An Empirical Classification of Wireless Network Behavior

Charlie Reis
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Understanding Wireless

• How will my network behave?
  • What assumptions hold in practice?
  • How to predict delivery, throughput?
  • How to build a realistic, usable model?
A Wired Mentality

- Undirected graph of connectivity
- Easy to reason about (e.g. routing)
Relevant for Wireless?

- Distance model widely used
- Not realistic, and already tricky
Closer to Reality

- Not a clean graph
- Irregular RF world
- Not binary or symmetric
- Routing in this context?
Unsatisfactory Explanations

- Usable simulators inaccurate
- RF models impossible to parametrize

- How will a real network behave?
Our Goal

- A better, *practical* understanding
  - Seek a *simple, usable, realistic* model
  - Guided by measurements
Contributions

- **Testbed software infrastructure**
  - Deploy experiments
  - Analyze and graph results

- **Test hypotheses**

- **Evaluate a measurement-based model**
SNIR as a Model

- **Signal to noise + interference ratio (SNIR)**
- Classical theory for reception

\[
\frac{\text{signal}}{\text{noise} + \text{interference}} > \text{threshold}
\]
But... we only have RSSI!

- **Only signal strength is reported by card**
  
  *(RSSI: received signal strength indicator)*

- Not the same "signal strength" as in SNIR

- **Can we use RSSI as a proxy for SNIR?**

- Want to predict multiple sender behavior
1. Basic packet reception
2. Variability
3. Asymmetry
4. Loss Burstiness / Independence
RSSI and Packet Reception

- Start in a controlled setting
  - Wires and Attenuators
  - Isolate as much as possible
RSSI works in isolation

- Signal strength predicts delivery
- Low variability

Delivery Probability vs RSSI across Attenuations
Testbed Experiments

- 802.11 ad hoc
- Avoid acks, etc
- Less repeatable
- Dept network
- Changing world
RSSI and Delivery in Reality

- Multiple thresholds
- Receivers don't match
- Not as sharp
RSSI Variation

- Short term variation
- Stable for long term
- Visible "shadowing"

RSSI Over Time
Competing Senders
Signal Interference

- **Competing Senders**
  - Receiver locks onto stronger signal
  - RSSI not predictive

\[ A \rightarrow C \]
\[ B \rightarrow C \]
Other RF Energy

Microwaves show same effect

Microwave
Variability in reality from:

- Receivers with different thresholds
- Impact from shadowing and interference
- High variability at small time scales

Yet, surprisingly consistent over time
Asymmetric Links

- Many links are asymmetric
  - Poorly understood in general

- Card or Environment?
## Asymmetric Links

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<tr>
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<th>Office</th>
<th>CSE 342</th>
<th>CSE 310</th>
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</thead>
<tbody>
<tr>
<td><strong>Original Machines</strong></td>
<td><img src="#" alt="Graph A" /></td>
<td><img src="#" alt="Graph B" /></td>
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- **Graph A**: Delivery Probability vs. RSSI for Node 10 -> Node 13
- **Graph B**: Delivery Probability vs. RSSI for Node 13 -> Node 10
What Causes Asymmetry?

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**Diagram A**
- **X-axis**: Average RSSI
- **Y-axis**: Delivery Probability

**Diagram B**
- **X-axis**: Average RSSI
- **Y-axis**: Delivery Probability
What Causes Asymmetry?

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<td><img src="image4.png" alt="Graph A" /></td>
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Implications for RSSI

- Local environments differ greatly
  
  Observed RSSIs are unique to receiver
Modeling Delivery

\[ A|B \rightarrow C = Rx_C (A_{rssi} - B_{rssi}) \]

Look up predicted SNIR for delivery probability
Extending to Throughput

- How many packets will be sent?

- Defer if channel not clear (independent events)

\[
\text{throughput} \approx \text{transmitRate} \times \text{deliveryProbability}
\]
Accuracy of Assumptions

- Predict competing sender delivery probabilities
- 86% prob. accuracy (70% for naive model)
- 78% for throughput (70% for naive model)
Applications

- **Improve routing protocols?**
  - Switch routes quickly, but go back

- **Similar work:**
  - Divert, ExOR
A Wired View, Revisited
New View of Wireless
Conclusions

- **Wireless needs different assumptions**
  - Physical environment matters
  - Capture it in a usable model via RSSI

- **Learn and improve wireless systems**
  - Implications for protocol / routing design