Visibility:
A New Metric for Protocol Design

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Visibility

What are we doing wrong?
Visibility

- It is difficult to observe what occurs deep within a sensor network.
- This is the direct result of energy constraints on a mote.
- This lack of visibility directly hinders development.
Contribution

- This talk is NOT about a debugging tool
- This talk is about quantifying how “easy” it is to debug a protocol
Visibility Cost

The energy required to diagnose the cause of a failure or behavior
Outline

- Survey of Failures
- The Visibility Metric
- PCP: Clean Slate Design
- V-Deluge: Incremental Improvement
- Conclusion
Outline

• **Survey of Failures**
• The Visibility Metric
• PCP: Clean Slate Design
• V-Deluge: Incremental Improvement
• Conclusion
What kinds of failures are observed in real deployments?
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  - System Interactions: software conflicts
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  - Network Problems: Saturation & Congestion
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  - Protocol Issues: Conflicts & Failures
What kinds of failures are observed in real deployments?

- **Identifiable Failures**
  - System Interactions: software conflicts
  - Network Problems: Saturation & Congestion
  - Protocol Issues: Conflicts & Failures

- **Unknown**
  - Collisions?
  - Interference?
  - Buggy code?
  - Hardware problems?
Effects of Failures on Deployment Performance

Great Duck Island: 58%

Peter Scott

Effects of Failures on Deployment Performance

Great Duck Island: 58%
Redwoods: 40%

Effects of Failures on Deployment Performance

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Potato Field: 2%

Effects of Failures on Deployment Performance

Great Duck Island: 58%
Redwoods: 40%
Potato Field: 2%
Volcan Reventador: 68%

Management and Debugging

- Sympathy
- Lightweight RPC
- Network Snooping Tools
Example Protocol: Collection Tree
Example Protocol: Possible Causes
Example Protocol: Possible Causes
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Example Protocol: Possible Causes
Example Protocol: Decision Tree

- **Receive No Packets?**
  - Y: Disconnection/Death
  - N: Sequ. # is zero?

- **Seq. # is zero?**
  - Y: Reboot
  - N: Duplicate Suppression?

- **Duplicate Suppression?**
  - Y: Duplicate Suppression
  - N: Above Max Tx?

- **Above Max Tx?**
  - Y: Egress Drop
  - N: Ingress Drop?

- **Ingress Drop?**
  - Y: Ingress Drop
  - N: Link Layer Failure

ACM SenSys - 2007
Outline

- Survey of Failures
- *The Visibility Metric*
- PCP: Clean Slate Design
- V-Deluge: Incremental Improvement
- Conclusion
Visibility Metric

**Visibility Cost**: The expected energy of traversing the decision tree to diagnose the cause of a behavior.
Visibility Metric

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Q1: cost = 0
Q2: cost = C
Q3: cost = C

Cause A
Cause B
Cause C
Cause D
Visibility Metric

Visibility Cost: The expected energy of traversing the decision tree to diagnose the cause of a behavior.

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<table>
<thead>
<tr>
<th>Cause</th>
<th>Q1: Y</th>
<th>Q1: N</th>
<th>Q2: Y</th>
<th>Q2: N</th>
<th>Q3: Y</th>
<th>Q3: N</th>
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<td>A</td>
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<td></td>
<td></td>
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<td>B</td>
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</tr>
<tr>
<td>C</td>
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<td>C</td>
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<tr>
<td>D</td>
<td></td>
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<td>2C</td>
<td></td>
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11/7/2007
Visibility Metric

Visibility Cost: The expected energy of traversing the decision tree to diagnose the cause of a behavior.
Visibility Metric

**Visibility Cost**: The expected energy of traversing the decision tree to diagnose the cause of a behavior.

Visibility Cost = 1.25 C
Increasing Visibility

Visibility Cost = 0.66 C

Remove Leaves From the Tree
Increasing Visibility

Reduce Cost of Questions

Visibility Cost = 0.00 C
Outline

- Survey of Failures
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- *PCP: Clean Slate Design*
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- Conclusion
A Design Example: Pull Collection Protocol
Diagnosing Why Packets Were Lost

Receive No Packets?

- Y: Disconnection/Death
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- Y: Reboot
- N: Jump in THLs?

Jump in THLs?

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Above Max Tx?

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- N: Ingress Drop?

Ingress Drop?

- Y: Ingress Drop
- N: Link Layer Failure
Diagnosing Why Packets Were Lost

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Eliminating Egress Drops

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Eliminating Ingress Drops

Traditional Rate Control
Eliminating Ingress Drops

Traditional Rate Control
Eliminating Ingress Drops

Traditional Rate Control
Eliminating Ingress Drops

Pull-Based Rate Control
Eliminating Ingress Drops

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Eliminating Ingress Drops

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      - No: Link Layer Failure

PCP Decision Tree

Receive No Packets?
  Y  |  Disconnection/Death
  N  |  Seq. # is zero?
      Y  |  Reboot
      N  |  Jump in THLs?
          Y  |  Duplicate Suppression
          N  |  Link Layer Failure

 Traverse the remainder with information included in packets, used by the protocol itself
Evaluating PCP

40-Node MoteLab Testbed

- PCP: sending as fast as possible.
- MultihopLQI: 1300ms, 800ms, and 20ms packet generation interval
- Interference-Aware Fair Rate Control (IFRC): Results from SIGCOMM 2006

Metrics:

- Reliability
- Throughput
- Fairness
- Visibility
PCP Performance

Throughput (pps) vs Delivery Probability

- IFRC
- MultihopLQI 1300ms
- MultihopLQI 800ms
- PCP
PCP Fairness

![Bar chart showing PCP Fairness comparisons]

- PCP
- Multi-hopLQI-1300ms
- Multi-hopLQI-800ms
- IFRC
- Multi-hopLQI-20ms

<table>
<thead>
<tr>
<th></th>
<th>Fairness (JFI)</th>
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<tbody>
<tr>
<td>PCP</td>
<td>0.75</td>
</tr>
<tr>
<td>Multi-hopLQI-1300ms</td>
<td>1.00</td>
</tr>
<tr>
<td>Multi-hopLQI-800ms</td>
<td>1.00</td>
</tr>
<tr>
<td>Multi-hopLQI-20ms</td>
<td>0.25</td>
</tr>
<tr>
<td>IFRC</td>
<td>1.00</td>
</tr>
</tbody>
</table>
PCP Visibility

- MultihopLQI visibility cost at 800ms interval: 1.615C
- PCP visibility cost: 0.00 C
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Applying Visibility: Deluge

- Dissemination Protocol
  - Advertises new binary with advertisement packets
  - Nodes send requests for new binary from best neighbor

- “Why does a node still have an out-of-date binary?”

- Two expensive causes to diagnose:
  - Suppressions due to misbehaving nodes
  - Interference during binary transmission
V-Deluge

- Suppressions Due to Misbehaving Nodes:
  - Identify and ignore faulty nodes
- Interference during binary transmission
V-Deluge

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V-Deluge Visibility

• Deluge Visibility:
  1.02 C

• V-Deluge Visibility:
  1.00 C
V-Deluge Performance

Total Packets Sent (thousands)

Time (sec)

Deluge
V-Deluge
V-Deluge Performance

Percentage of Nodes with Full Binary

Time (sec)

Deluge
V-Deluge
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Future Work

- Refining the visibility metric
- Visibility in networks with multiple protocols depends on isolation between protocols
Conclusions

- We should consider the visibility of a protocol along with traditional metrics
- The visibility metric provides a new way for thinking about and comparing protocols
- Visibility has broader implications: systems, languages
Comments & Questions?

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Management and Debugging

Sympathy

Receive No Packets?
- Disconnection
  - Reboot
- Seq. # is zero?
- Duplicate Suppression?
  - Alien Failure?
    - Default Overload?
      - Overload
      - Alien Failure
    - Gamma Ray?
      - Alpha Radiation
    - Deadlock
  - Duplicates
    - Egress Drop
  - Above Max Tx?
    - Ingress Drop?
      - Suppression?
        - Suppression
        - Link Layer Failure
Management and Debugging

Sympathy

Receive No Packets?

- Disconnection
- Link Layer Failure
Increasing Visibility

Reduce Probability of Expensive Causes

Visibility Cost = 0.43 C
Conclusions

• Are we just changing the question:
  “Why is the network dropping packets?” becomes
  “Why is a node not sending any packets?”