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

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- ***Survey of Failures***
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- Identifiable Failures
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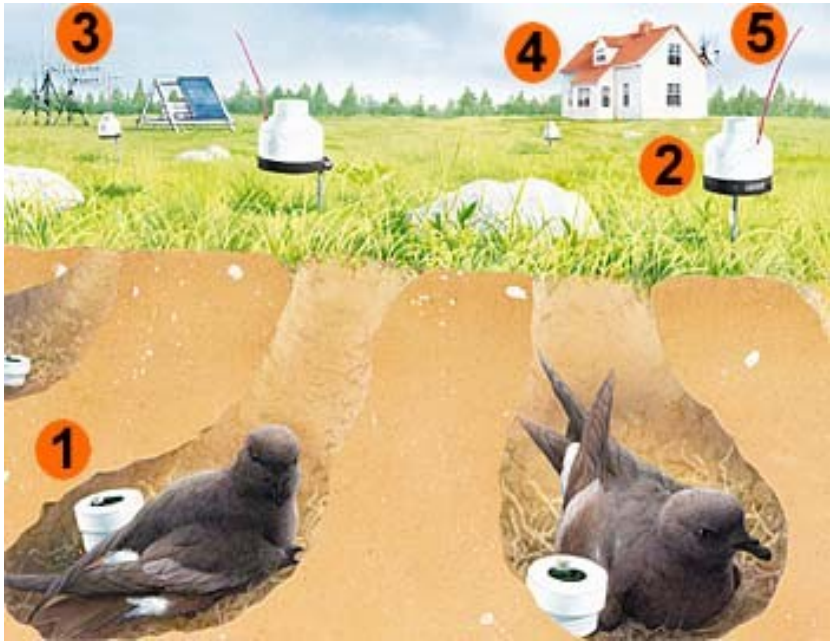
  - Network Problems: Saturation & Congestion
  - Protocol Issues: Conflicts & Failures
- ***Unknown***
  - Collisions?
  - Interference?
  - Buggy code?
  - Hardware problems?

Effects of Failures on Deployment Performance



Peter Scott

Great Duck Island: 58%

R. Szewczyk, J. Polastre, A. Mainwaring, and D. Culler. An analysis of a large scale habitat monitoring application. In *Proceedings of the Second ACM Conference On Embedded Networked Sensor Systems (SenSys)*, 2004.

Effects of Failures on Deployment Performance

Great Duck Island: 58%
Redwoods : 40%

G. Tolle, J. Polastre, R. Szewczyk, D. Culler, N. Turner, K. Tu, S. Burgess, T. Dawson, P. Buonadonna, D. Gay, , and W. Hong. A macroscope in the redwoods. In *Proceedings of the Third ACM Conference on Embedded Networked Sensor Systems (SenSys)*, 2005.

Effects of Failures on Deployment Performance

Great Duck Island: 58%
Redwoods : 40%
Potato Field: 2%

K. Langendoen, A. Baggio, and O. Visser. Murphy loves potatoes: Experiences from a pilot sensor network deployment in precision agriculture. In *the Fourteenth Int. Workshop on Parallel and Distributed Real-Time Systems (WPDRTS)*, 2006.

Effects of Failures on Deployment Performance

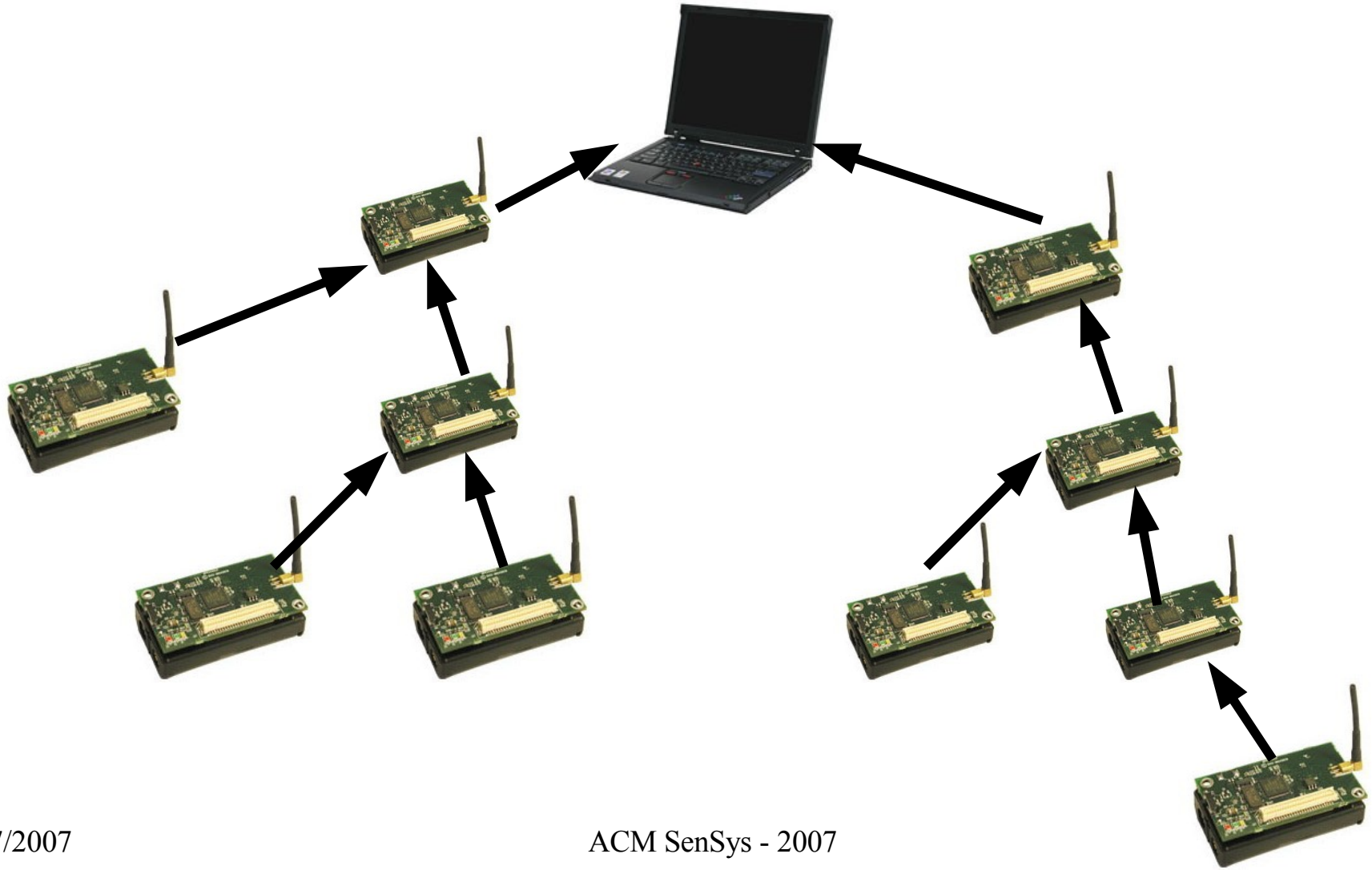
Great Duck Island: 58%
Redwoods : 40%
Potato Field: 2%
Volcan Reventador: 68%

G. Werner-Allen, K. Lorincz, J. Johnson, J. Leess, and M. Welsh. Monitoring volcanic eruptions with a wireless sensor network. In *Proceedings of the Second European Workshop on Wireless Sensor Networks (EWSN)*, 2005.

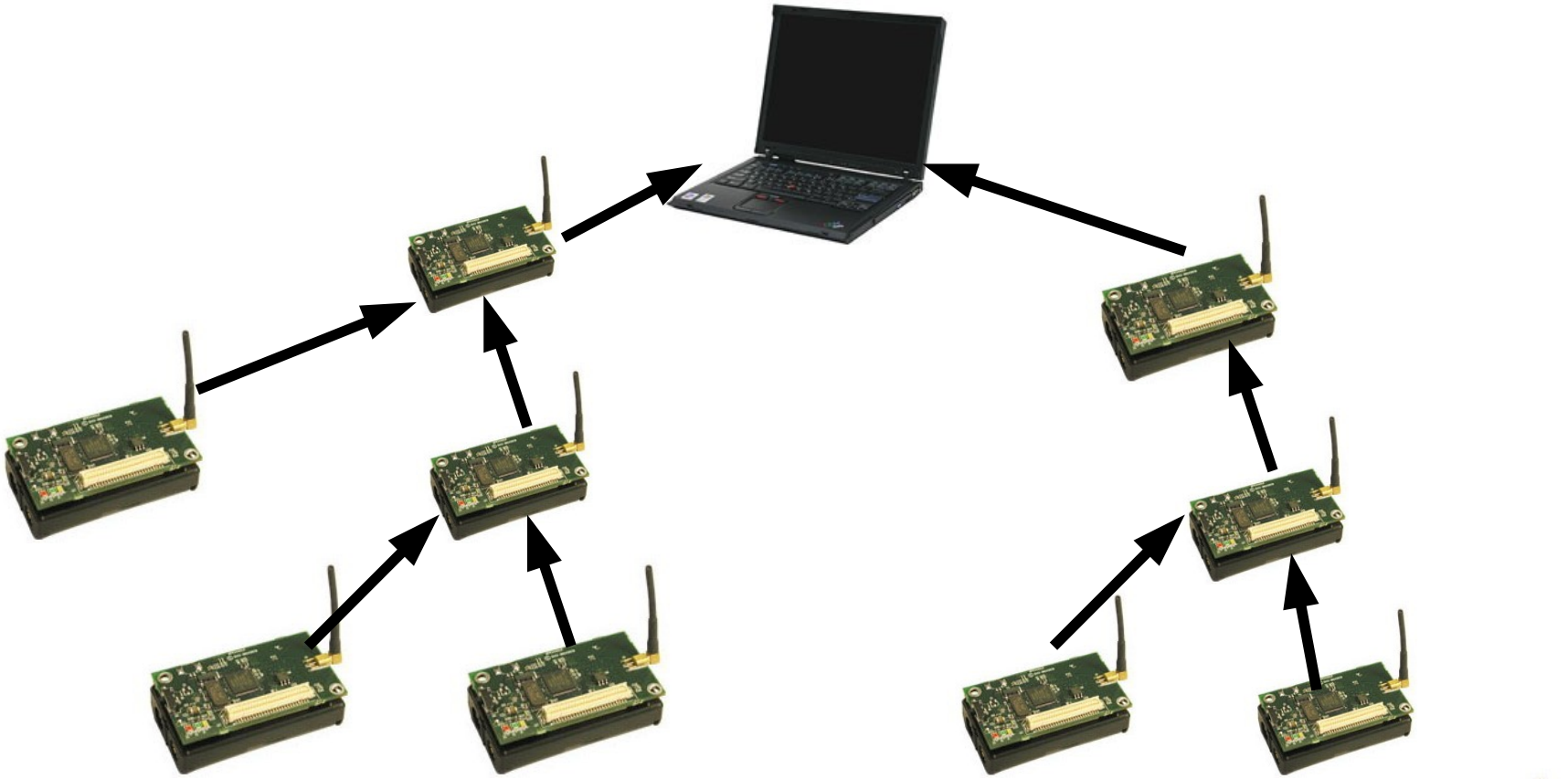
Management and Debugging

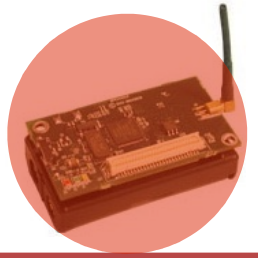
- Sympathy
- Lightweight RPC
- Network Snooping Tools

Example Protocol: Collection Tree



Example Protocol: Possible Causes





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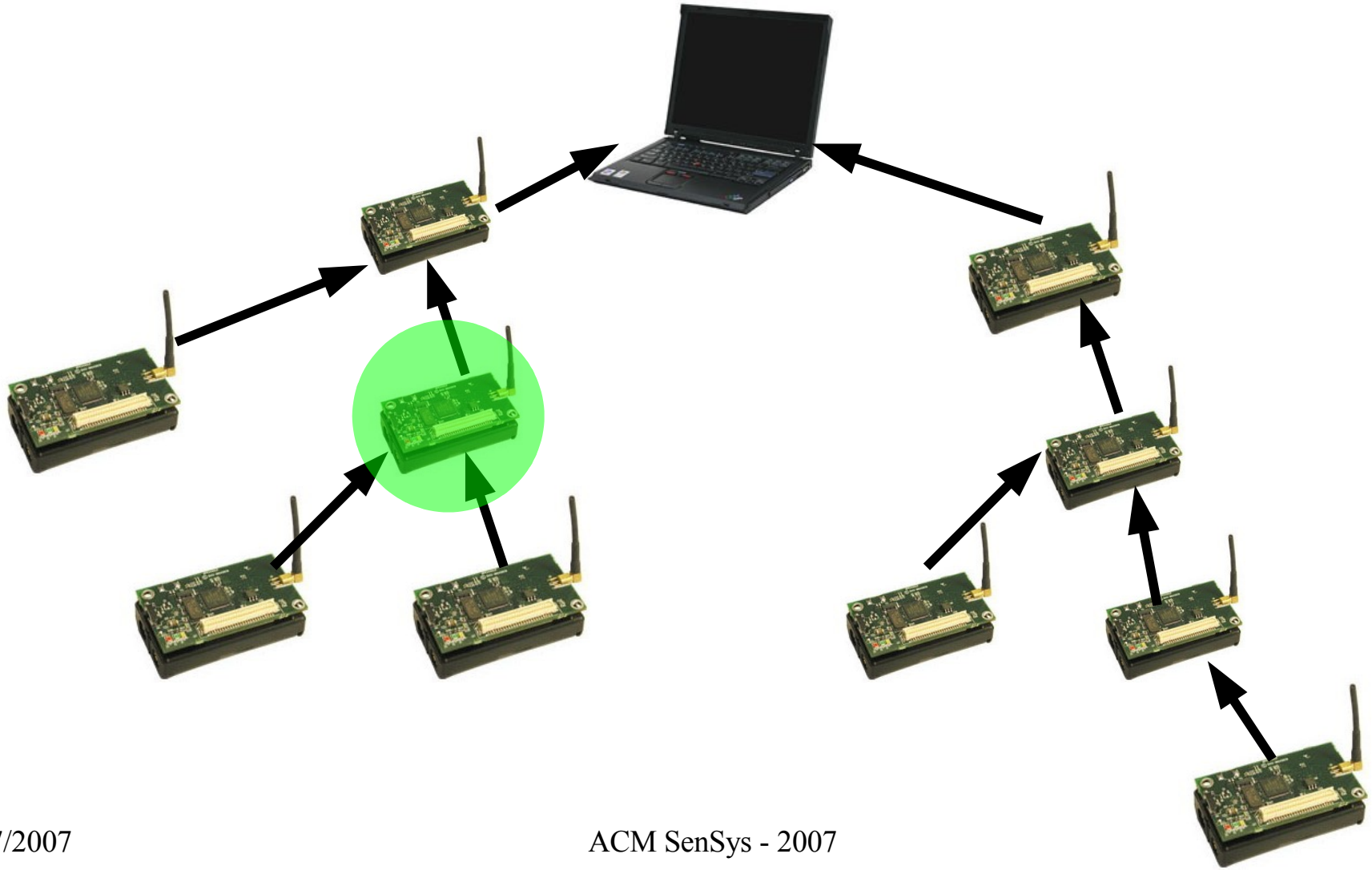

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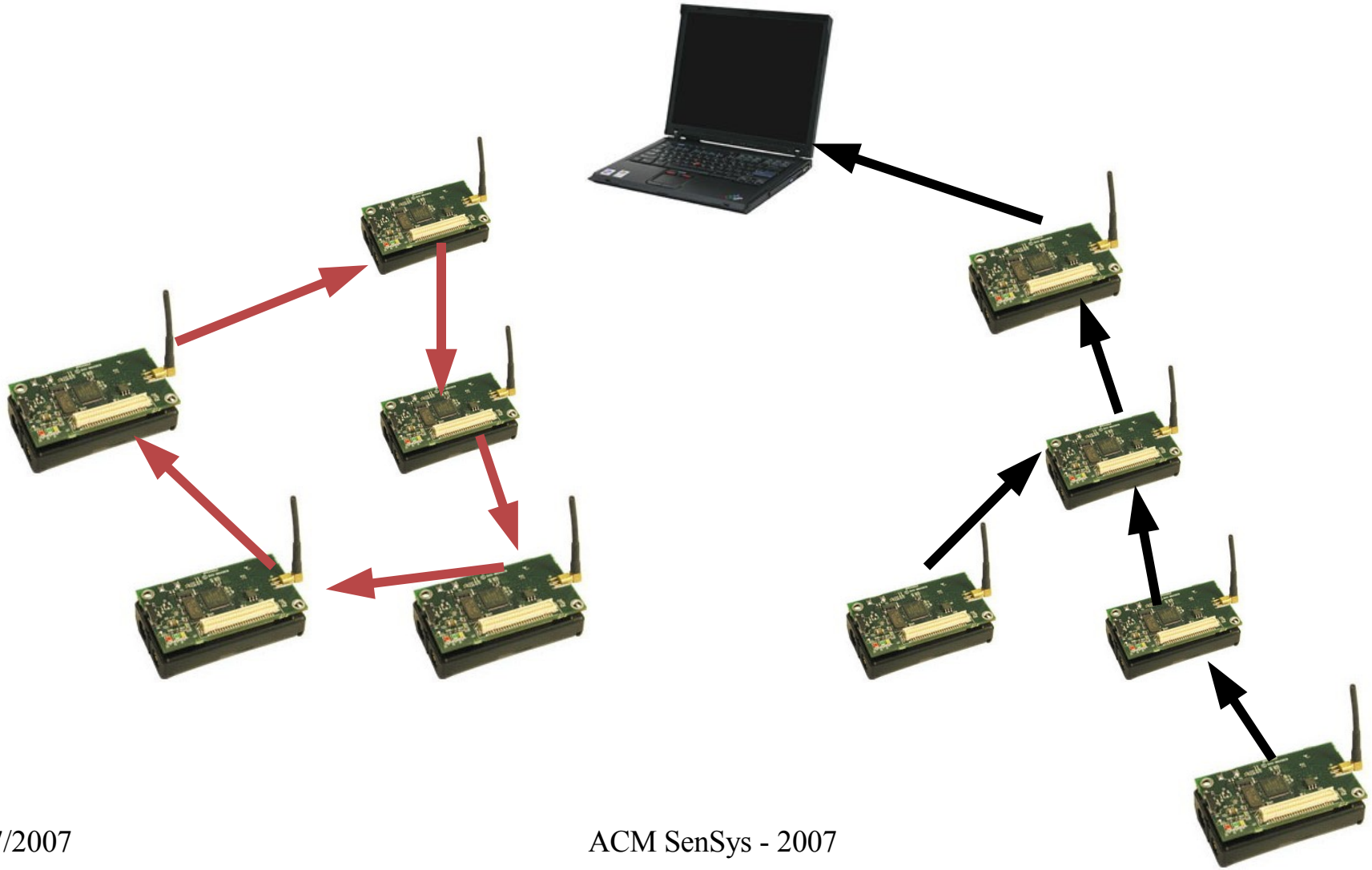

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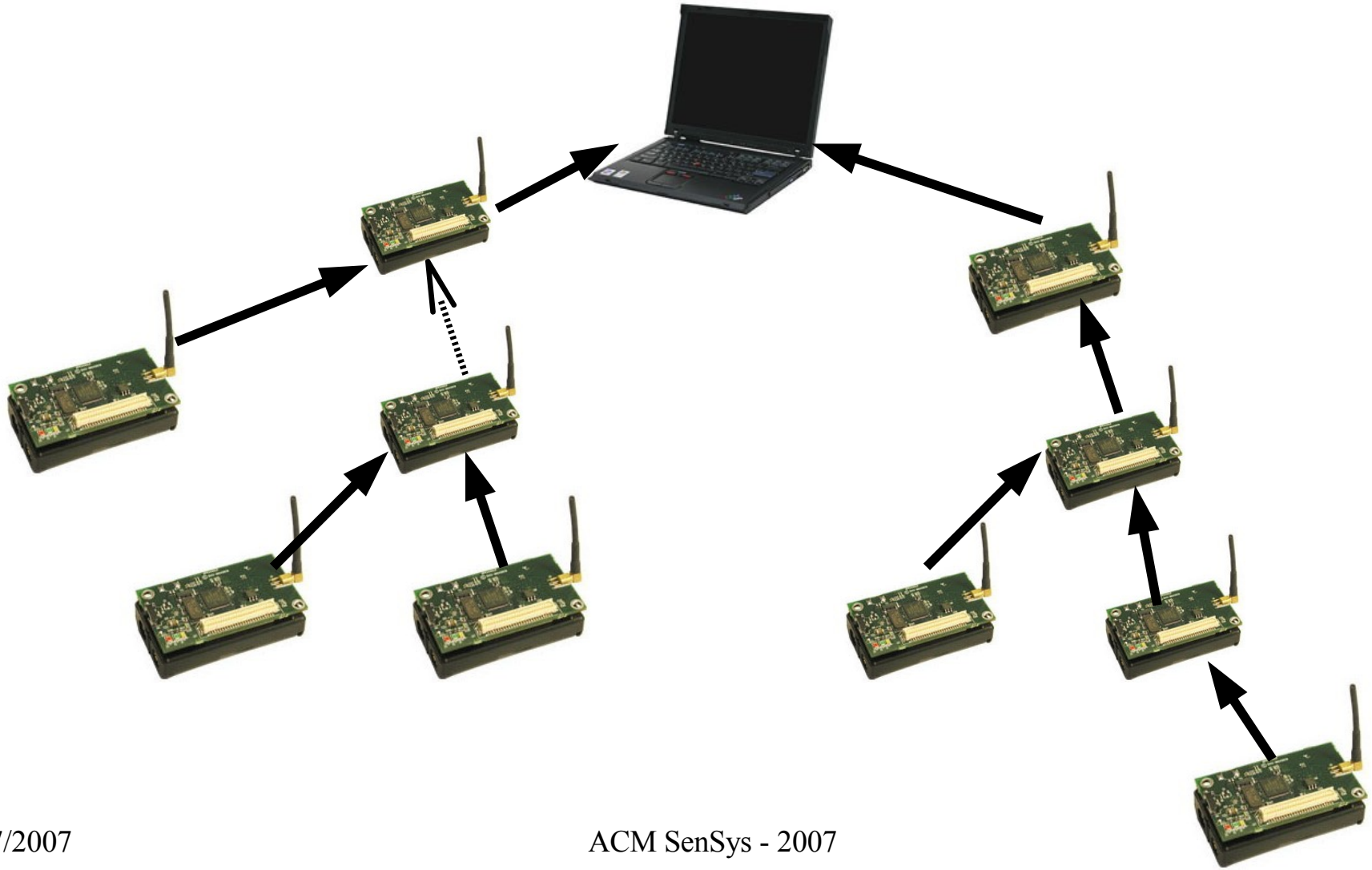

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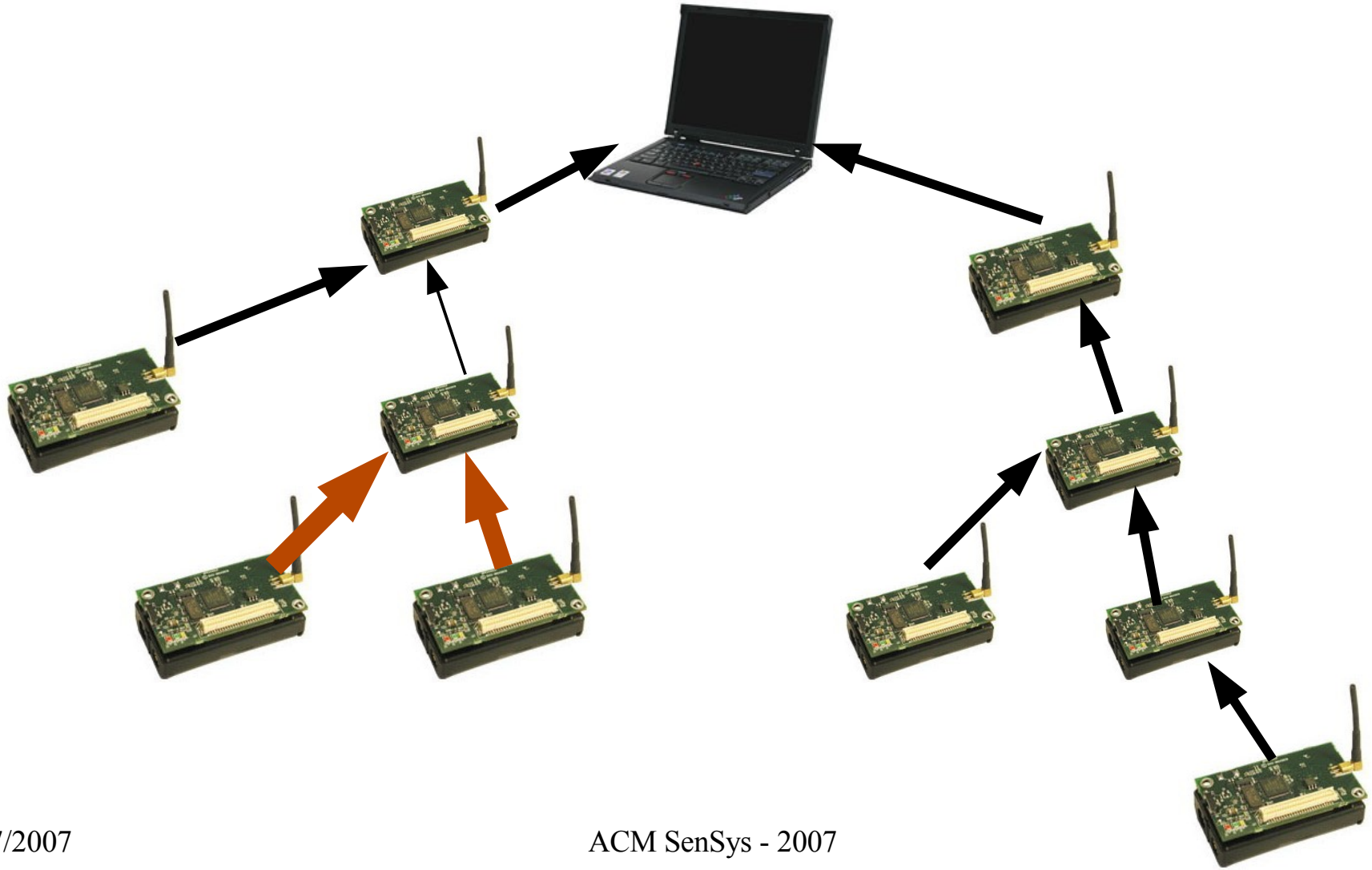

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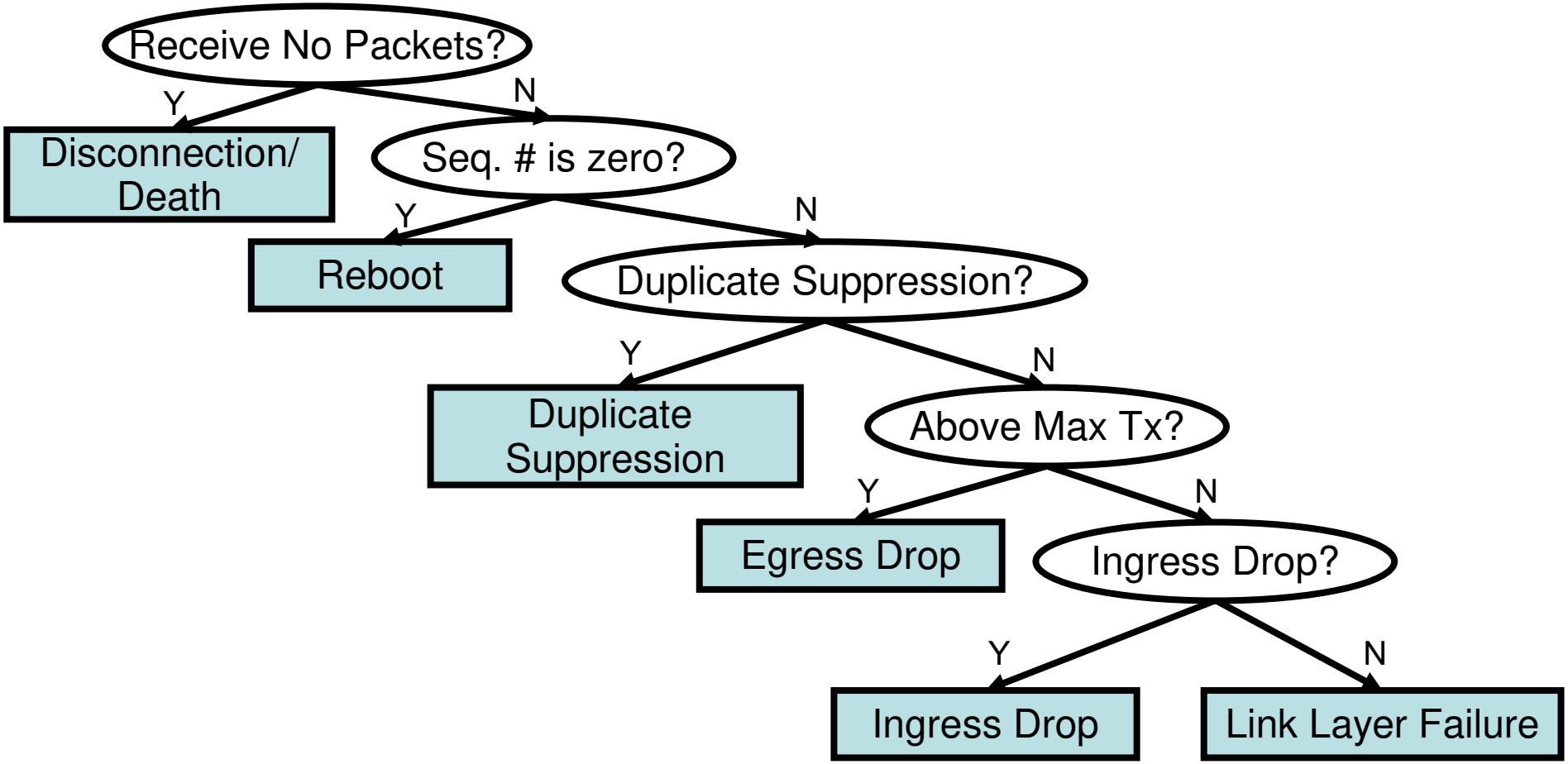

Outline

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- ***The Visibility Metric***
- PCP: Clean Slate Design
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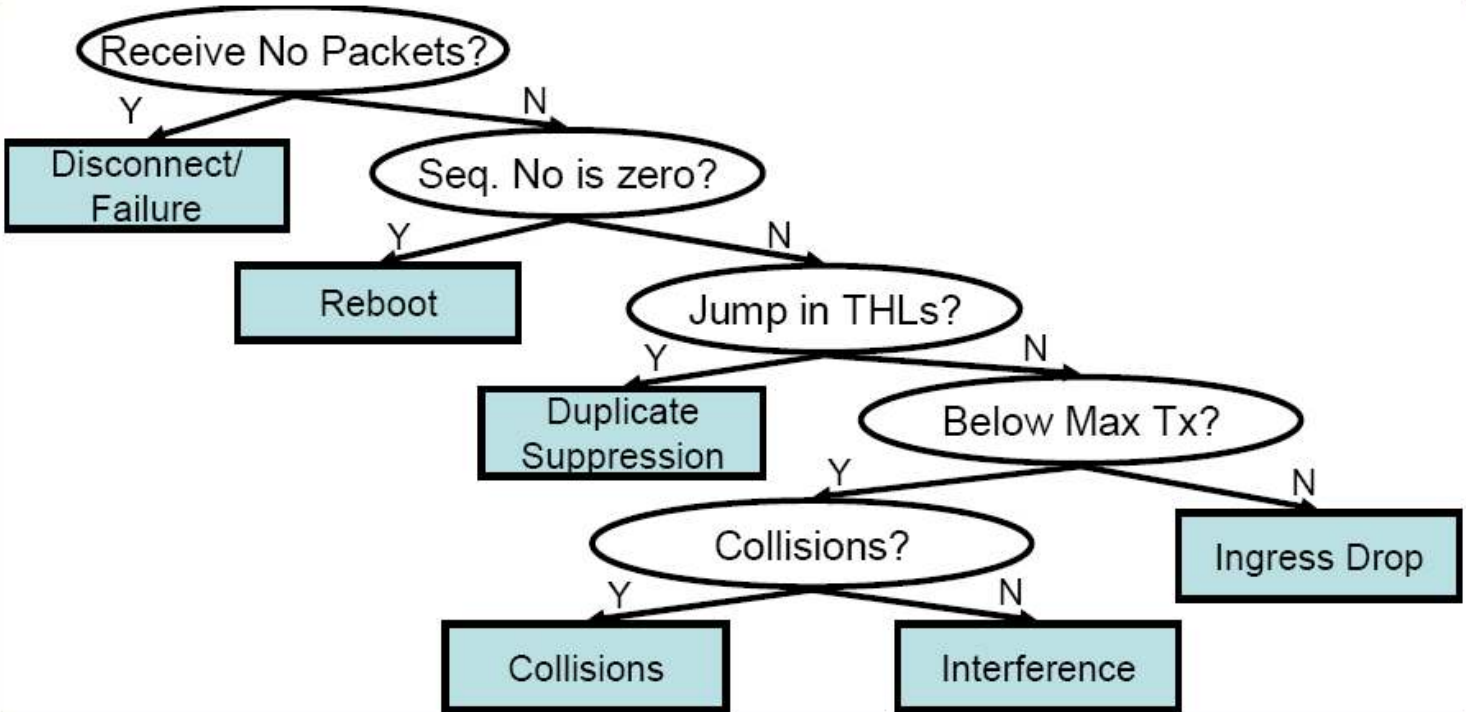
Visibility Metric

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



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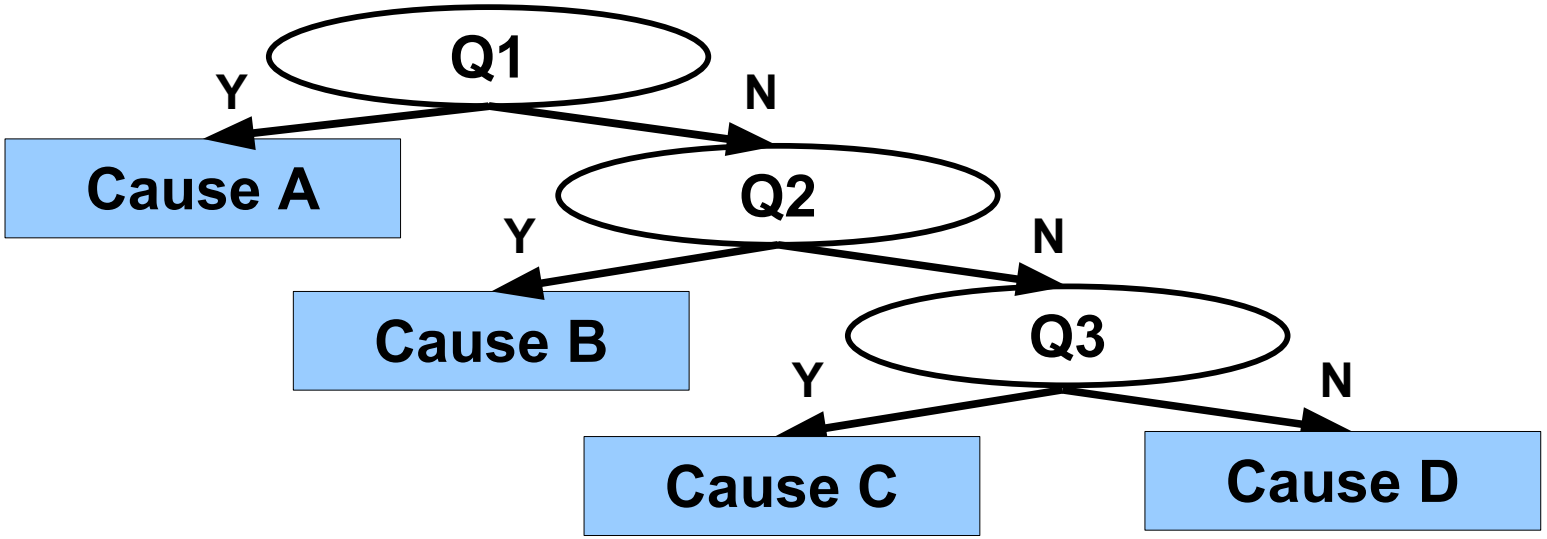

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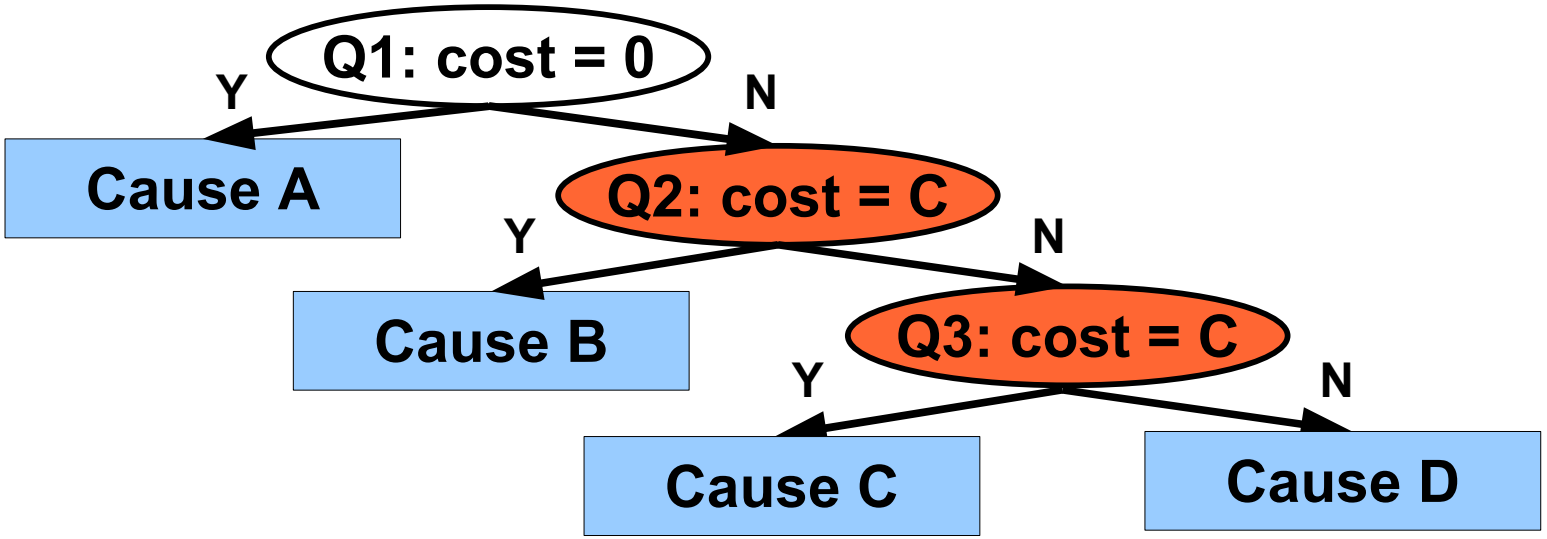

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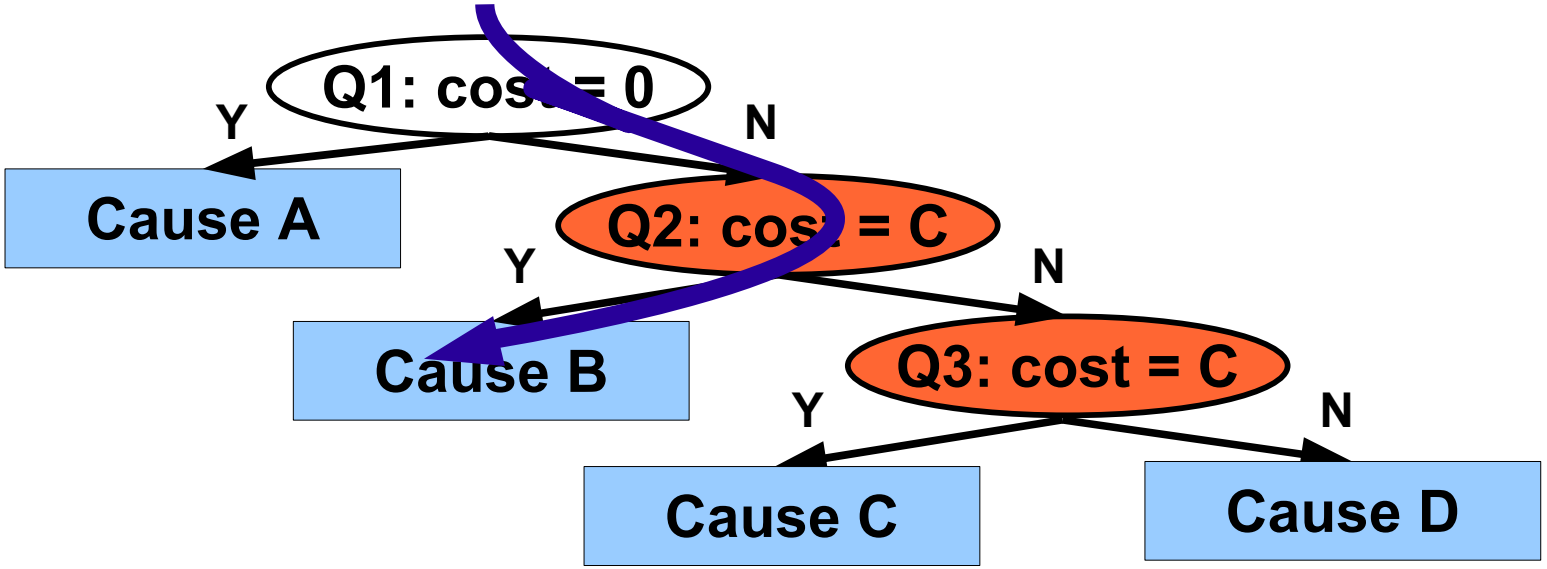

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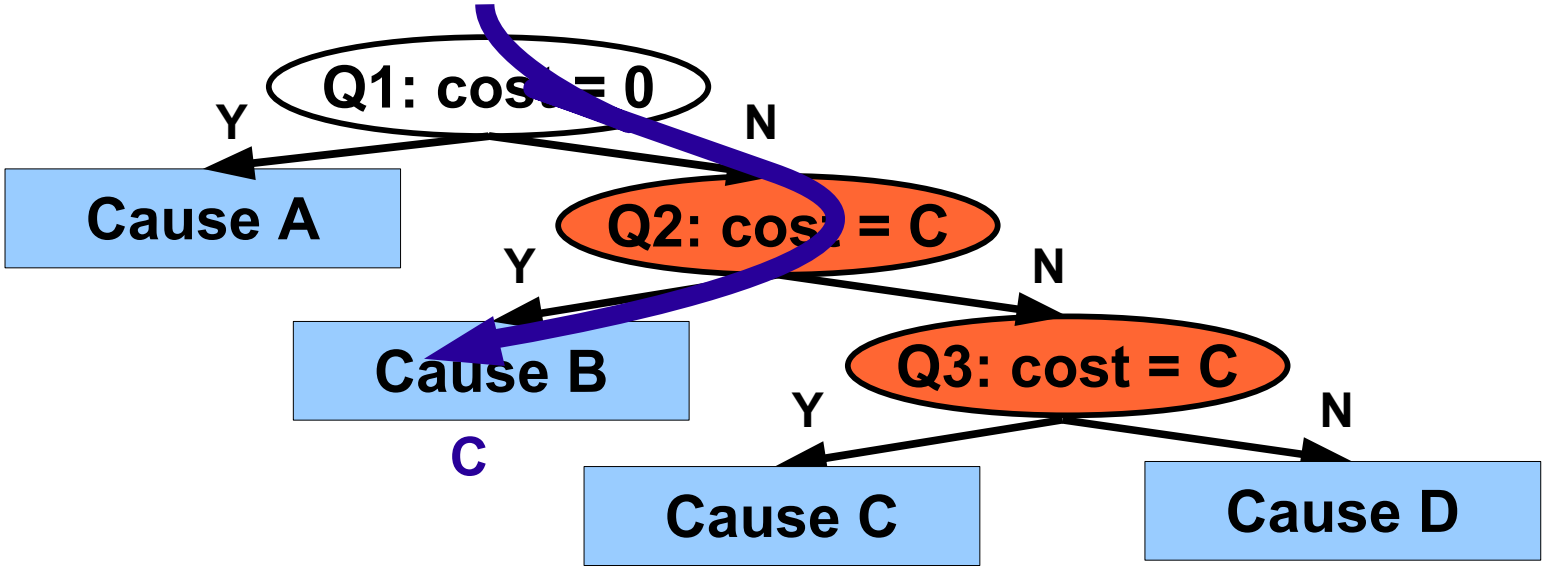

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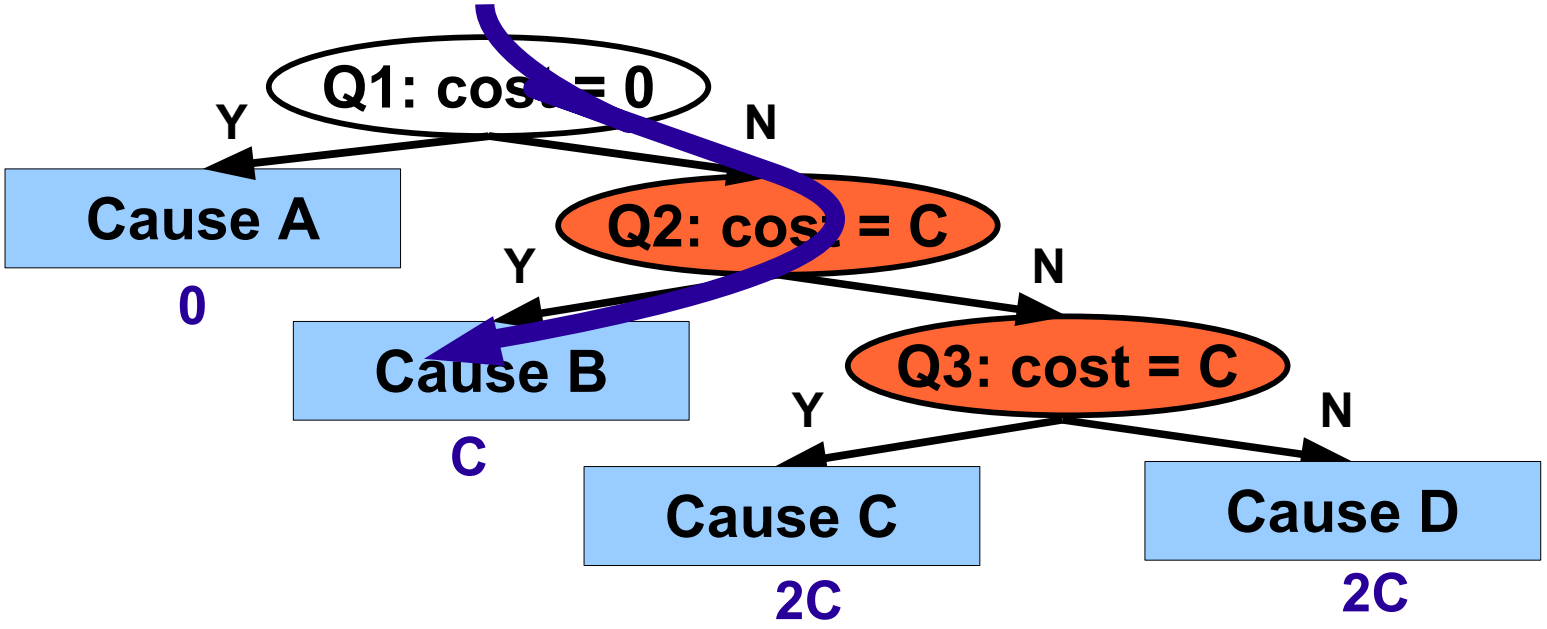

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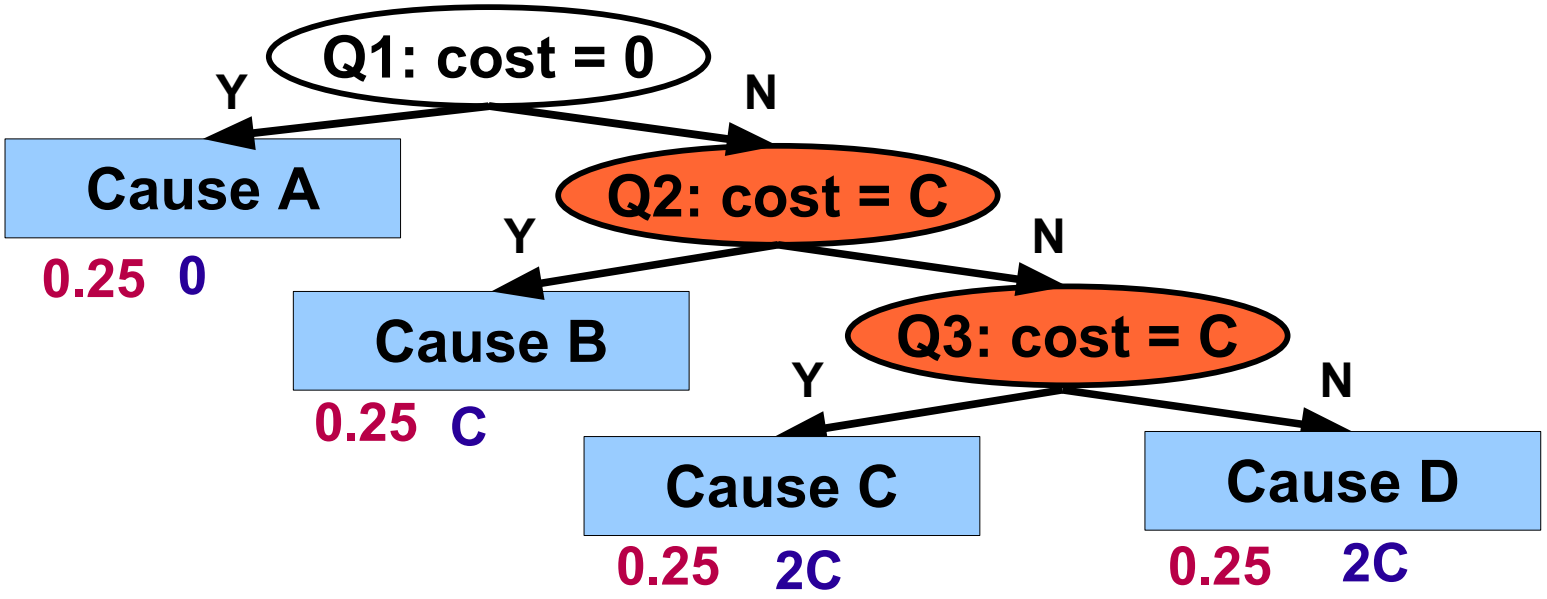

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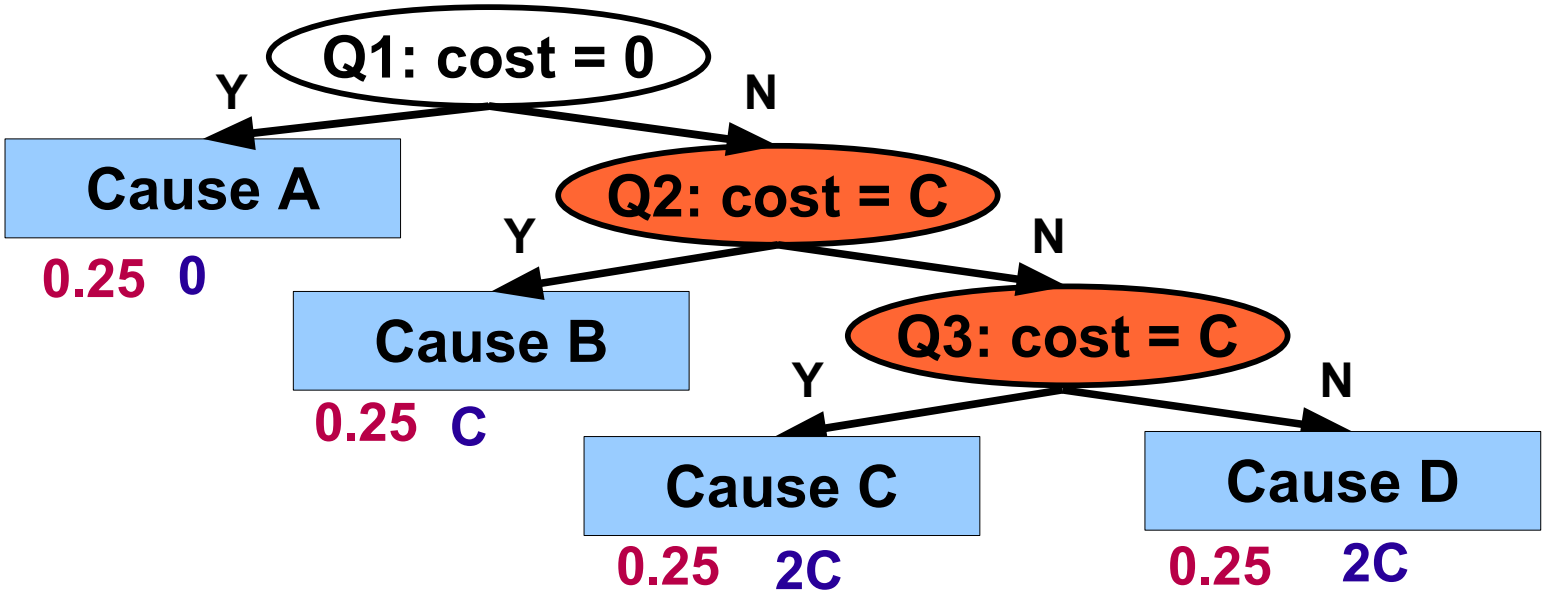
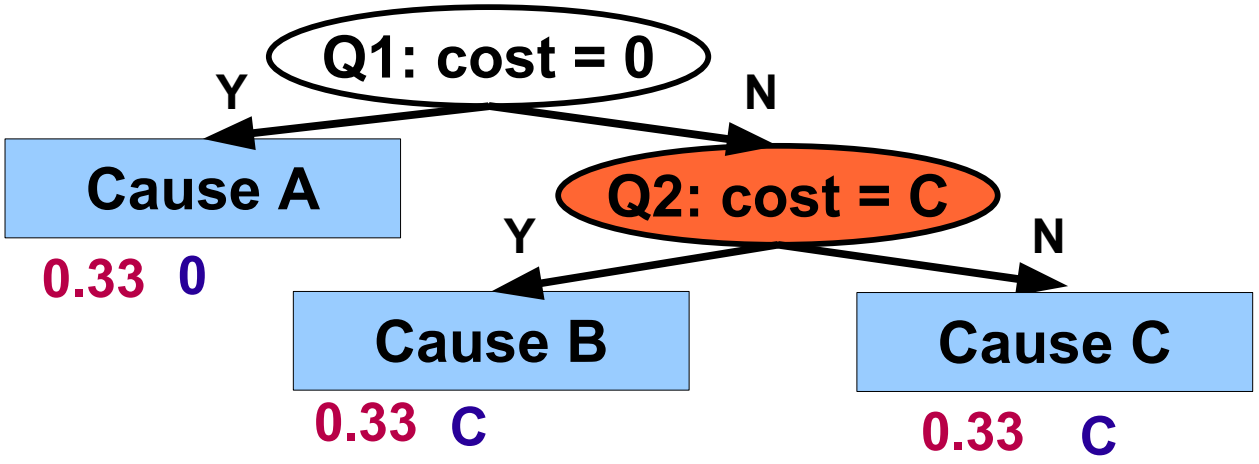


Visibility Cost = 1.25 C

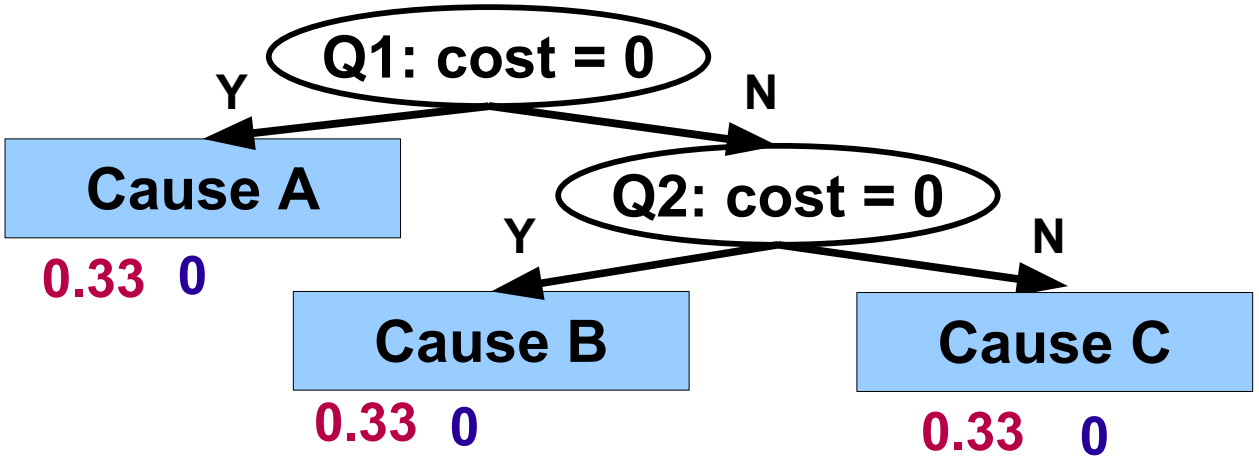
Increasing Visibility



Remove Leaves From the Tree

Visibility Cost = 0.66 C

Increasing Visibility



Reduce Cost of Questions

Visibility Cost = 0.00 C

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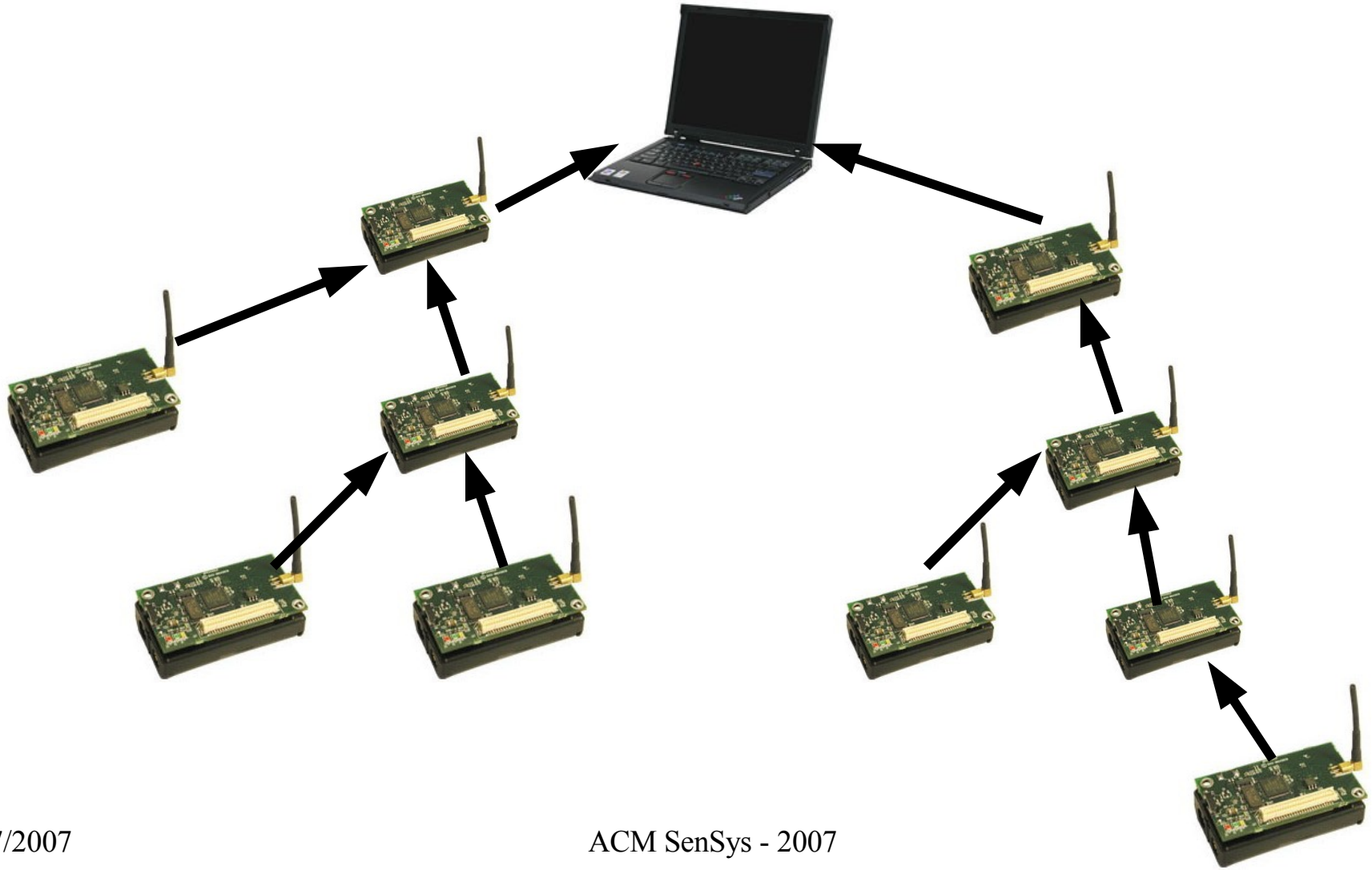
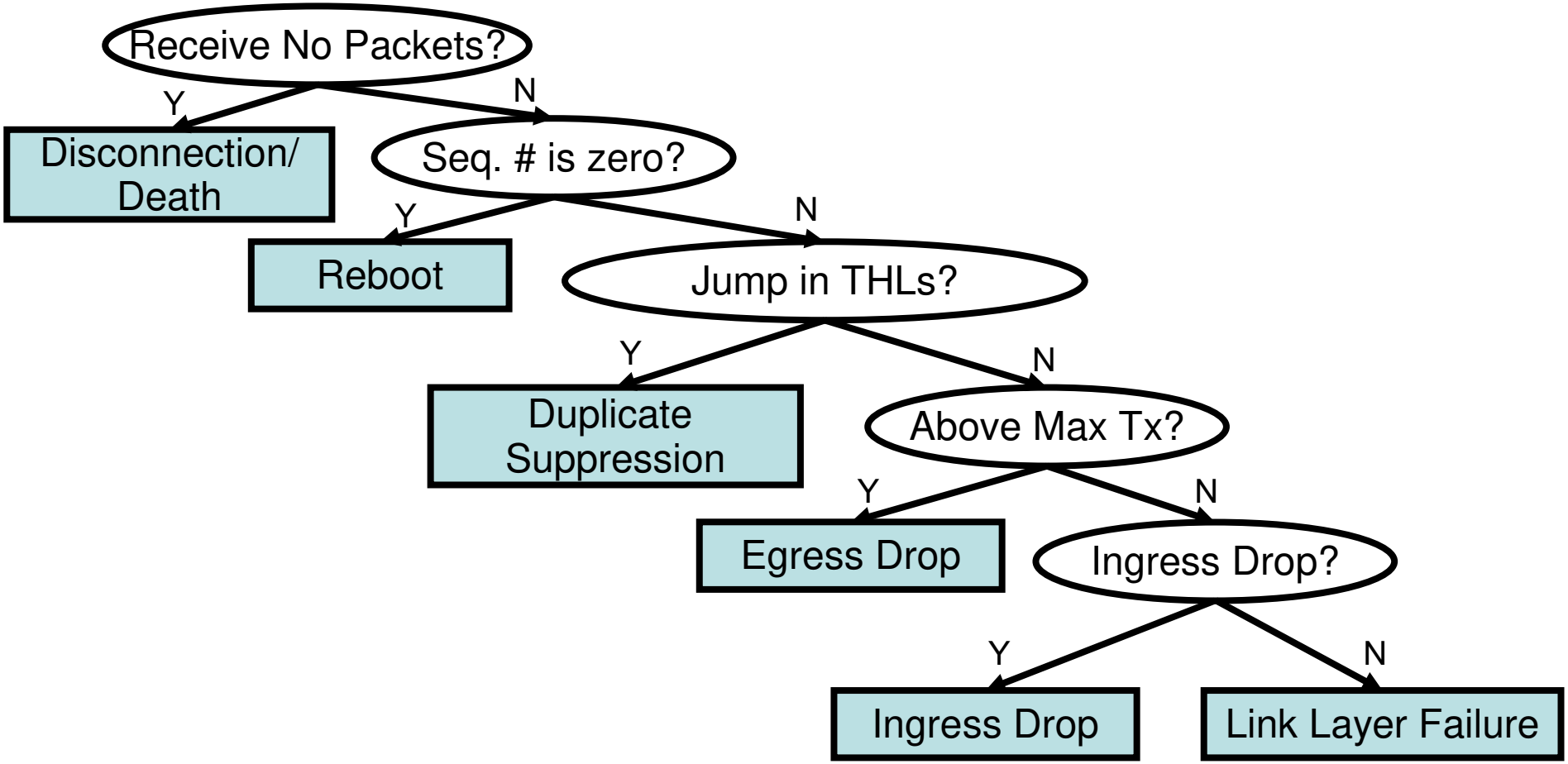
A Design Example: Pull Collection Protocol



Diagnosing Why Packets Were Lost



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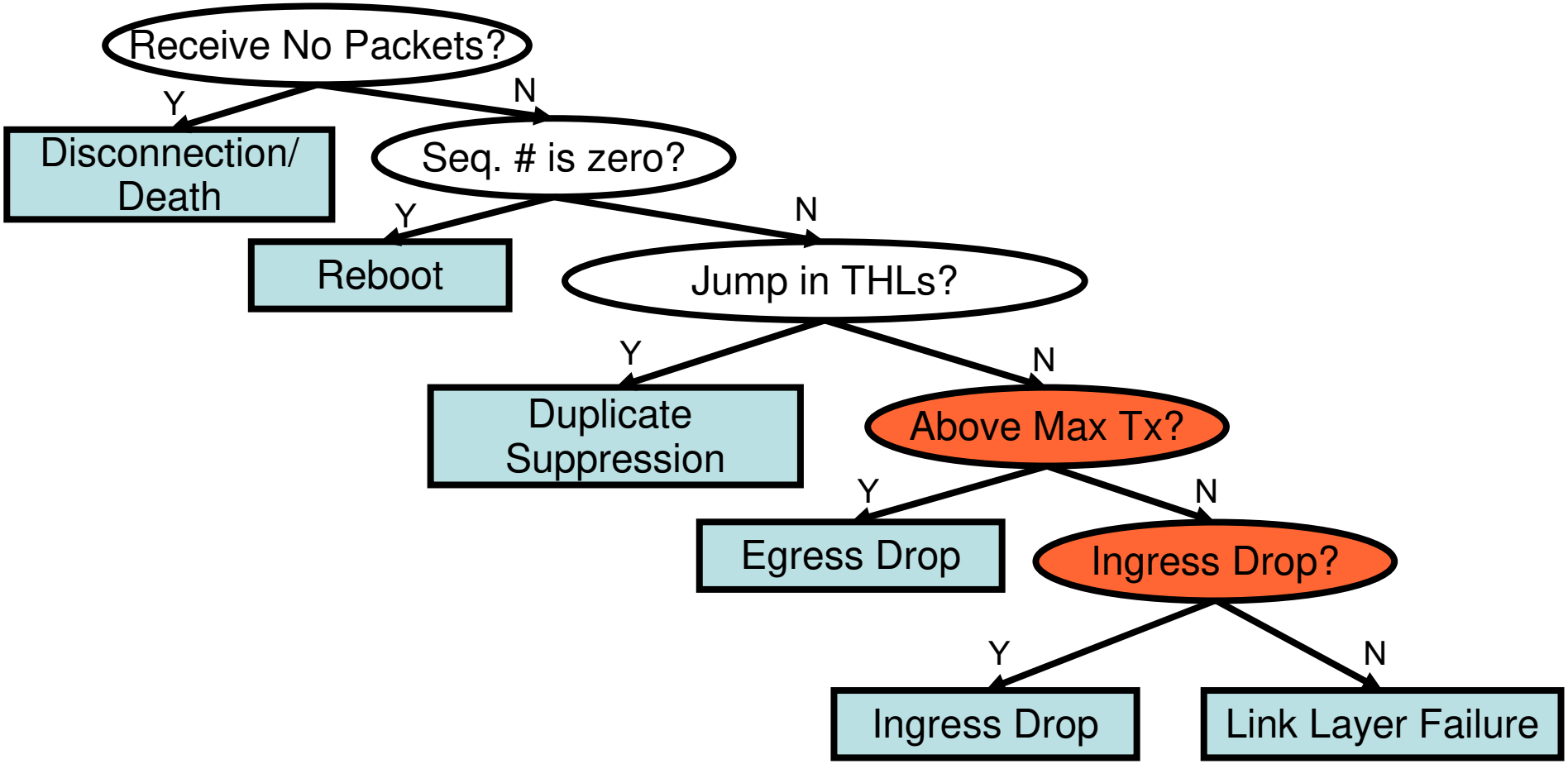
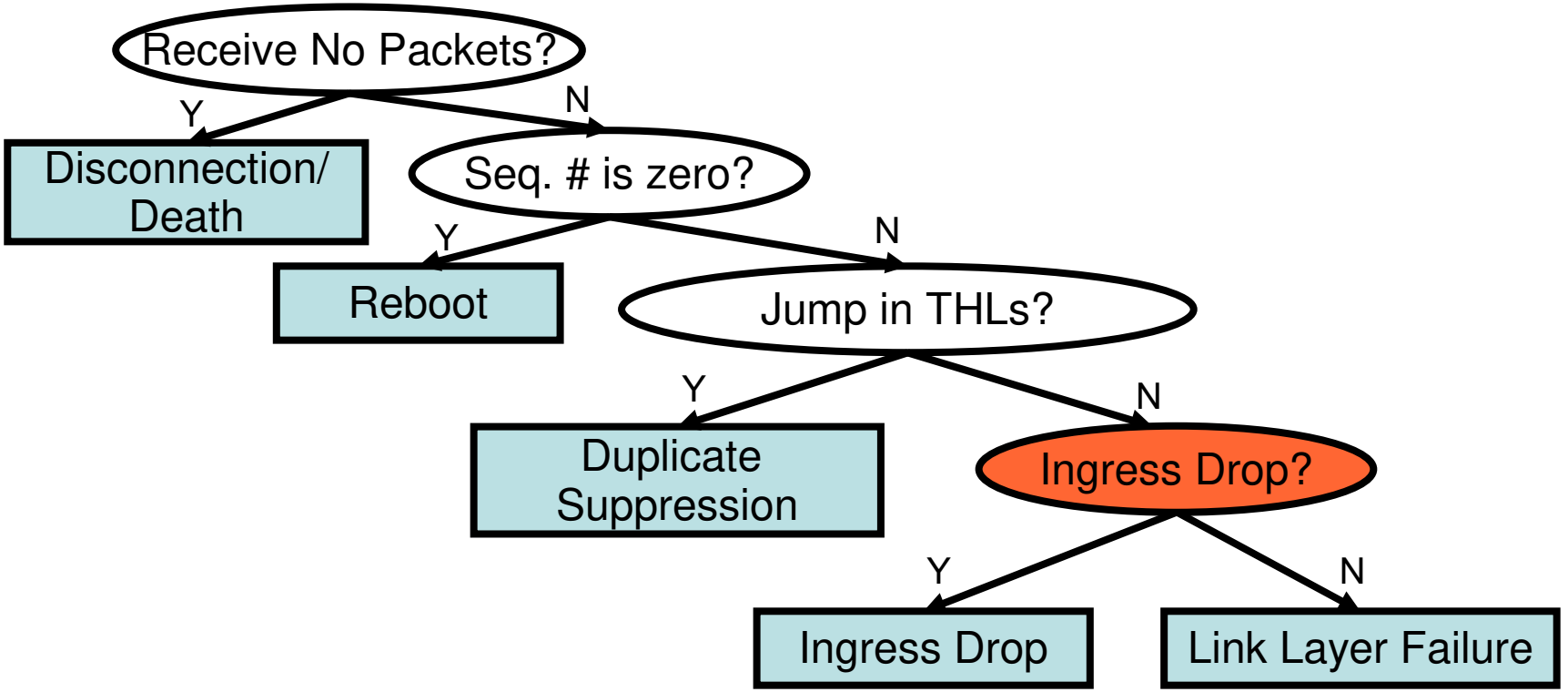


Eliminating Egress Drops



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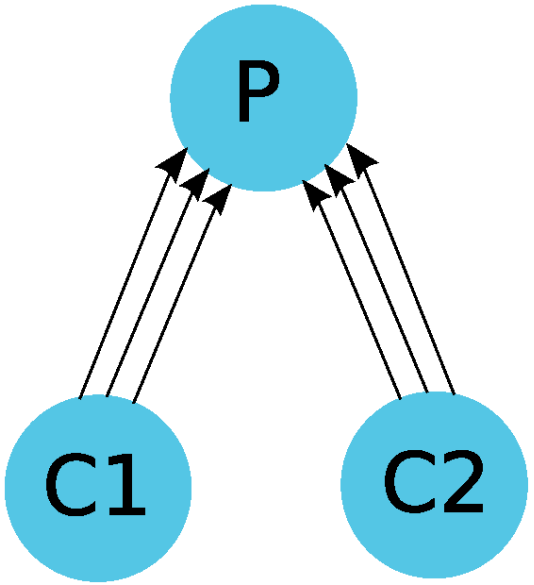
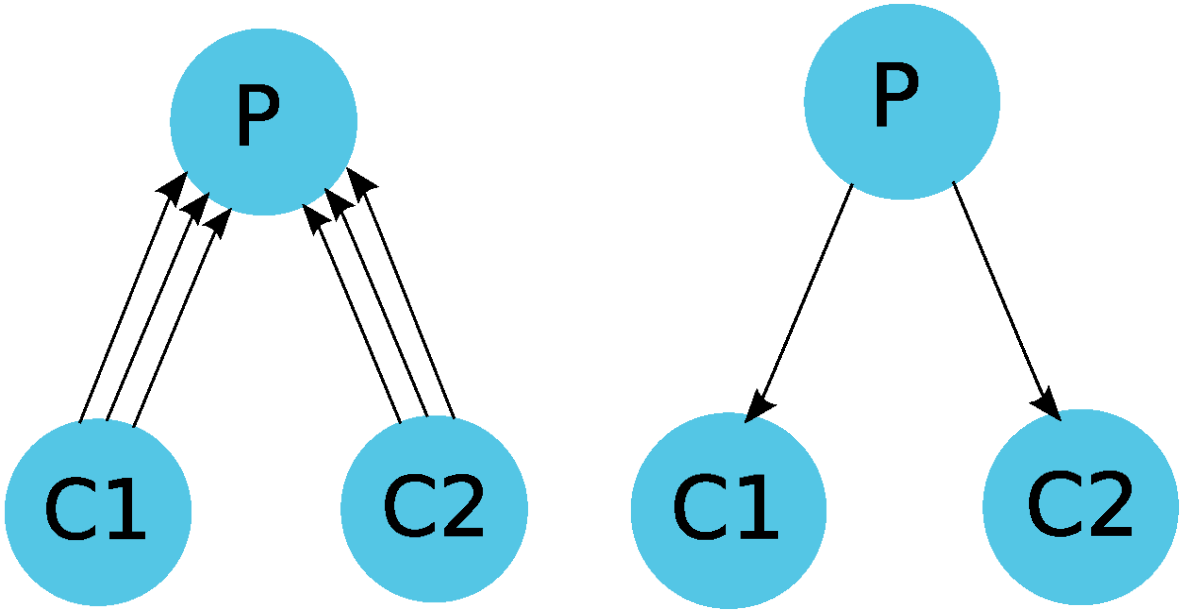


Traditional Rate Control

Eliminating Ingress Drops



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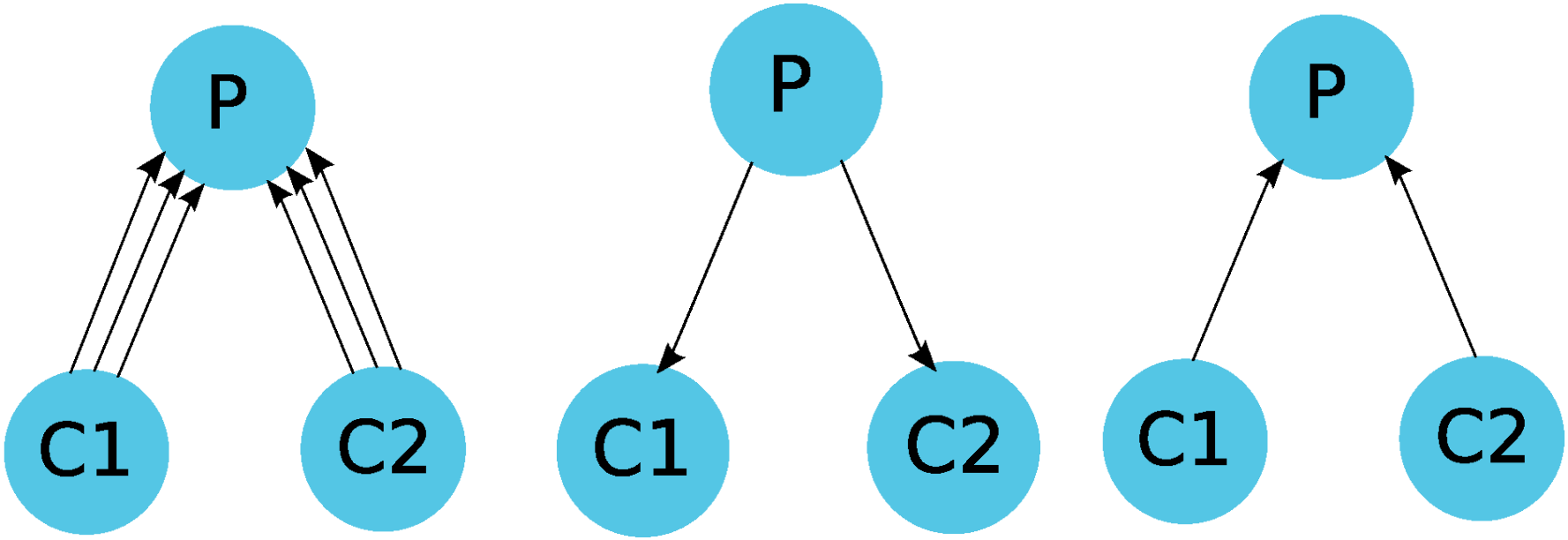

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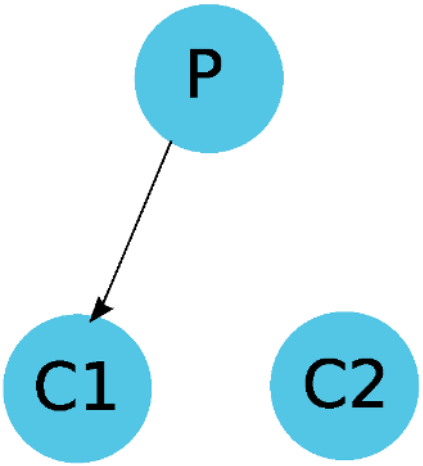

Pull-Based Rate Control

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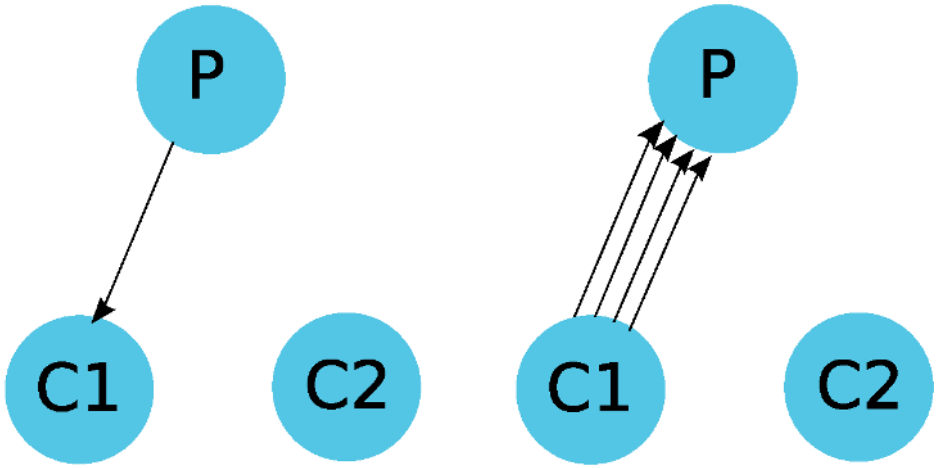

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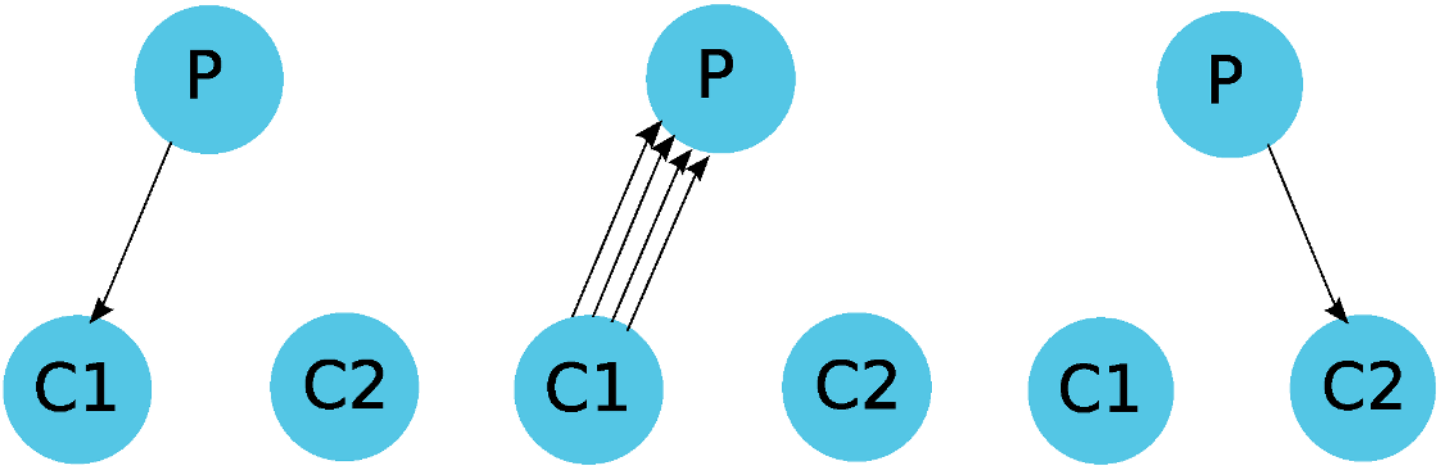

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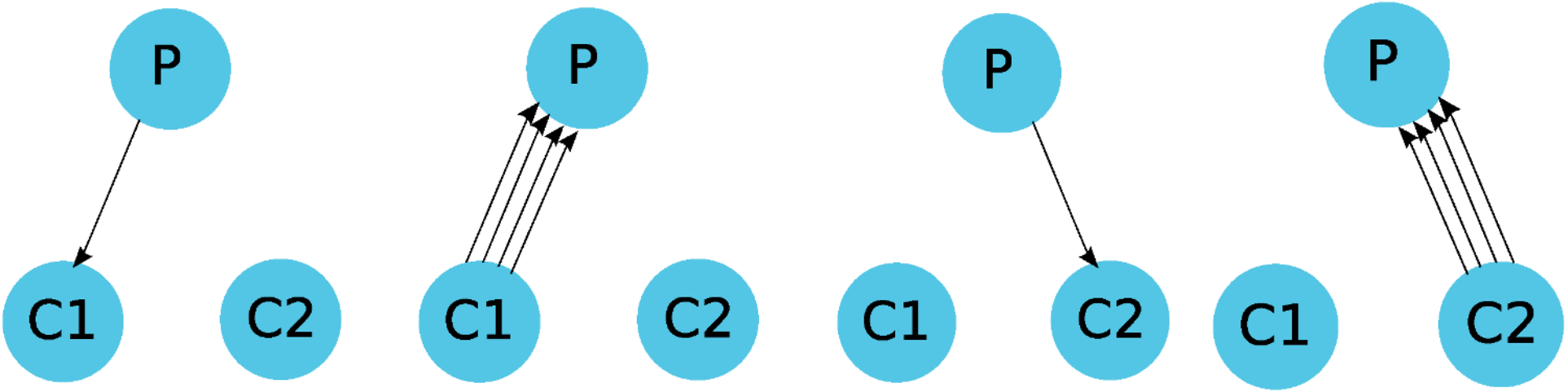

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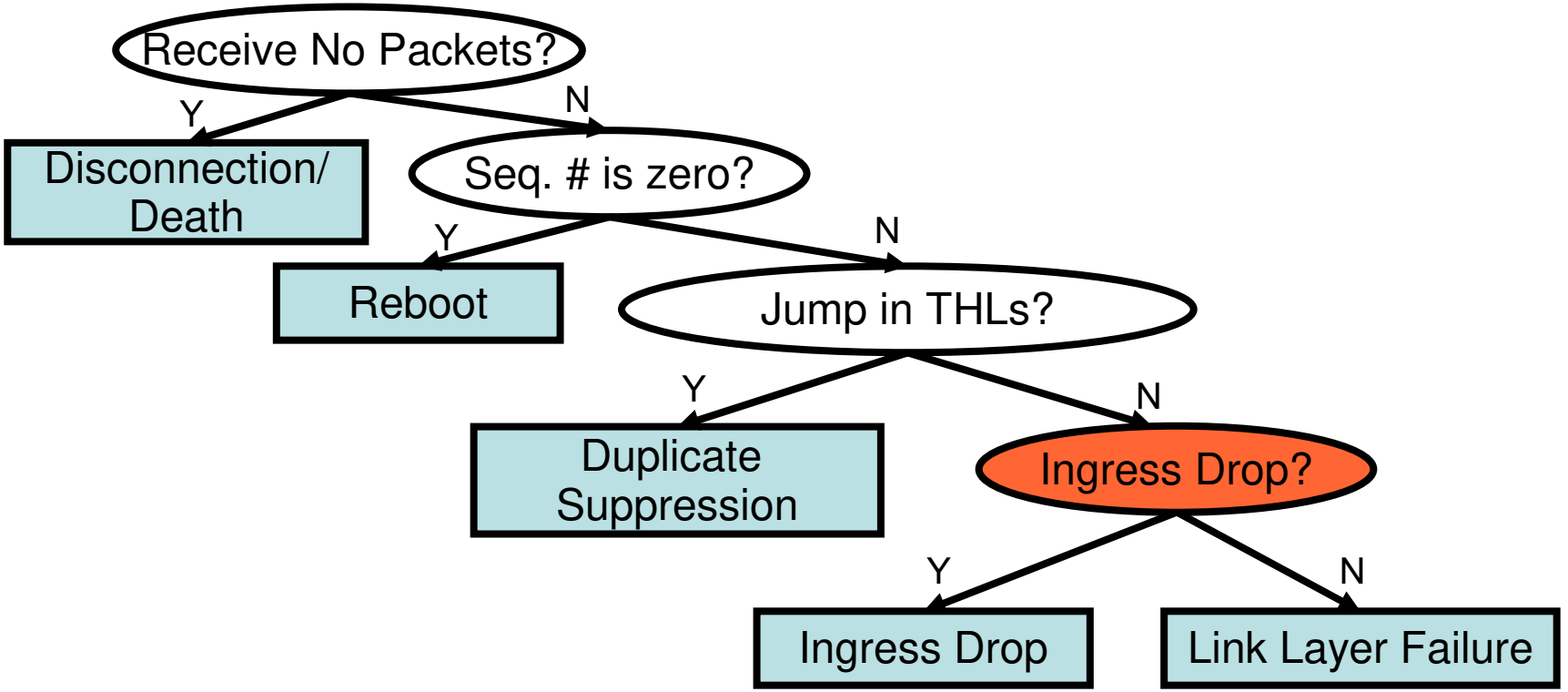

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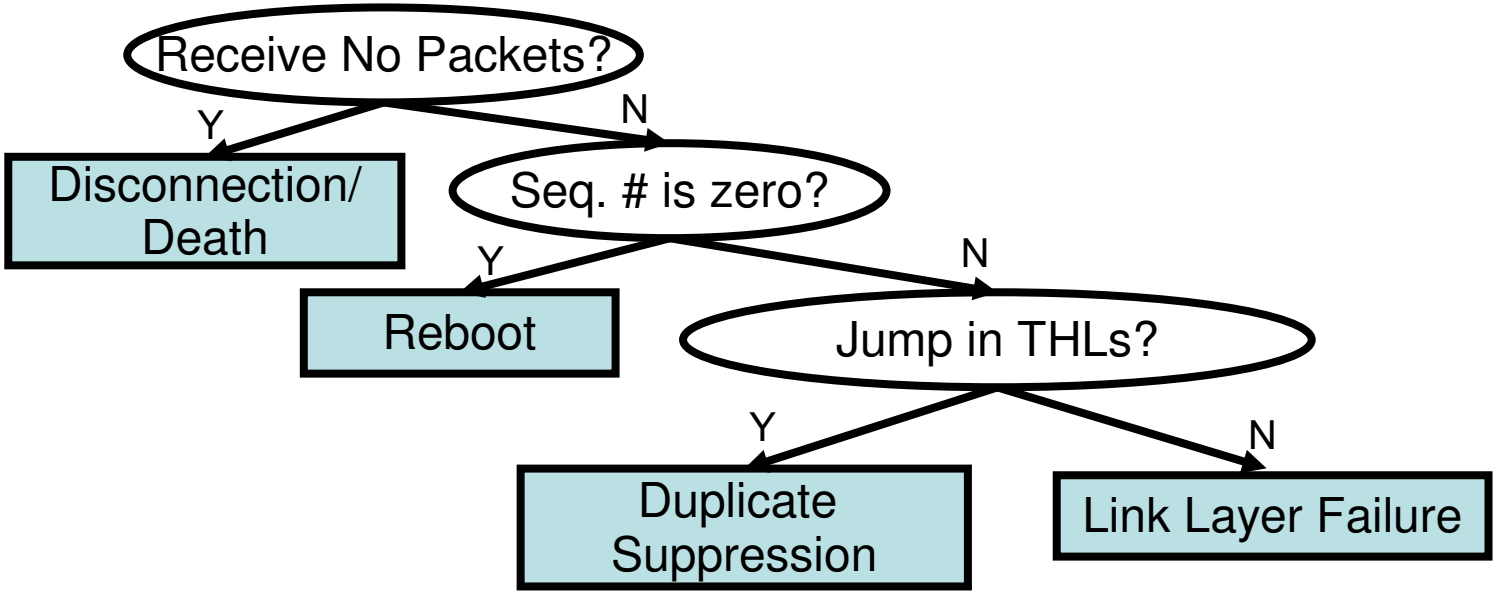
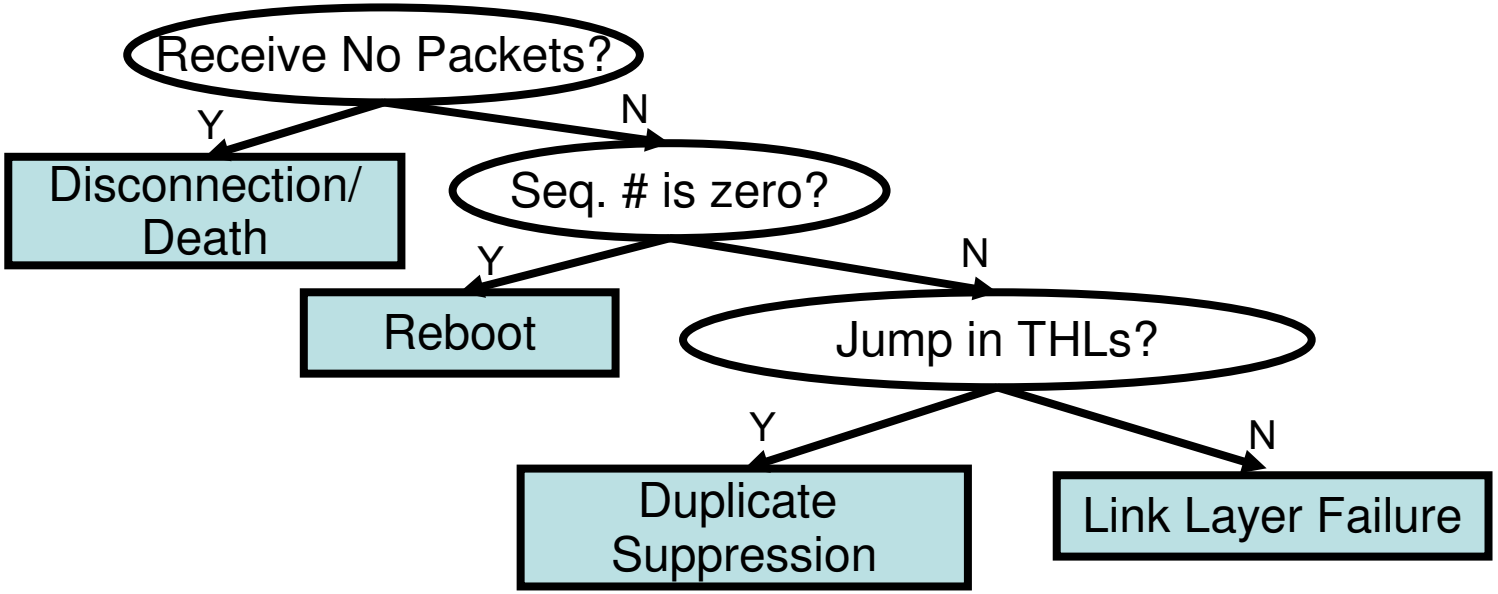


PCP Decision Tree



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

Evaluating PCP

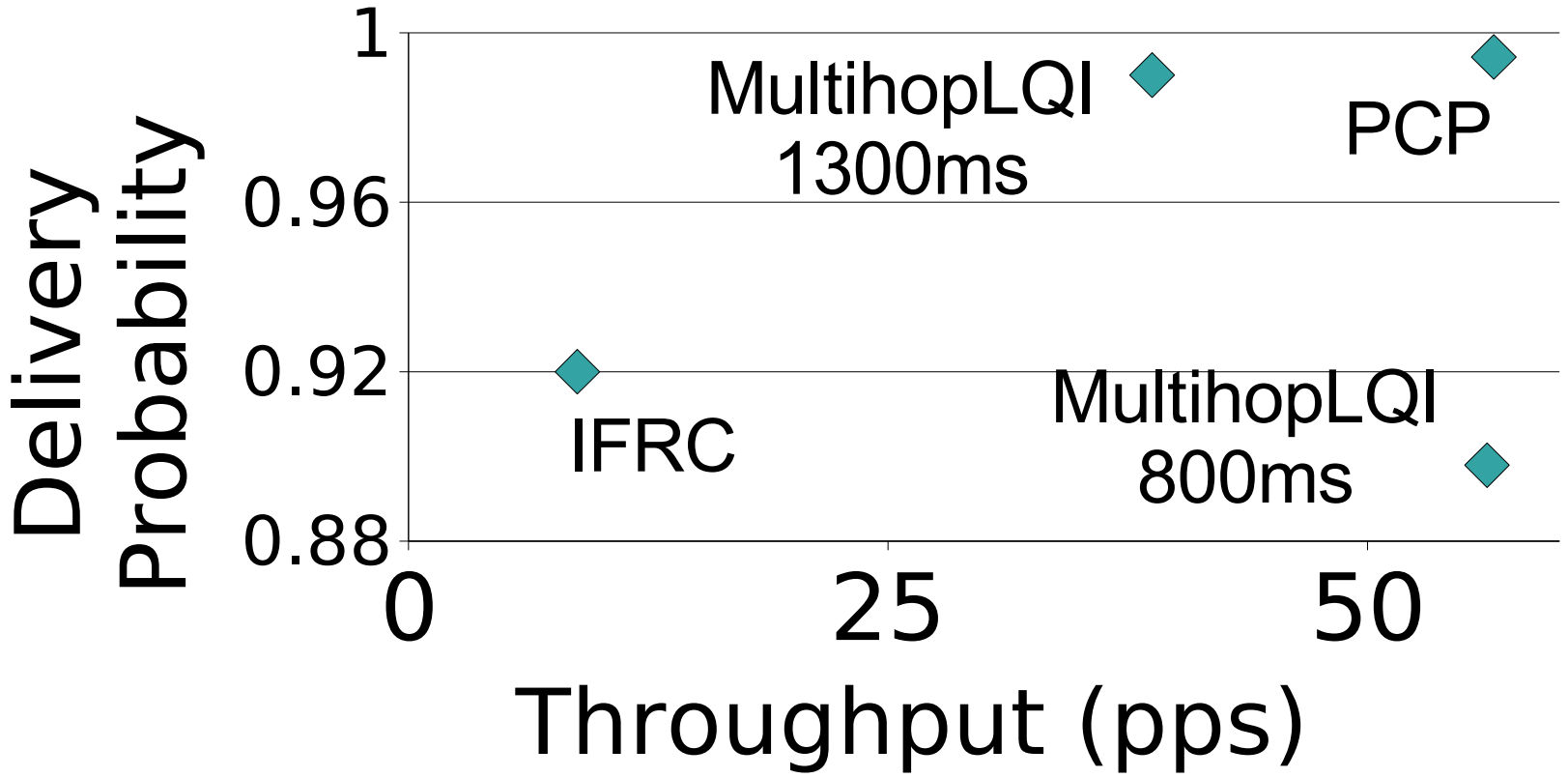
40-Node MoteLab Testbed

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

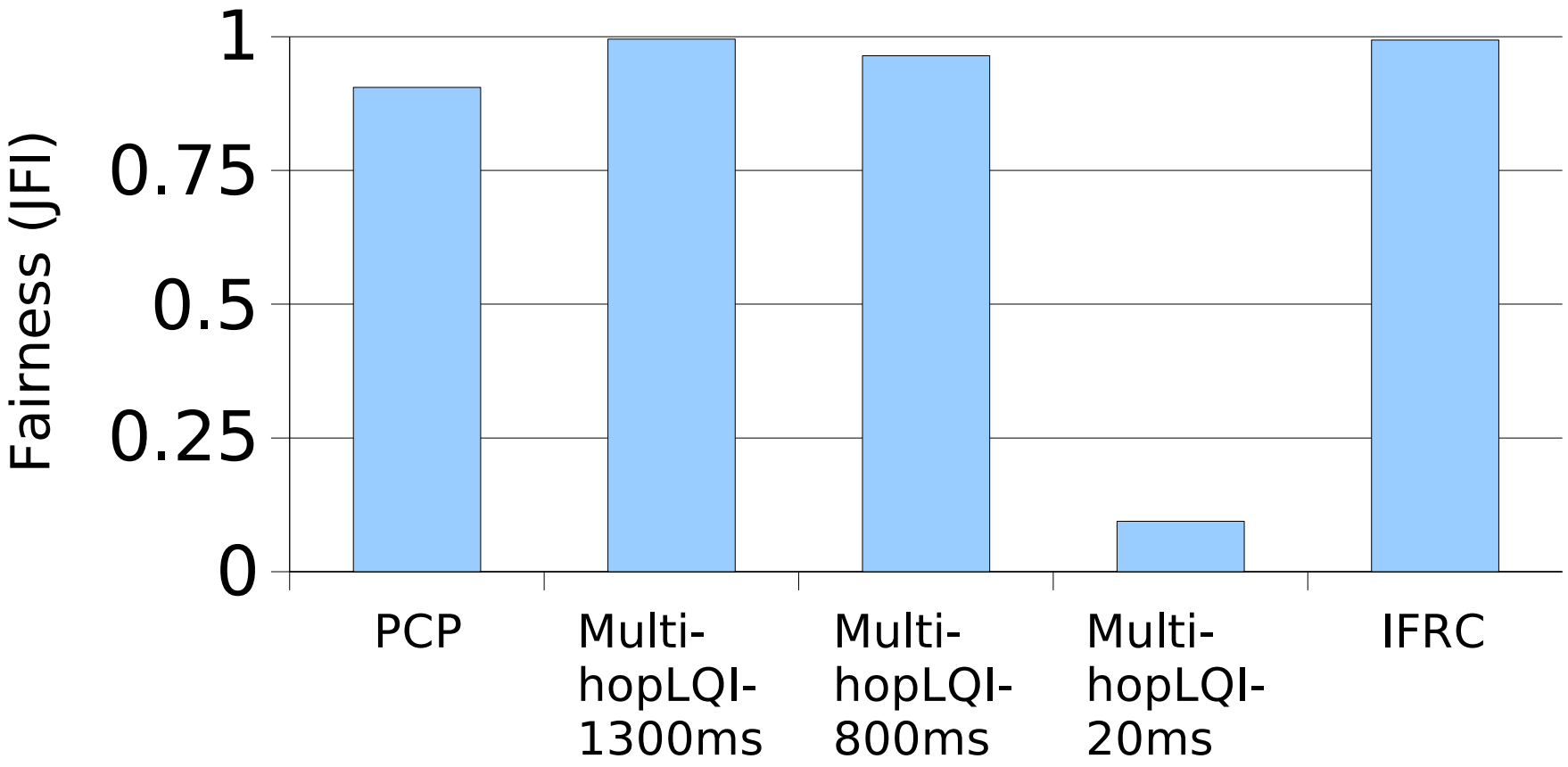
Metrics:

- Reliability
- Throughput
- Fairness
- Visibility

PCP Performance



PCP Fairness



PCP Visibility

- MultihopLQI visibility cost at 800ms interval: 1.615C
- PCP visibility cost:

  0.00 C

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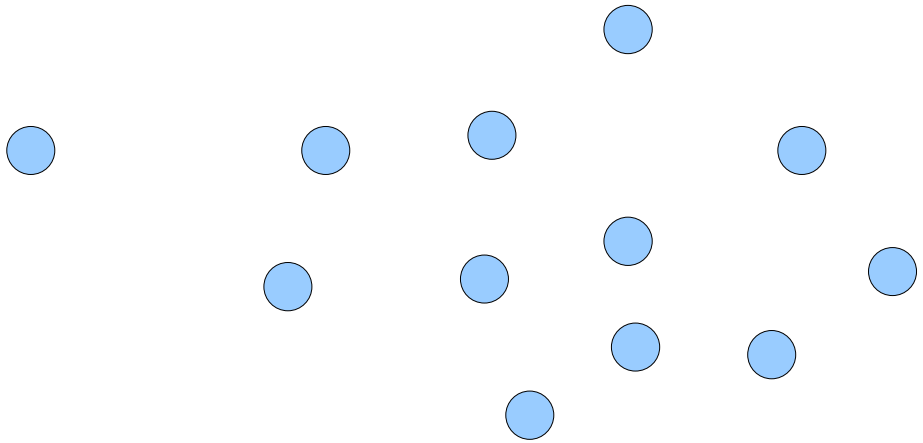
Applying Visibility: Deluge

- 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



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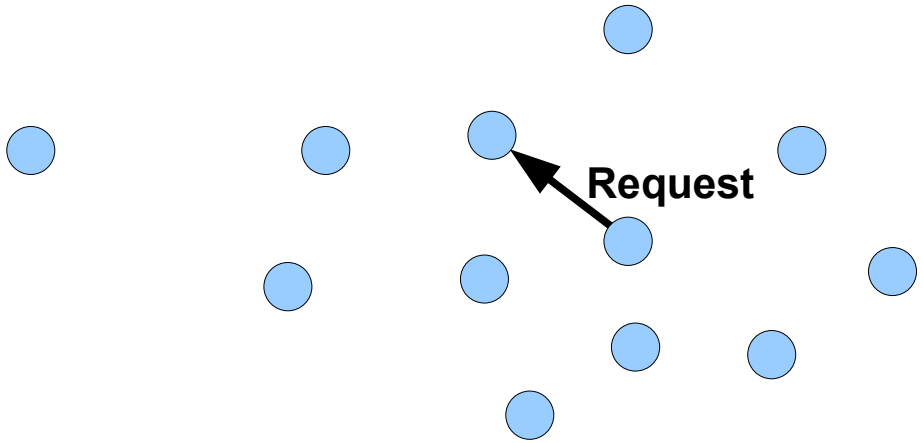

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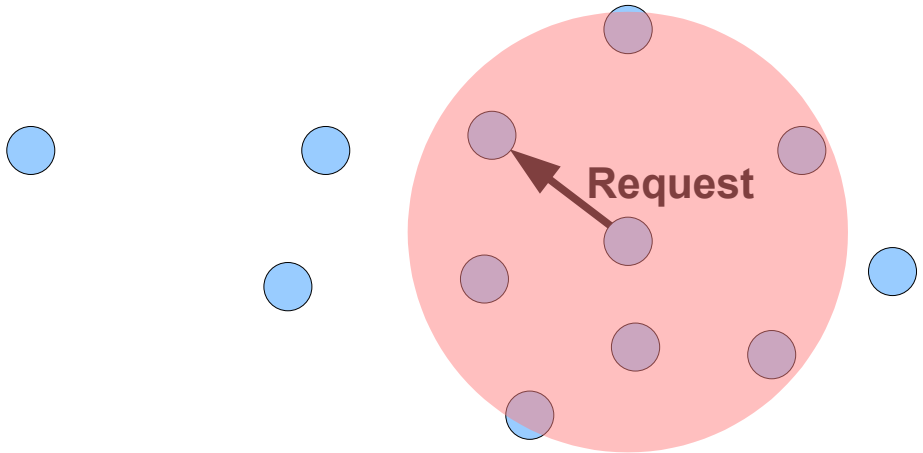

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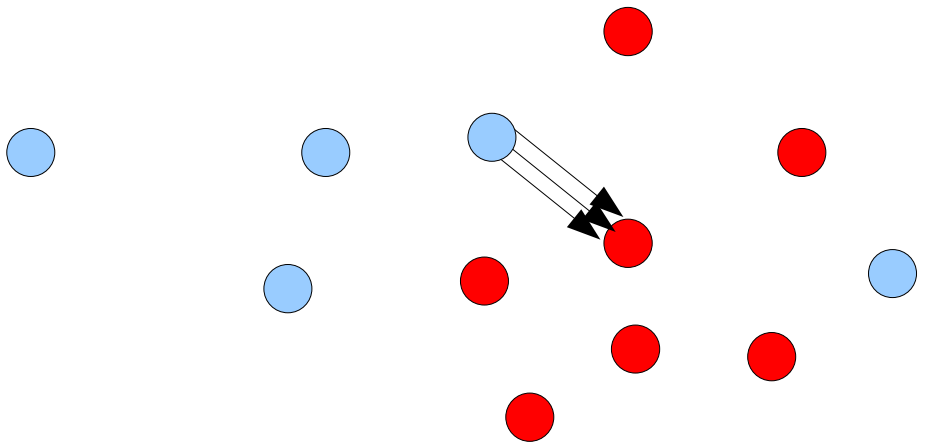


V-Deluge Visibility

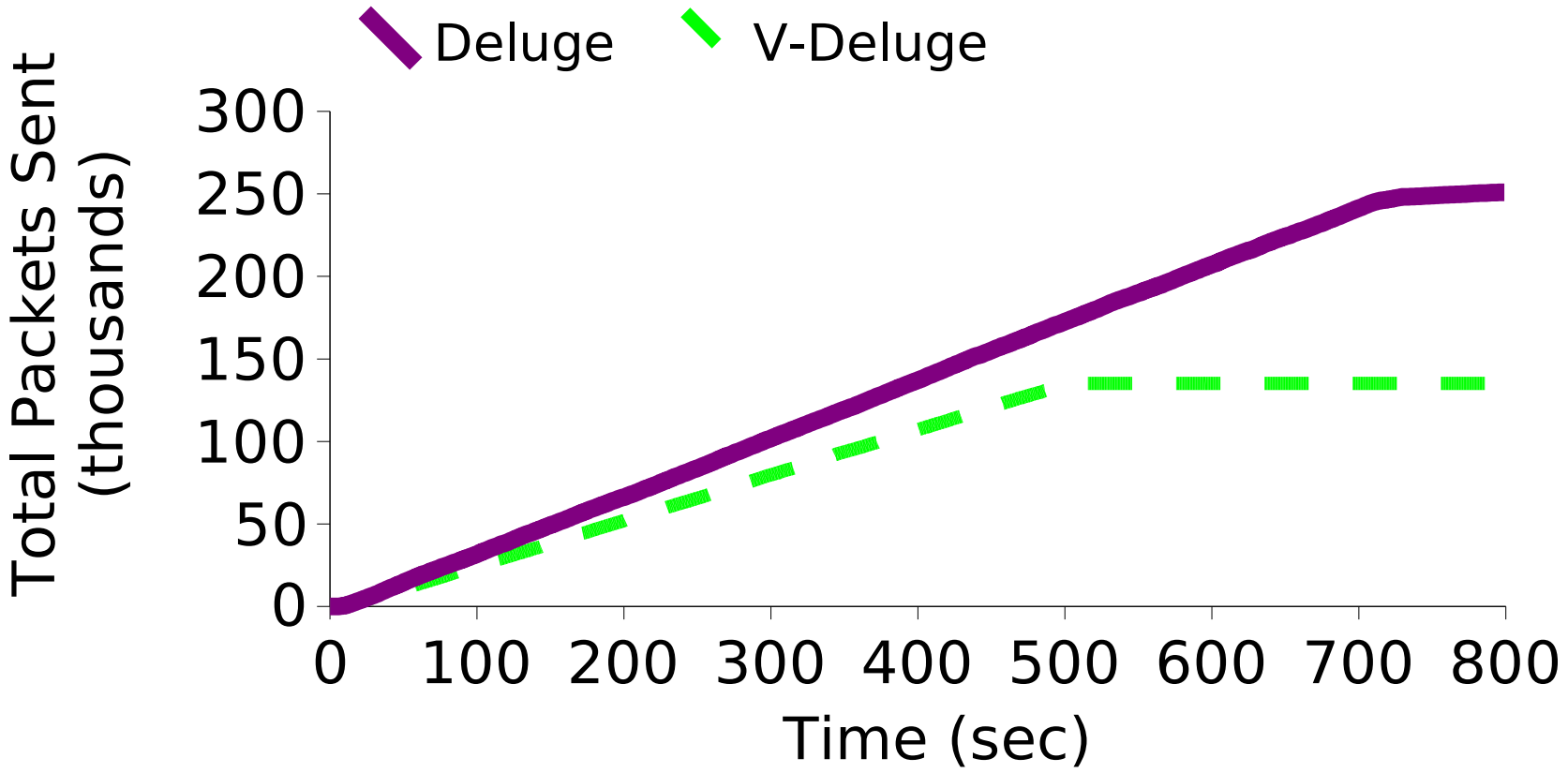
- Deluge Visibility:

  1.02 C

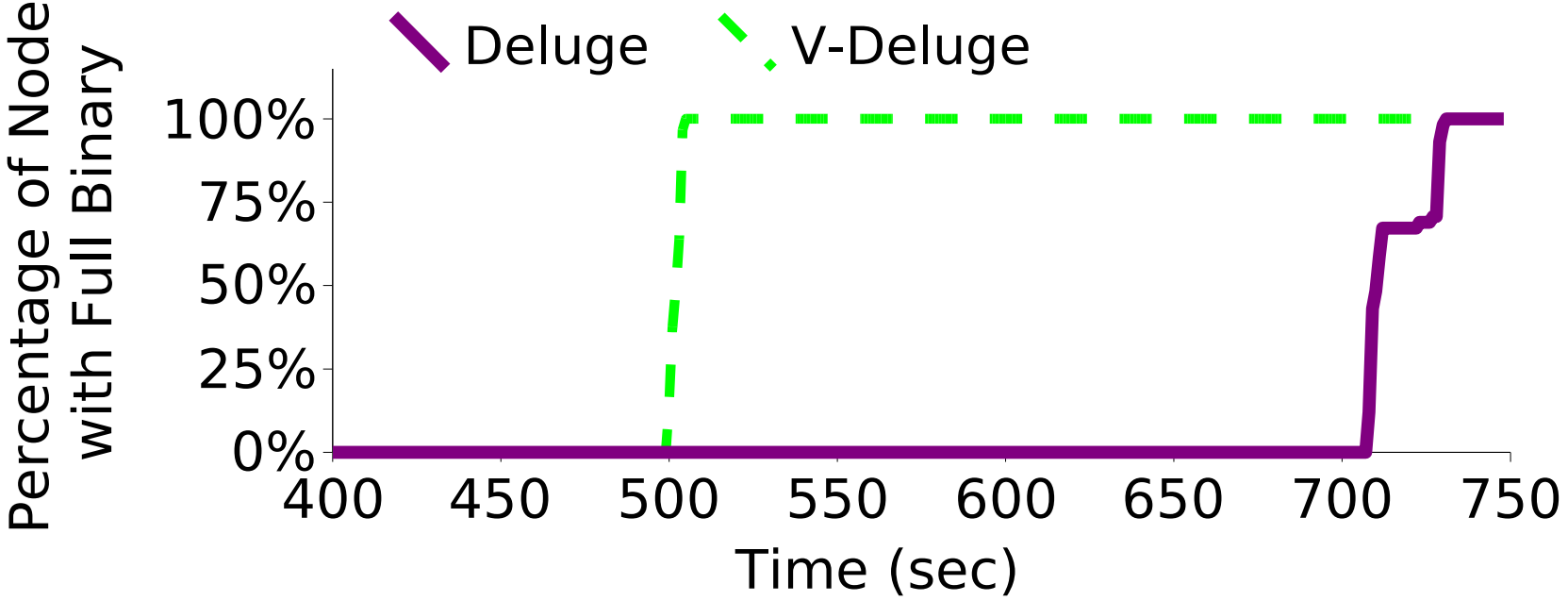
- V-Deluge Visibility:

  1.00 C

V-Deluge Performance



V-Deluge Performance



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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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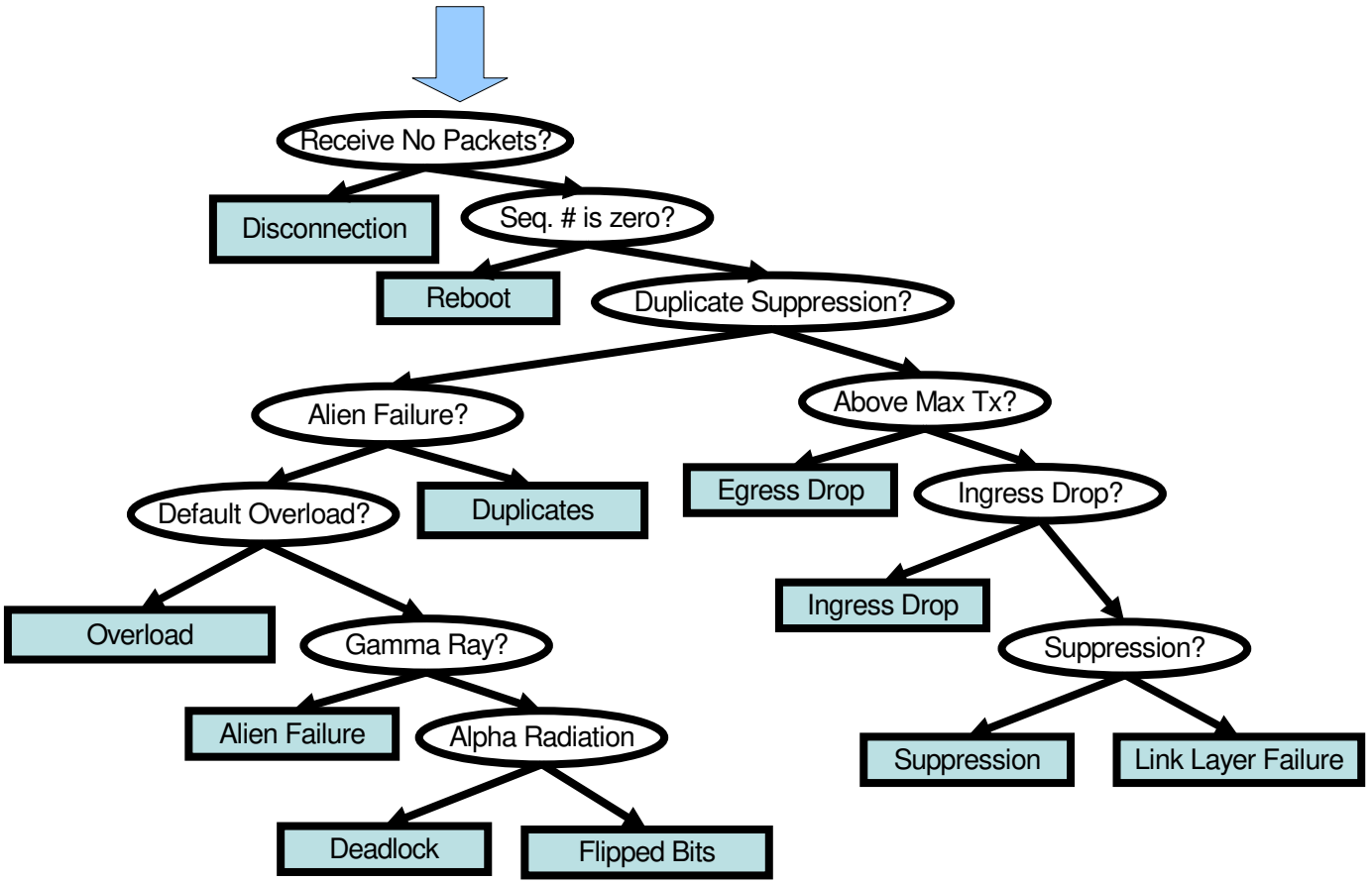
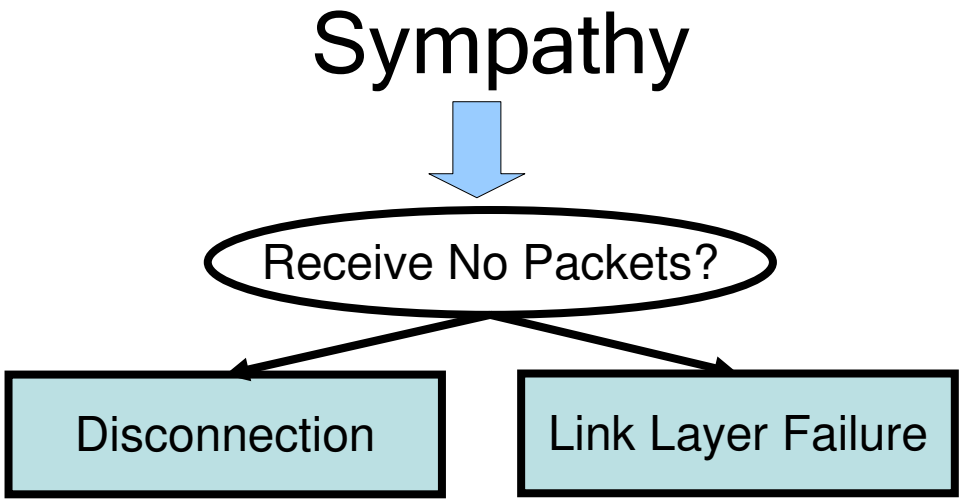
Extra Slides

Management and Debugging

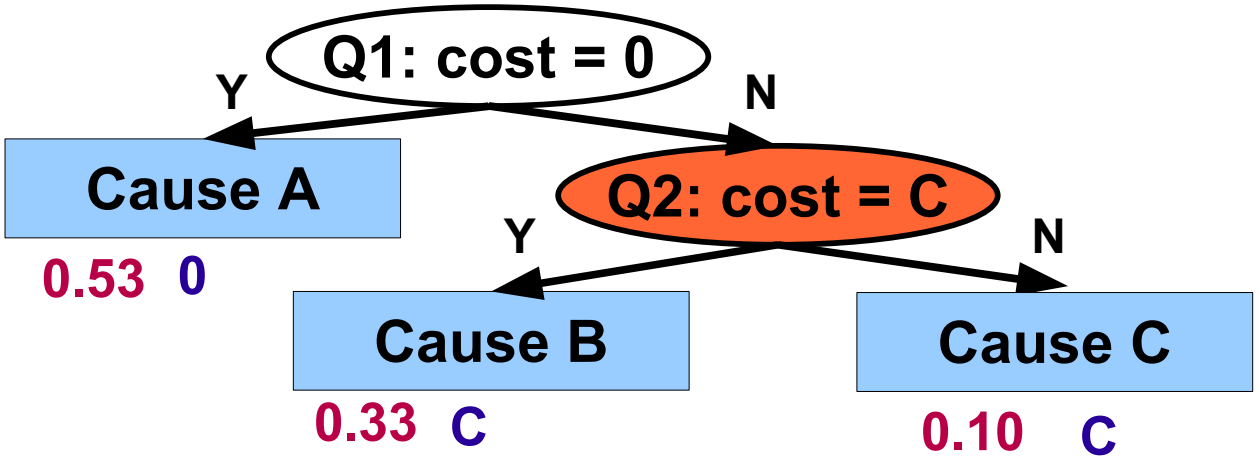
Sympathy



Management and Debugging



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?”