Span: Topology Maintenance for Energy Efficiency in Ad Hoc Wireless Networks

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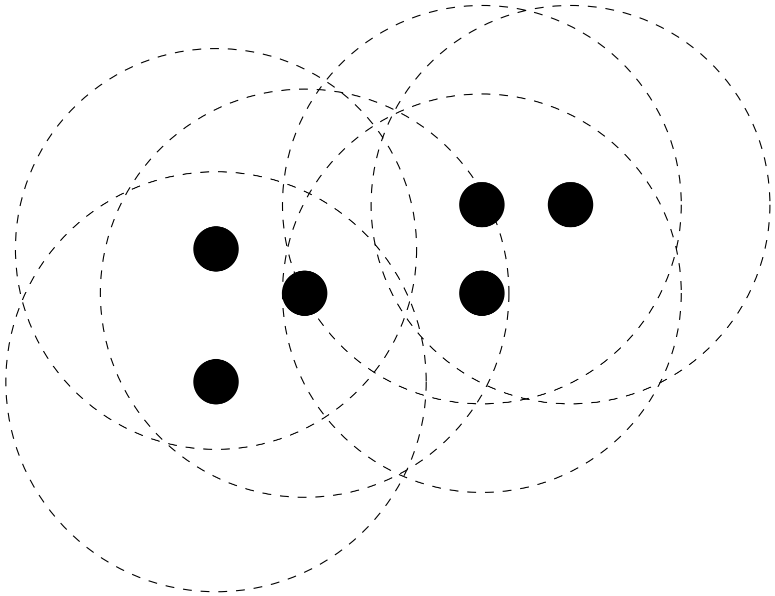
Multihop Wireless Ad Hoc Networks

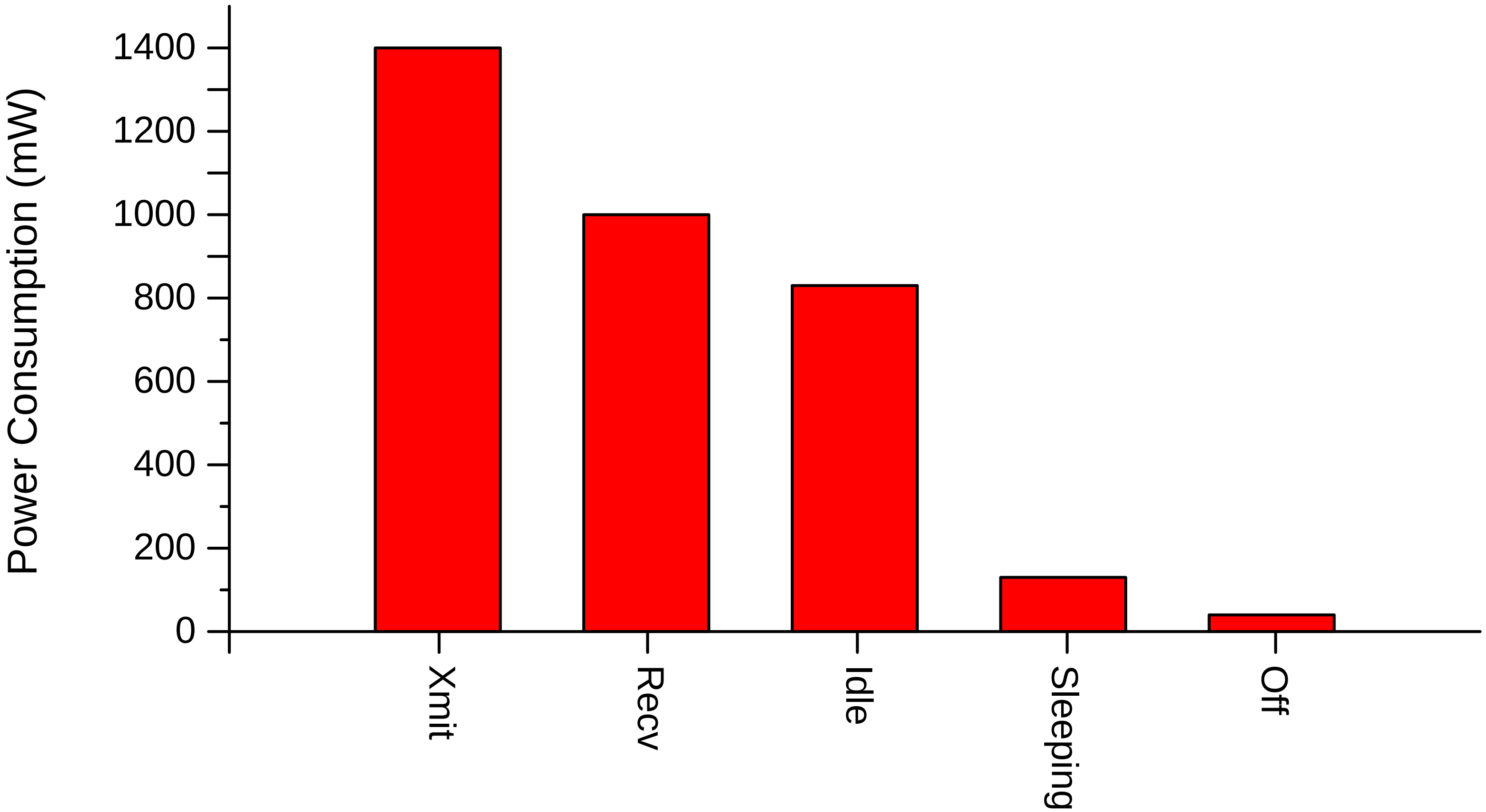
- No *a priori* network infrastructure
- Not every node is within range of every other node
- Wireless devices are very power-hungry: energy is an issue



Problem

- How can we reduce energy consumption in a wireless ad hoc network:
  - without significantly increasing loss rates, and
  - without harming latency?

Experimentally-Measured 802.11 NIC Power Consumption



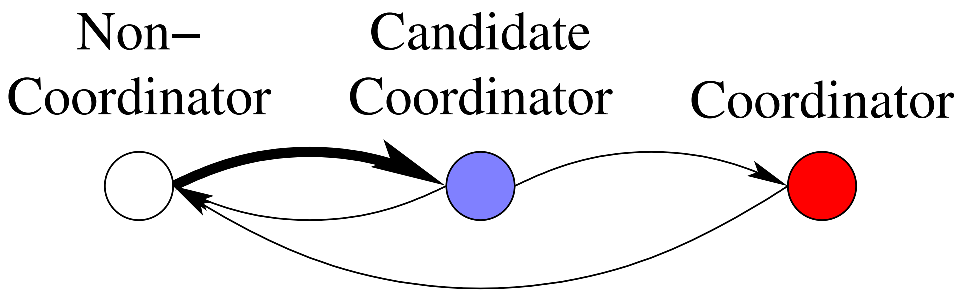
Two Key Observations

1. (Experiments): idle energy consumption is relatively large
2. In a dense network, not all nodes are needed to route packets

Span: Topology Maintenance for Energy Efficiency

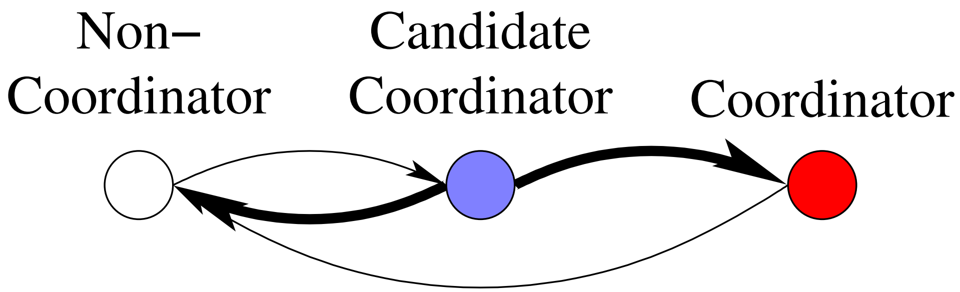
- Some nodes are **coordinators**
  - Stay awake and route packets
- All other nodes operate in powersaving mode
- Span carefully elects coordinators to provide connectivity and limit loss rate

Node States



- **Eligibility rule**: some pair of your neighbors is disconnected (cannot reach each other through coordinators)
- Upon becoming a candidate, the node starts a timer

Candidate Coordinator Actions

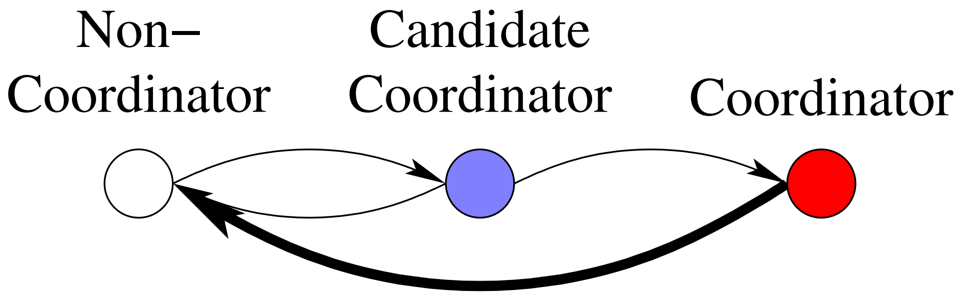


- If still eligible after a delay, nodes announce themselves as coordinators
- Otherwise the candidate becomes a non-coordinator

Delay to Announcement

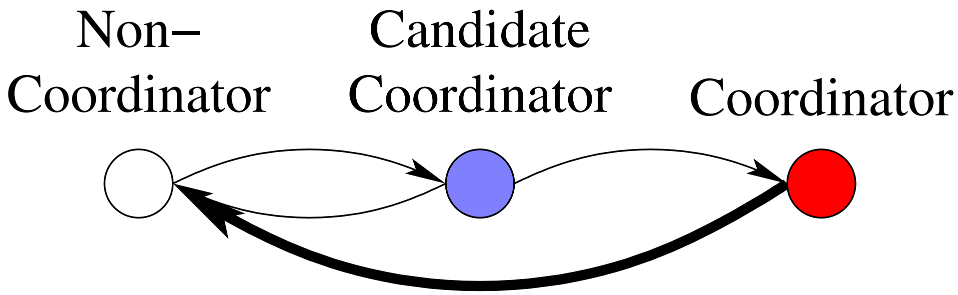
- Divide time into slots of length one maximum link propagation delay
  - Number of neighbors = number of slots
- Each candidate picks a slot at random
  - Less energy $\Rightarrow$ more likely to pick a later slot
  - More utility $\Rightarrow$ more likely to pick an earlier slot

Coordinator Withdraw Rule



- **Withdraw Rule**: every pair of nodes in radio range is connected through coordinators.

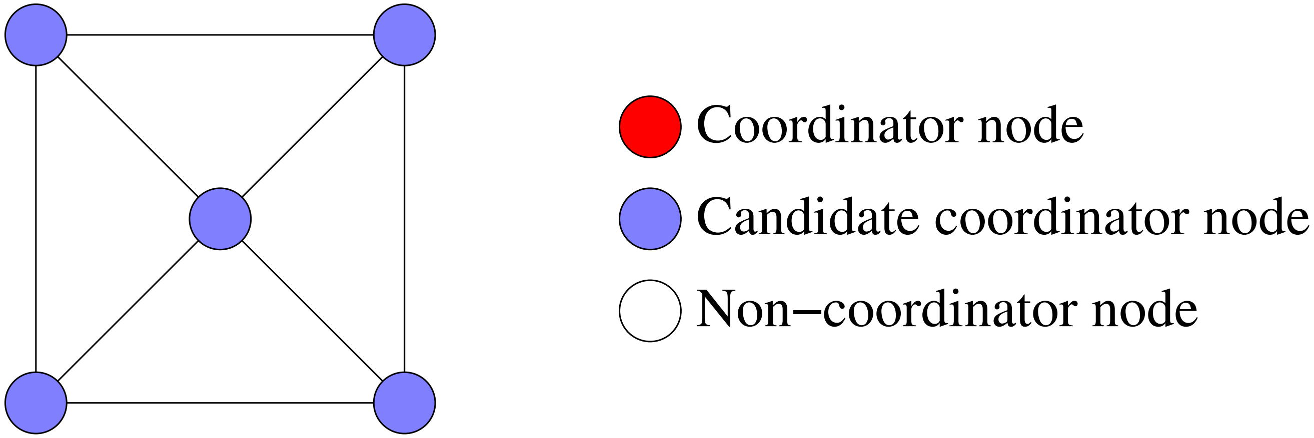
Coordinator Rotation Rule



- **Rotation rule**: withdraw if every two nodes in radio range are connected through other nodes.

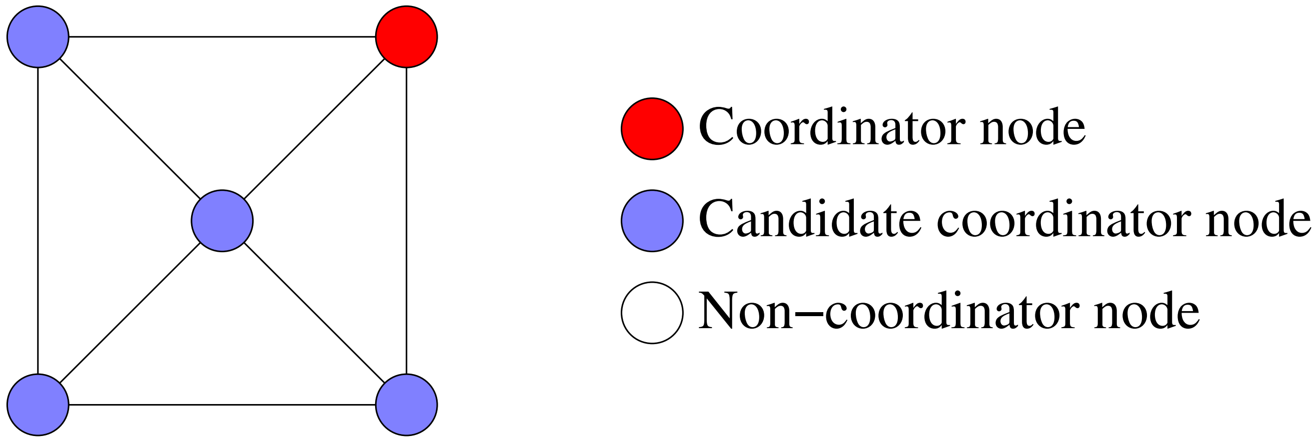
Example (1/7)

- One possible sequence of events
- **Eligibility rule**: some pair of your neighbors is disconnected (cannot reach each other through coordinators)



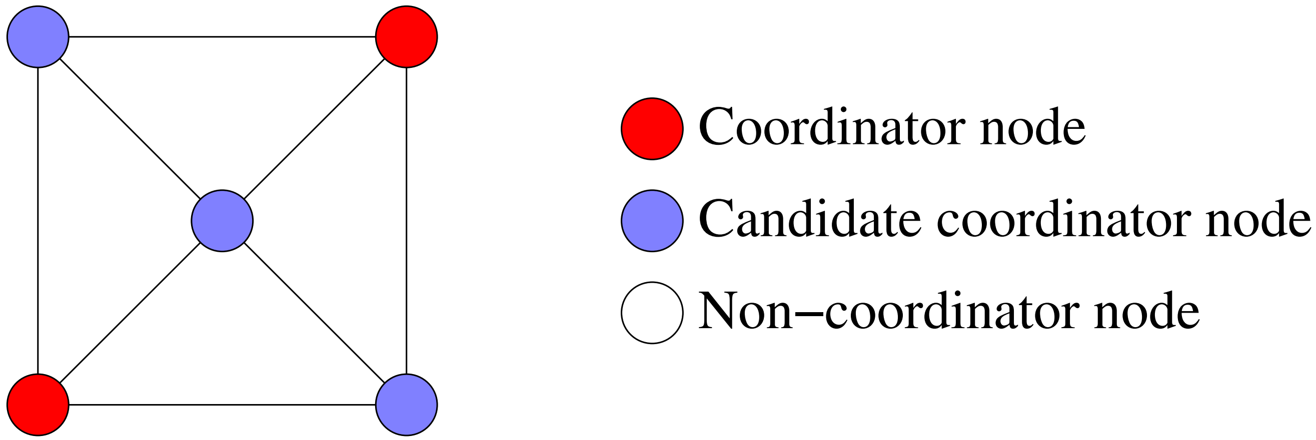
Example (2/7)

- **Eligibility rule**: some pair of your neighbors is disconnected (cannot reach each other through coordinators)



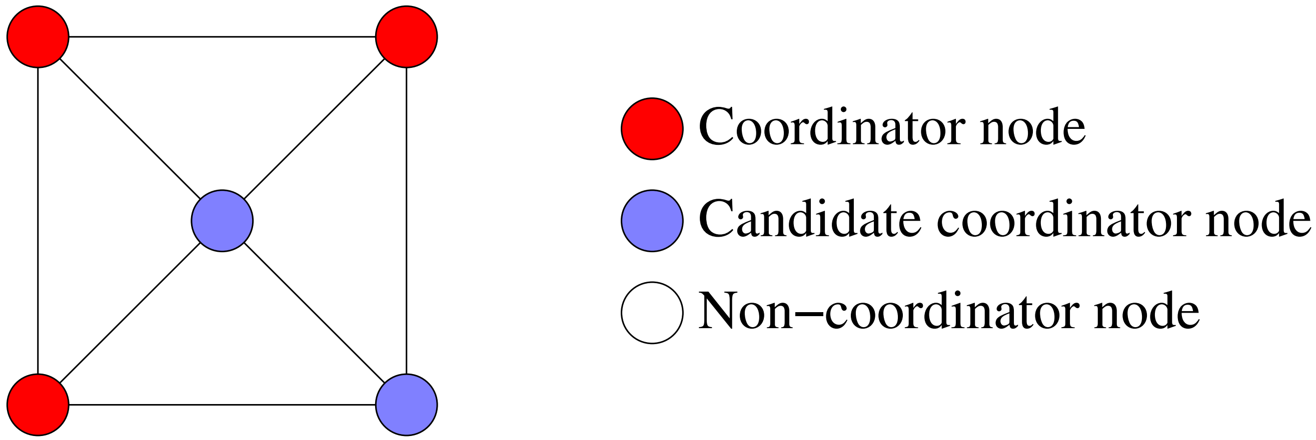
Example (3/7)

- **Eligibility rule**: some pair of your neighbors is disconnected (cannot reach each other through coordinators)



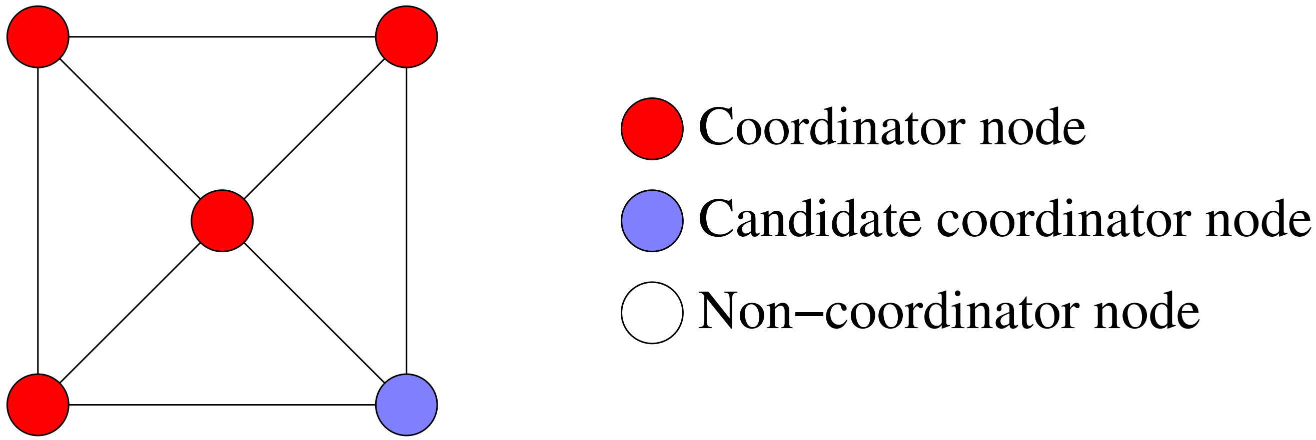
Example (4/7)

- **Eligibility rule**: some pair of your neighbors is disconnected (cannot reach each other through coordinators)



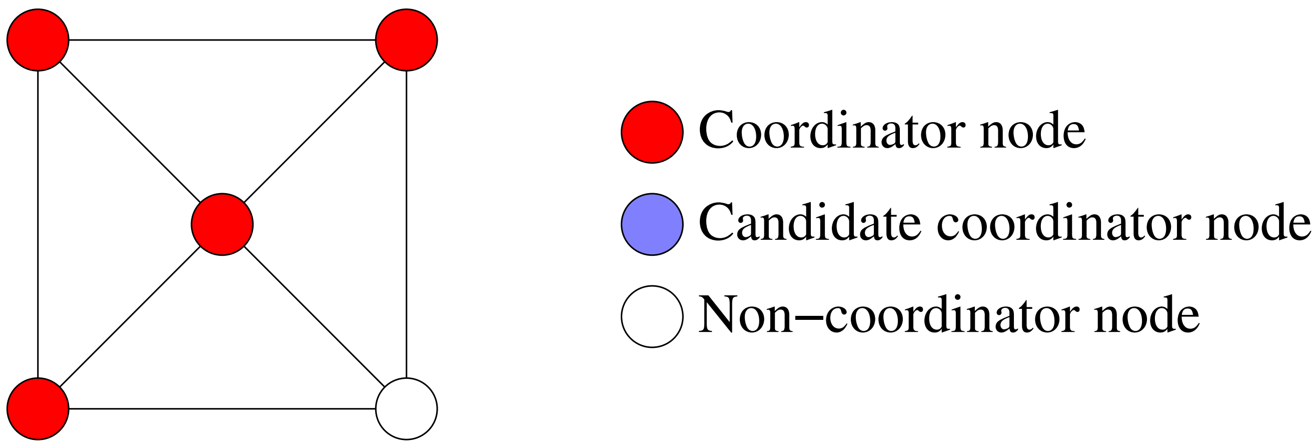
Example (5/7)

- **Eligibility rule**: some pair of your neighbors is disconnected (cannot reach each other through coordinators)



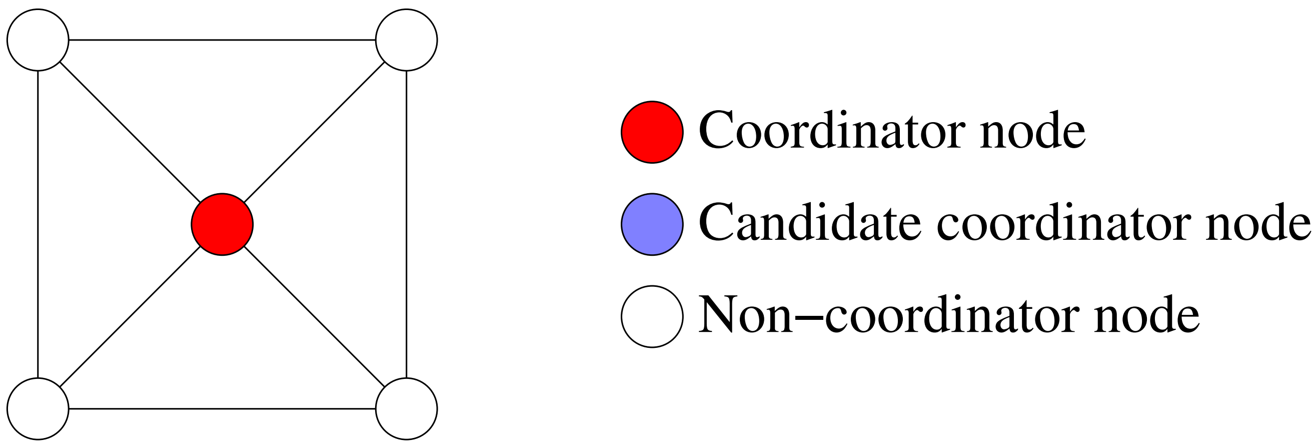
Example (6/7)

- **Withdraw Rule**: every pair of nodes in radio range is connected through coordinators.



Example (7/7)

- **Withdraw Rule**: every pair of nodes in radio range is connected through coordinators.



Summary

- Local decisions by each node lead to a globally-desirable topology
  - Ensures that every node is at most one hop away from some coordinator
  - Ensures that all coordinators are connected

Interaction with Routing Protocols

- In general, coordinators route and forward packets
- For example, geographical forwarding:
  - Mark non-coordinator entries in routing table
  - Prefer to choose coordinators as next routing hop
  - Use non-coordinators if preferred next hop is not found

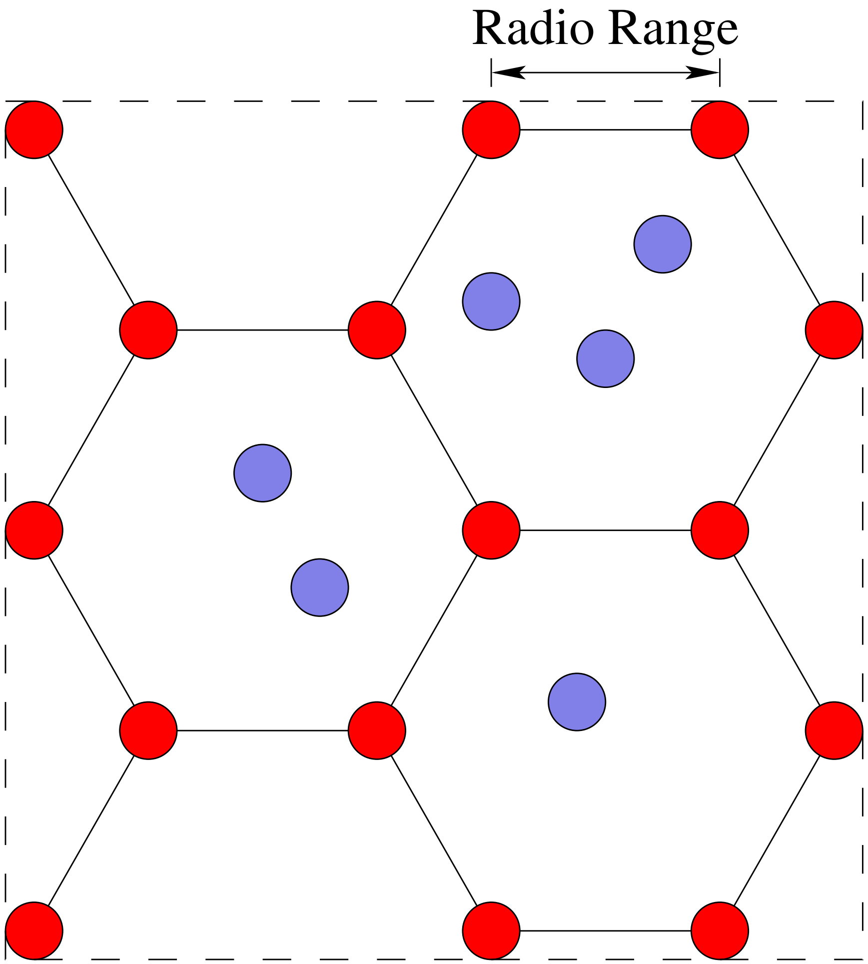
Span Limitations

- Announcements and withdrawals are done with broadcast messages
  - Everyone must wake up to receive them
- May introduce congestion, contention if some paths are merged together
- We ran experiments to quantify the benefits/limitations

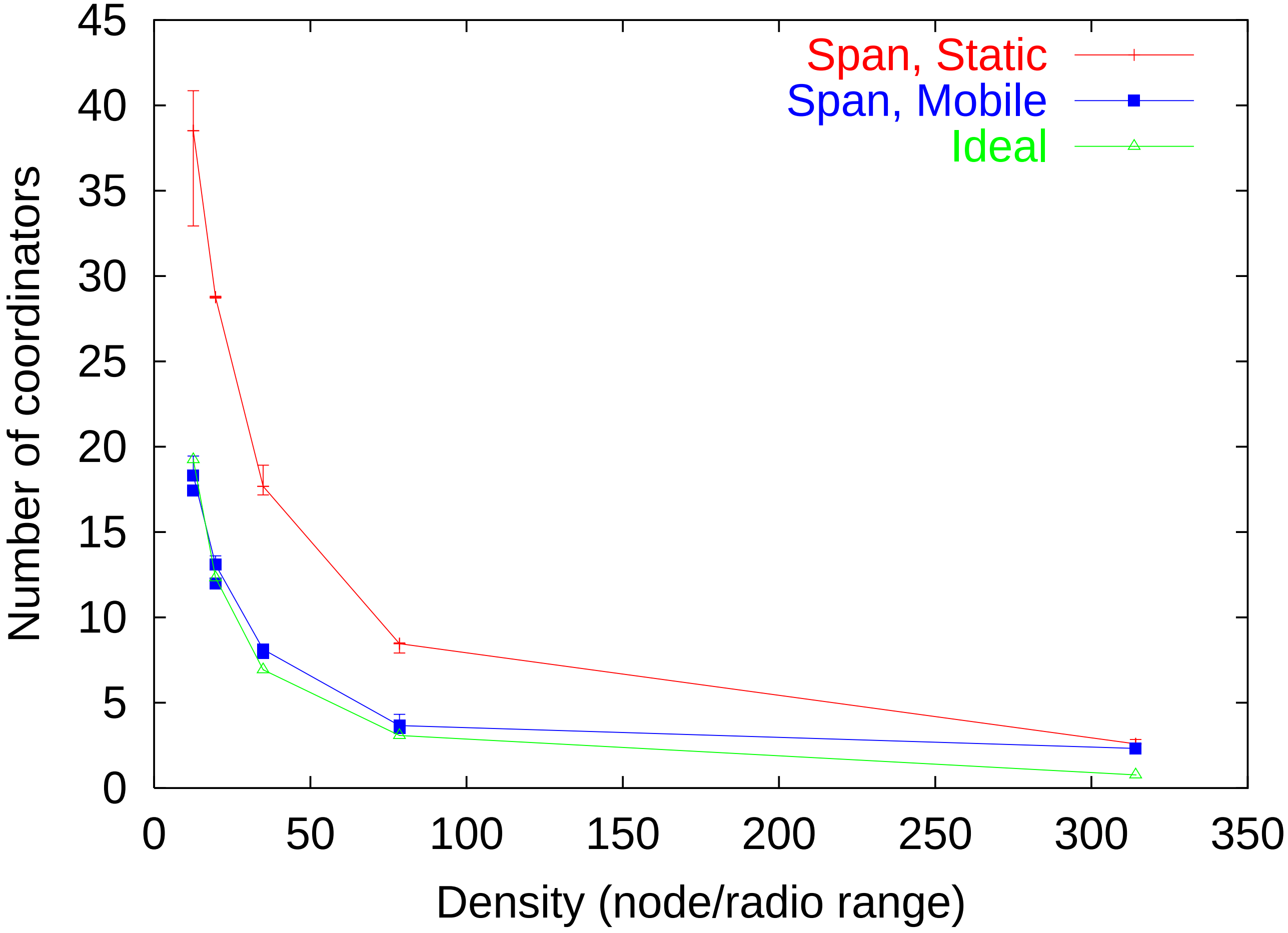
`ns` Simulation Experiments

- Geographical forwarding
  - Two-hop distance vector
- Modes:
  - 802.11 MAC
  - 802.11 ad hoc powersaving mode (PSM) MAC
    - Synchronization, Beacon Period, ATIM Window
  - Span over 802.11 PSM

Ideal Coordinator Layout



Number of Coordinators

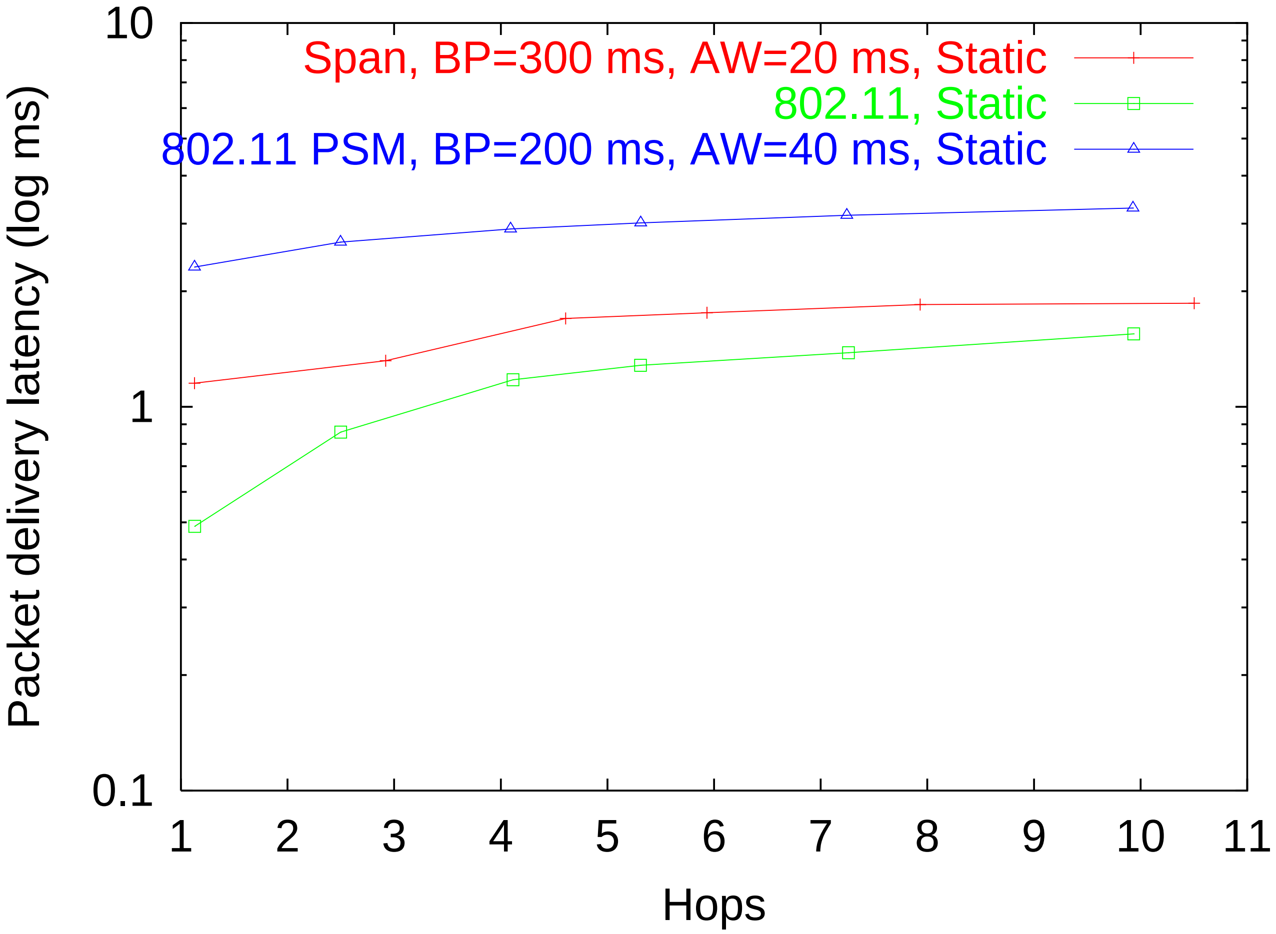


- 100 nodes, varying simulation area

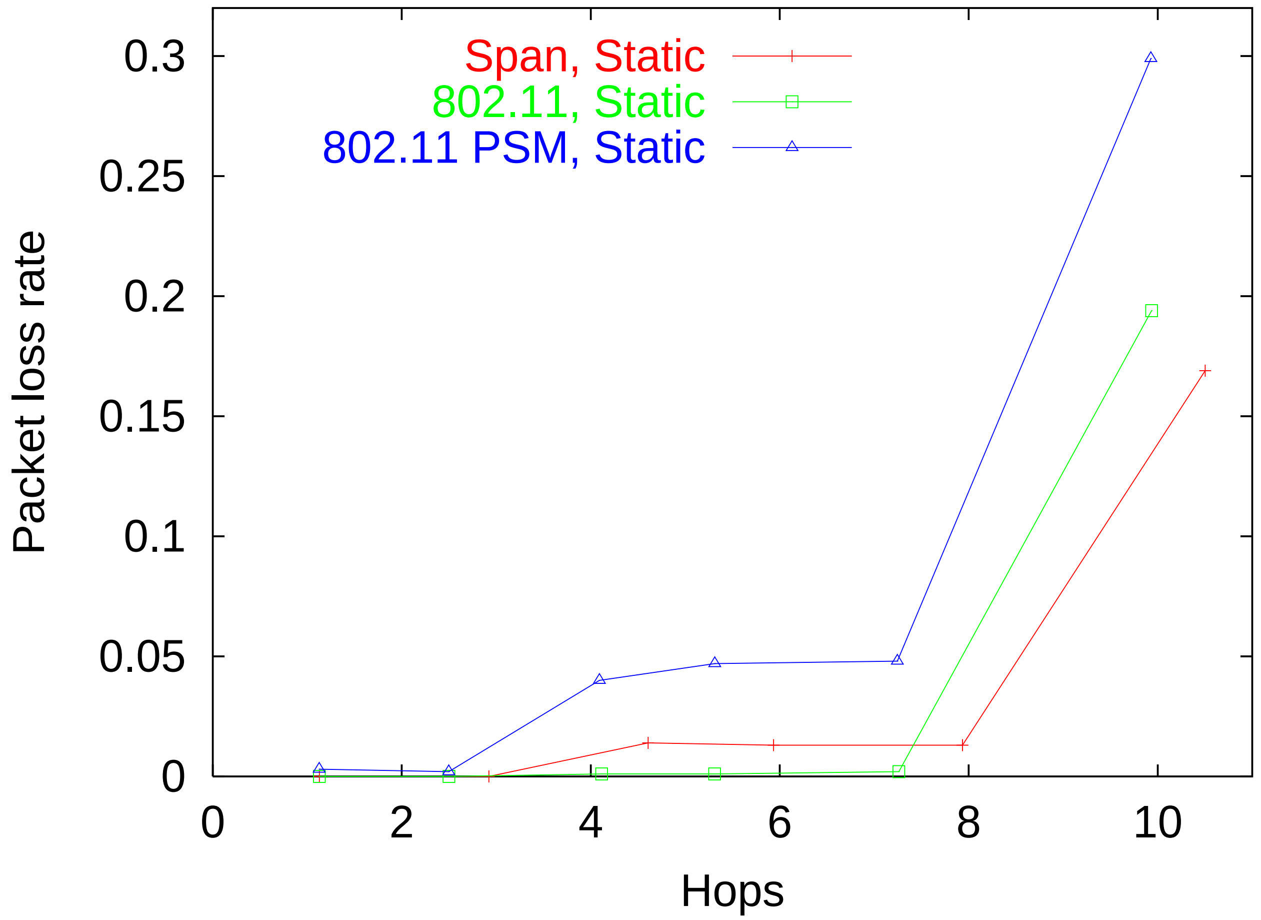
Traffic Simulations

- 120 nodes; variable geography size, packet interval
  - 16 "Source/Sink" nodes, producing 16 CBR flows, packet size 128 bytes
    - Stay up as coordinators
    - Don't move, but may forward packets
    - Located at left and right sides of rectangular area
- Forwarding nodes in middle
- Hops directly reflects size of the topology,
  - since most of hops should be more or less horizontal

Packet Latency

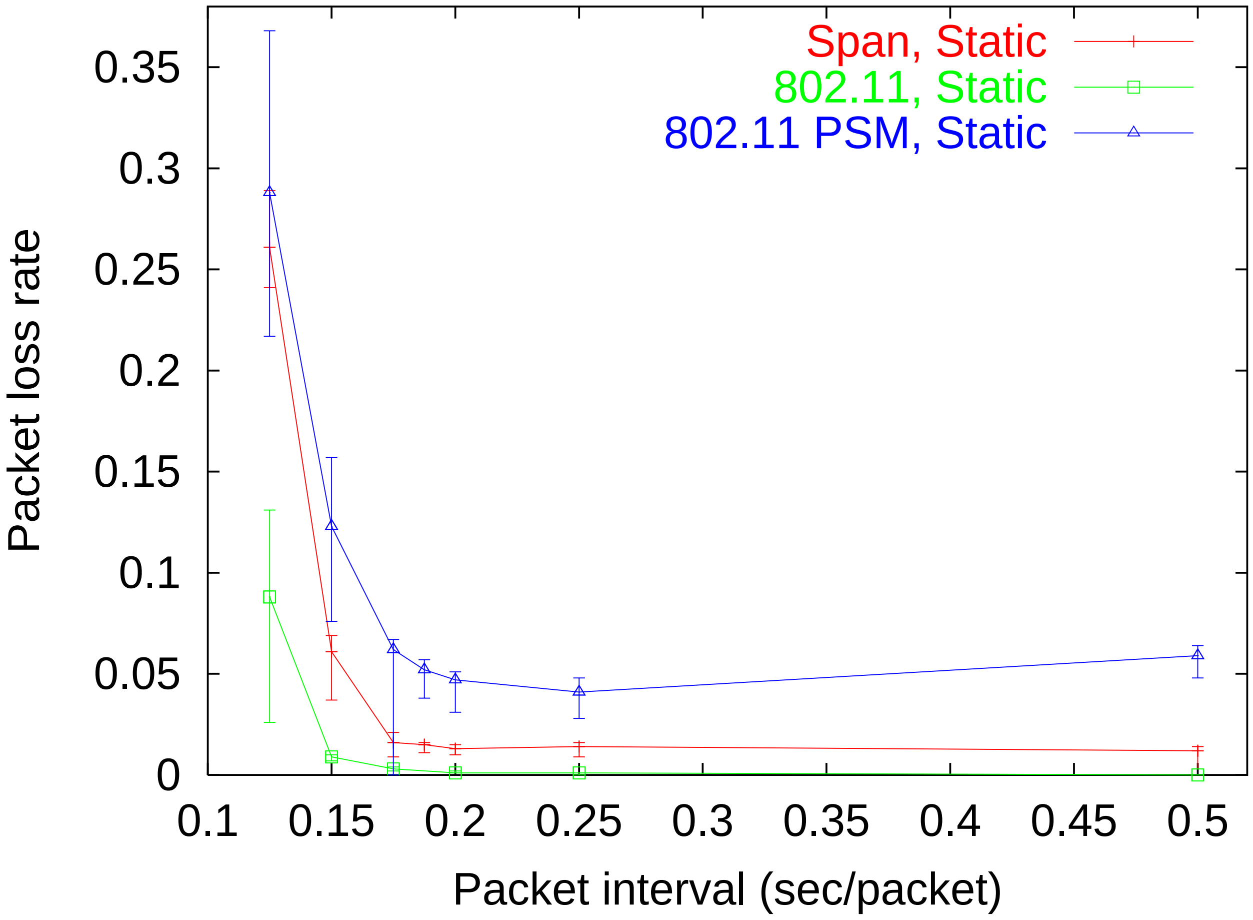


Packet Loss



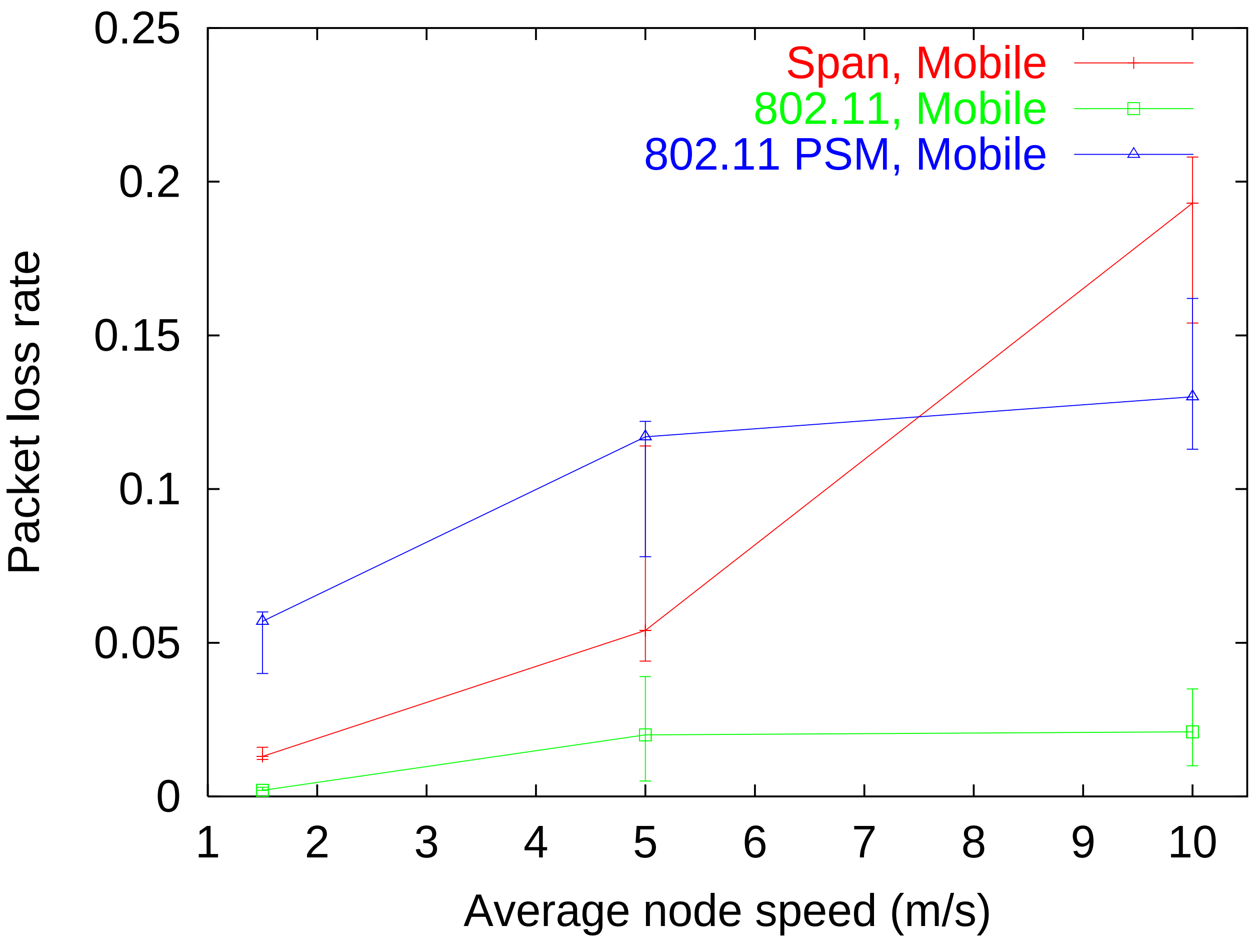
Span, Static
802.11, Static
802.11 PSM, Static
0.3
0.25
0.2
0.15
0.1
0.05
0
Packet loss rate
0
2
4
6
8
10
Hops

Packet Loss



- Average 5-6 hops

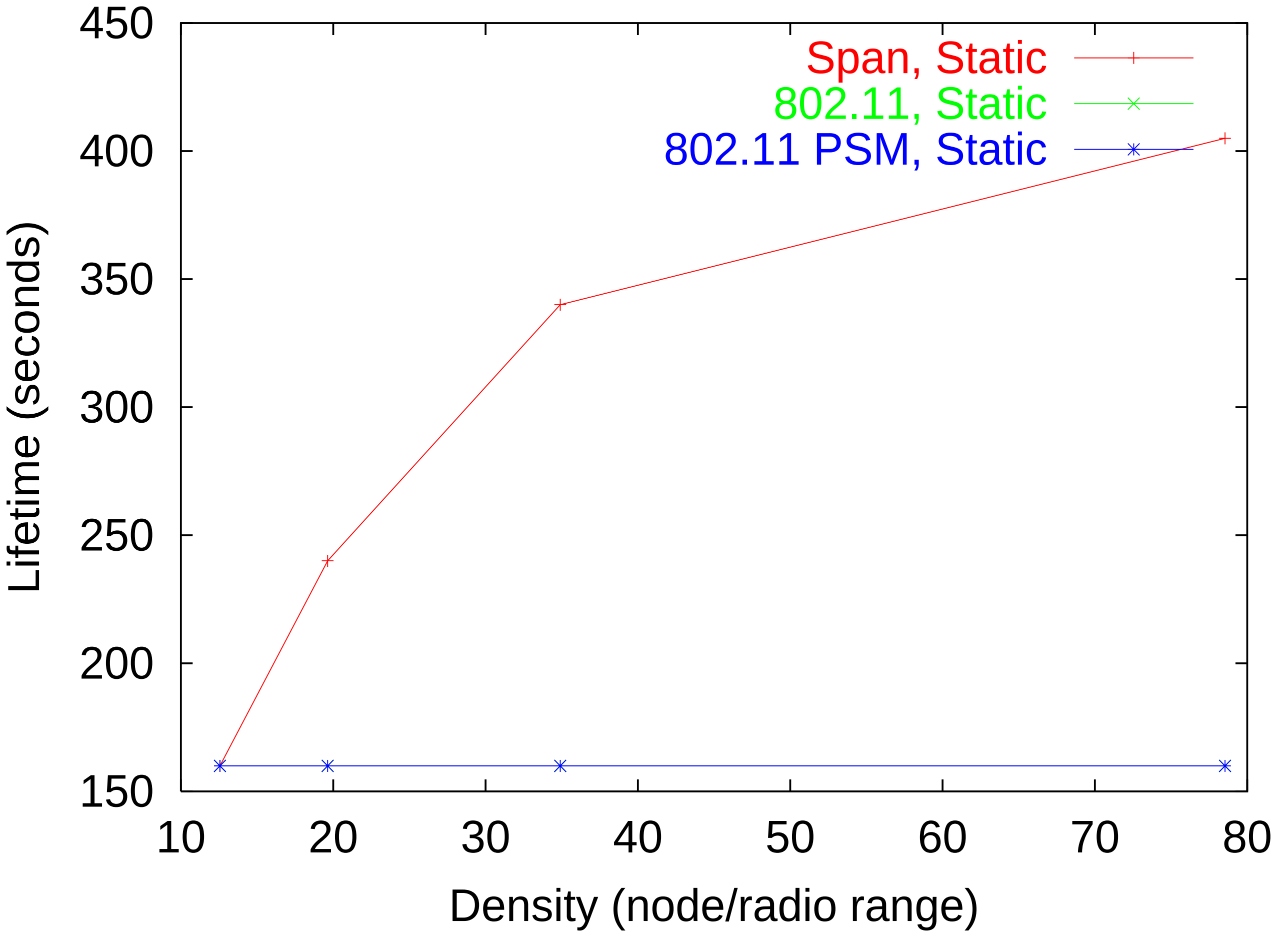
Packet Loss for Mobility



Network Lifetime

- Senders and receivers have initial energy of 2000 J
- Other nodes start with 160 J
- Network lifetime = time until 90% delivery rate

Network Lifetime



Related Work

- Turn radio off when the media is busy: PAMAS MAC layer [Singh98]
- Turn radio off based on local node density: AFECA [Xu00]
- Use distributed algorithm to build connected topology with small transmit range [Rodoplu98]
  - Reduce transmission power
  - Avoid receiving wasted packets
  - But still have to listen for traffic

Conclusion

- Span preserves connectivity and capacity, but allows most nodes to operate in power saving mode.
- For sufficiently-dense networks, we increase lifetime dramatically.