Diagnosing Wireless Packet Losses in 802.11: Collision or Weak Signal?

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University of Wisconsin Madison

INFOCOM 2008
The Goal
Distinguishing between collision and weak signal

Consider a wireless link:

TRANSMITTER

RECEIVER
The Goal
Distinguishing between collision and weak signal

Consider a wireless link:

TRANSMITTER  PACKET  ERROR  RECEIVER
The Goal
Distinguishing between collision and weak signal

Consider a wireless link:

Q. What caused the packet loss?
The Goal
Distinguishing between collision and weak signal

Wireless Errors
The Goal
Distinguishing between collision and weak signal

Wireless Errors

Collision
The Goal
Distinguishing between collision and weak signal

Wireless Errors

Collision

Weak Signal

Signal Attenuation / Fading

Multipath

Mobility
The Goal
Distinguishing between collision and weak signal

Wireless Errors

Collision

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Signal Attenuation / Fading
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Mobility

Q. Can we discern between these two?
Q. Why is it important to distinguish between errors?
Q. Why is it important to distinguish between errors?

What should be done ideally?

- Packet Loss
  - Event
  - Collision
  - Weak Signal
    - Cause
      - Backoff
      - Tune Data Rate, Power
    - Action

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Diagnosing Wireless Packet Losses in 802.11
Q. Why is it important to distinguish between errors?

What should be done ideally?

- Packet Loss
  - Collision
  - Weak Signal
  - Action: Backoff
    - Tune Data Rate, Power

What do we do currently in 802.11?

- Packet Loss
  - Action: Backoff
    - Decrease Data Rate (after X retries)
Q. Why is it important to distinguish between errors?

What should be done ideally?

- **Packet Loss**
  - **Event**
  - **Cause**:
    - **Collision**
    - **Weak Signal**
  - **Action**:
    - **Backoff**
    - **Tune Data Rate, Power**

What do we do currently in 802.11?

- **Packet Loss**
  - **Event**
  - **Cause**
  - **Action**:
    - **Backoff Decrease Data Rate (after X retries)**

Throughput Energy
Collision vs. Weak Signal

Inferring the cause of error

- ‘Collision Detection’ is hard!
- Given an error packet, can we conduct a post-mortem?
Collision vs. Weak Signal

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Inferring the cause of error

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Example

```
1 0 0 1 1 1 0 1 0 1 1 0 1
```

TX Packet
Collision vs. Weak Signal

Inferring the cause of error

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- Given an error packet, can we conduct a post-mortem?

Example

<table>
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<th>TX Packet</th>
<th>RX Packet</th>
</tr>
</thead>
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<td>1 0 0 1 1 1 0 1 0 1 1 0 1</td>
<td>1 1 0 1 1 0 1 1 0 0 1 1 1</td>
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Collision vs. Weak Signal

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<th>TX Packet</th>
<th>RX Packet</th>
<th>Error Bitmap</th>
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<tr>
<td>1 0 0 1 1 1 0 1 0 1 1 0 1</td>
<td>1 1 0 1 1 0 1 1 0 0 1 1 1</td>
<td>0 1 0 0 0 1 1 0 0 1 0 1 0</td>
</tr>
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</table>

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A Simple Approach

Diagnosing Wireless Packet Losses in 802.11
A Simple Approach
A Simple Approach

Metrics used to discern the cause:

- Received signal strength (RSS)
- Bit error rate (BER)
- Error rate per symbol (EPS)
- Symbol error rate (SER)
- Symbol error burst length (S-Score)
A Simple Approach

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Bit Error Rate (BER)

- Percentage of total bits in error
Metrics: Intuition

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Collision:

Packet 1

Packet 2

Time
Metrics: Intuition

Bit Error Rate (BER)
- Percentage of total bits in error

Collision:
- Packet 1
- Packet 2
- RX Packet

Time
Metrics: Intuition

Bit Error Rate (BER)
- Percentage of total bits in error (Higher in collision?)

Received Signal Strength (RSS)
- RSS \sim (S+I/n)
Metrics: Intuition

**Bit Error Rate (BER)**
- Percentage of total bits in error (Higher in collision?)

**Received Signal Strength (RSS)**
- \( \text{RSS} \sim (S+I/n) \)
Metrics: Intuition

Bit Error Rate (BER)
- Percentage of total bits in error (Higher in collision?)

Received Signal Strength (RSS)
- RSS \sim (S+I/n) (Lower in weak signal?)
Symbol Error Rate (SER)

- Percentage of symbols which are in error
Symbol Error Rate (SER)

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Symbol Error Rate (SER)

- Percentage of symbols which are in error

1 2 3 4 5 6 7 8 9 10
Symbol Error Rate (SER)

- Percentage of symbols which are in error (Higher in collision?)

1 2 3 4 5 6 7 8 9 10

SER = 5/10 = 0.5
Metrics: Intuition

Symbol Error Rate (SER)
- Percentage of symbols which are in error (Higher in collision?)

Error Per Symbol (EPS)
- Percentage of bits in error averaged over the symbols which are in error
Metrics: Intuition

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Diagnosing Wireless Packet Losses in 802.11
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S-Score
- Measure of number of consecutive symbols in error
### Metrics: Intuition

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*WiNGS Lab, UW-Madison*  
*Diagnosing Wireless Packet Losses in 802.11*
### Metrics: Intuition

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- Measure of number of consecutive symbols in error

![S-Score Diagram](diagram.png)

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Diagnosing Wireless Packet Losses in 802.11
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\[ S\text{-Score} = \sum_{i=1}^{n} |B_i|^2 \]
Summary of Approach

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Diagnosing Wireless Packet Losses in 802.11
Experiment Design
Causing errors due to weak signal

Weak Signal
- Environment free of other 802.11 transmissions
- Enabled reception of packets in error
- Client mobility induced errors due to dynamic channel conditions
Collisions

- Disabled backoffs, enabled reception of packets in error
- Packet logs at the receivers are synchronized using common packets
- Collisions are identified using overlap in packet transmission times
Empirical Results: BER

98% of weak signal packets have a BER of 12% or less

26% of collision packets have BER of 12% or less

Cutoff value of 12% BER: Detects 74% of collisions with 2% false positives
98% of weak signal packets have an EPS of 22% or less
30% of collision packets have the same EPS of 22% or less.
Metric-Vote

- Output a collision if any of the metrics vote for a collision
A Metric-Vote Scheme

**Metric-Vote**
- Output a collision if any of the metrics vote for a collision

**Performance**

**Table: Accuracy for Collision/Weak Signal**

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<thead>
<tr>
<th></th>
<th>BER</th>
<th>EPS</th>
<th>S-Score</th>
<th>Metric-Vote</th>
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</thead>
<tbody>
<tr>
<td><strong>Collision</strong></td>
<td>55.0</td>
<td>52.4</td>
<td>44.1</td>
<td>59.7</td>
</tr>
<tr>
<td><strong>Weak Signal</strong></td>
<td>99.43</td>
<td>97.80</td>
<td>98.74</td>
<td>97.40</td>
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</tbody>
</table>

- Accuracy: % of weak signal (or collision) packets which are correctly identified
Why is the accuracy low for collision packets?
Some Observations

Why is the accuracy low for collision packets?

- **Strong Capture Effect**
Some Observations

Why is the accuracy low for collision packets?

- **Strong Capture Effect**

  ![Diagram showing Strong Capture effect]

  - T1
  - R1
  - T2
Some Observations

Why is the accuracy low for collision packets?

- Strong Capture Effect
- Colliding Packet Size

<table>
<thead>
<tr>
<th>1000 byte</th>
<th>1000 byte</th>
<th>More Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 byte</td>
<td>200 byte</td>
<td>Less Errors</td>
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A Joint Metric: SER-EPS

Symbol Error Rate (SER)

Error Per Symbol (EPS)

Collision (1400,1400)
Collision (1400,200)
Signal
- **Platforms**: Linux based laptop, Netgear SPH101 VoWiFi phone

  - **COLLision Inferencing Engine (COLLIE)**
    - AP relays the error packet back to the client
    - Client performs collision inferencing

  - COLLIE based Link Adaptation
    - Enhanced Auto Rate Fallback to make it collision-aware
Mobile Scenario

- Mobile Client, Presence of other traffic

Throughput improvement $\sim 30\%$

Throughput (kbps) vs. Time (secs)

- w/ COLLIE
- w/o COLLIE
Collision Scenario

- Static client, Presence of additional collision sources

Throughput improvement as high as 60%
Results (3)

Voice call emulation

- Netgear SPH-101 VoWiFi phone using TI chipset and proprietary rate adaptation algorithm

![Graph showing reduction in wasted retransmissions]

- Reduction in wasted retransmissions $\sim 40\%$

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Diagnosing Wireless Packet Losses in 802.11
Summary

- We addressed the fundamental question of ‘what caused a packet to be in error – collision or weak signal?’
- Distinguishing between errors lead to improvement in throughput, energy efficiency

Future Work

- Design better metrics
- Design a low overhead protocol
- Study the impact of non-802.11 interference sources
- Enhance/design link adaptation mechanisms
Questions?
Backup slides
Empirical Results: Other Metrics

- **S-Score**
  - Cutoff value of 500: 98% of signal packets and 26% of collision packets

- **RSS**
  - High variation
  - Delivery probability is a function of $S/(I+n)$ instead of $(S+I)/n$, receiver sensitivity
98% of packets in error due to weak signal have an RSS of about -73 dBm or less

10% of packets suffering collision have RSS of -73 dBm or less
98% of the weak signal packets have an S-Score of 500 or less
26% collision packets have an S-Score of 500 or less
Multi-AP Assistance

- APs are synchronized (using opportunistic common packet receptions)
- Information about packet reception is aggregated at the COLLIE server