Multipath Load Balancing in Multi-Hop Wireless Networks

University of Waterloo

Evan Jones

Martin Karsten

Paul Ward

Multi-hop Wireless Networks

- Nodes with radios
- Self configure to form a network

- Cheap and easy to deploy
- Robust

- Alternative to traditional wired infrastructure
- "Last mile" Internet access

Motivation for Load Balancing

- Multi-hop wireless has low bandwidth
  - Chain with ideal MAC: one quarter channel capacity
- Avoid congestion by distributing load

Can load balancing improve throughput?

Previous Work

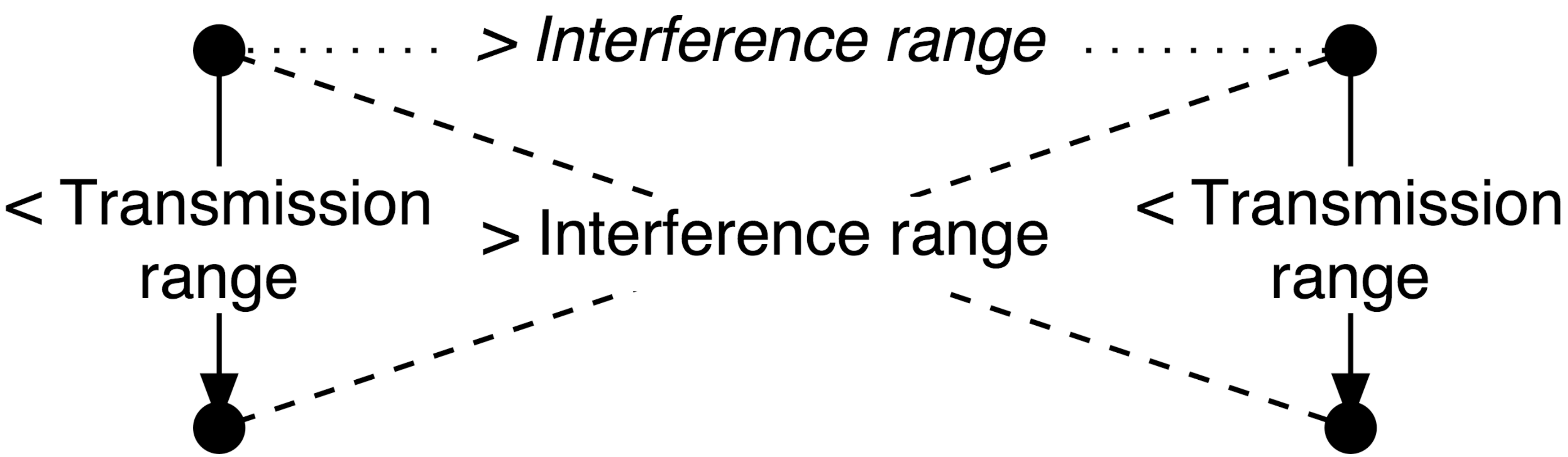
- Improve reliability with backup paths
- Can decrease delay
- Theoretical analysis: improves aggregate throughput
- Improves performance when used with directional antenna, packet caching, new routing metrics

Understanding Load Balancing

- No mobility
- Fixed power transmissions
- Single channel
- Omnidirectional antennas

Protocol Model of Interference

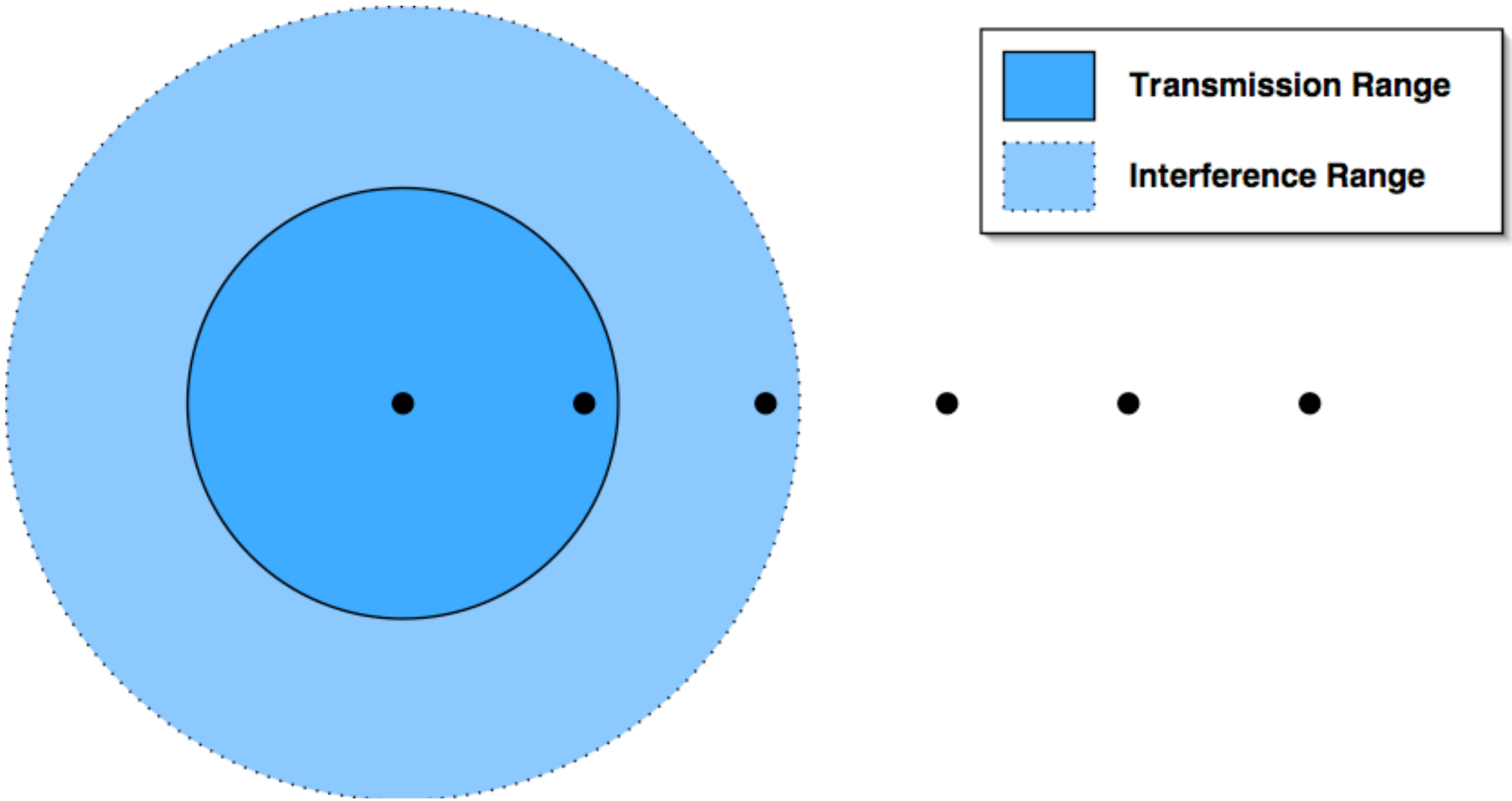
- Nodes must be within transmission range
- No other transmitters within interference range
- Carrier sensing: senders must be outside interference range



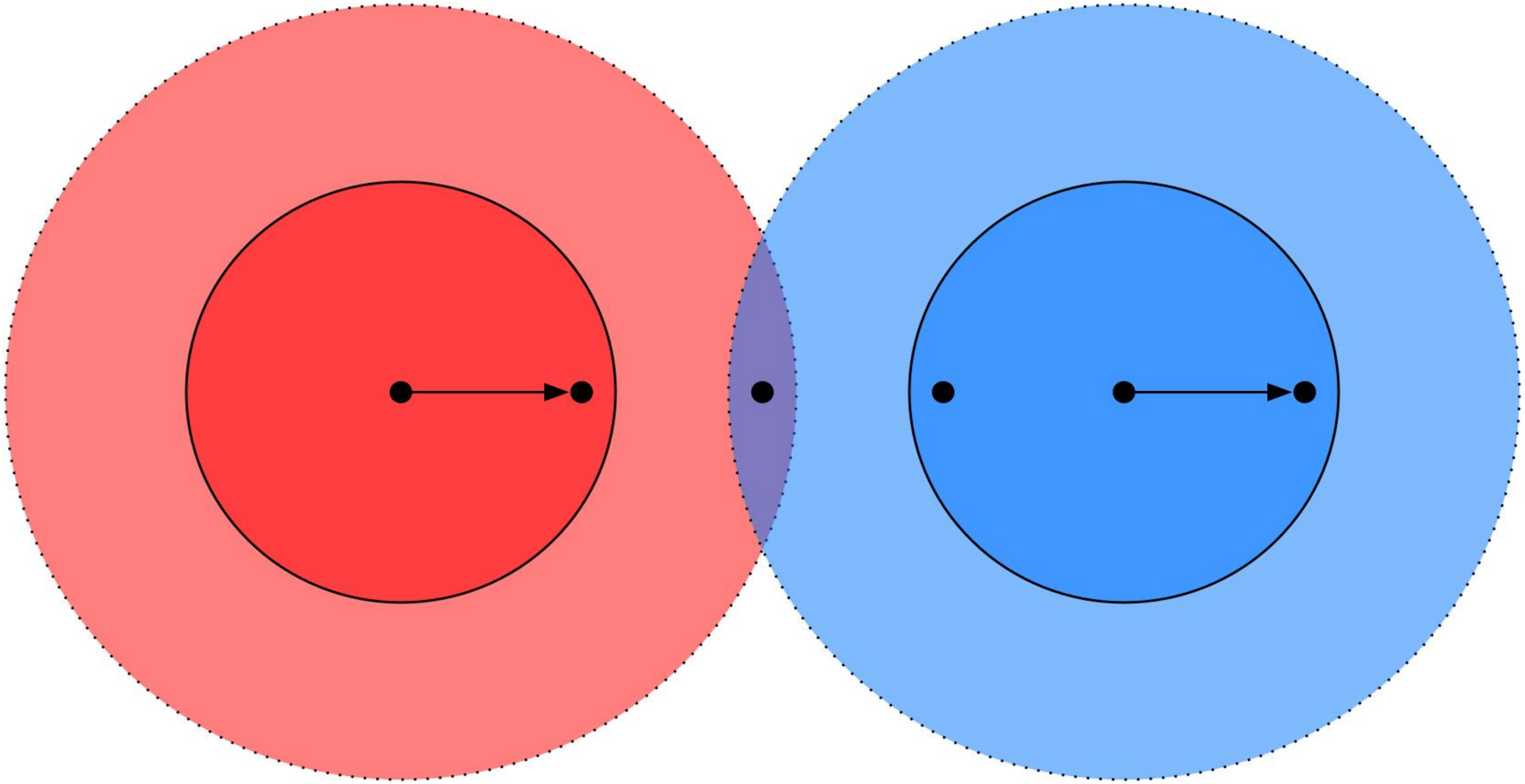
Simplifying Assumptions

- No MAC overhead
- Rate limited sender
- Nodes spaced at maximum range
- Fixed sized packets
- Interference range = $2 \times$ (transmission range)

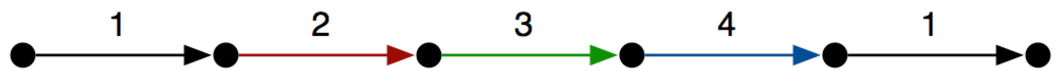
Chain Topology



Chain Topology

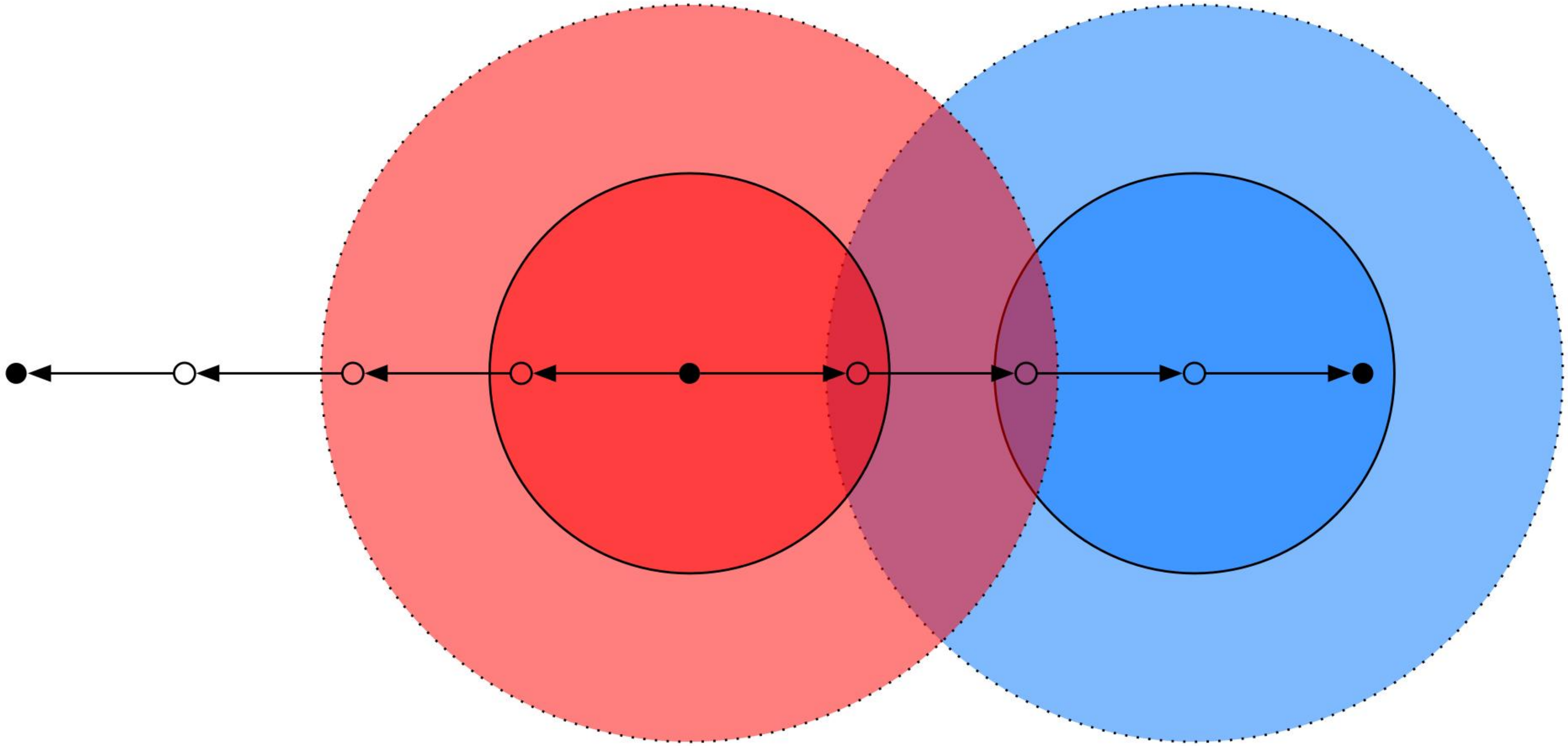


Chain Topology

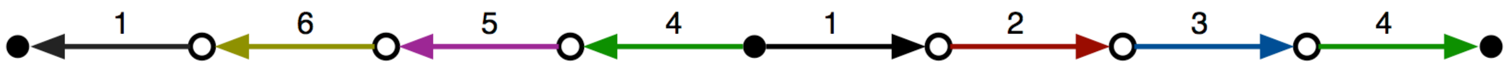


Rate = ¼

Two Directions: Out



Two Directions: Out

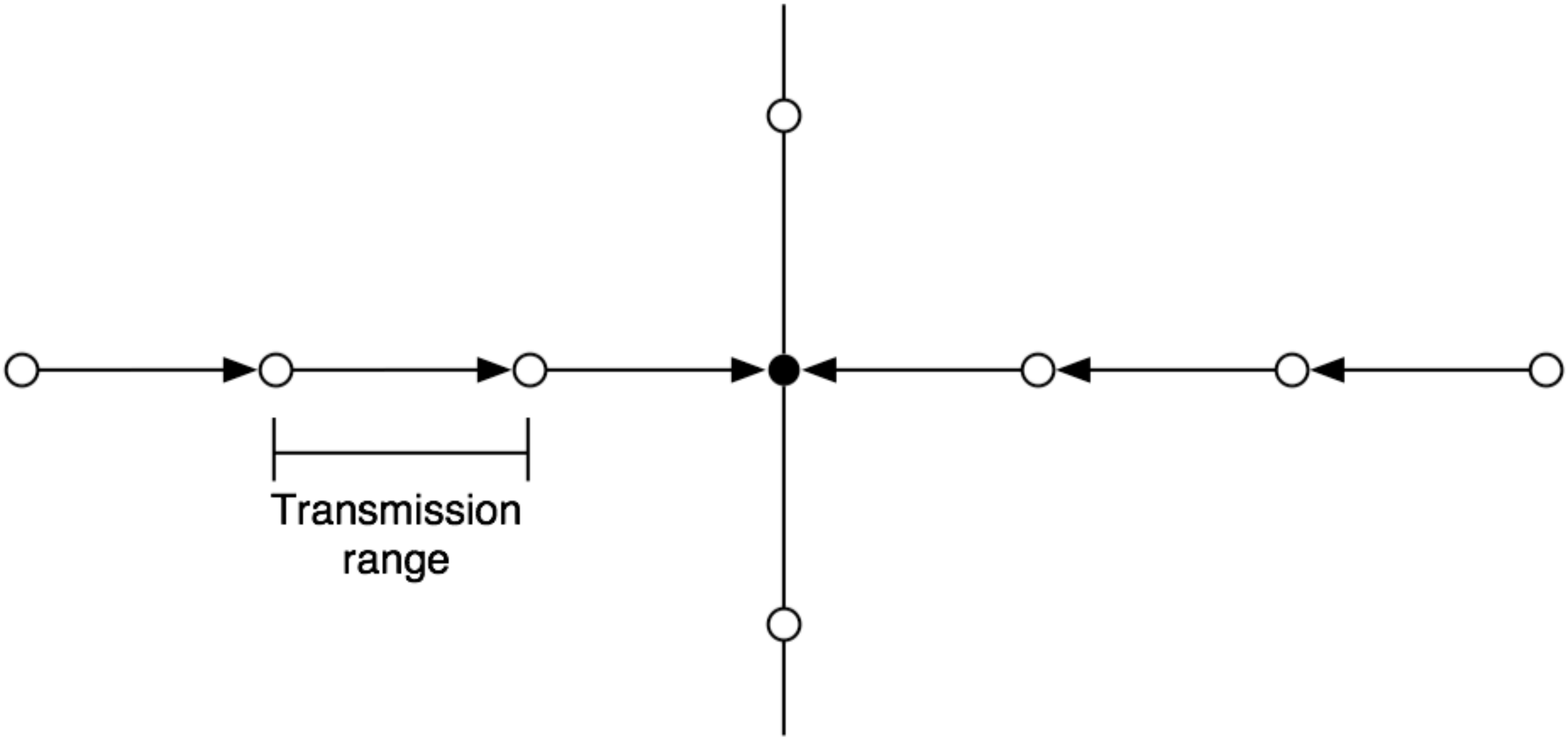


Rate = ⅓

Two Directions: In

Rate = ½

Cross Topology



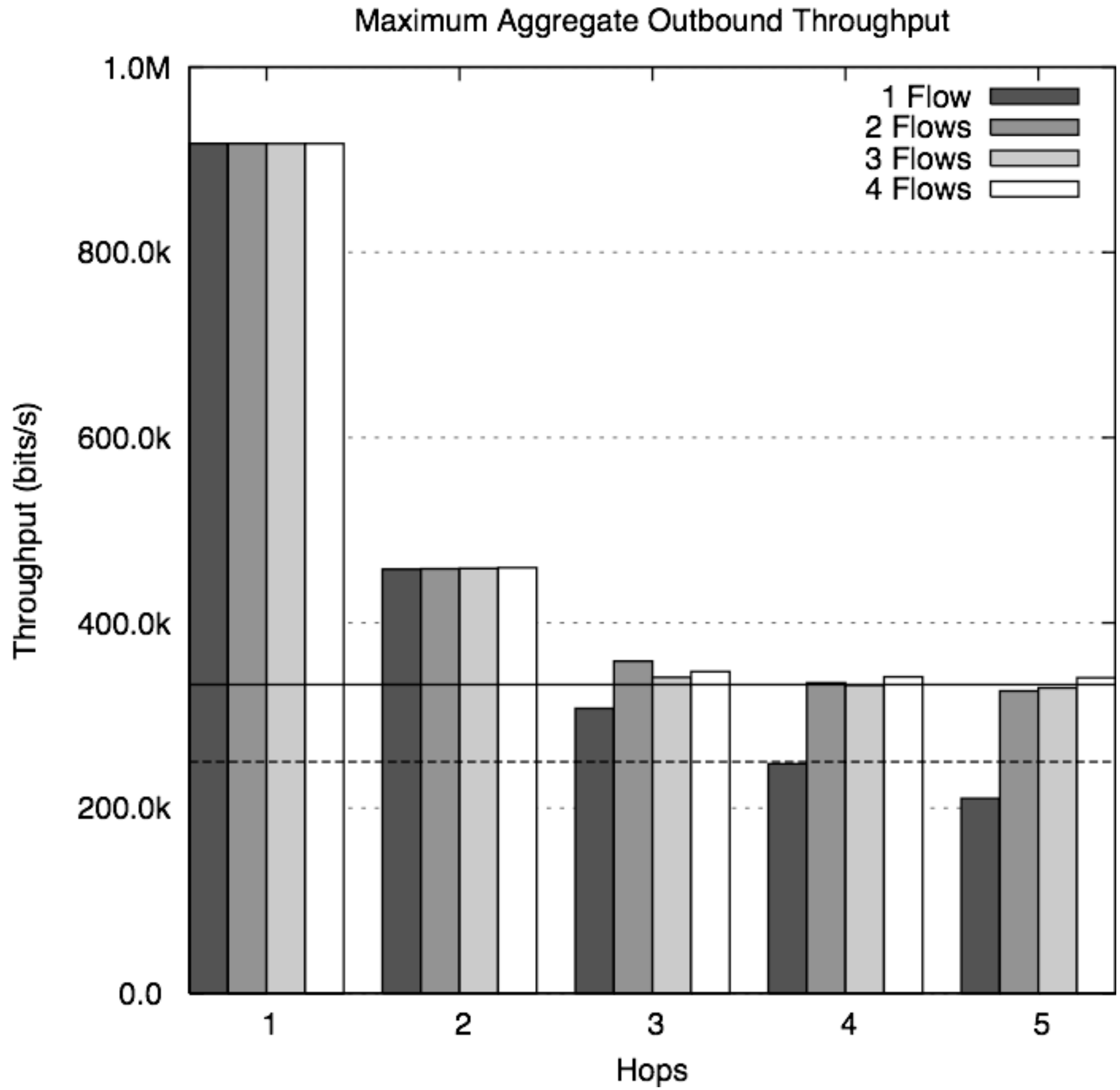
Cross Throughput

Dir.	Paths (l=2T)			
	1	2	3	4
Out	¼	⅓	⅓	⅓
In	¼	½	½	½

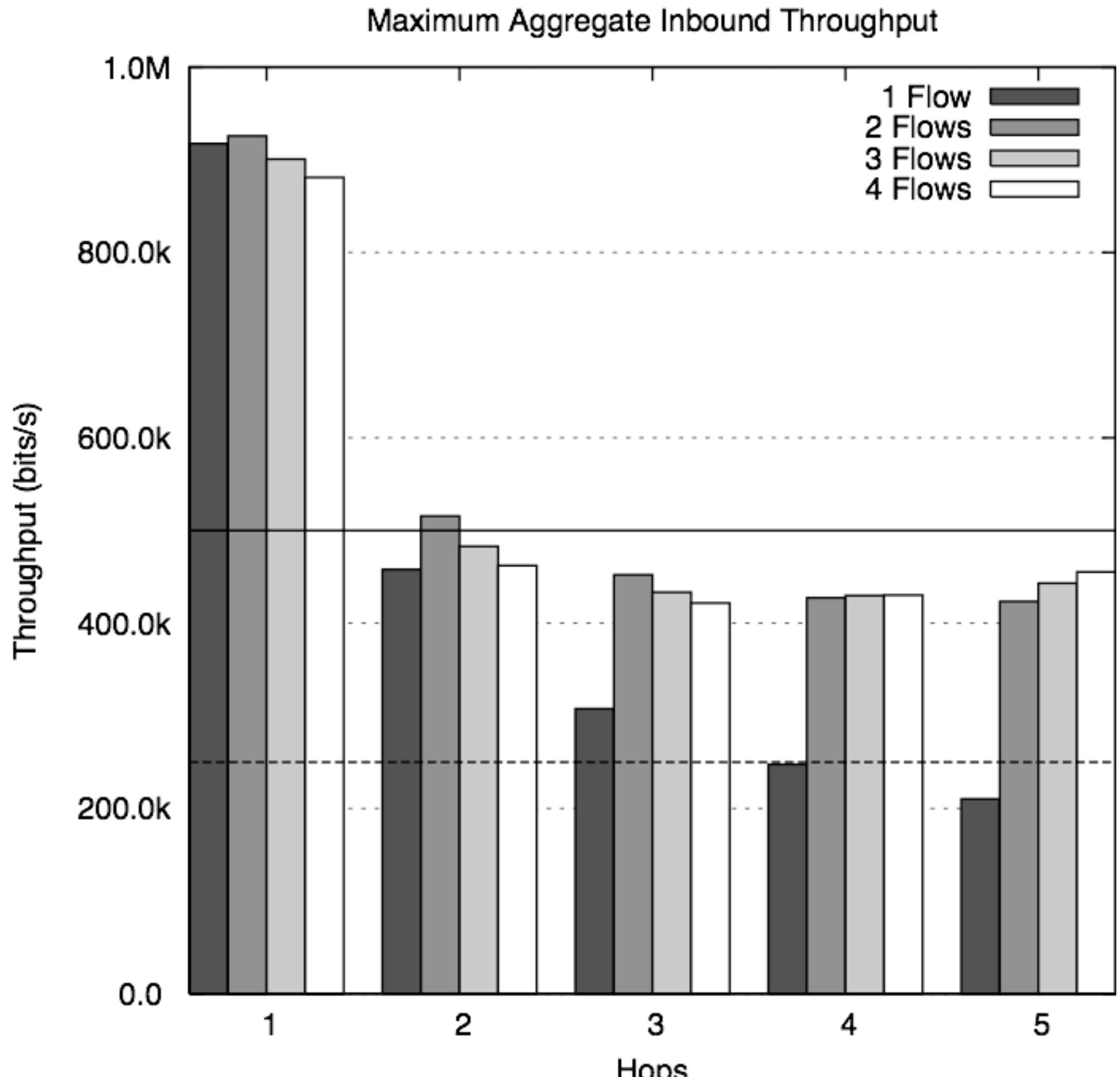
More Realistic Model

- MAC protocol: 802.11
- Power capture model of interference
  - If SNR > threshold: packet received
  - Two ray ground model
- Simulated with ns2
  - T = 250m, I = 550m = 2.2 T
- 1 Mbps data rate, 1500 byte packets
- CBR sources, rates scaled from low to high load

Cross: Throughput Out



Cross: Throughput In



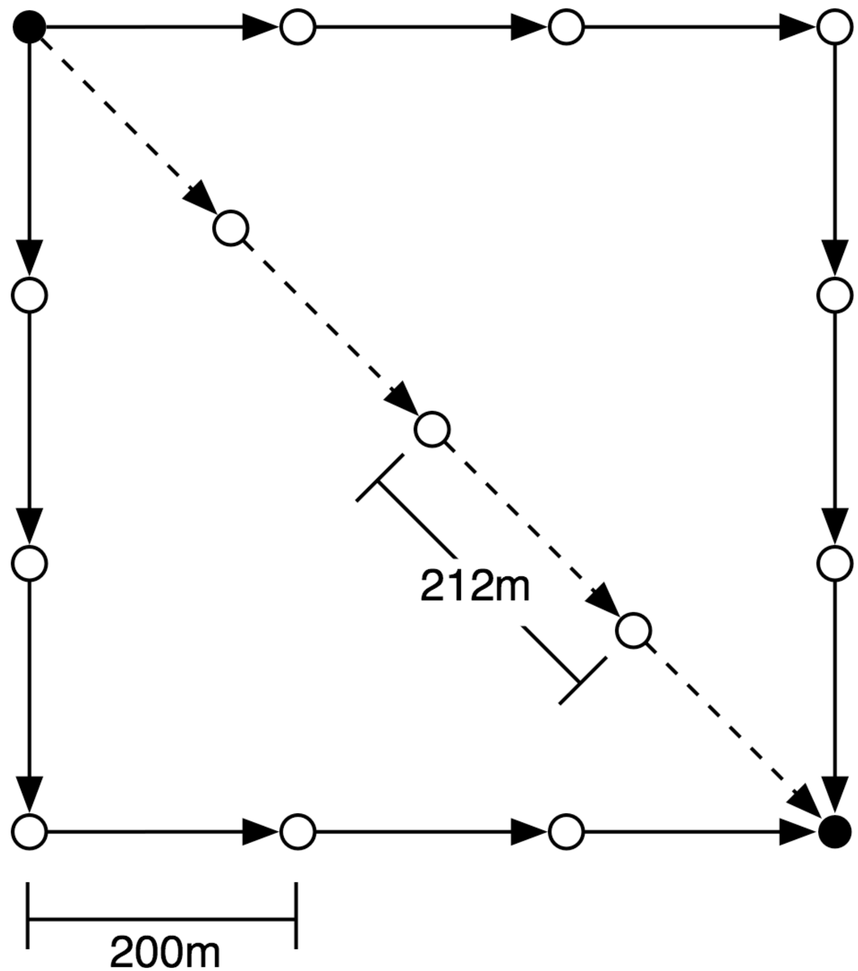
End Points: Observations

- Protocol model results match ns2 results
- Load balancing can improve throughput
  - Up to 101% increase in throughput
- 2 hops or less: no benefit
- Diminishing returns after adding second flow
- No delay improvement

Simple Multipath Topology

- Two flows
- At least three hops in the shortest path
- Concurrent transmissions must by outside interference range
  - ns2: Physical separation > 550m
- Simple case: 4×4 grid

Simple Multipath: 4×4 Grid



4×4 Grid Performance

Metric	Single Path	Edge Path	Multipath
Path Length (hops)	4	6	6
Throughput (bps)	252 720	196 440	267 840
Avg. Delay at 120 kbps	54.4 ms	80.8 ms	78.9 ms

Grid Routing

- Routing using node location
  - Half of the paths have > 35% throughput improvement
- Heuristic using network topology
  - Half of the paths have > 20% throughput improvement
- Some paths have 80% throughput improvement

Load Balancing Conclusions

- Can improve throughput
- Increases delay
  - Longer paths
  - Higher probability of collision

- Need at least three hops
- Longer paths are better
- Diminishing returns with more than two flows
- Very sensitive to interference

Future Work

- Multiple gateways
- Using TCP
- Multiple flows
- Multi-channel networks
- Random topologies

Questions?