Span: An Energy-Efficient Coordination Algorithm for Topology Maintenance in Ad Hoc Wireless Networks

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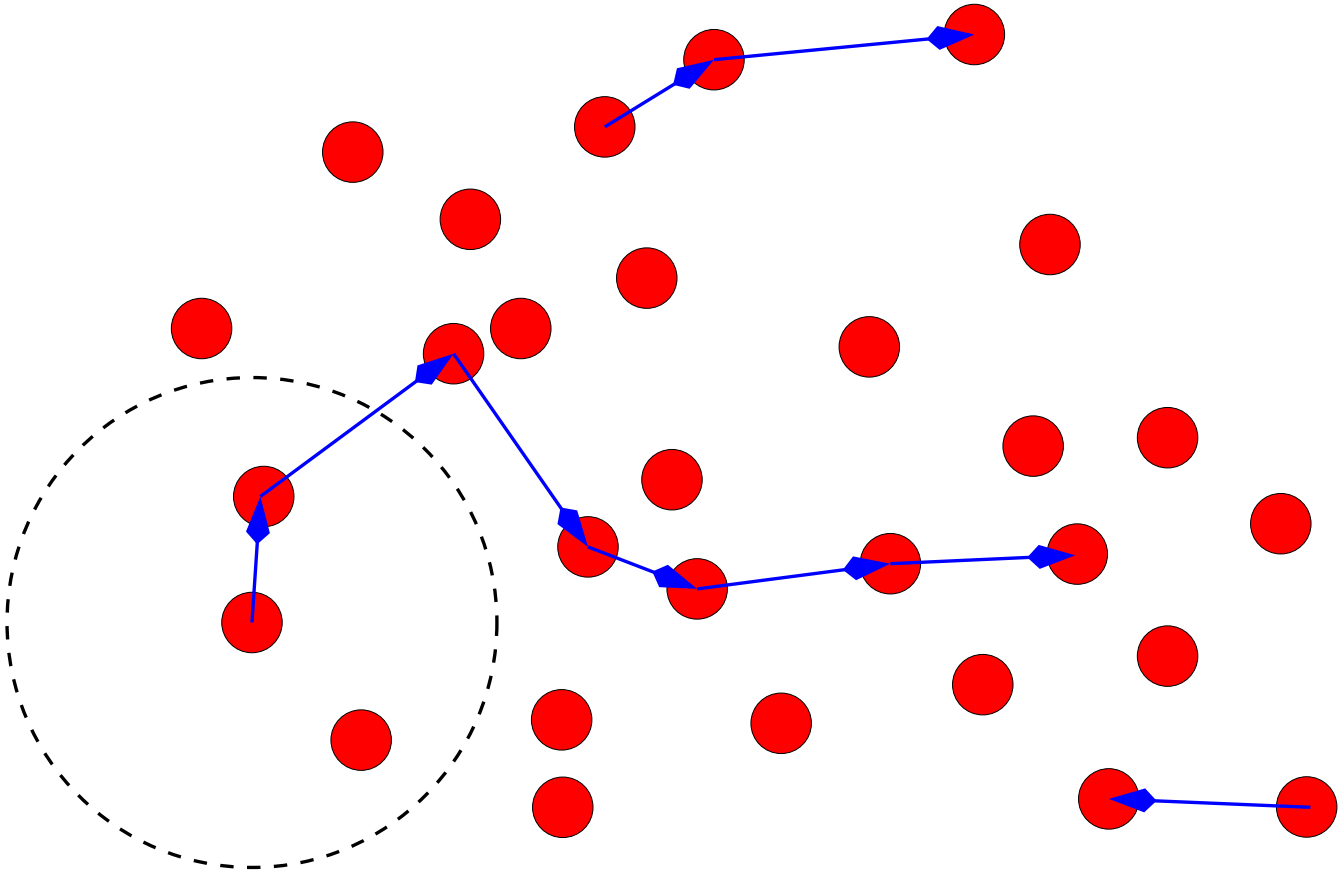
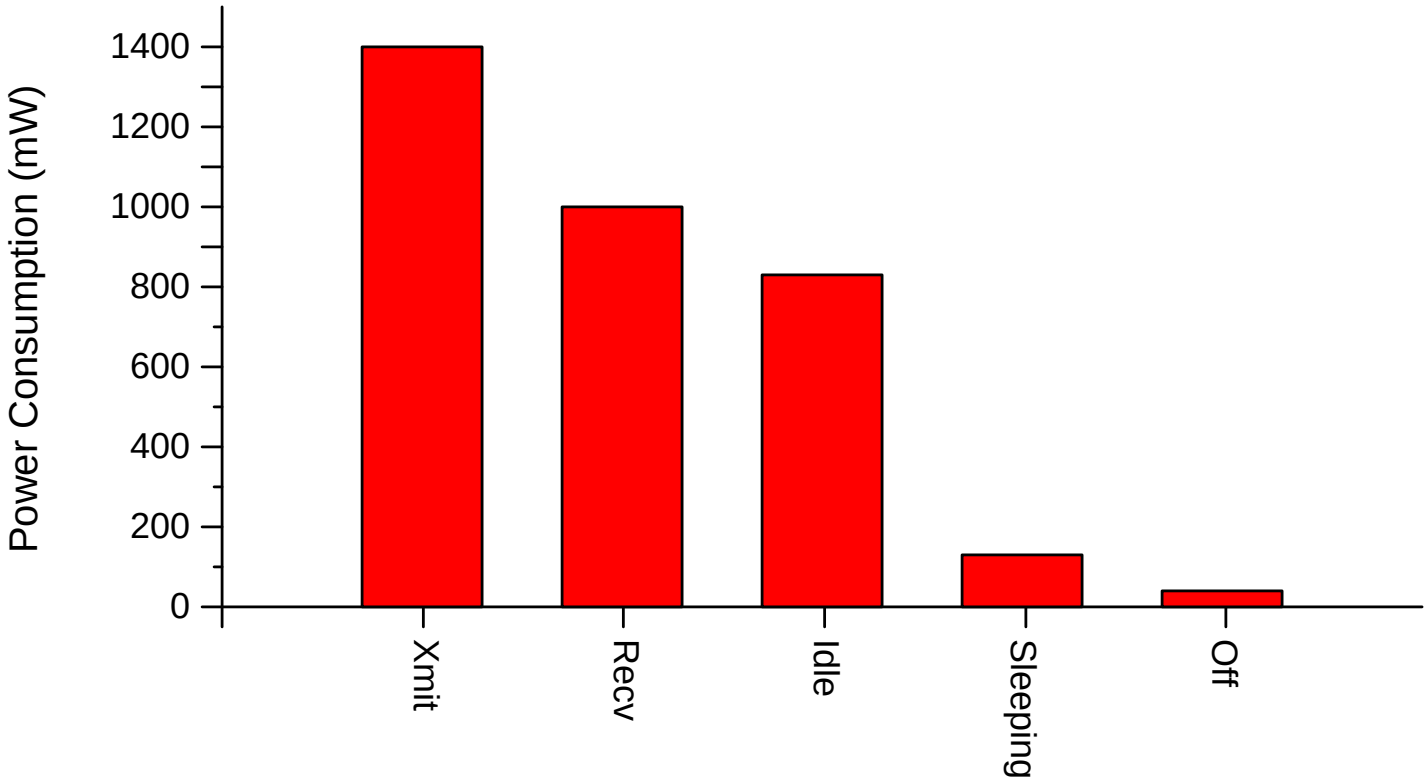
http://www.pdos.lcs.mit.edu/span/

How can you save energy in an ad hoc network?



How much energy can you save?

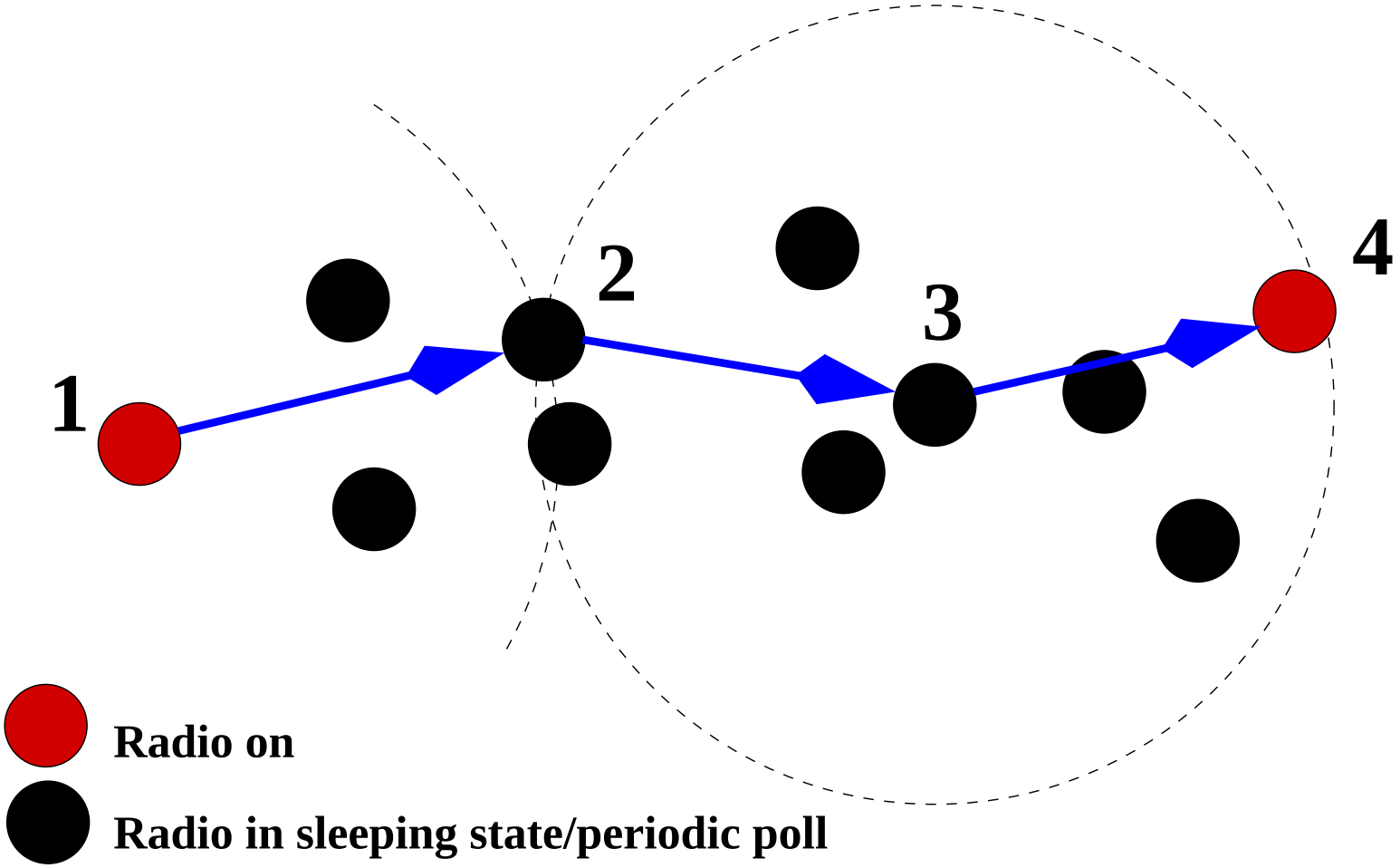


- Sleeping state power is 5.5 times less than that of idle state

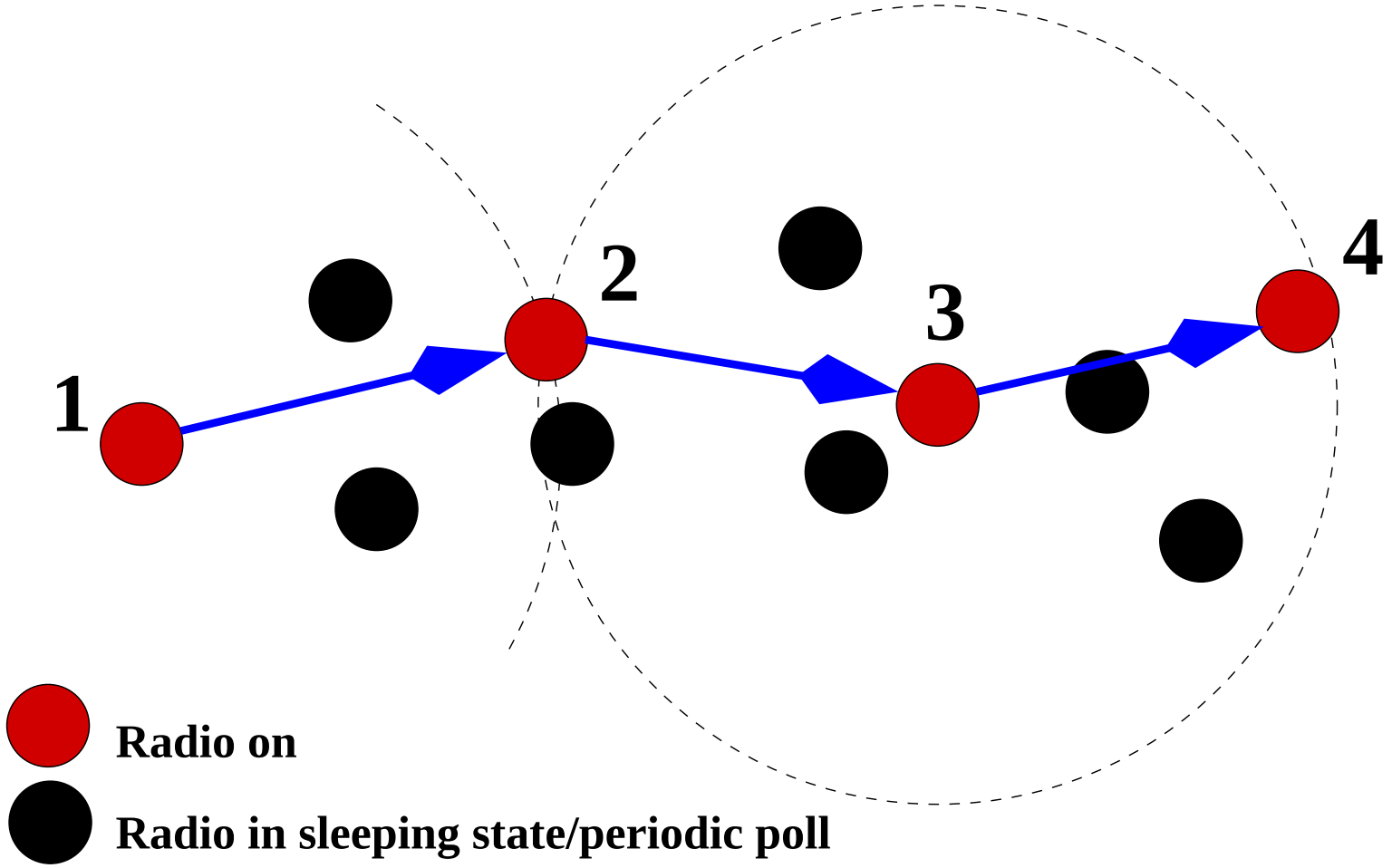
Leaving radios in the sleeping state

- MAC layer buffers packets for sleeping nodes
- A sleeping node wakes up periodically to poll for packets
- Sender sends packets when it receives a poll message

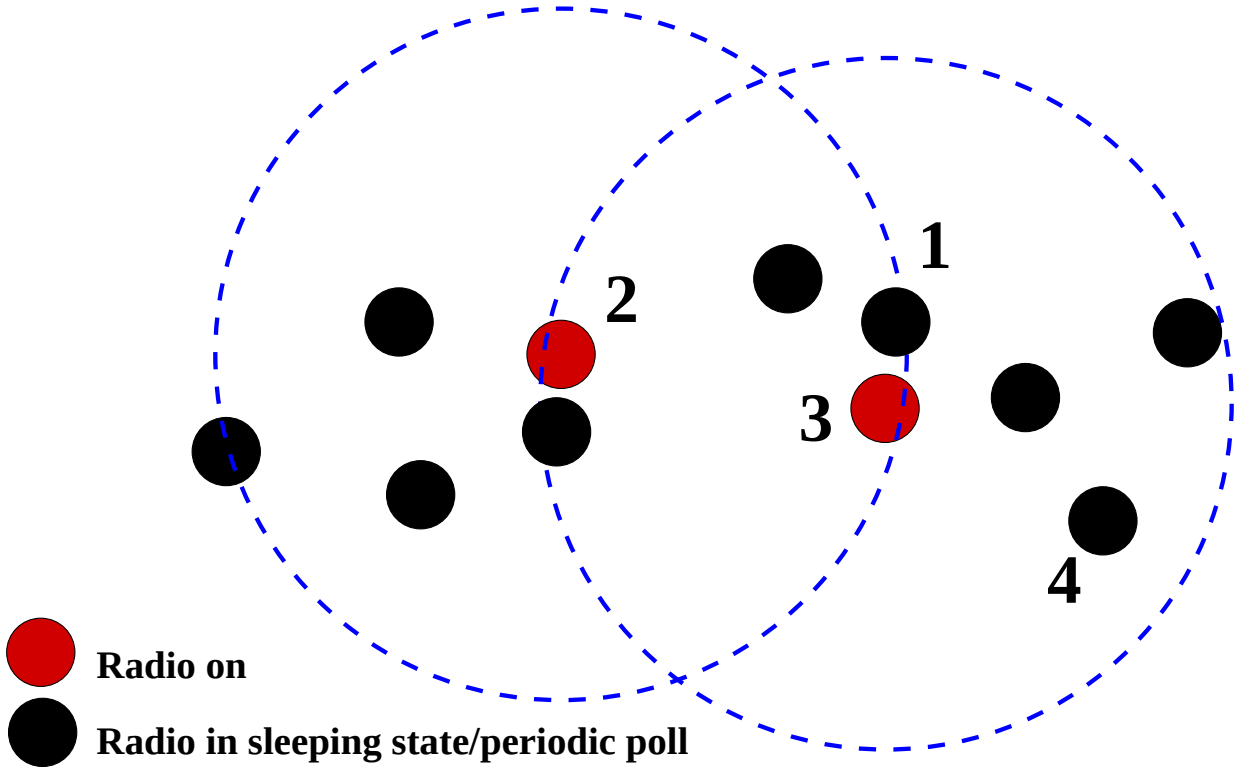
Routing with sleeping nodes result in high latency



Solution: leave some radios on to route packets

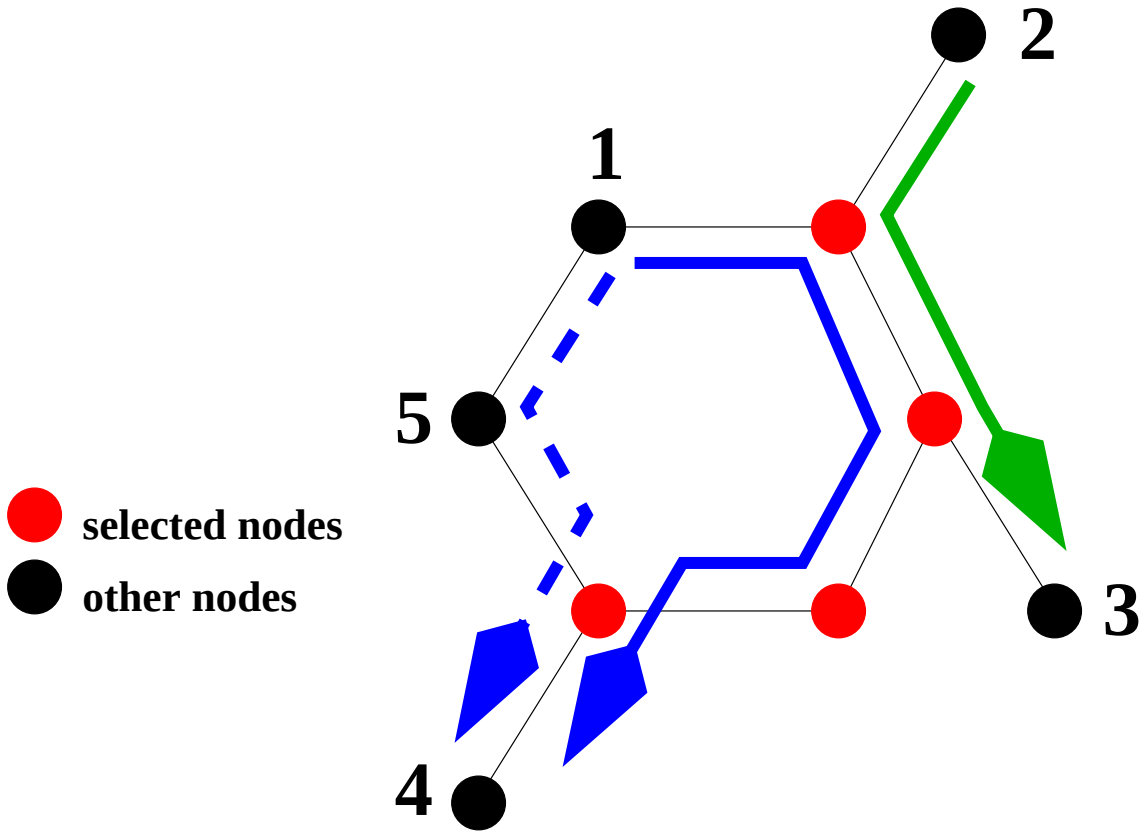


Small number of nodes can provide connectivity



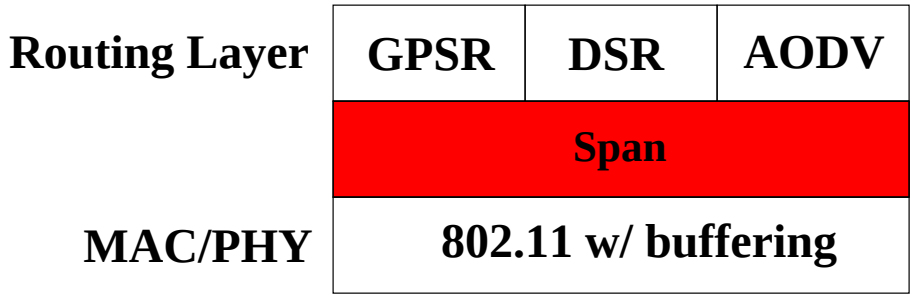
- Redundant routes are removed

Which nodes do we select to preserve capacity?



Span

- Span elects *coordinators* who keep their radios on
- Coordinators are carefully selected so they
  - Form a connected backbone that provides connectivity and
  - Preserve routing capacity among other sleeping nodes
- Routing protocols use coordinators when selecting routes
  - If cannot find route, use any node



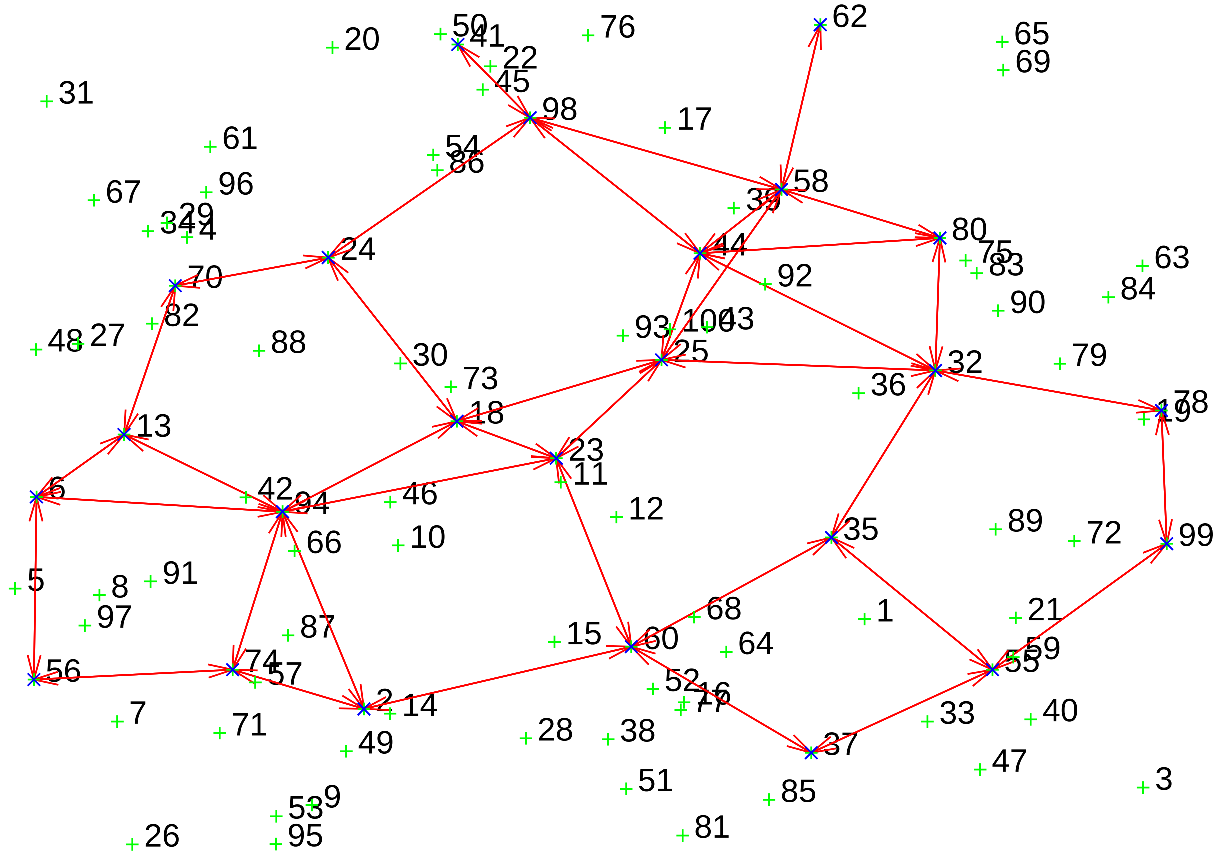
Distributed election algorithm

- Localized broadcasts: neighbors, coordinators, on/sleeping
- Broadcasts contain connectivity information: if nodes A and B can both hear coordinator C, they are connected

  Adapts to obstacles and topology

  Does not use geographic information
- Has rules for electing, rotating, and withdrawing
- Uses random backoff equation to delay announcement

Example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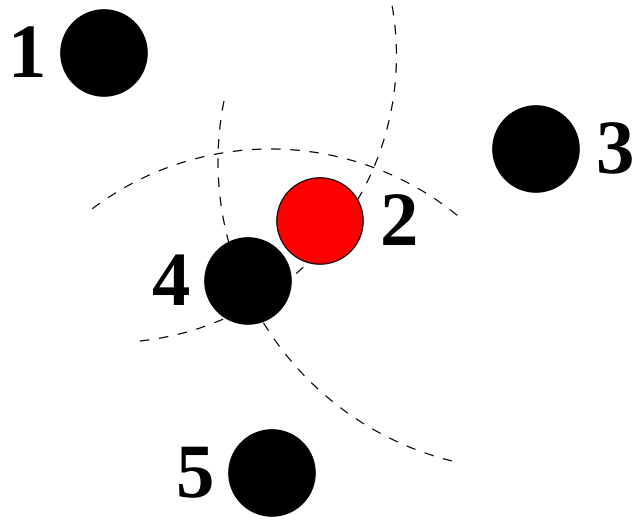
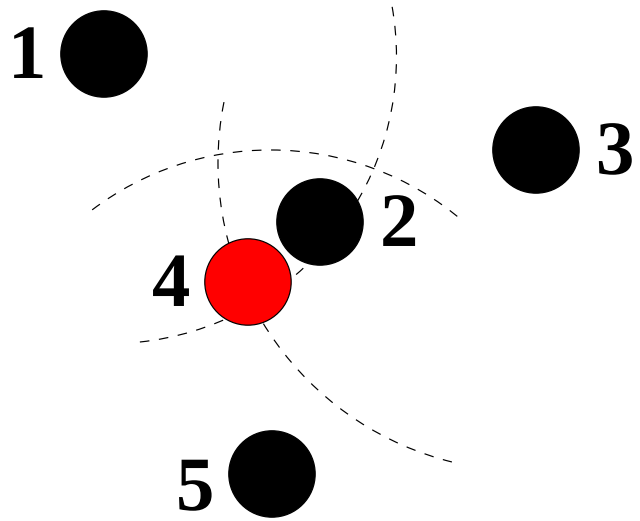
Rule for electing coordinators



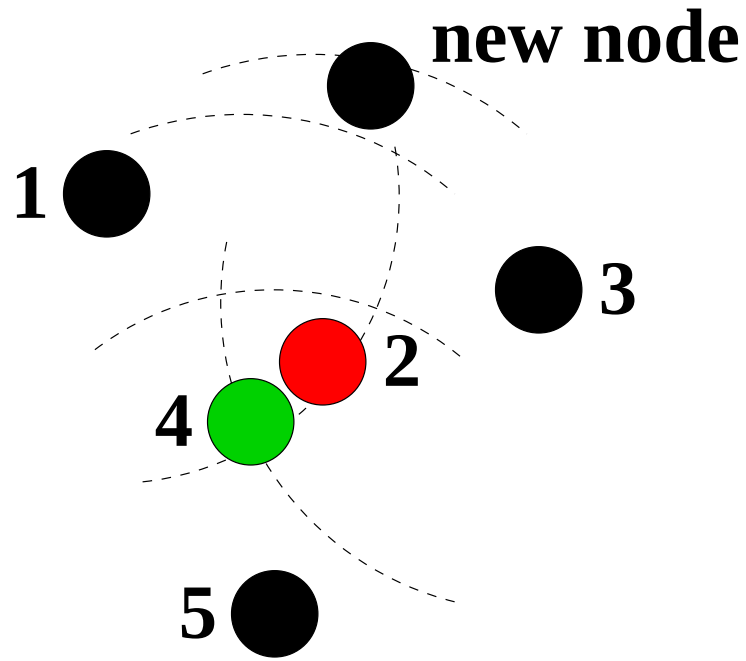
- A node should become a coordinator if two neighbors cannot reach each other through one or two other coordinators

Rule for rotating coordinators



- Periodically, a coordinator withdraws if a neighbor can provide connectivity for the same set of nodes

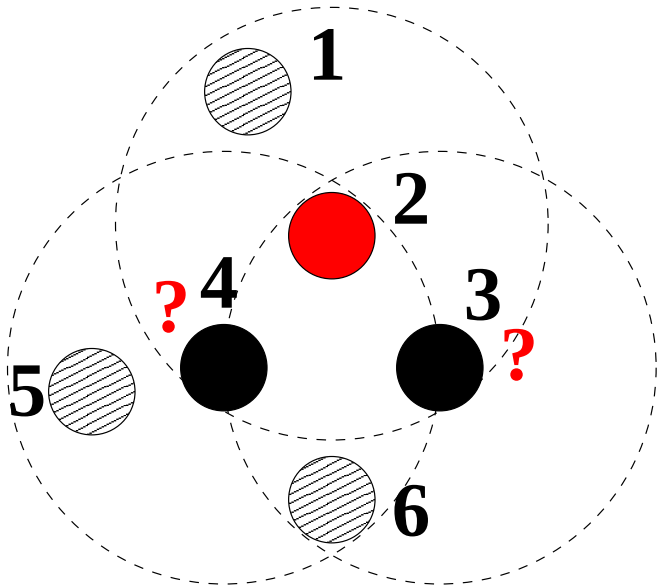
Rule for switching to sleeping state



- A coordinator switch to sleeping state if all its neighbors are connected via one or two other coordinators

Randomized delay equation resolves ties in election

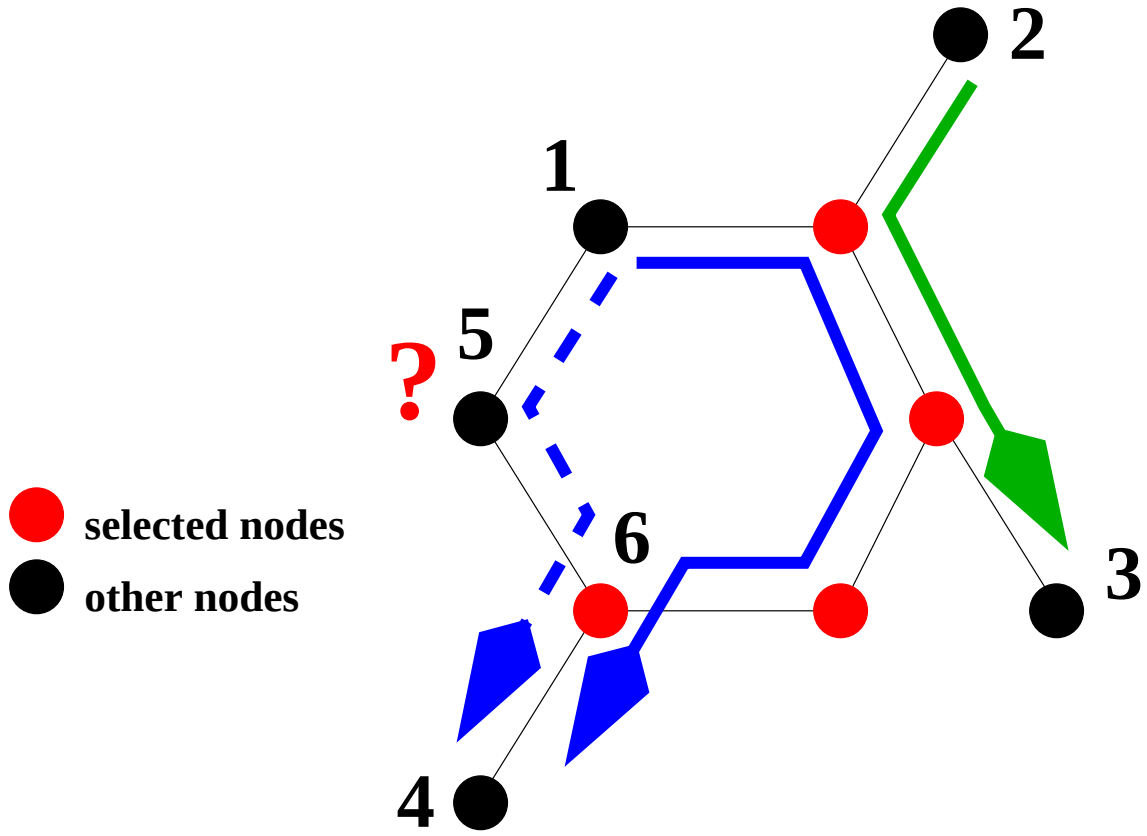
node 4
4 neighbors
connect 5/6 pairs



node 3
3 neighbors
connect 2/3 pairs

$$delay = \left(\left(1 - \frac{E_r}{E_m} \right) + \left(1 - \frac{C_i}{\binom{N_i}{2}} \right) + R \right) \times N_i \times T \qquad (1)$$

How does Span preserve capacity

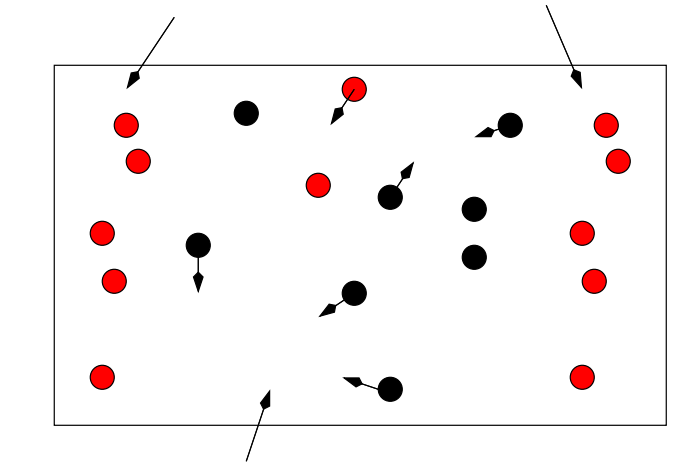


- To node 5: neighbors 1 and 6 are disconnected

Algorithm summary

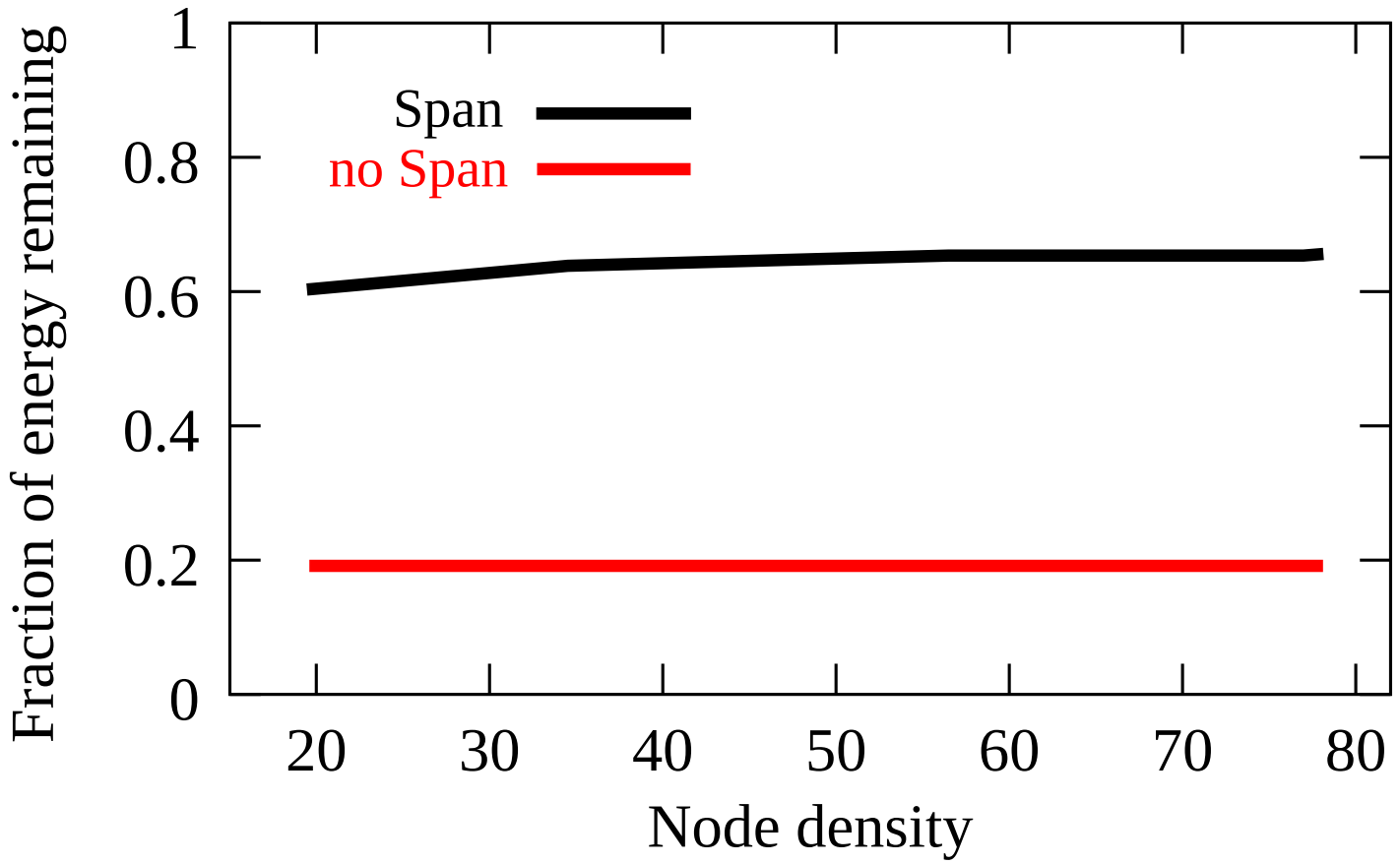
- Span elects a backbone of coordinators
  - Provides connectivity
  - Preserves network capacity
- Other radios operate in sleeping state to save energy
- Distributed algorithm elects, rotates, and withdraws coordinators
  - Localized broadcasts convey sense of connectivity

Simulation results in *ns*



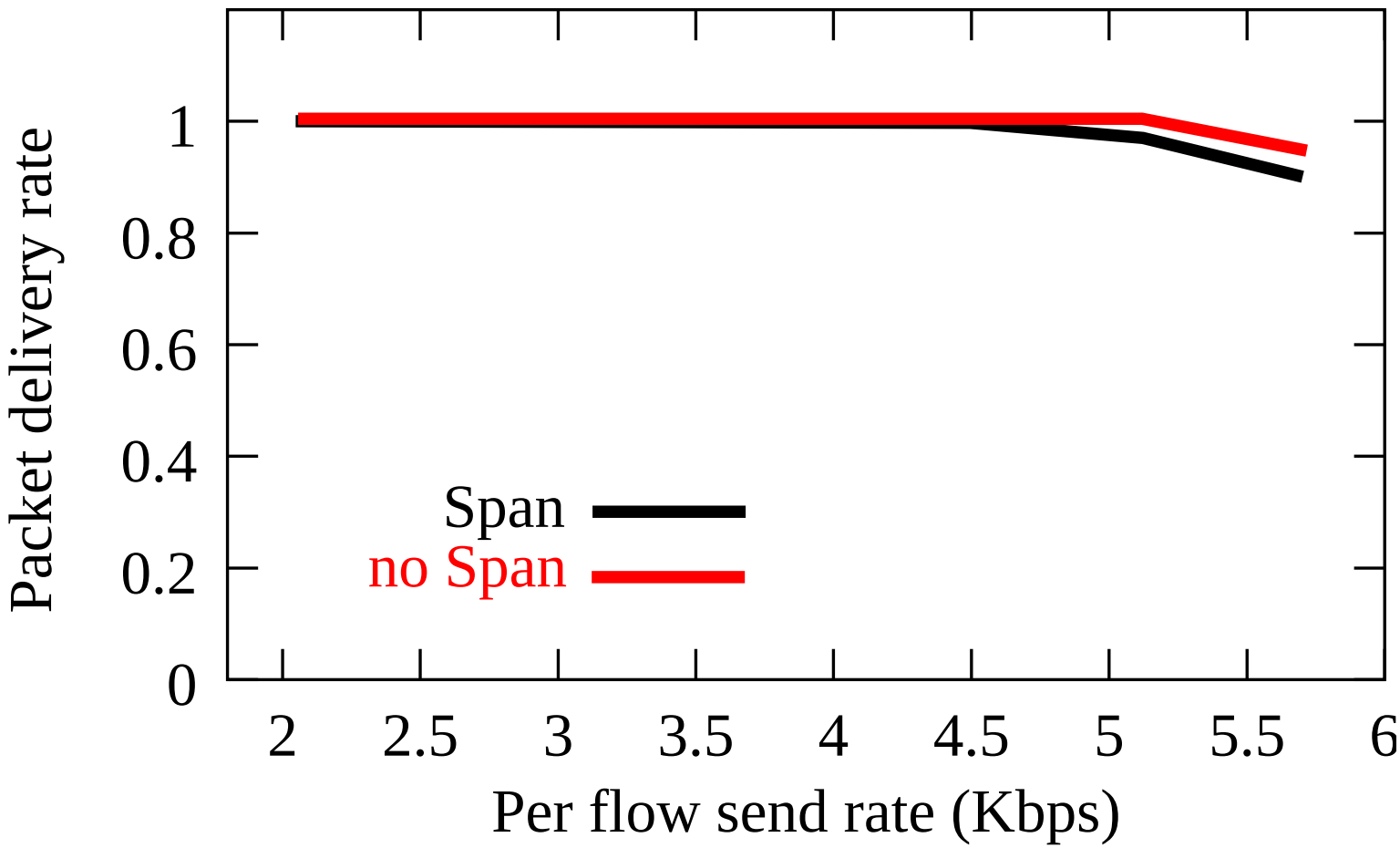
- Uses geographic forwarding to route packets
- Uses 802.11 to buffer packets for sleeping nodes
- 20 stationary nodes send and receive packets across network

Span saves energy

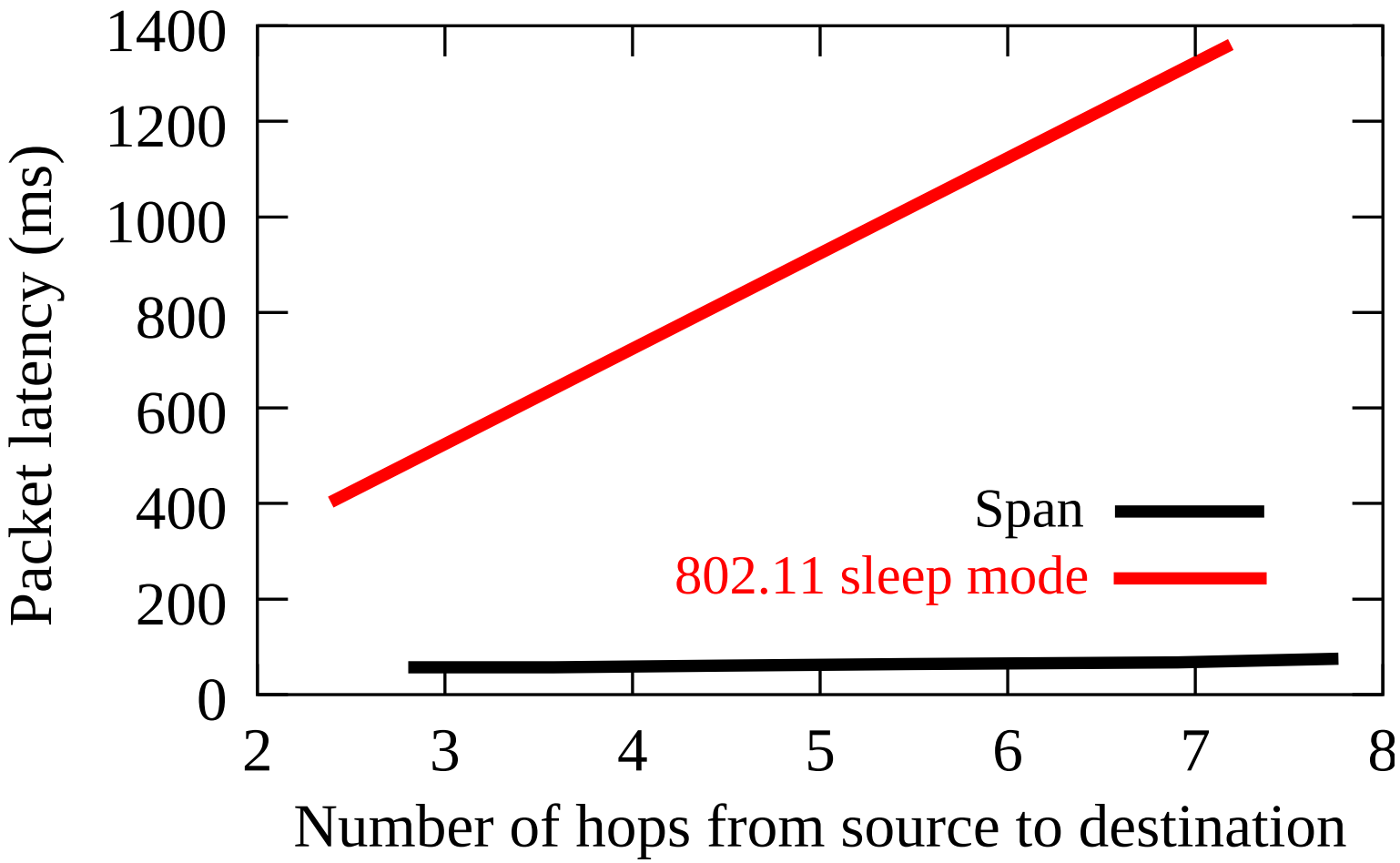


- Maximum possible saving: 5.1

Span preserves routing capacity



Span improves latency over 802.11 sleep mode



Related work

- GAF and AFECA both have similar goals as Span

  GAF uses geographic information

  AFECA may keep too many or too few radios on

- Span uses energy-aware MACs (e.g. 802.11, PAMAS)

- Minimum energy routing schemes reduce transmission energy, Span reduces the amount of time each radio needs to stay up

Conclusion

- Span coordinators route packets
- Other radios operate in sleeping state, save energy
- Span coordinators form a connected backbone that
  - Decreases energy consumption
  - Preserves routing capacity
  - Offers lower packet latency than using sleeping nodes
- Distributed algorithm elects, rotates, and withdraws coordinators
- Check out implementation progress at:

  http://www.pdos.lcs.mit.edu/span/