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Dynamic Optical Networking via Overlay Control of Static Lightpaths

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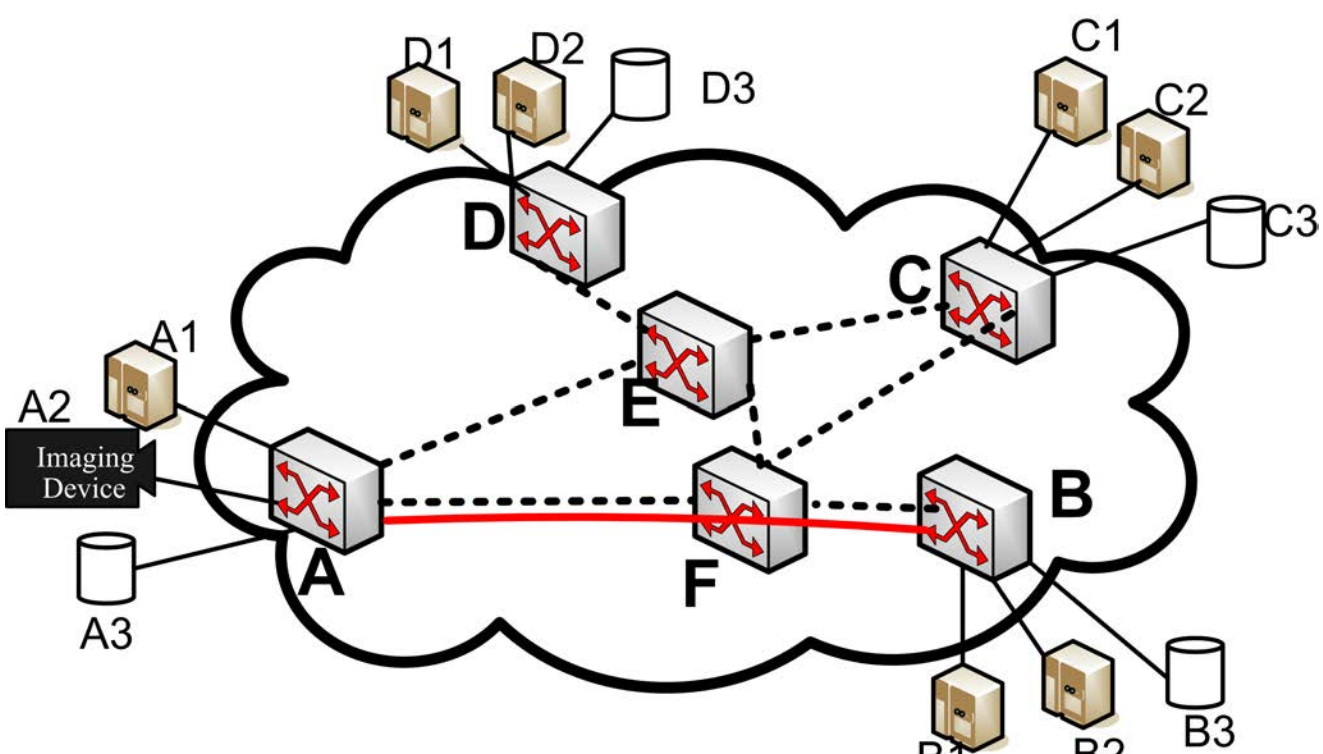
Outline

- Dynamic Optical Networking: Vision vs. Reality
- Edge Reconfigurable Optical Networks (ERONs)
- ERON Dimensioning
- Simulation Results

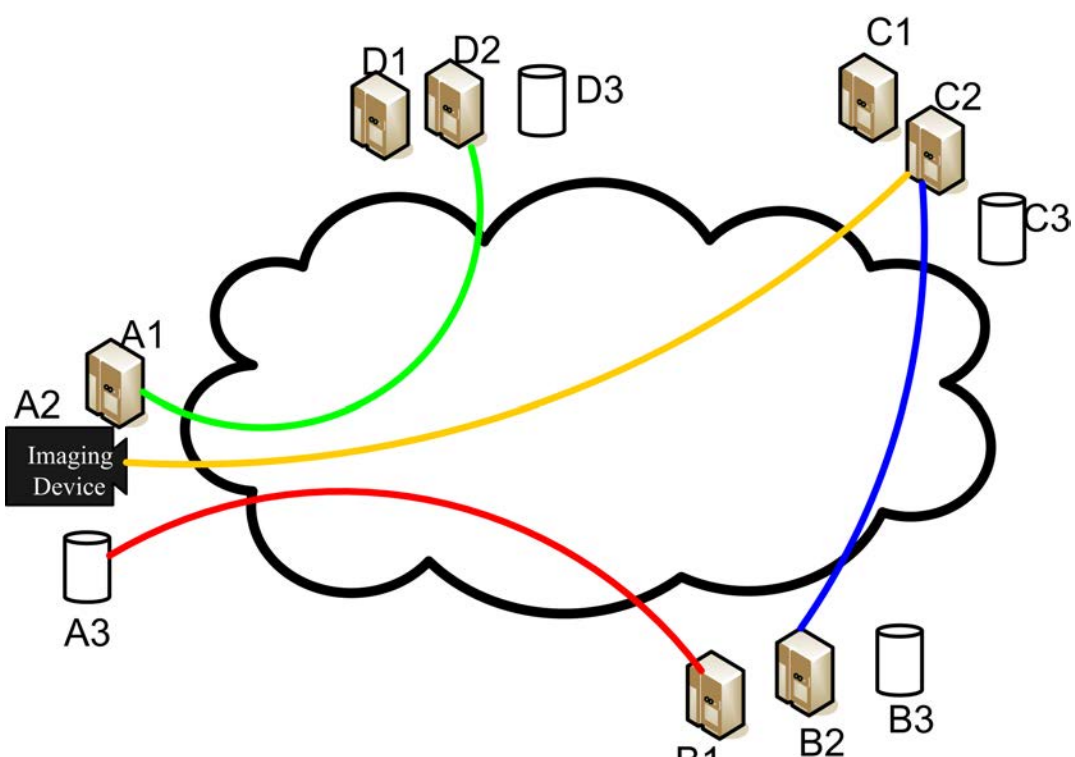
Dynamic Optical Networking: Vision

- E2E transparent lightpaths with optical switching
- Hundreds of λs
- On-demand optical connections
- Highly reconfigurable core networks



Dynamic Optical Networking: Reality

- P2P connections with OEO
- Few λs
- Long-lived, leased lightpaths
- Mostly statically configured core networks



Application Requirements vs. Infrastructure Limitations

- Application and Research Collaboration Requirements:
  - Lightpaths across multi-domain networks
  - Distributed coordination of network & network-attached resources
  - Connection establishment/termination based on user requirements

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- Application and Research Collaboration Requirements:
  - Lightpaths across multi-domain networks
  - Distributed coordination of network & network-attached resources
  - Connection establishment/termination based on user requirements
- Infrastructure Limitations:
  - Lack of capabilities for rapid/automatic lightpath establishment
  - High administrative burden $\longrightarrow$ coordinate multiple providers
  - High cost of (semi-)permanent lightpaths

Static Topologies

- Collection of independent lightpaths; assembled by
  - NRENs
  - academic/research communities
  - large government/private organizations

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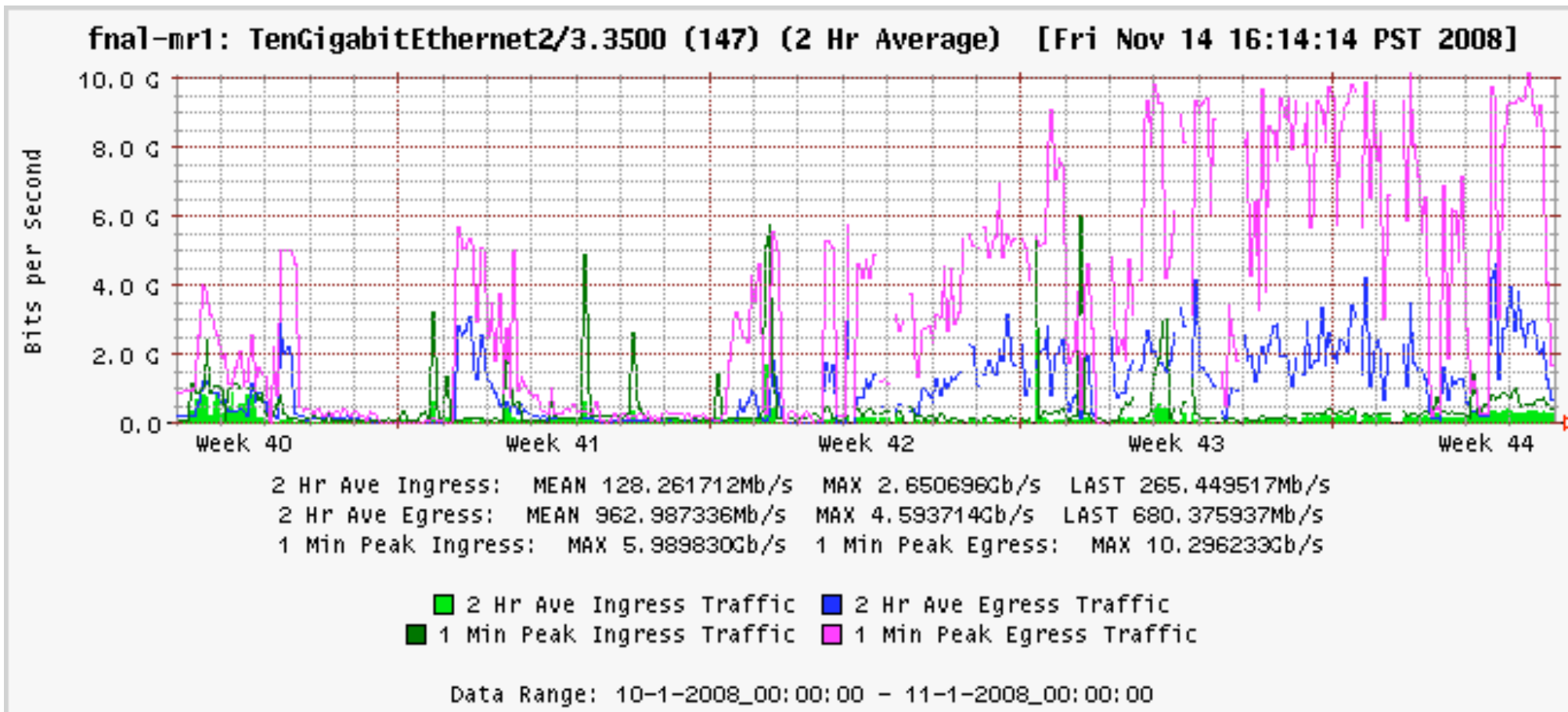
- Collection of independent lightpaths; assembled by
  - NRENs
  - academic/research communities
  - large government/private organizations
- Each lightpath:
  - established on an “as needed basis”
  - dedicated between two end-users
    $\longrightarrow$ high-end devices, instruments, . . .
  - held in place for long time periods ($>$ months)

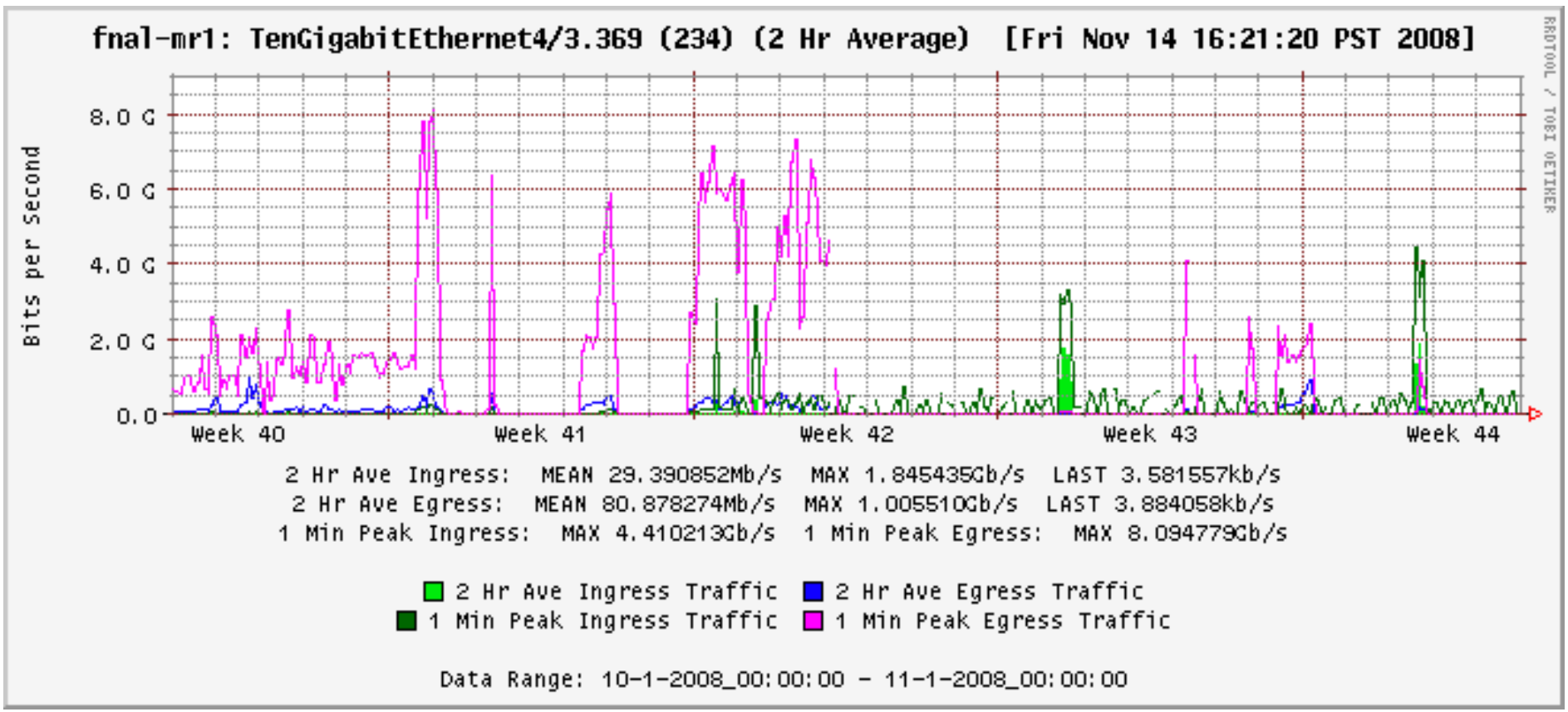
Challenges

- Applications require sporadic access to lightpaths
  $\longrightarrow$ extremely low utilization
- Dedicated lightpaths
  $\longrightarrow$ only available to small fraction of potential users

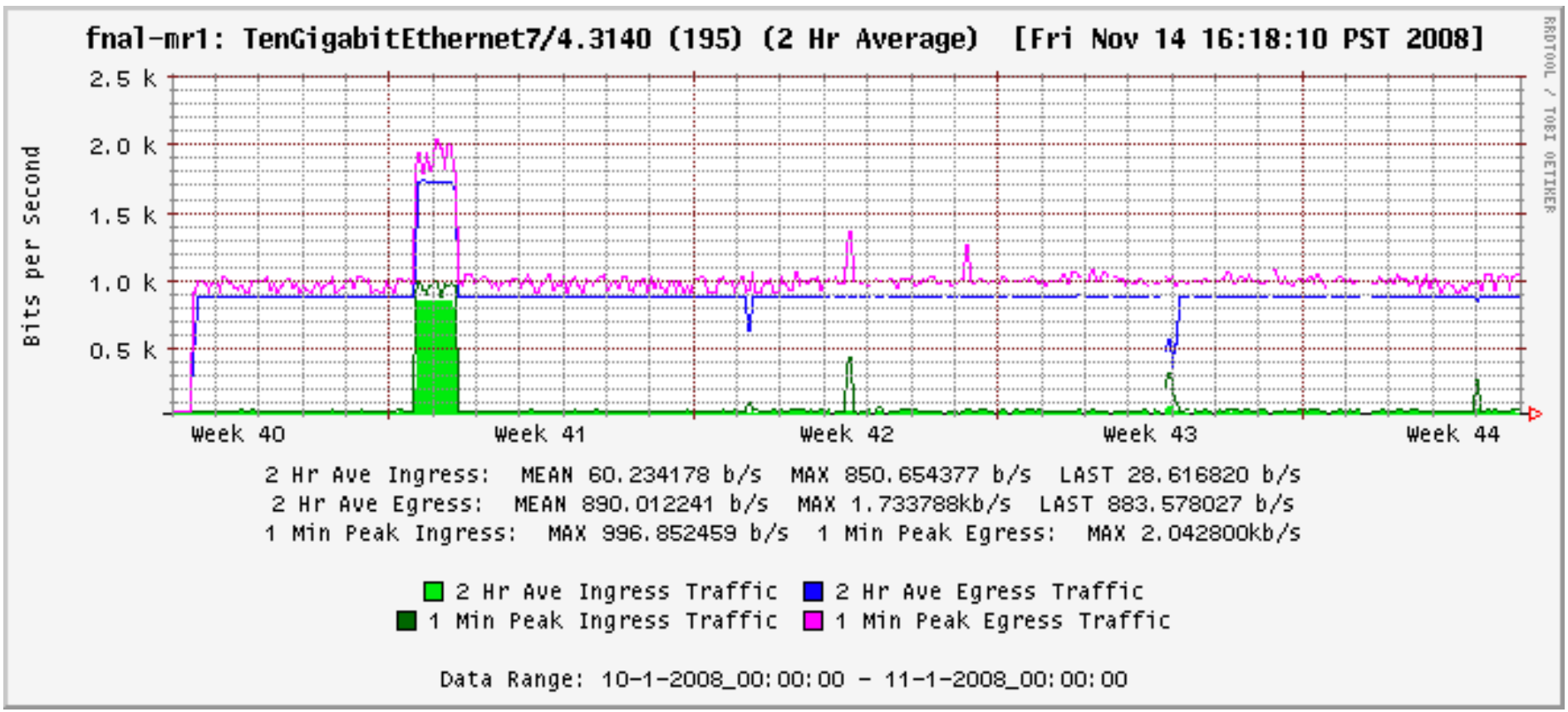
Utilization (1)



Utilization (2)



Utilization (3)



Edge Reconfigurable Optical Networks

- ERON goal:

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- Overlay network:
  - optical switching capabilities at edge nodes
  - under user (not network provider) control

ERON Components

1. A collection of permanent lightpaths
   - leased, connect organization's sites
   - define static logical topology

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   - MEMS optical switches
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2. Edge hardware $\longrightarrow$ under user control
   - MEMS optical switches
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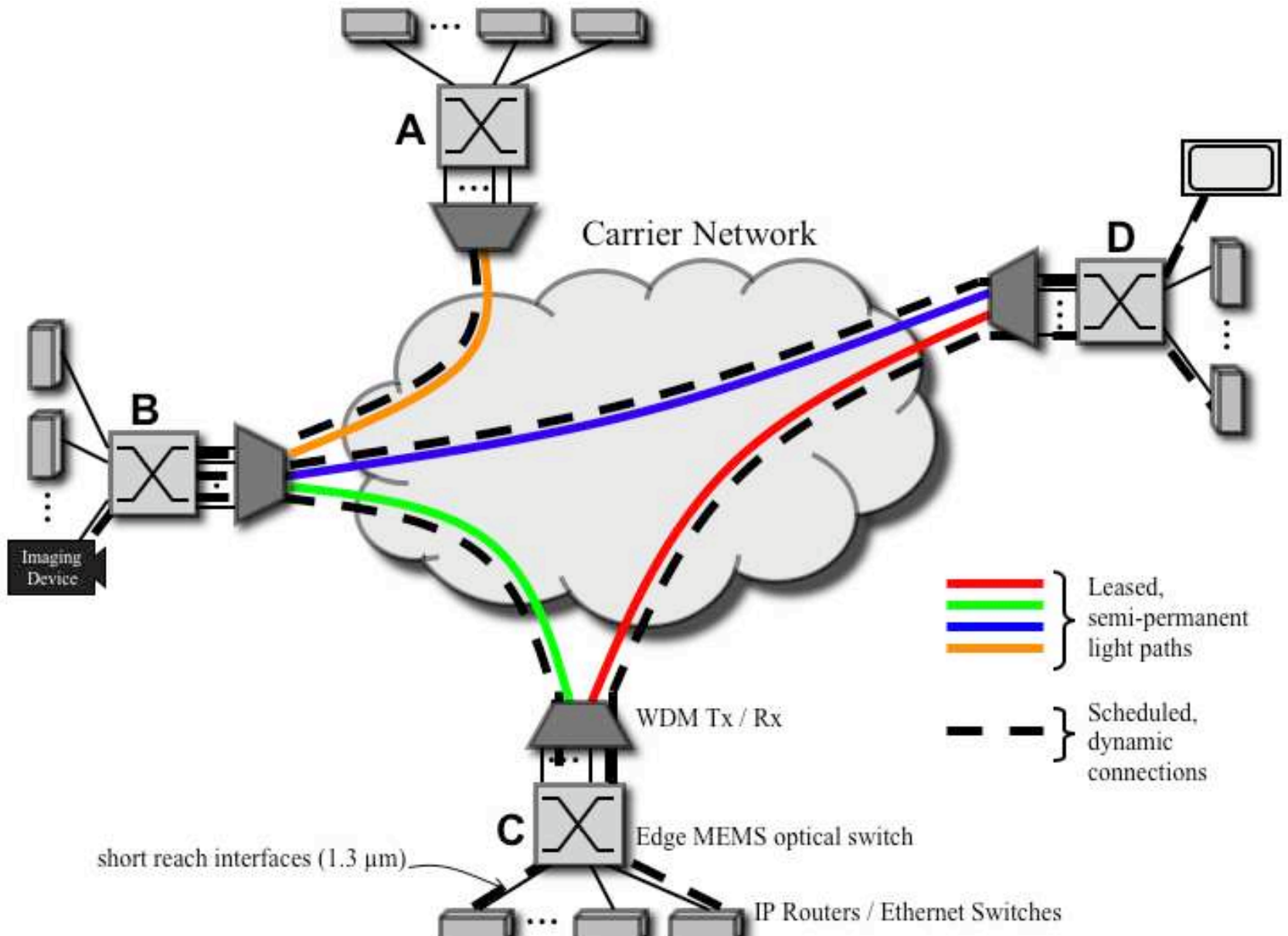
3. Control software $\longrightarrow$ implements control overlay
   - GMPLS signaling
   - resource broker

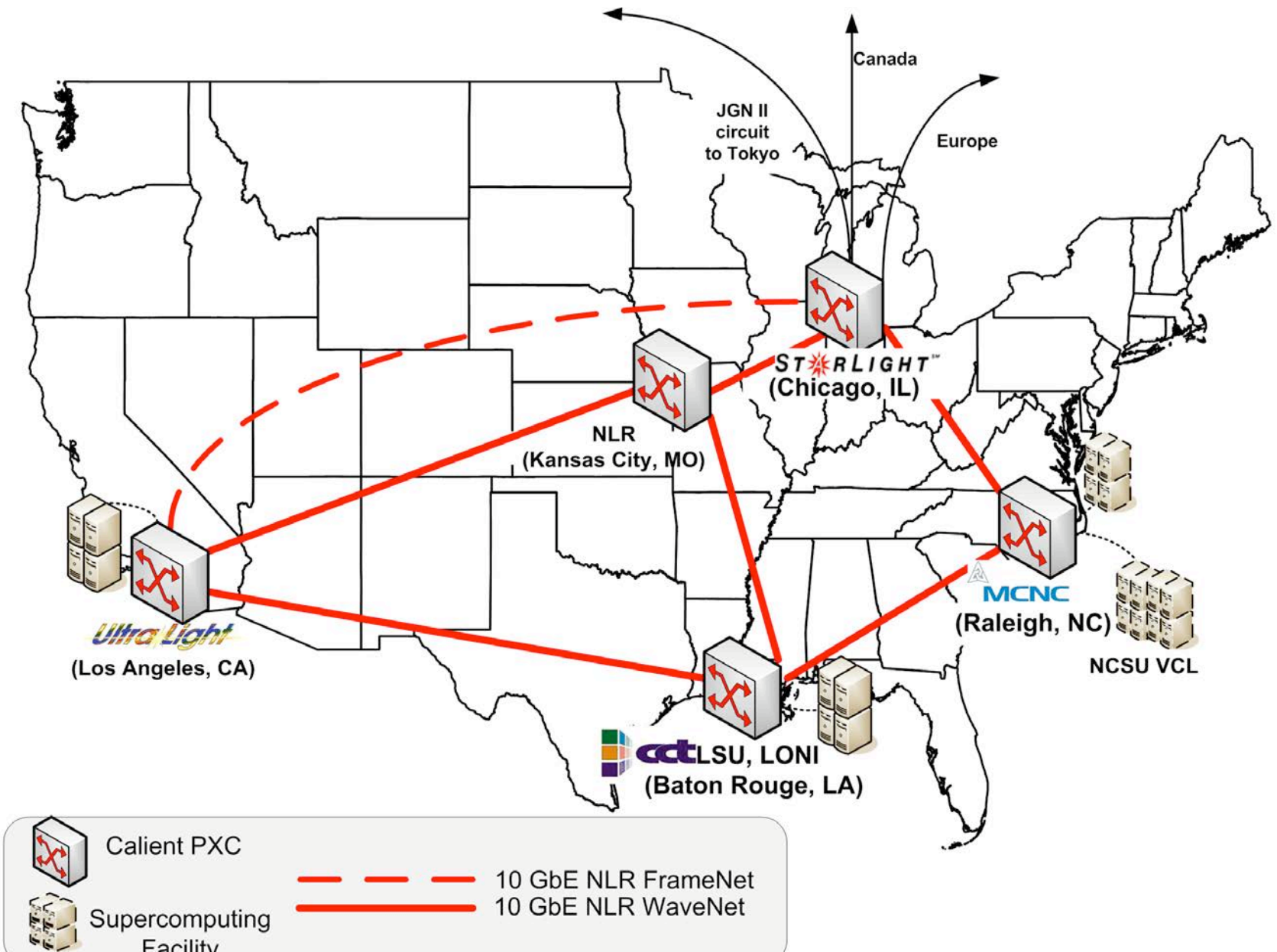
ERON


A
Carrier Network
D
B
Imaging Device
WDM Tx / Rx
C
Edge MEMS optical switch
short reach interfaces (1.3 μm)
IP Routers / Ethernet Switches
Leased, semi-permanent light paths
Scheduled, dynamic connections

ERON Benefits

- Dynamic connections over static topology
- Multihop connections (transparent to network provider)
- Lightpath sharing among multiple users
- Increased “degree of connectivity”
- Higher utilization
- Amortization of high resource cost over many users/applications

EnLIGHTened Computing Testbed



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  - reduced number of lightpaths
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- ERON deployment costs:
  - hardware and software expense (one-time, mostly)
  - possibility of blocking
- Savings?
  - reduced number of lightpaths
  - blocking probability $\leq 10^{-3} \longrightarrow$ QoS metric
- Objective:
  - quantify practically achievable benefits
  - no attempt to find optimal solutions

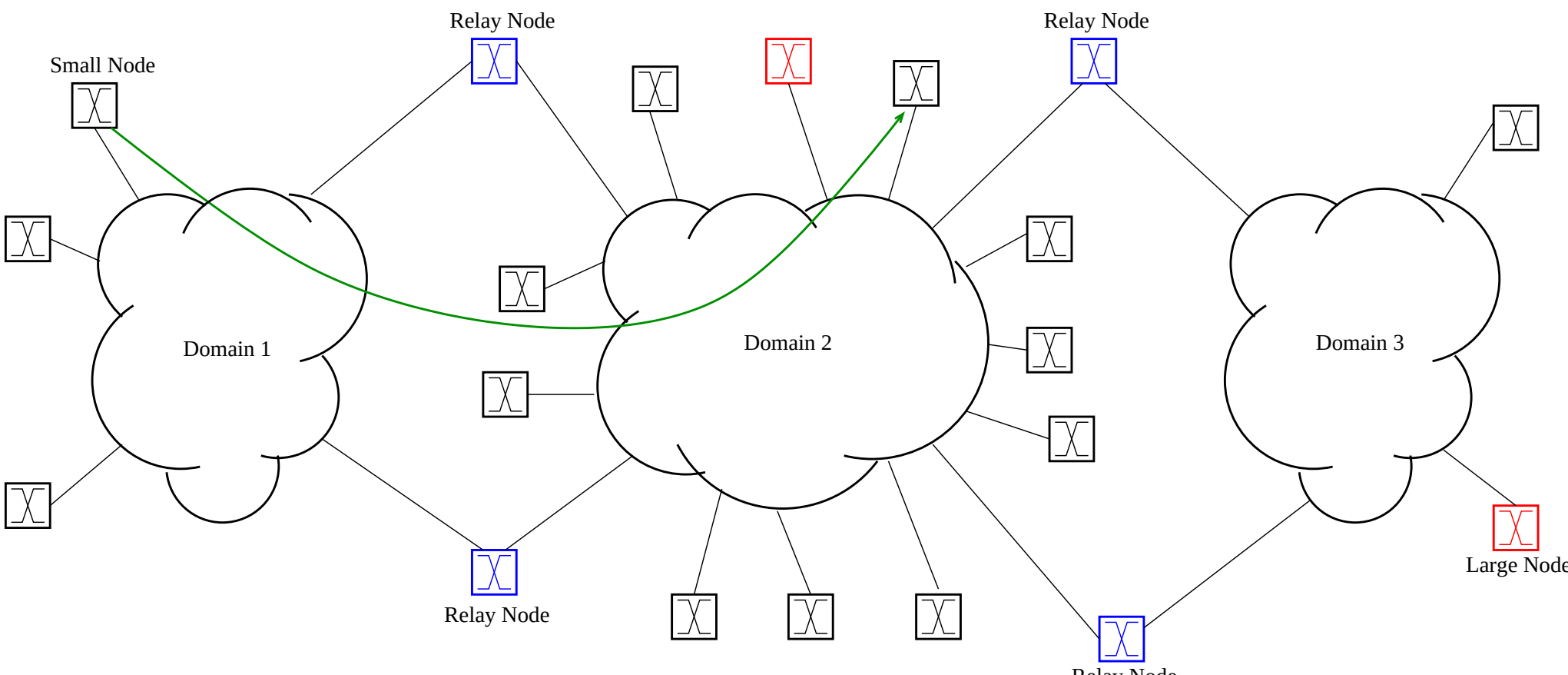
ERON Topology Design

1. Start with static topology $\longrightarrow$ link capacities
2. Run simulation $\longrightarrow$ link utilizations
3. Consider each link in isolation
   - Erlang-B $\longrightarrow$ target link utilization
4. Reduce capacity of link with smallest relative link utilization
5. Repeat from Step 2 while BP$< 10^{-3}$

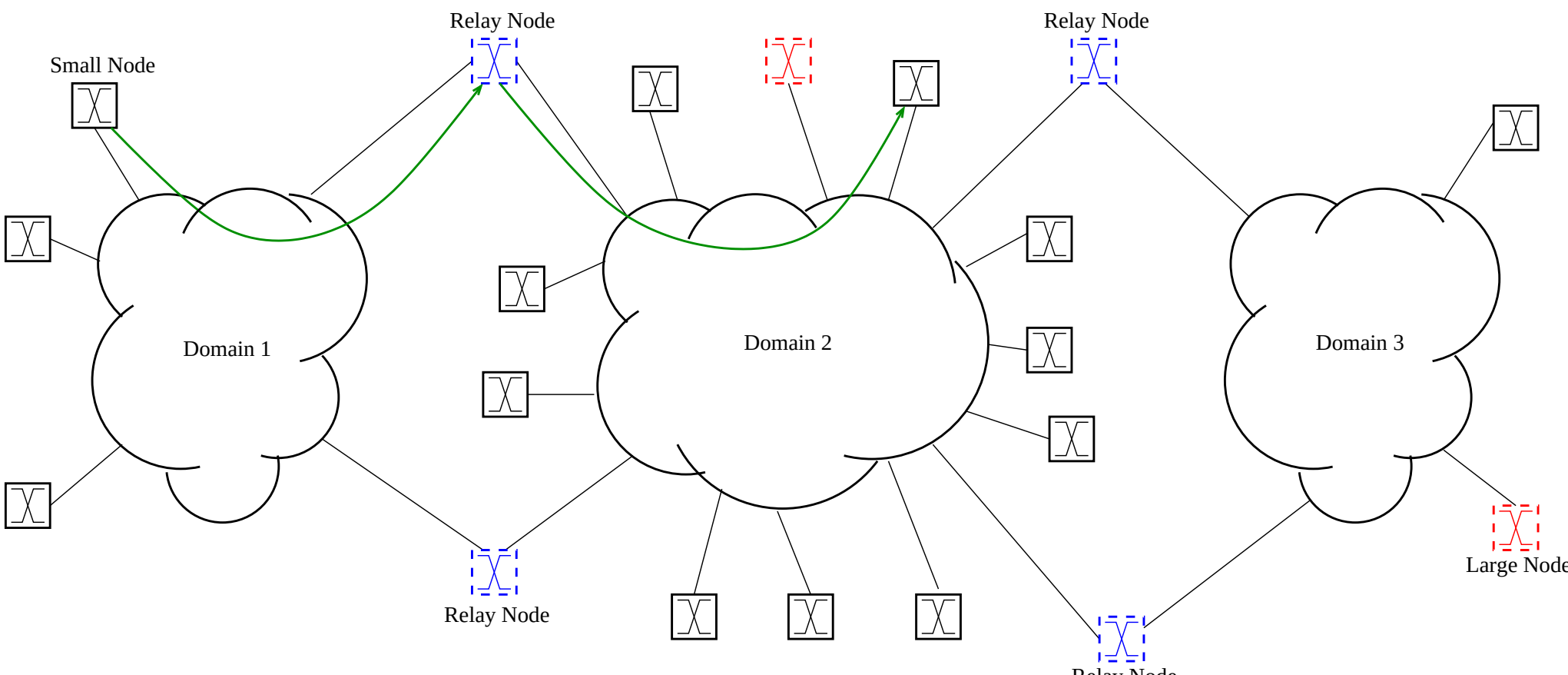
Assumptions: Topology

- $M = 100$ users (end-devices)
- $D = 3$ domains
- $N = 20$ nodes ($\leftrightarrow$ MEMS switches)
  - $N_L = 6$ large nodes (including $N_R = 4$ relay nodes)
  - $N_S = 14$ small nodes
- Domains under different administrative control
  - lightpaths terminate at boundaries
  - end-to-end lightpaths $\leftrightarrow$ intra-domain lightpaths
  - end-to-end lightpath consists of $1 - 3$ intra-domain lightpaths

Three-Domain Topology



Three-Domain Topology



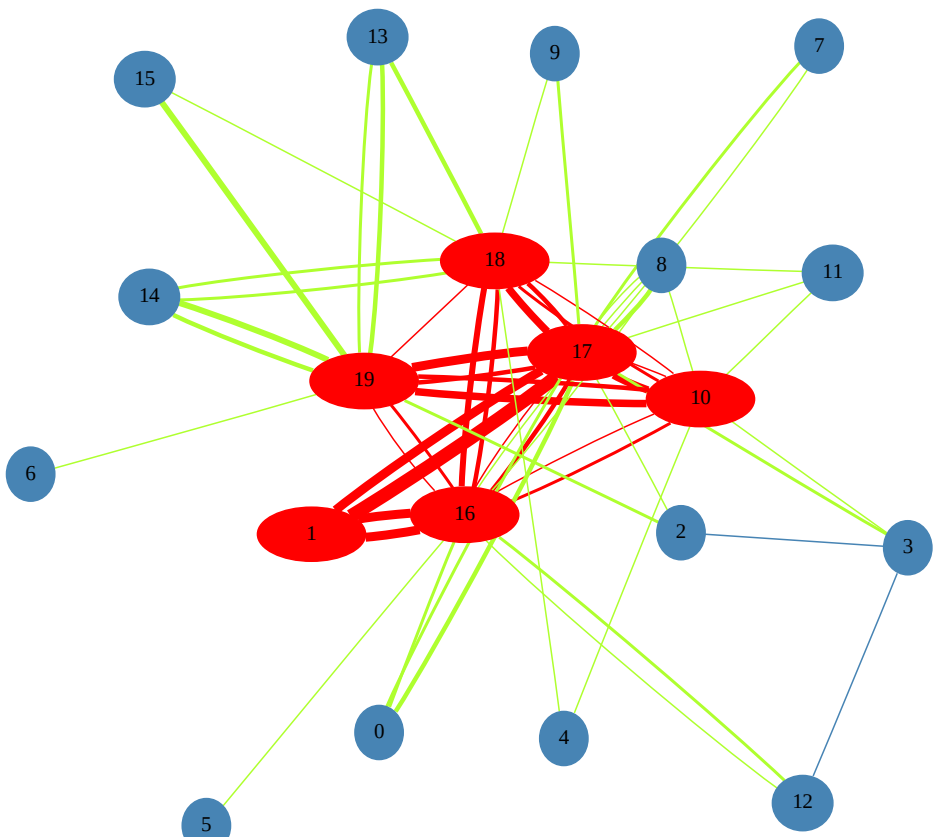
Assumptions: Traffic

- Lightpath capacity: 10 Gbps
- Traffic distribution:
  - 40% Large-Large
  - 40% Large-Small
  - 20% Small-Small
- Traffic Pattern:
  - uniform
  - distance decreasing
  - distance increasing

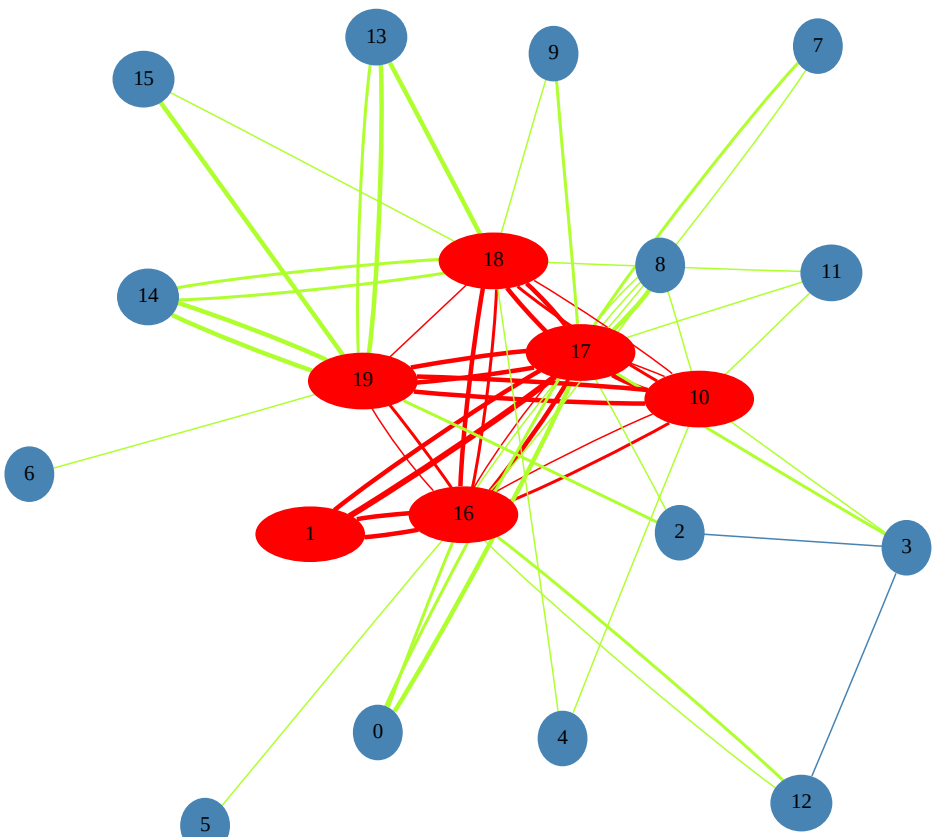
Simulation Scenarios

- Low traffic scenario
  - aggregate traffic: 5, 10, 100, 150, 200, 250, 300 Gbps
- High traffic scenario
  - aggregate traffic: 1.0, 1.5, 2.0, 2.5, 3.0 Tbps

Topology Visualizations: Low Traffic, 100 Connections

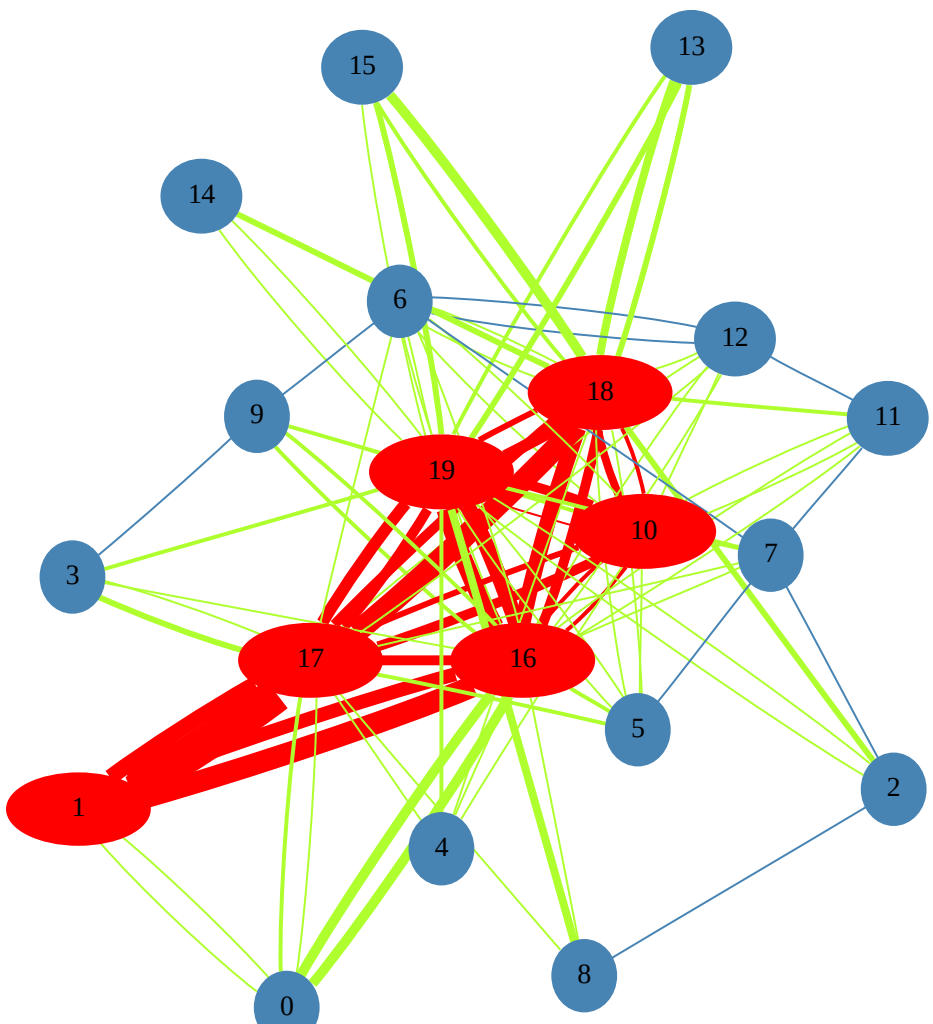


Static topology: 141 LPs

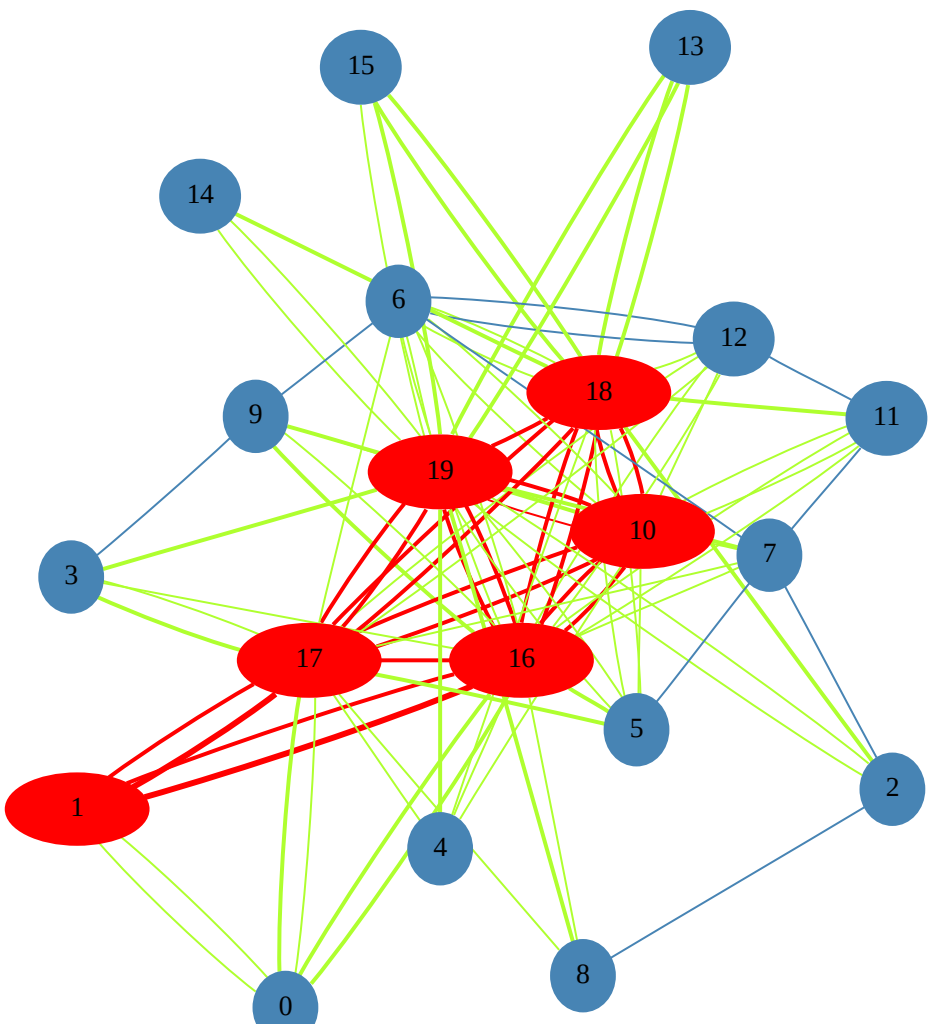


ERON: 114 LPs

Topology Visualizations: Low Traffic, 200 Connections

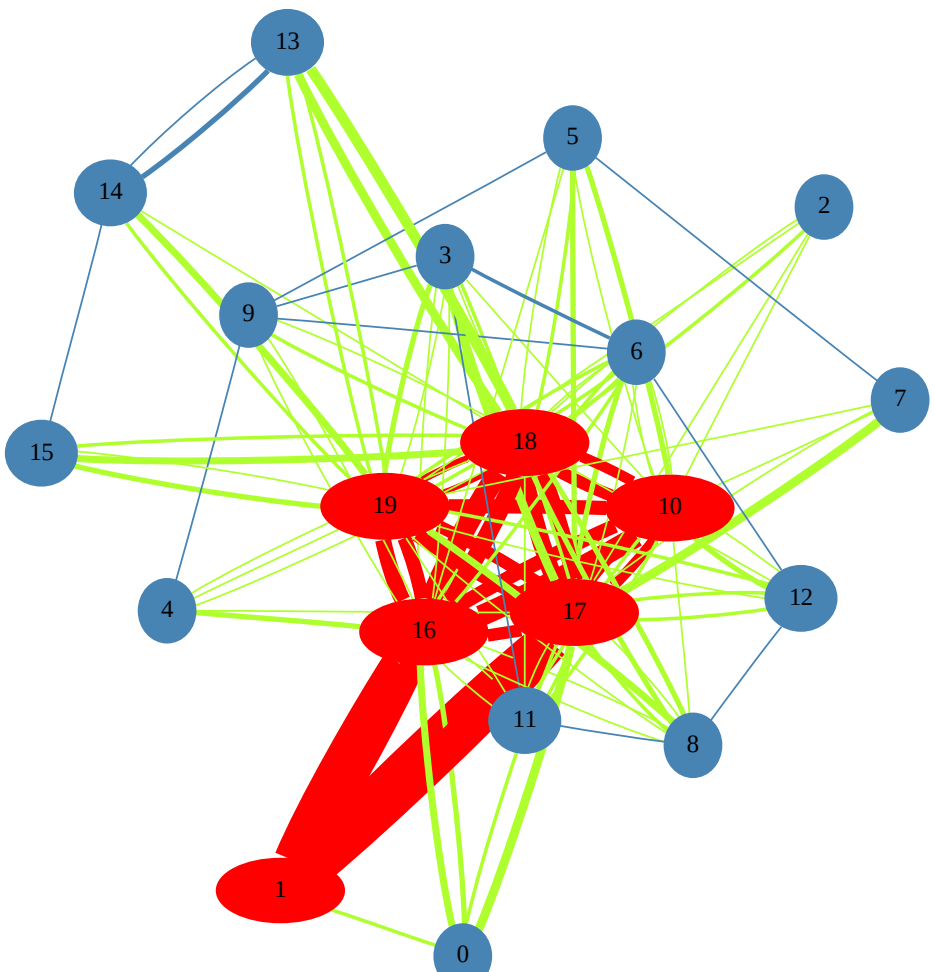


Static topology: 254 LPs

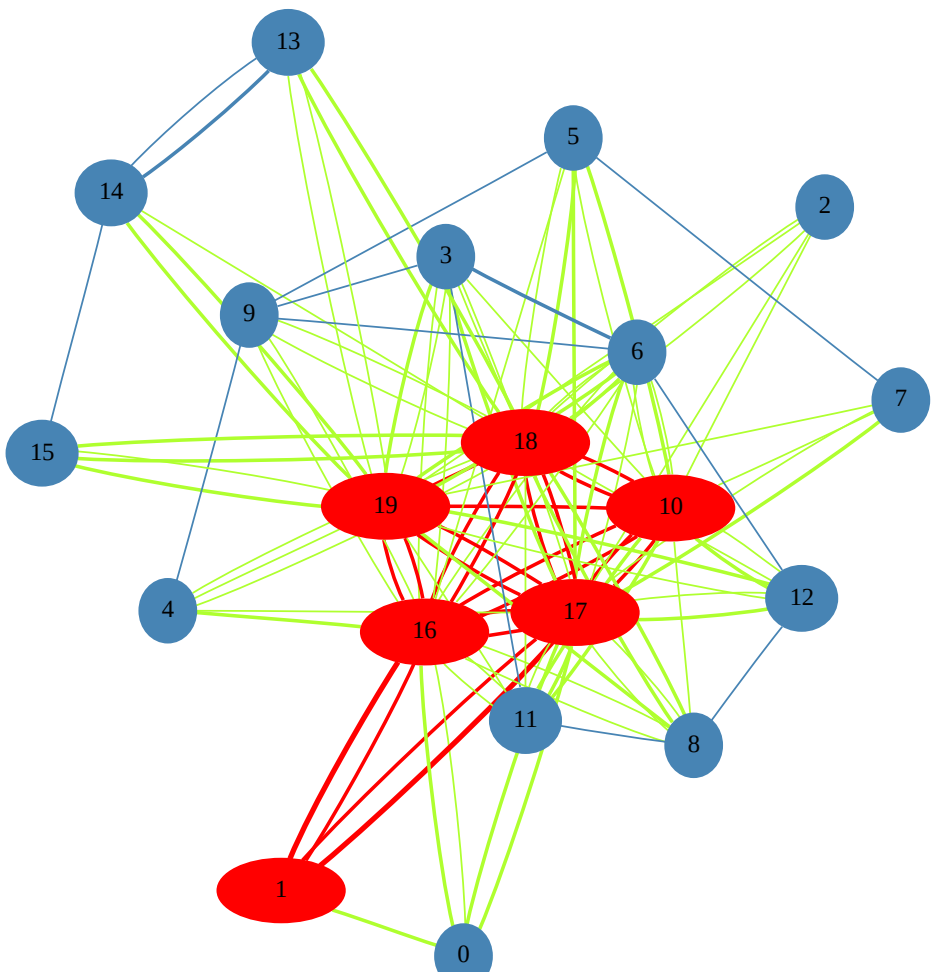


ERON: 143 LPs

Topology Visualizations: Low Traffic, 300 Connections

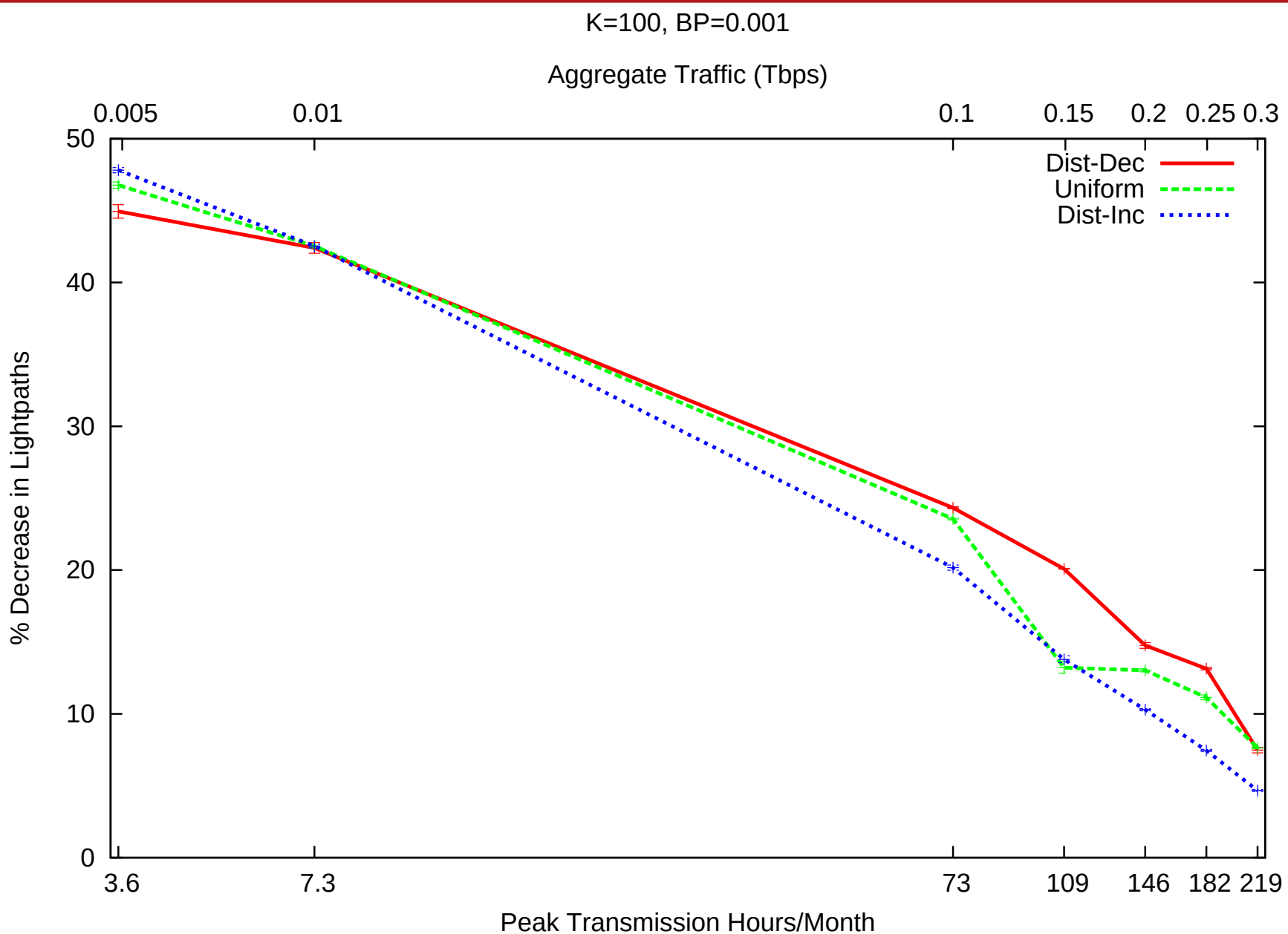


Static topology: 376 LPs

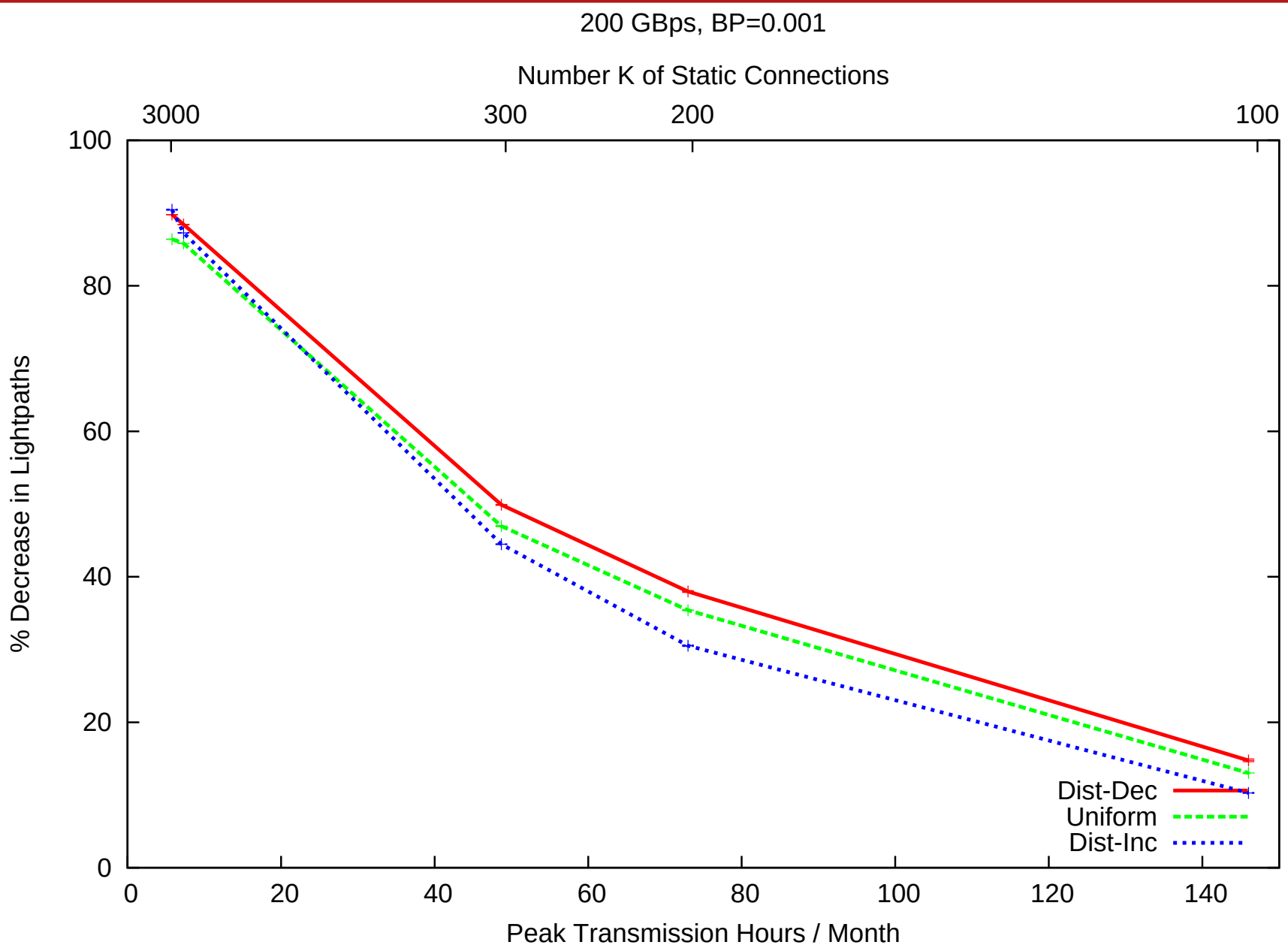


ERON: 173 LPs

Low Traffic Scenario: Effect of Traffic Amount



Low Traffic Scenario: Effect of # of Connections



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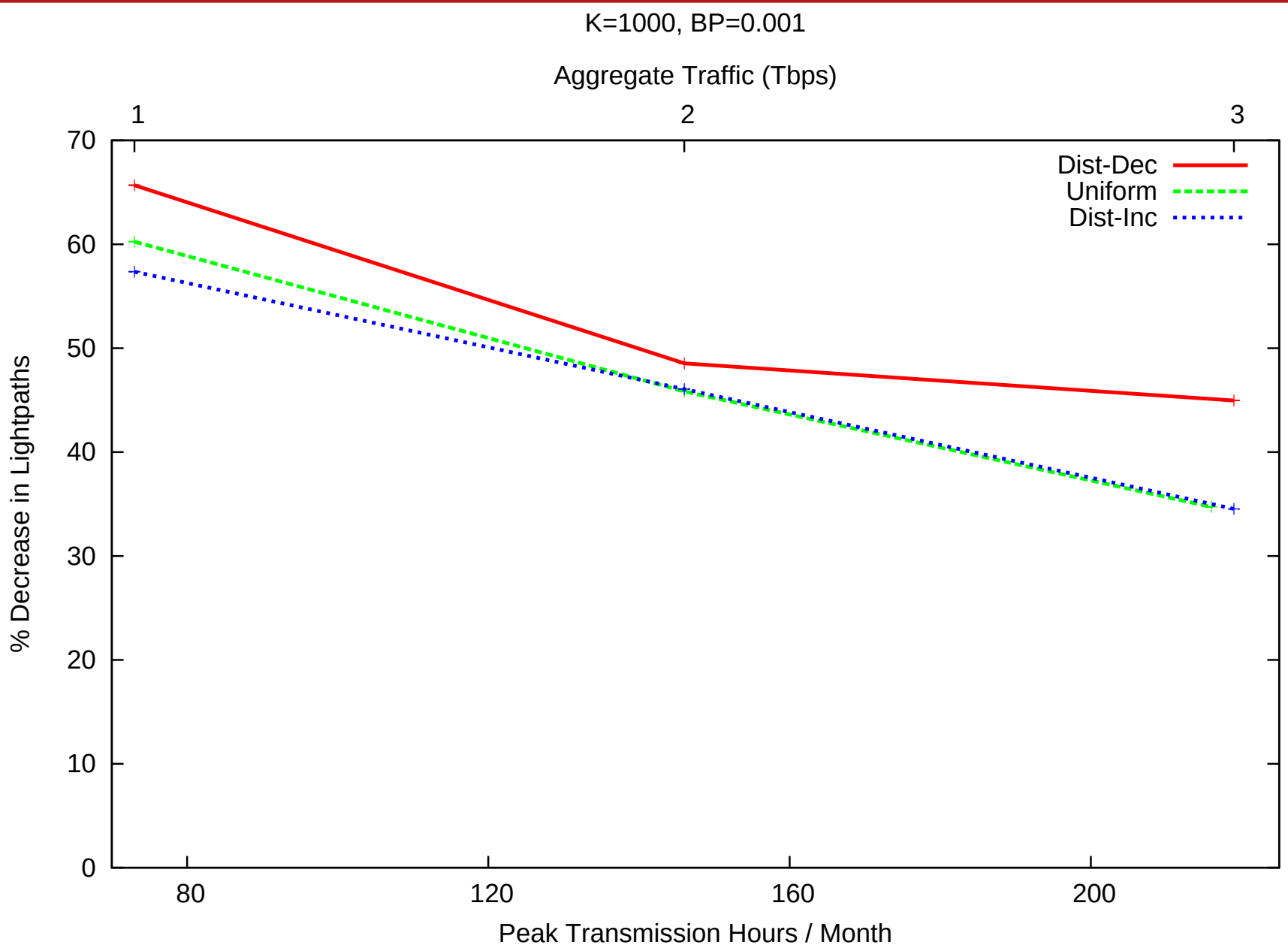

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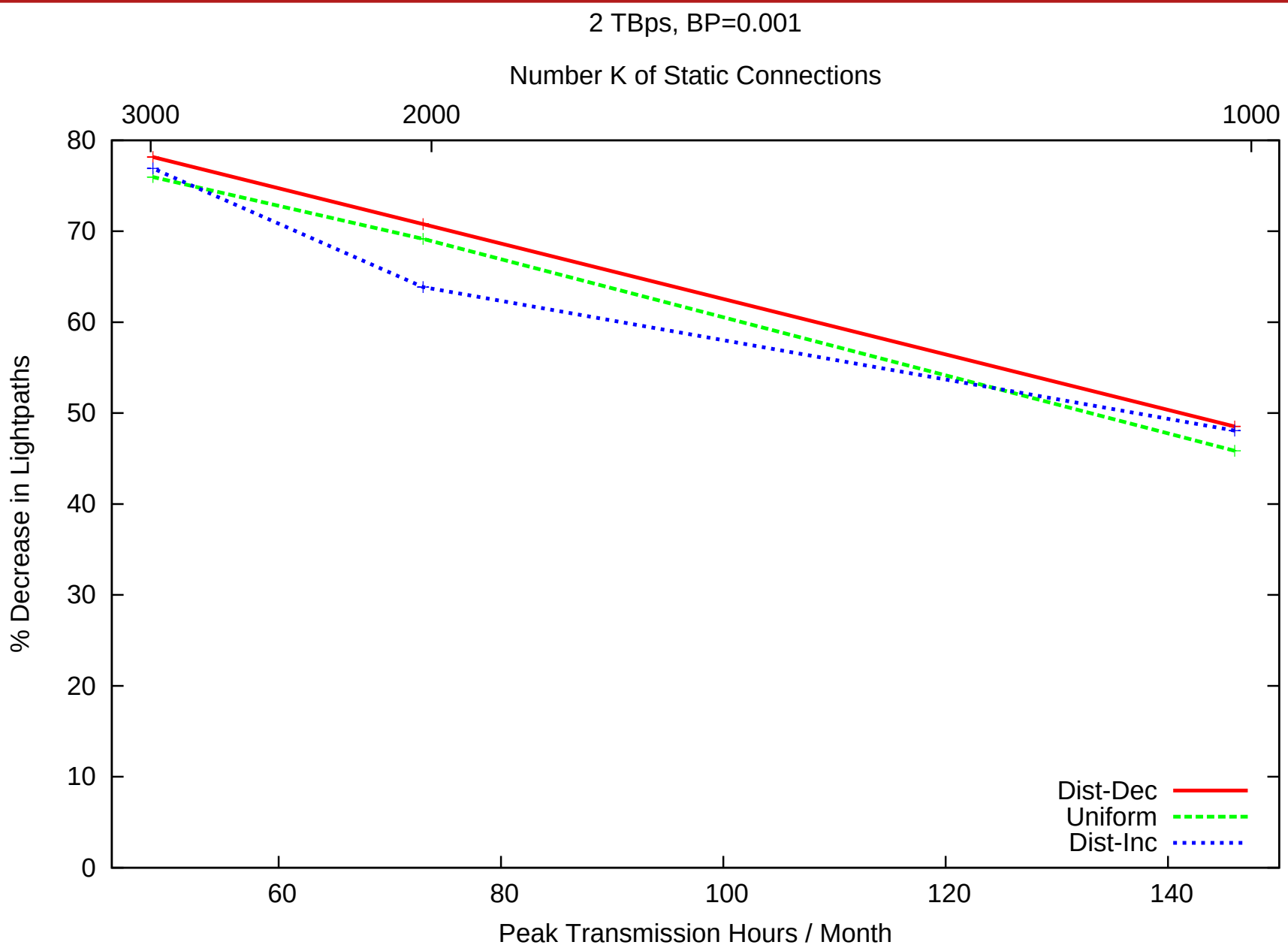

Summary

- ERON overlay control networks: medium-term solution
  - static topologies $\longrightarrow$ ERON $\longrightarrow$ reconfigurable core
- Easy to implement and deploy
  - use existing hardware and software technology
- Substantial benefits:
  - user-controlled dynamic optical networking
  - lightpath savings
  - sharing $\longrightarrow$ higher utilization, “degree of connectivity”
  - low blocking