Link-level Measurements from an 802.11b Mesh Network

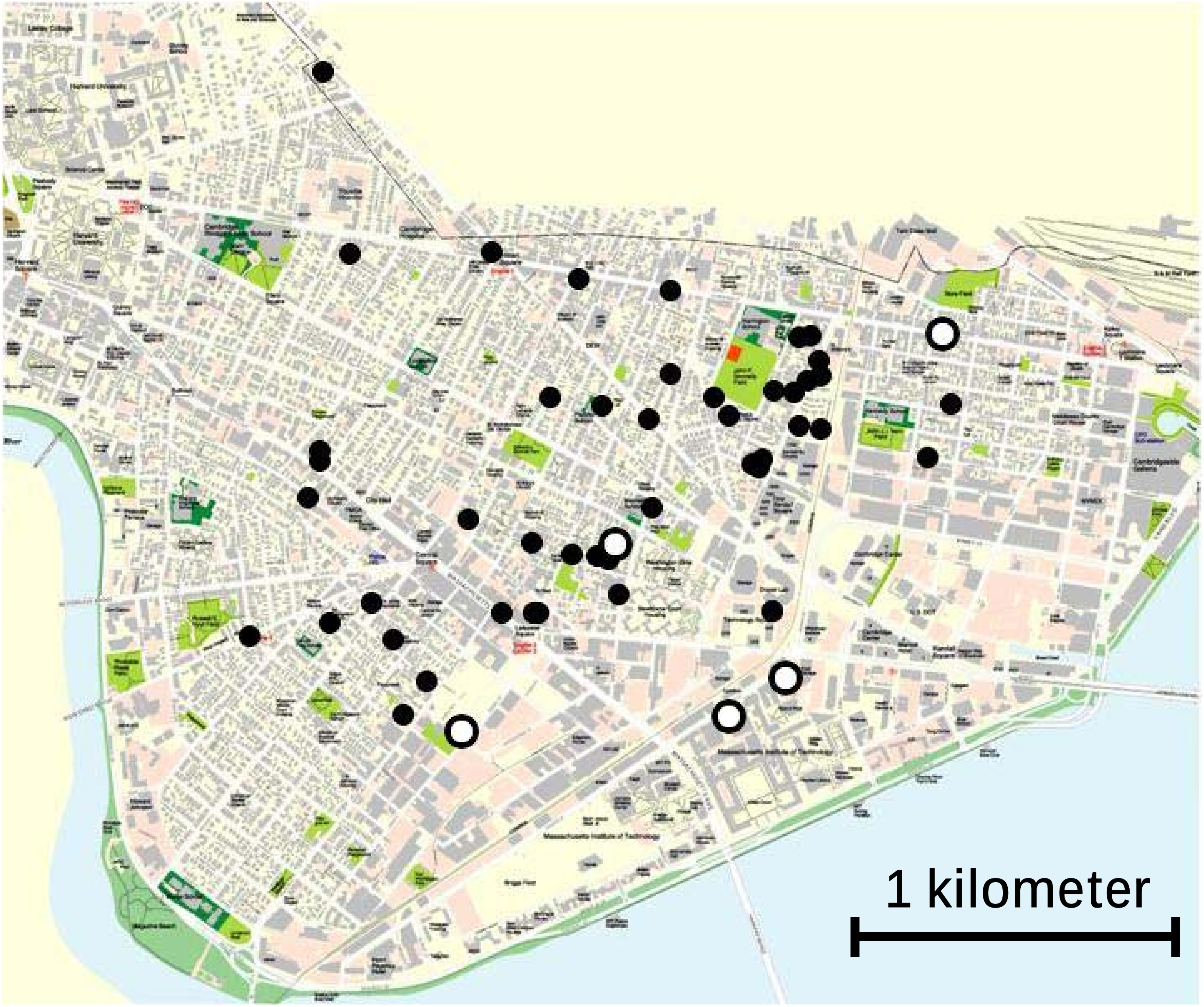
Dan Aguayo
John Bicket, Sanjit Biswas, Robert Morris
MIT

Glenn Judd
CMU

What this talk is about

- Roofnet is a multi-hop, wireless mesh net
- Packet loss makes protocol design hard
- This talk explores the reasons for loss
- Results relevant for sensors and community meshes
- Focus is on long outdoor links

Roofnet provides Internet access



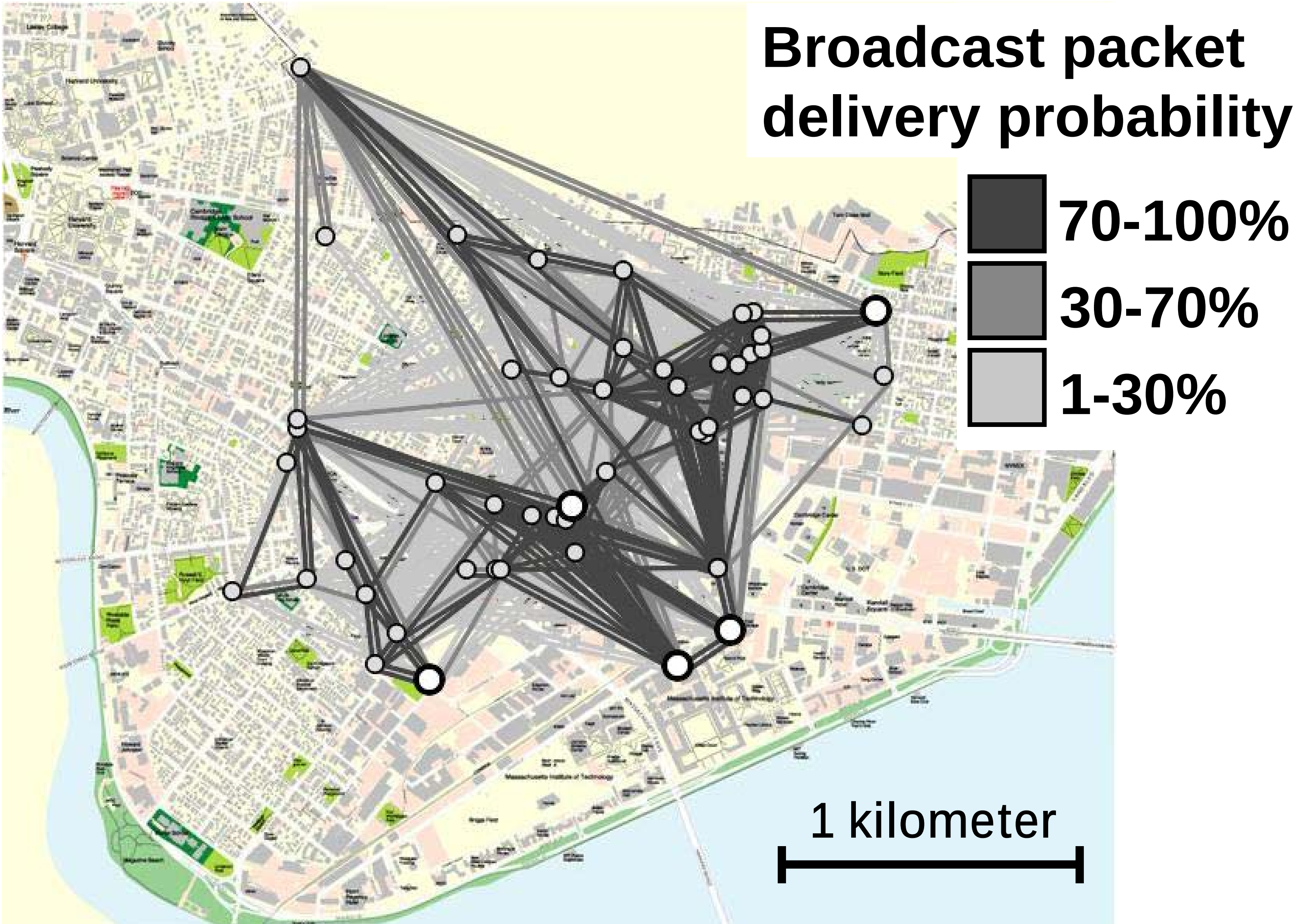
Omni-directional antennas

+ Easy to deploy

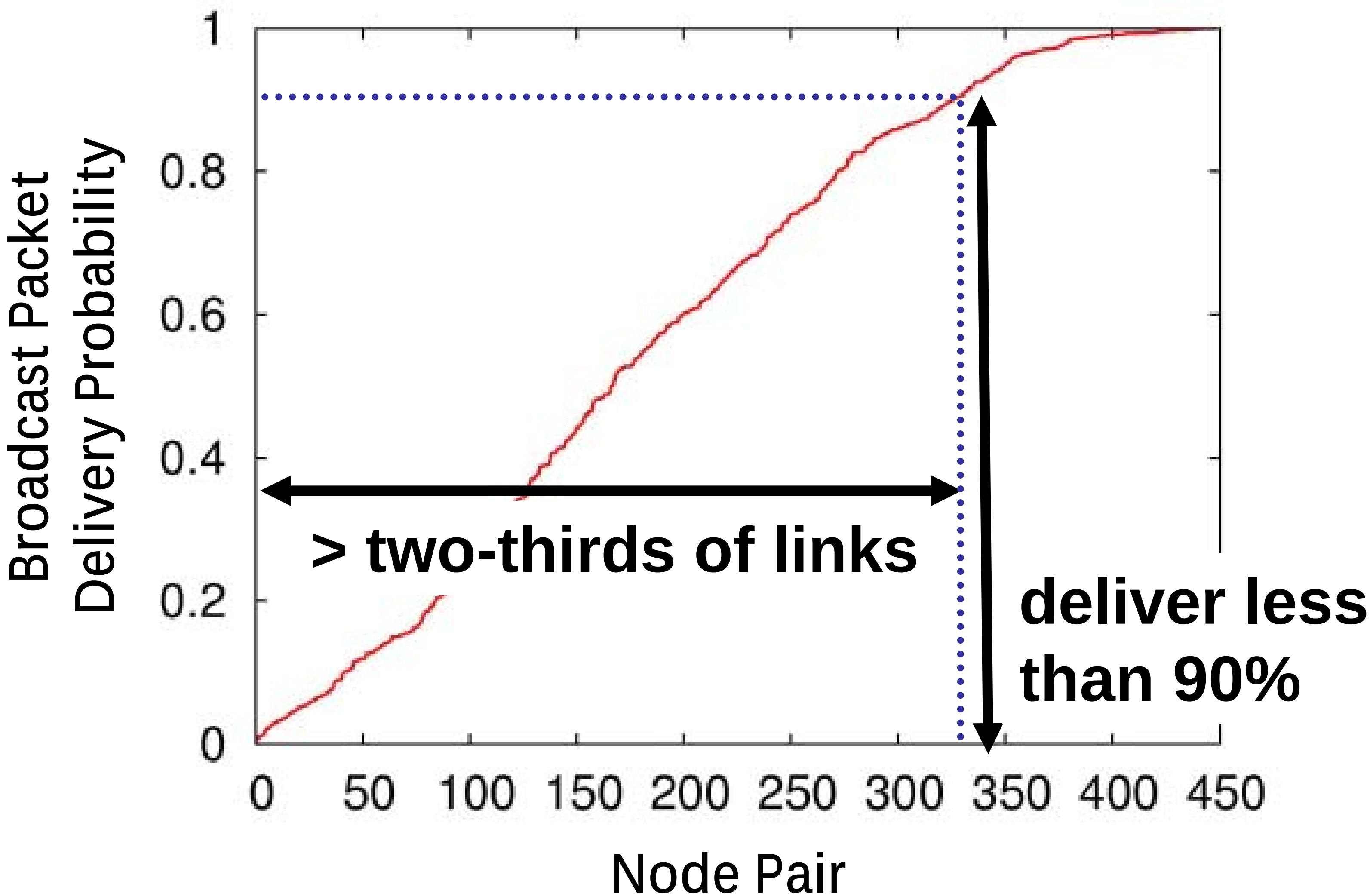
+ Provide high connectivity

- Don’t allow engineered link quality

Lossy radio links are common



Delivery probabilities are uniformly distributed



Protocols should exploit intermediate-quality links

- Link-quality-aware routing (ETX, LQSR)
- 802.11 transmit bit-rate selection
- Multicast data distribution
- Opportunistic protocols (OMAC, ExOR)

This talk investigates the causes…

Rest of the talk: Hypotheses for intermediate delivery rates

1. Marginal signal-to-noise ratios
2. Interference: Long bursts
3. Interference: Short bursts (802.11)
4. Multi-path interference

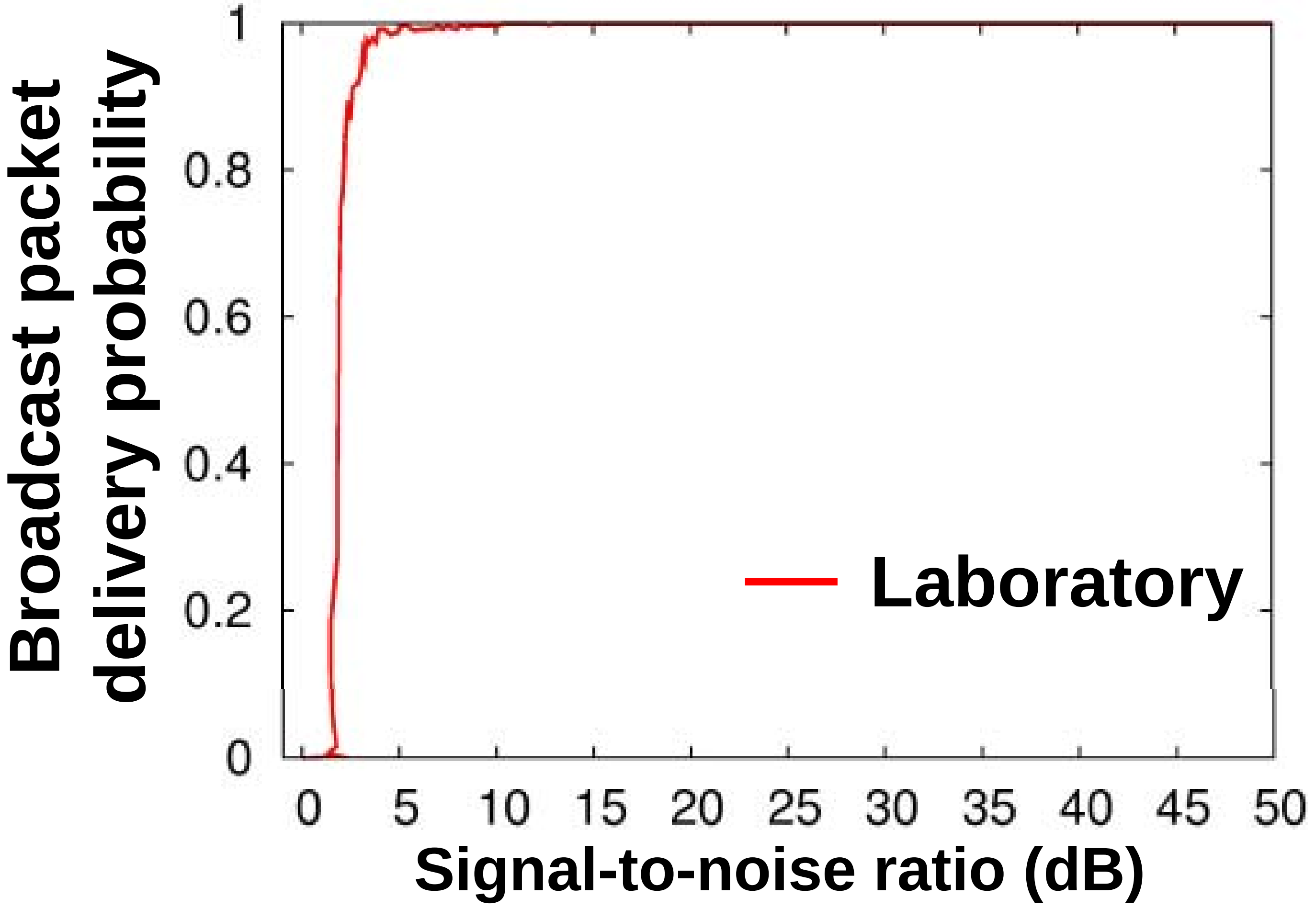
Methodology: Link-level measurements of packet loss

- Goal: all-pairs loss rates
- Each node broadcasts for 90 seconds
- All other nodes listen
- Raw link-level measurements:
  - No ACKs, retransmissions, RTS/CTS
  - No other Roofnet traffic
  - No 802.11 management frames
  - No carrier sense

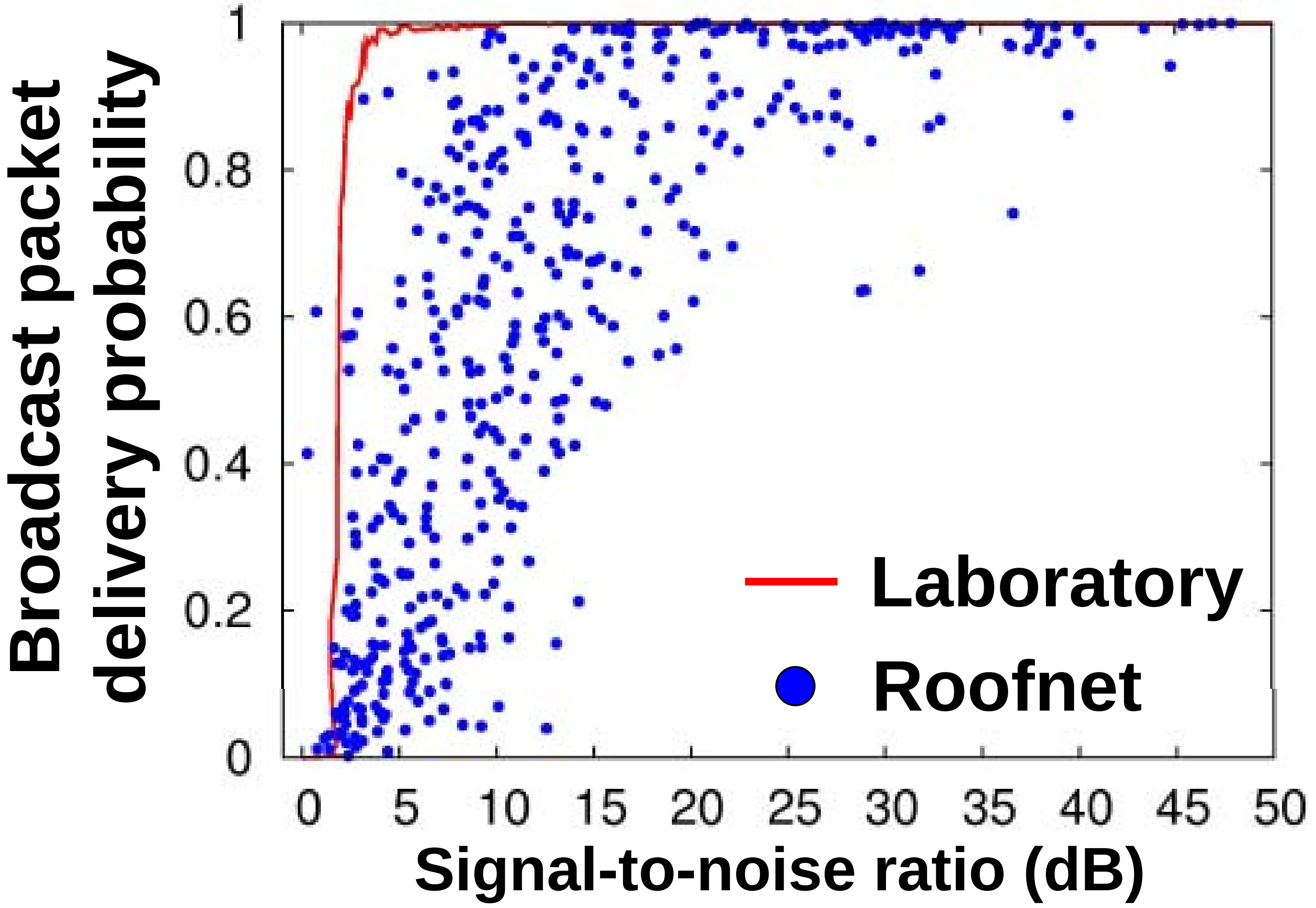
Hypothesis 1: Marginal S/N

- Simplified model for packet loss:
  - P(delivery) = f(signal/noise)
  - Signal strength reflects attenuation
  - Noise reflects interference
- Perhaps marginal S/N explains intermediate delivery probabilities

Delivery vs. S/N with a cable and attenuator

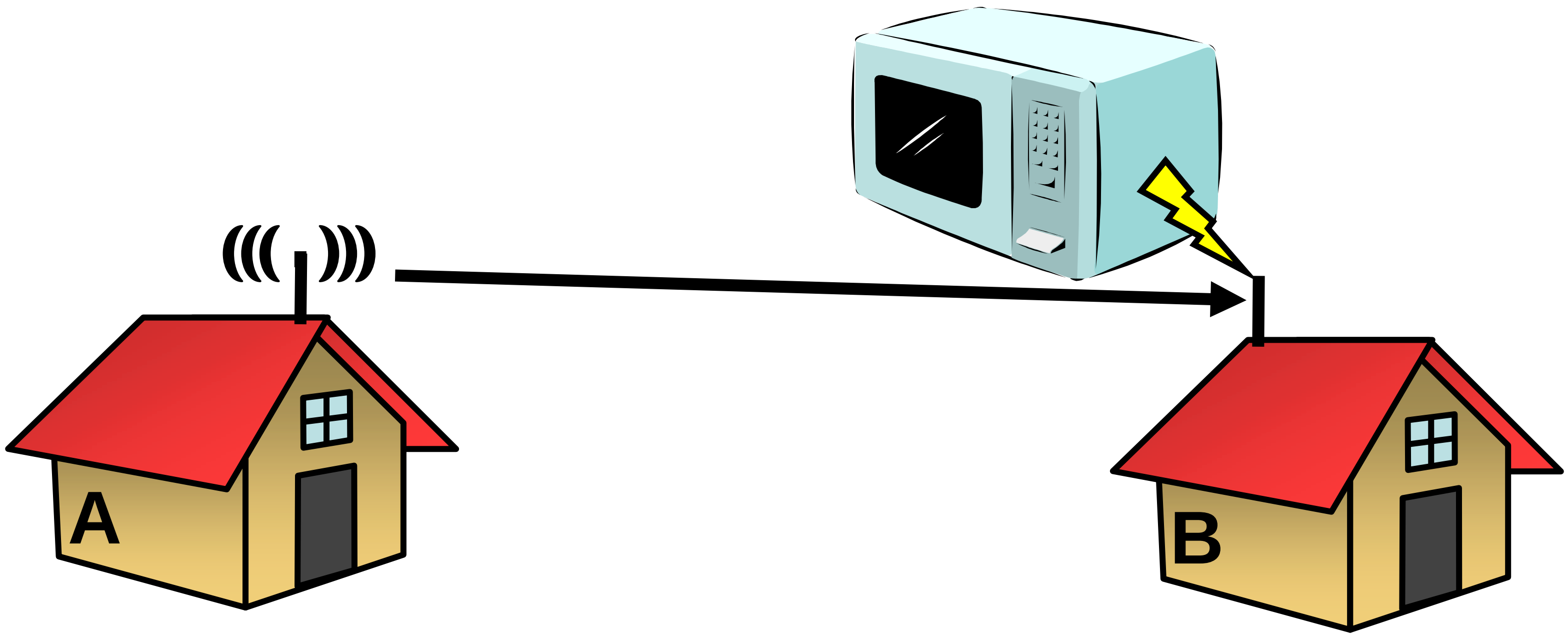


Delivery vs. S/N on Roofnet



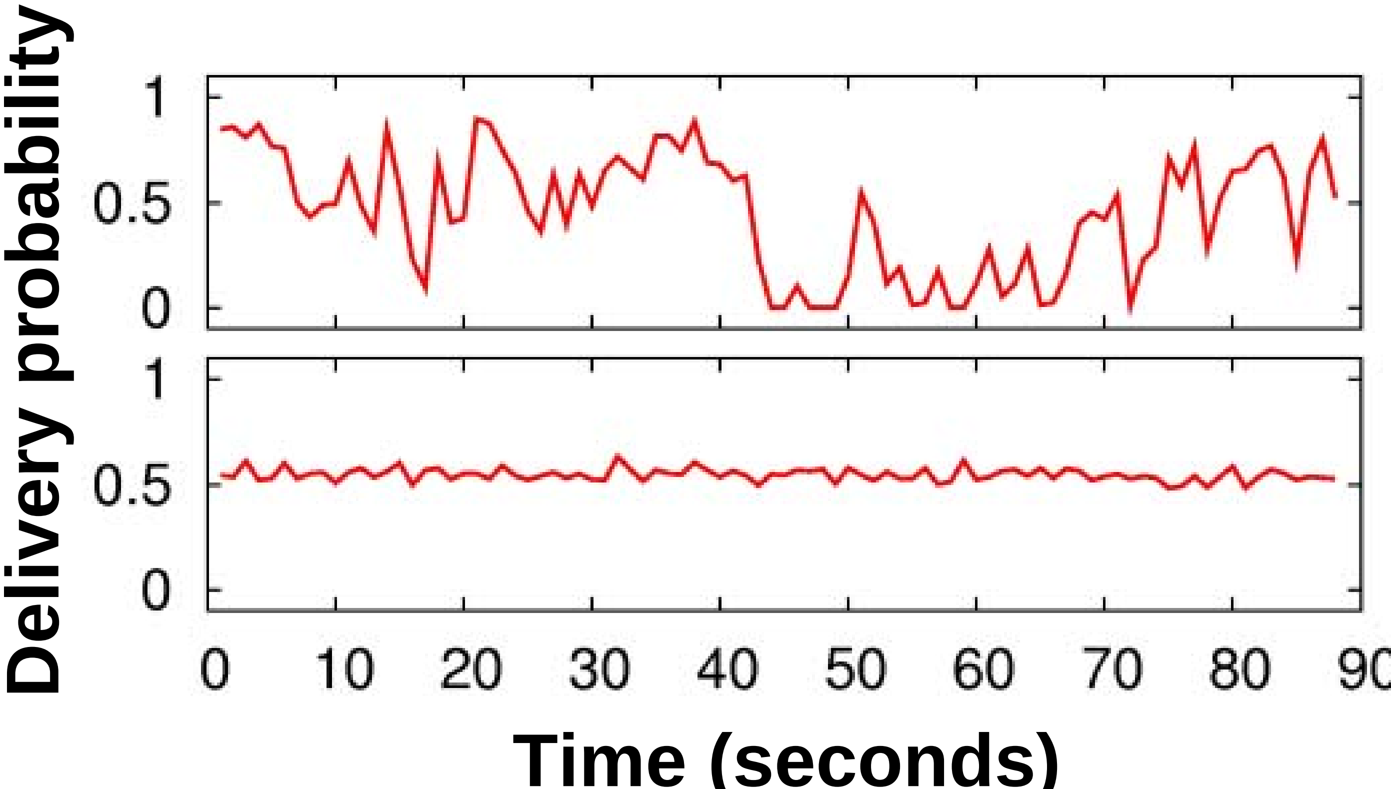
S/N does not predict delivery probability for intermediate-quality links

Hypothesis 2: long bursts of interference



Bursty noise might corrupt packets without affecting S/N measurements

Loss over time on two different Roofnet links

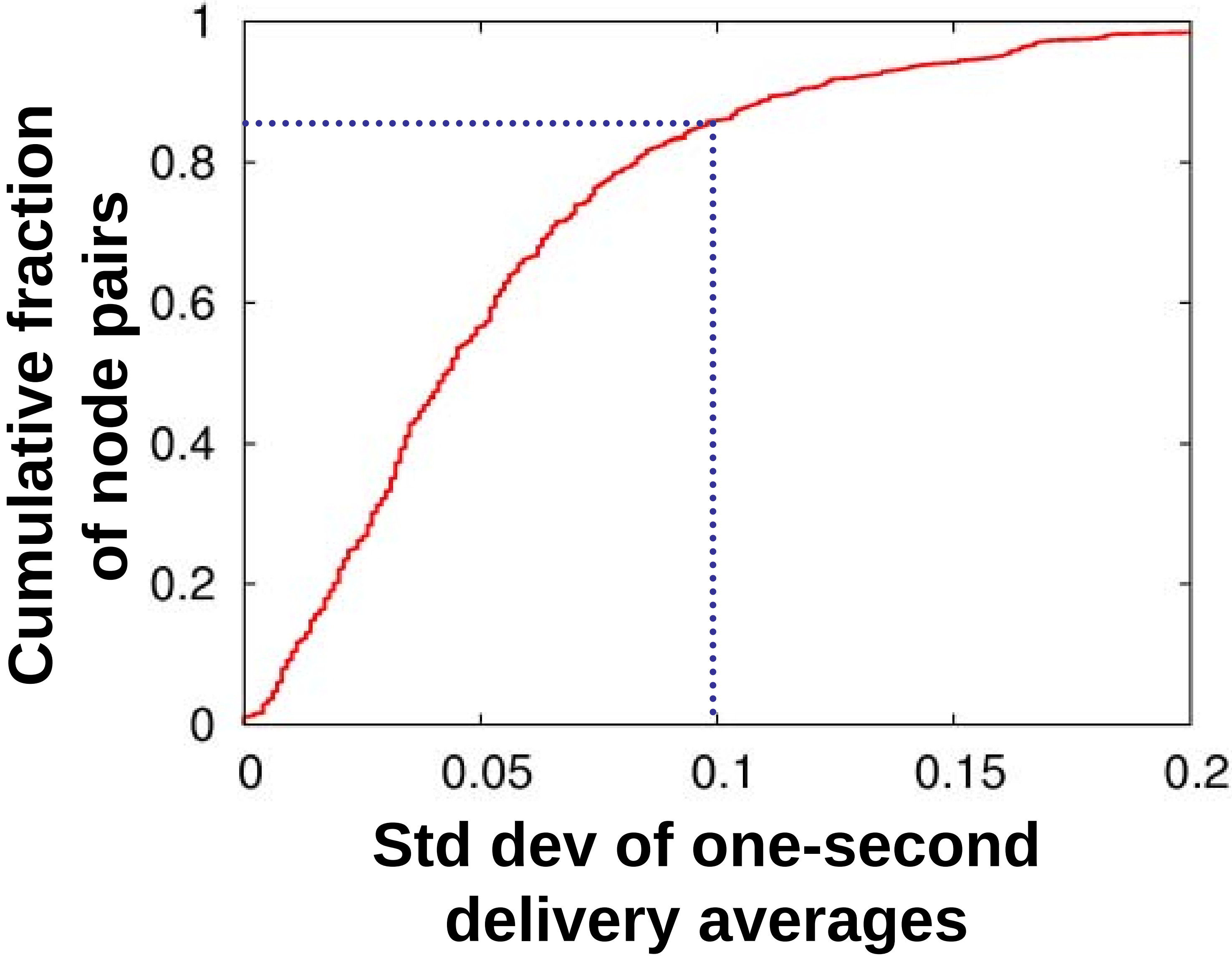


avg: 0.5
stddev: 0.28

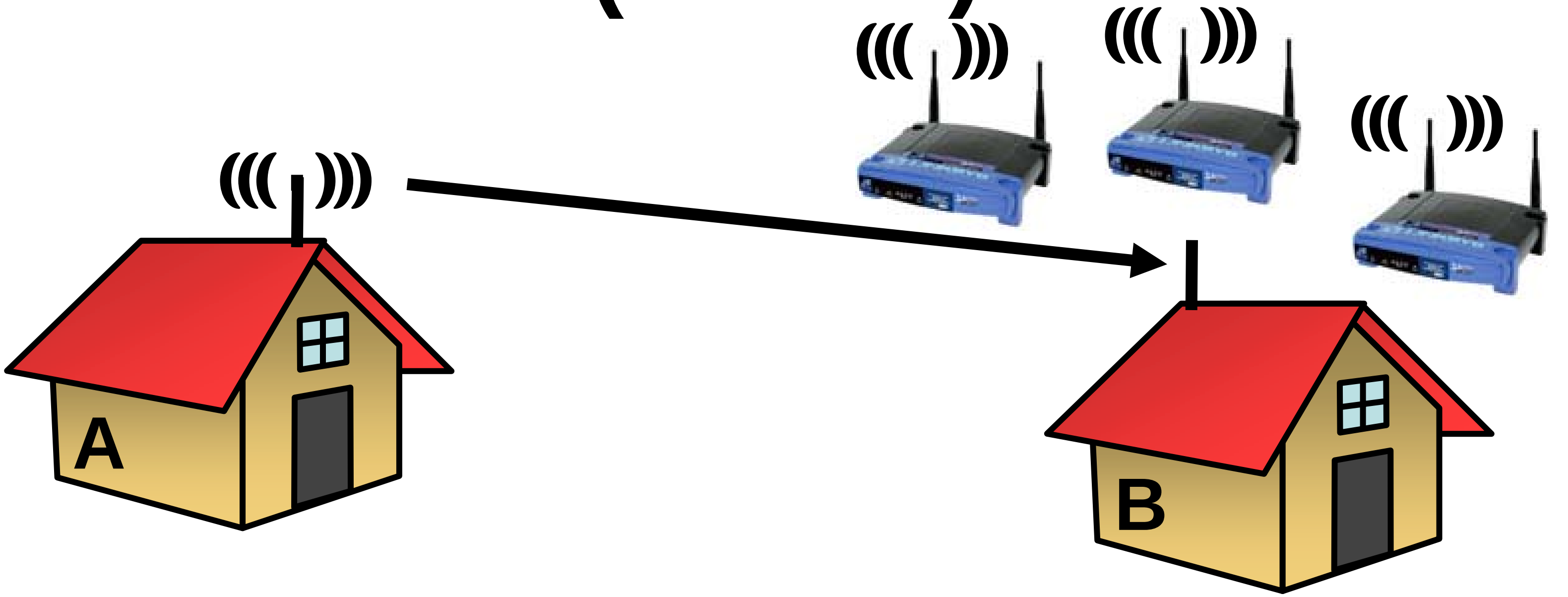
avg: 0.5
stddev: 0.03

The top graph is consistent with bursty interference. The bottom graph is not.

Most links aren't bursty



Hypothesis 3: short bursts of interference (802.11)

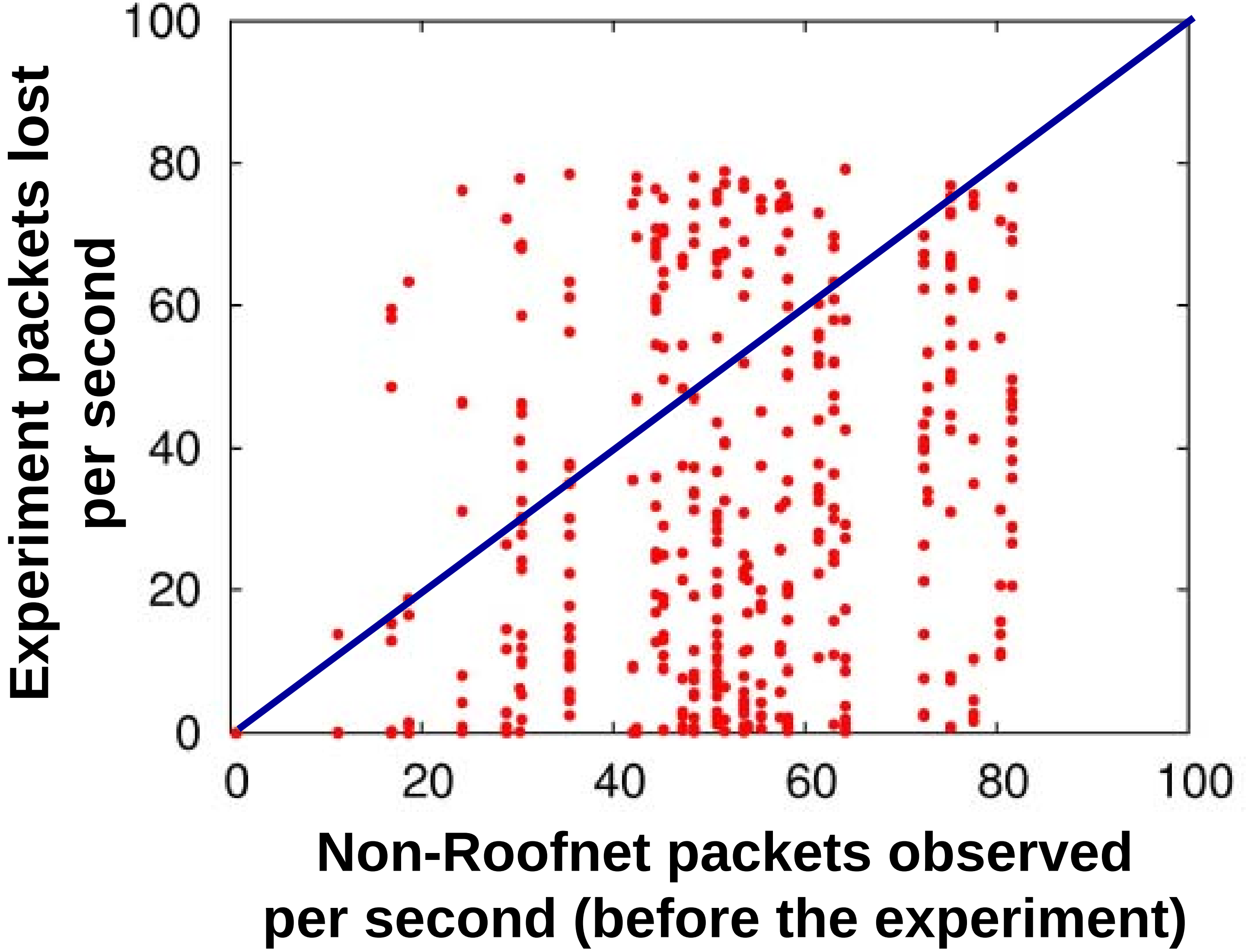


- MAC doesn't prevent all concurrent sends
- Outcome depends on relative signal levels
- Hypothesis: When a nearby AP sends a packet, we lose a packet.

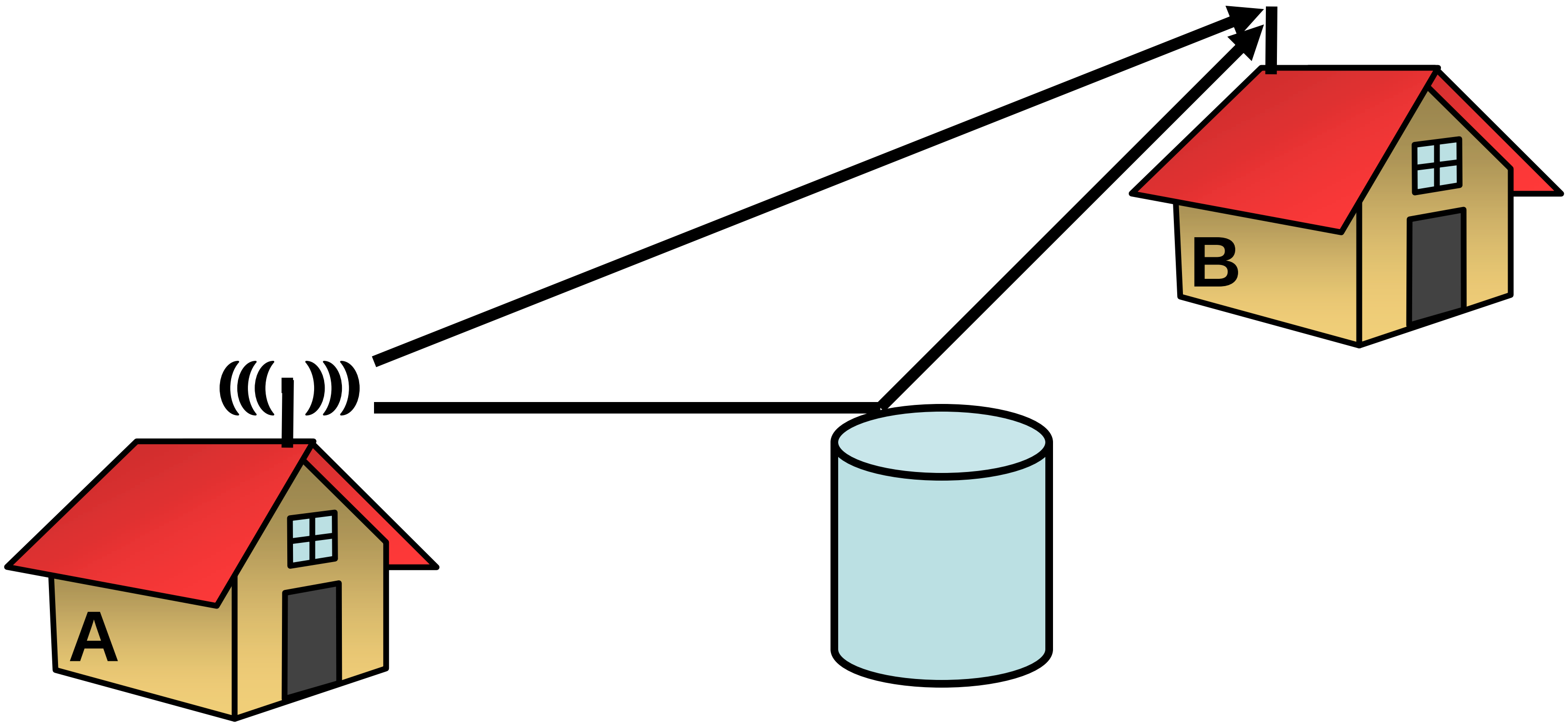
Methodology: record non-Roofnet 802.11 traffic

- Goal: measure non-Roofnet traffic
- Before the broadcast experiments
- Each node records all 802.11 traffic

No correlation between foreign traffic observed and packets lost

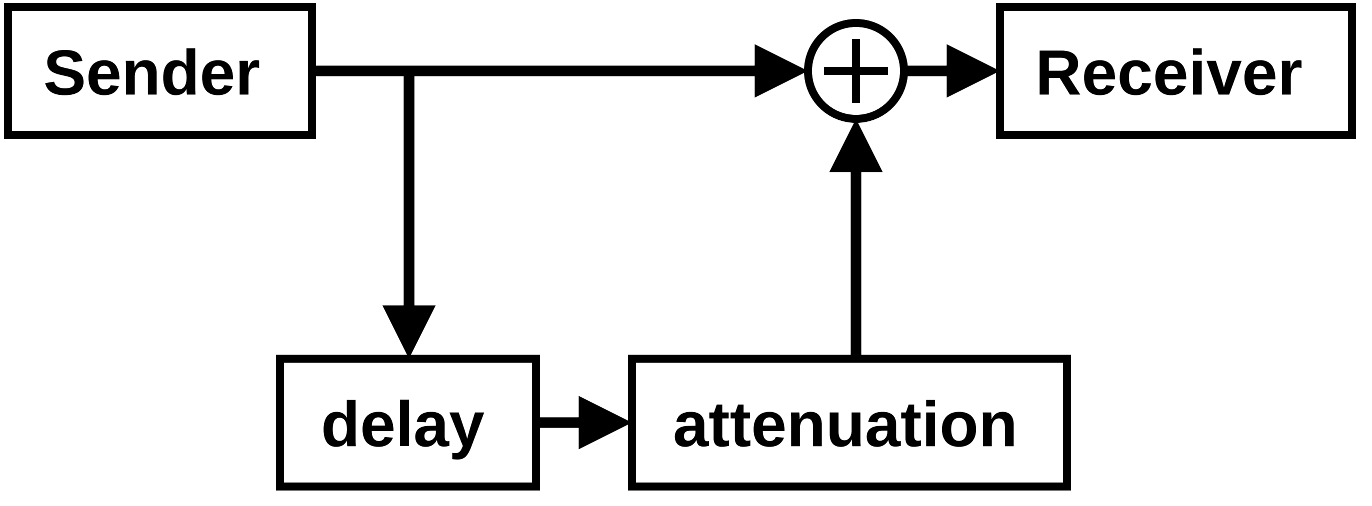


Hypothesis 4:
Multi-path interference

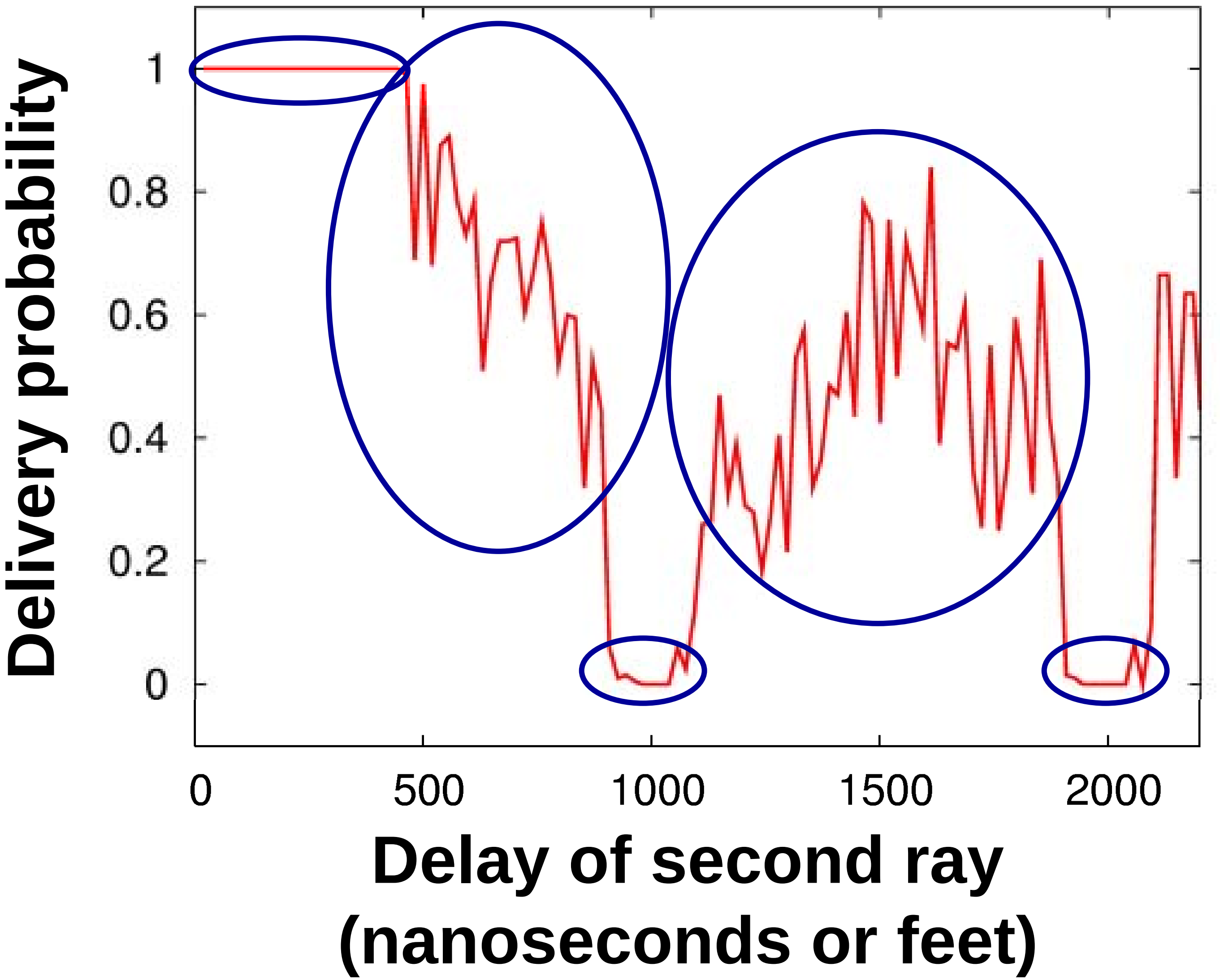


Reflection is a delayed and attenuated copy of the signal

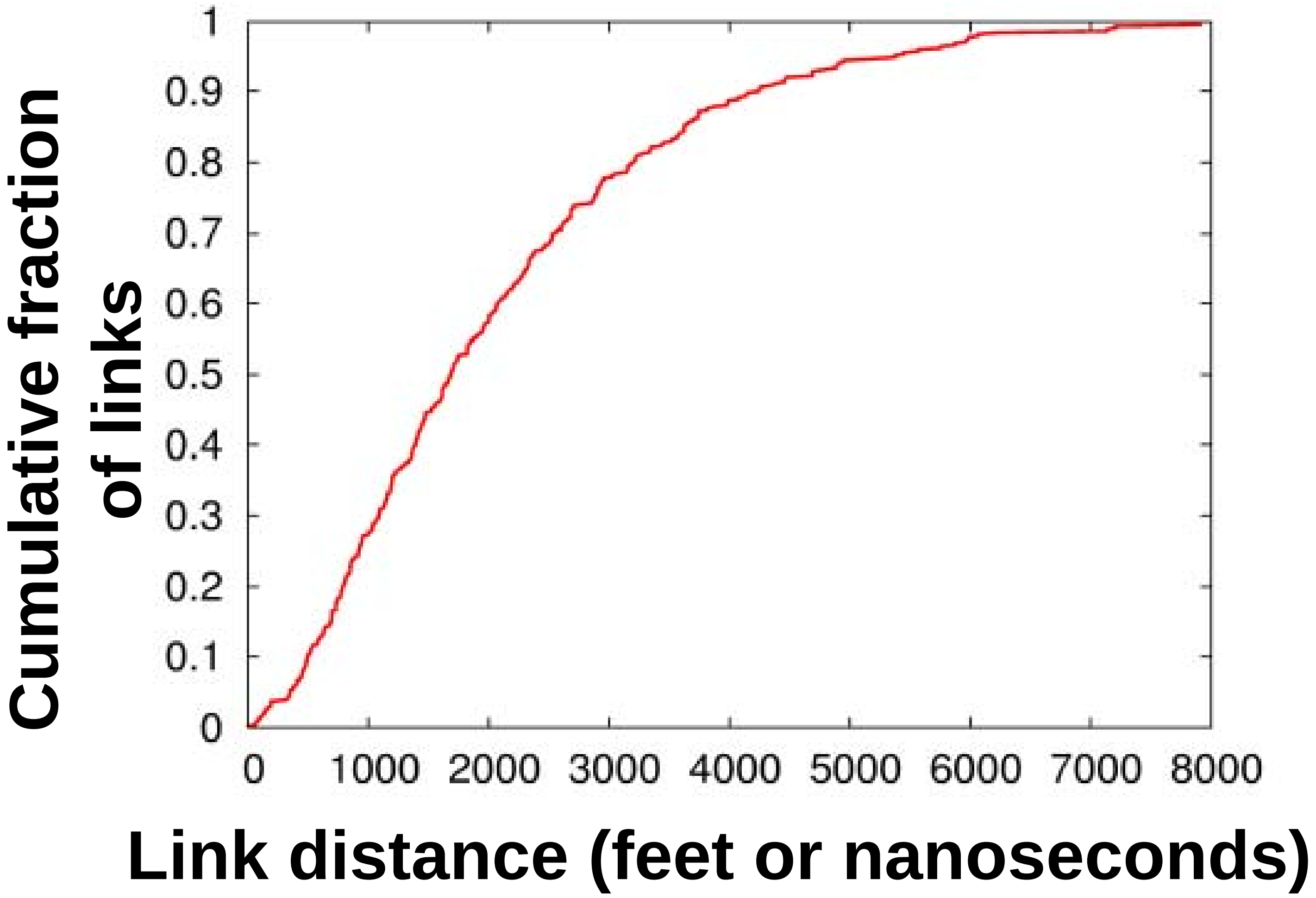
A channel emulator to investigate multi-path effects



A reflection can cause intermediate packet loss



Roofnet links are long



It’s reasonable to expect delays >500 ns

Related Work

- Measurements of AP networks: Eckhardt and Steenkiste 1996; Kotz 2003
- Sensor net measurements: Ganesan 2002; Woo 2003
- Protocol design: Lundgren 2002; Yarvis 2002; De Couto 2003; Woo 2003; Draves 2004

Summary

- Most Roofnet links have intermediate loss rates
- S/N does not predict delivery probability
- Loss is not consistent with bursty interference
- Multi-path is likely to be a major cause

Questions?

roofnet@pdos.csail.mit.edu

http://pdos.lcs.mit.edu/roofnet