Announcements

- HW1 Q5, go to TA office hours
- SVN setup
- TA office hour changed to F 1130-130pm
Wireless Propagation

• Received power falls rapidly
• Need certain SNR
• In reality
  – Slow and Fast Fading
• Need to measure to understand what wireless TX and RX looks like in reality

http://en.wikipedia.org/wiki/Fading
Wireless Link Dynamics

![Graph showing PRR and RSSI over time]

- PRR (Packet Reception Rate)
- RSSI (Received Signal Strength Indicator)

Time in secs: 2 to 10

RSSI values range from -92 to -80 dBm.

PRR values vary, with a peak of 1.0 and a drop to approximately 0.9 over 1 second.
Sampling Bias

• Log RSSI or other channel information only on received packets

• Potential problem
  – measurement studies
  – link quality estimation

• Solution?
Rest of the slides are from Daniel Aguayo’s SIGCOMM talk
Link-level Measurements from an 802.11b Mesh Network

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John Bicket, Sanjit Biswas, Robert Morris
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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

Broadcast packet delivery probability

- 70-100%
- 30-70%
- 1-30%

1 kilometer
Delivery probabilities are uniformly distributed.

![Graph showing delivery probabilities and node pairs](image)

- **Node Pair**
- **Broadcast Packet Delivery Probability**

- > two-thirds of links deliver less than 90%
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:
  – $P(\text{delivery}) = f(\text{signal/noise})$
  – Signal strength reflects attenuation
  – Noise reflects interference

• Perhaps marginal S/N explains intermediate delivery probabilities
Delivery vs. S/N with a cable and attenuator

![Graph showing broadcast packet delivery probability vs. signal-to-noise ratio (dB). The x-axis represents signal-to-noise ratio in dB, ranging from 0 to 50, and the y-axis represents broadcast packet delivery probability ranging from 0 to 1. A line is plotted for Laboratory data.](image)
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

The top graph is consistent with bursty interference. The bottom graph is not.
Most links aren’t bursty

Cumulative fraction of node pairs

Std dev of one-second delivery averages

21
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

Experiment packets lost per second vs. Non-Roofnet packets observed per second (before the experiment)
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

![Graph showing delivery probability vs. delay of second ray in nanoseconds or feet]
Roofnet links are long

It’s reasonable to expect delays >500 ns
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