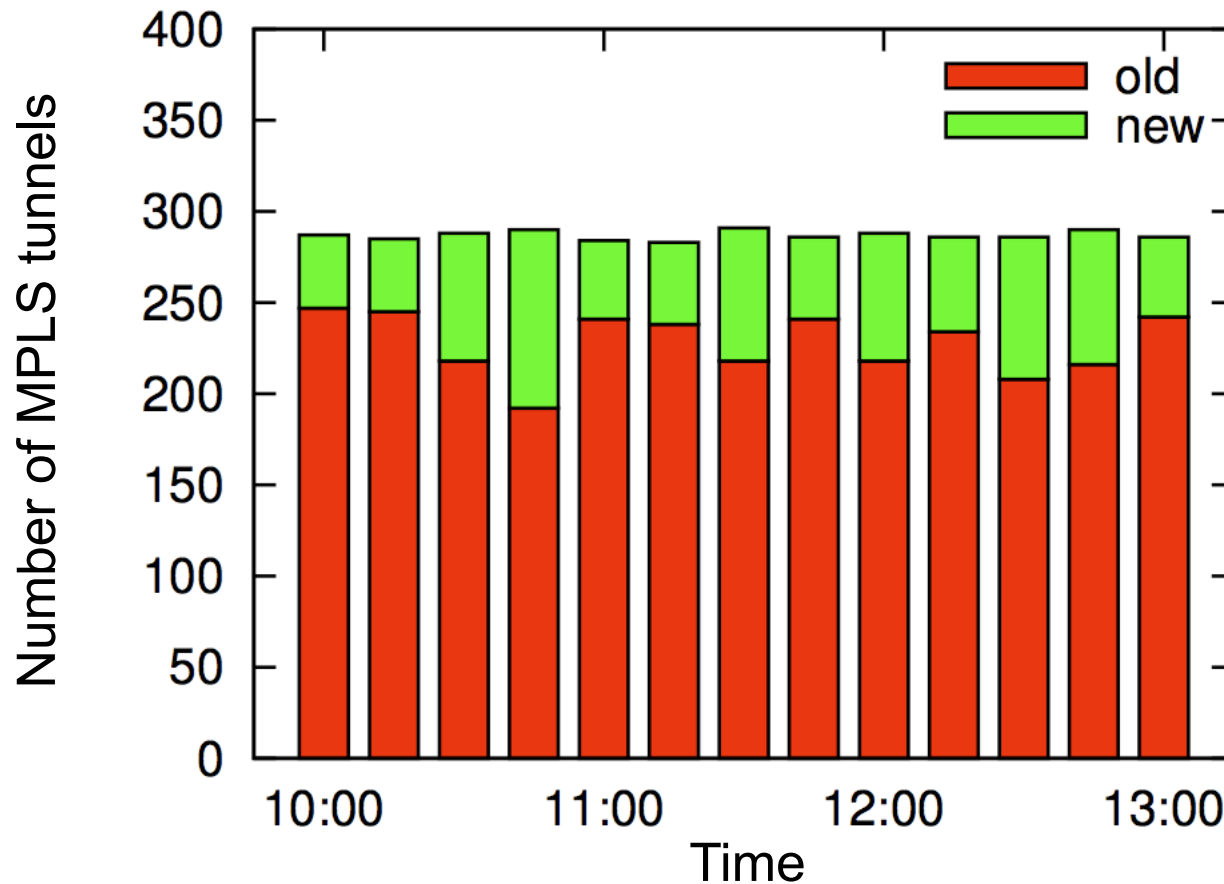
# Delay



- Medium: 15ms, 17ms, 20ms



# Stability of the solution



~70% tunnels remain the same from the previous period.

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## Conclusion and Future Work

- Power-aware routing and traffic engineering is both feasible and beneficial.
- Need better protocol support and hardware/system support.
  - E.g., keep-alive messages.
- Need better handling of potential congestion induced by link failures and traffic bursts.
- Distributed solutions?

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*Questions and Comments?*