Network Simulation and Testing

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Wireless Papers

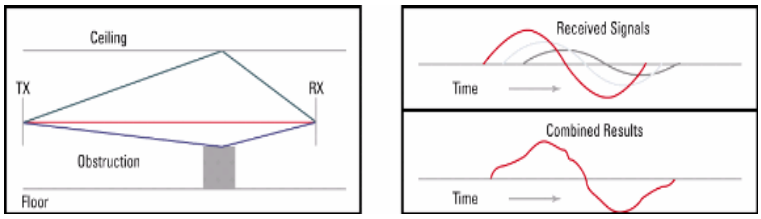
- John Bicket, Daniel Aguayo, Sanjit Biswas, Robert Morris. Architecture and Evaluation of an Unplanned 802.11b Mesh Network. In Proceedings of ACM MobiCom 2005
- Daniel Aguayo, John Bicket, Sanjit Biswas, Glenn Judd, Robert Morris. Link-level Measurements from an 802.11b Mesh Network In Proceedings of ACM SIGCOMM 2004
- Jerry Zhao, Ramesh Govindan. Understanding Packet Delivery Performance In Dense Wireless Sensor Networks. In Proceedings of ACM SenSys 2003
- Dongjin Son, Bhaskar Krishnamachari, John Heidemann. Experimental Analysis of Concurrent Packet Transmissions in Low-Power Wireless Networks. In Proceedings of ACM SenSys 2006

Cause of Wireless Misses

1. Signal Attenuation

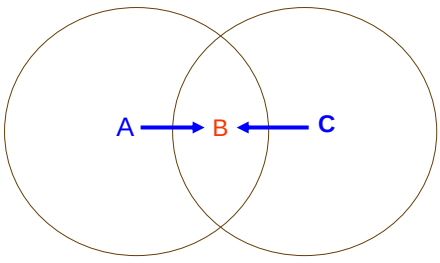
- Attenuation: $(10/L)\log_{10}(P_i/P_o)$
  - L: distance
  - P_i : receiving power
  - P_o : transmitting power
- Signal Strength: $\sim 1/r^a$
  - r: distance
  - $2 \leq a \leq 5$

2. Multi-Path Problem



Source: Wireless Lan, Multipath and Diversity
http://www.cisco.com/en/US/tech/tk722/tk809/technologies_tech_note09186a008019f646.shtml

3. Hidden Terminal Problem



Link Metrics

- PRR
  - Packet reception rate, packet delivery rate, link quality
  - The metric really important
- Alternatives
  - RSS/RSSI
    - Received signal strength/indicator
  - S/N
    - Signal to noise ratio
  - SINR
    - Signal interference noise ratio

Wireless Link Characteristics

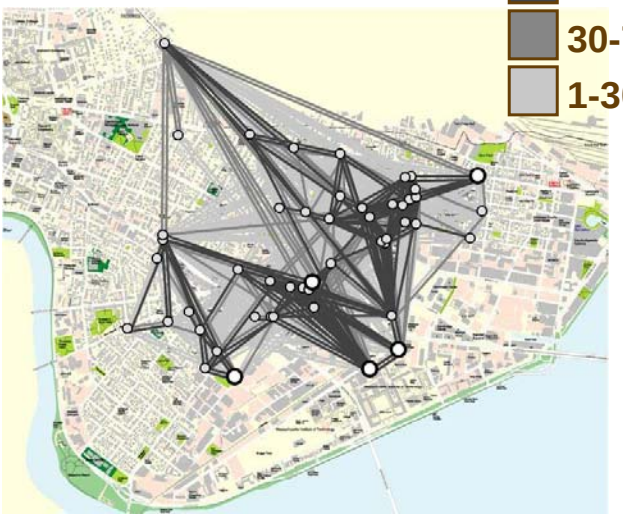
Mesh Network Link

Testbeds

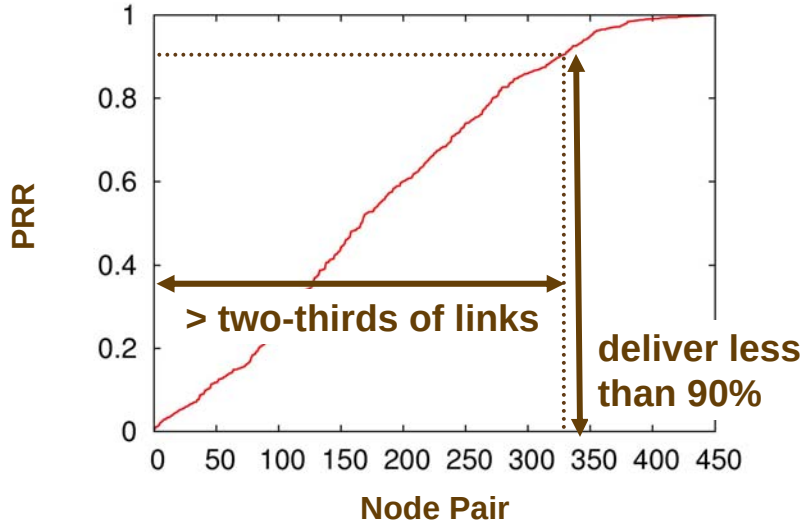
Sensor Network Link

Roofnet

Lossy Links



PRR Distribution



Why Intermediate PRR Links

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

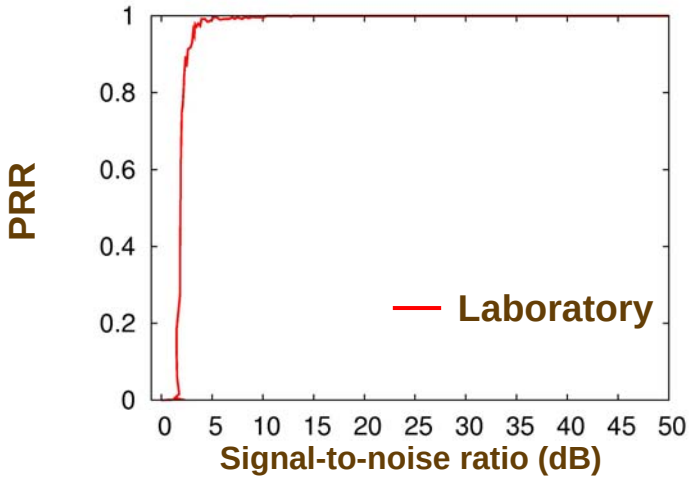
Methodology

- All-pairs PRR
- 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

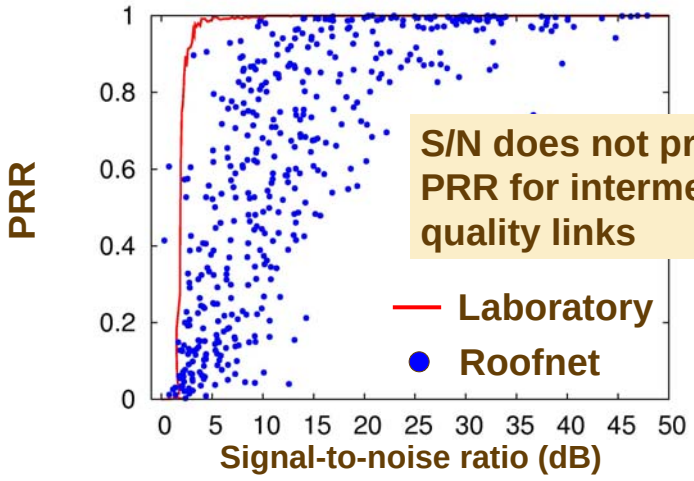
Marginal S/N?

- Packet losses due to
  - Attenuation + Interference
- Simplified model
  - PRR = f(signal/noise)
  - Signal strength reflects attenuation
  - Noise reflects interference

PRR to S/N in Lab

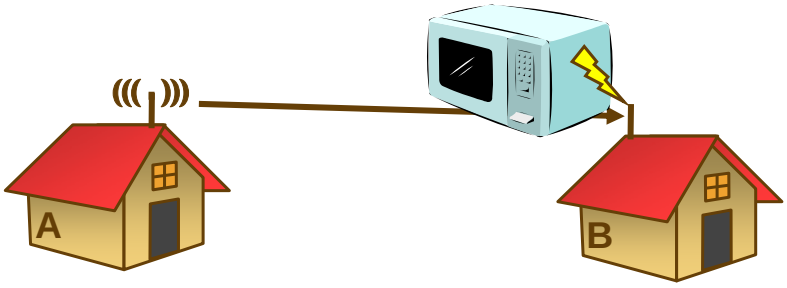


PRR to S/N on Roofnet



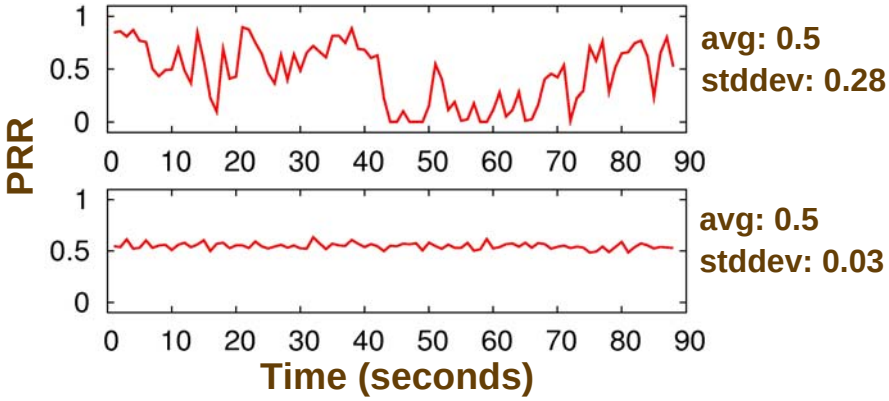
S/N does not predict PRR for intermediate-quality links

Long-Term Interference?



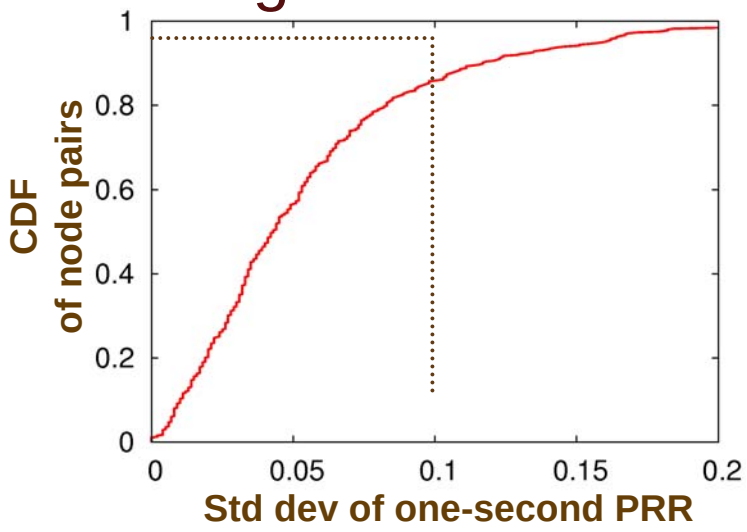
Bursty noise might corrupt packets without affecting S/N measurements

Two Roofnet Links

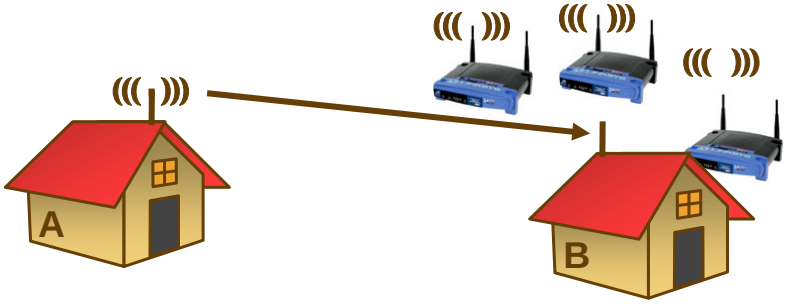


The top graph is consistent with bursty interference. The bottom graph is not.

Little Long-Term Interference



Short-Term Interference?

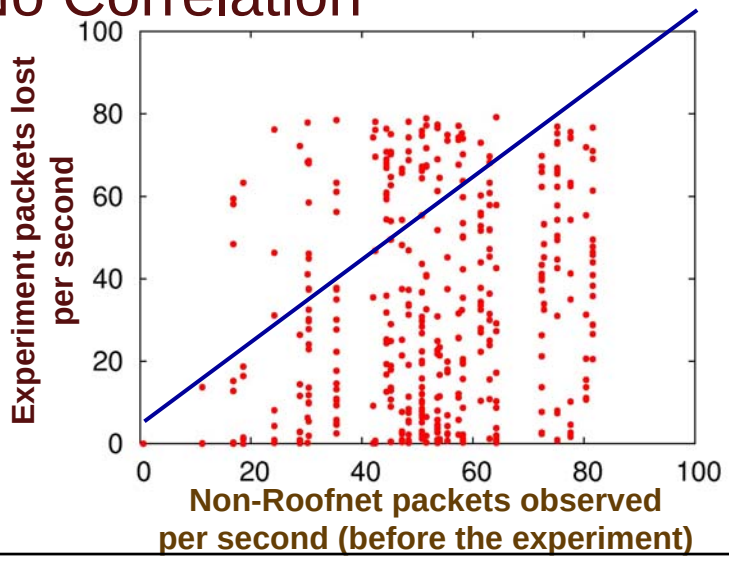


- MAC doesn't prevent all concurrent sends
- Outcome depends on relative signal levels
- Hypothesis: When a nearby AP sends a packet, we lose a packet.

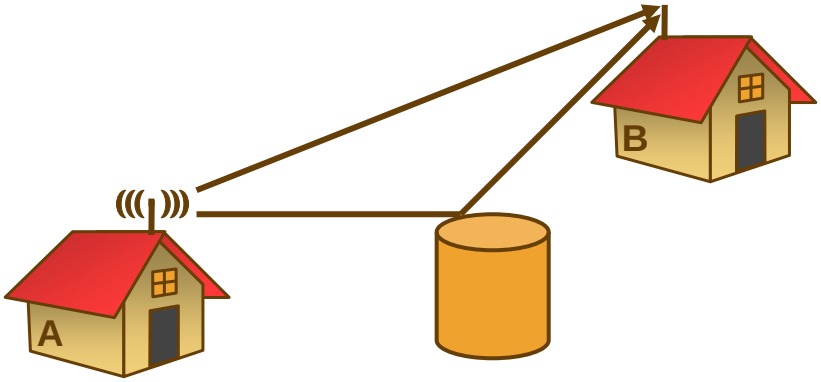
Methodology

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

No Correlation

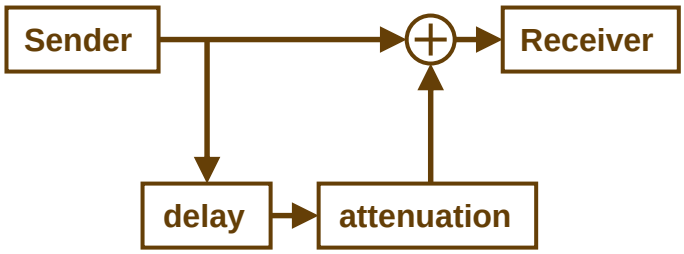


Multi-Path Interference?

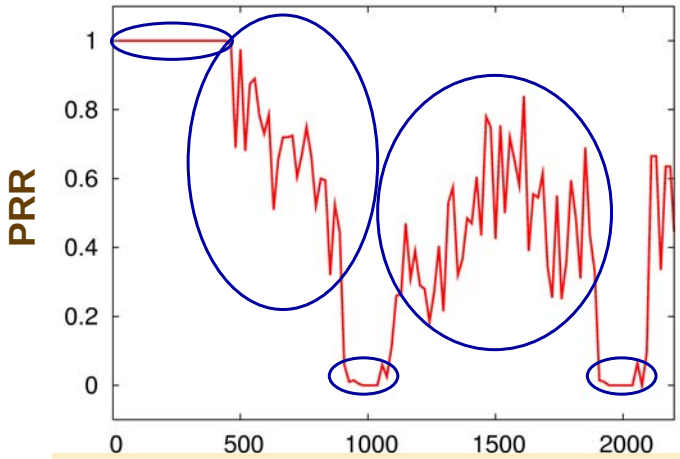


Reflection is a delayed and attenuated copy of the signal

Emulator for Multi-Path Effect

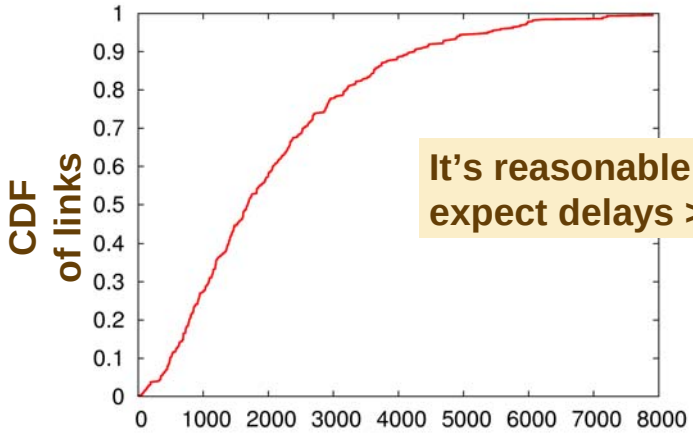


Intermediate PRR



Delay of second ray (nanoseconds or feet)

Long Links



It's reasonable to expect delays >500 ns

Link distance (feet or nanoseconds)

Summary

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

Wireless Link Characteristics

Mesh Network Link

Testbeds

Sensor Network Link

Deployment

- Area
  - 4 square kilometers
  - Cambridge, Messachusetts
- Most nodes
  - In buildings
  - 3~4 story apartment buildings
  - 8 nodes are in taller buildings
- Each Rooftnet node is hosted by a volunteer

Hardware

- PC running Linux
  - Omni-directional antenna
  - 802.11b card
    - Same 802.11b channel
    - RTS/CTS disabled
    - Ad hoc mode

Software

- Automated
  - Allocating addresses
  - Finding a gateway between Roofnet and the Internet
  - Choosing a good multi-hop route to that gateway

Addressing

- Roofnet nodes
  - Low 24 bits are the low 24 bits of the node's Ethernet address
  - High 8 bits are an unused class-A IP address block
  - Only works inside Roofnet
- Hosts
  - Allocate 192.168.1.x via DHCP
  - NAT between the Ethernet and Roofnet

Gateways

- 4 users share their wired Internet access
- Gateway nodes
  - Advertise itself to Roofnet
  - Act as a NAT for Roofnet to the Internet
- Other nodes
  - Select the gateway with the best route metric

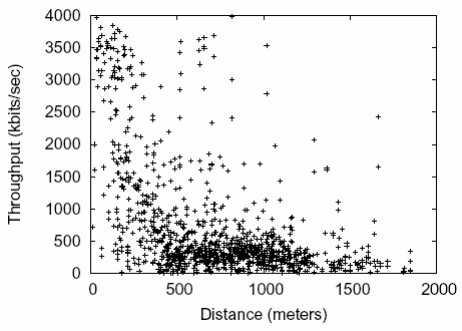
Routing: Srcr

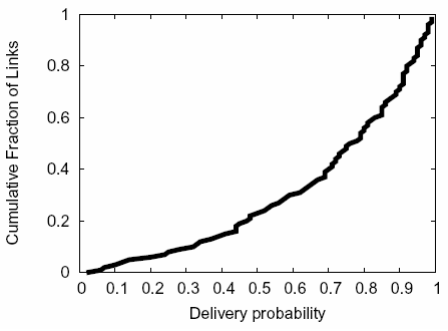
- Find the highest throughput route between any pair of Roofnet nodes
- Source-routes data packets like DSR
- Learning fresh link metrics
  - Forward a packet
  - Flood to find a route
- Finding a route to a gateway
  - Each Roofnet gateway periodically floods a dummy query
  - When a node receives a new query, it adds the link metric information
  - The node computes the best route

Routing Metric

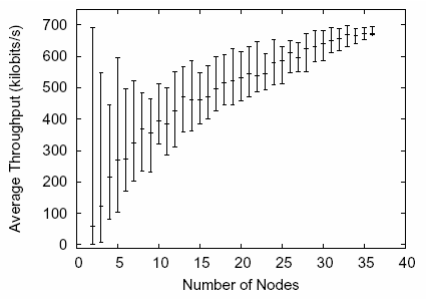
- ETT (Estimated Transmission Time)
  - Predict the total amount of time it would take to send a data packet
  - Capacity + PRR
    - Periodic 1500-byte broadcasts
- Bit-rate Selection
  - 802.11b transmit bit-rates
    - 1, 2, 5.5, 11 Mbits/s
  - Sample Rate
    - Base decisions on actual data transmission
    - Periodically sends a packet at some other bit-rate
    - Judge which bit-rate will provide the highest throughput

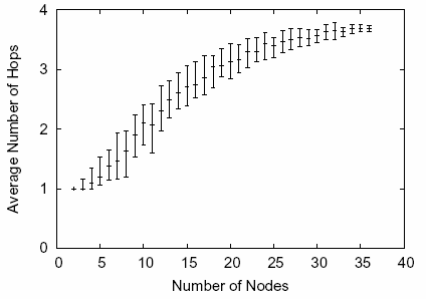
PRR and Distance



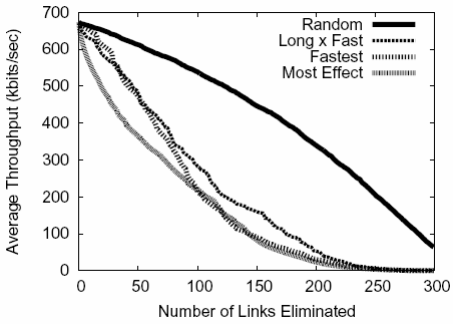


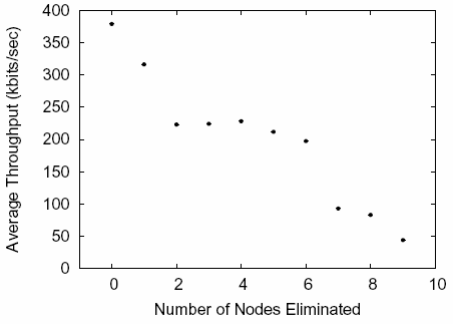
Throughput vs. Delay





Robustness





Usage

- 160kbps avg rate for 94% of the time
- Gateway's radio busy for ~70% of the time
- Data traffic
  - 48% one hop to gateway\
  - 36% two hops
- TCP >> UDP (<1%)
- 30% data was P2P file sharing

Sensor Network Testbeds

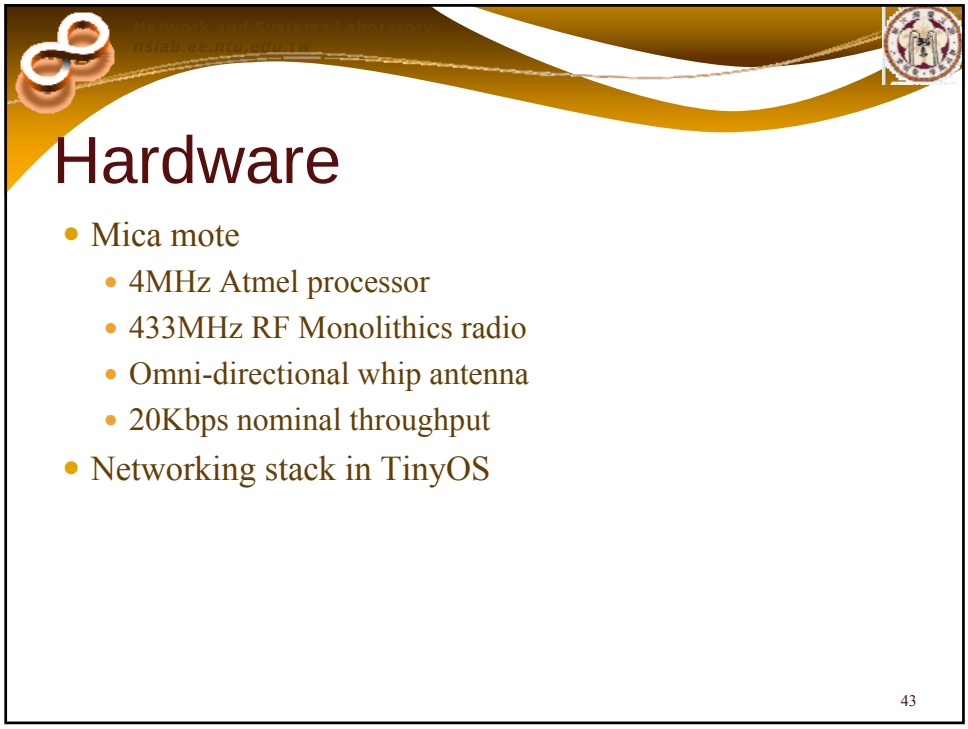
- *I:* Indoor office building
- 2m * 40m hallway
- 60 motes placed in a line
  - 0.5m apart
  - 025m apart near the edge of the communication range
  - Removed some nodes from near the transmitter
- Harsh due to significant multi-path reflection effects

Outdoor Testbed

- *H*: 150m * 150m segment of a state park
- Downhill slope with foliage and rocks
- Multi-path problems due to foliage & rocks

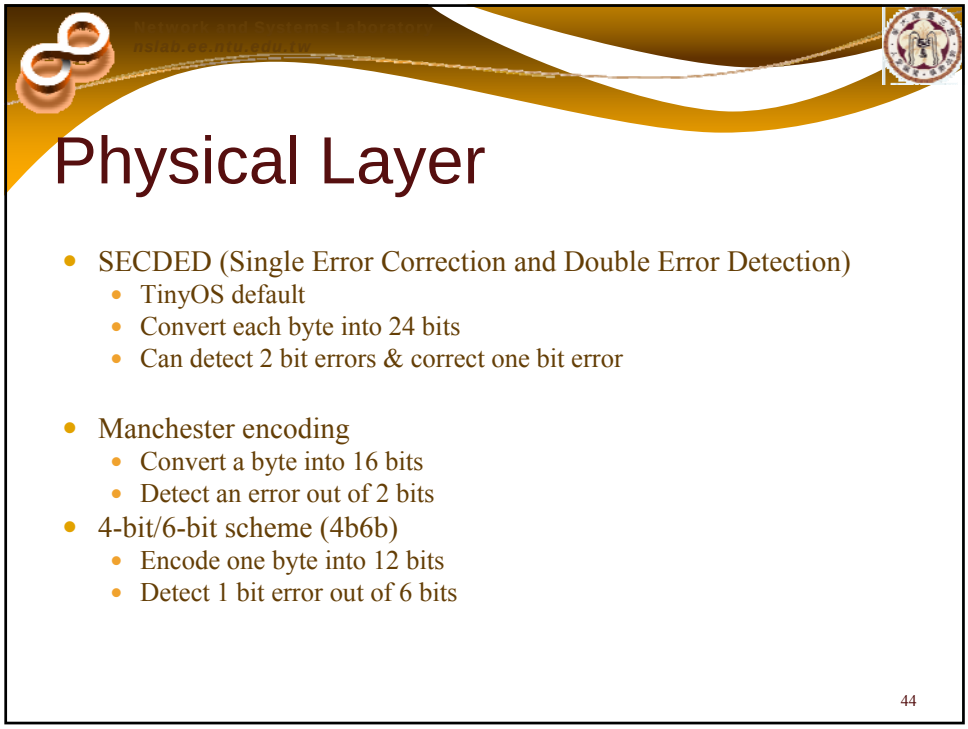
Parking Garage

- *O:* 150m * 150m open parking lot
  - No obstacles
  - Multipath only due to ground reflections
  - Not much to sense



Hardware

- Mica mote
  - 4MHz Atmel processor
  - 433MHz RF Monolithics radio
  - Omni-directional whip antenna
  - 20Kbps nominal throughput
- Networking stack in TinyOS



Physical Layer

- SECDED (Single Error Correction and Double Error Detection)
  - TinyOS default
  - Convert each byte into 24 bits
  - Can detect 2 bit errors & correct one bit error
- Manchester encoding
  - Convert a byte into 16 bits
  - Detect an error out of 2 bits
- 4-bit/6-bit scheme (4b6b)
  - Encode one byte into 12 bits
  - Detect 1 bit error out of 6 bits

MAC Layer

- Simplified CSMA/CA
  - TinyOS default
  - Random back off upon carrier sense
  - Link layer ACK: Send 4 byte ACK to the sender
- Authors added retransmission scheme
  - When there's no ACK, retransmit up to 3 times

Transmit Power

- Three settings are considered
  - High
  - Medium
  - Low

Wireless Link Characteristics

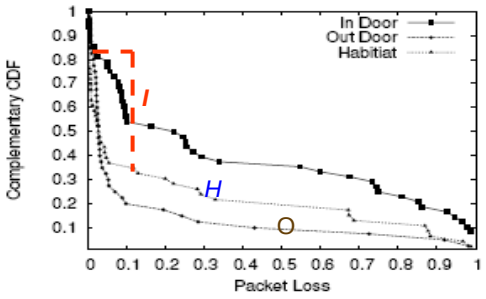
Mesh Network Link

Testbeds

Sensor Network Link

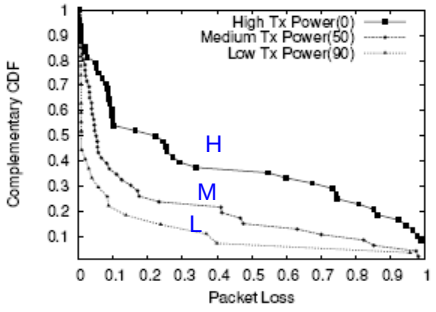
Effect of the Environment

- 4b6b coding
- High Tx power
- Outdoor better
  - No obstacles



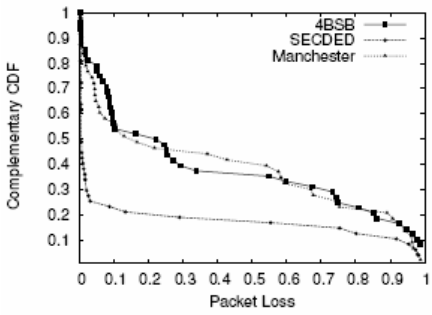
Effect of Tx Power

- Indoor
- 4b6b coding
- Lower power better
  - Reduced communication range
  - Reduced multi-path problem



Effect of Codec

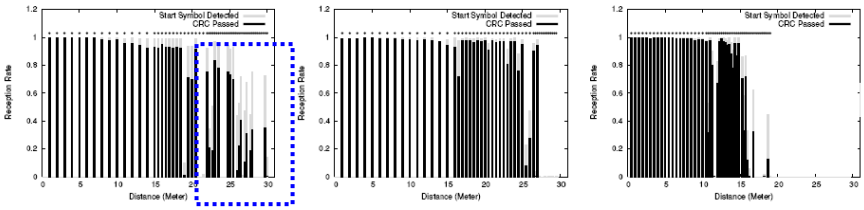
- Indoor
- High Tx Power
- SECDED better
- Not much difference bwtwen 4B6B and Manchester



Spatial Characteristics

- 4B6B
- High Tx Power
- Gray area due to multi-path problems

I O H



Multi-Path Problem

- No frequency diversity
- Motes use a single, narrow frequency band

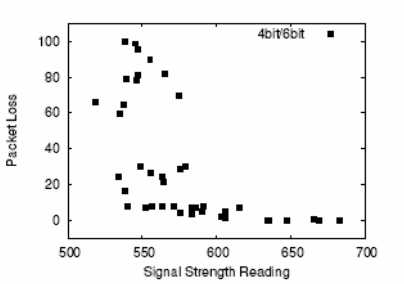
- UWB (Ultra Wide Band) might be better?
  - 3.1 – 10.6 GHz
  - Bandwidth > 500MHz
  - Data rate > 54Mbps
  - Low power

Lessons

- Selecting a shortest path simply based on the geographic distance or hop count is not sufficient!
- Nodes need to carefully select neighbors based on the measured PRR

RSS vs. PRR

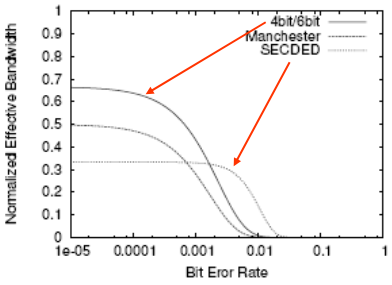
- Can signal strength by itself estimate link quality?
- Unfortunately, NO



High Tx Power, I

Coding Schemes

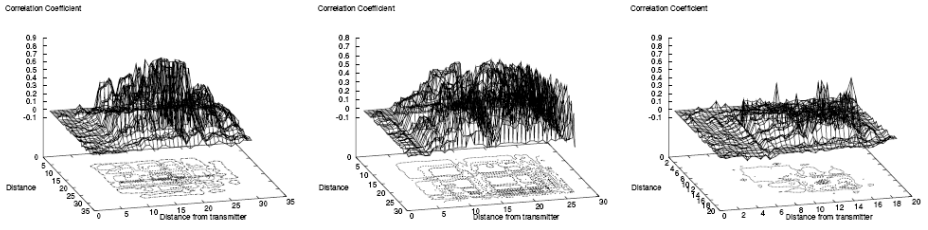
- Can sophisticated physical layer coding schemes mask the gray area?
- Not necessarily, SECDED has the lowest effective bandwidth
- Need to avoid links in the gray area + bandwidth efficient coding scheme



Spatial Correlation

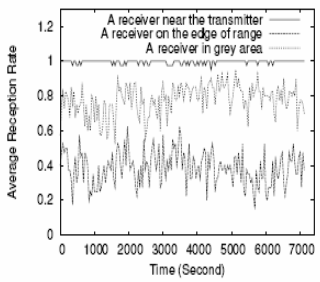
- Are two receivers in their linear topology likely to see similar loss patterns?
- Different correlation characteristics
  - I & O show noticeably higher correlated packet loss than H
- At the physical layer, independent losses are a reasonable assumption

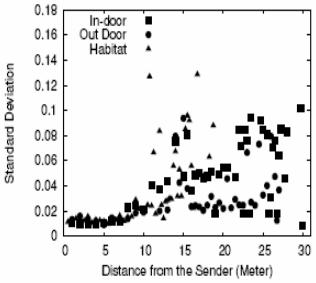
I *O* *H*



Temporal Characteristics

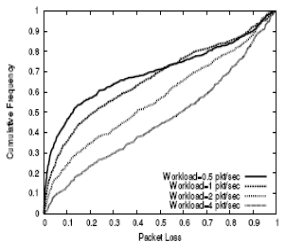
- Large variations
- Big standard deviations



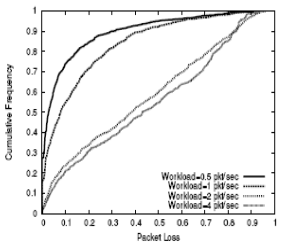


Retransmission Scheme

- Too many packet loss
- 50% - 80% communication energy for retransmissions
- Better MAC is required



I



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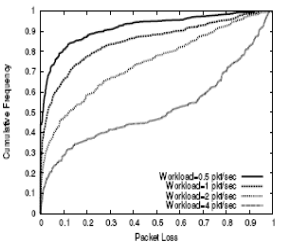
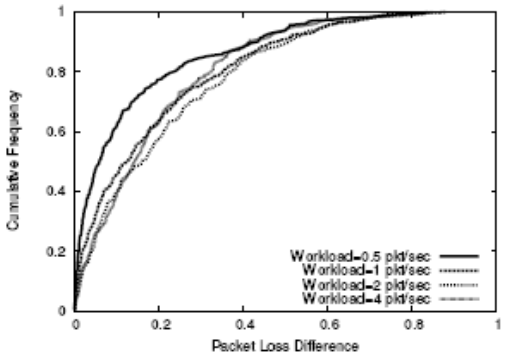


H

Asymmetry

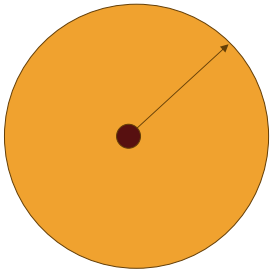
- Asymmetry in wireless communication is well known
- But the extent is not



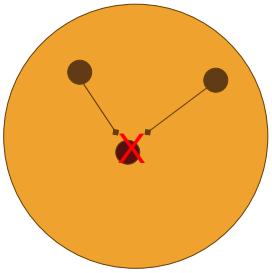
Re-Cap

- PRR ~ Distance
  - Attenuation
- PRR ~ Distance not clearn
  - Multi-path
- Roofnet
  - Intermediate-quality link
  - S/N not a good indicator
- Sensornet
  - Gray link
  - RSS not a good indicator
- But may be a threshold to identify good links?

- Two simplified models form the basis of >95% of the literature on wireless networks:

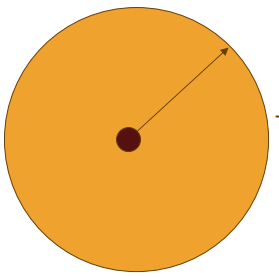


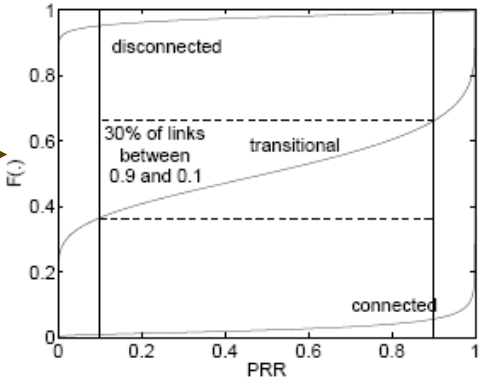
Circular radio range with perfect reception within & zero reception outside



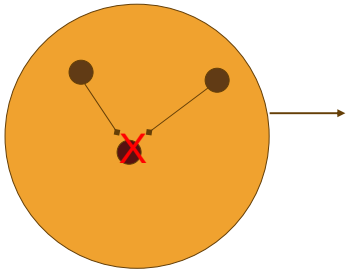
Collision with simultaneous transmissions within range

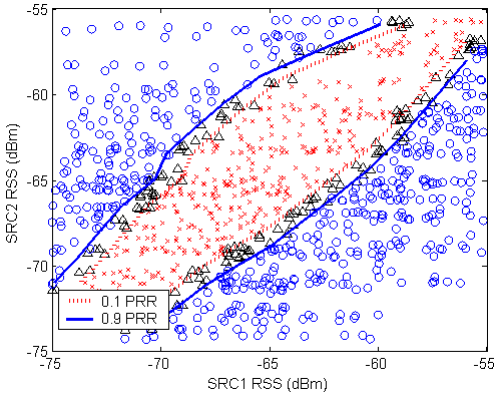
Bimodel PRR



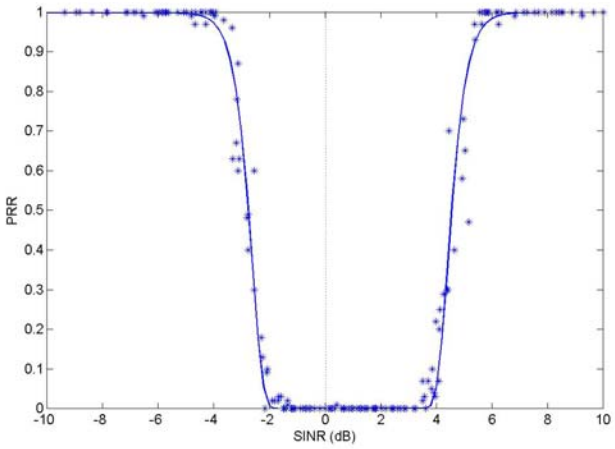


Not Necessarily True





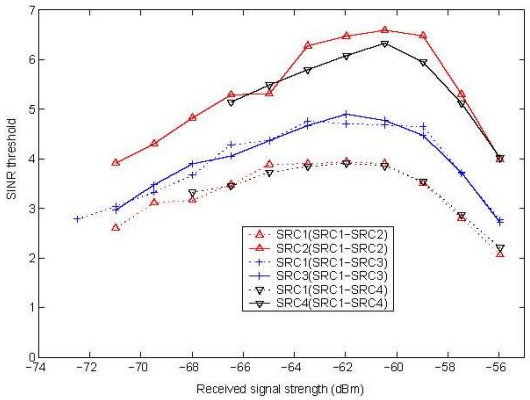
PRR Based on SINR



$$PRR = (1 - 0.5\exp^{-\beta_0 SINR + \beta_1})^{8(2f-l)}$$

SINR Threshold

- Depend on
  - Hardware
  - Tx/Rx



Wireless Simulation

- Open space models
  - PRR ~ Distance/RSS/SNR
  - PRR ~ SINR
- Indoor models
  - ???
  - Alternative
    - Measurement
    - Trace-driven simulations

Questions?