# An Empirical Classification of Wireless Network Behavior

Charlie Reis

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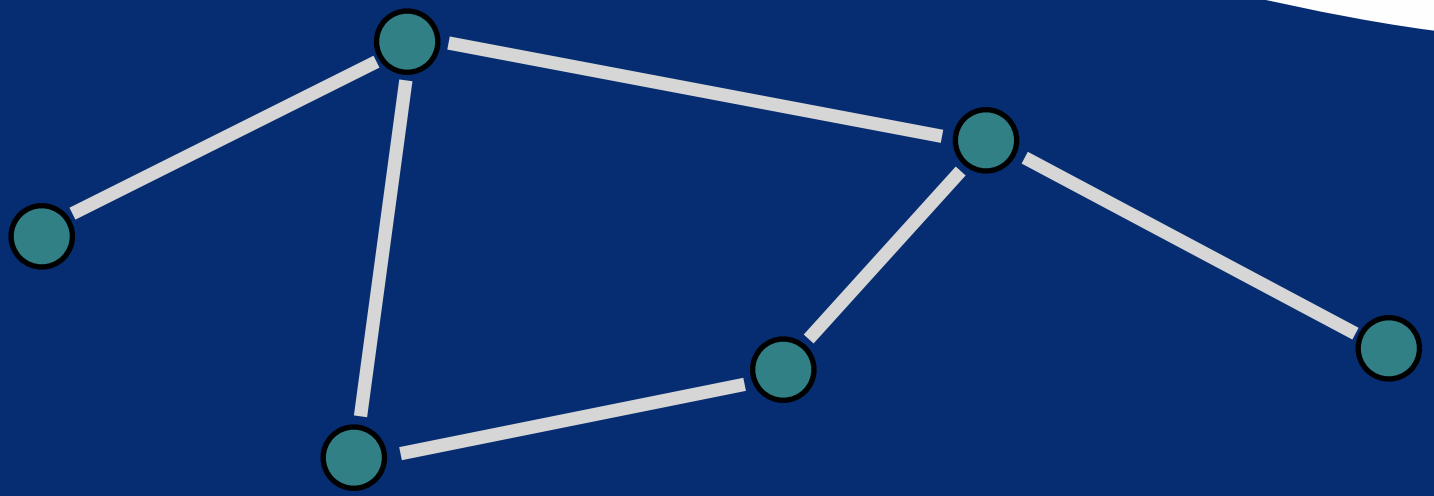
# Understanding Wireless

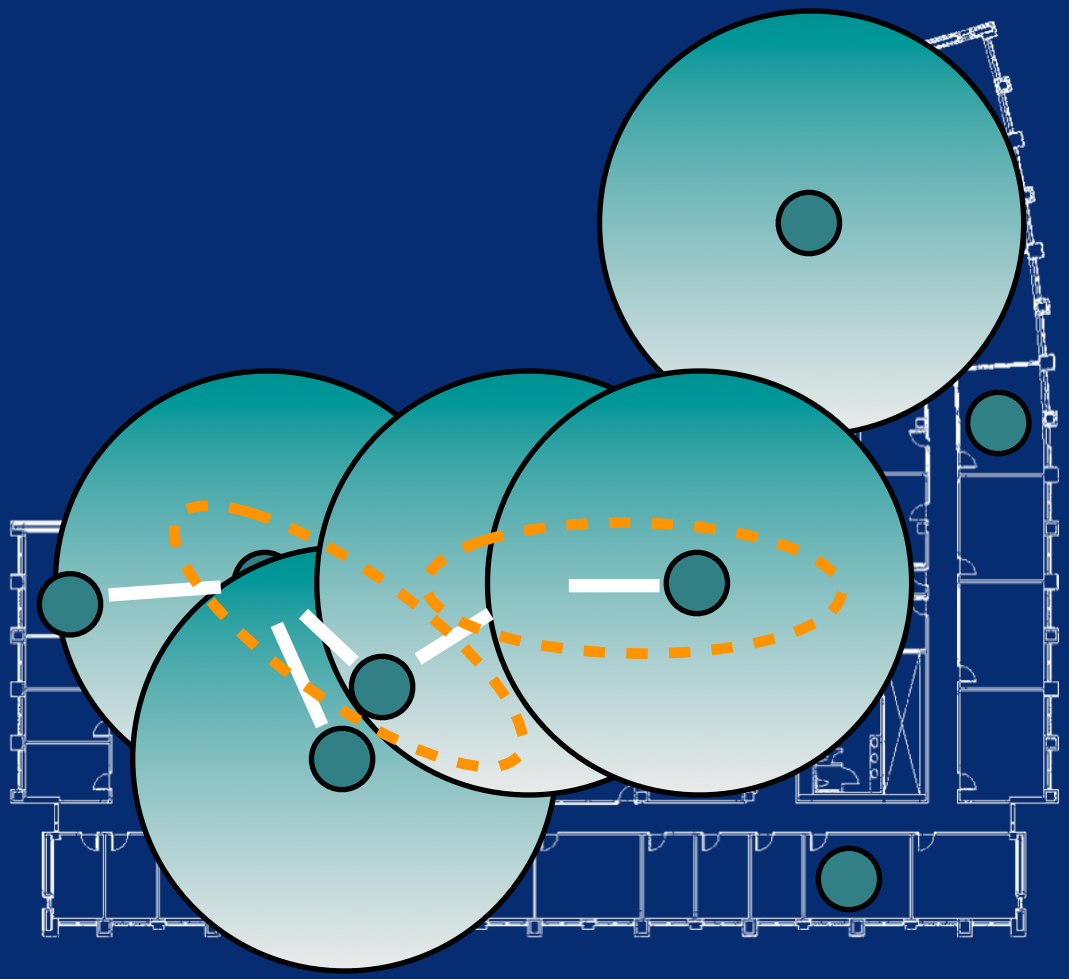
- **How will my network behave?**
  - What assumptions hold in practice?
  - How to predict delivery, throughput?
  - How to build a realistic, usable model?

# A Wired Mentality



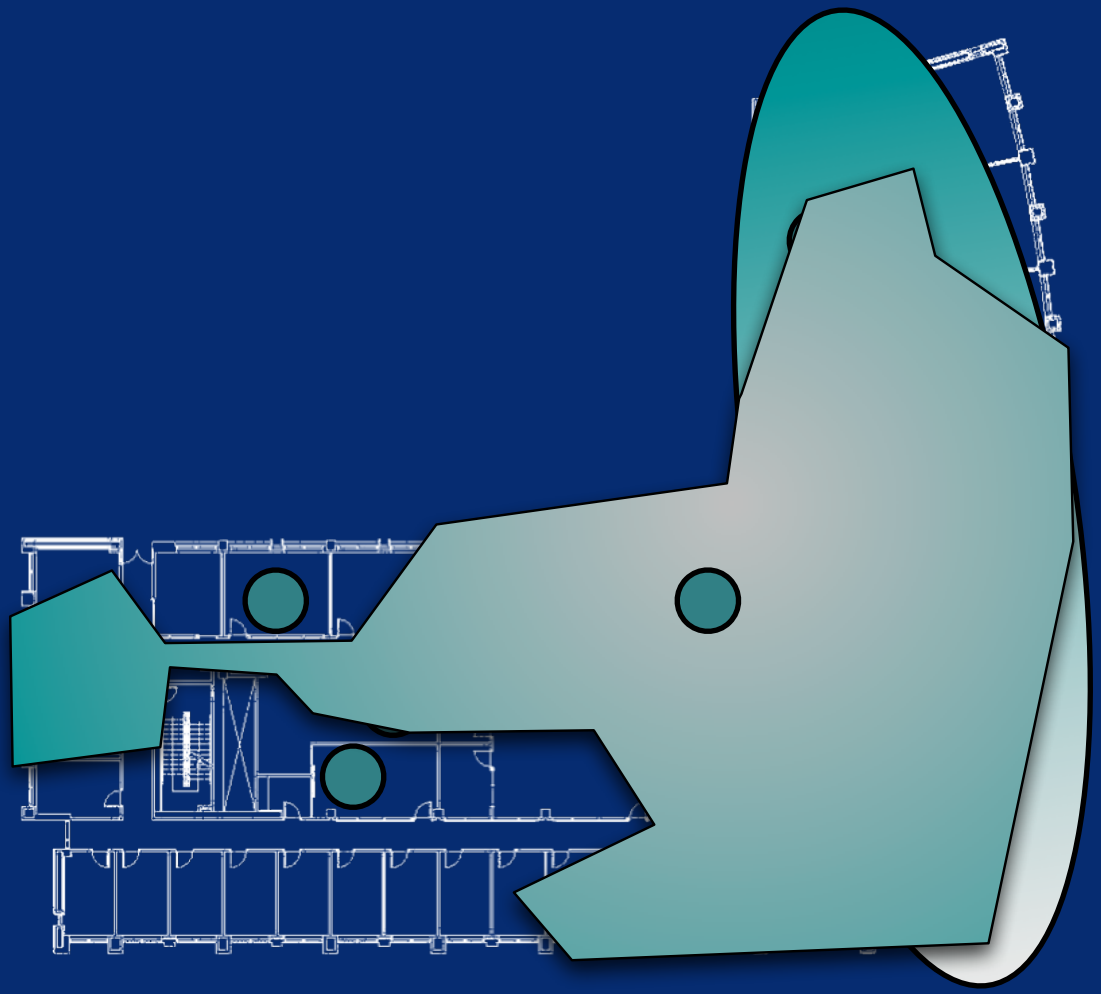
- **Undirected graph of connectivity**
- **Easy to reason about (eg. routing)**

# 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

$$\frac{signal}{noise + \cancel{interference}} > threshold$$

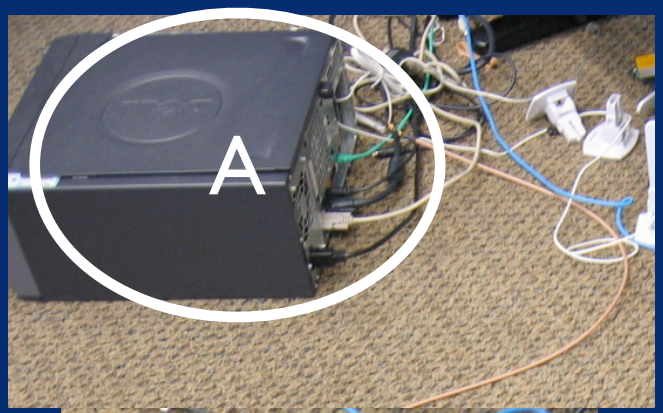
# But... we only have RSSI!

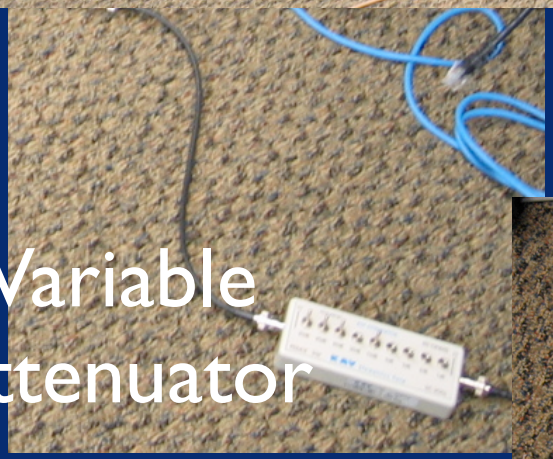
- **Only signal strength is reported by card**
  *(RSSI: received signal strength indicator)*
  - Not the same "signal strength" as in SNIR
- **Can we use RSSI as a proxy for SNIR?**
  - Want to predict multiple sender behavior

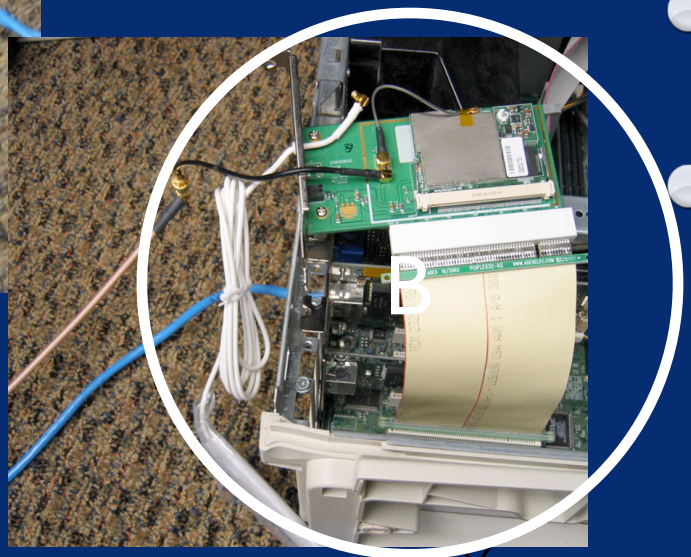
# Investigate RSSI

1. **Basic packet reception**
2. **Variability**
3. **Asymmetry**
4. **Loss Burstiness / Independence**

# RSSI and Packet Reception

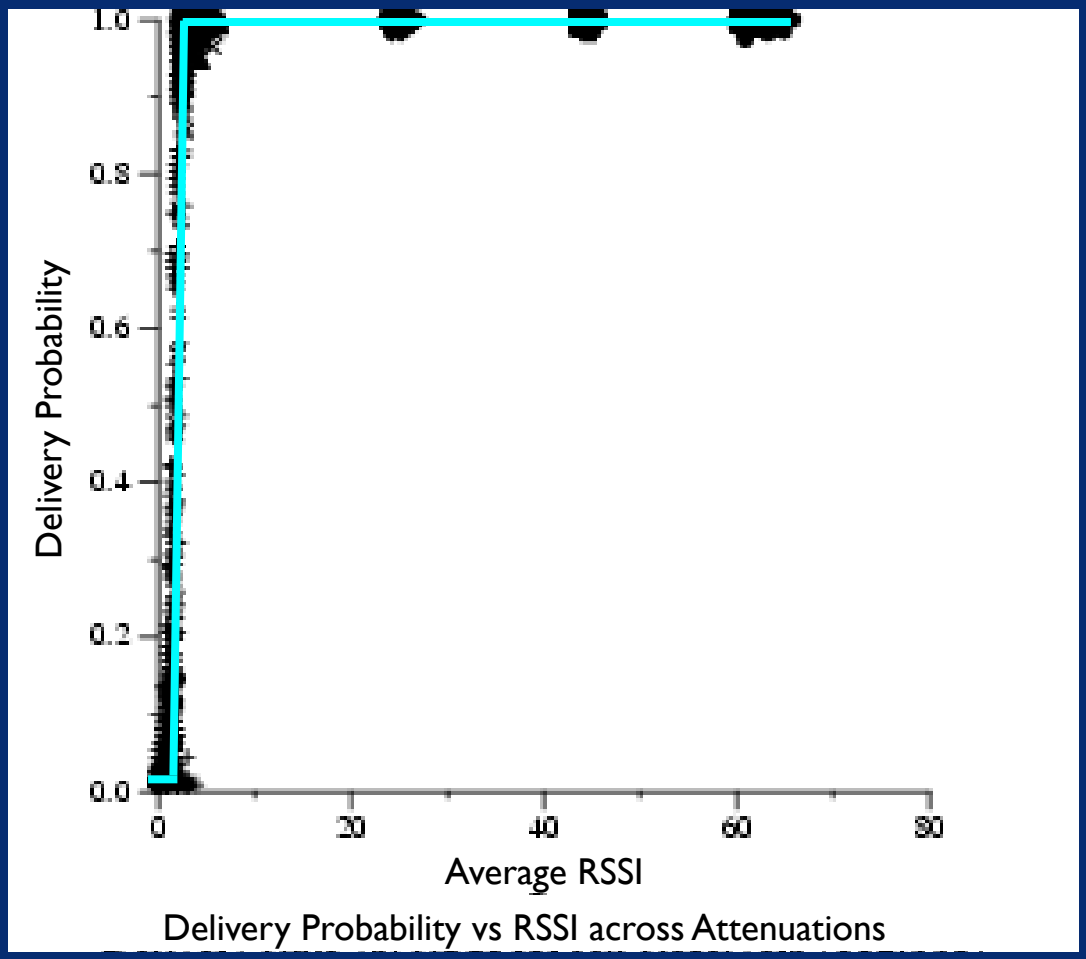



- **Start in a controlled setting**
  - Wires and Attenuators
  - Isolate as much as possible

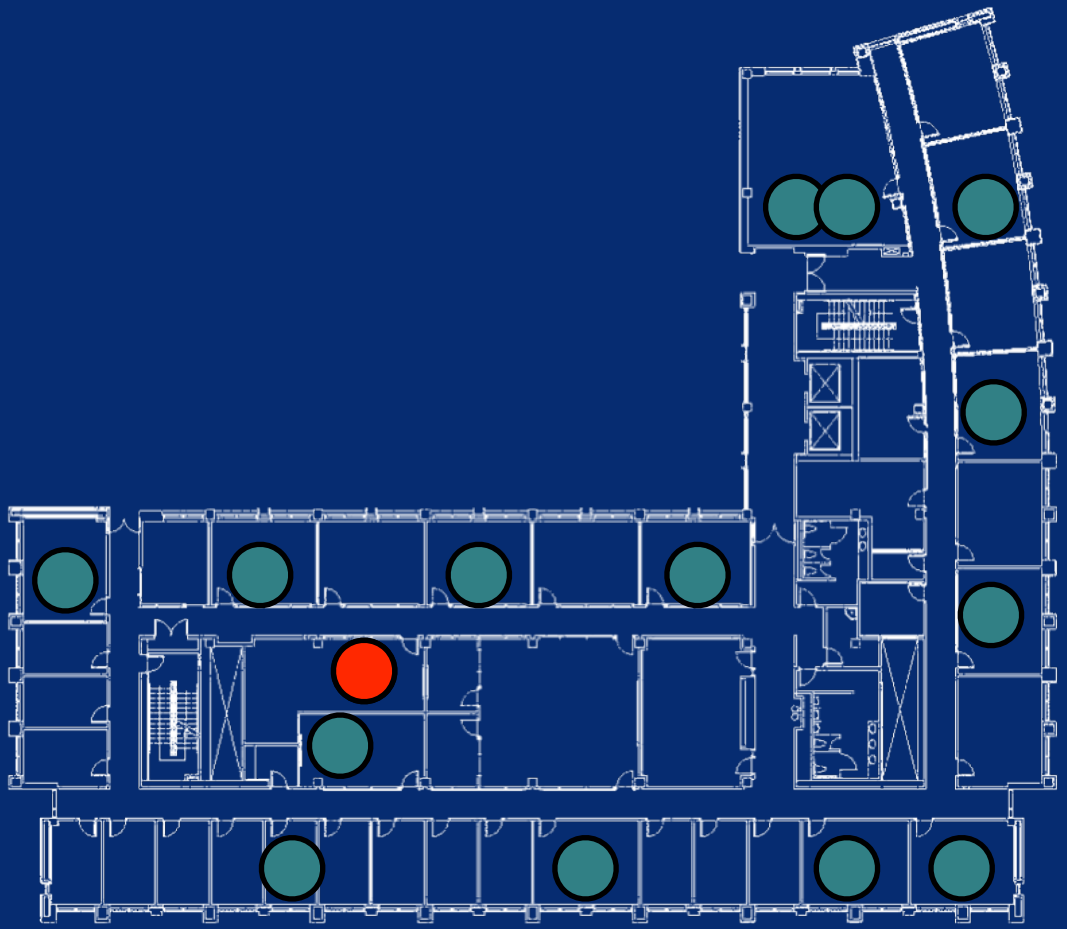
# RSSI works in isolation



Delivery Probability vs RSSI across Attenuations

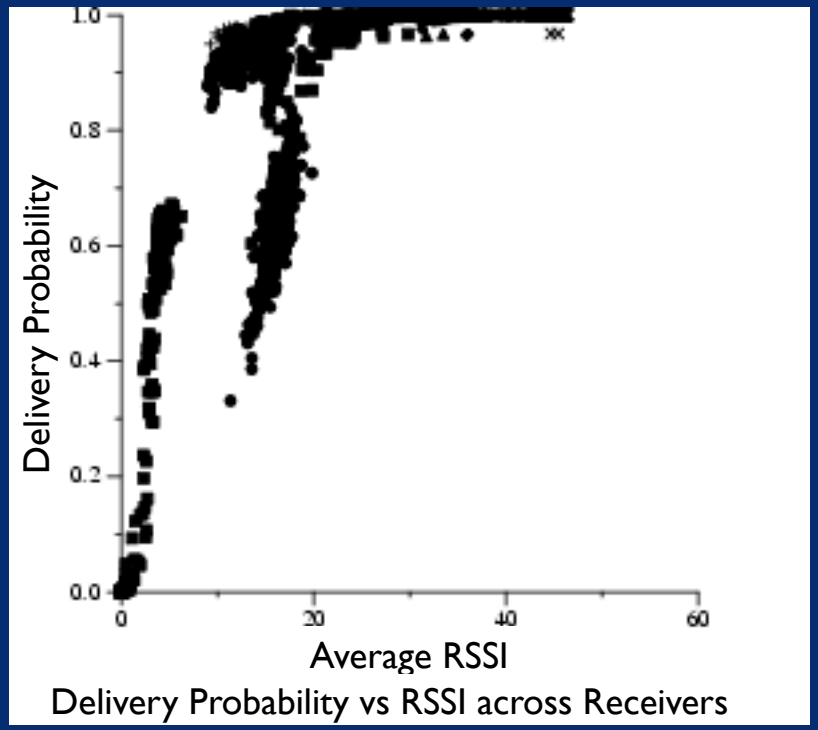
- **Signal strength predicts delivery**
- **Low variability**

# Testbed Experiments



- **802.11 ad hoc**
  - Avoid acks, etc
- **Less repeatable**
  - Dept network
  - Changing world

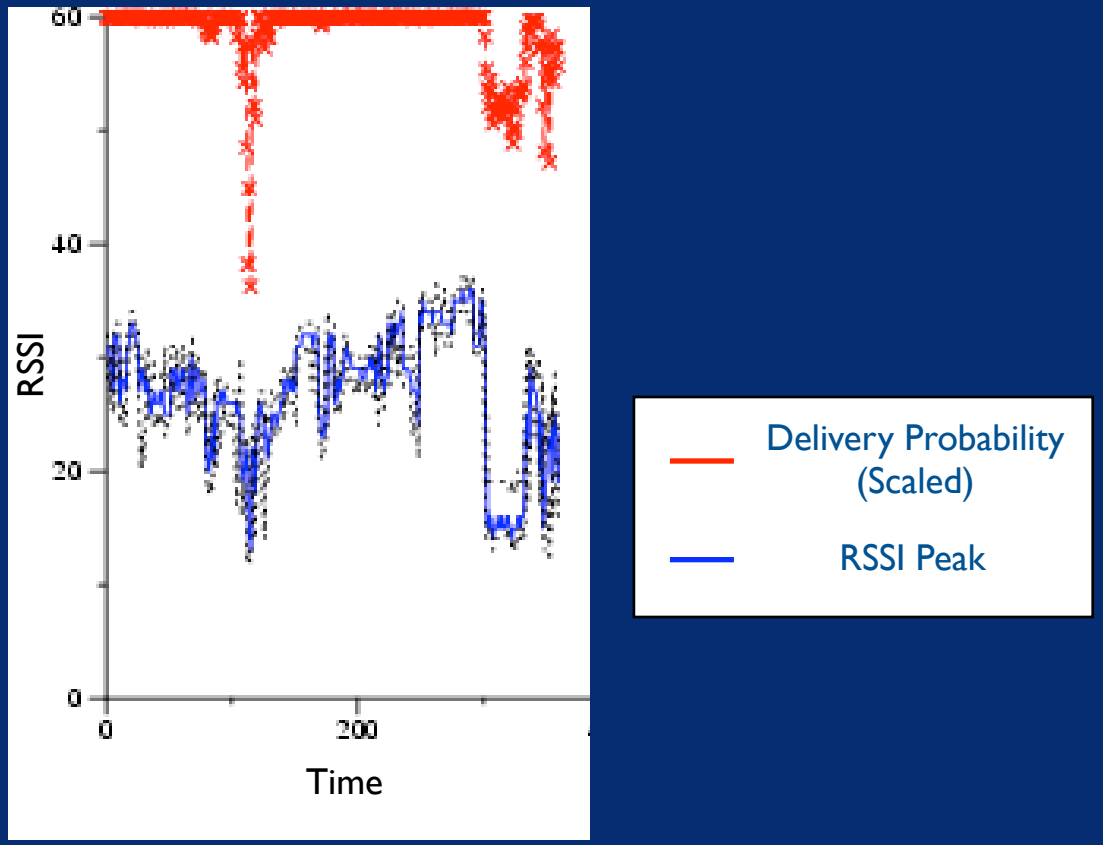
# RSSI and Delivery in Reality




Delivery Probability

- **Multiple thresholds**
  - Receivers don't match
- **Not as sharp**

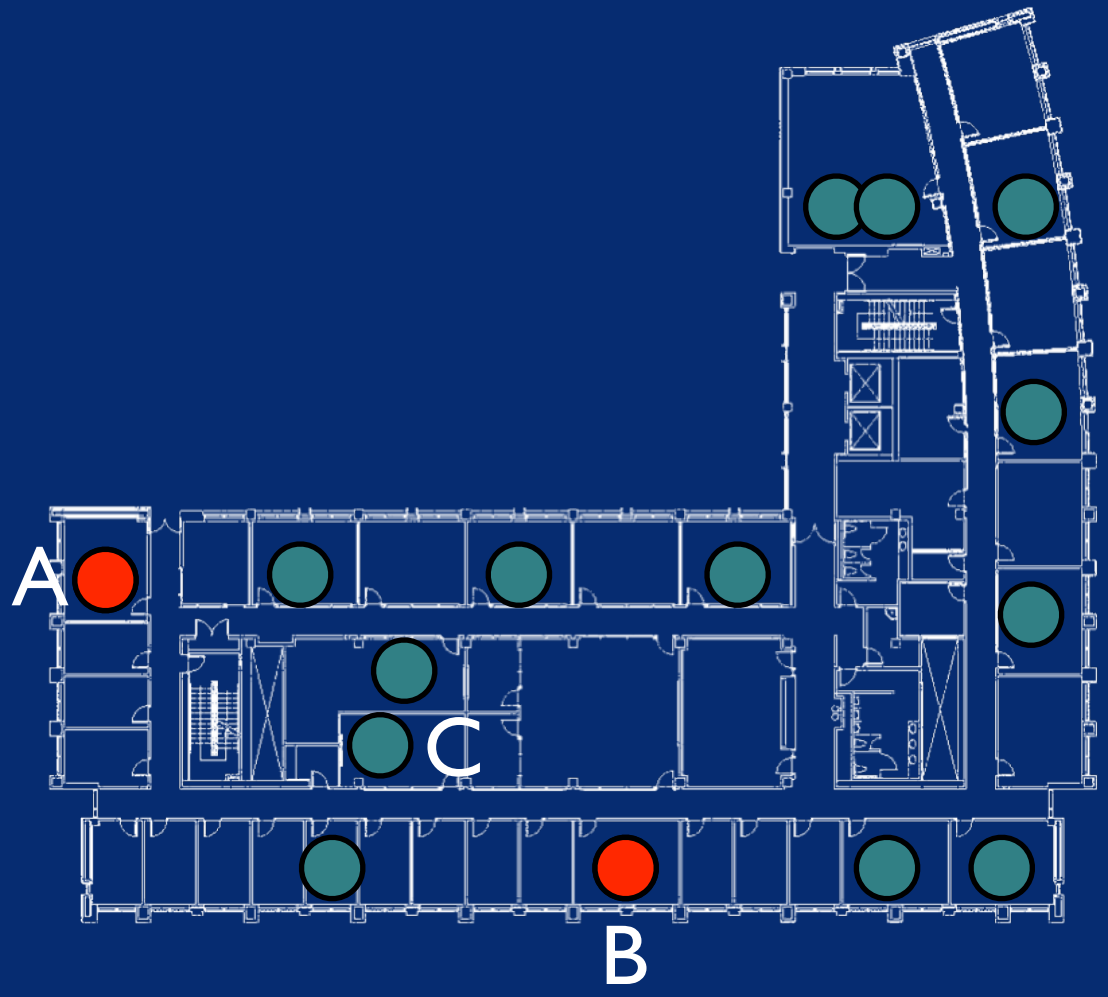
# RSSI Variation



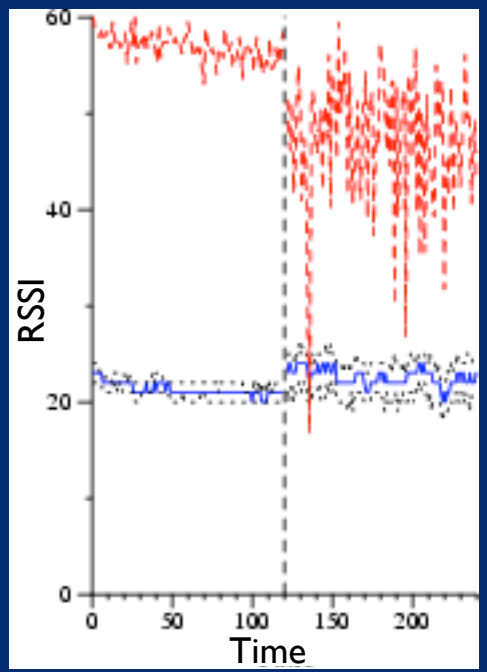

RSSI Over Time

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

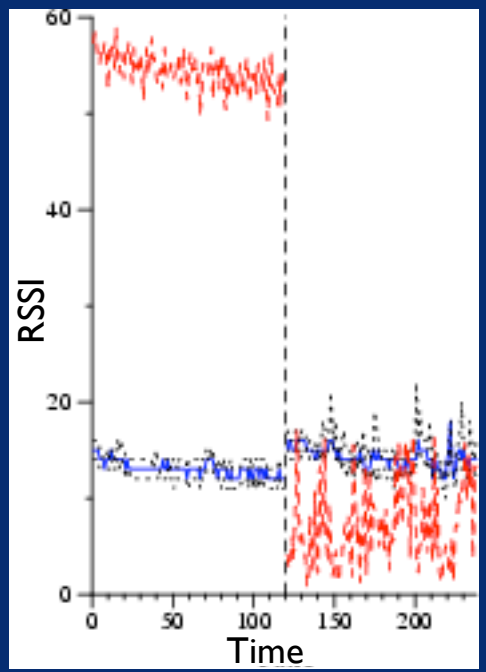
# Competing Senders



# Signal Interference



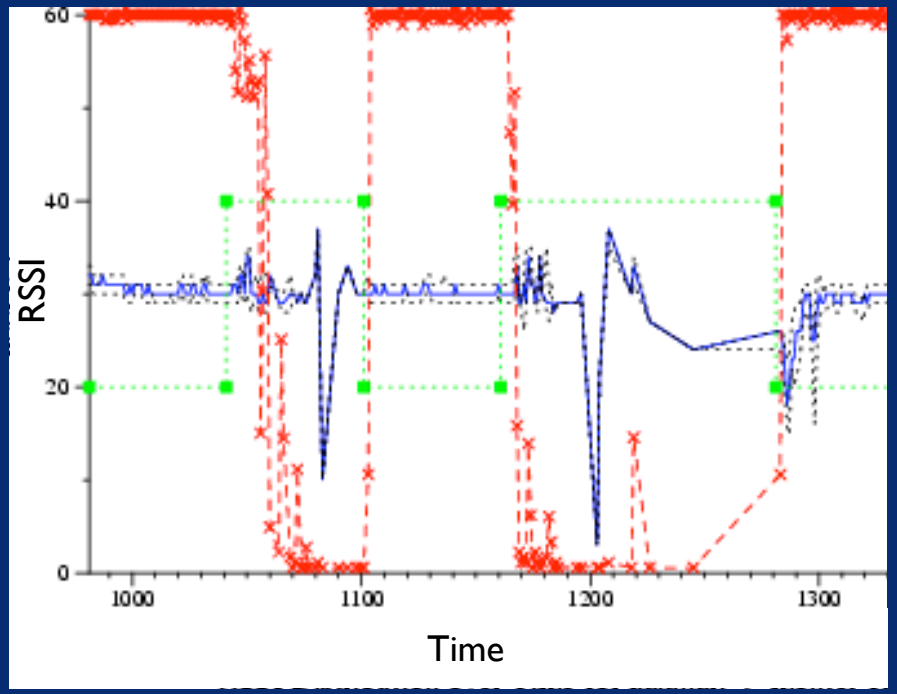

A → C




B → C

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

# Other RF Energy




Microwave

- **Microwaves show same effect**

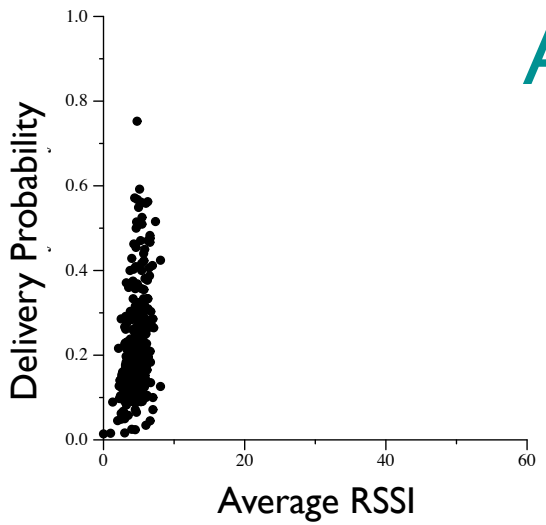
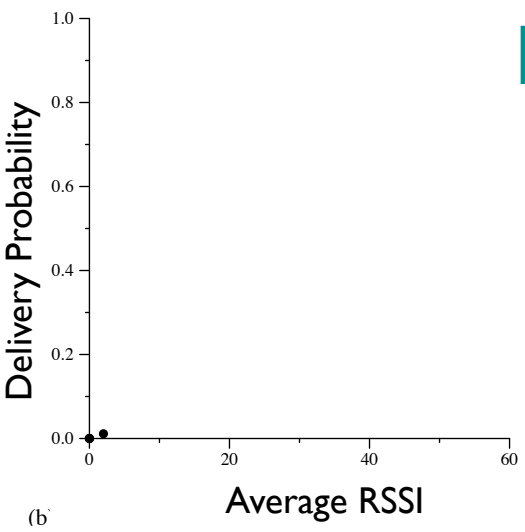
# RSSI Observations

- **Variability in reality from:**
  - Receivers with different thresholds
  - Impact from shadowing and interference
  - High variability at small time scales
- **Yet, surprisingly consistent over time**

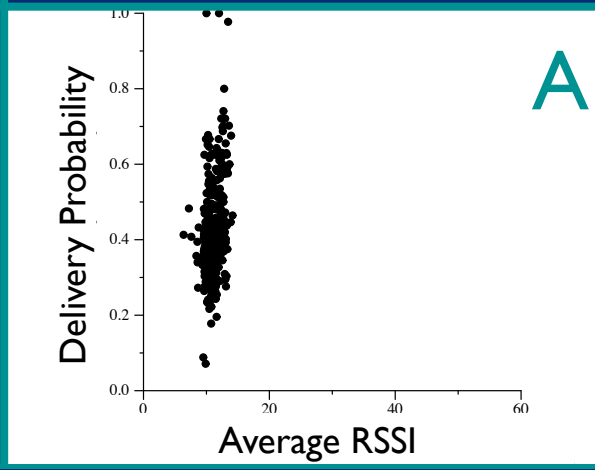
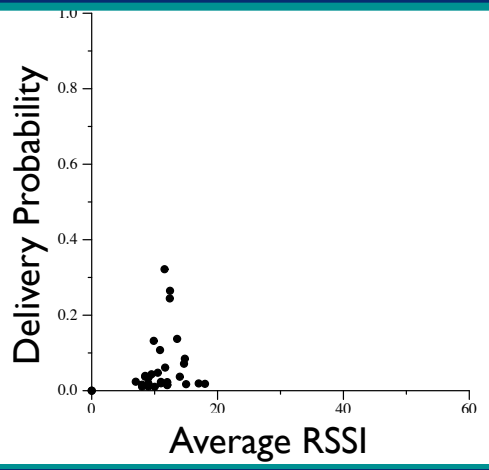
# Asymmetric Links

- **Many links are asymmetric**
  - Poorly understood in general
- **Card or Environment?**

# Asymmetric Links

| Office | CSE 342 | CSE 310 |
| --- | --- | --- |
| Original Machines |  A |  B |

# What Causes Asymmetry?

| Office | CSE 342 | CSE 310 |
|---|---|---|
| Swapped Cards |  A |  B |

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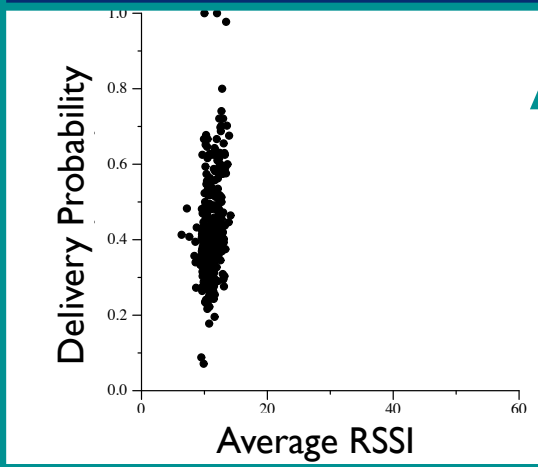
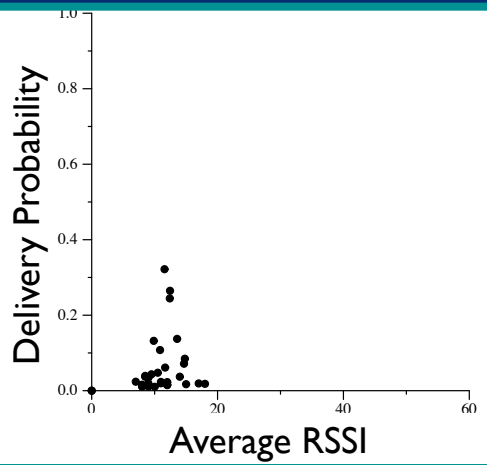
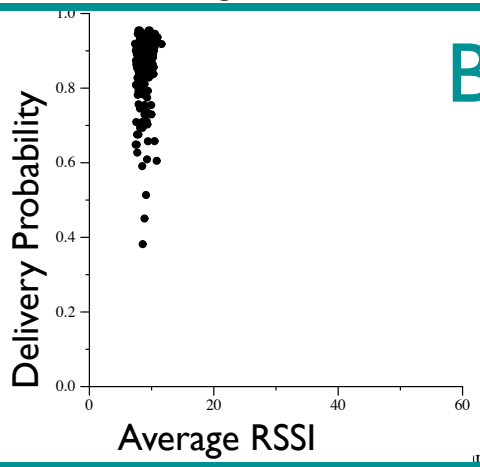
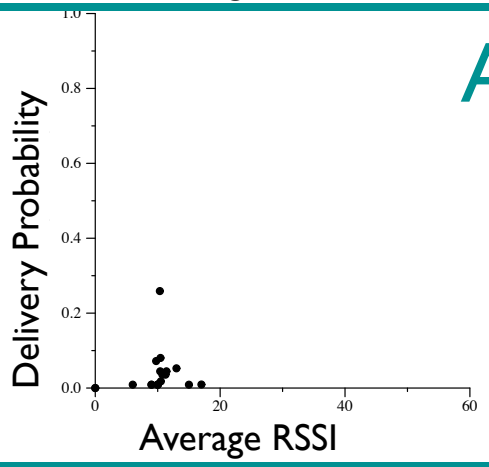
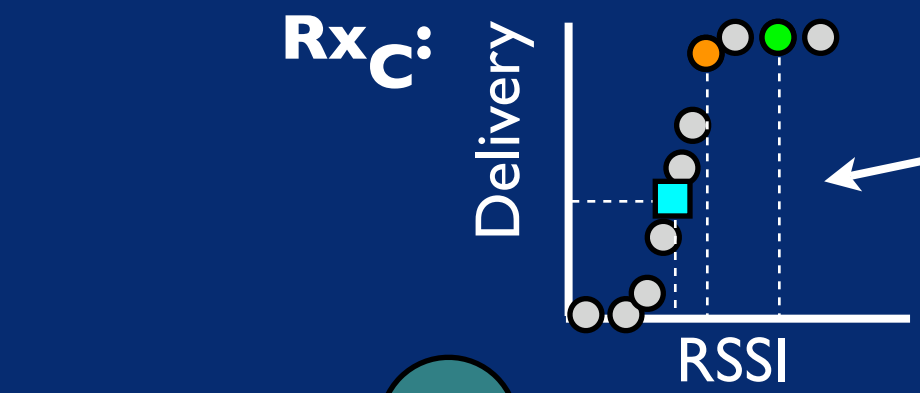
| Swapped Cards |  A |  B |
| Swapped Boxes |  B |  A |

# Implications for RSSI

- **Local environments differ greatly**
  - Observed RSSIs are unique to receiver

# Modeling Delivery

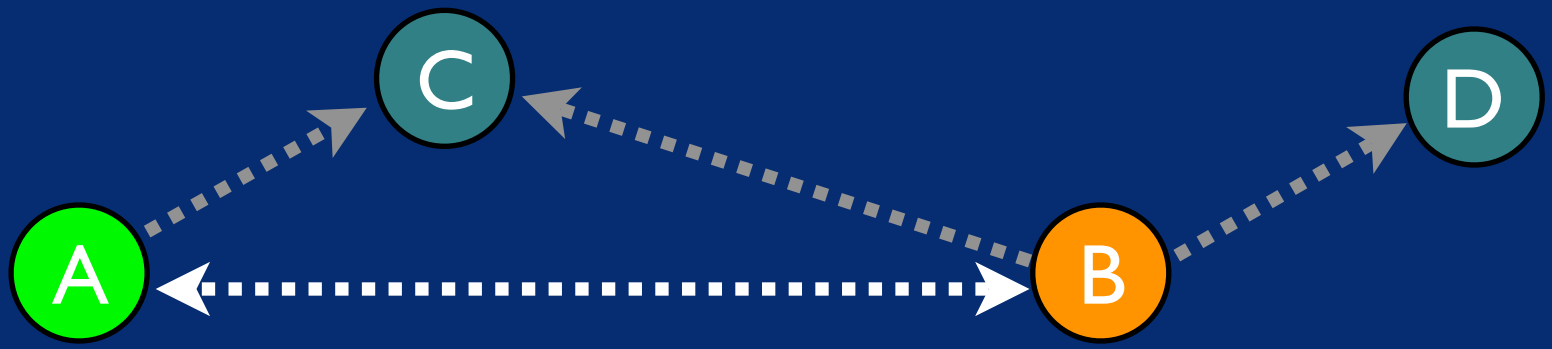



Look up predicted SNIR for delivery probability


- $A|B \rightarrow C = Rx_C\left(\frac{A_{rssi}}{B_{rssi}}\right)$

# Extending to Throughput

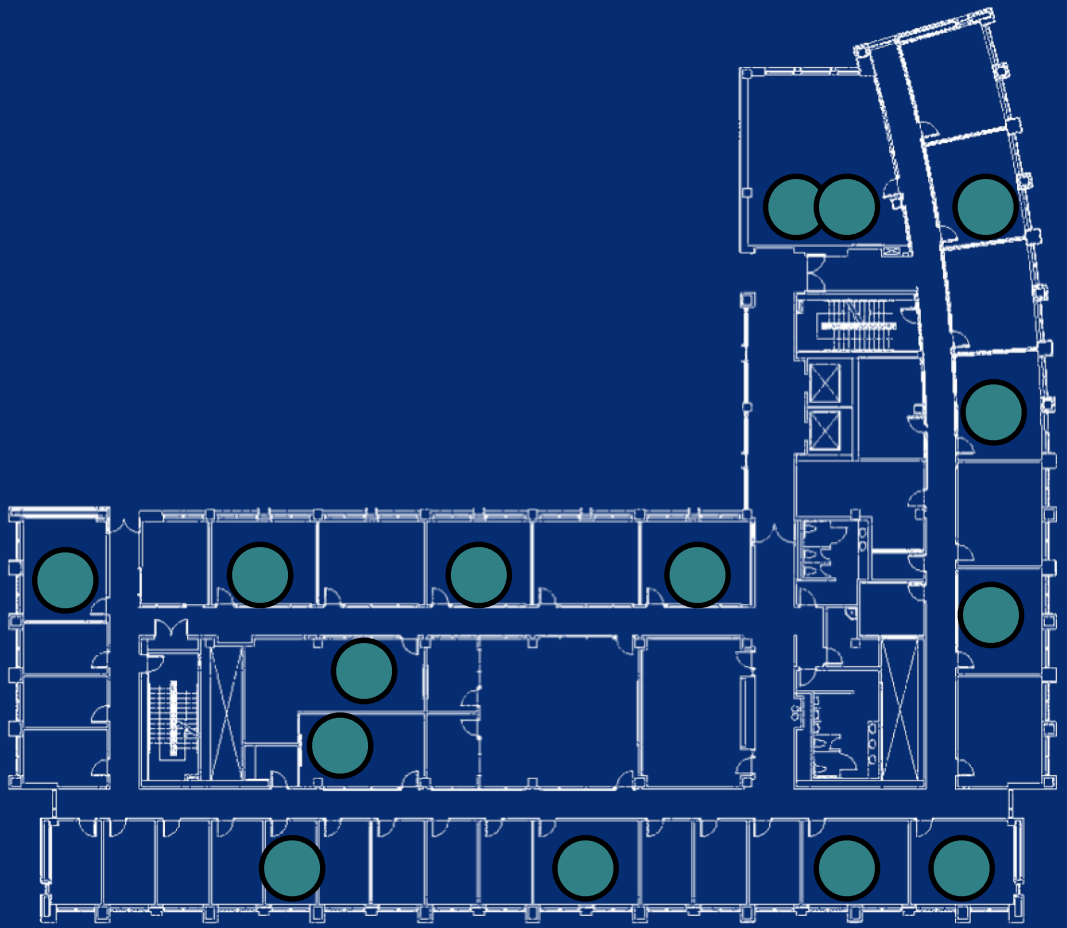
- **How many packets will be sent?**




- Defer if channel not clear (independent events)

***throughput ≈ transmitRate x deliveryProbability***

# Accuracy of Assumptions

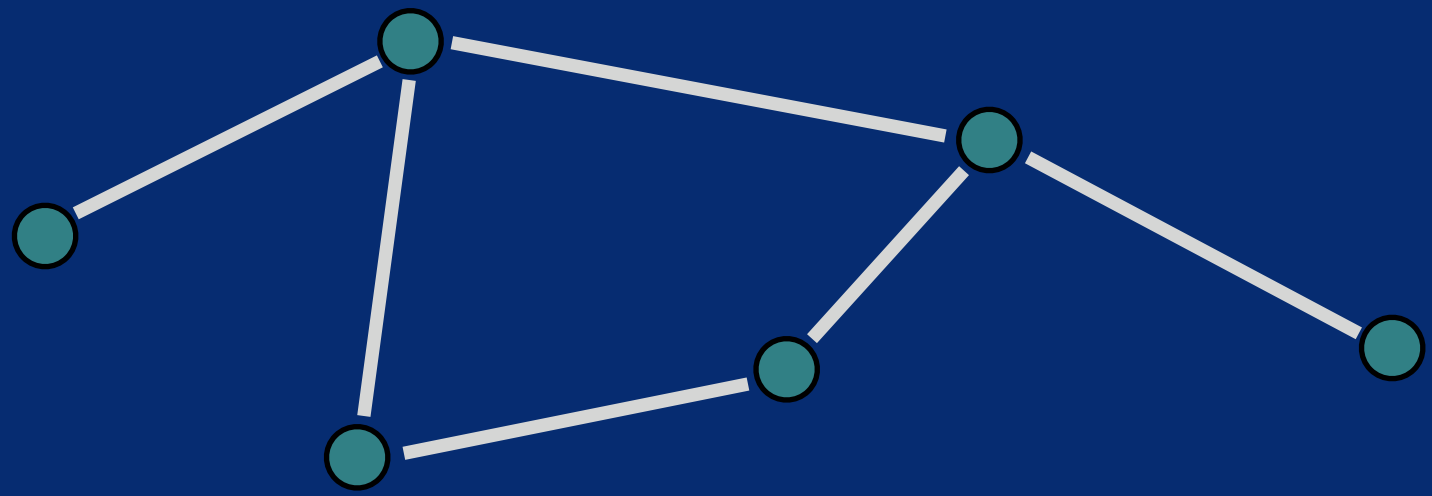


- Predict competing sender delivery probabilities
  - **86% prob. accuracy** (70% for naive model)
  - **78% for throughput** (70% for naive model)

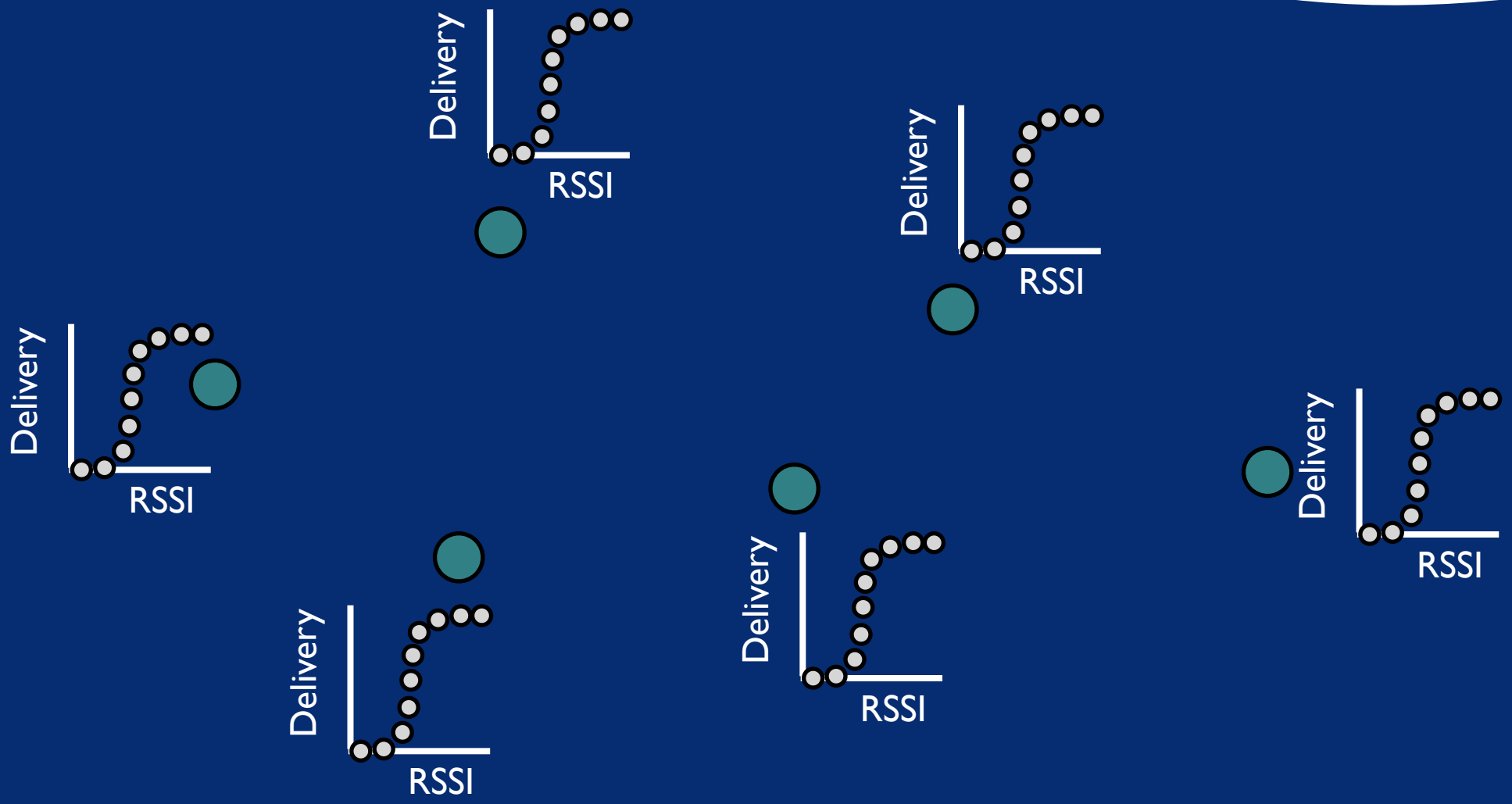
# Applications

- **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