Throughput Limits of Multi-Hop Wireless Networks

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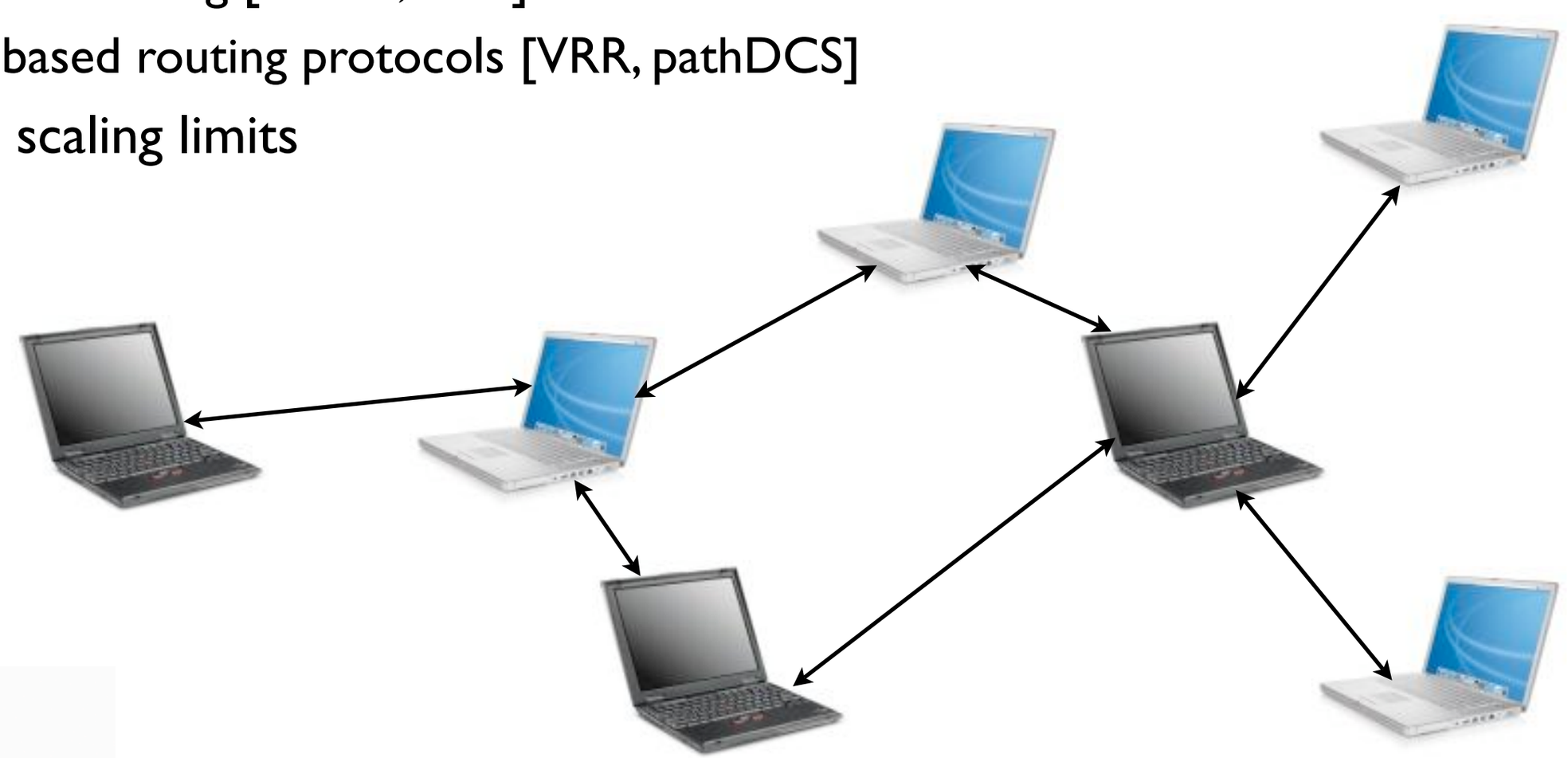
Motivation

- Multi-hop wireless networks focus of research
  - System is naturally cooperative: nodes route each others' traffic
- P2p based wireless applications are interesting
- Much previous work on Ad Hoc Routing
  - Ad hoc routing [AODV, DSR]
  - Key based routing protocols [VRR, pathDCS]
- Known scaling limits



Known Factors

- Global network capacity grows only with $O(\sqrt{n})$
  - per node capacity *decreases*
- Dynamically controlling radio power can improve capacity
- Shortest path routing is constrained by capacity in the center of the network
- Limited understanding of the factors that determine achievable network capacity

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Approach

- We study theoretical limits of a multi-hop wireless network
  - Determine optimal capacity of idealized network
    - Idealized radio model
    - Optimal routing
  - Give upper-bound for what is achievable under specific conditions

- Use multi-commodity flow problem (LP) to find optimal capacity
  - Study under a variety of parameters (e.g. size, density, traffic pattern)
  - Systematically explored parameter space (220,000 instances)

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Formulation

- Input parameters to formulation are
  - Specific network graph (physical layout and radio model)
  - Specific traffic workload

- Solution provides
  - Optimal routing
  - Resulting per-node throughput
    - As a function of wireless link bandwidth (*L*)
    - Results presented are for per node bandwidth

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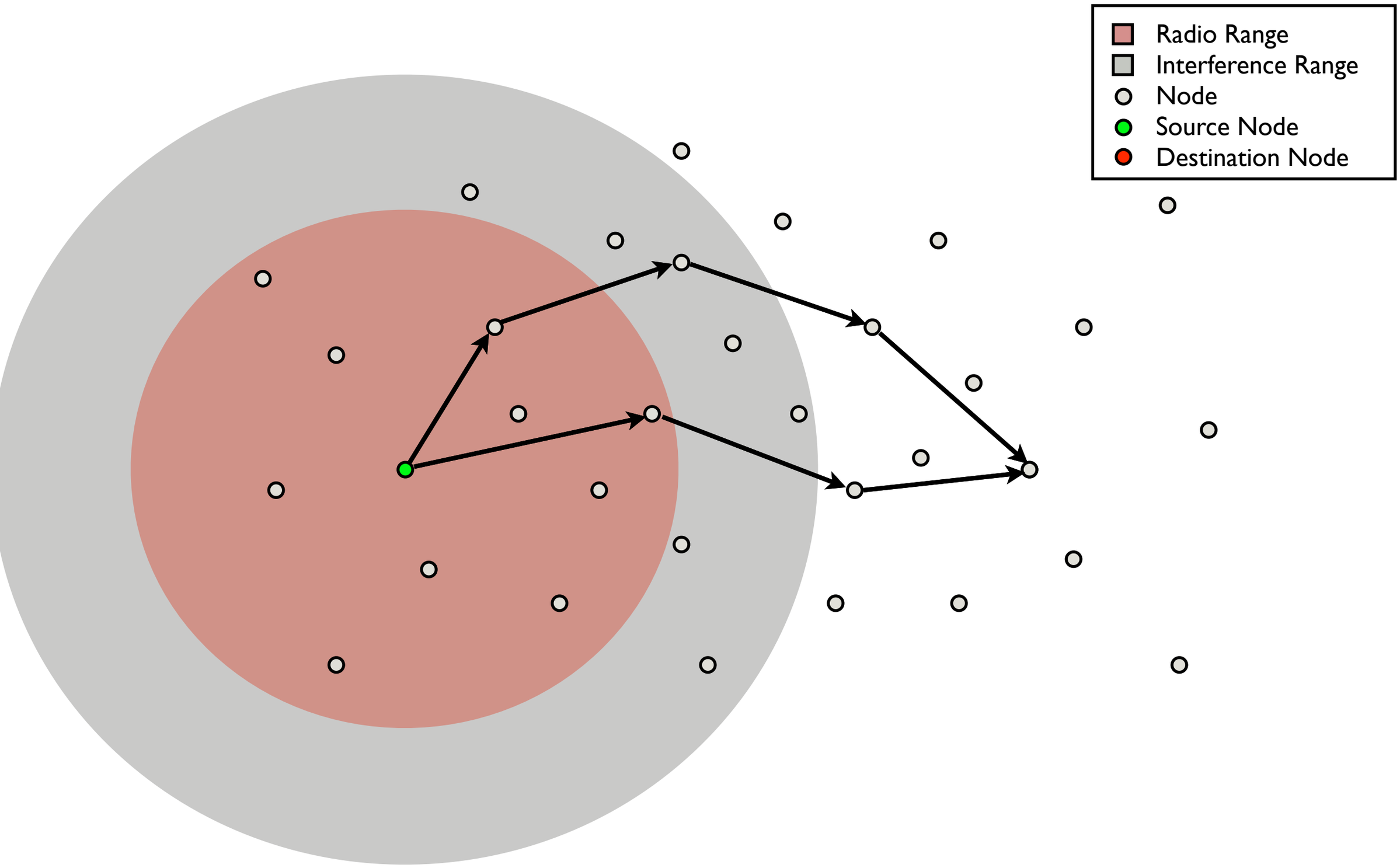
Factor Studied

- Node placement
- Network size
- Traffic workload
- Path selection
- Radio Control
- Others, including : Non-ideal MAC Protocol, Radio Characteristics

Introductory Example



Experimental Conditions

- Multi-hop wireless network with no infrastructure connection
- Stationary networks
- Nodes distributed uniformly
- All nodes originate an equal amount of data
- All nodes receive zero or more units of data
- All links have equal capacity

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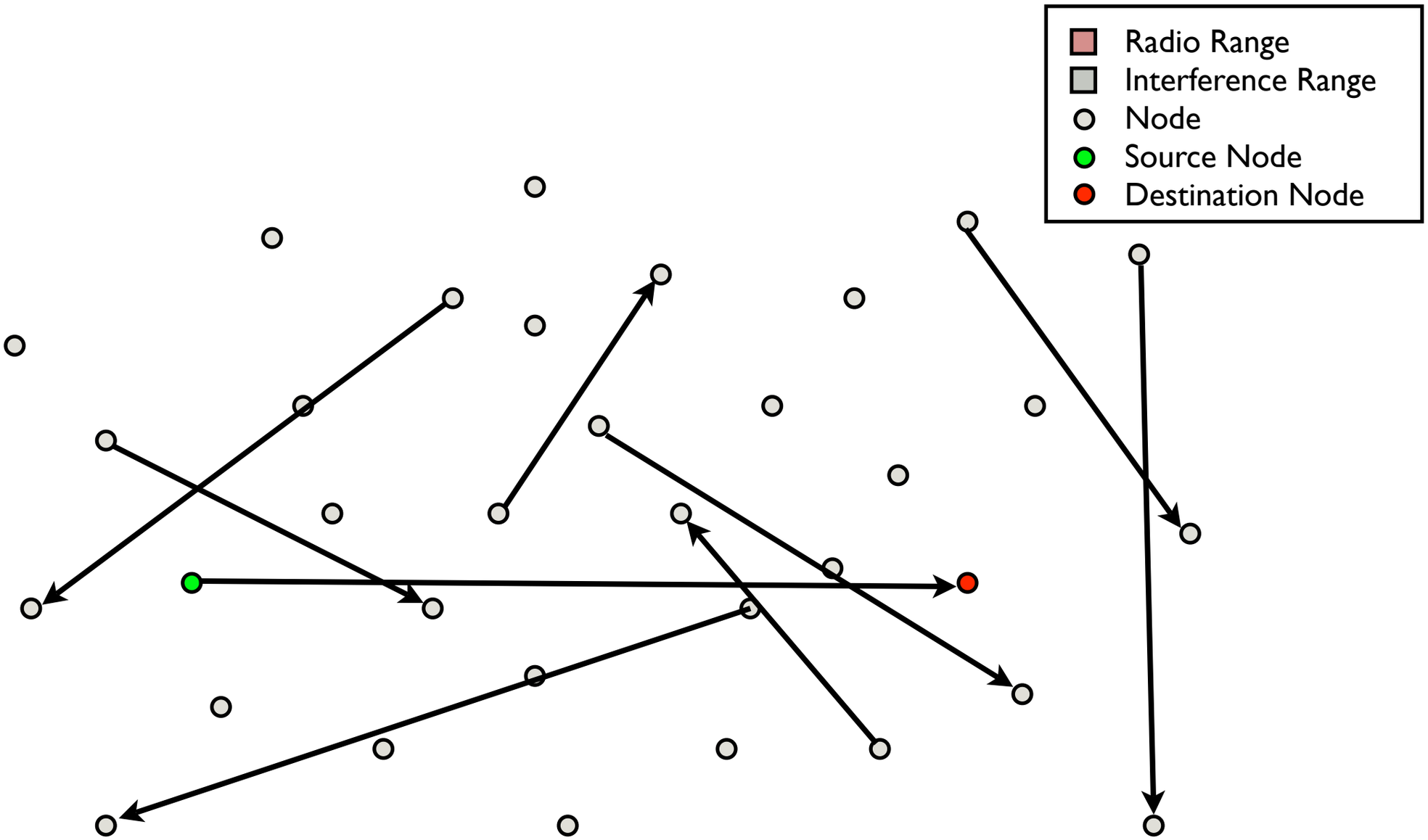
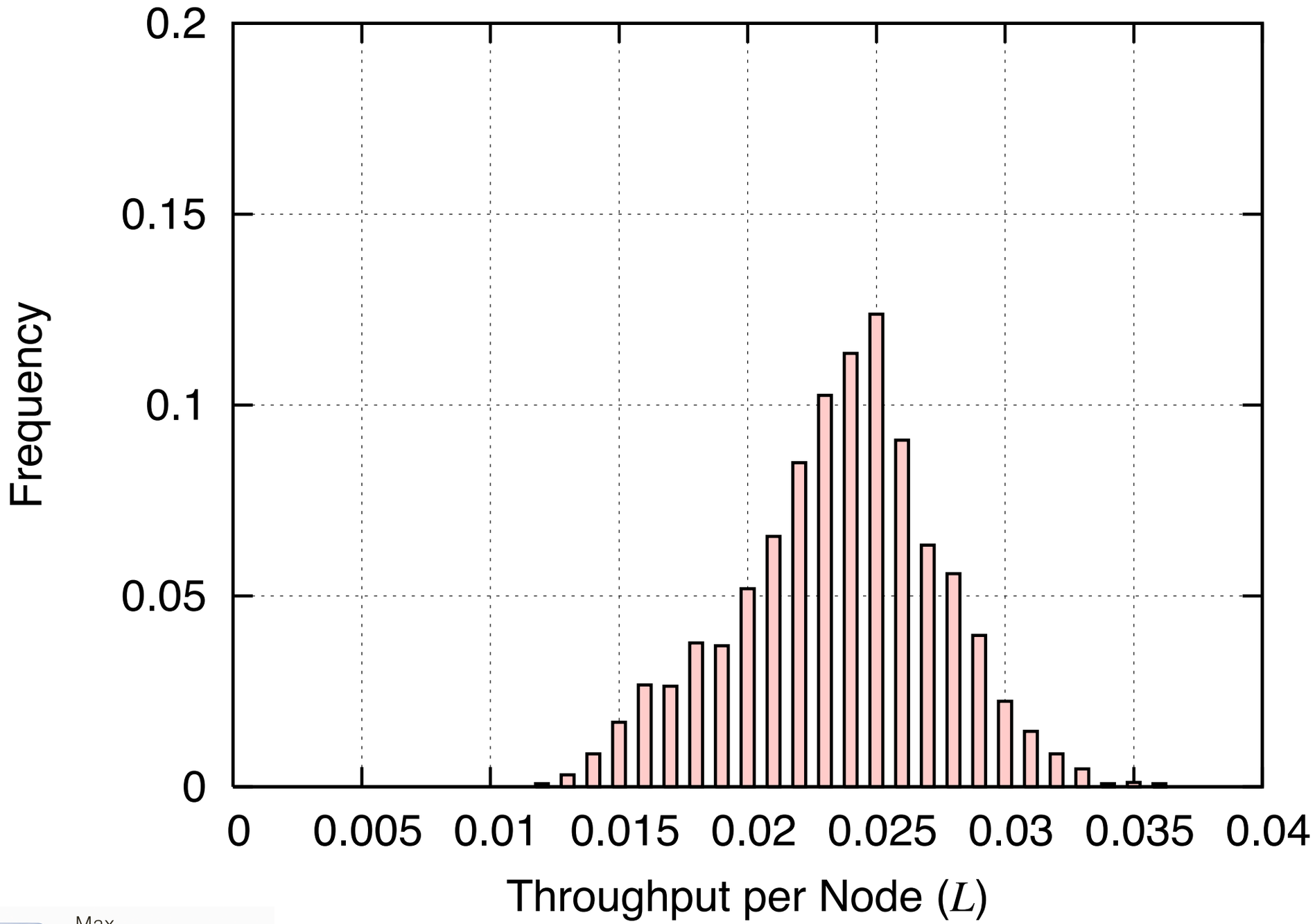
Traffic patterns



How do placement and traffic affect capacity?



50 Nodes, 50 node placements, 50 Random traffic patterns

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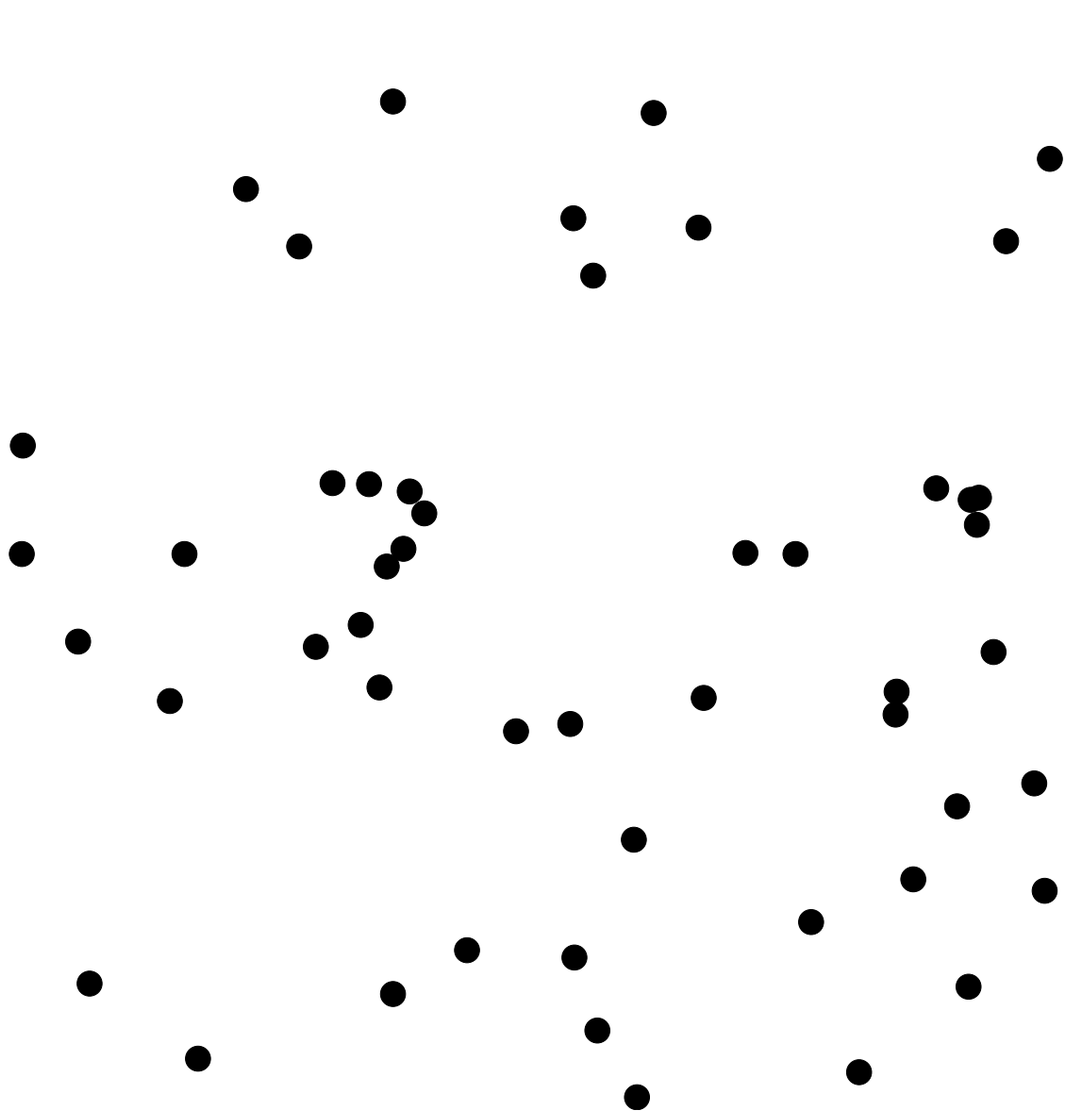
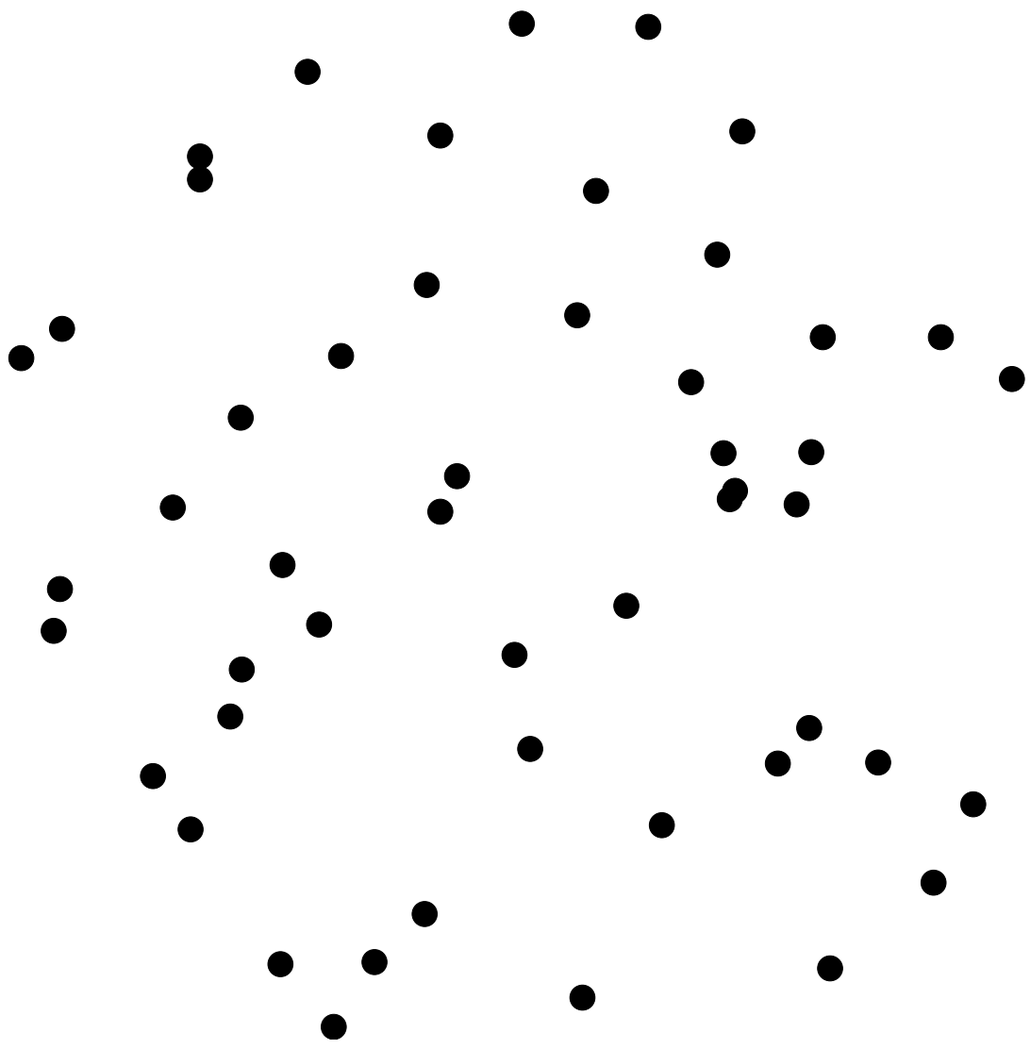
Which network is better?





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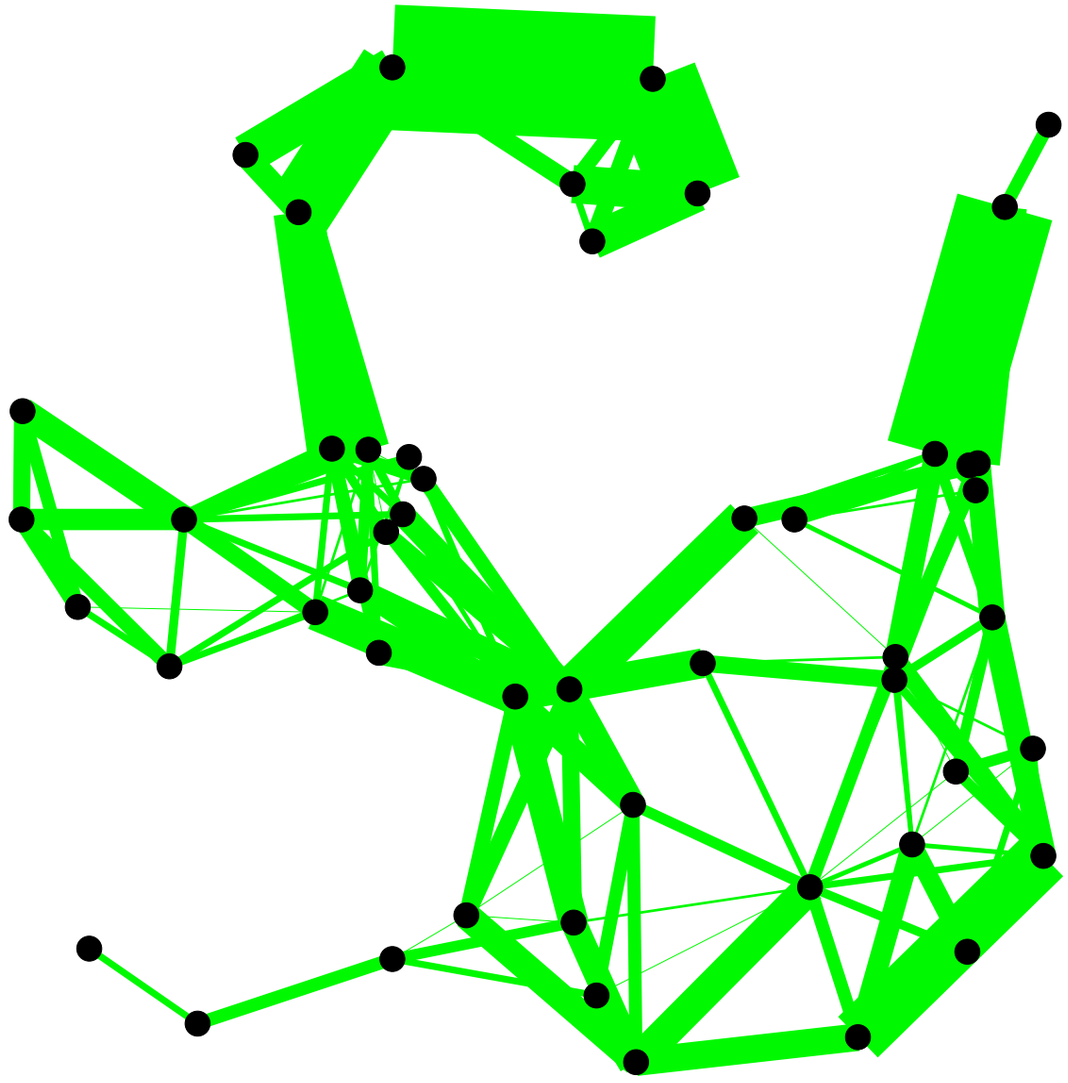
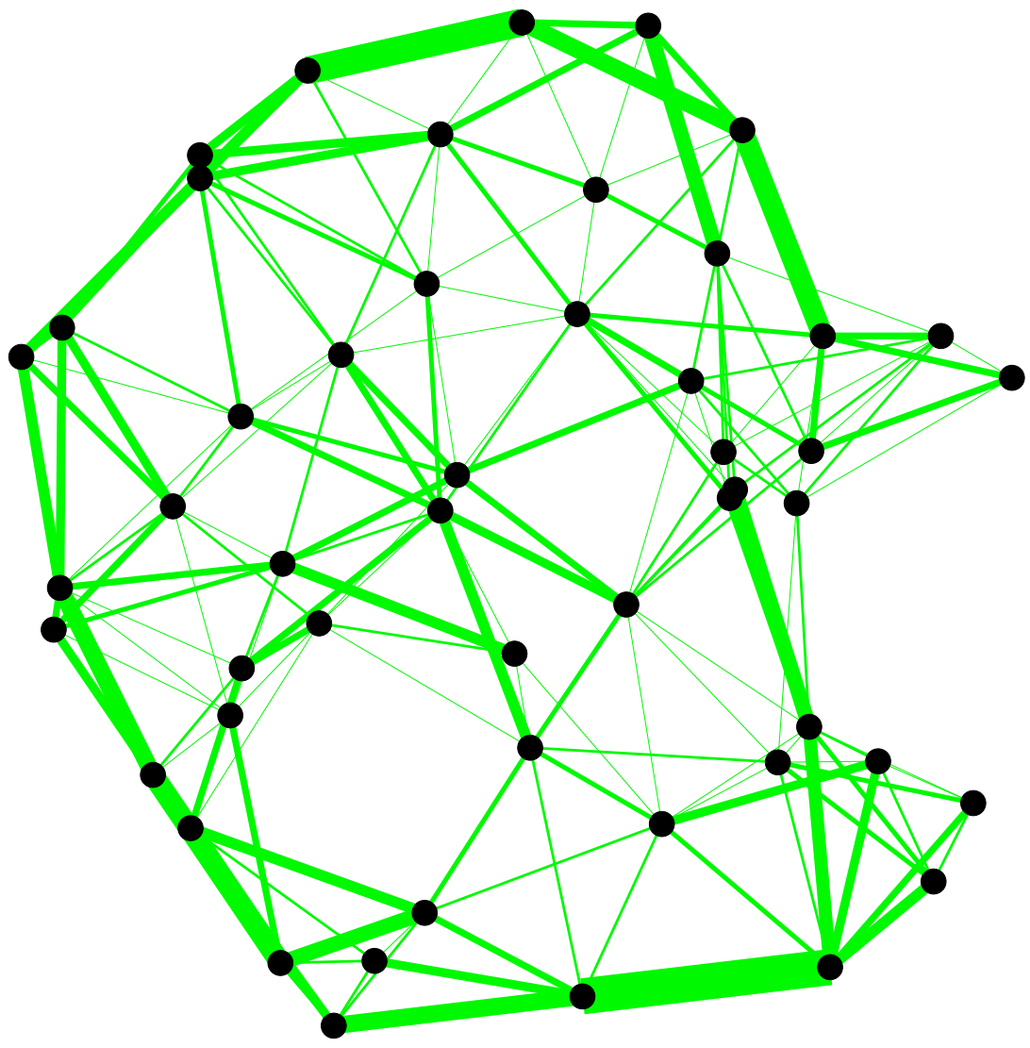
Which network is better?



Poor Placement (0.121 *L*)



Good Placement (0.359 *L*)

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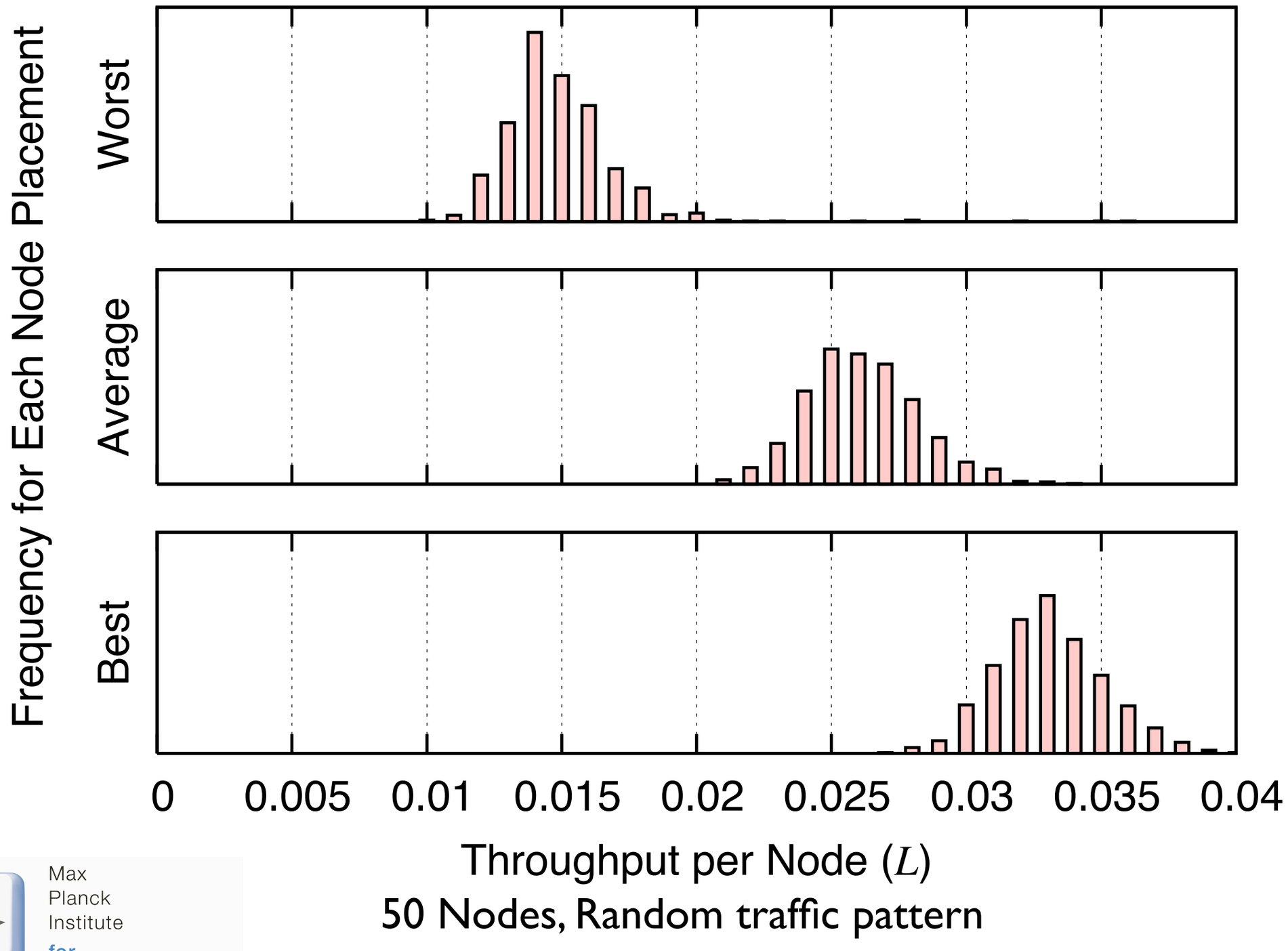
What is the impact of node placement?



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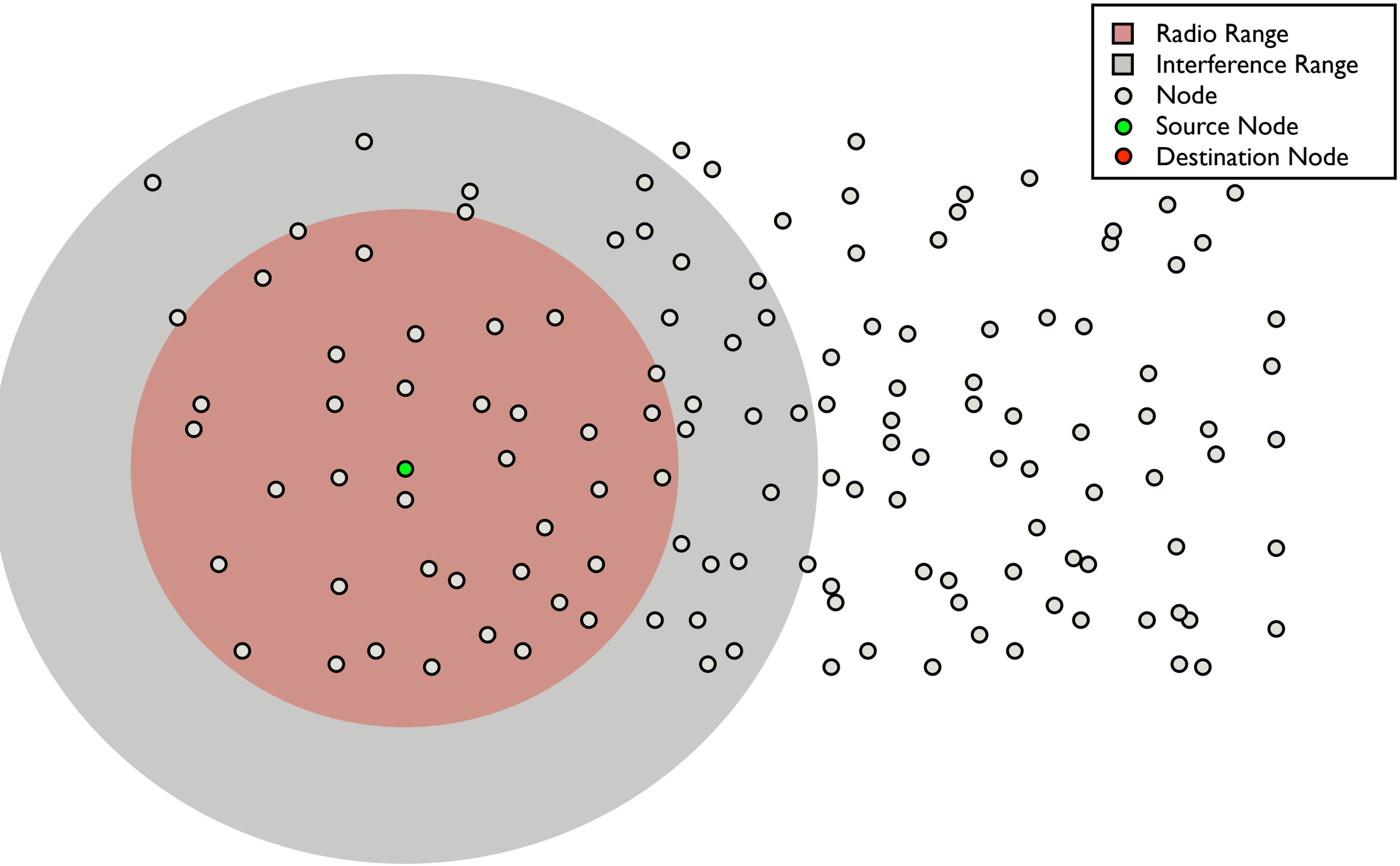
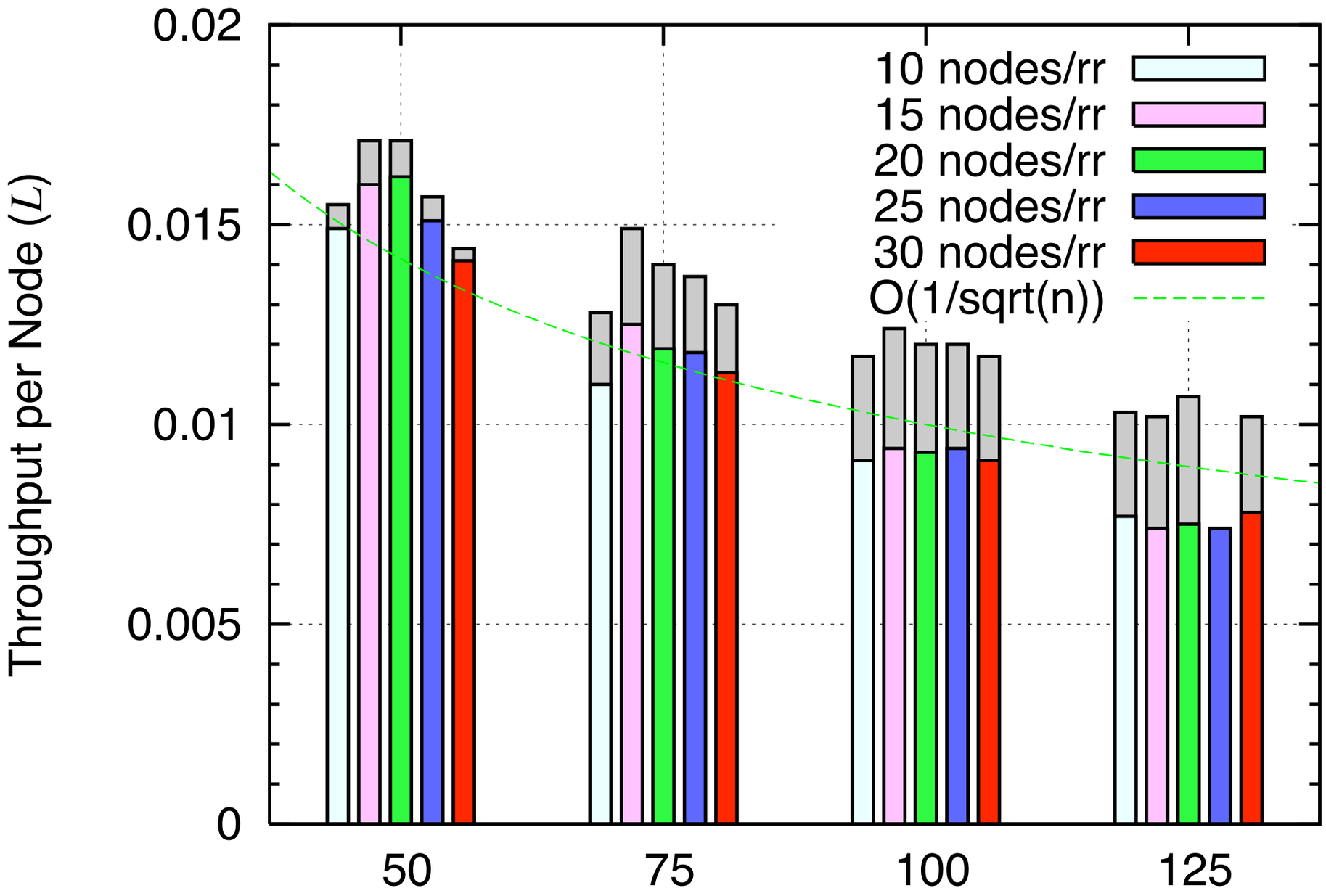
Network Size/Density Example



Size vs. Throughput



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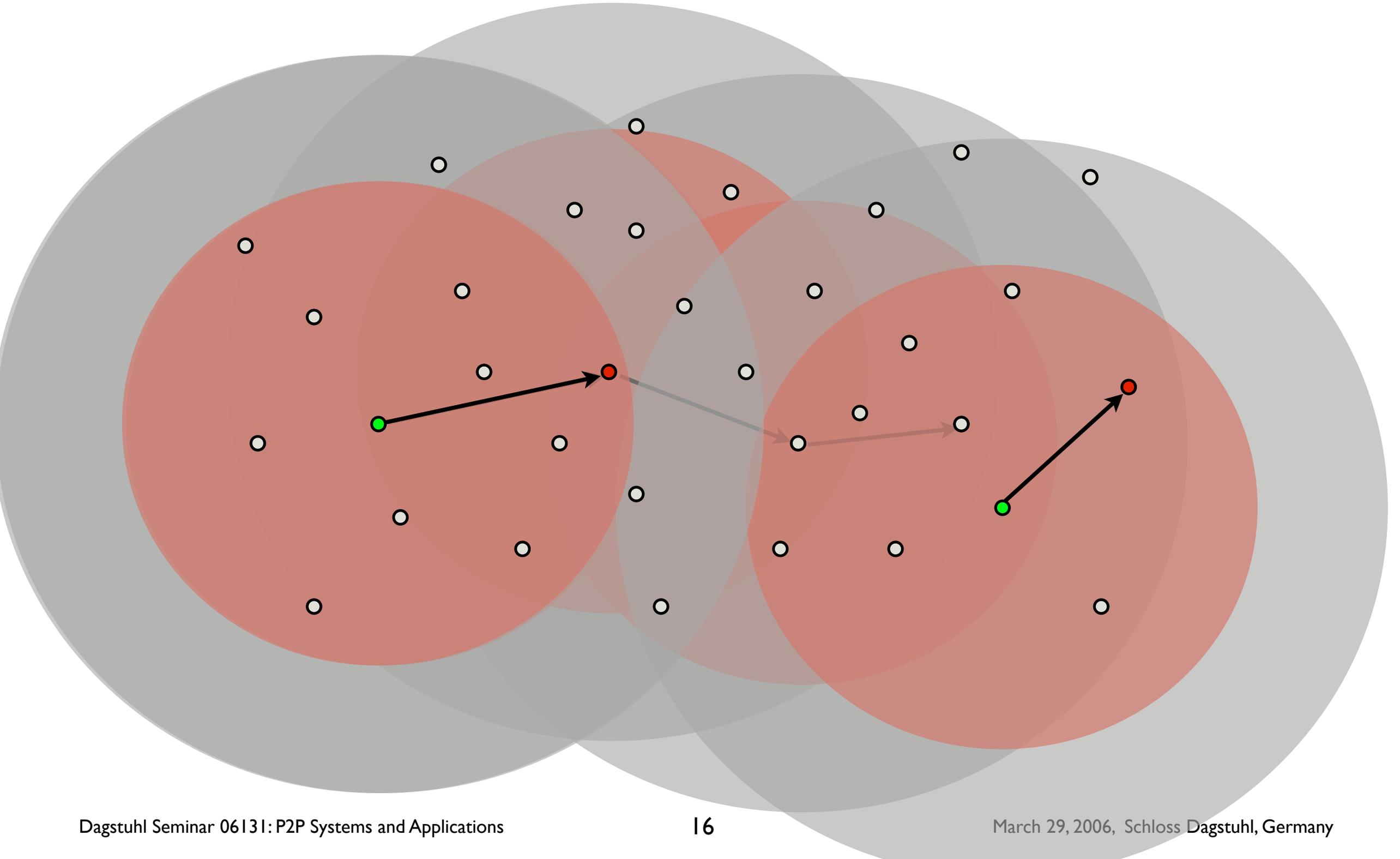
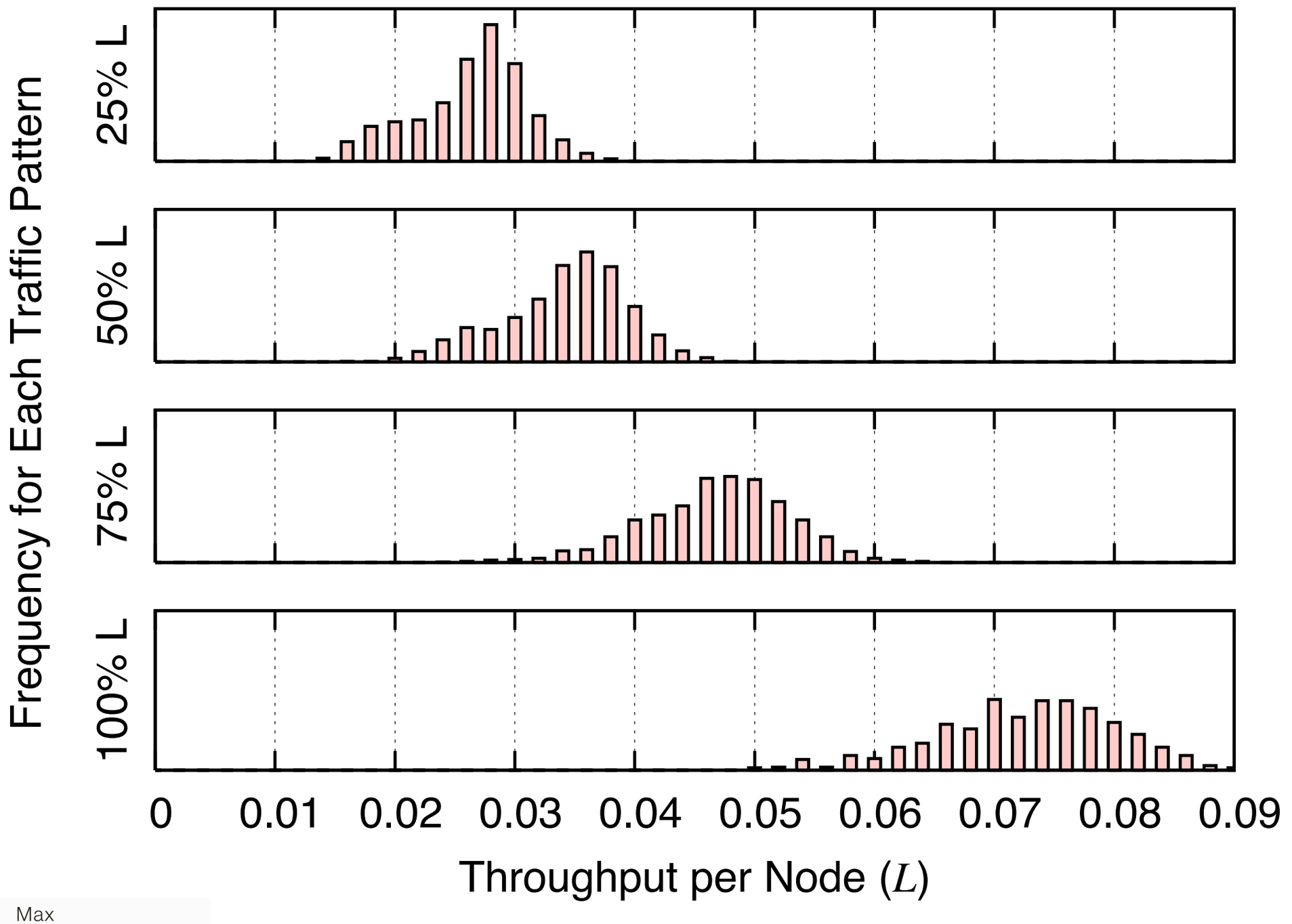
Effect of Traffic Locality



How much does local communication help?



50 Nodes, Random traffic pattern

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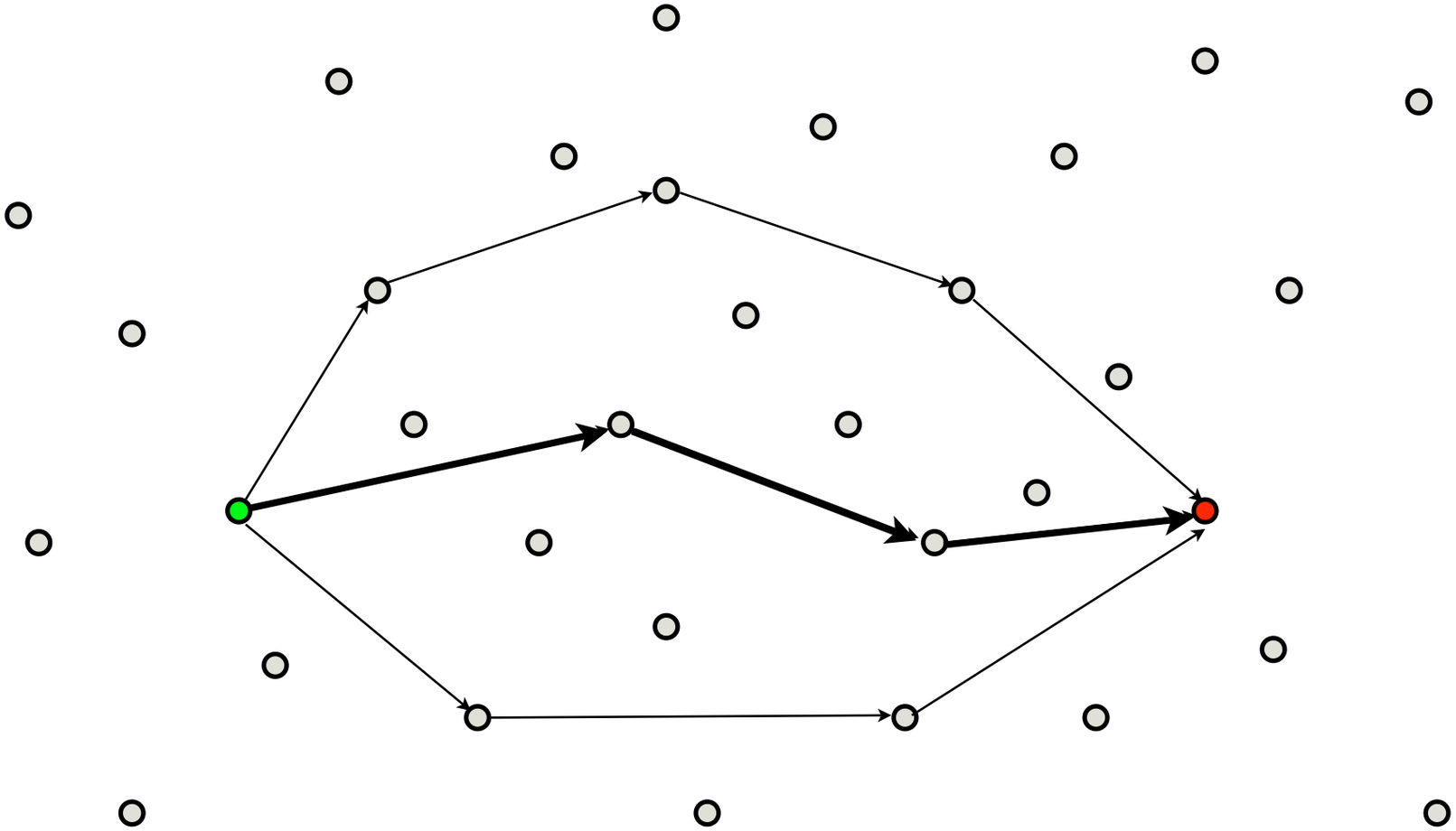
What if we restrict routing?



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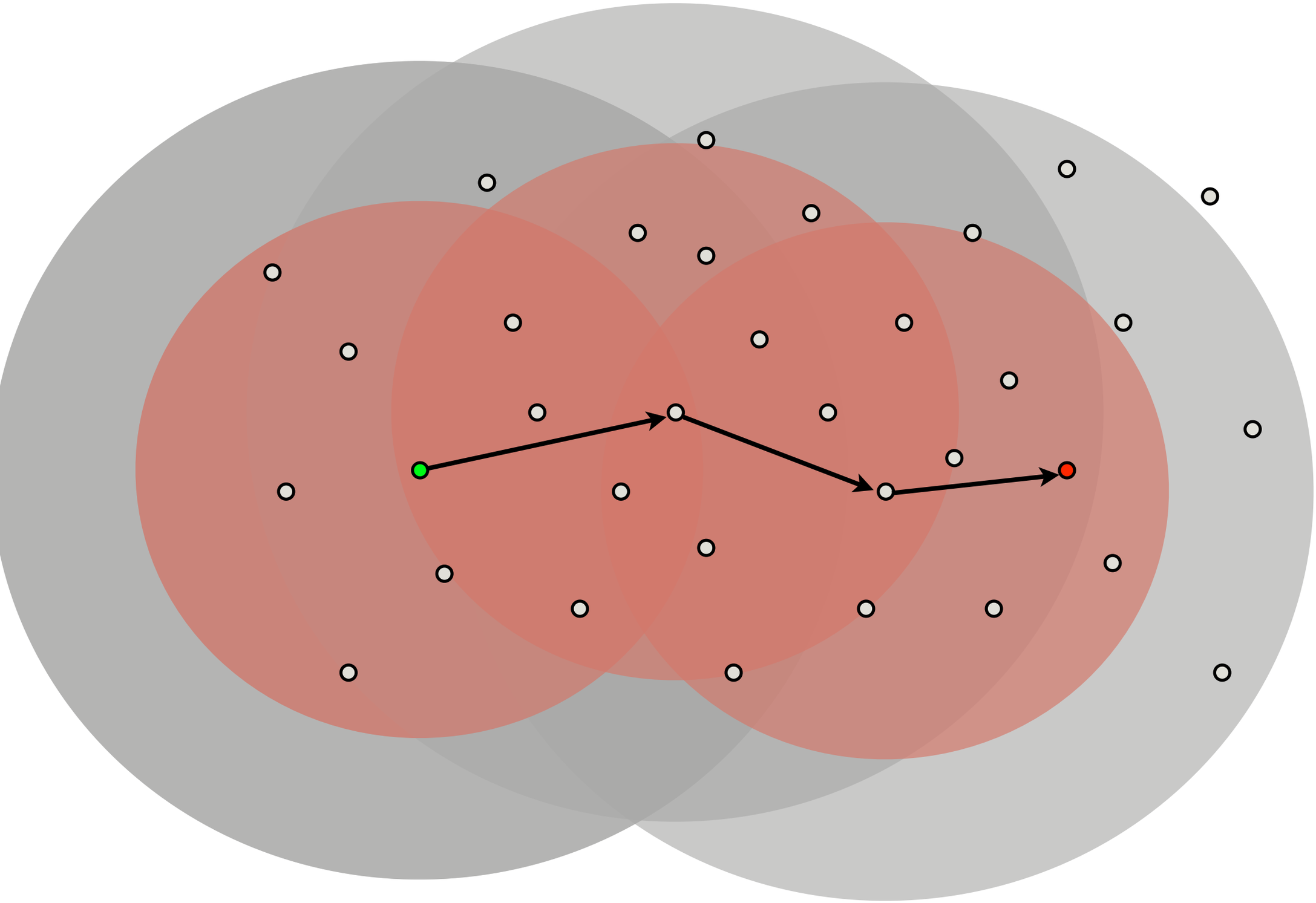
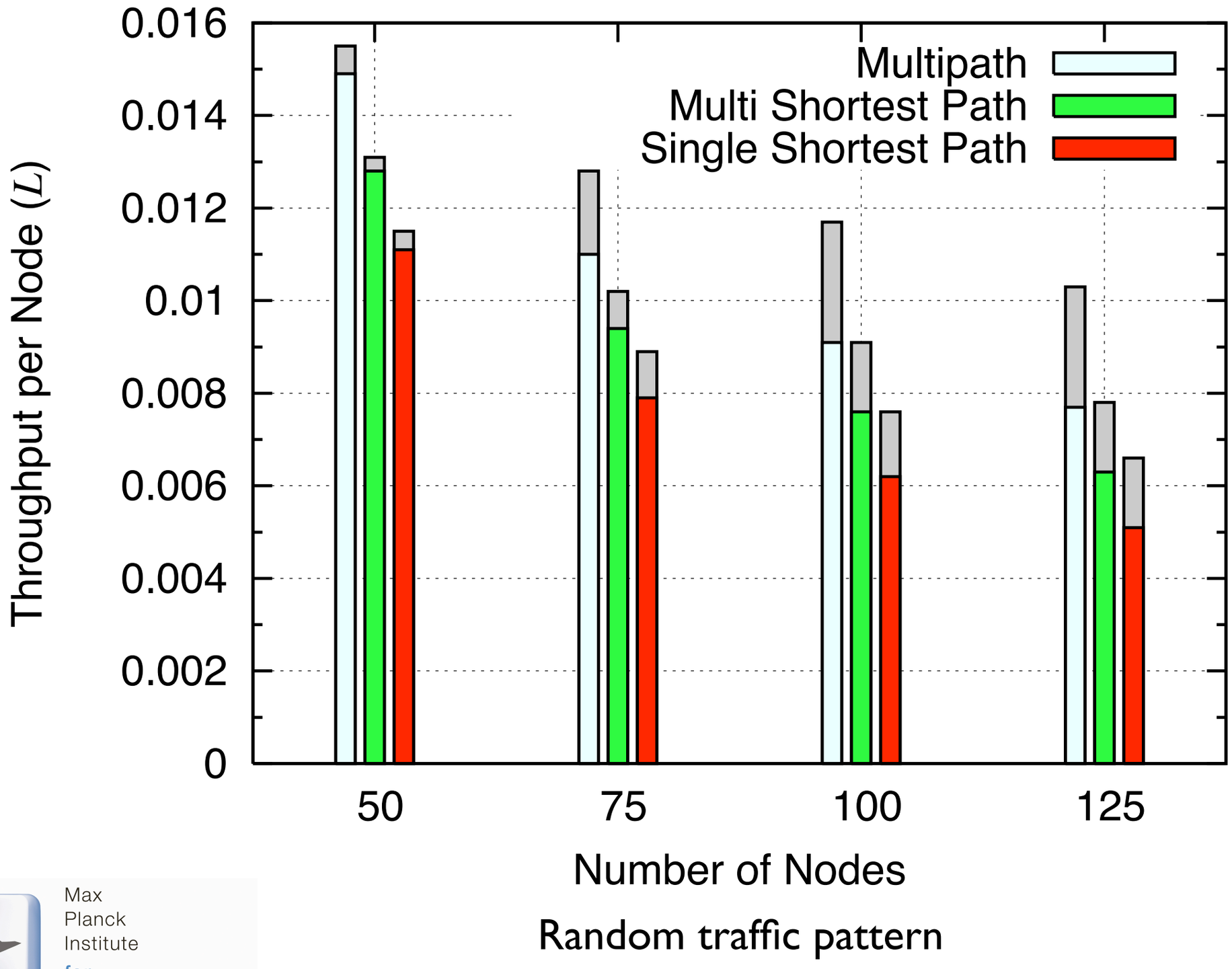


How does path selection impact capacity?



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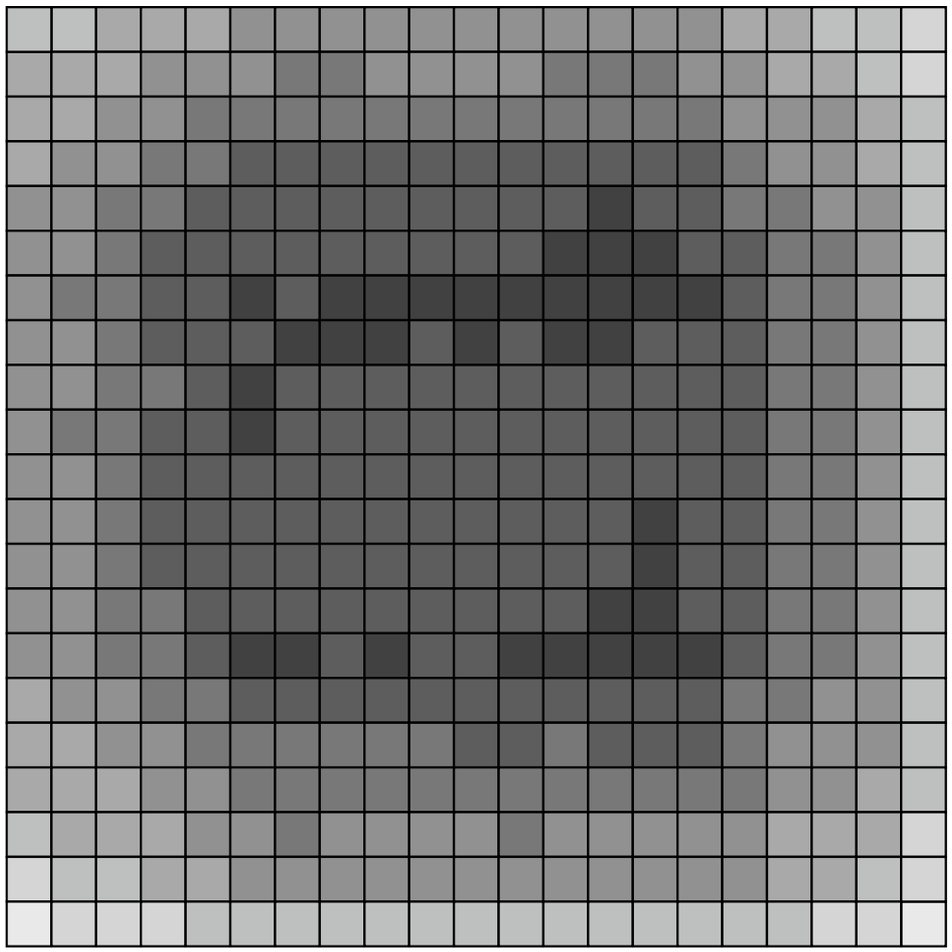
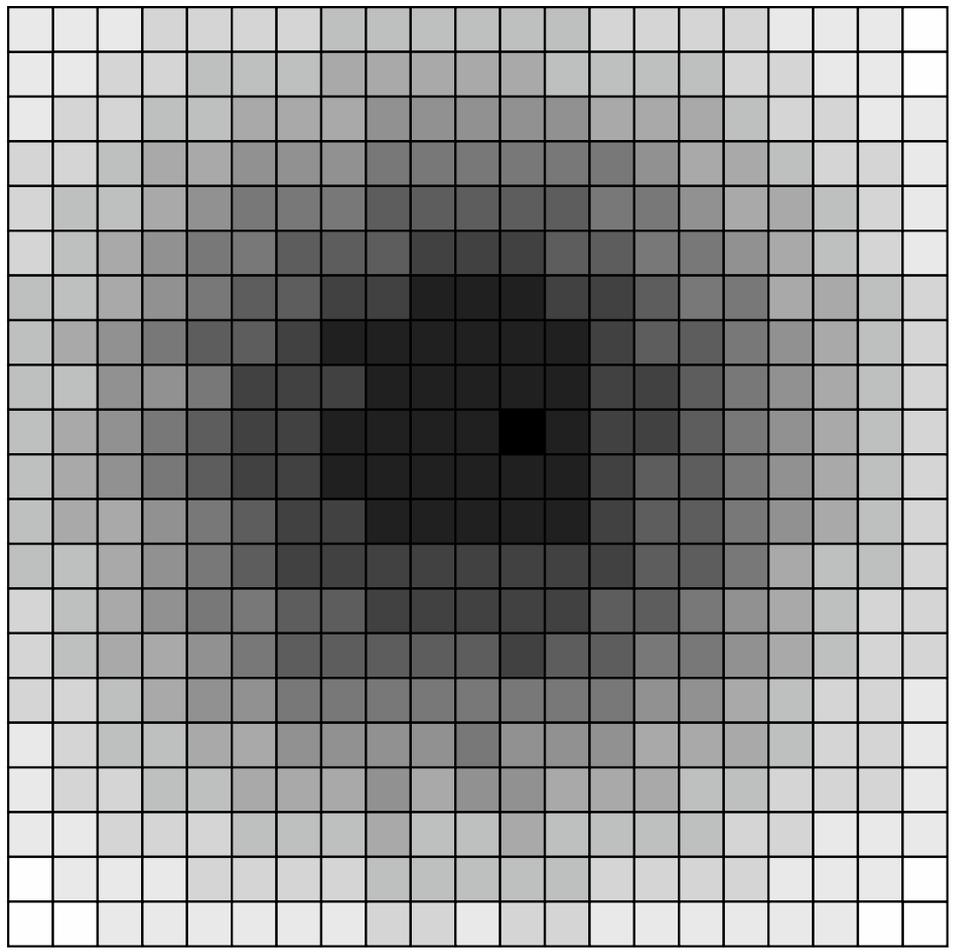
How does shortest path impact congestion?



Multi-path



Shortest Path

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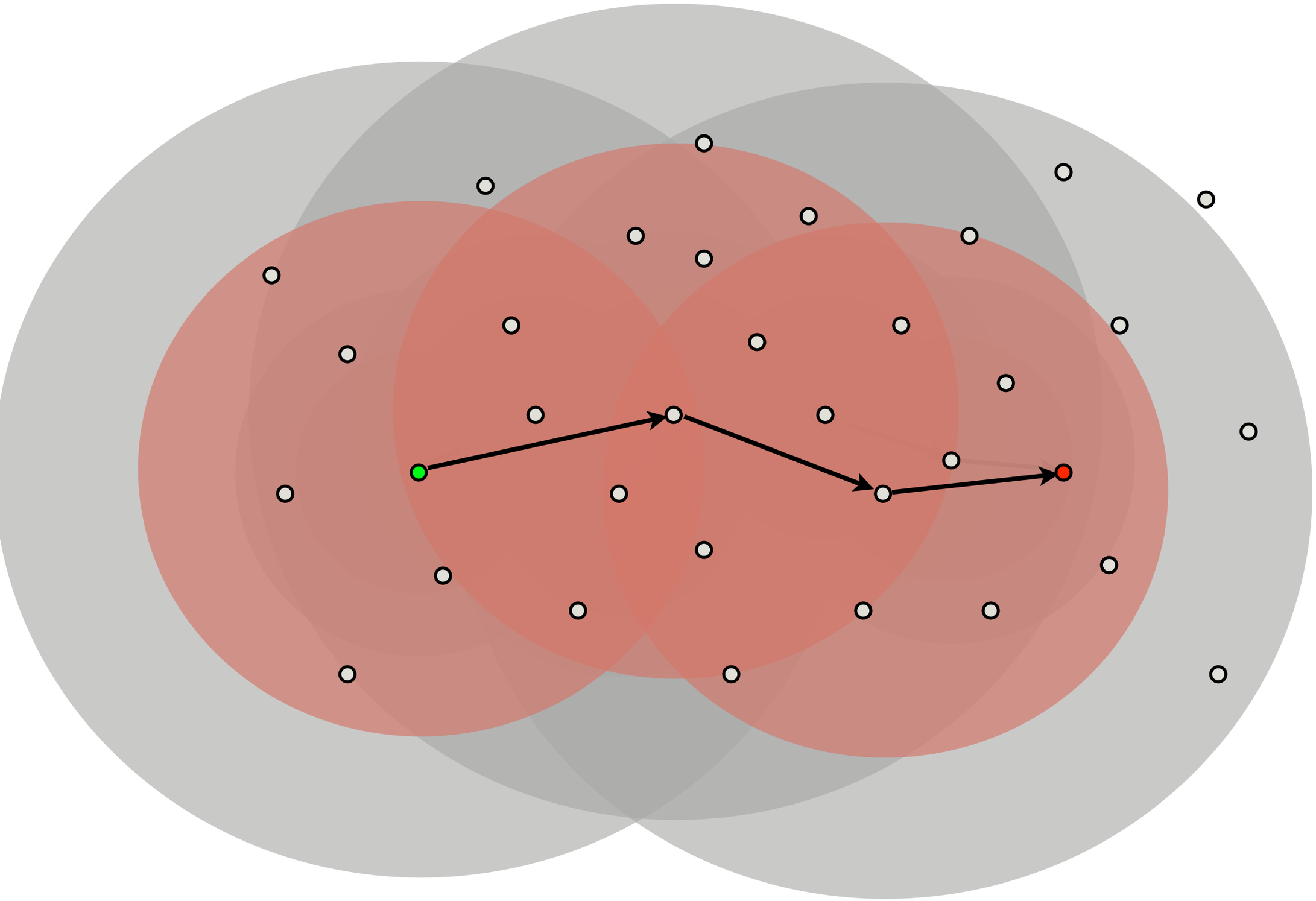
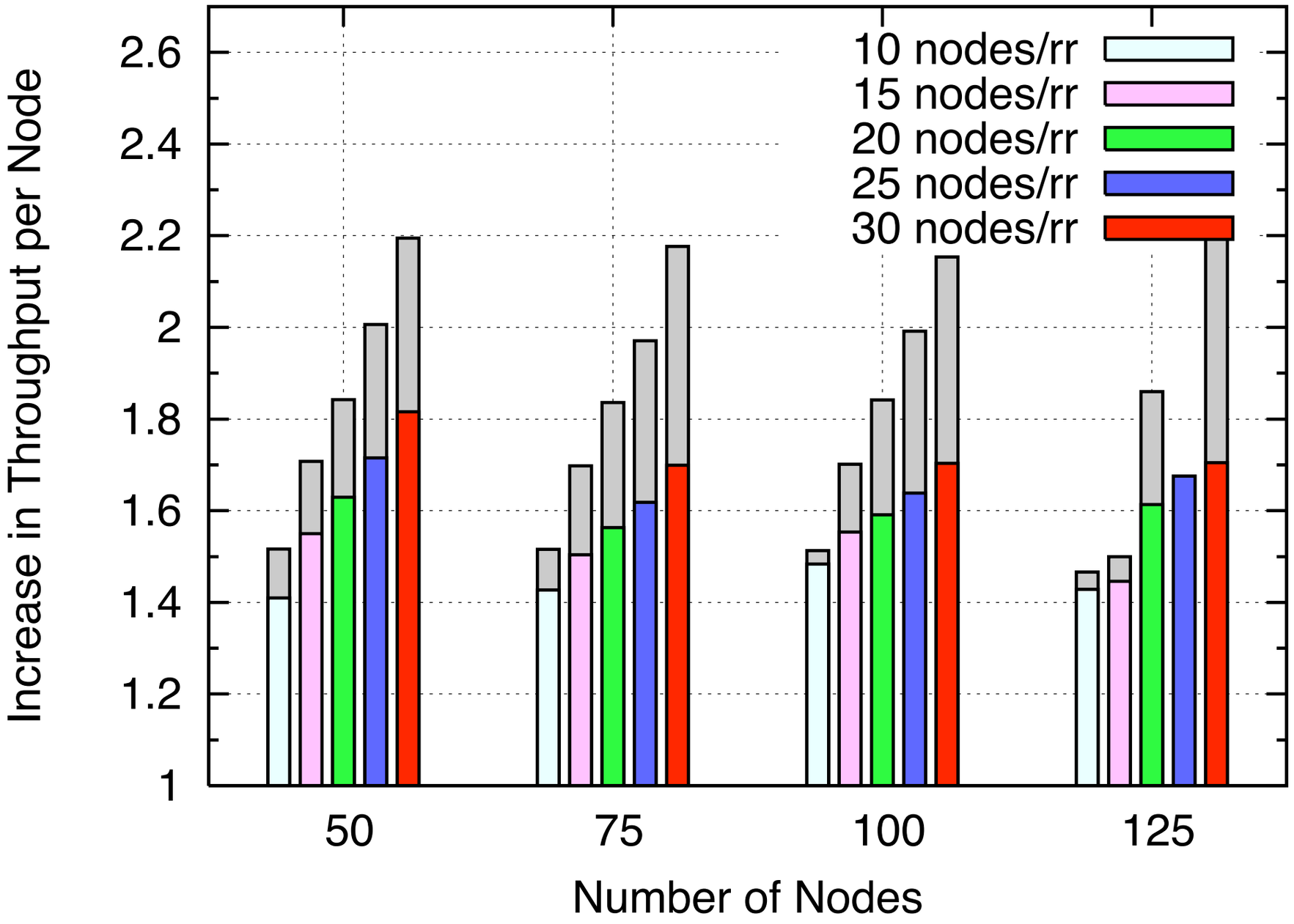
50 Nodes, Random traffic pattern

What if we adapt transmission power?

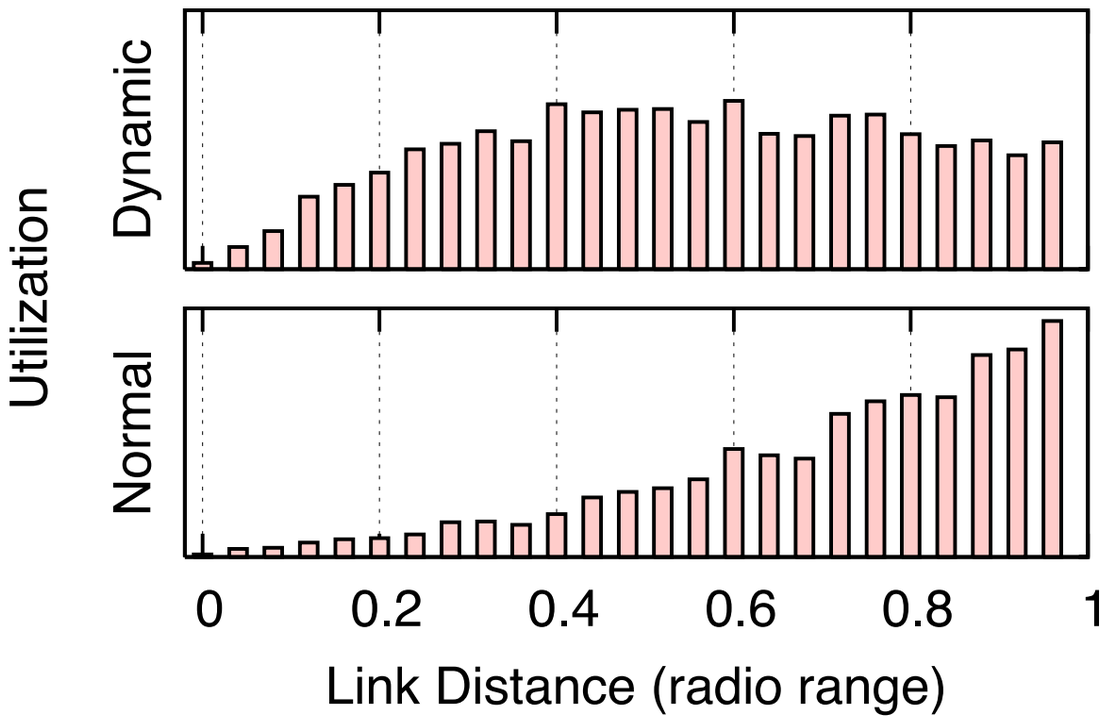


How much does dynamic radio power help?

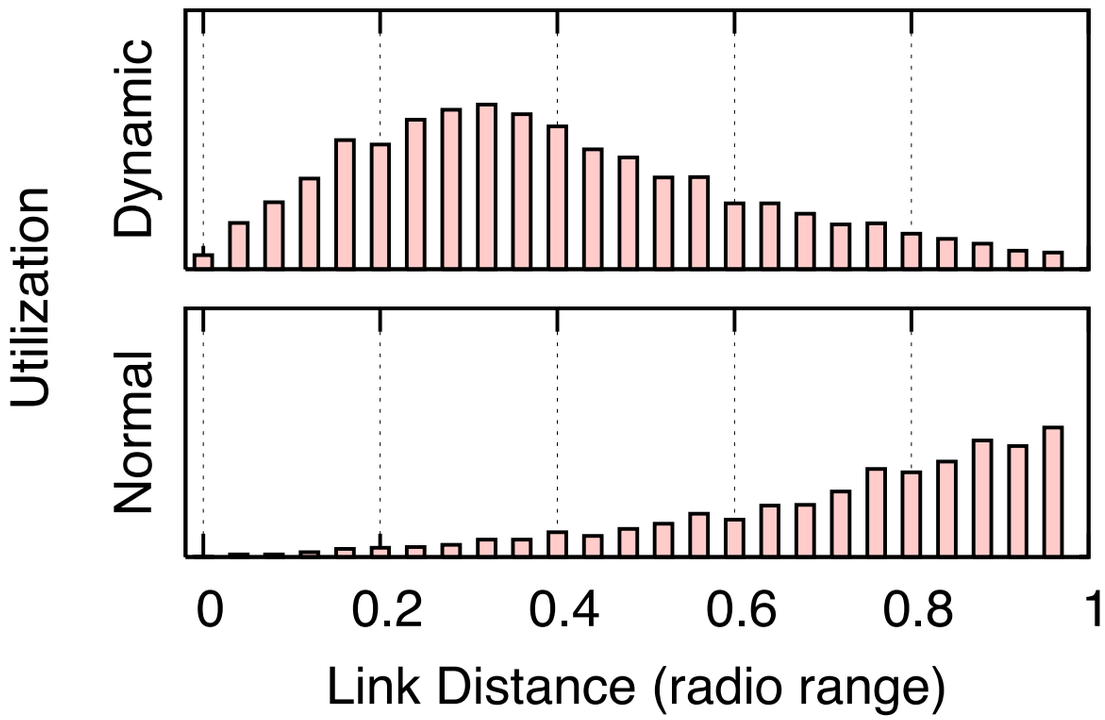


Random Traffic Pattern

What links are used?



50 Nodes, 10 Nodes per radio range
Random traffic pattern



50 Nodes, 30 Nodes per radio range
Random traffic pattern

Conclusion

- Systematically studied factors that influence network capacity
  - Shortest path congest middle of the network
  - Locality in traffic pattern is needed for scalability
  - Dynamic power control can significantly increase capacity
- Provide insights to application, protocol and network designers
- Future work
  - Mobility
  - Empirically based radio models

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Questions?

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