Demand-Aware Multi-Source IP-Multicast

Minimal Congestion via Link Weight Optimization

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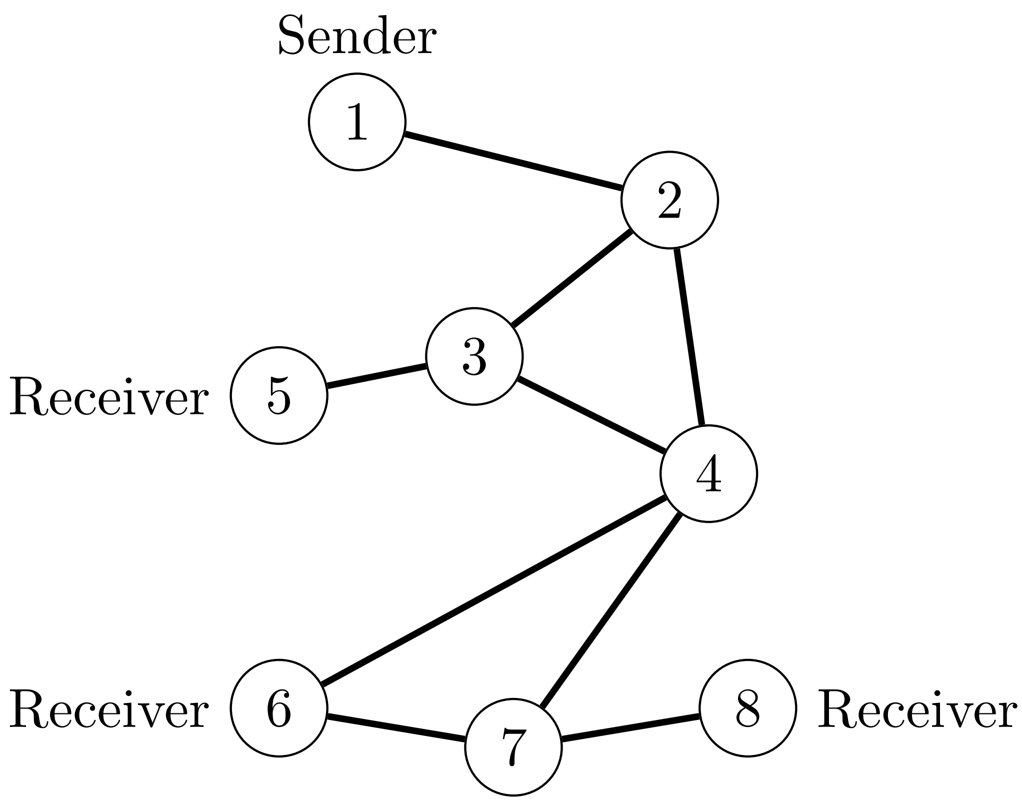
https://www.tu.berlin/eninet

Quick Recap: Multicast



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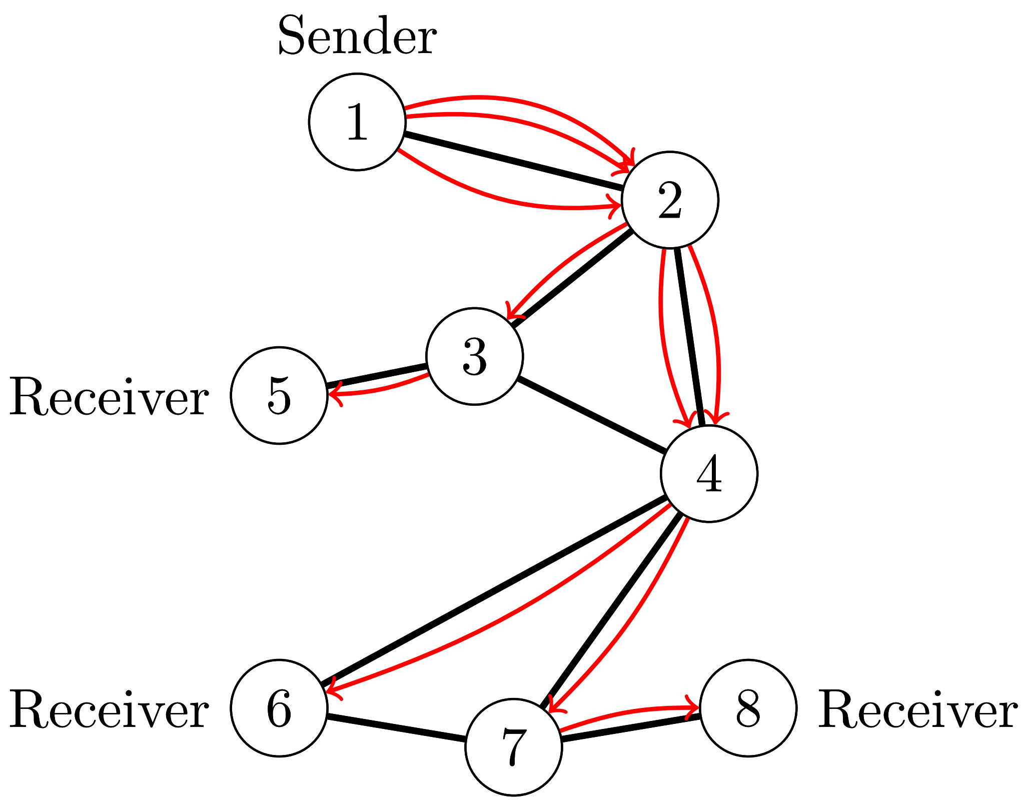

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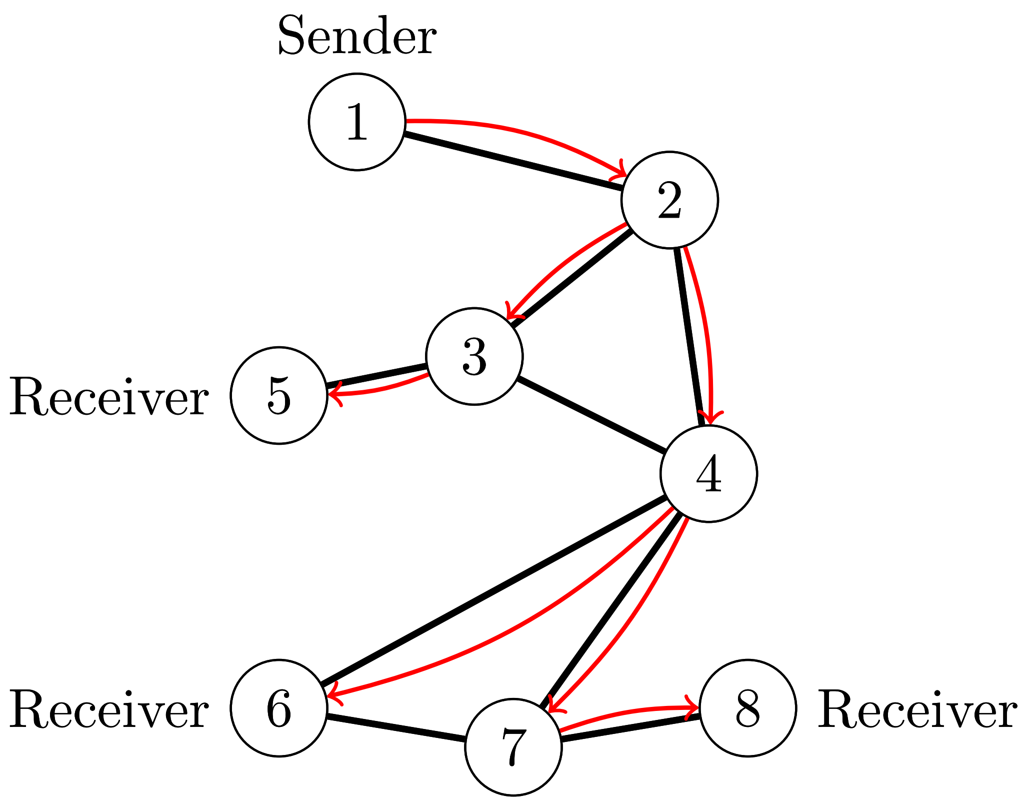


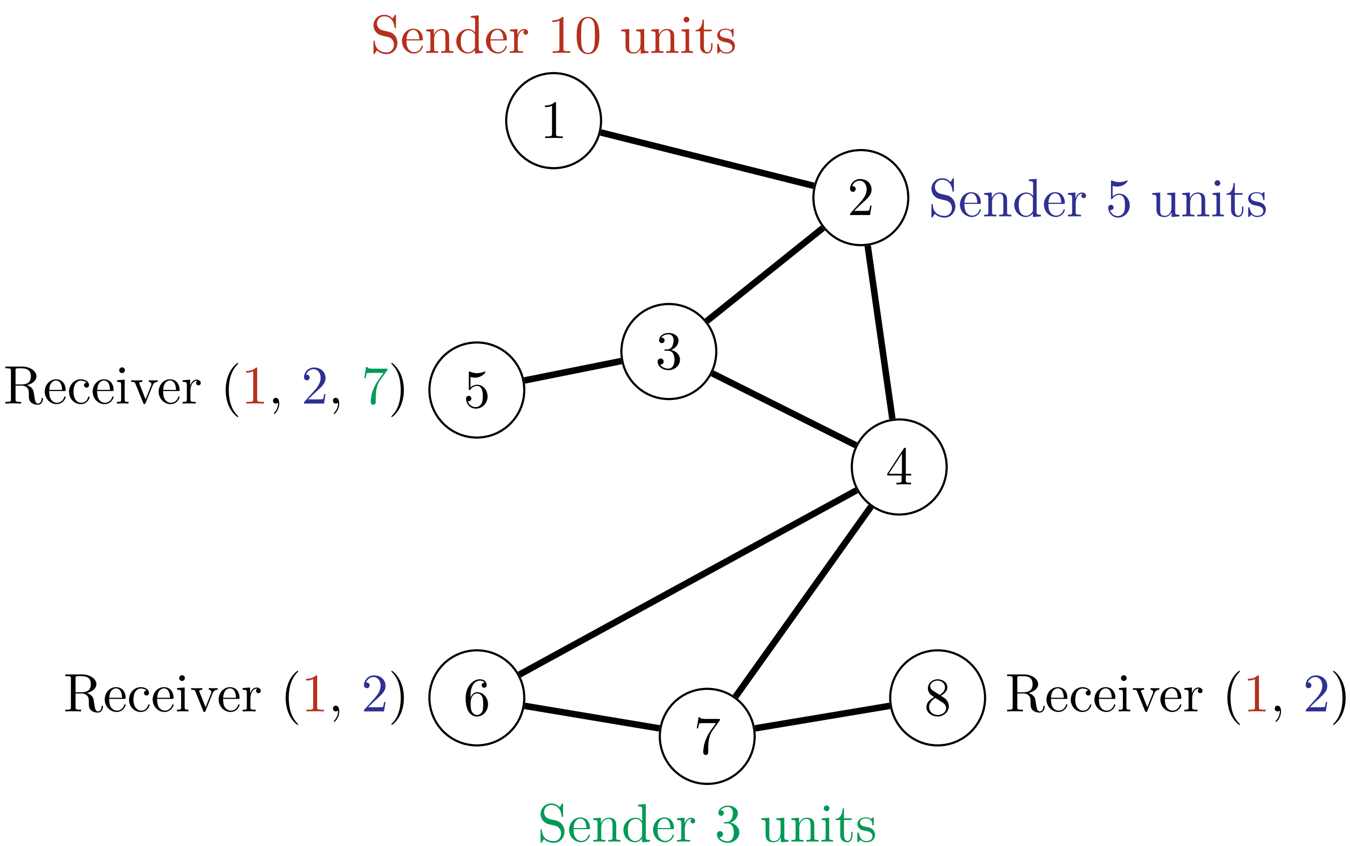
Quick Recap: Multicast

- Not a new idea, lots of research on routing, tree construction, protocols etc.
- Widely used intra-domain: financial networks, mDNS, CCTV, etc.
- Also used inter-domain: IPTV, software updates, etc.
  - However, limitations due to security and privacy considerations
  - Most ISPs don’t allow general purpose IP multicast
- Relevant protocols: IGMP, MLD, BIER, PIM

Motivation

- Multicast can improve efficiency in distributed systems
- Multicast senders often have fixed bandwidth requirements
  - Often known in advance
  - E.g., CCTV cameras have certain bitrate, IoT sensors, etc.
- Existing methods are demand-oblivious
- Leads to congestion and suboptimal resource usage
- New focus: Demand-aware link weight optimization

Motivation


Sender 10 units
1
2
Sender 5 units
3
Receiver (1, 2, 7)
5
4
Receiver (1, 2)
6
7
8
Receiver (1, 2)
Sender 3 units

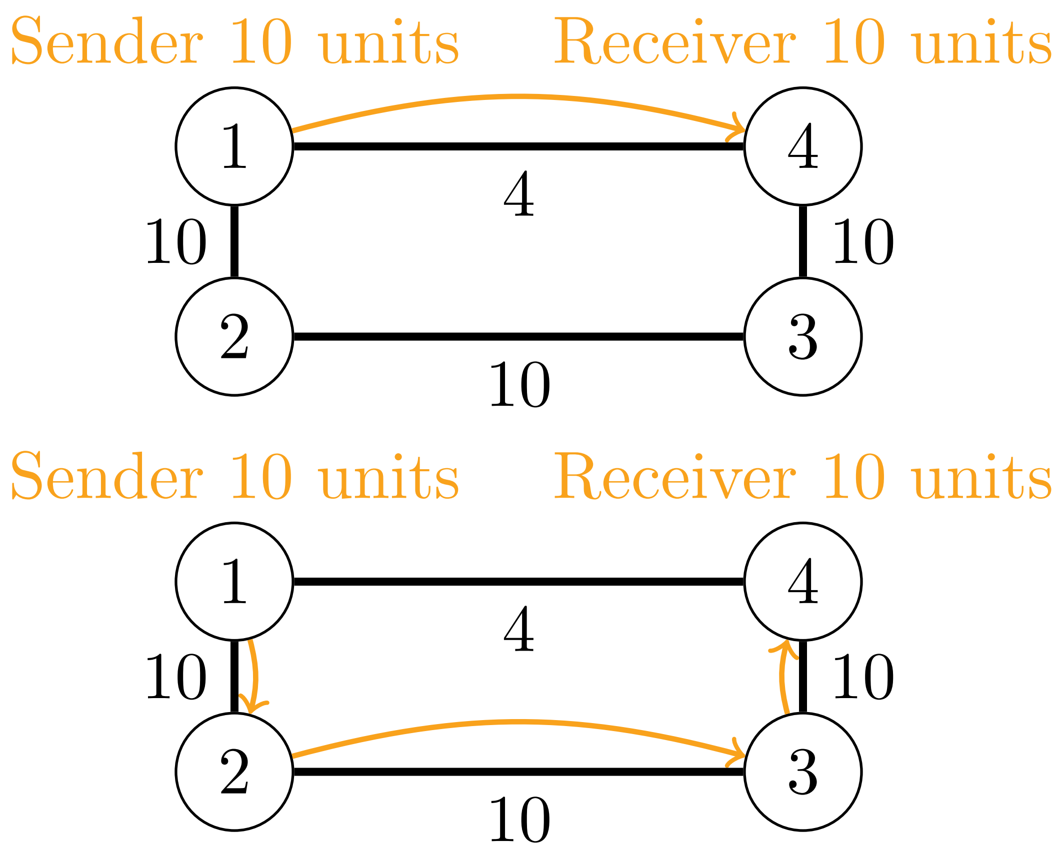
Contributions

- Formalize demand-aware multicast problem
- Prove it is NP-hard under several restrictions
- Propose a MILP formulation for optimal solutions
- Design two fast heuristics: DA-Picky & DA-Hybrid
- Empirical validation on real and synthetic topologies

Problem Definition

- Network model: Directed symmetric graph, link capacities
- Goal: Minimize maximum congestion via link weight assignment
- Multicast trees follow shortest paths based on weights
- Unsplittable flows, duplicable at intermediate nodes

Problem Definition



Complexity Results

- Demand aware Multicast is NP-hard:
  - Even with only two link weights
  - Even with a single receiver
  - Even on planar graphs with small degrees
- No approximation unless P = NP
- (Proof not in this talk)

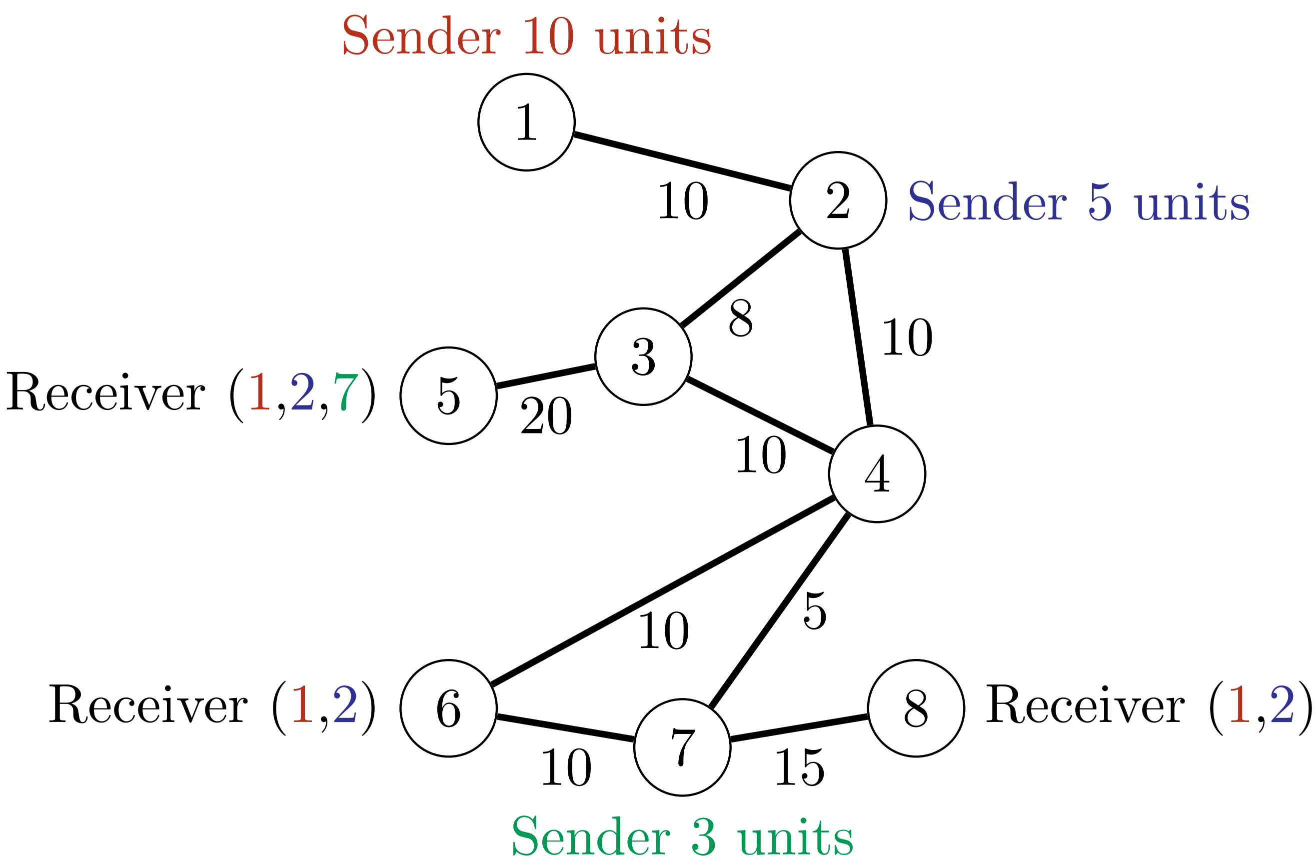
MILP Formulation

- Optimize congestion
- Integer variables for link weights, distances, and activities
- Ensures:
  - Unique shortest paths
  - Flow conservation
  - Congestion constraints

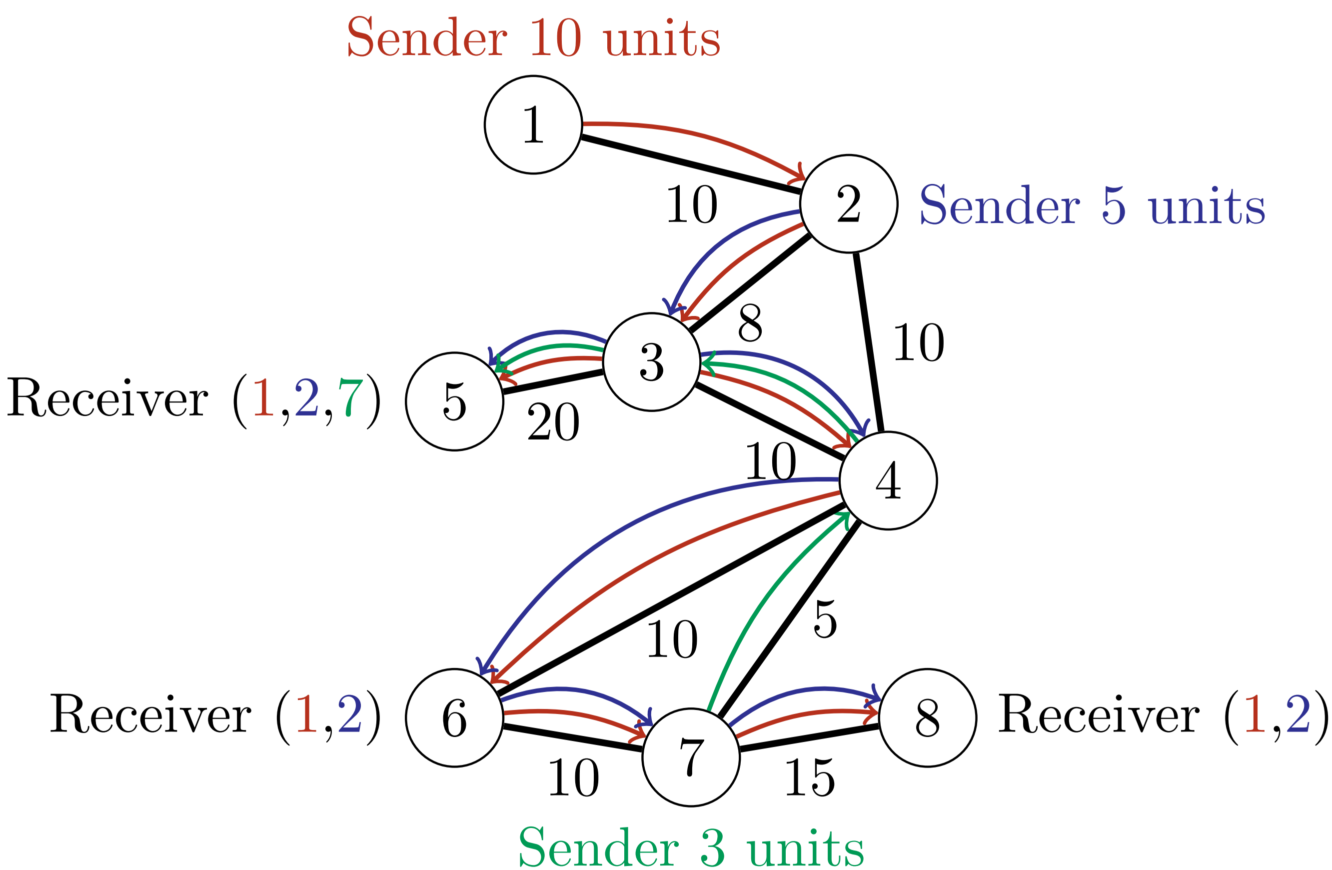
Heuristics

- Oblivious baseline: Link weight = 1 / capacity
- DA-Picky:
  - Prioritizes high-demand sources
  - Adds links incrementally
- DA-Hybrid:
  - Builds max bottleneck spanning trees
  - Assigns weights based on demand

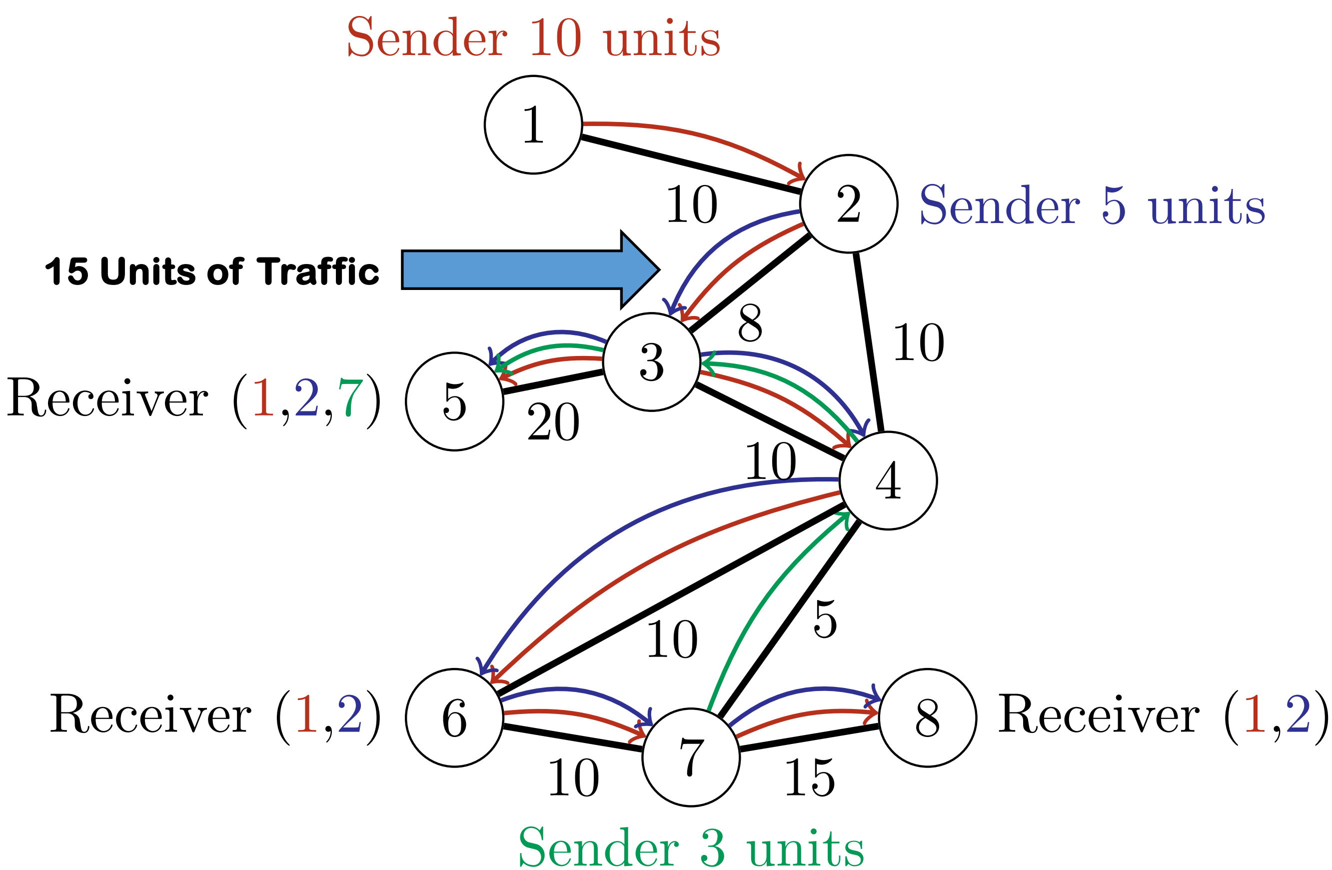
Example: Capacities



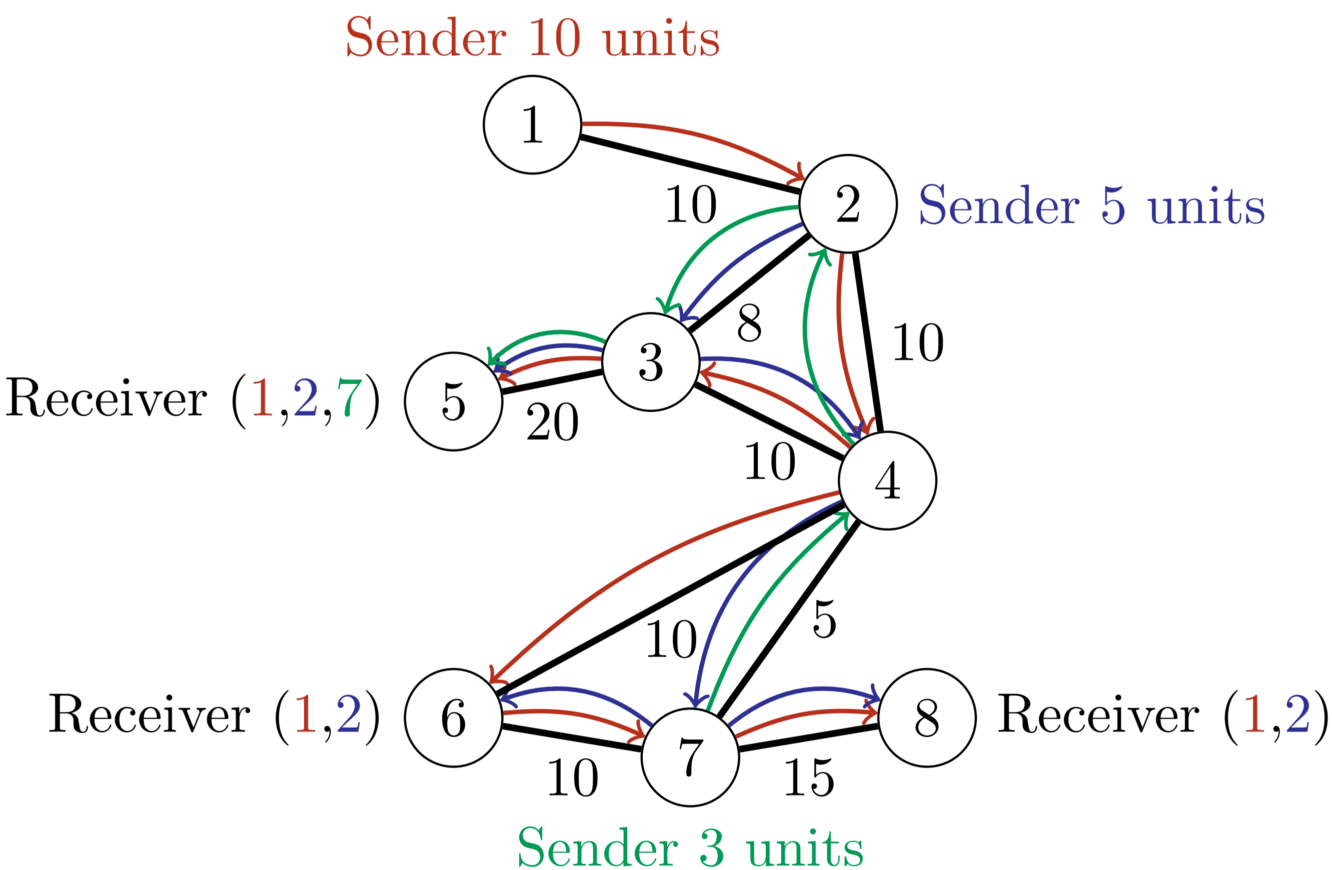
Example: Traditional approach



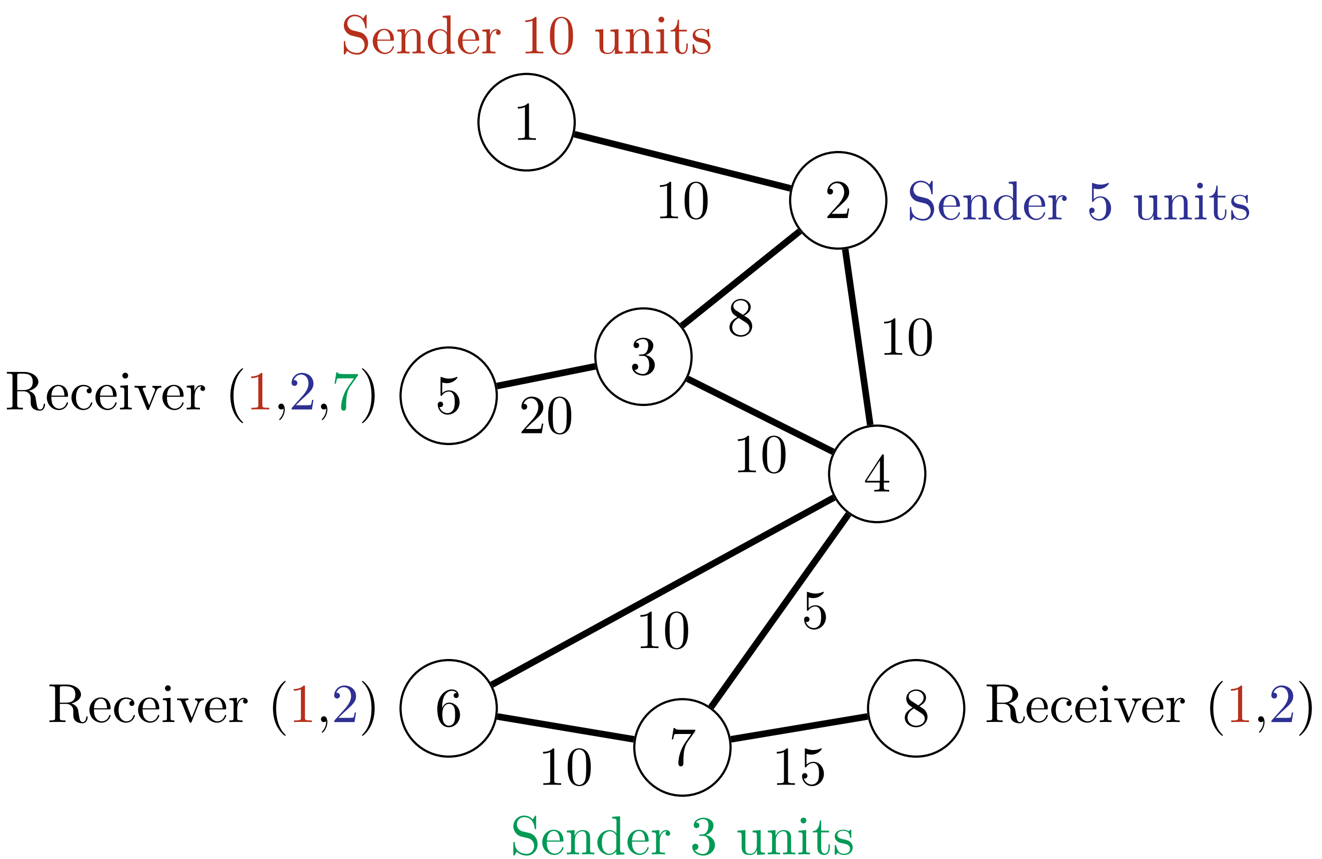
Example: Traditional approach



Example: DA-Hybrid



Example: Capacities



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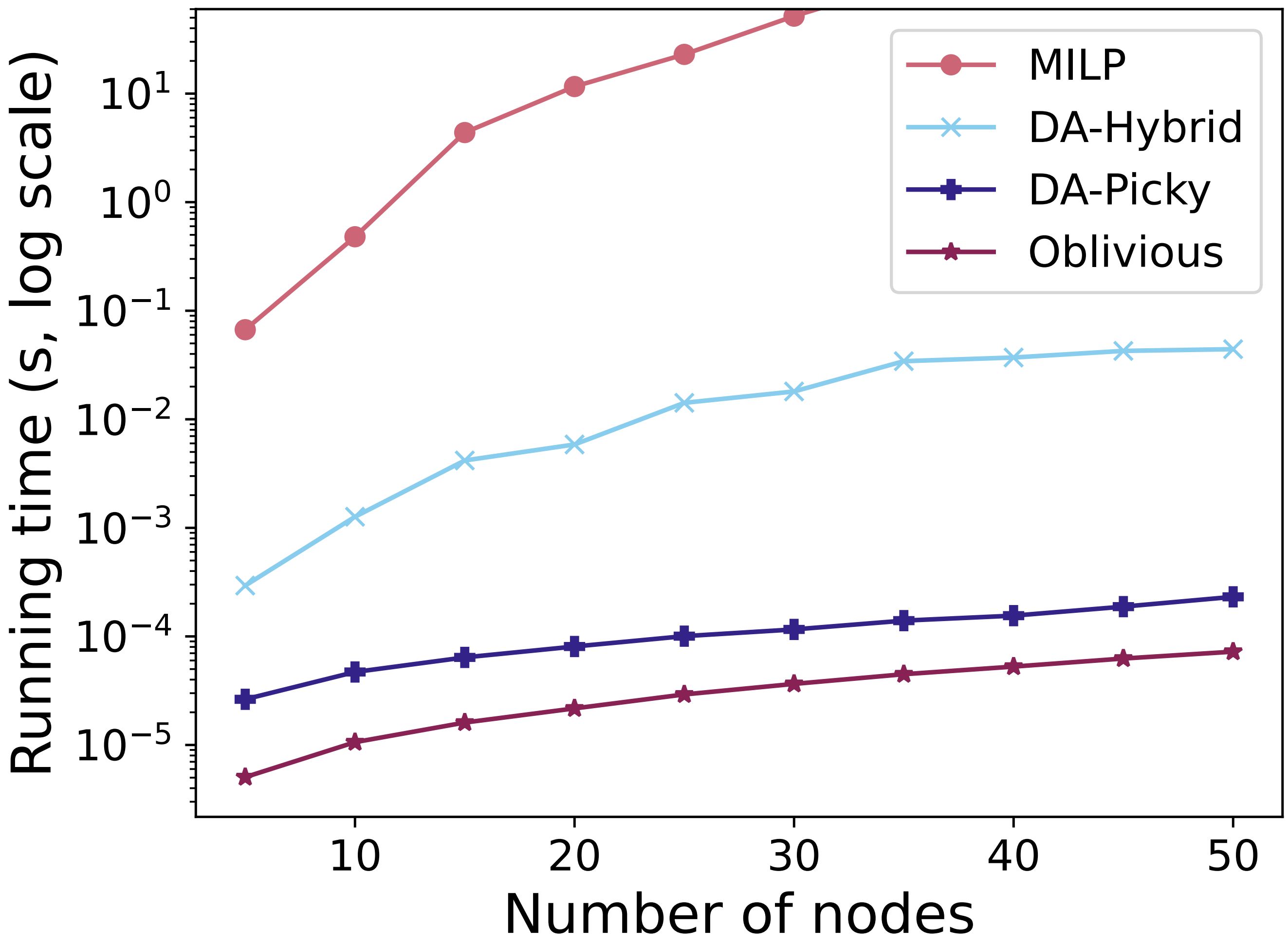
Evaluation Setup

- Topologies:
  - Topology Zoo
  - IGen synthetic
  - Campus mesh
  - National ISP
- Demands/Capacities:
  - Uniform random
  - Gravity model

Key Results

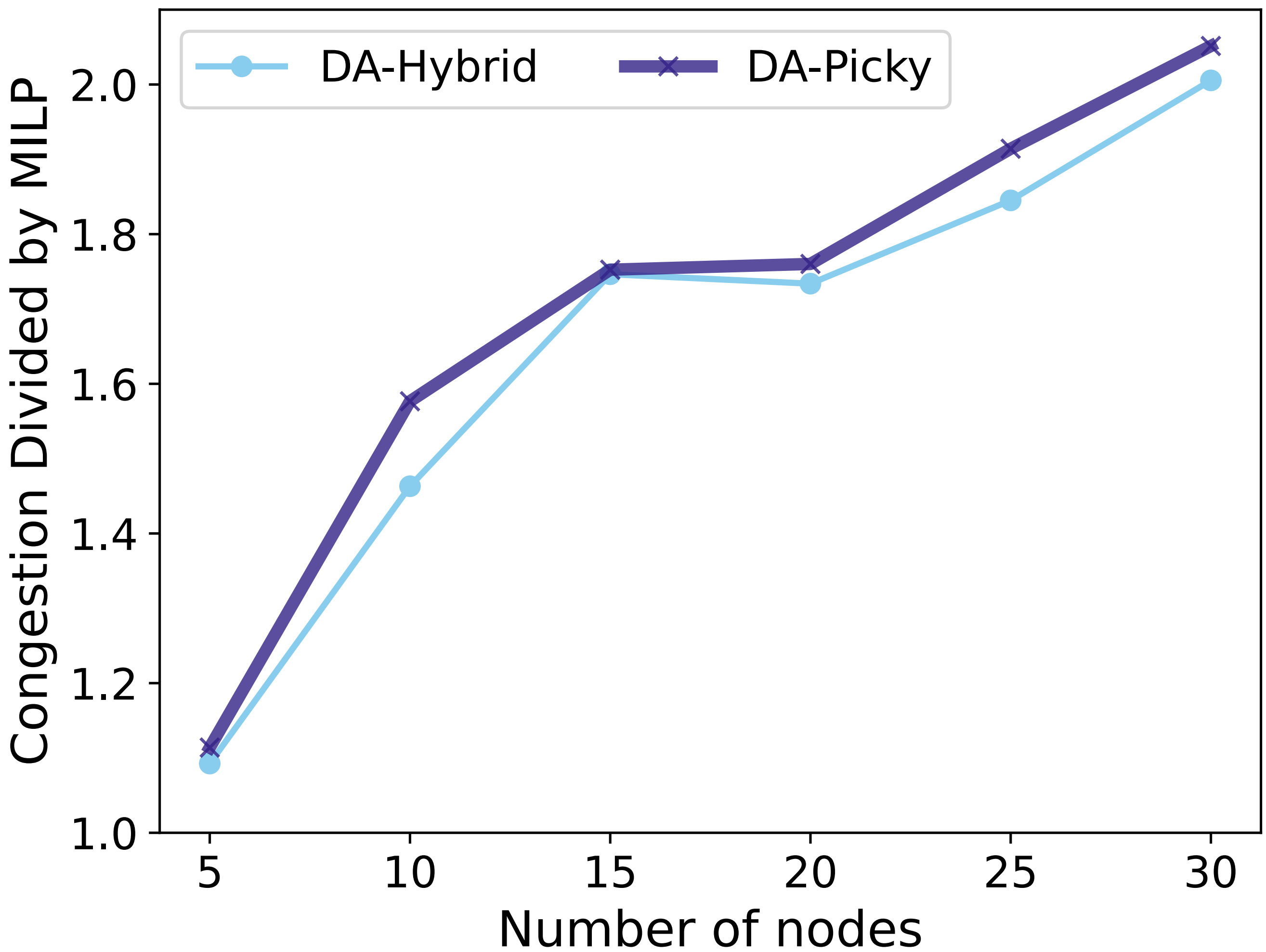
- DA algorithms outperform oblivious:
  - Lower congestion
  - DA-Hybrid slightly better than DA-Picky
- Running time:
  - MILP slow for large graphs
  - Heuristics scale well

Results



Running time (s, log scale)
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10
20
30
40
50
Number of nodes
MILP
DA-Hybrid
DA-Picky
Oblivious

Results



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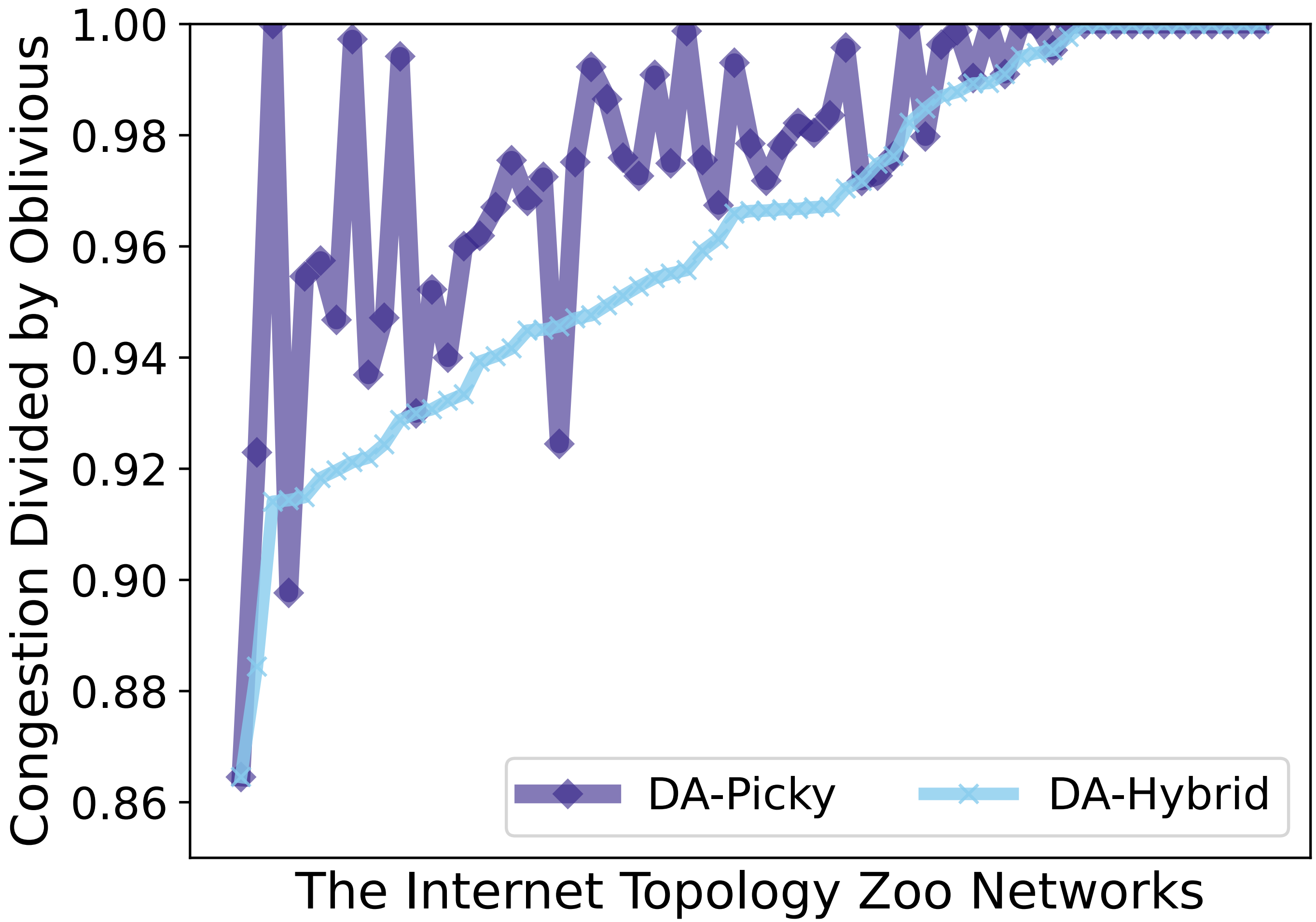
Results

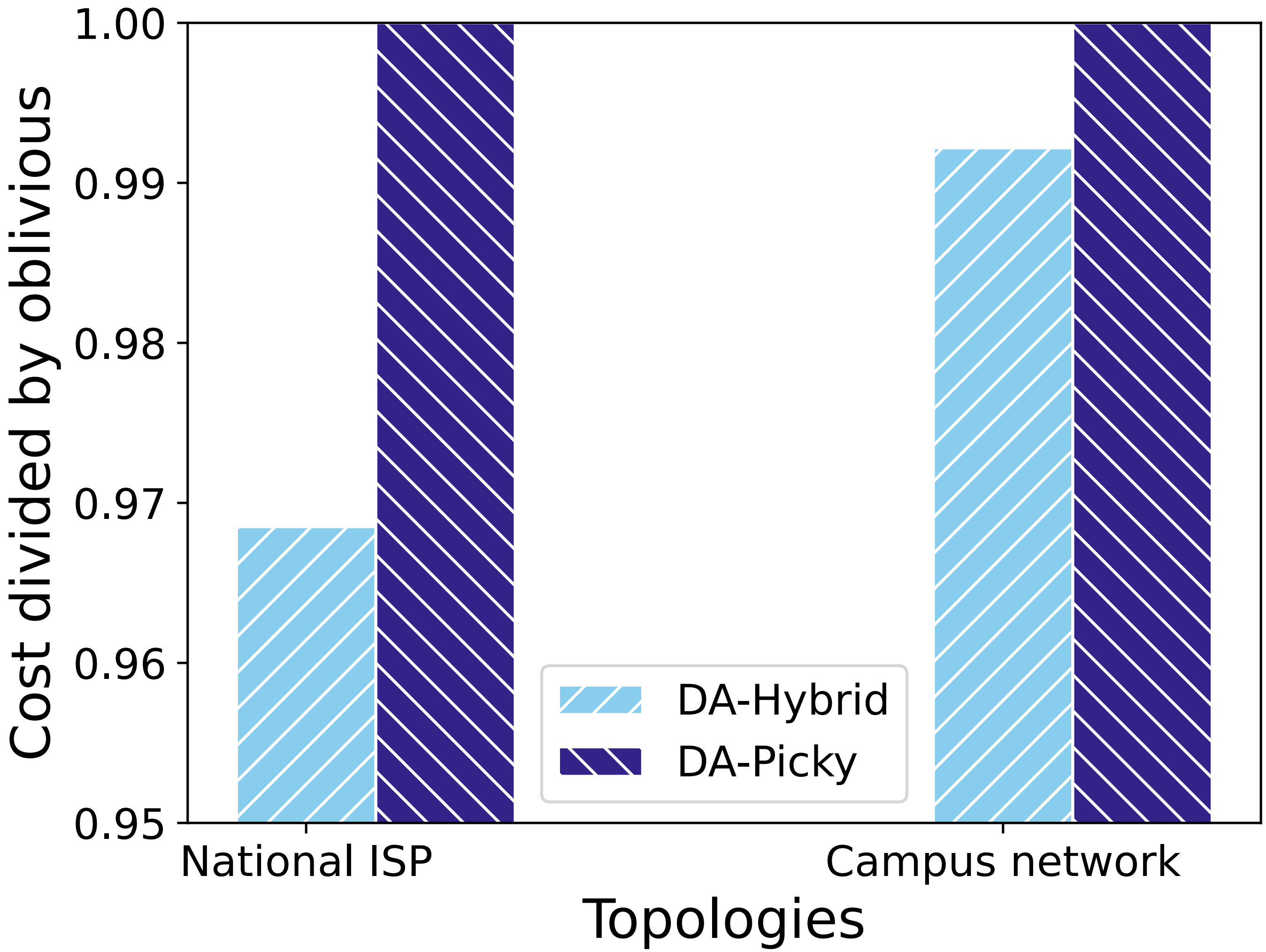


1.00
0.98
0.96
0.94
0.92
0.90
0.88
0.86
Congestion Divided by Oblivious
DA-Picky
DA-Hybrid
The Internet Topology Zoo Networks

Case Study - National ISP

- Real topology and realistic demands
- DA-Hybrid reduces congestion close to optimal
- Fast enough for practical use

Results



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Conclusion

- Demand-aware multicast is computationally hard
- Practical heuristics offer good performance
- Significant congestion reduction over traditional methods
- Future: Dynamic demands, online algorithms, protocol extensions

Our group's website:
tu.berlin/en/eninet