Towards a Wireless Lexicon

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Low Power Wireless

- Low cost, numerous devices
  - Wireless sensor networks
  - 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

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

C transmits to D
Collision Timing Affects Reception

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

PRR $\approx 50\%$

PRR $\leq 5\%$

PRR $\geq 95\%$
Time Scales Affect Link Distributions

14 seconds

Channel 26
Losses Are Not Independent
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 validation
- Example: temporal correlation in 802.15.4
Temporal Correlation

- Loss rate is not $L^k$
- 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 ( )

![Graph showing RSSI (dBm) over time with vertical bars representing average PRR.](image)
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 $n_{t-1}, n_{t-2}, n_{t-3}, \ldots$ 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
- Burst of losses can cause rapid link value changes
- Measure how many times protocol switches parents
- Using CPM doubles changes over other methods

![Diagram showing source and sinks with 50% and 10% values]
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

![Graph showing packet reception rate vs node pair with two delay lines: 1s Delay and 10ms Delay. The graph highlights a bimodal distribution with a peak around node pair 400-500.]
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 $[0, 1]$

$IPI = 10\text{ms}$
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.”