# Towards a Wireless Lexicon

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# Low Power Wireless

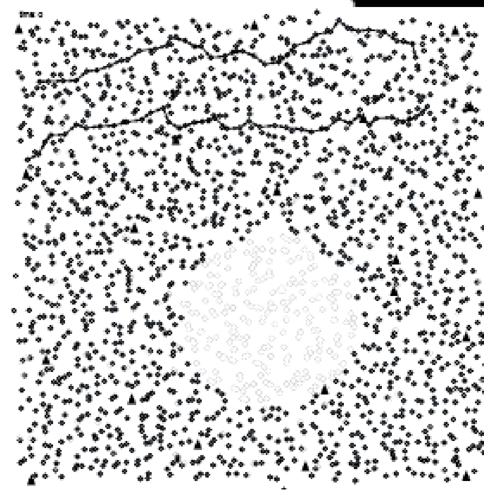
- Low cost, numerous devices
  - Wireless sensornets
  - Personal area networks (PANs)
- Ad-hoc networks
  - No infrastructure
  - Self healing, self-assembling, self-...
- Energy issues -> low bit rate and simple coding
  - 802.15.4: 250kbps, OQPSK, DSSS (32->4)
    - 20mA RX, 8-18mA TX, -31 - 0 dBm
    - <2% of energy goes to RF!

# Wireless Protocol Design

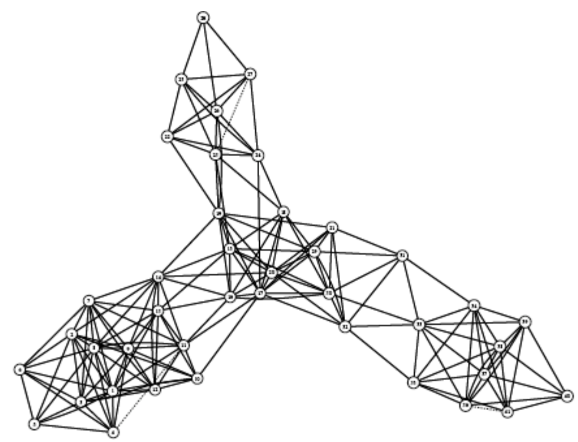
- Huge gulf between theory and practice
- Algorithm research uses simple models
  - Tractable analysis
  - Clear reasoning and evaluation
  - Difficult to apply results to real networks
- Systems research uses testbeds
  - Not reproducible
  - Each testbed is different
  - Difficult to understand why it worked (and when it won't!)

# Describing a Network

- Algorithmic approach:
  - "We simulated a network with 2000 nodes distributed on a perturbed grid. The communication graph used is the unit disk graph on the nodes."



- Systems approach:
  - "We evaluated our implementation on a 40-node indoor testbed. The motes collectively form a connected topology with a diameter of eight hops."



# The Problem

- We do not have a lexicon to describe the complexities of real-world wireless networks.
- We don't even know what's really important!
- Hypothesis: Once we have such a lexicon and can quantify it, then we can define formalisms that better model the real world.

# Outline

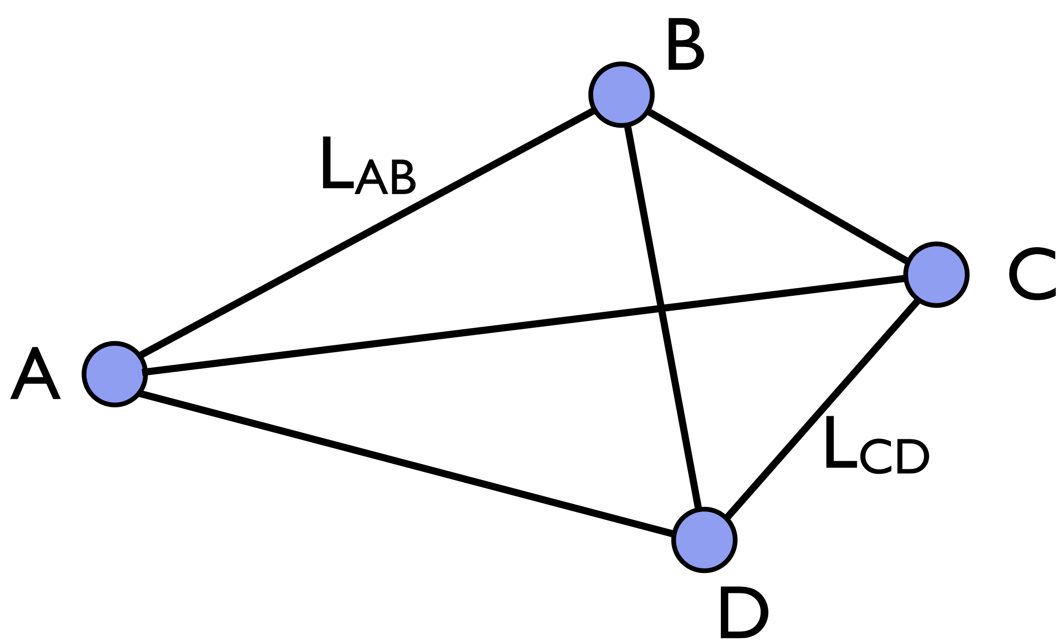
- Describing networks
- Real-world dynamics
- A first step at modeling
- A metric proposal: bimodality percentiles

# Real World Dynamics

- Wireless networks are not graphs
- Collision timing affects reception
- Intermediate links can be unstable
- Time scales affect link distributions
- Packet losses are not independent
- Asymmetric links exist and change over time

# Not a Graph

- A graph assumes link independence
- Transmissions can affect distant nodes
- This is not a binary relationship



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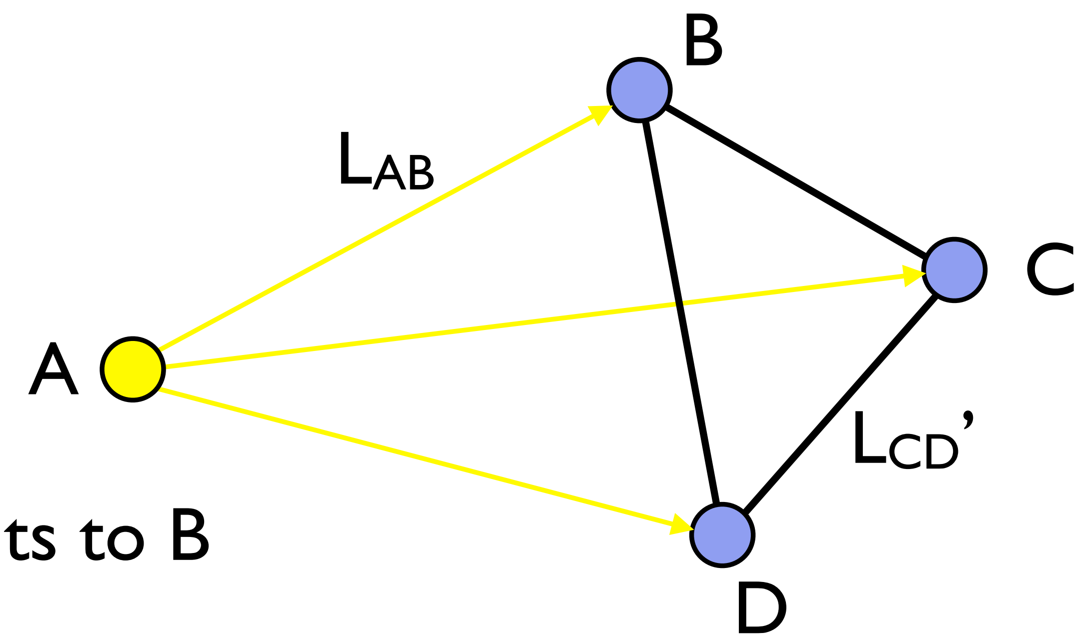


A transmits to B

# Not a Graph

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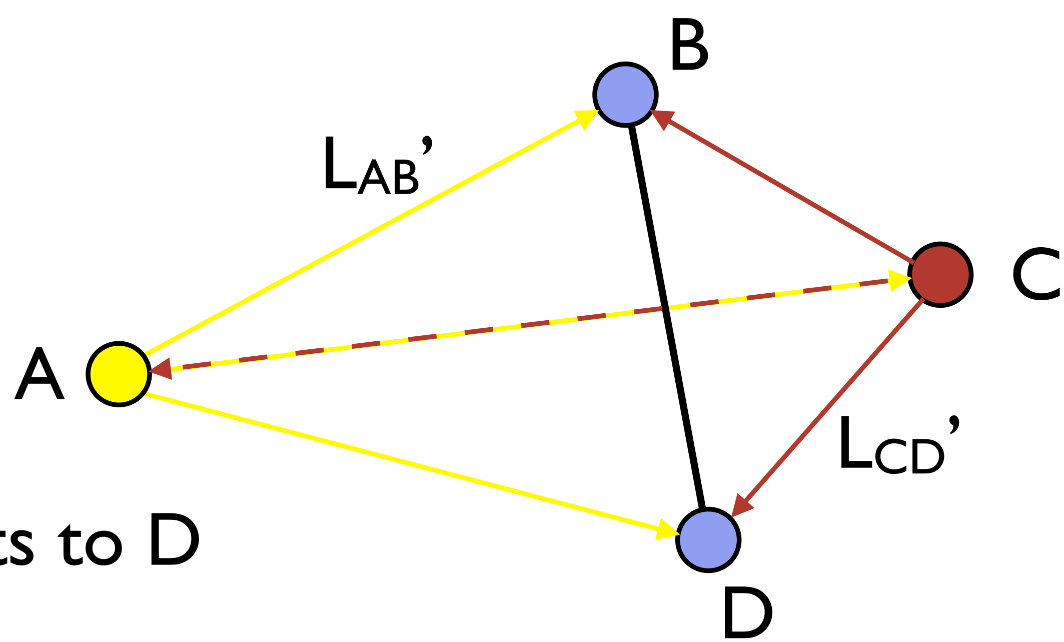
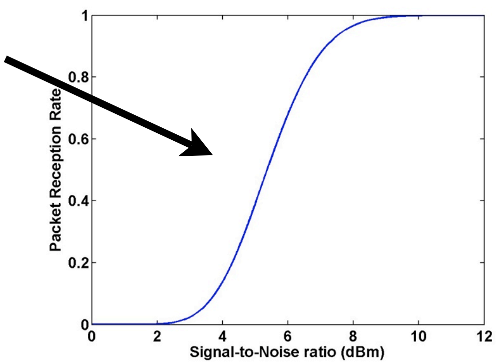
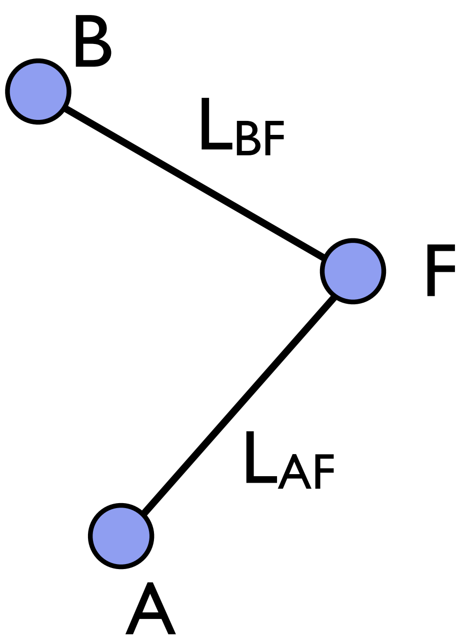


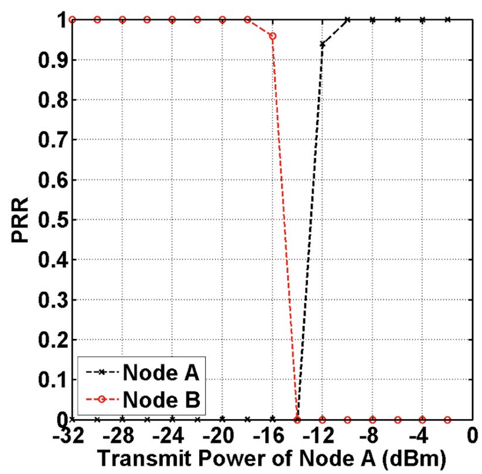

C transmits to D

# Collision Timing Affects Reception

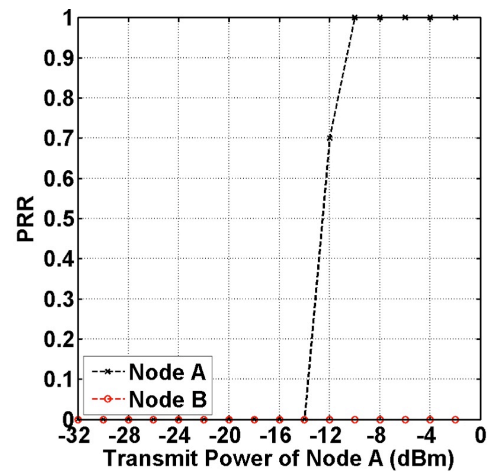
- Signal-to-noise ratio determines bit error rate
- If $L_{BF} >> L_{AF}$, then F can receive B's signal well
- But *when* transmissions occur matters
  - No B receptions if A is 720us earlier



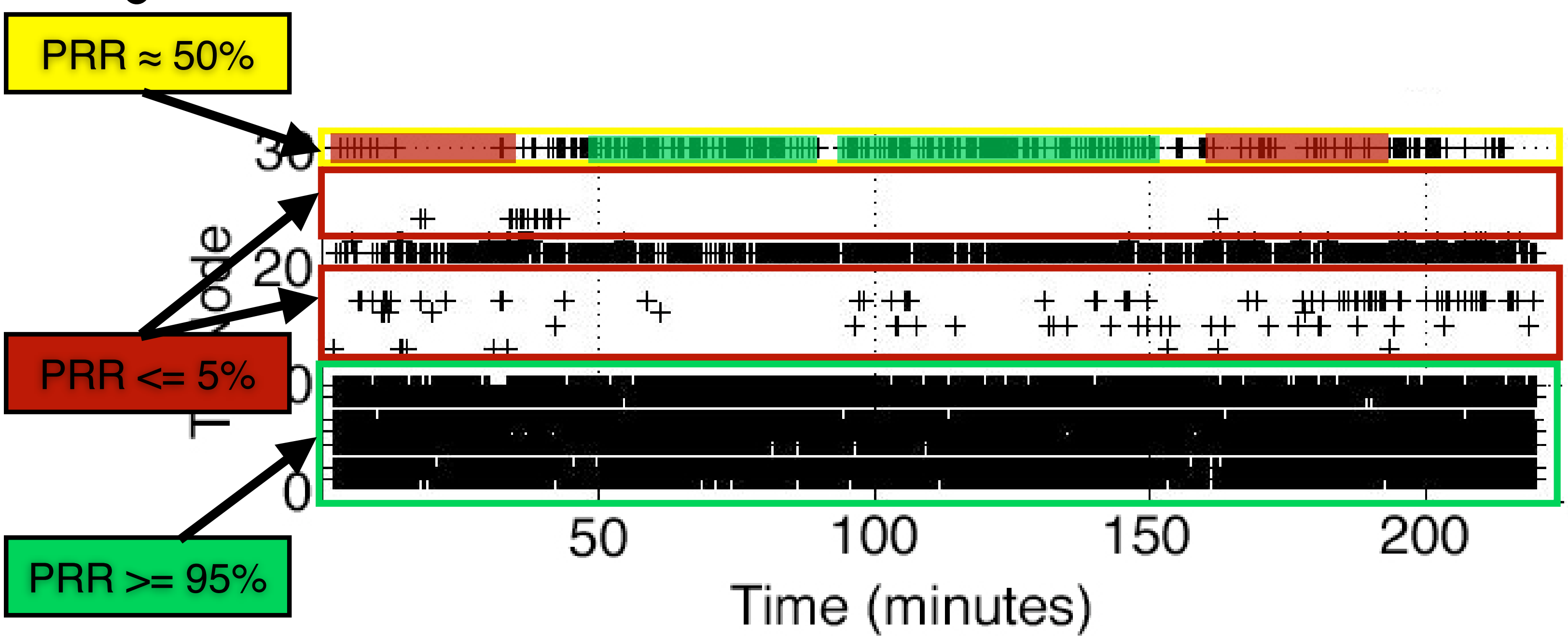

Synchronized Transmits



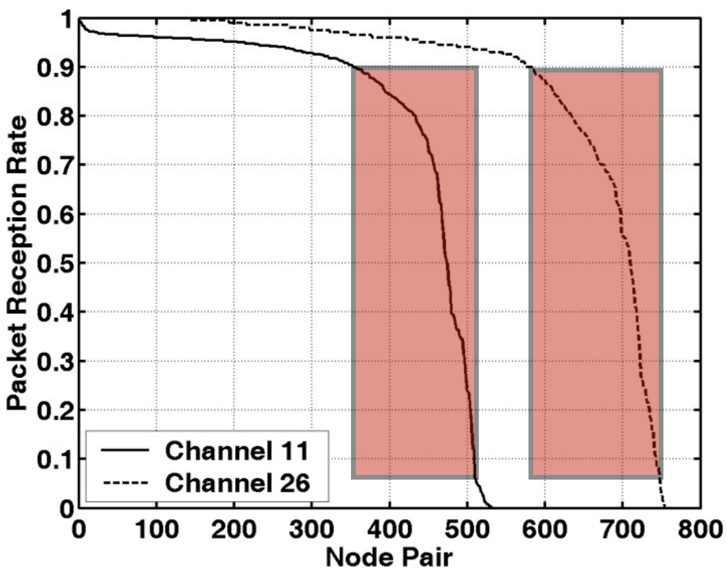

A Transmits 720us Earlier

# Intermediate Links Are Unstable

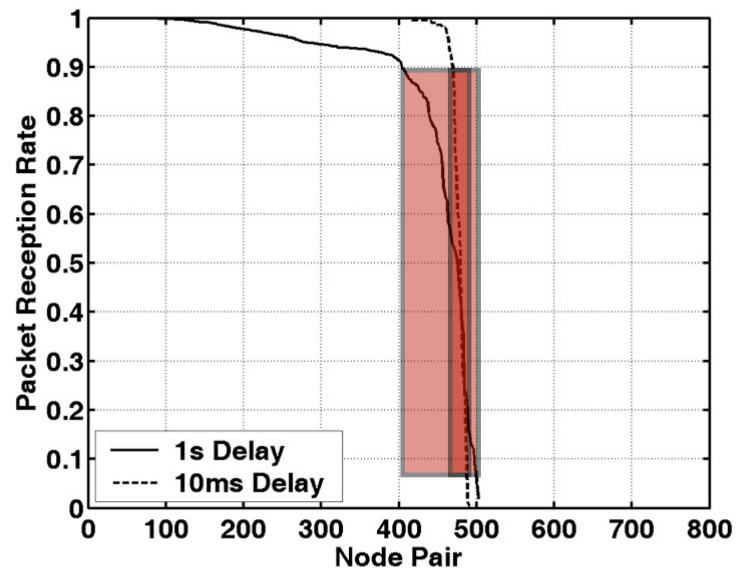
- So why not a weighted graph of link qualities?
- What does an intermediate link look like?
- A perfect MAC layer will not solve the problem
-



# Time Scales Affect Link Distributions

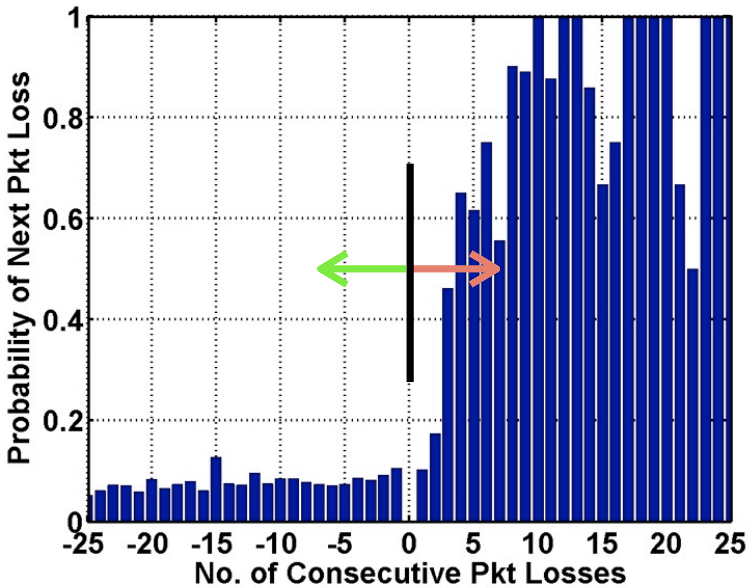



14 seconds

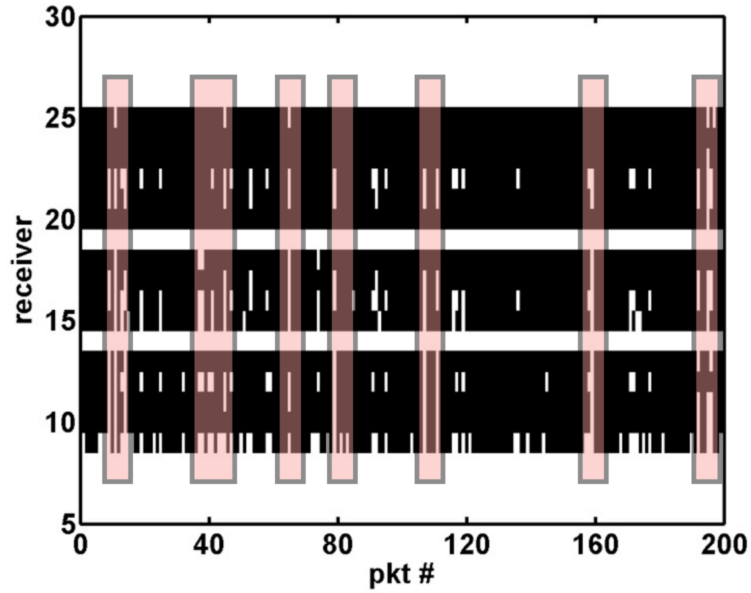



Channel 26

# Losses Are Not Independent

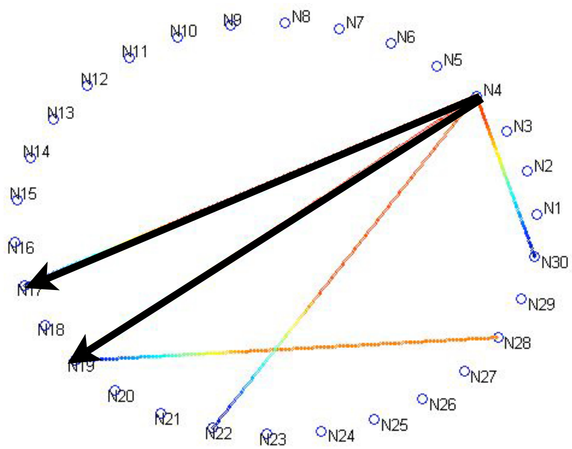



Time

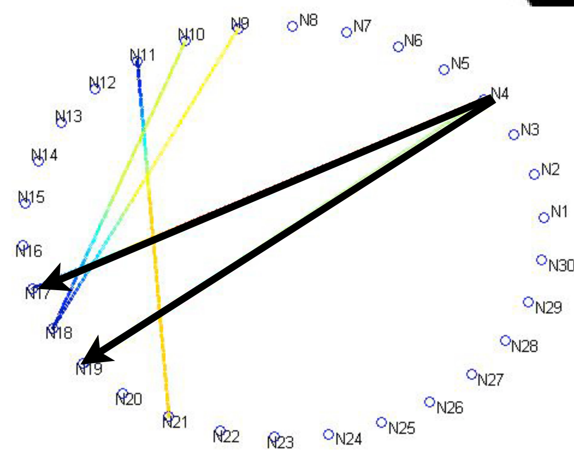



Space

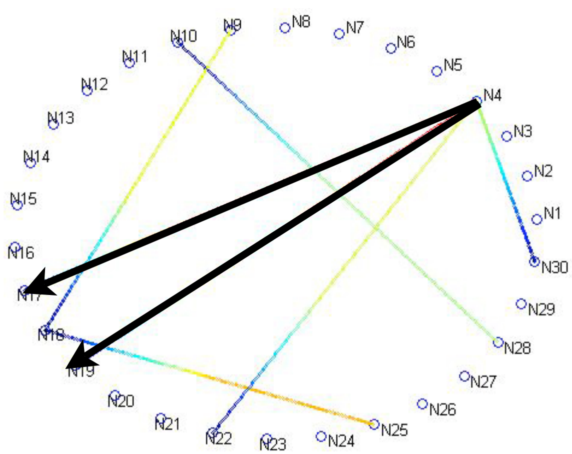
# Asymmetry Over Time

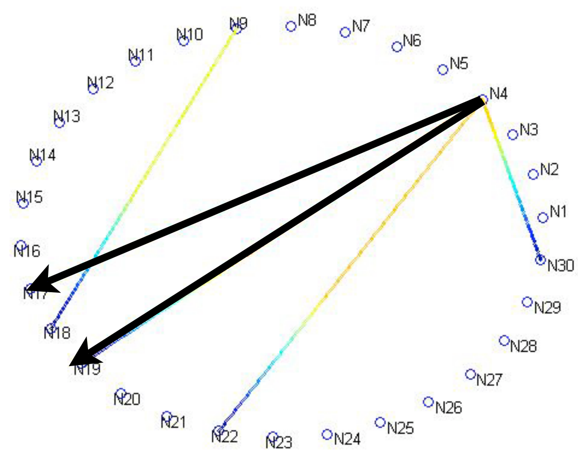



Hour 1




Hour 2



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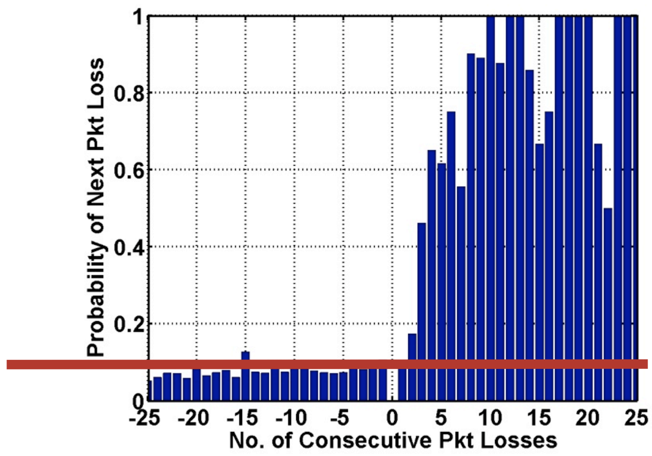
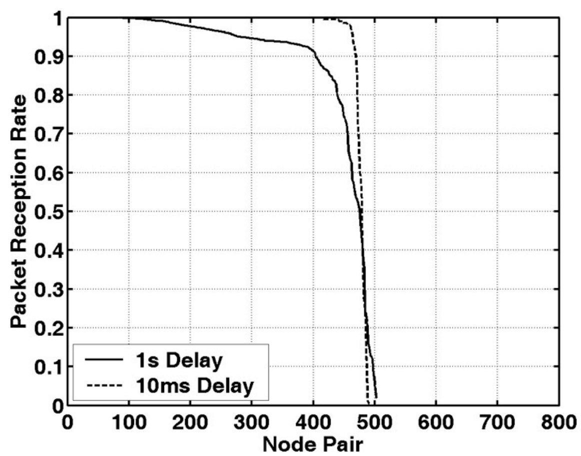
# A First Step at Modeling

- Start by modeling underlying physical phenomena
- Simplify to distill simpler models
- Scientific approach
  - Measure real networks
  - Try to recreate representative environments in simulation
  - Enables model <u>validation</u>
- Example: temporal correlation in 802.15.4

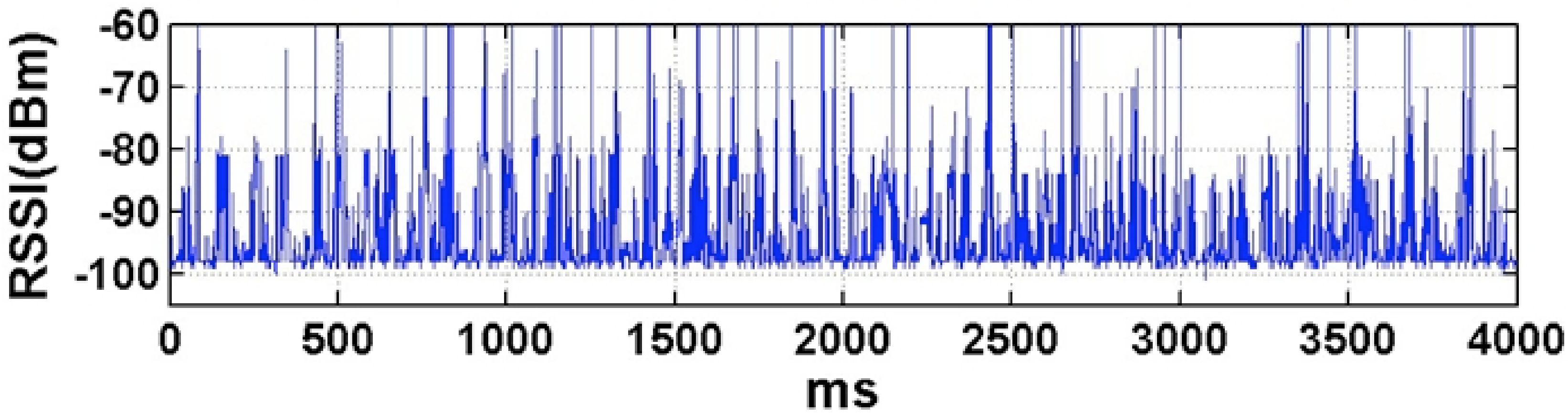
# Temporal Correlation

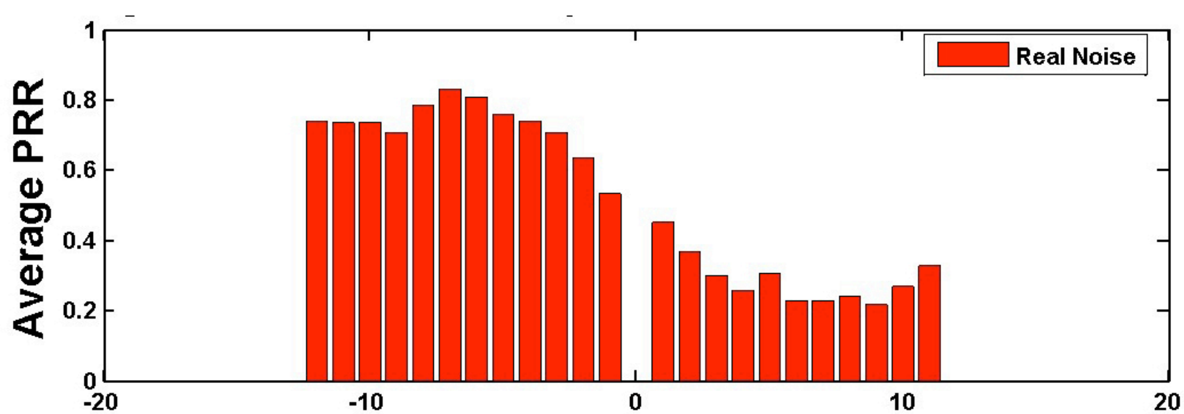
- Loss rate is <u>not</u> $L^k$
- Over 100 packets in 1s, <10% of links are intermediate
- Connectivity changes quickly
- Two causes: signal and noise
  - Signal: long term trends
  - Noise: short term bursts



# Short Term Bursts (  )



# First Step: CPM

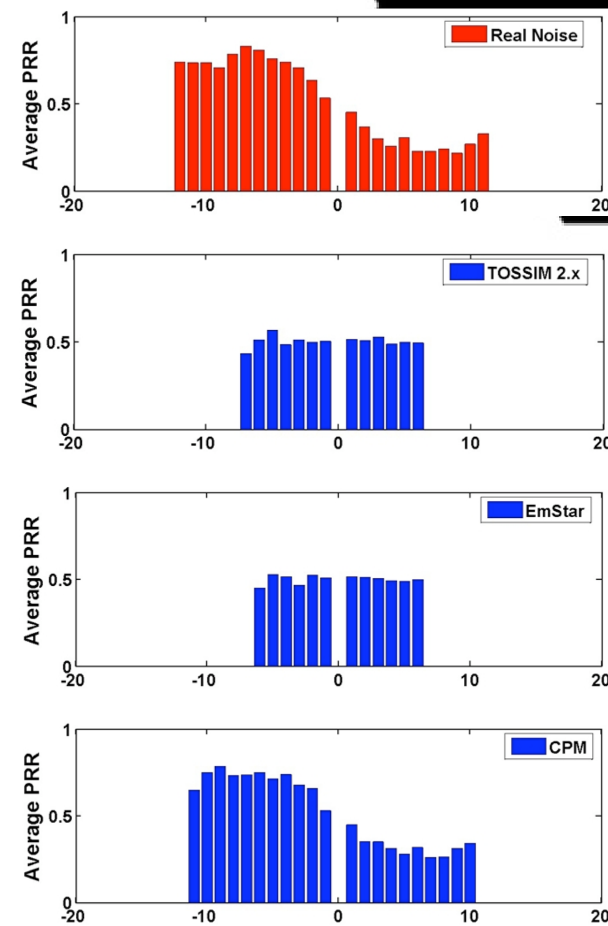
- If we can simulate it, we can model it
  - Refine and simplify simulation
- CPM: Closest Pattern Matching
  - Generate conditional probability distributions from a trace
  - “Given prior noise readings $n_{t-1}$, $n_{t-2}$, $n_{t-3}$, ... what is $n_t$?”

Real Noise

EmStar

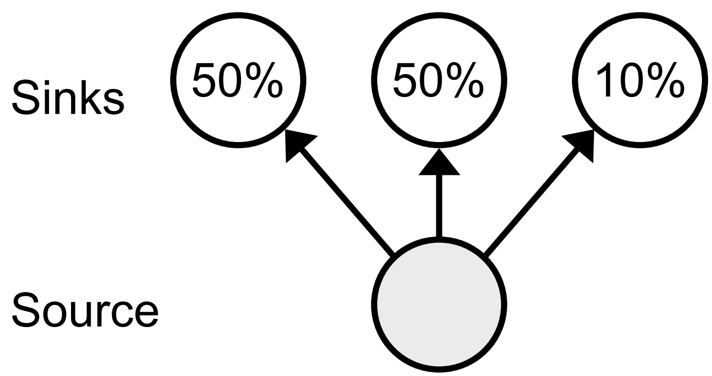
ns2

CPM



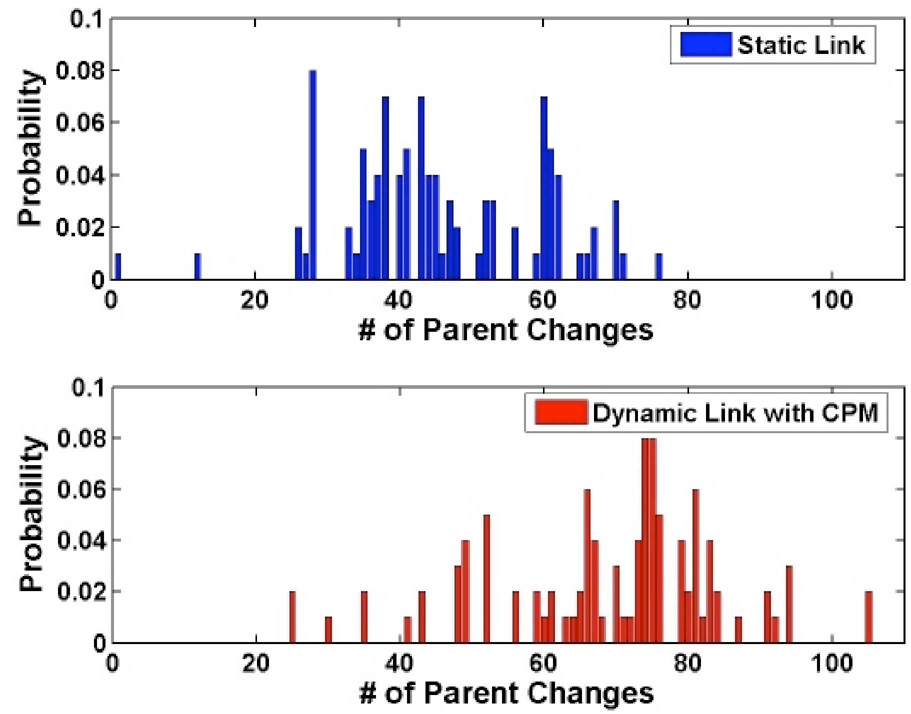
# Protocol Effects

- Link estimator in TinyOS 2.0 collection tree protocol uses acknowledgments to measure ETX
- Bursts of losses can cause rapid link value changes
- Measure how many times protocol switches parents
- Using CPM doubles changes over other methods



# Protocol Effects

- Source sends 100,000 packets as quickly as possible
- Run 100 trials, compare with independent packet loss
- Average parent change count doubles



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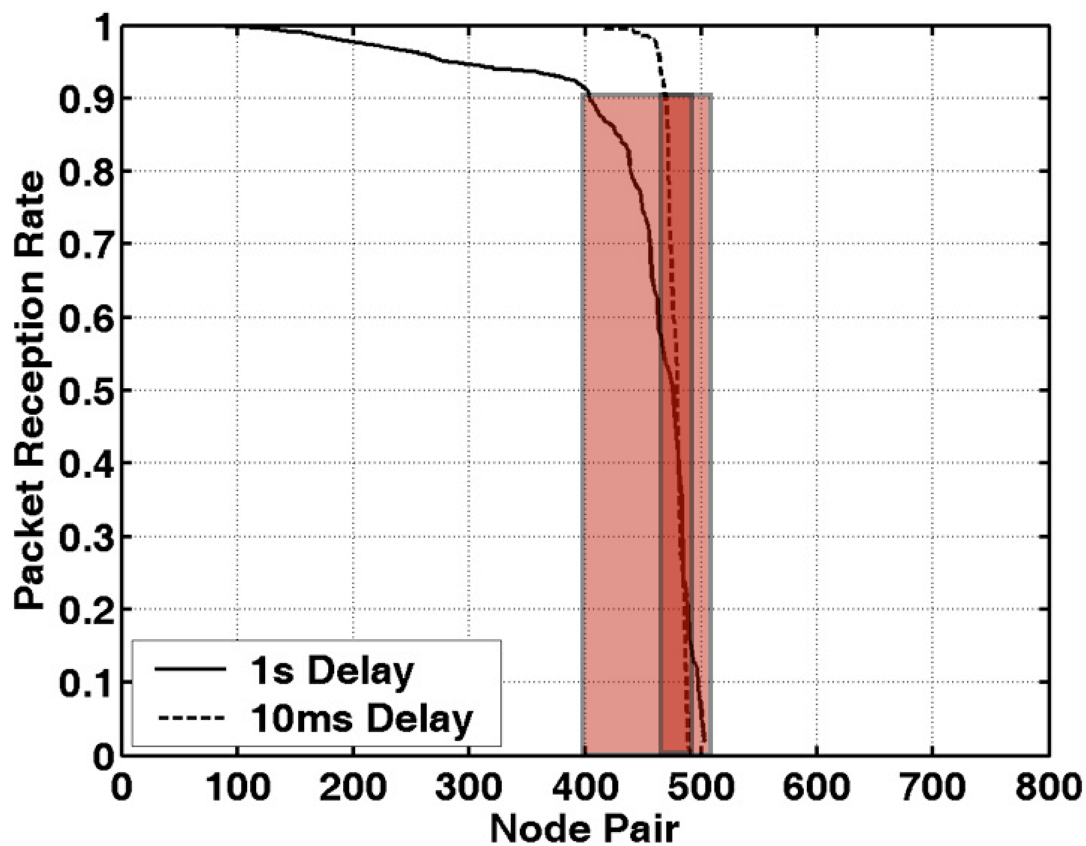
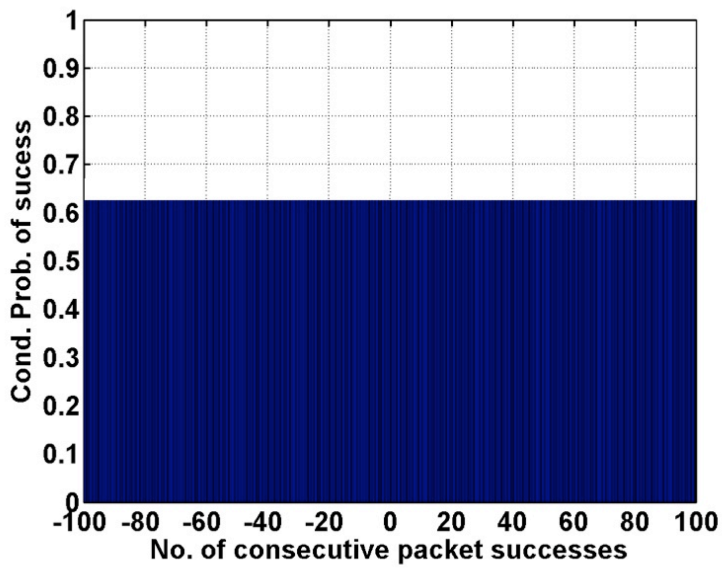
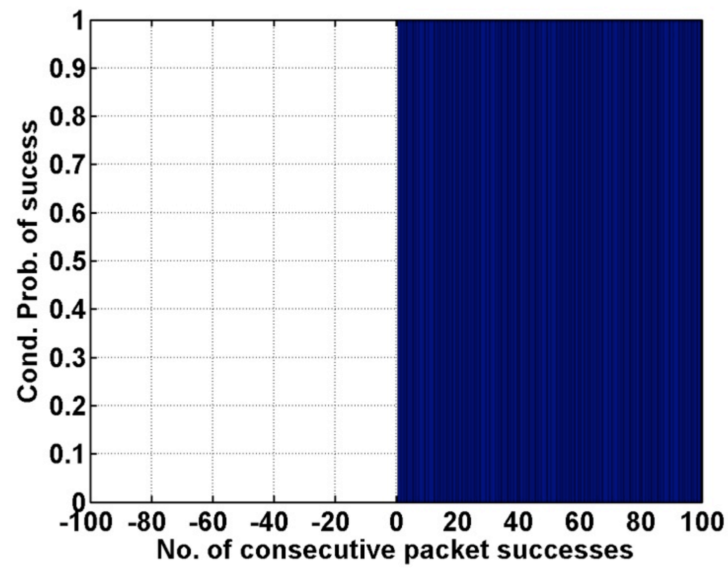
# Link Bimodality



# Independent or Bimodal?




Independent



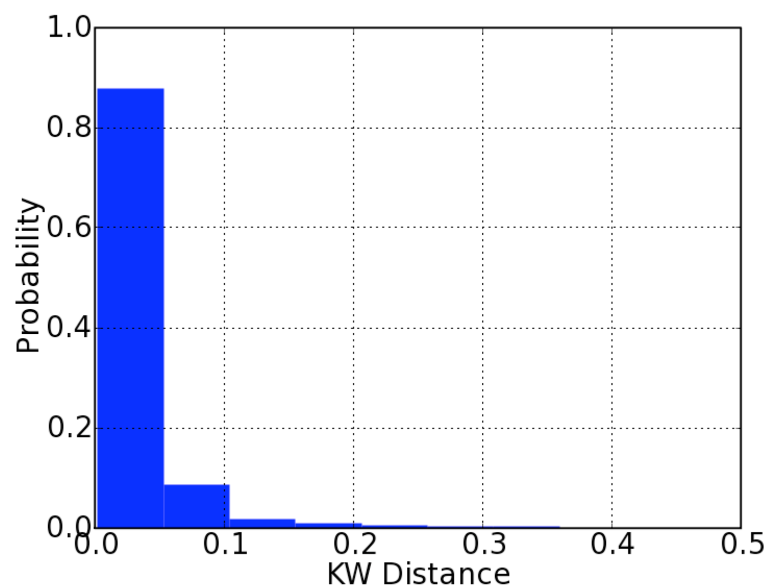

Bimodal

(note the X-axis is inverted from prior plots)

# Bimodality Measure

- Bimodality measure $\beta = \frac{L}{I}$
  - *L* is KW distance of CPDF from bimodal link
  - *I* is KW distance of intermediate PRR link from bimodal
  - $\beta$ is typically in range of [0,1]

IPI = 10ms



# Bimodality Percentiles

- Hypothesis: $\beta$ percentiles represent an important property of a network
  - E.g., 10th percentile of 0.01, 90th percentile of 0.4
- Test: compute $\beta$ distributions for other link layers
  - Verifies this experimental methodology with prior results
- Test: control $\beta$ in simulation and observe protocol effects
  - Link estimators: ETX vs. other approaches

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# Towards a Lexicon

- Measure networks to find important properties
- Protocol-driven evaluation
  - Network properties are important to quantify and describe if they affect protocol behavior
  - CPM leads to more next hop changes in routing protocols
- Quantify the properties:
  - "We used a 40-node indoor testbed that has an $\alpha$ of 0.8, a $\beta$ of 0.01/0.4, a $\gamma$ 3.3 and a $\delta$ of 500ms."
  - "We simulated a 40-node network that has an $\alpha$ of 0.8, a $\beta$ of 0.01/0.4, a $\gamma$ 3.3 and a $\delta$ of 500ms."

# Questions