Spatial Reuse in 802.15.4 Wireless Networks

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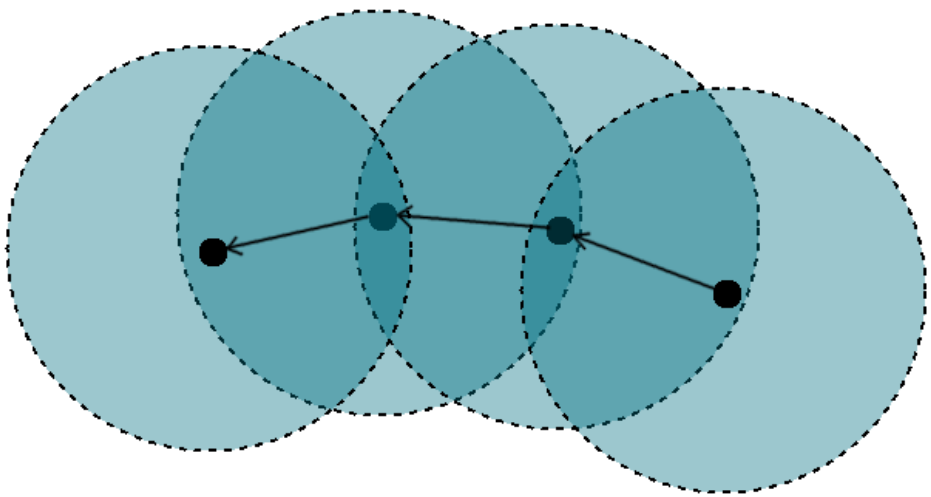
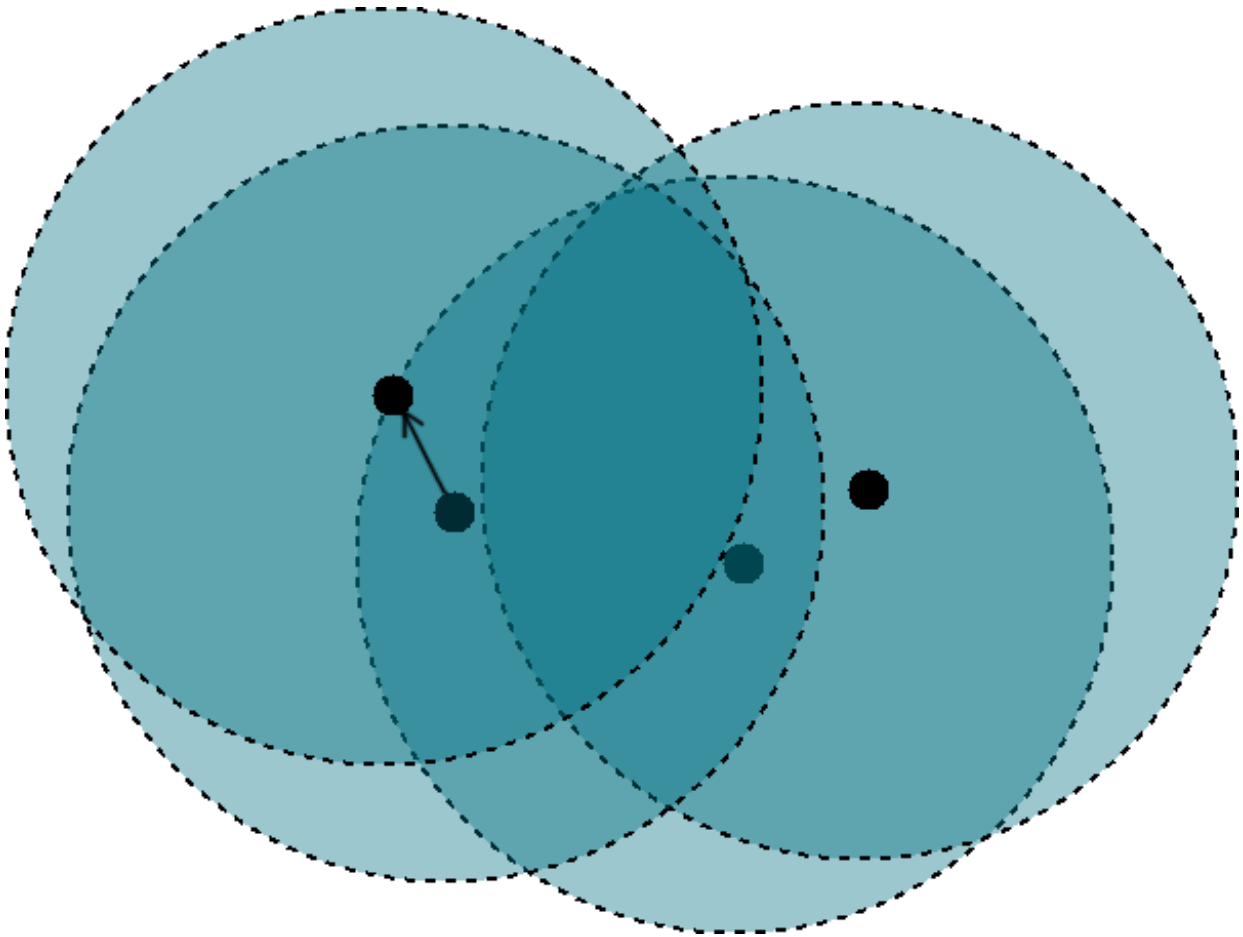
Motivation

- We can never have enough capacity!
- Capacity is especially a concern in wireless multi-hop networks
  - Broadcast medium
  - Forward traffic
- Effective capacity scales with $\frac{1}{\sqrt{n}}$ where n is the number of nodes [Gupta,Kumar]
  - Uniform density
  - All nodes sourcing traffic
  - Random selection of destination



Spatial Reuse

Two or more nodes successfully transmitting simultaneously within the same frequency band



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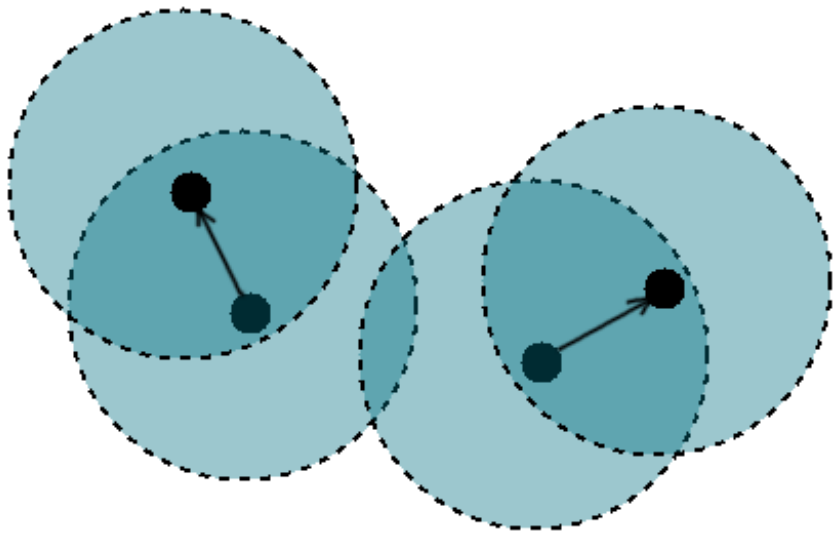


Questions to Answer

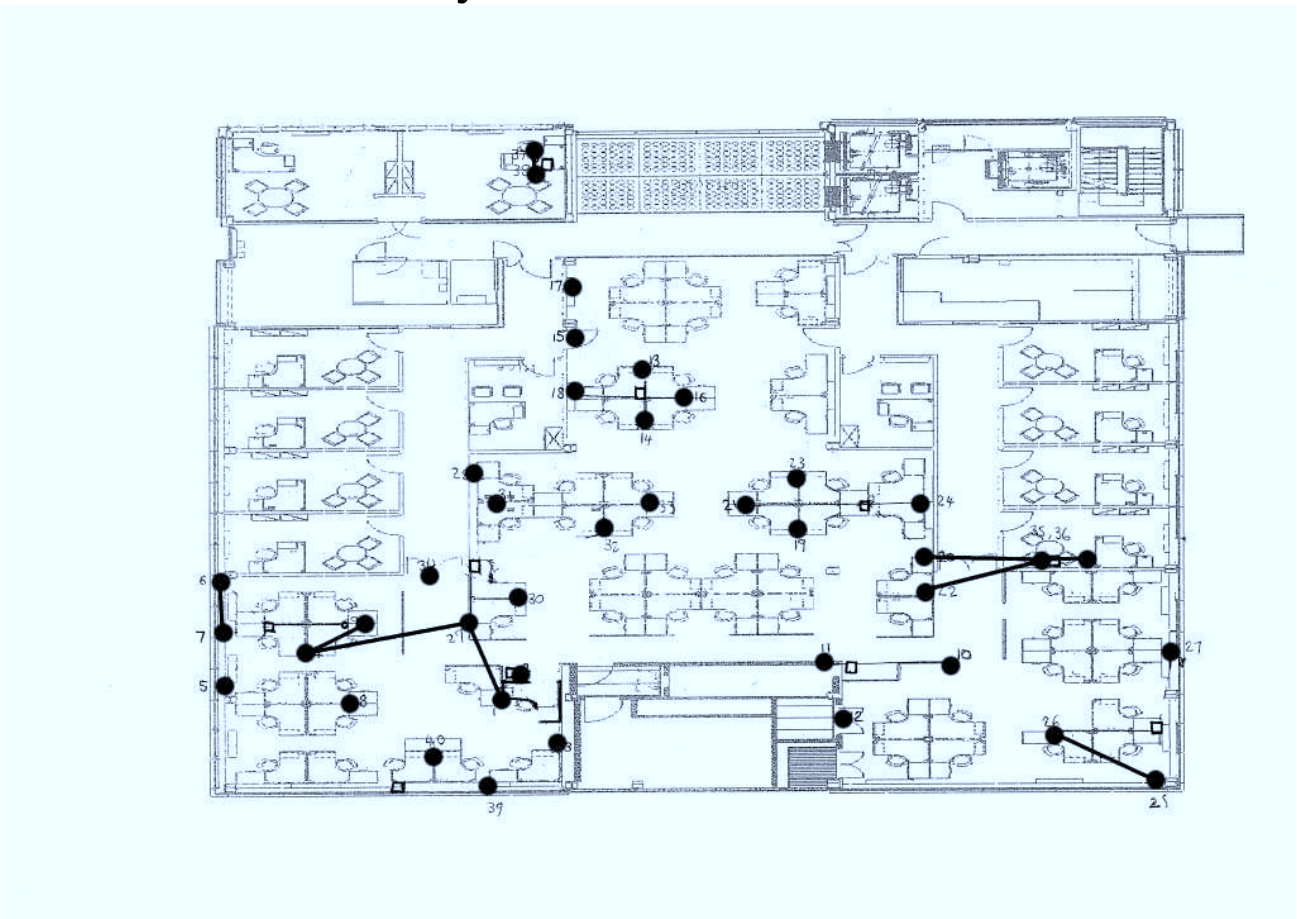
- Does power control enable us to achieve good spatial reuse in practice?
- To what extent does CSMA/CA limit spatial reuse?
- Are there any opportunities for spatial reuse at granularities lower than a packet?

Is Power Control Practical in Dense Wireless Networks?

- CC2420 radio provides programmable transmit power
- 40 nodes deployed in an open plan area and enclosed offices
- Experiment:
  - Round-robin through every mote
  - Send 1000 packets at each power level (1-31)
  - MTU-sized packets (127 bytes including MAC header)
  - Channel 26 (non-overlapping with Wifi channels in use)
  - pseudo-random payload

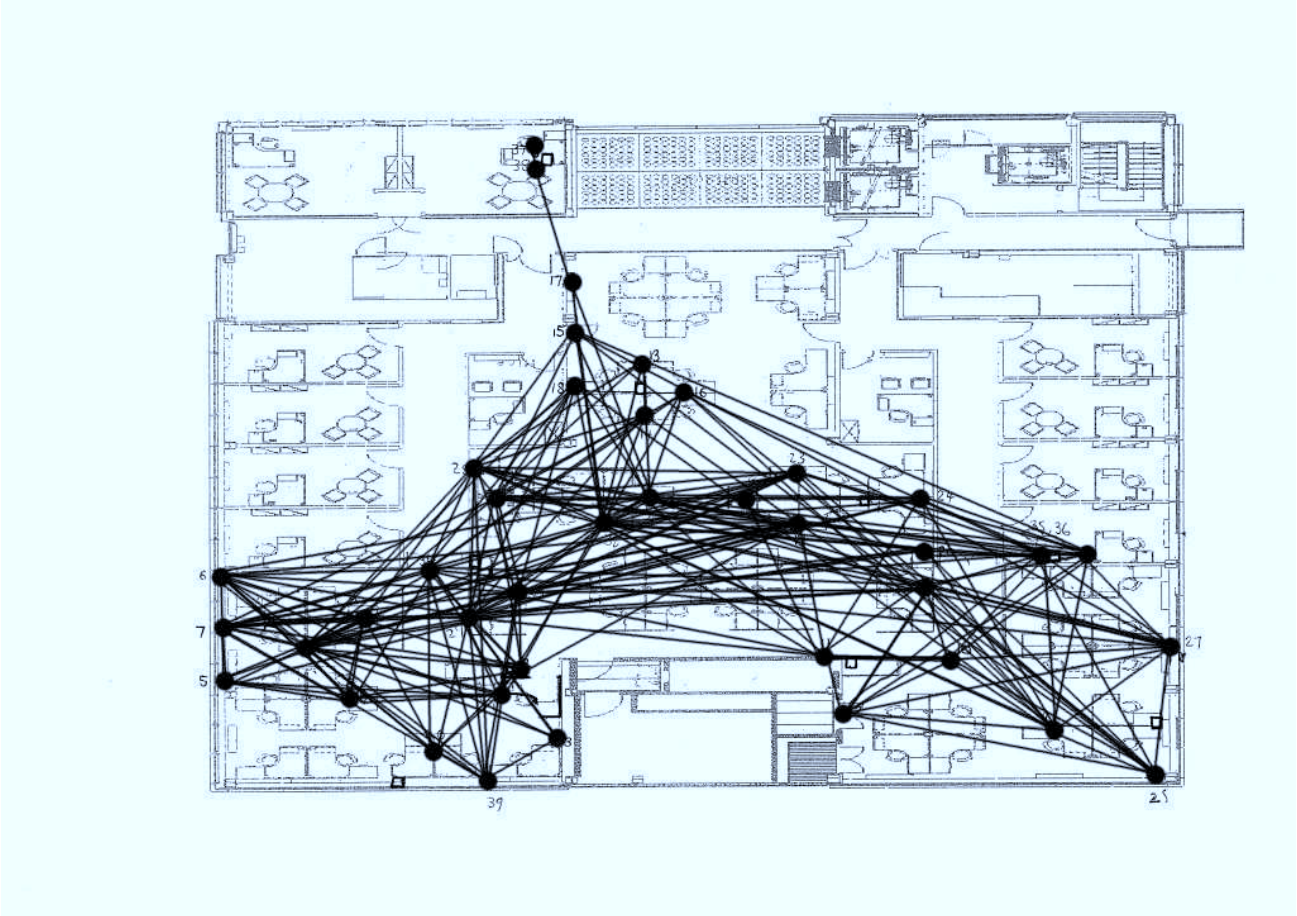
CC2420 Power Control Too Coarse Grained

- "Link" defined as a unidirectional path with PRR $> 30\%$
- Power level 2 has only 14 links



CC2420 Power Control Too Coarse-Grained

- "Link" defined as a unidirectional path with PRR $> 30\%$
- Power level 3 is connected, long links



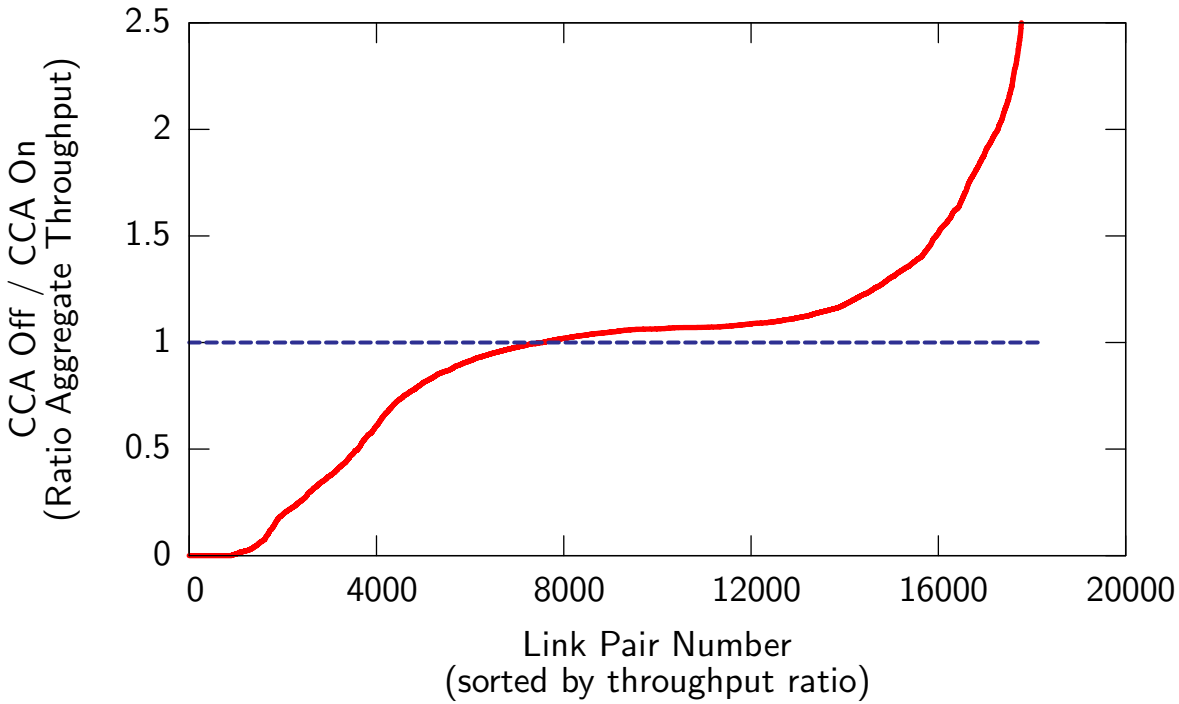
To What Extent Does CSMA Inhibit Spatial Reuse?

- Clear Channel Assessment
  - Received energy $<$ threshold
  - Not currently receiving valid 802.15.4 packet
- Strawman Experiment:
  - Don't do CCA
  - Don't do backoffs
  - Ensure packets overlap
  - Compare throughputs attained with CCA on vs. CCA off

Experiment: Throughput with CCA On vs. CCA Off

- All possible pairs of senders, $\binom{40}{2} = 780$ pairs
- Channel 26, MTU-sized packets, pseudo-random payloads
- Senders synchronised with RBS [Elson *et al.*]
- Each sender broadcasts 200 packets as fast as possible
- For each sender pair (a, b)
  - Each sender individually
  - Both senders with CCA off (must remain synchronised)
  - Both senders with CCA on
- Record reception of all packets

CCA Sometimes Inhibits Spatial Reuse

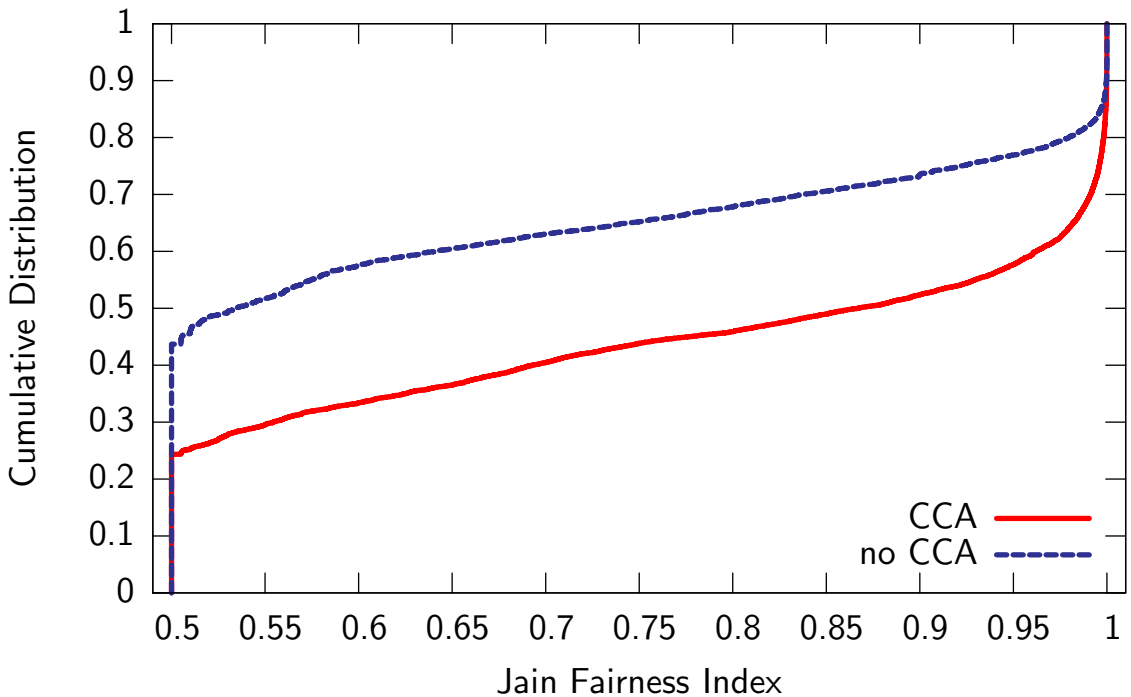


- 35% have greater aggregate throughput with CCA on
- 30% have greater aggregate throughput with CCA off
- Little difference in remaining 35%

CCA Improves Fairness

Jain Fairness Index, single number describing how fairly capacity is shared between n flows

- 1 : both links achieved equal throughput
- 0.5 : one link was starved

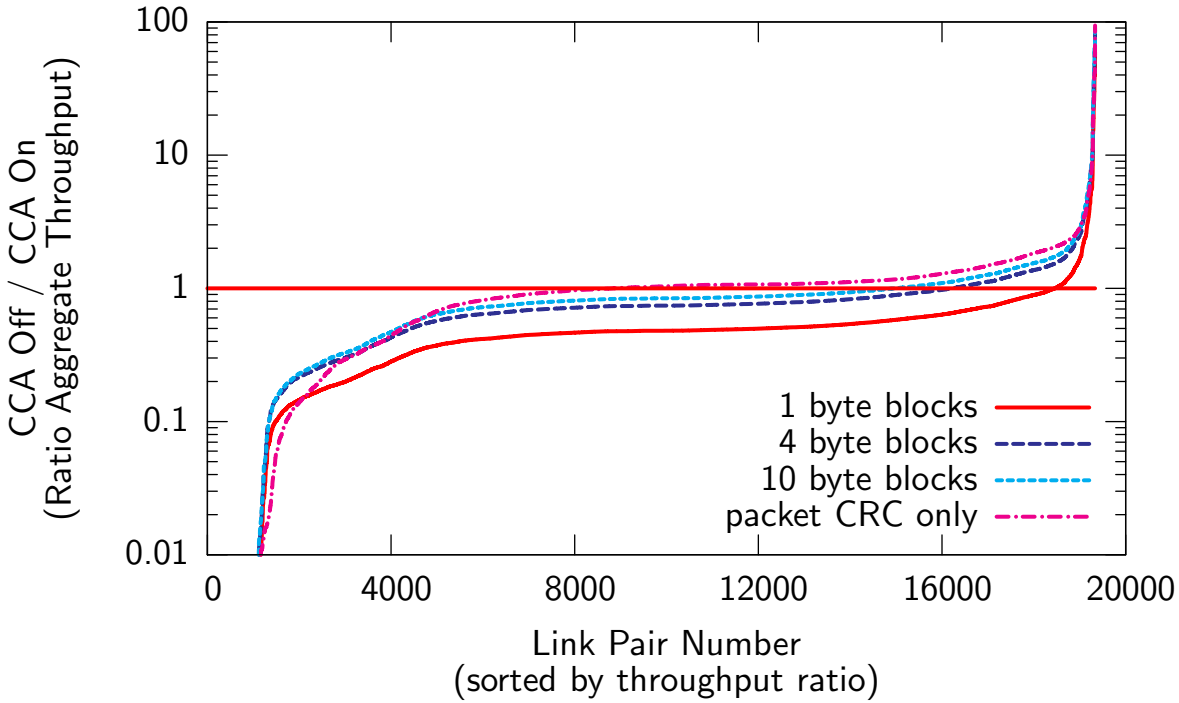


Partial Packet Recovery

Want to understand whether spatial reuse can occur at granularity lower than per packet

- Same as previous experiment
- But, additional CRCs throughout the payload
- Tell radio we even want corrupt packets passed up stack
- Discard individual corrupted blocks

Additional CRCs Mostly Wasted Overhead



For synchronised senders, errors are such that entire packets are lost

Summary

- In dense deployments CC2420 power control provides too coarse a granularity to maximise spatial reuse
- CSMA/CA can inhibit spatial reuse
- In the worst case, spatial reuse acts at a packet granularity

Future Work

- When does CCA make little difference to aggregate throughput?
  - Perfect spatial reuse
  - CCA on and off equally bad (hidden terminals)
  - One link starved with CCA off, sharing with CCA on
- Different bitrates
  - Not supported by our 802.15.4 hardware
  - Planning to build 802.11 testbed
- How does spatial reuse relate to wireless network coding?
  - Both seek to maximise capacity
  - Coding relies on overhearing, "opposite" of spatial reuse

Questions