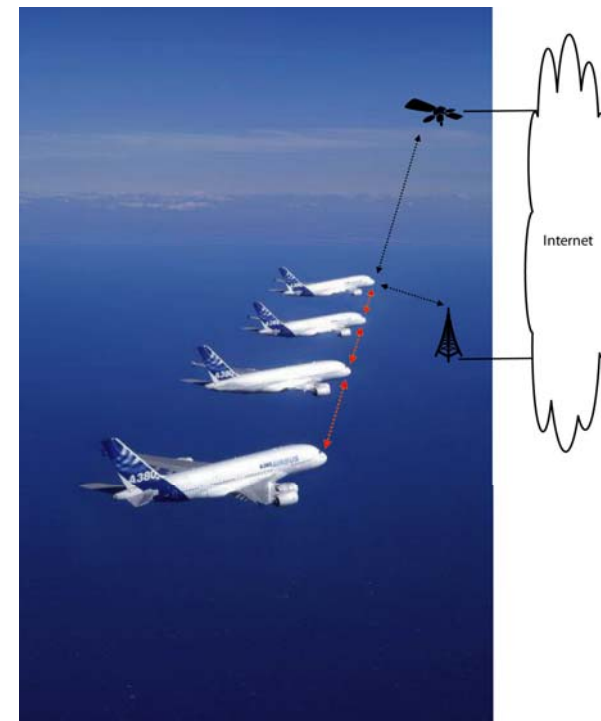




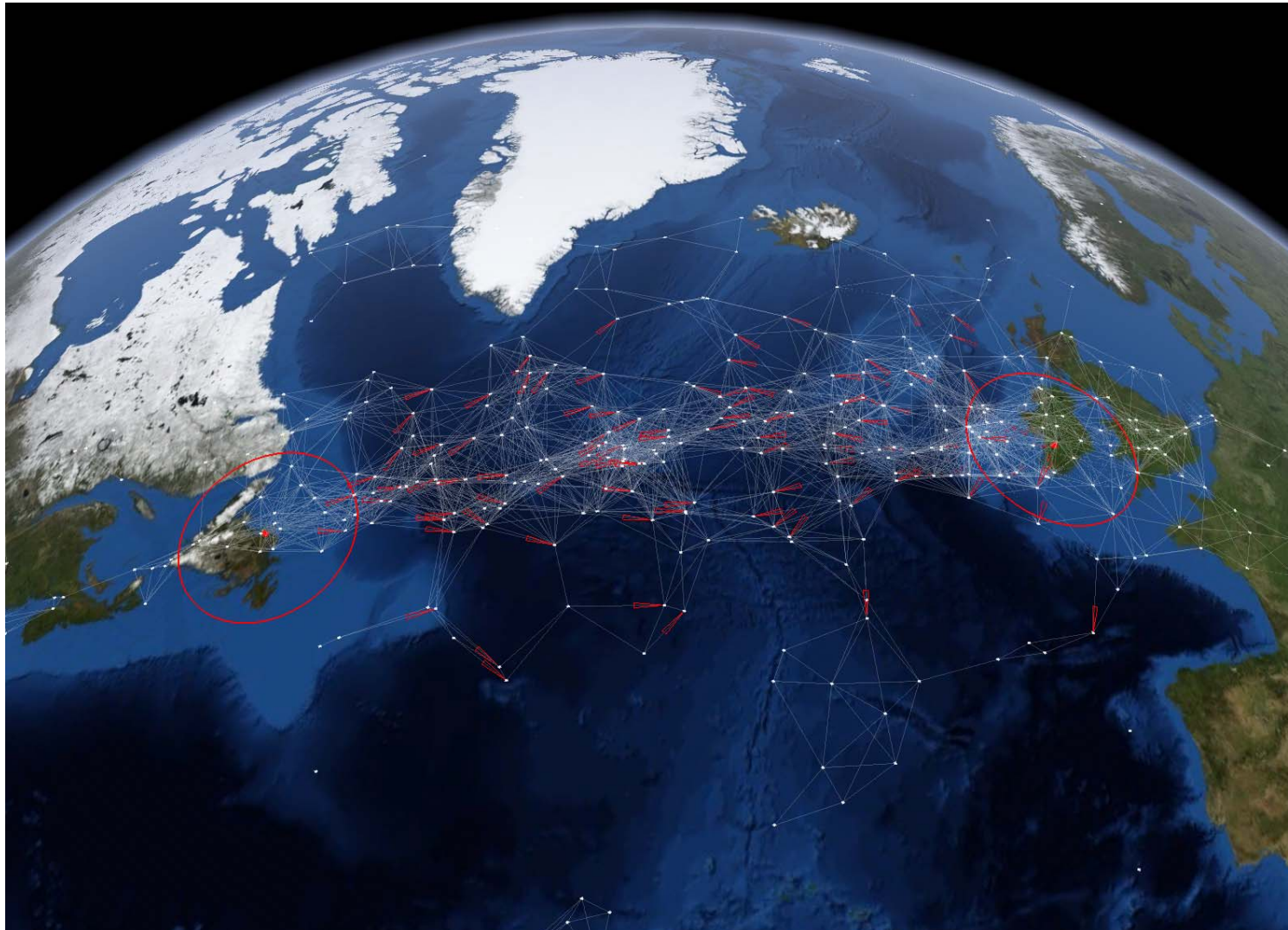
Routing in the Sky

Daniel Medina
German Aerospace Center (DLR)





The Airborne Internet





Outline

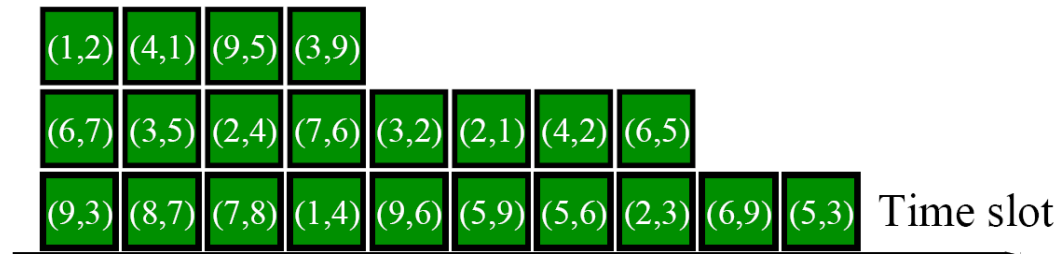
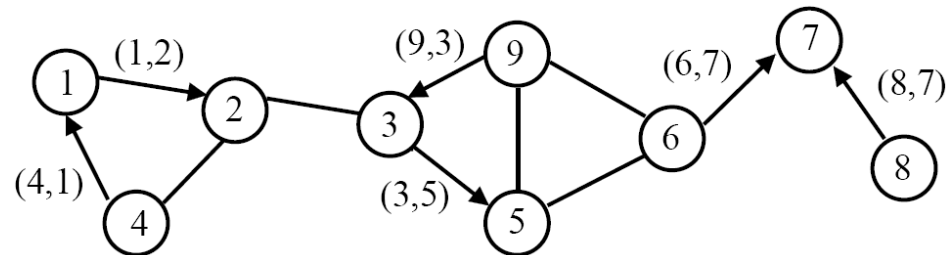
- The Airborne Internet
- **Spatial TDMA with Multibeam Antennas**
- Distributed Geographic Routing and Scheduling (DGRS)
- Simulation Results
- Conclusions



Spatial TDMA

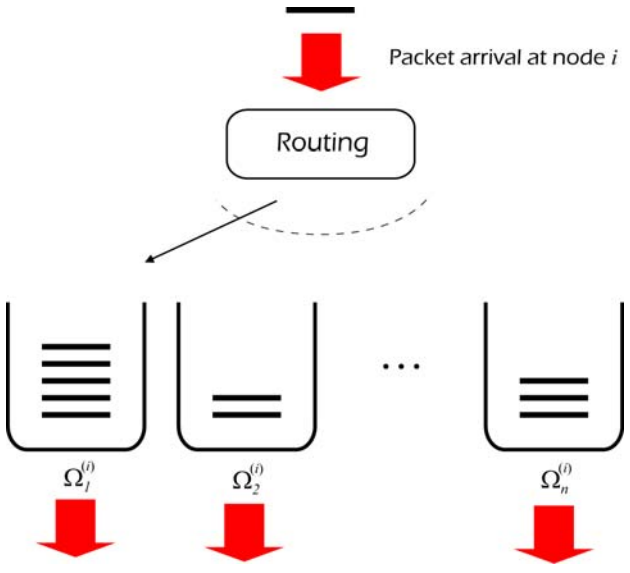
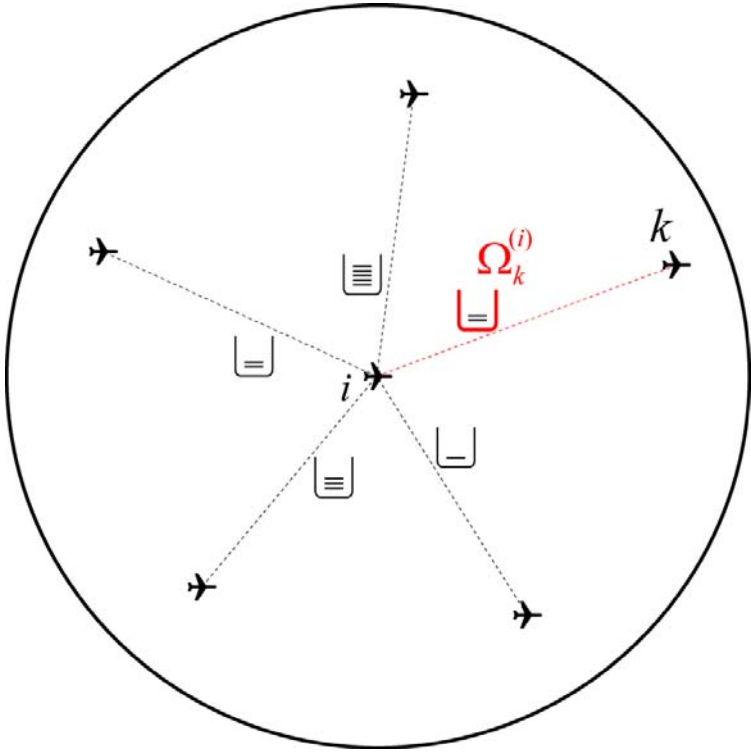
➤ First described in...

➤ R. Nelson and L. Kleinrock, "Spatial TDMA: A collision-free multihop channel access protocol", IEEE Transactions on Communications, 1985.



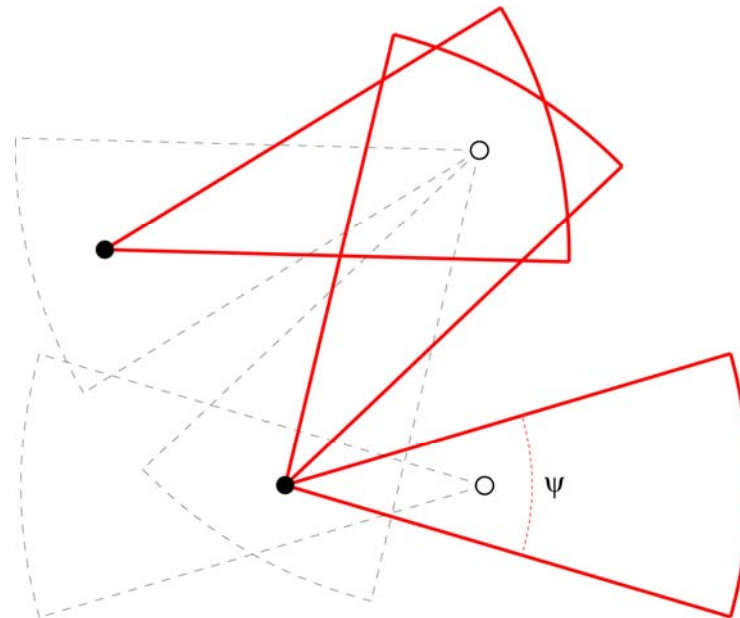


Spatial TDMA - Queueing





Spatial TDMA with Multibeam Antennas



In any given time slot:

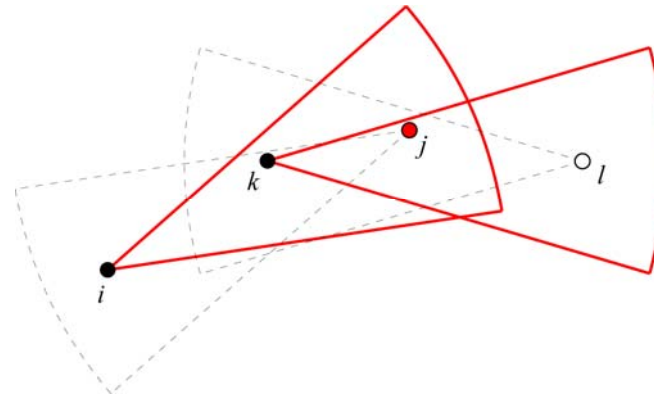
c1) A node may only either **transmit** or **receive**

c2) A node may activate at most **K** beams



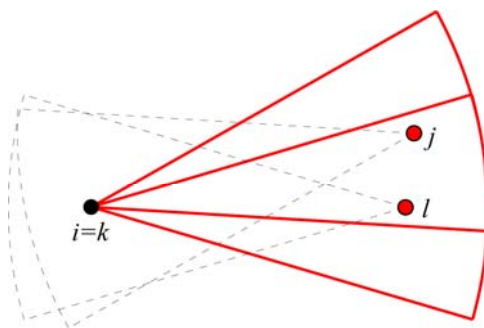
Spatial TDMA with Multibeam Antennas

c3) Two links (i,j) and (k,l) may be activated only if neither receiver hears both transmitters

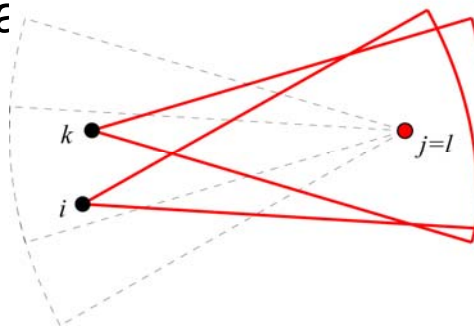


Special case ($i=k$ or $j=l$):
less

A node may not activate beams with



angular separa





Sánchez et al. (KTH, 2001)

Reuse Adaptive Minimum Hop Algorithm (RA-MHA)

- Routing limits the potential network throughput
- When interference reduction measures such as narrow antenna beamwidth are used, the problem that a node cannot receive and transmit at the same time becomes an important limiting factor



- With directional antennas, flexibility in a node's **routing** decision can greatly increase its ability to satisfy bandwidth demand during link **scheduling**

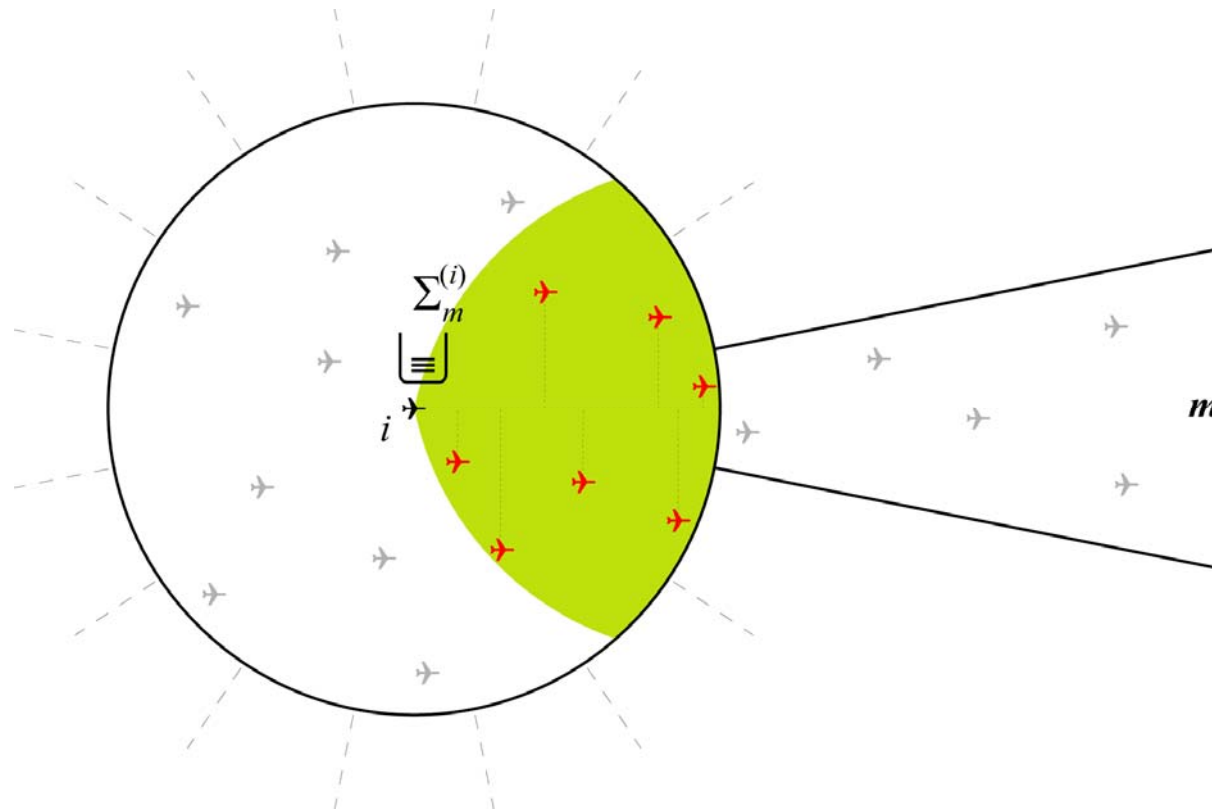


Outline

- The Airborne Internet
- Spatial TDMA with Multibeam Antennas
- **Distributed Geographic Routing and Scheduling (DGRS)**
- Simulation Results
- Conclusions



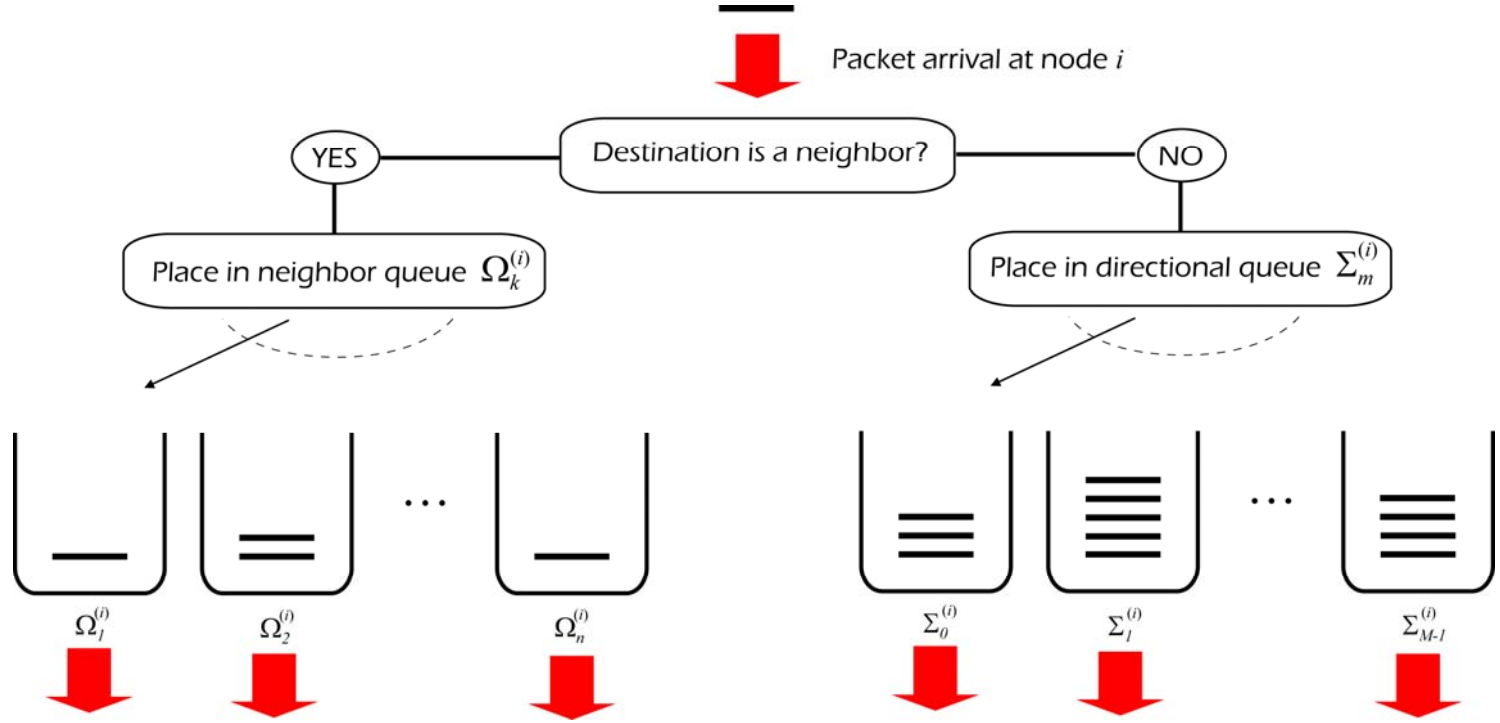
Next hop candidates $\mathcal{N}_m^{(i)}$



- $\Sigma_m^{(i)}$ Queue holding packets at node i with destination in sector m
 $\mathcal{N}_m^{(i)}$ Set of next hop candidates at node i for sector m

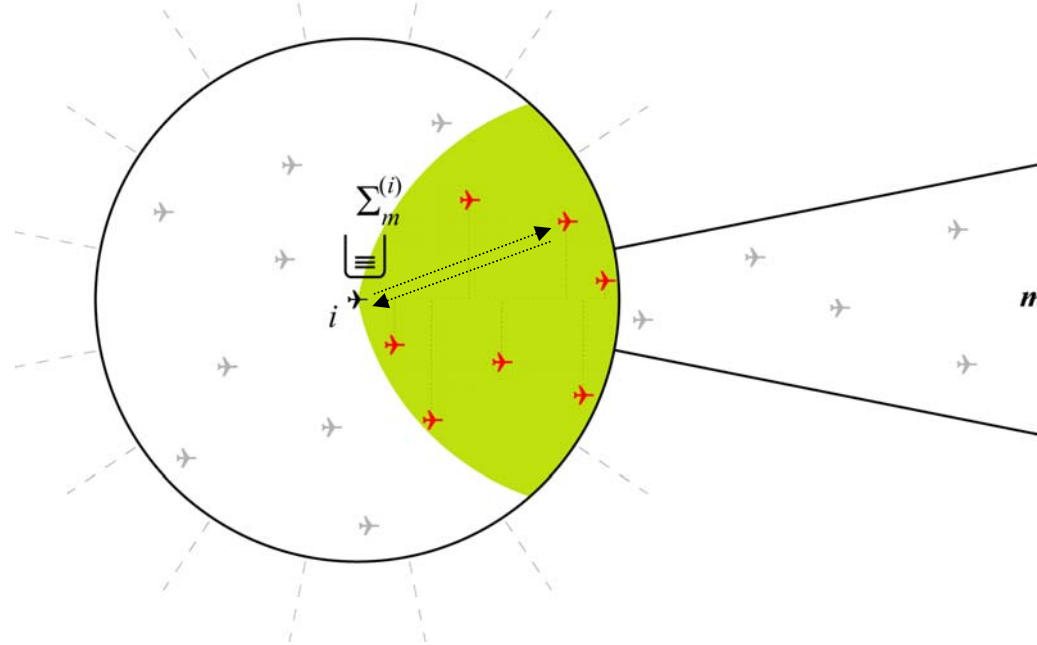


A node's queues



Distributed Geographic Routing and Scheduling (DGRS)

- Neighbors periodically exchange HELLO messages containing their ID, position and tx/rx schedule
- From this, a **Candidate Availability Table** (CAT) is generated
- When a queue requires additional bandwidth, a three-way handshake REQ/REPLY/CONFIRM is used to obtain additional resources from the foremost candidate with available slots





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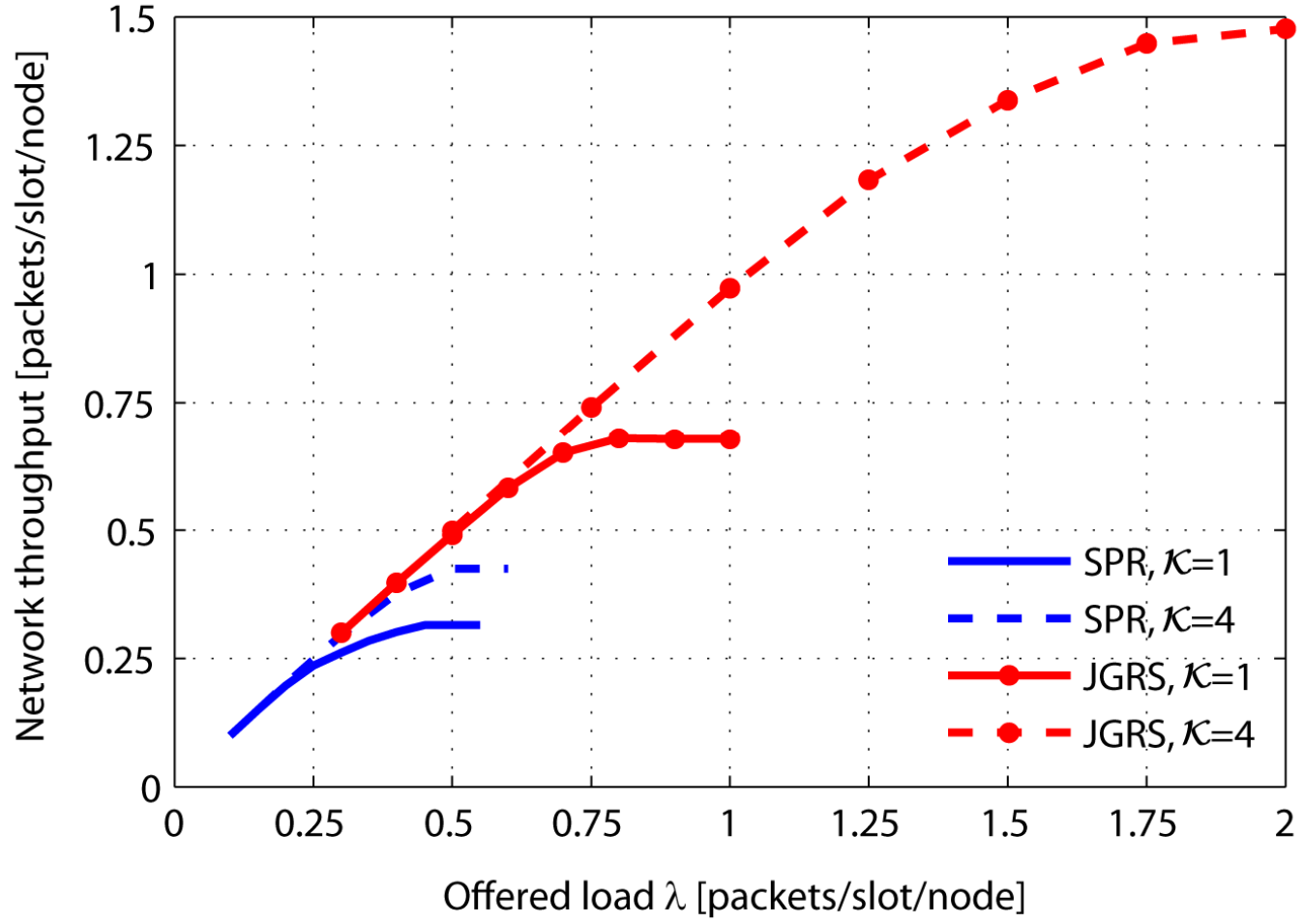
Simulation Results

- Compare throughput of DGRS and SPR (single-path routing)
- 100 nodes uniformly distributed over square area
- A subset of nodes generate CBR traffic to random destination
- Simulation parameters
 - Beamwidth (ψ) and number of simultaneous beams (K)
 - Density (connectivity)
 - Traffic matrix



Simulation Results – Throughput vs Offered Load

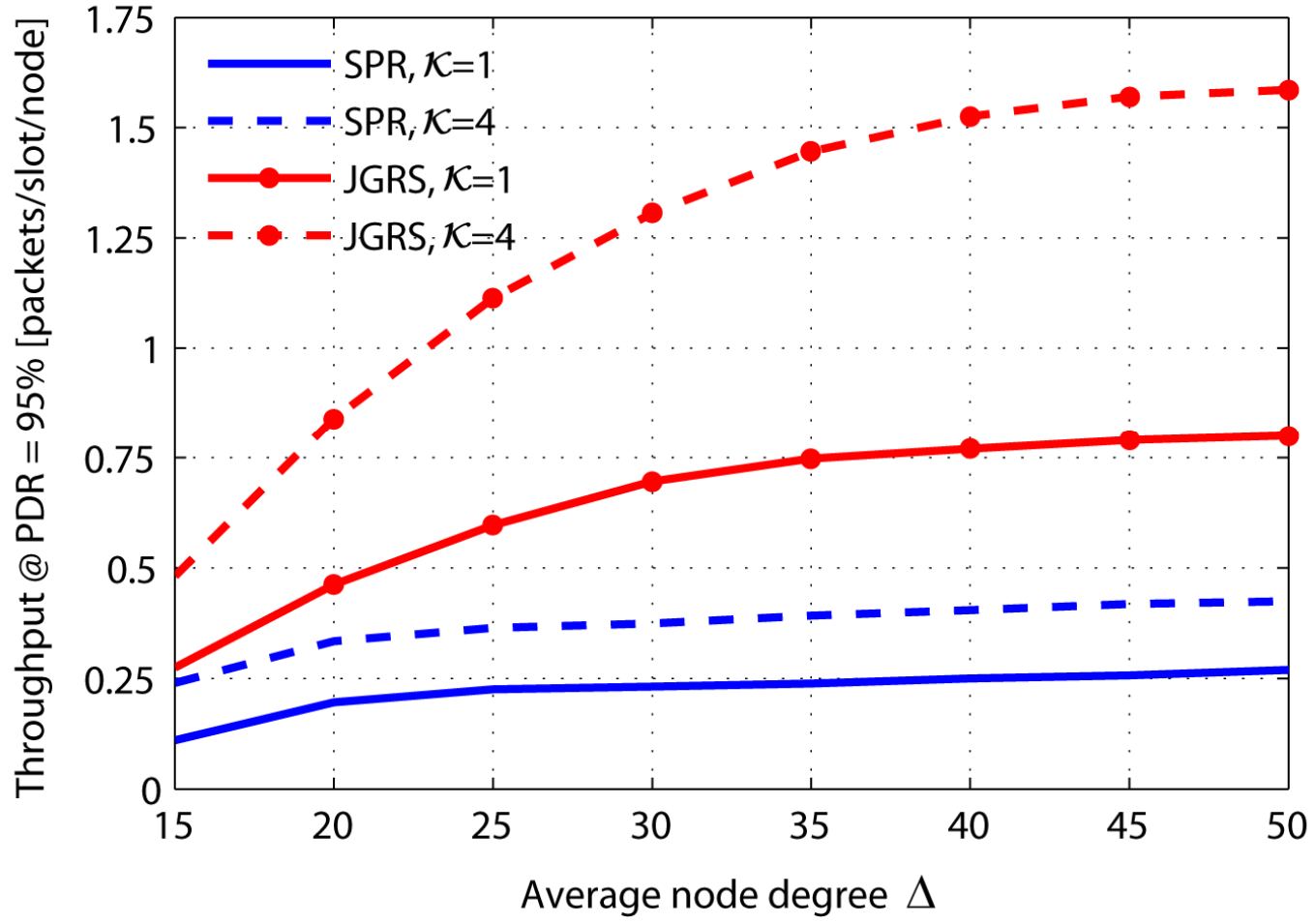
$\Delta = 25, n_s = 10, \psi = 30^\circ$





Simulation Results – Throughput vs Density

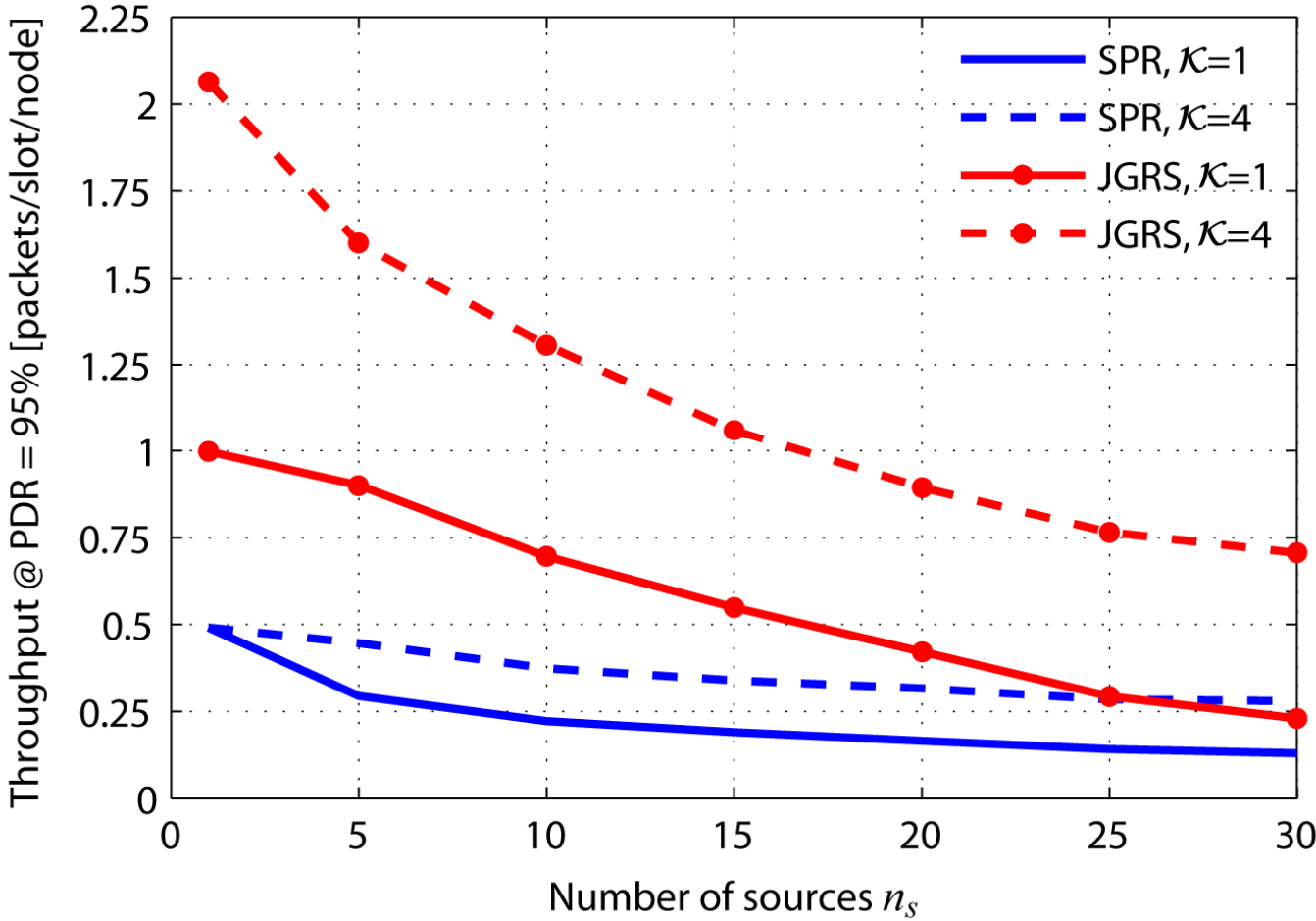
$n_s = 10, \psi = 30^\circ$





Simulation Results – Throughput vs Traffic Level

$\Delta = 30, \psi = 30^\circ$





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Conclusions

- The introduction of directional antennas in multihop wireless networks provides an interesting opportunity to combine:
 - position-based **routing**
 - channel access **scheduling**
- By introducing a degree of freedom in the routing function, DGRS performs **load balancing** among next hop candidates
- When the direct path is congested, DGRS spatially **spreads** traffic to exploit available bandwidth elsewhere in the network, increasing network throughput
- Exactly how much can be gained depends on:
 - antenna characteristics
 - network density
 - traffic matrix and characteristics



Future Work

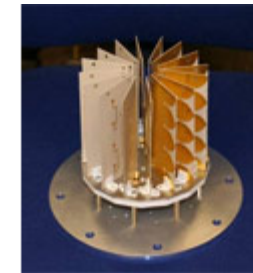
- Demonstration
 - Quadcopters
 - 802.11 cards and software
 - Sectorized antennas



+



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Questions?