Simplifying Datacenter Network Debugging with PathDump



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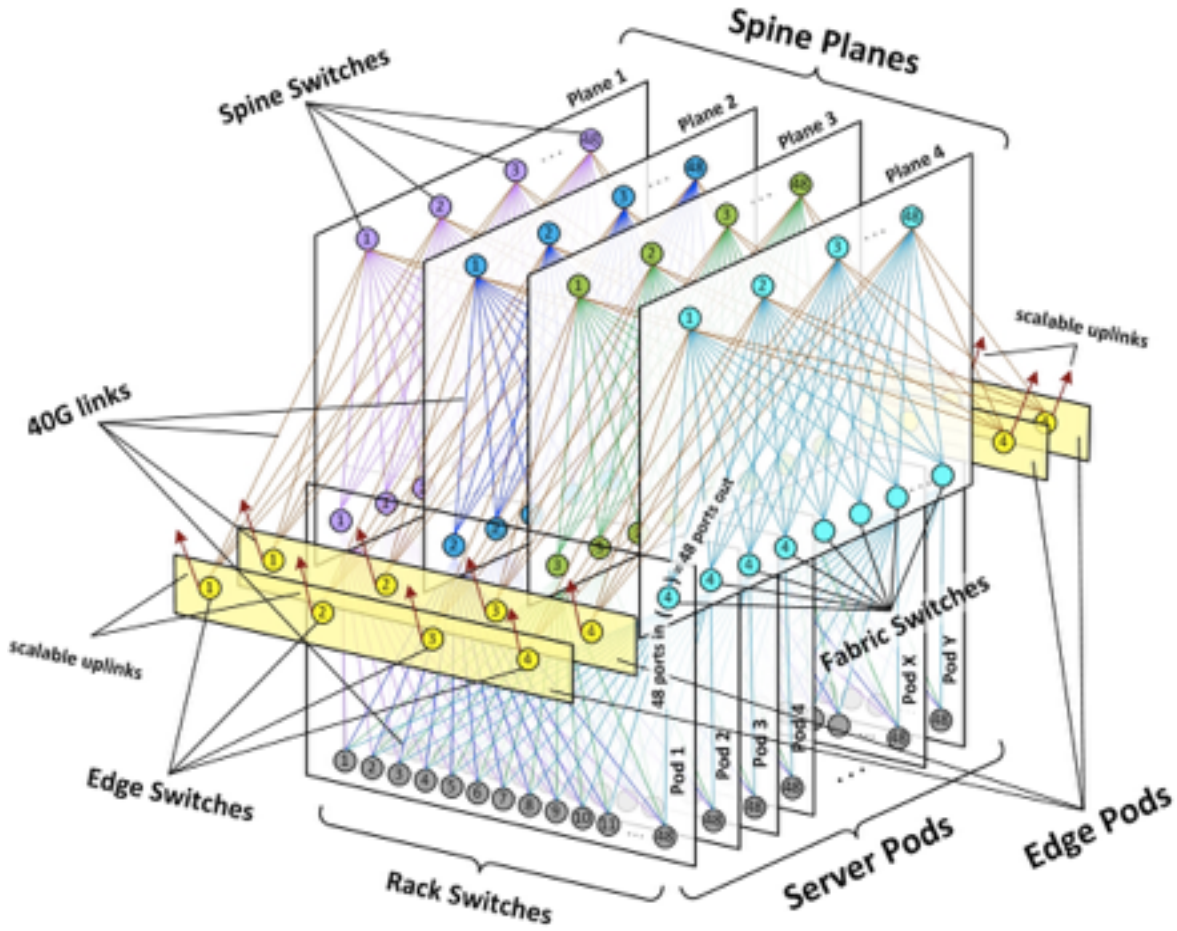
†University of Edinburgh, ‡Cornell University

Datacenter networks are complex

- Increasingly larger scale
  - Over 10k switches, 100k servers
  - Each server with 10 to 40 Gbps
  - Aggregate traffic > 100 Tbps



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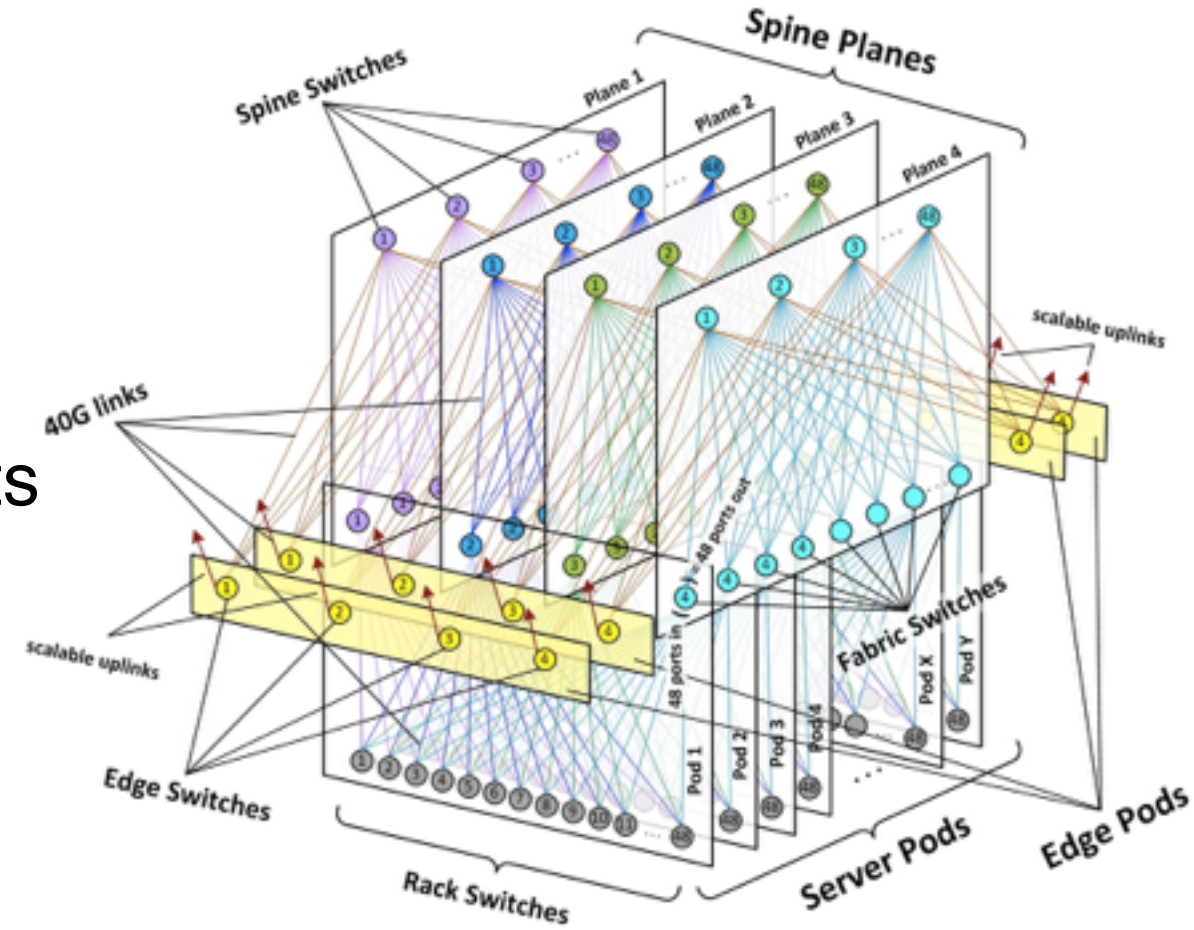

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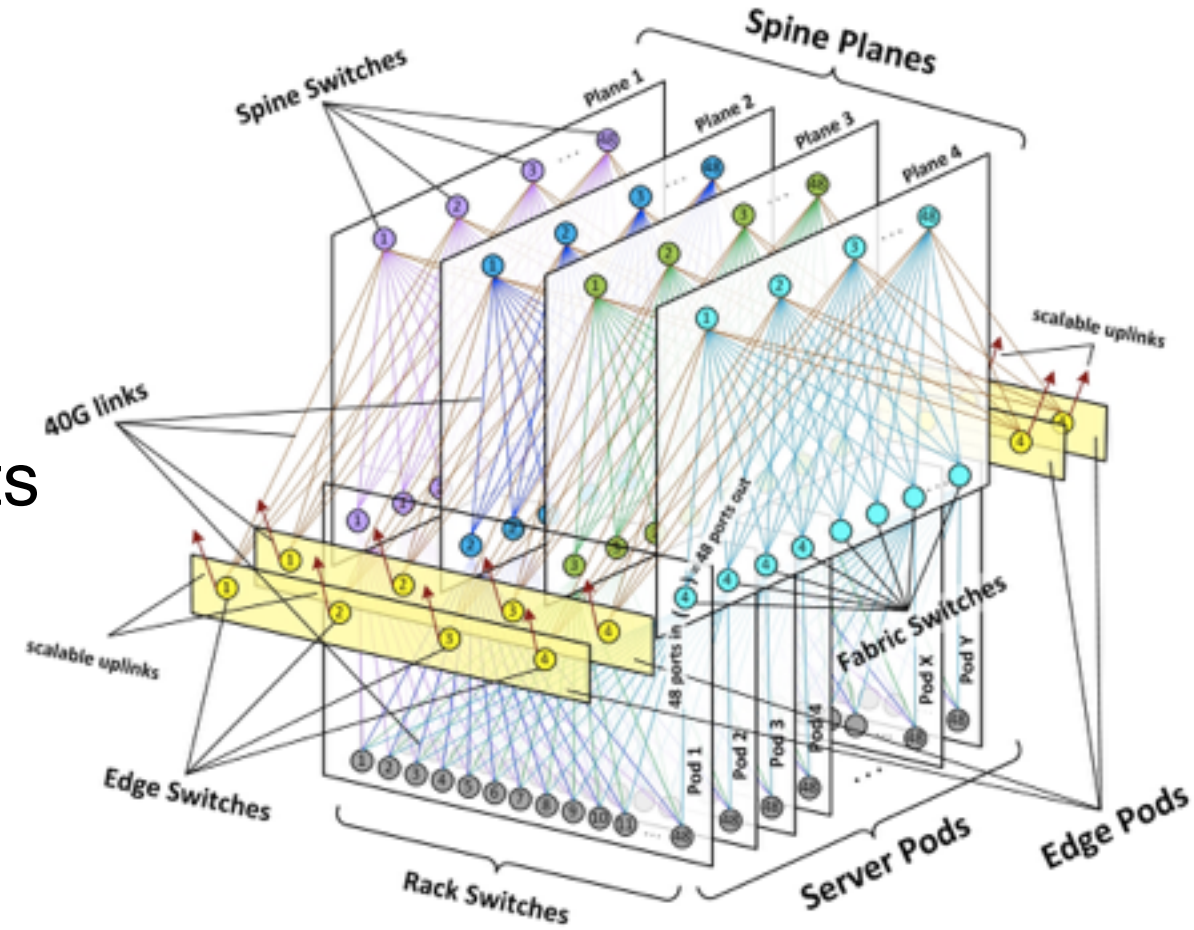
- Complex policies
  - Security, isolation, etc.
- Network programmability
  - Too many possible configurations



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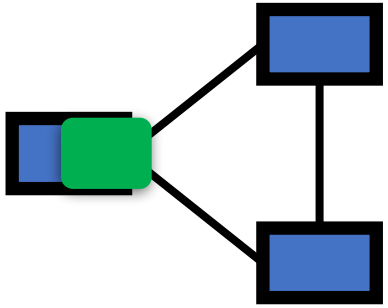
Network problems are inevitable

Loops



Failures, bugs

- Result: **Mismatch** between network behavior and operator intent

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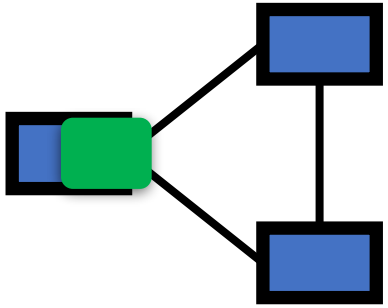

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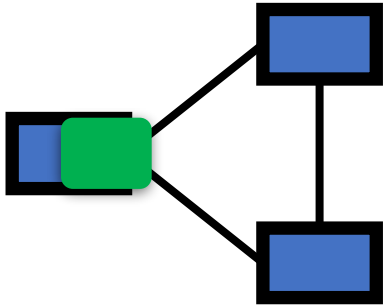

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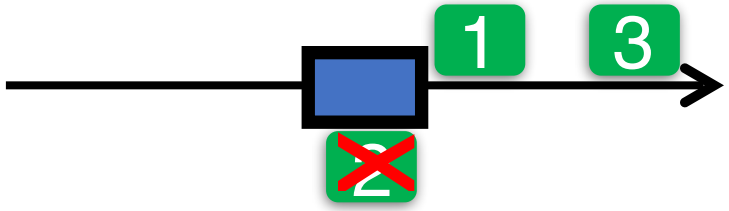
Silent random packet drops



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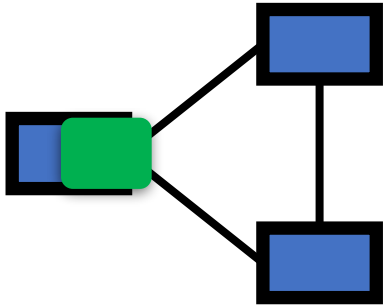

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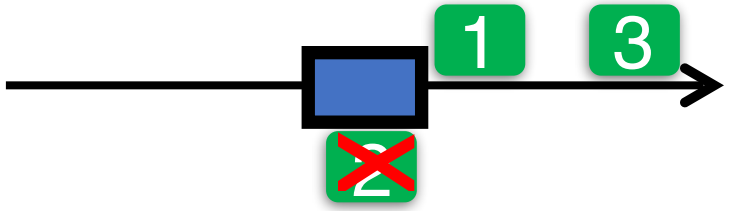

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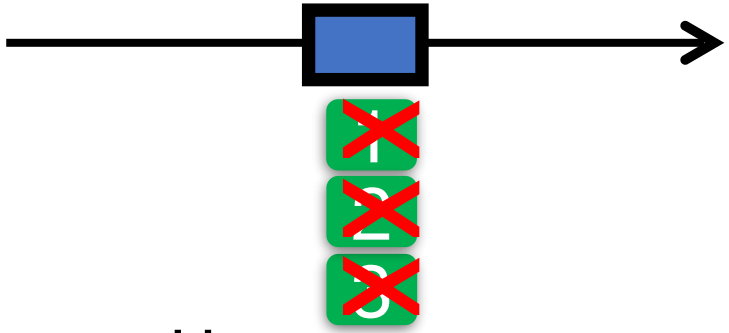

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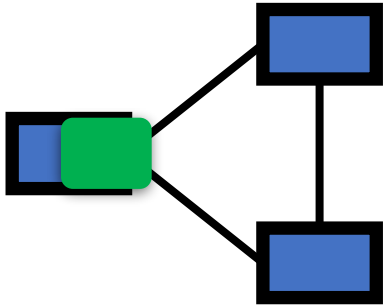

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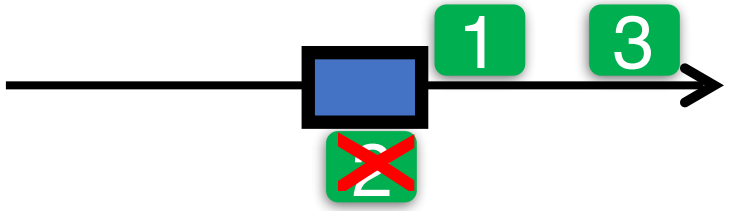

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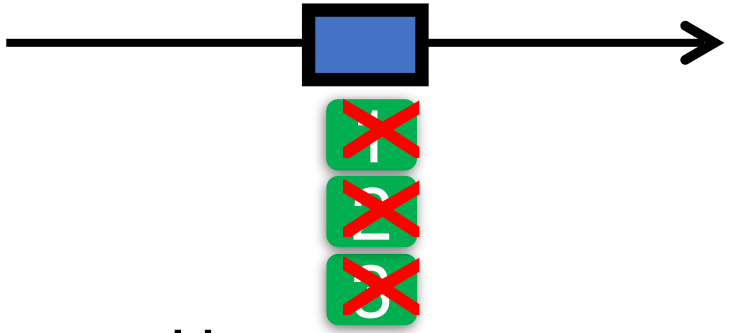

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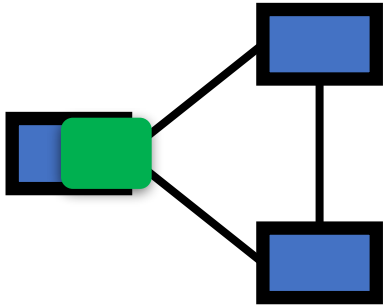

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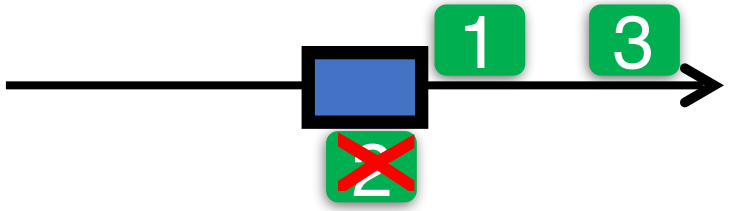

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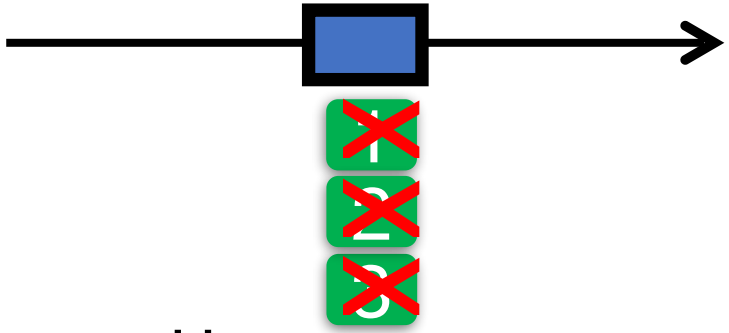

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- Result: **Mismatch** between network behavior and operator intent
- Lots of research efforts in building network debuggers

Network debuggers are even more complex

Existing designs: **in-network techniques**

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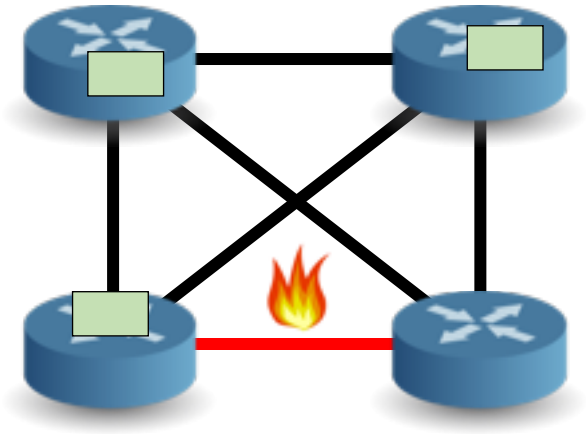
Idea: Use programmability of network switches to capture debugging information

Network debuggers are even more complex

Static analysis of data plane snapshots

E.g.: HSA [NSDI'12], Anteater [SIGCOMM'11]



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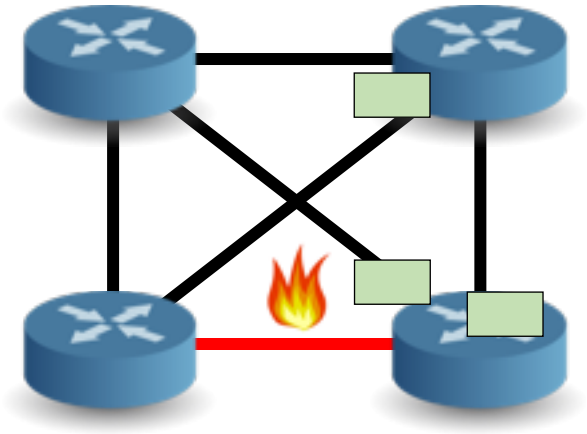

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- Capturing consistent network state is a hard problem

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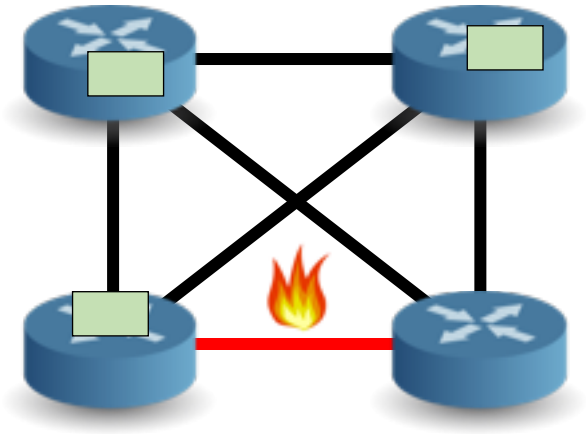
Per-switch per-packet logging

E.g.: NetSight [NSDI'14]



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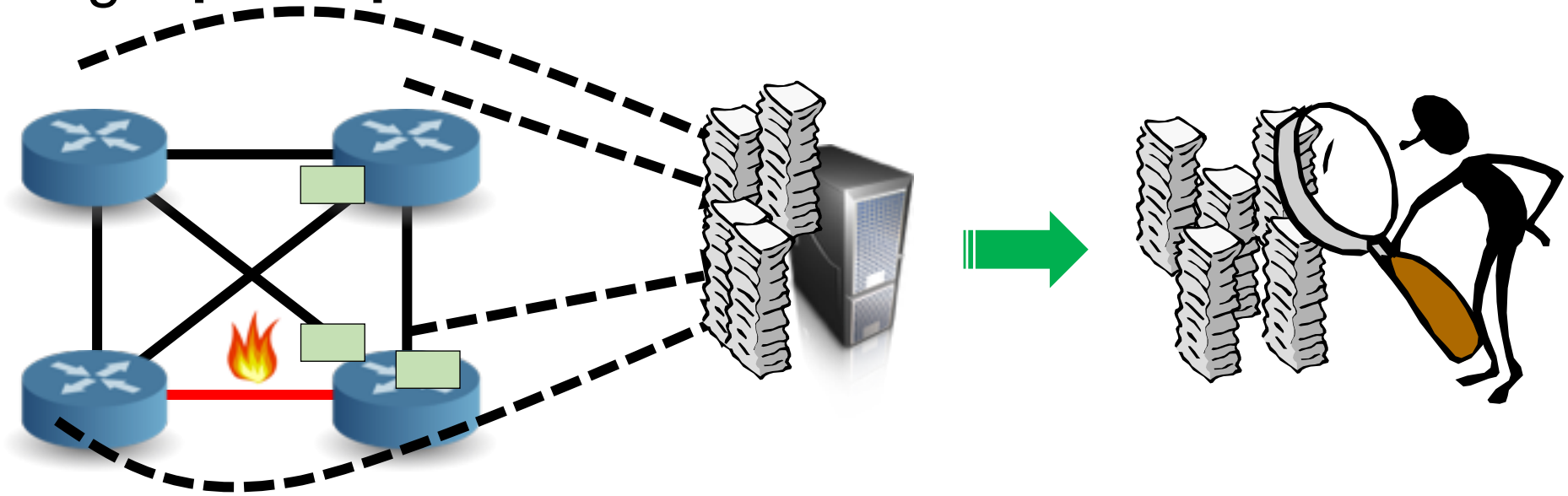

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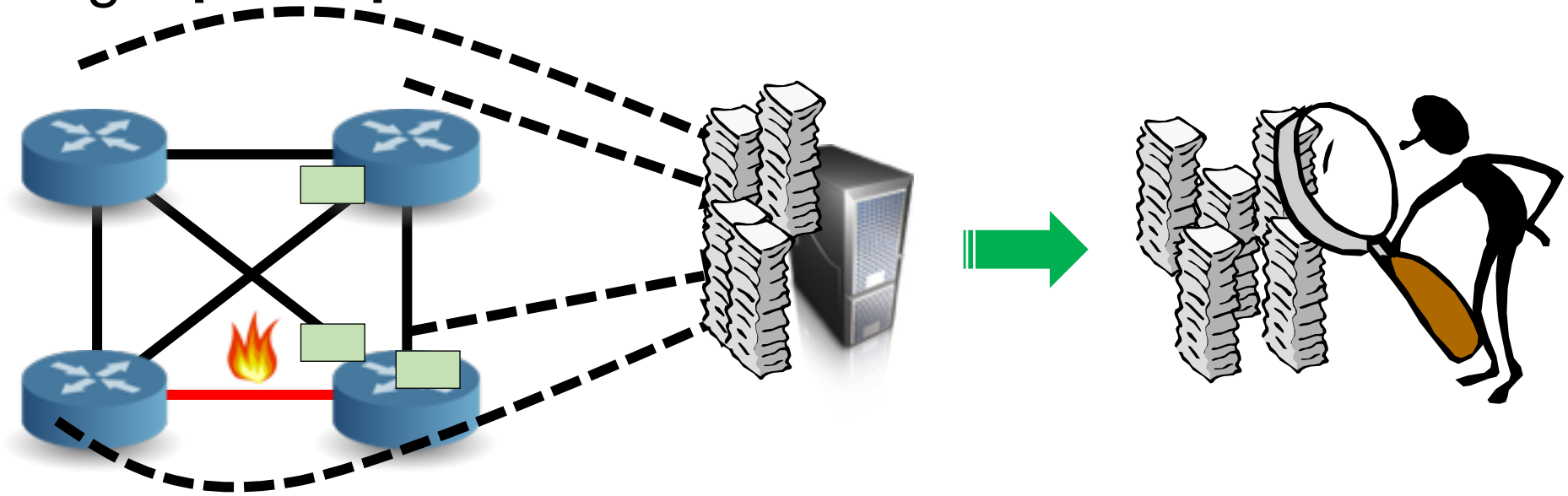
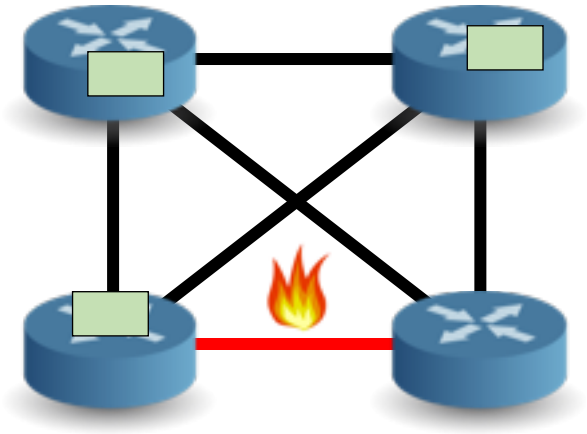


- High bandwidth and processing overhead

Network debuggers are even more complex

Selective packet sampling and mirroring

E.g.: Everflow [SIGCOMM'15], Planck [SIGCOMM'14], sFlow



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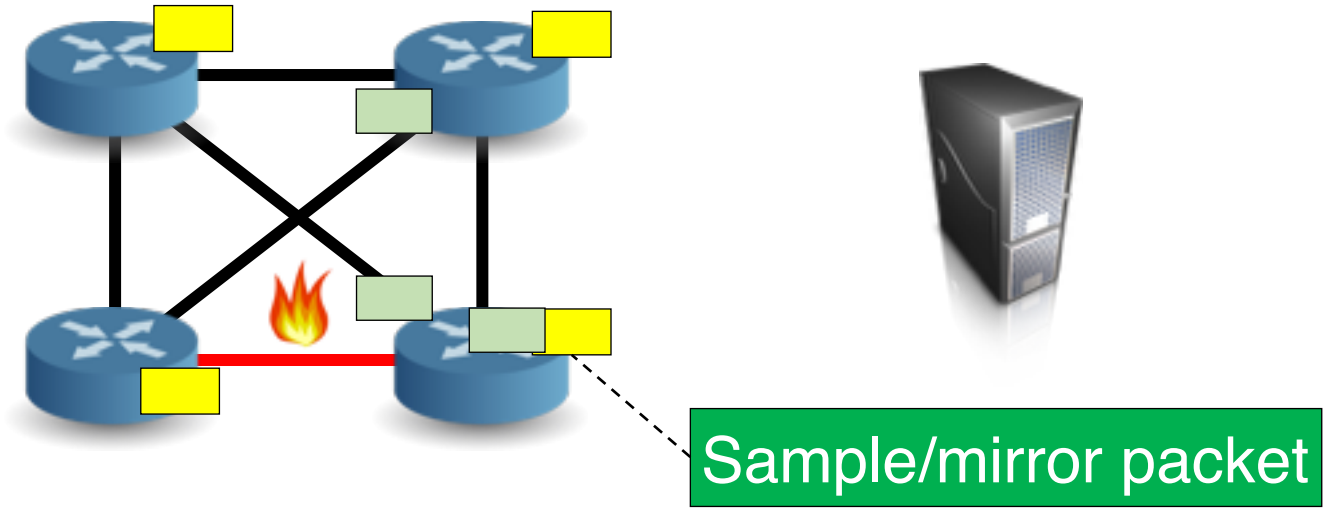

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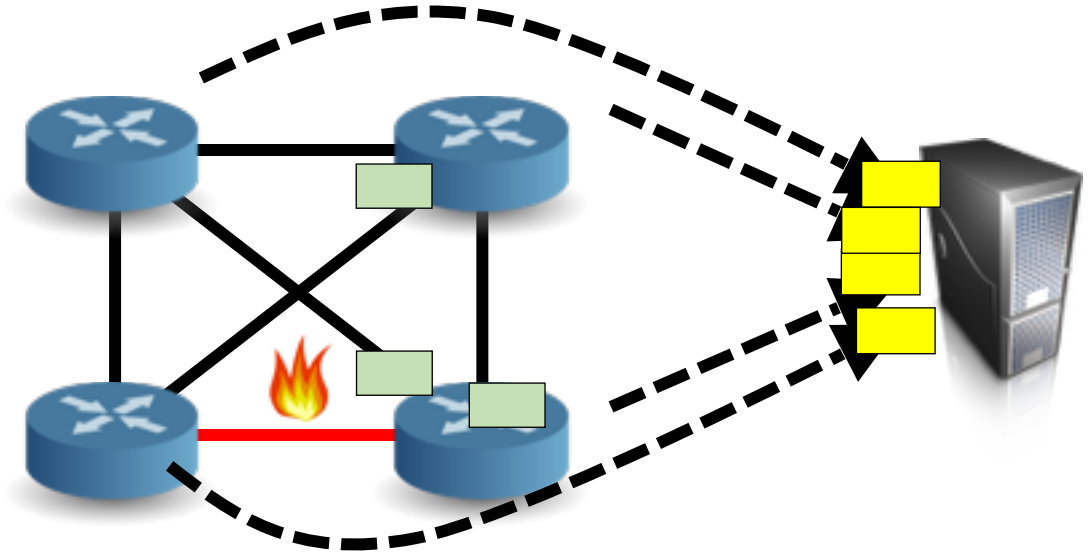

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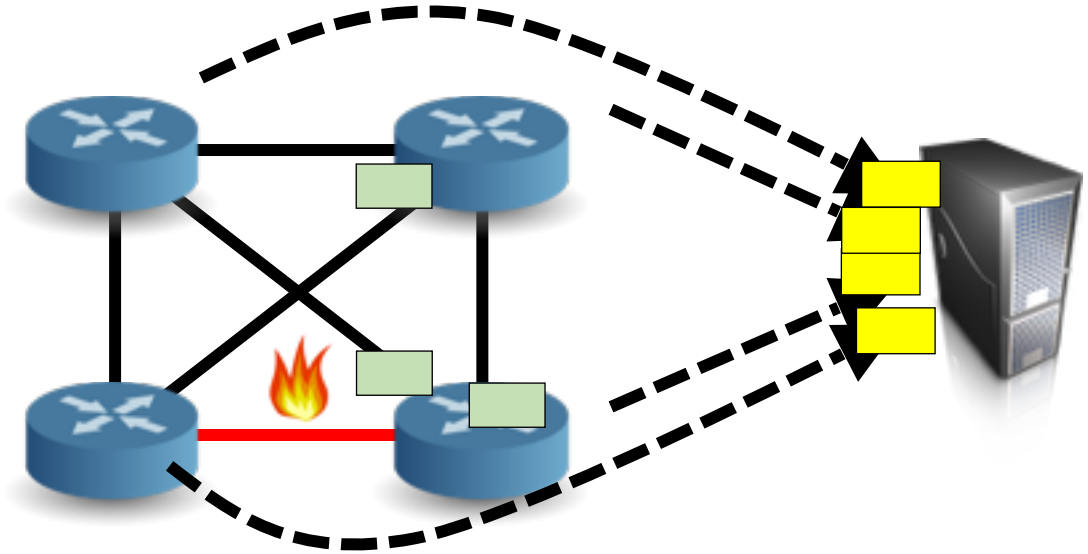
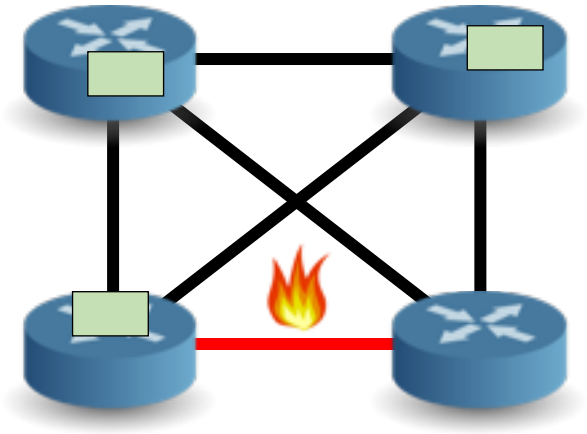


- Identifying packets to sample for debugging problems is complex

Network debuggers are even more complex

SQL-like queries on switches

E.g.: Pathquery [NSDI'16]



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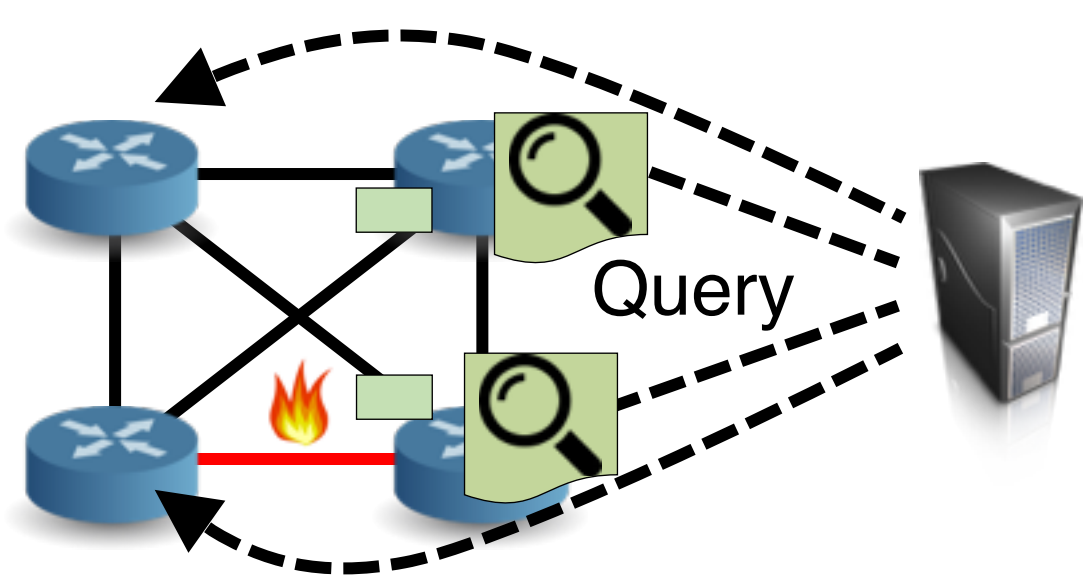

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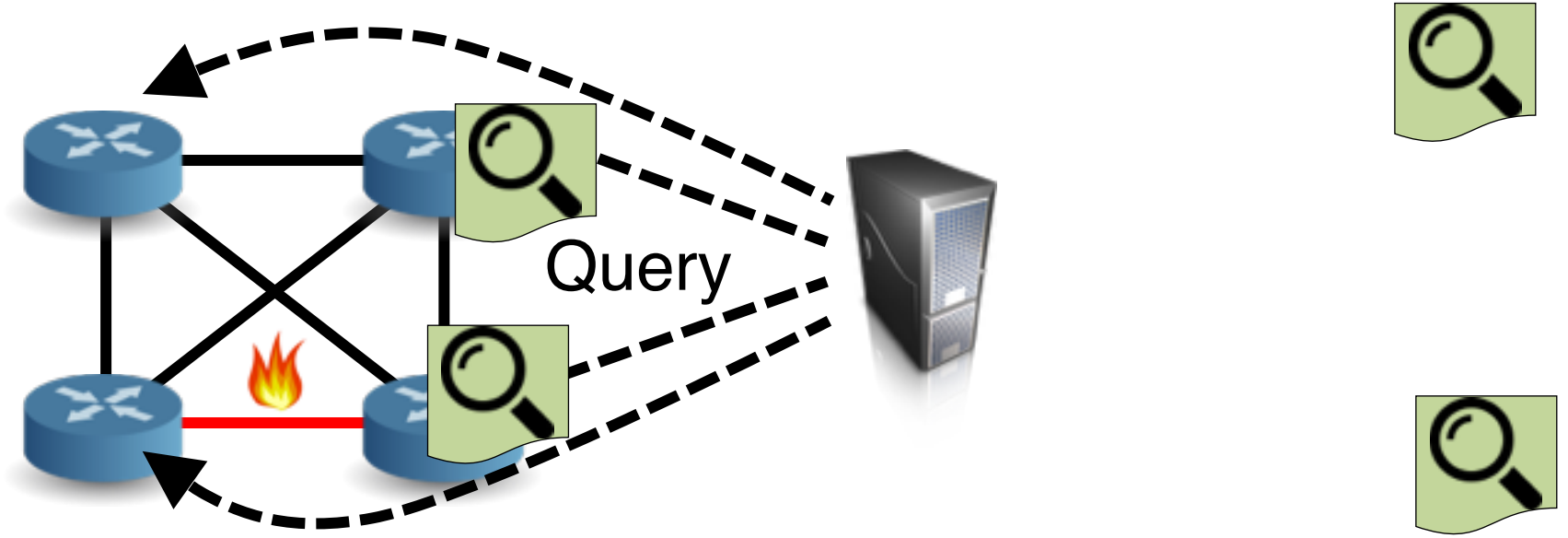
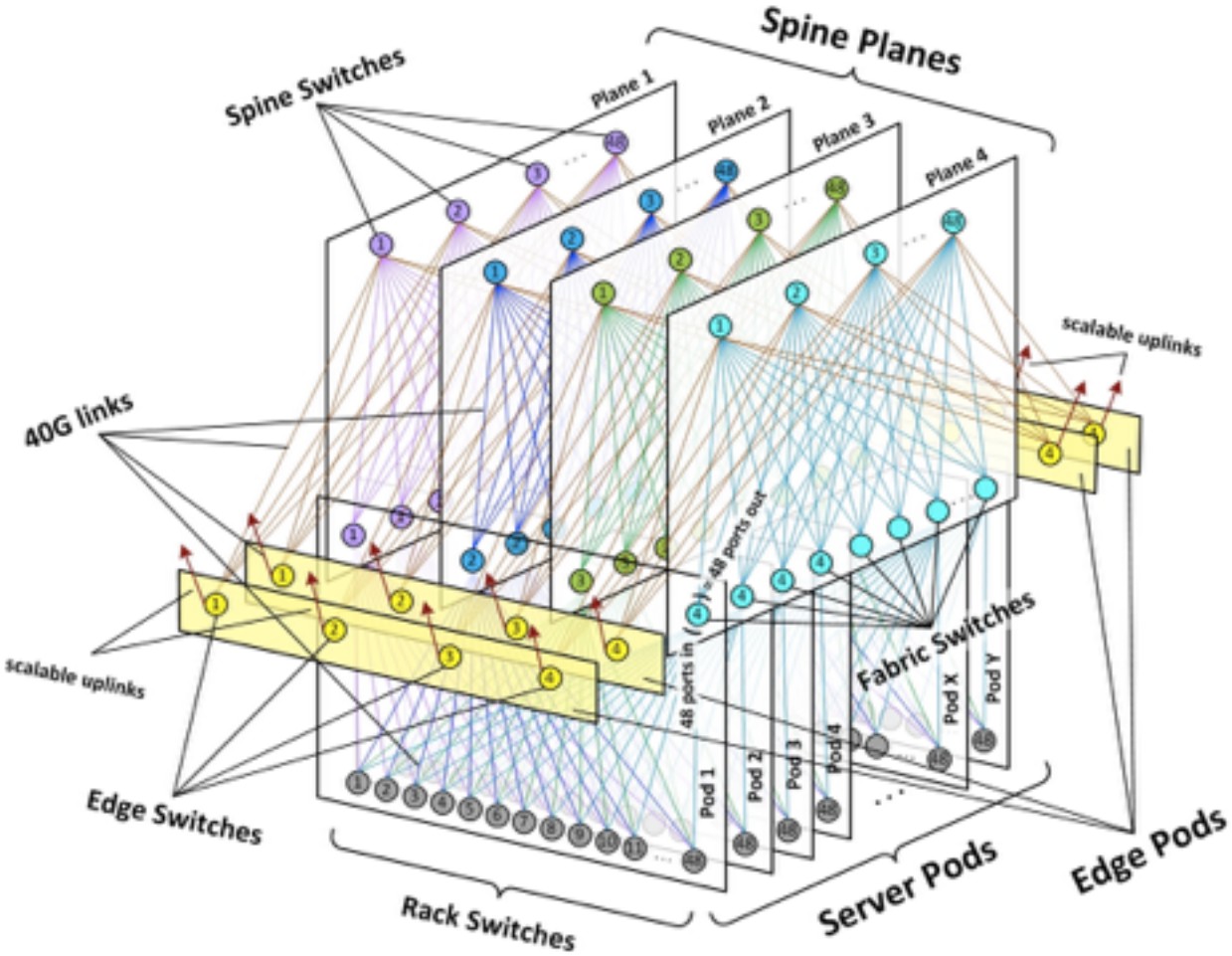


- Requires dynamic installation of switch rules

Summary: Complex networks and debuggers



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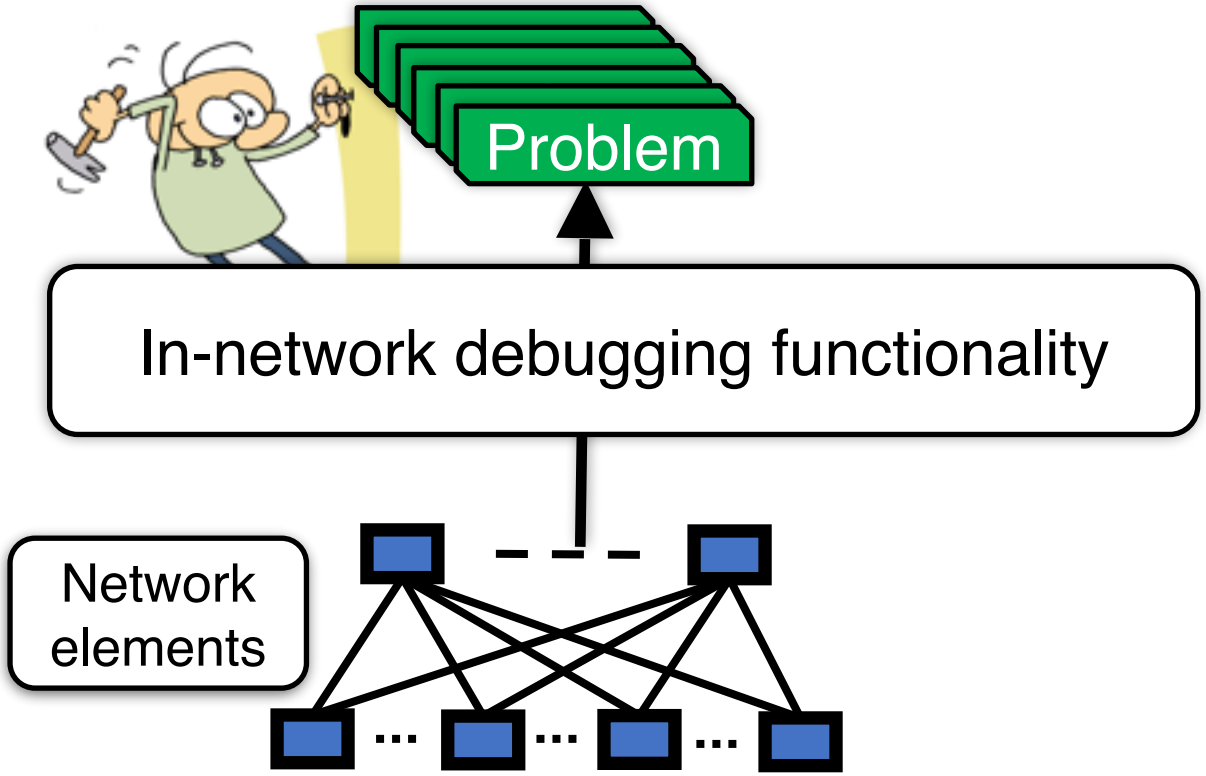
Complex networks

- Data plane snapshots
- Per-switch per-packet logs
- Packet mirroring
- Packet sampling
- Dynamic rule installation

Network debuggers even more complex

PathDump: (Simple) In-network + End-hosts



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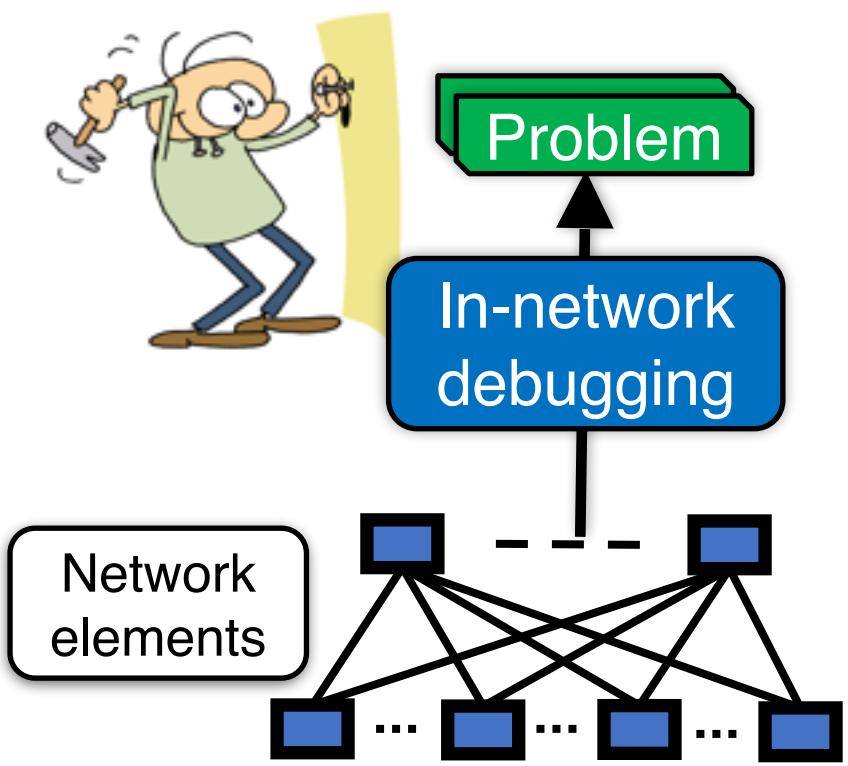
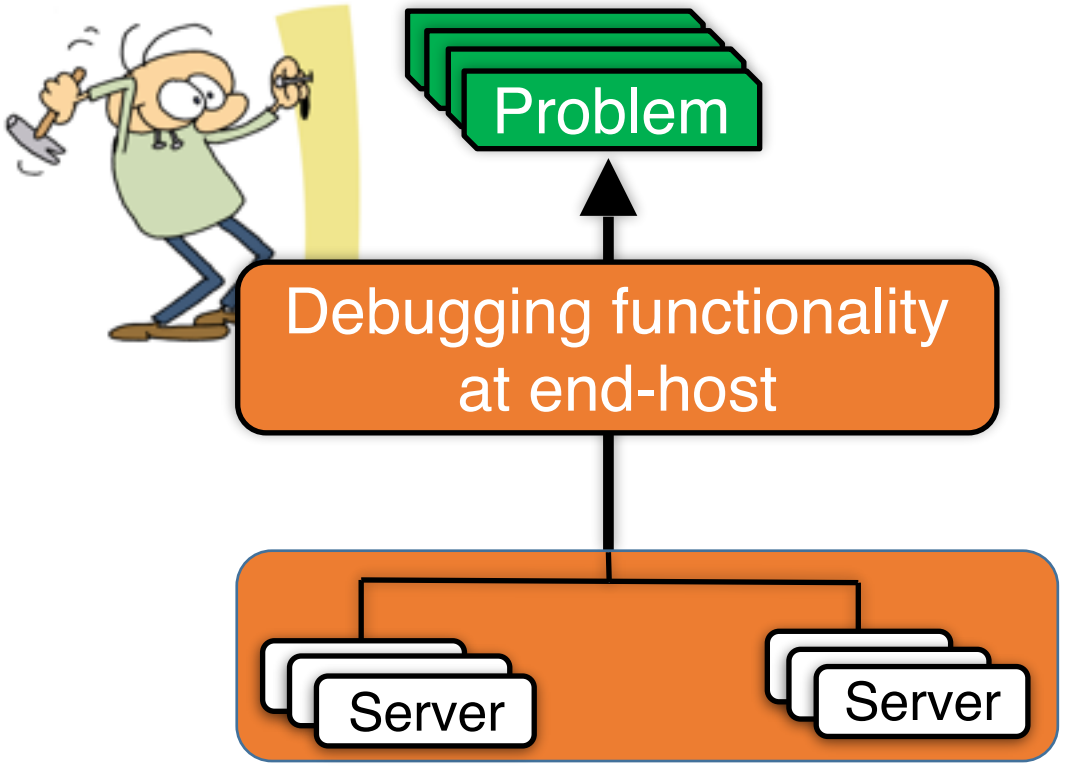
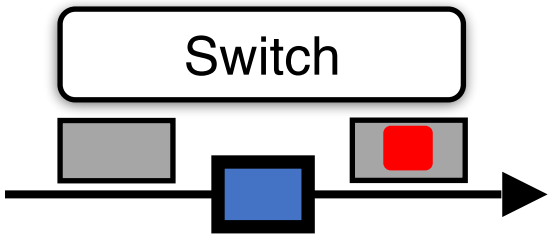




- Use end-hosts for most debugging problems
- In-network functionality for a small number of debugging problems

PathDump in a nutshell



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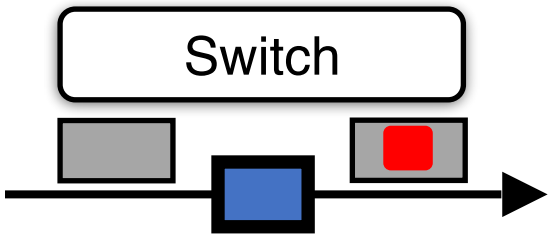

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- No data plane snapshots
- No per-switch per-packet logs
- No packet sampling
- No packet mirroring
- No dynamic rule installation

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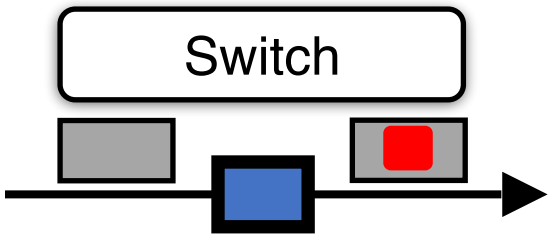

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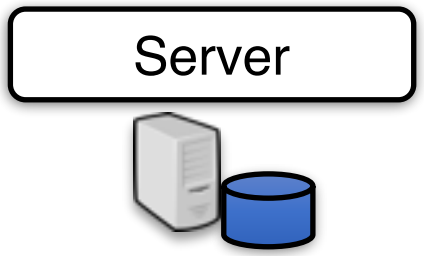

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- Stores and updates flow-level statistics
- Exposes API for debugging purposes

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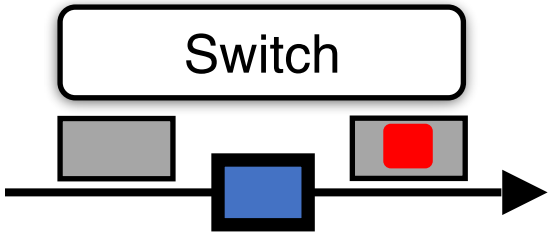

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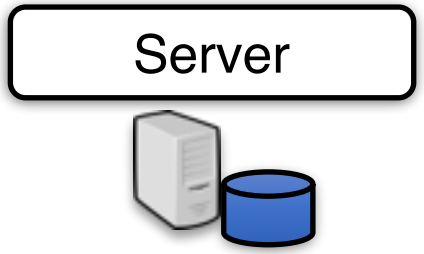

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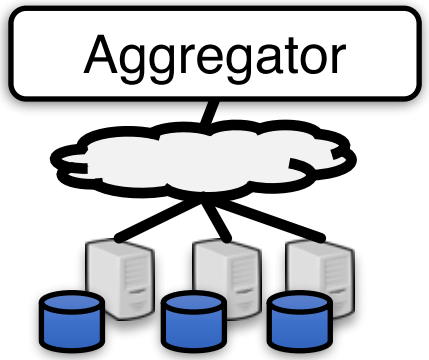

- Enables slicing-and-dicing of statistics across flows (potentially stored at various end-hosts)

PathDump: Three challenges

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Coverage

How to support large class of debugging functionalities?

Debug more than 85% of reported network problems

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Packets not reaching destination

How to handle packet drops and loops caused by network problems?

Exploit load balancing (e.g. ECMP) and identify spurious packet drops

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Data plane/end-host resources

Switch resources and packet header space are limited

CherryPick: Per-packet path tracing technique

10s of flow rules at switch

PathDump should not hog user app's resources at end-host

Two VLAN tags in the packet

25% of one core / 100MB of mem. at end-host

PathDump architecture

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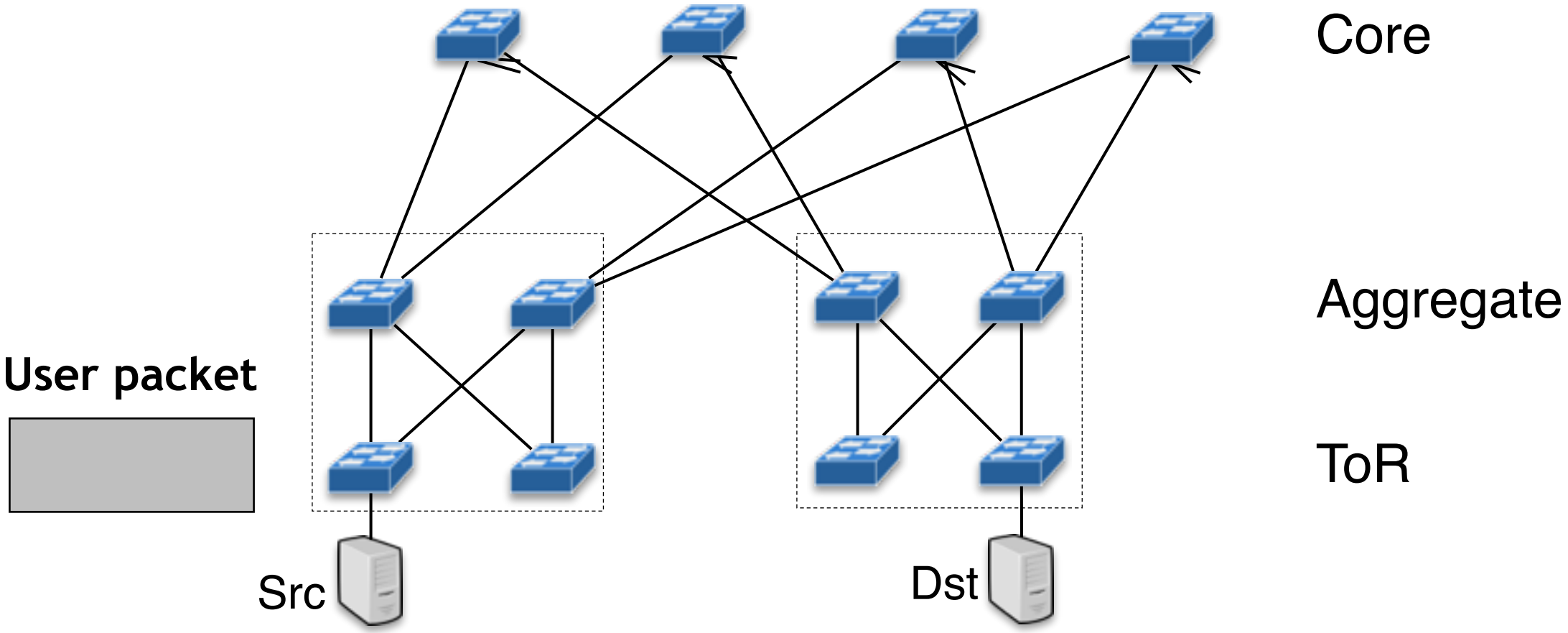

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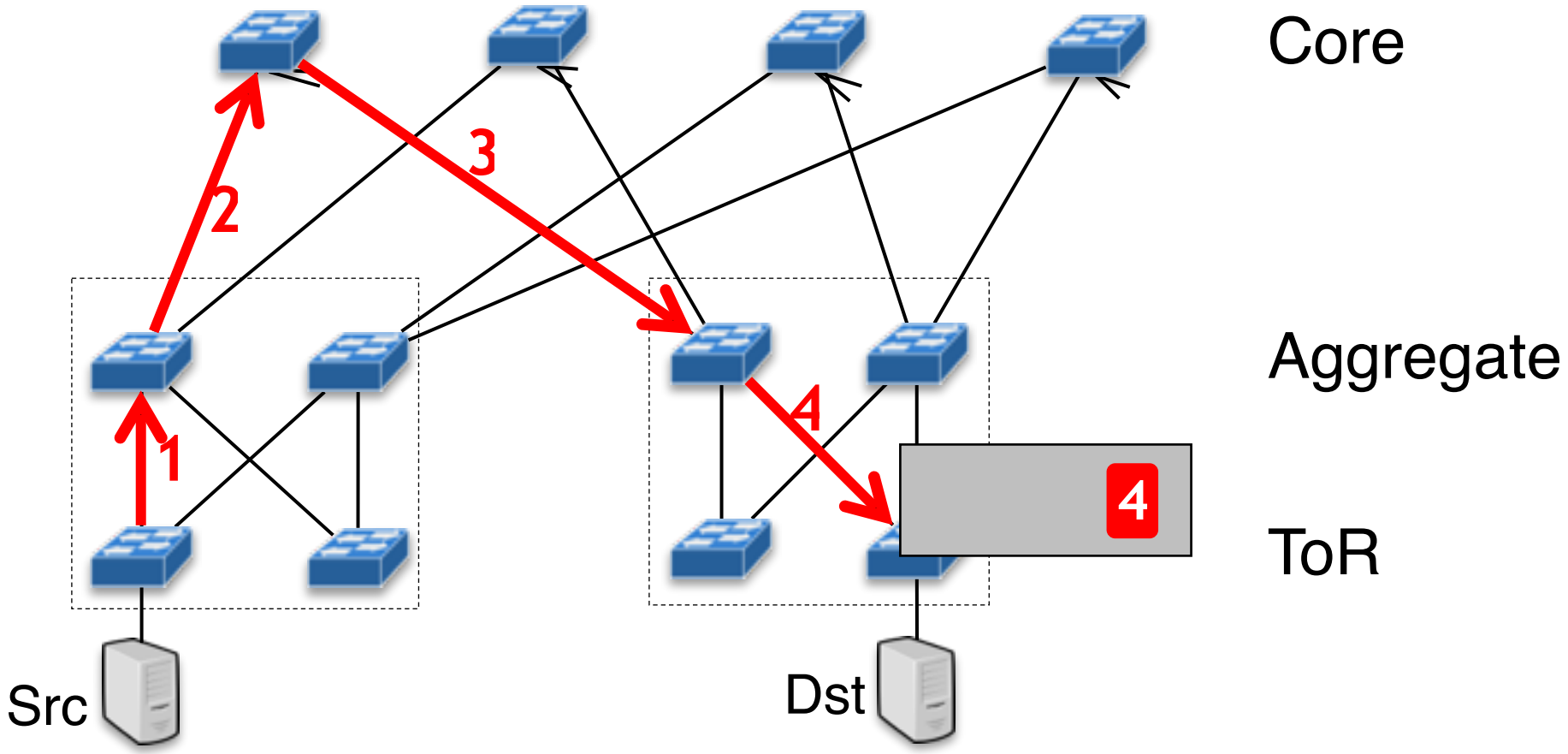

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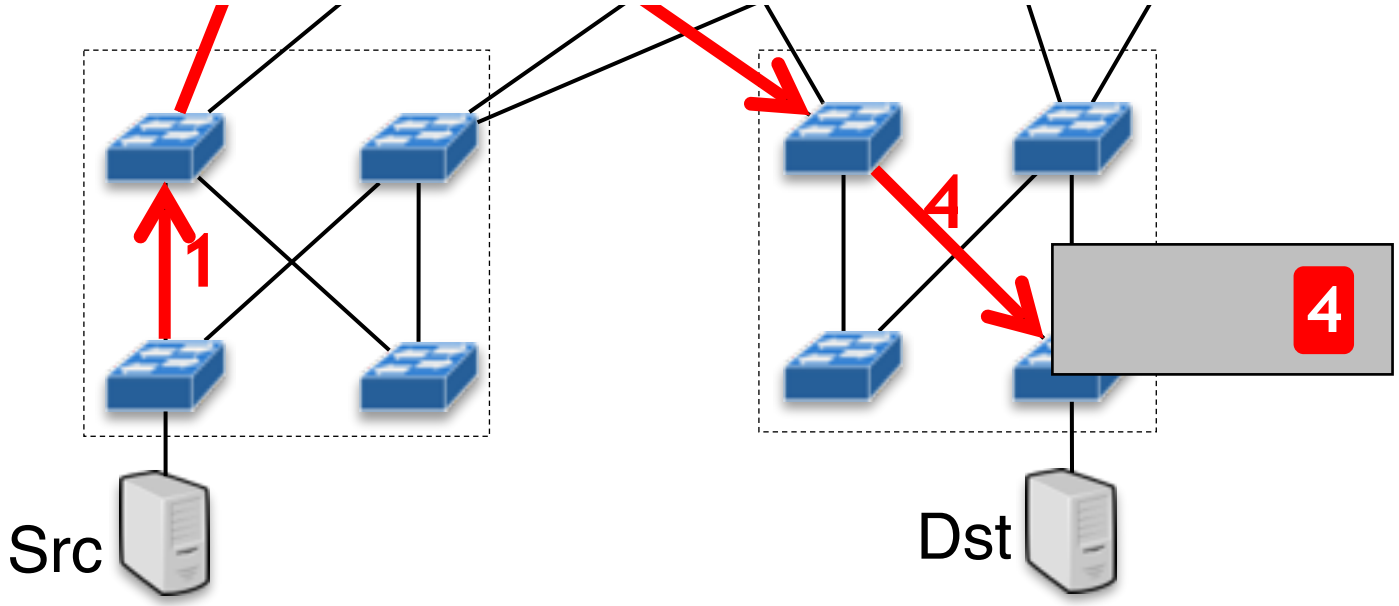
- Packet header space limitation

- Cherrypick [SOSR'15] for current deployments



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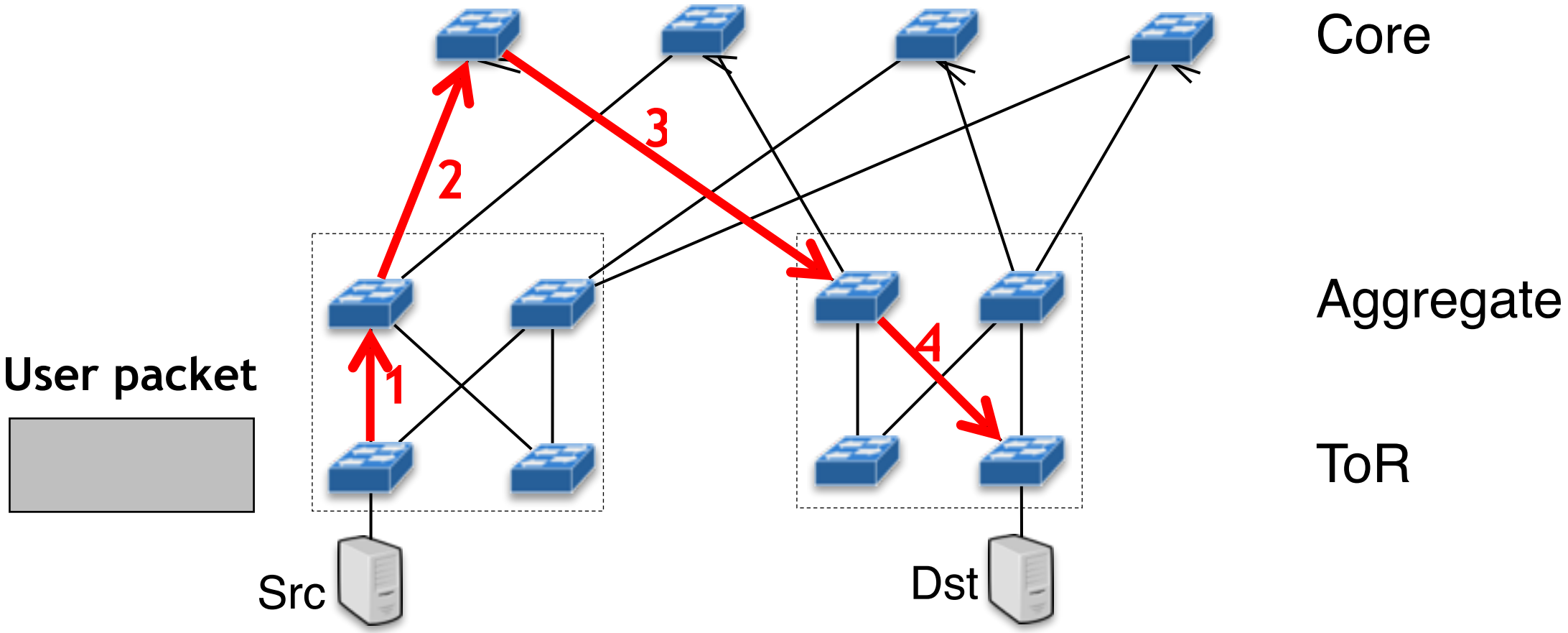

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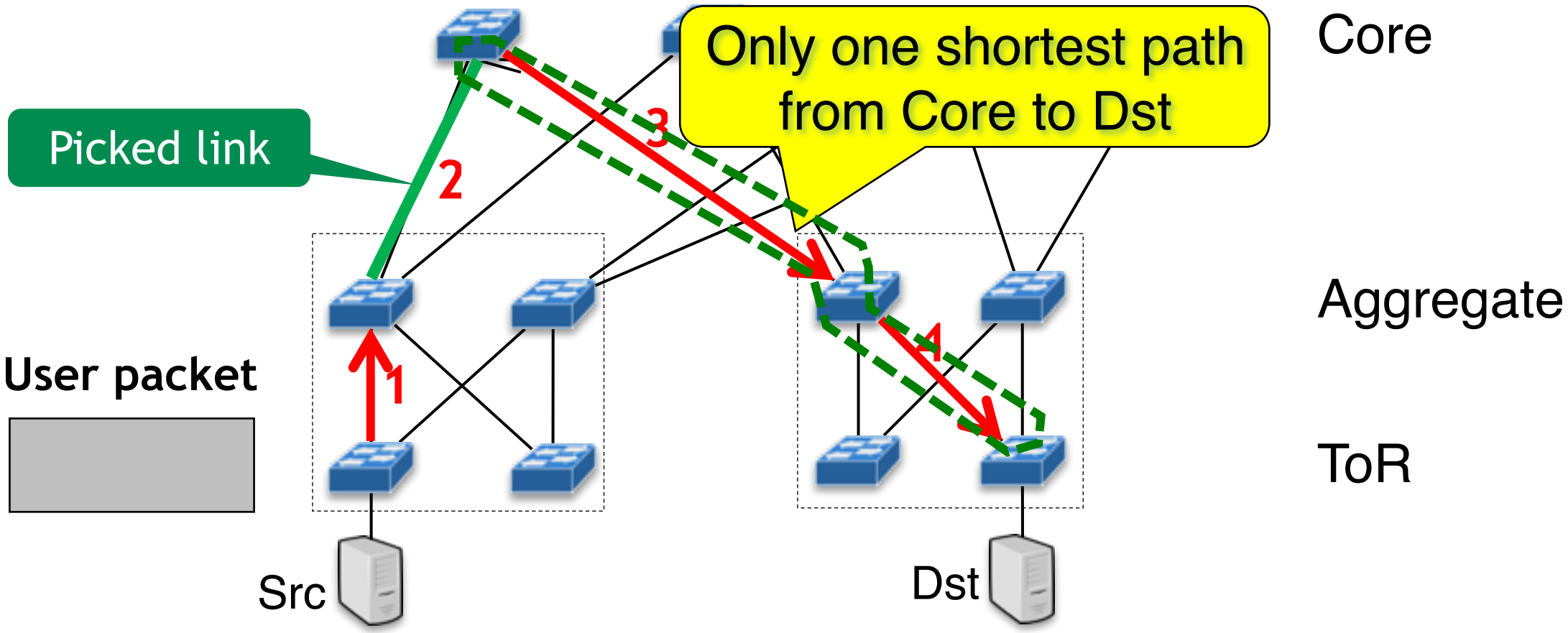

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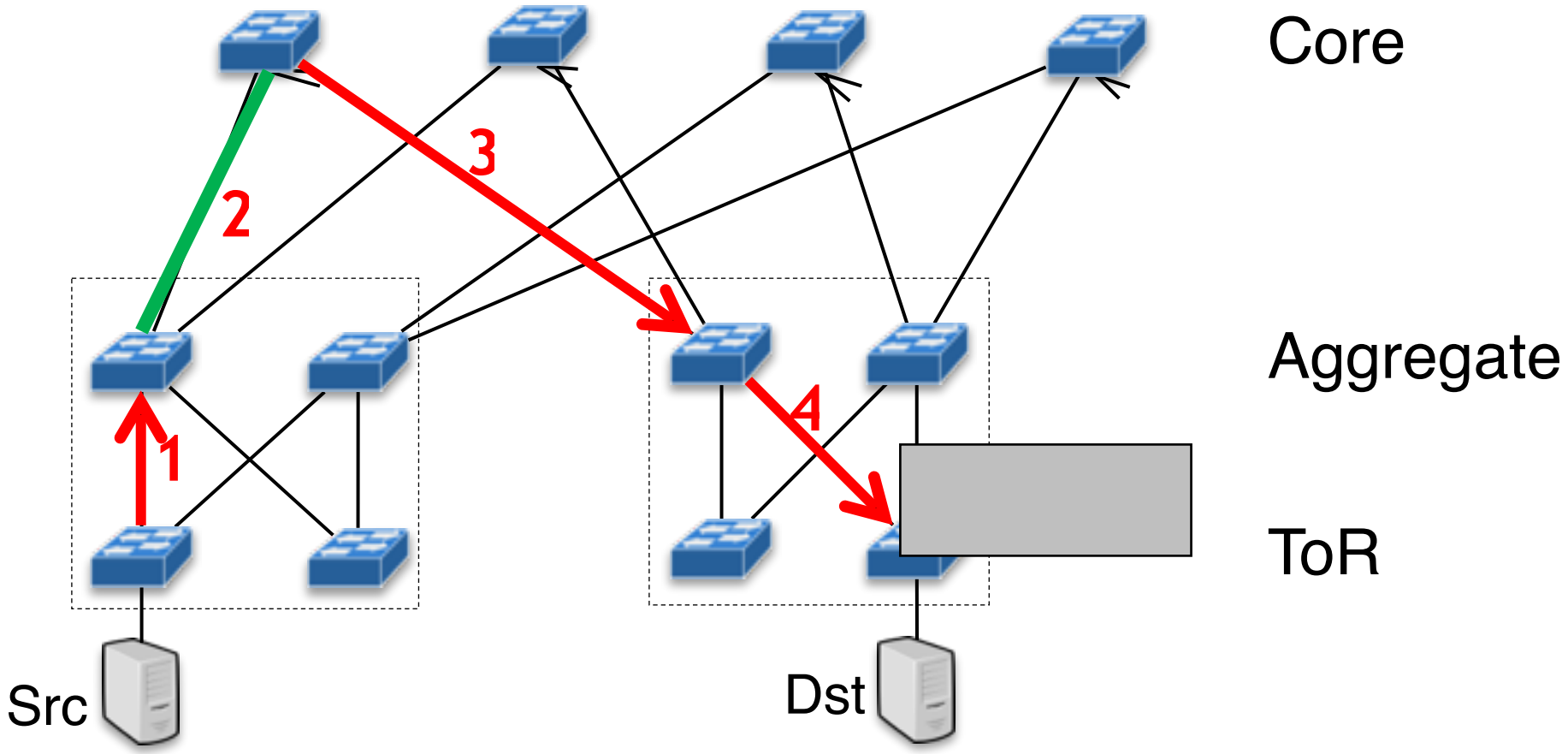

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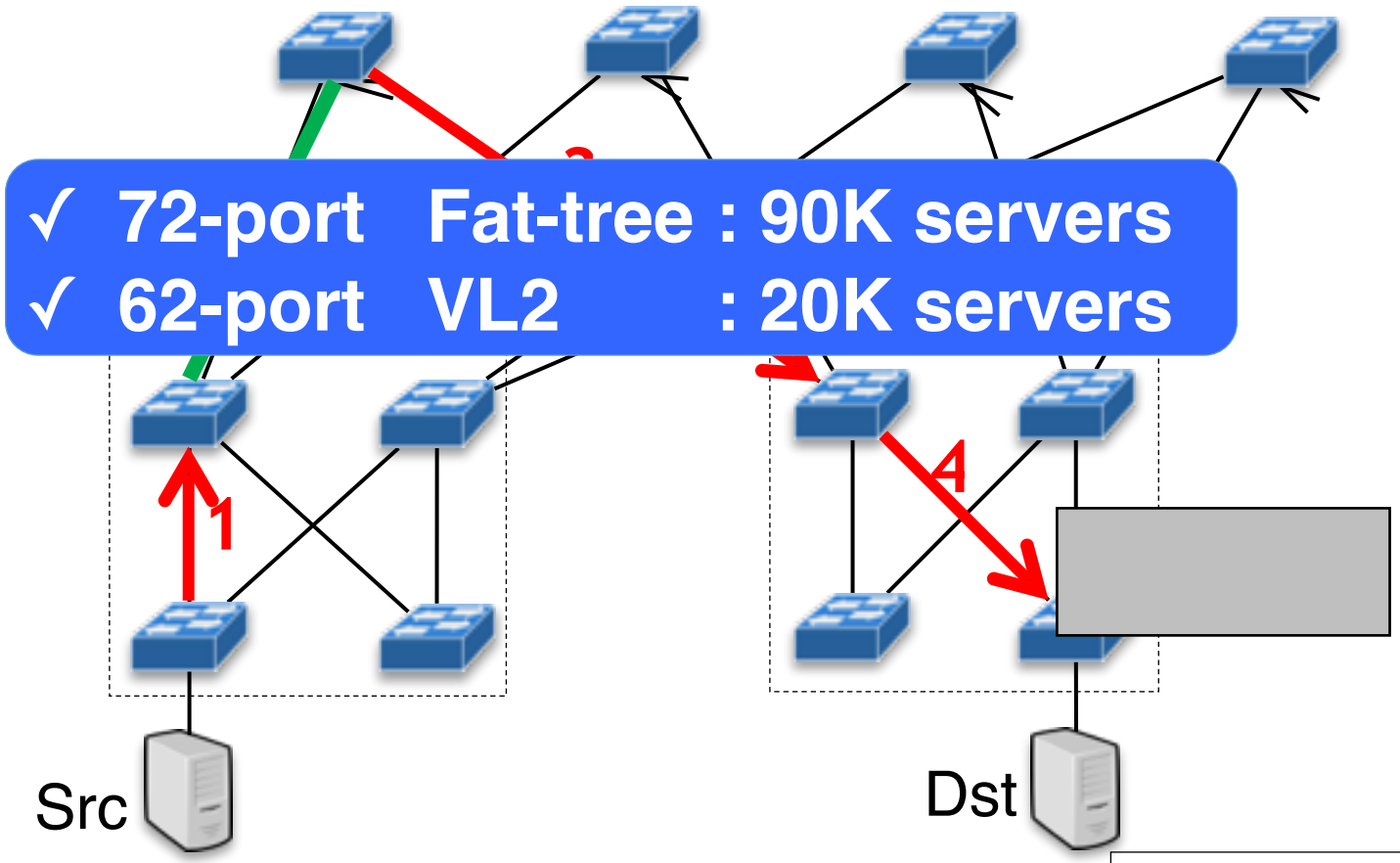

More details in our paper

PathDump architecture

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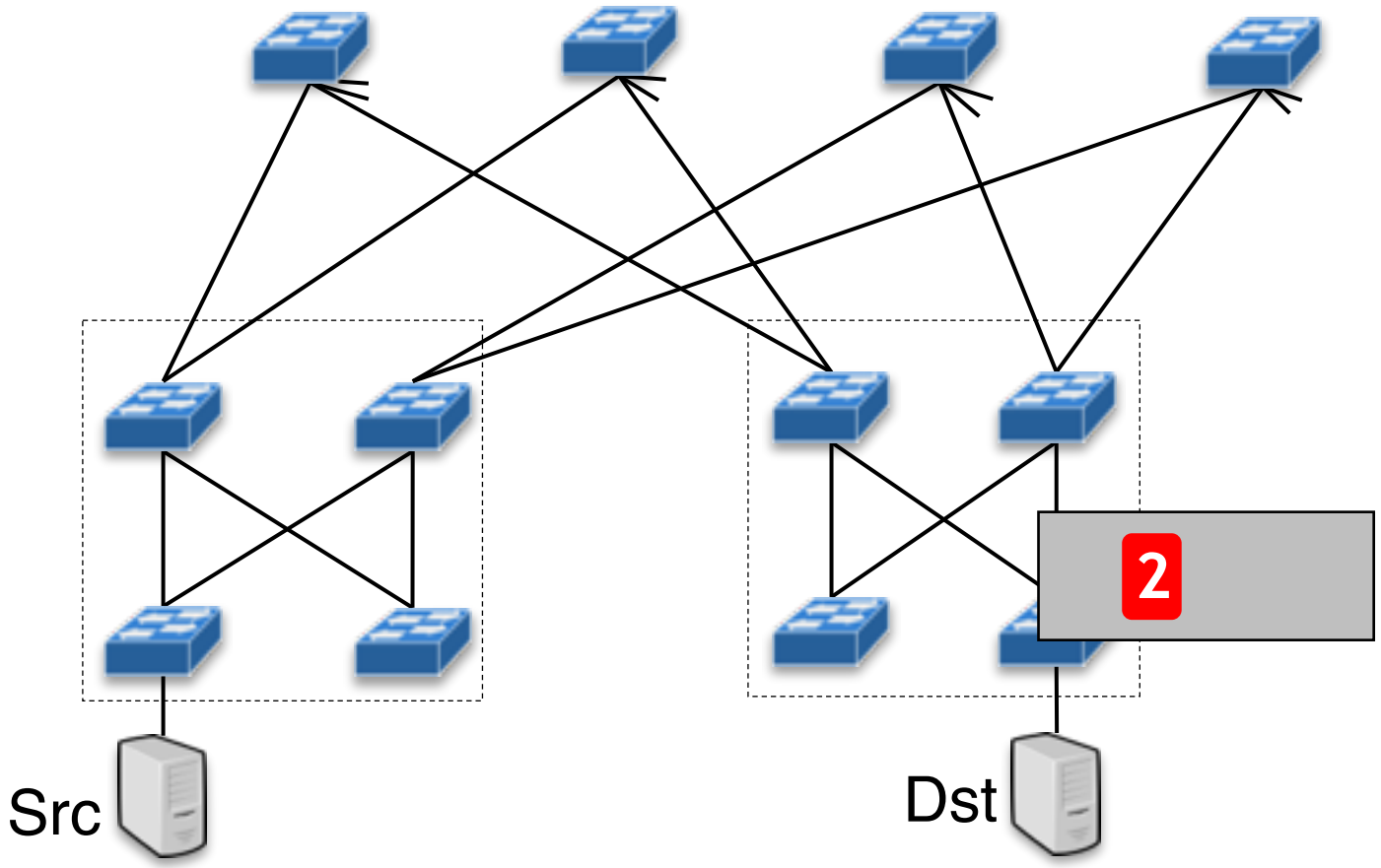

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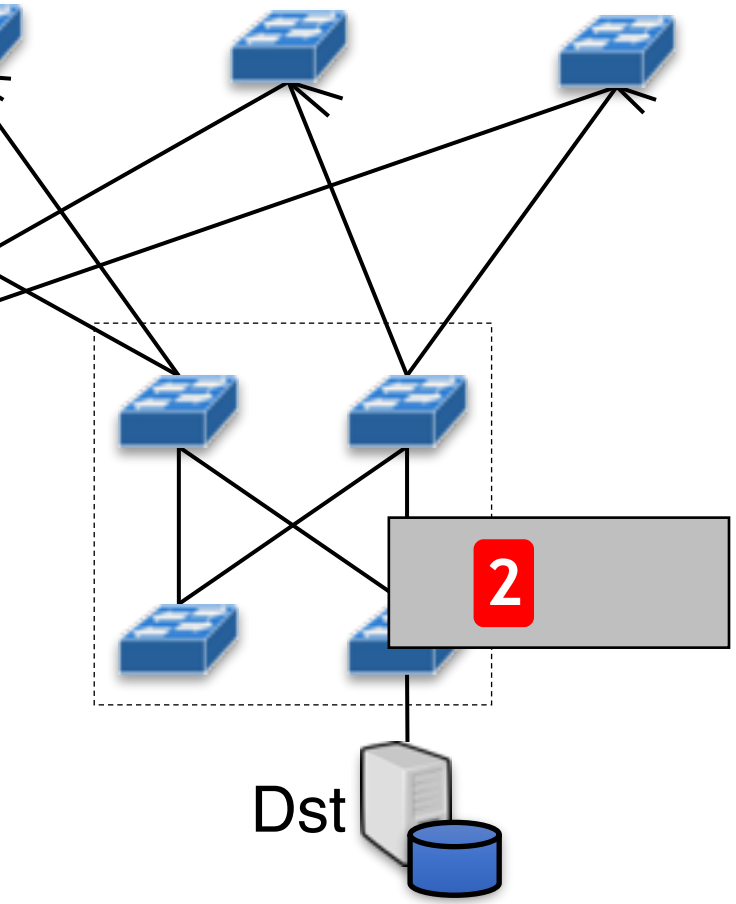

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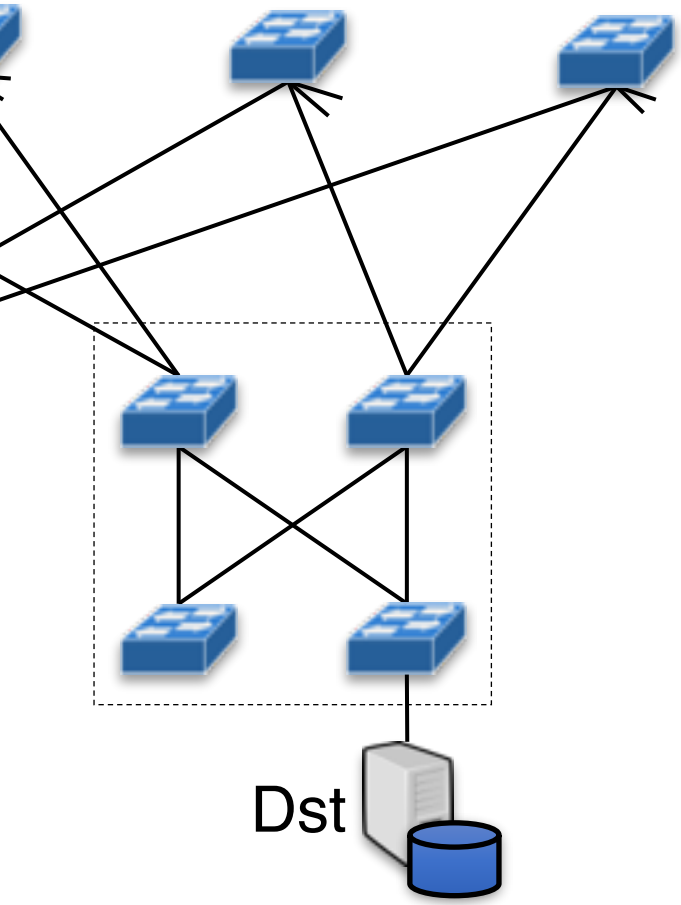

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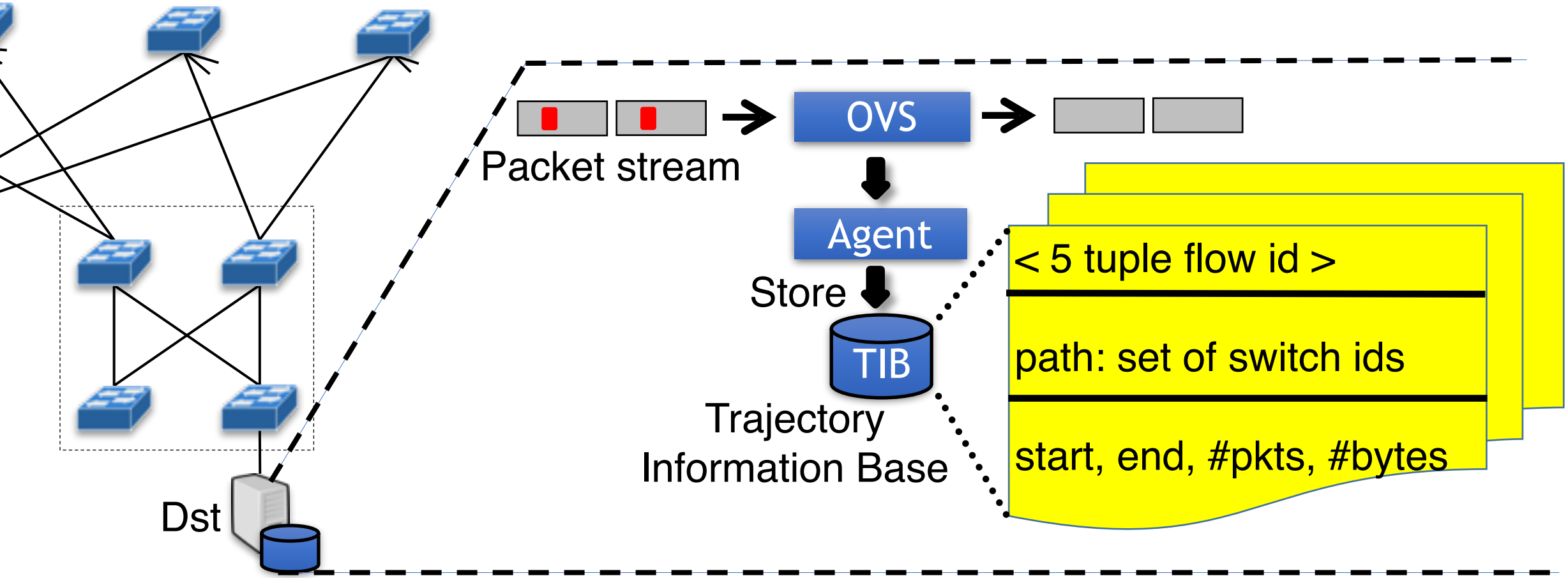
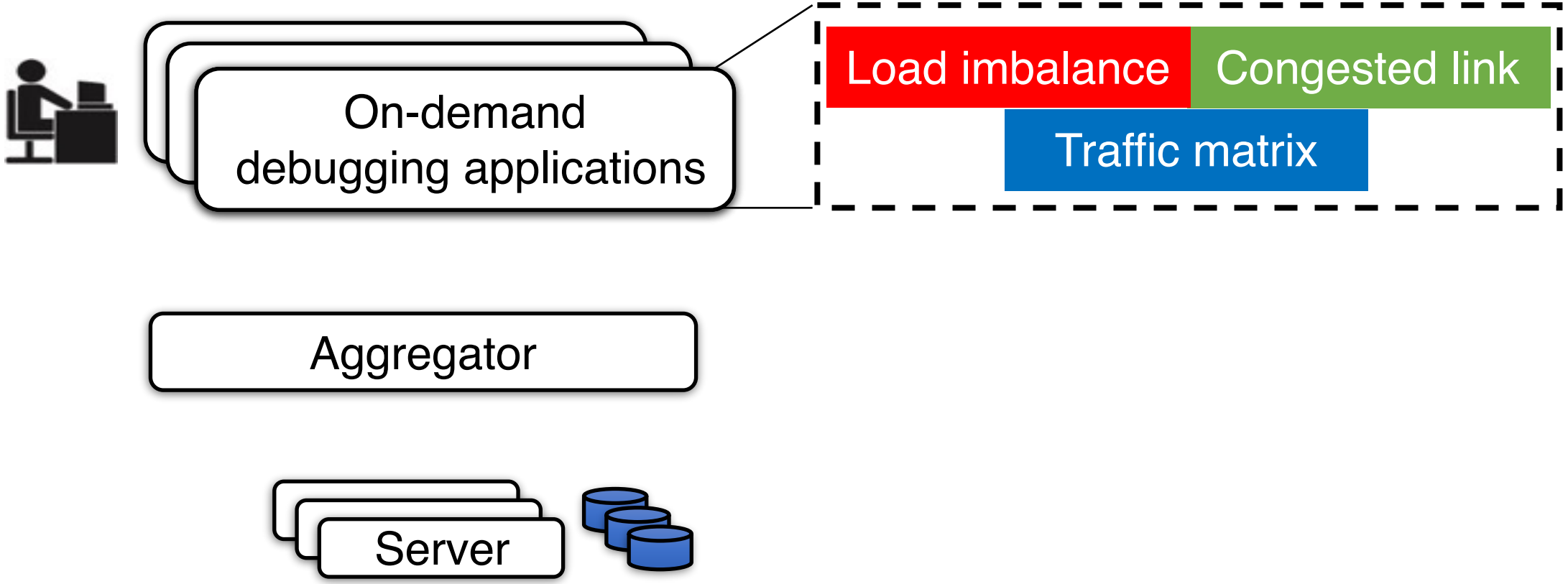


PathDump architecture

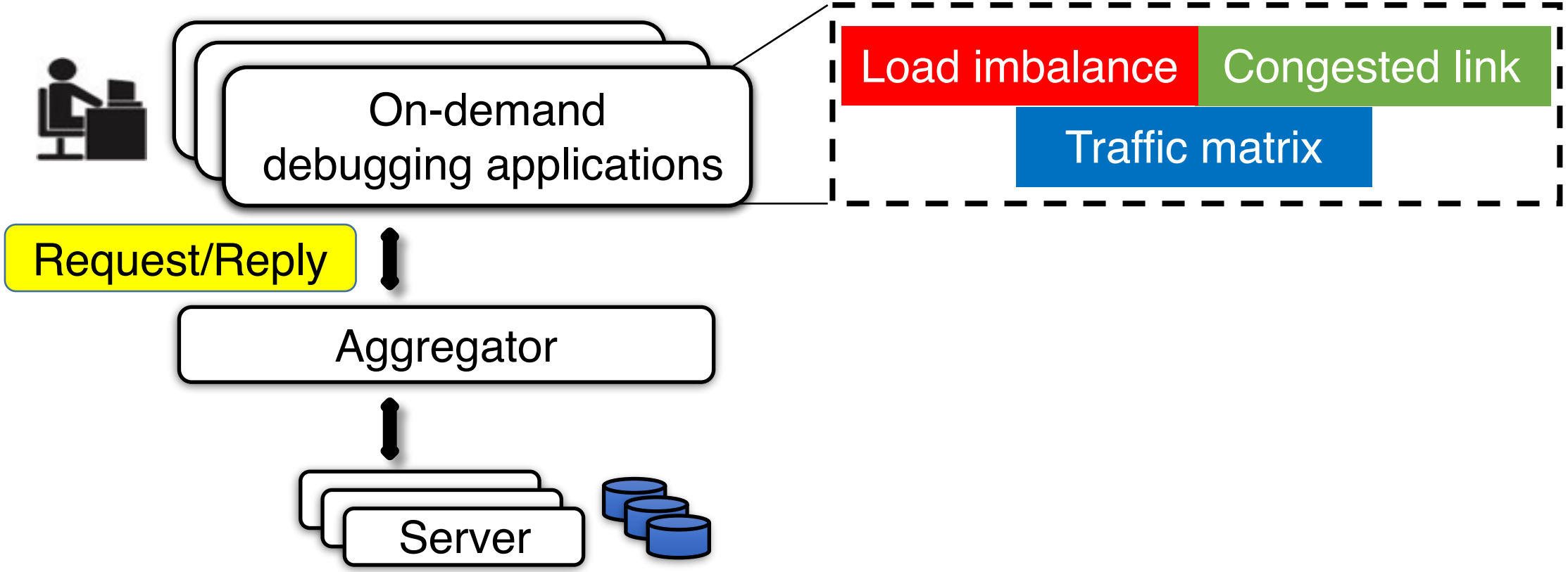
3. Aggregator runs debugging applications

On-demand vs. Event-driven



PathDump architecture

3. Aggregator runs debugging applications
On-demand vs. Event-driven



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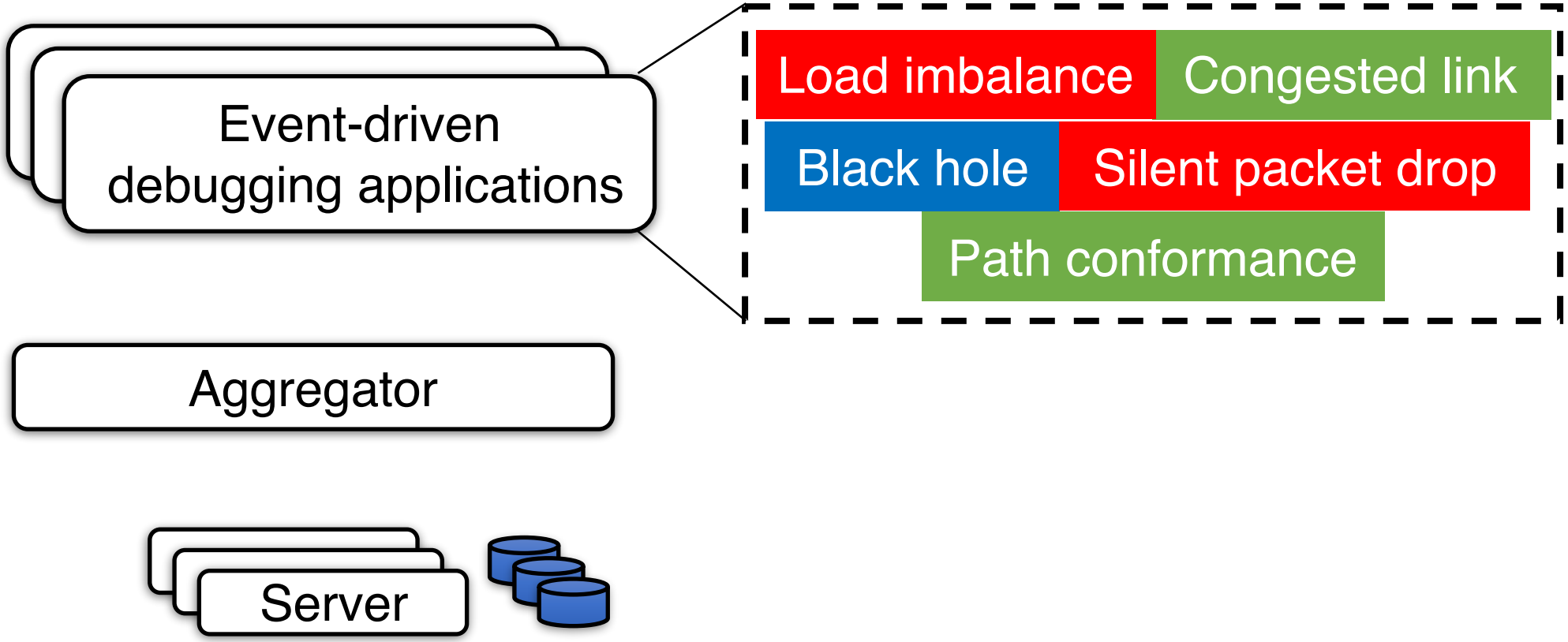

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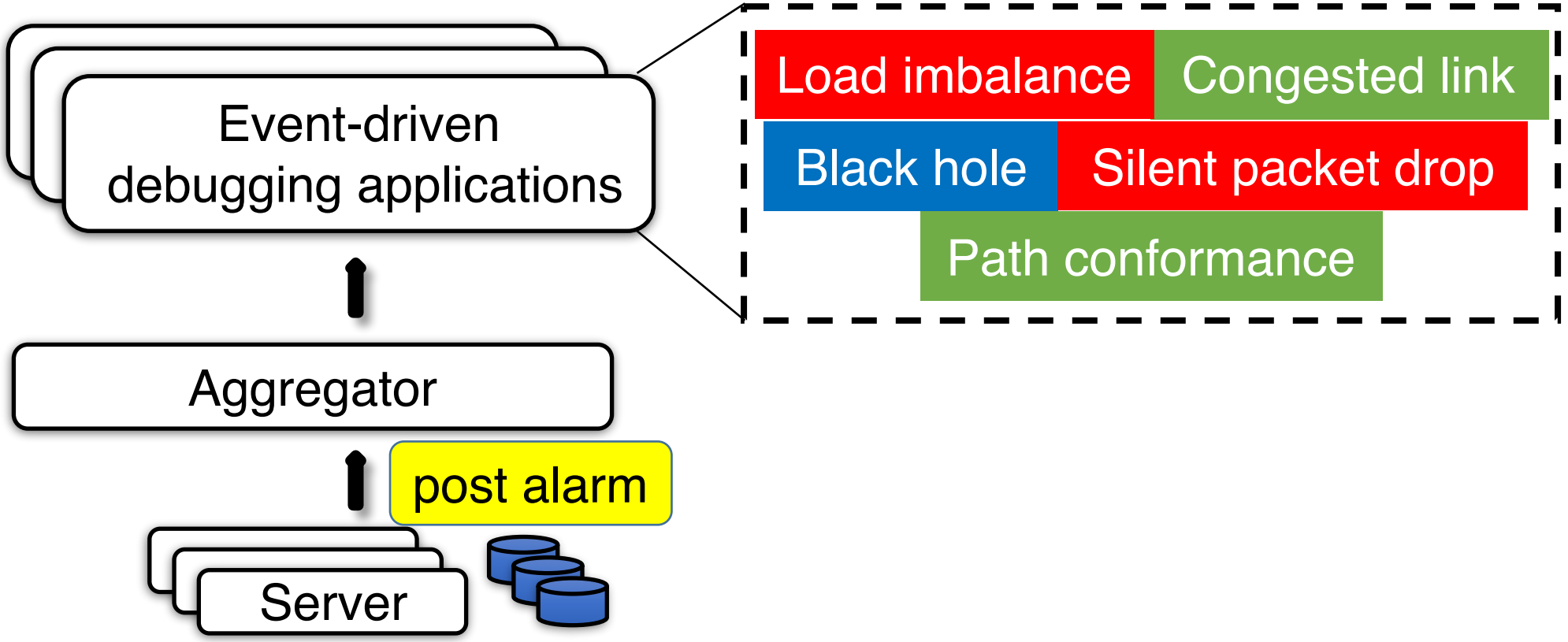
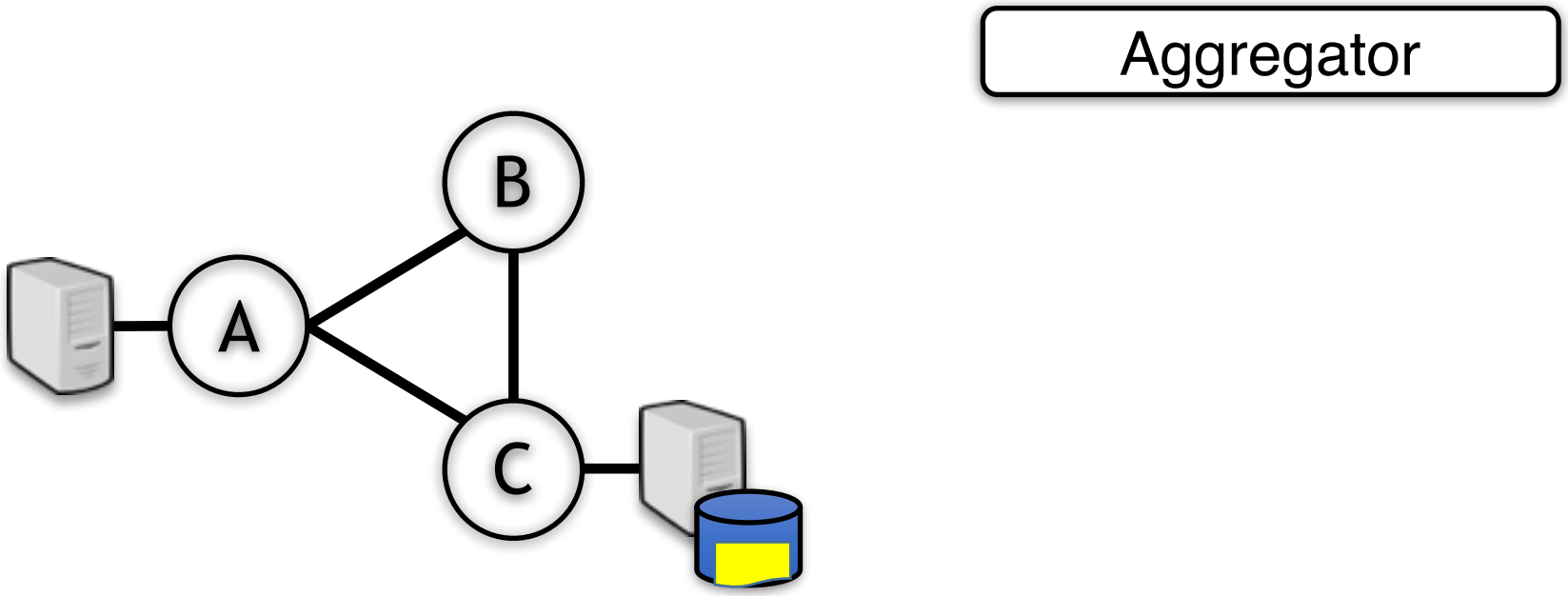


PathDump interface

A small set of simple APIs enables a variety of debugging applications



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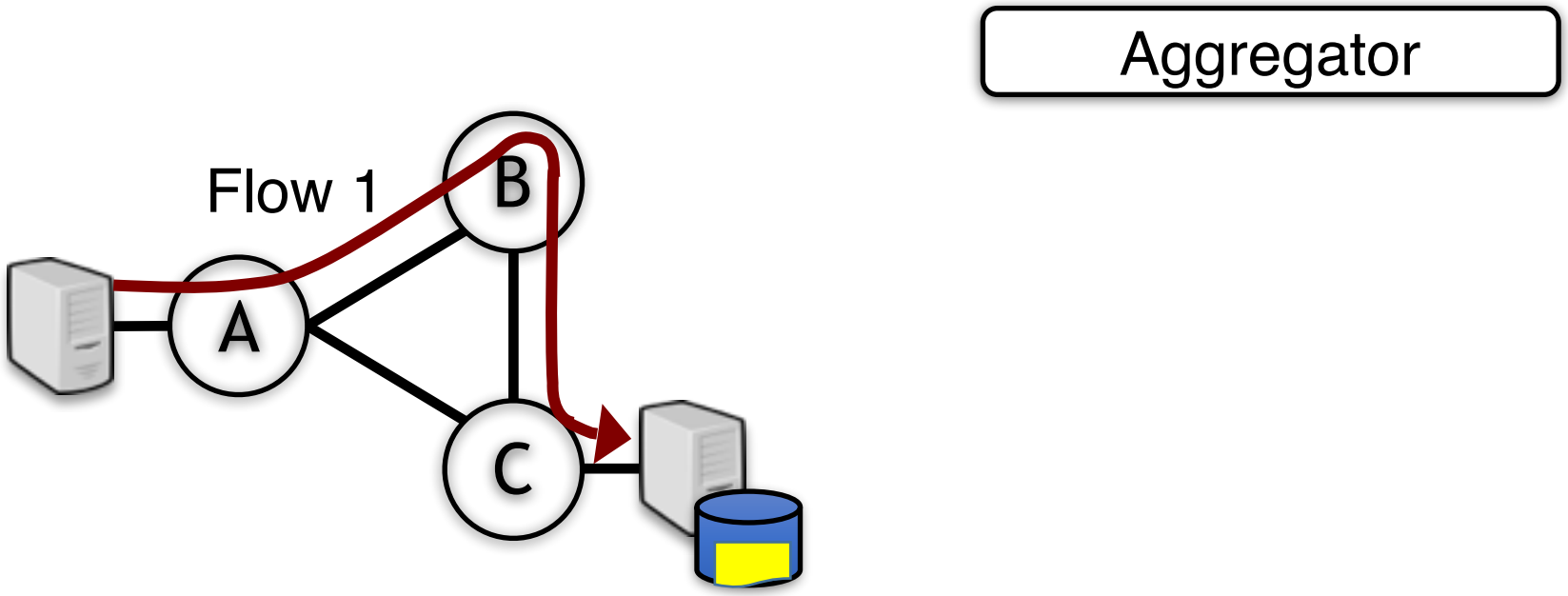

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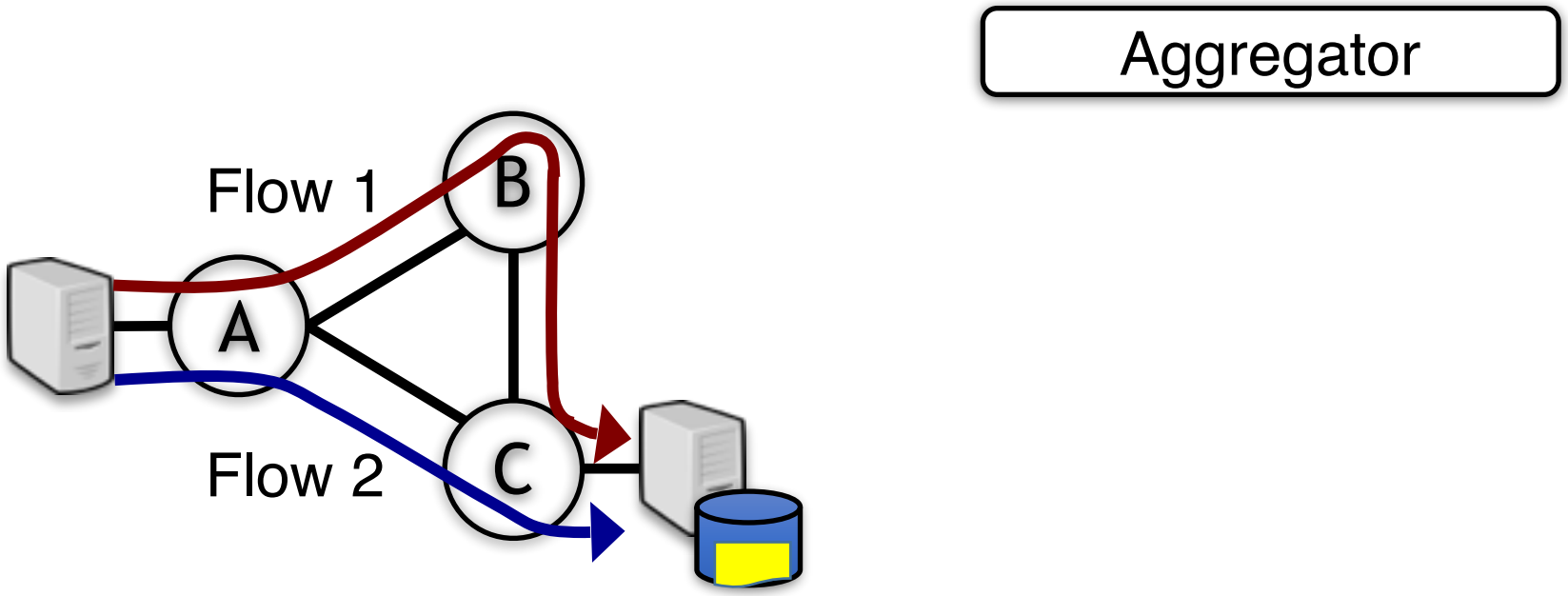

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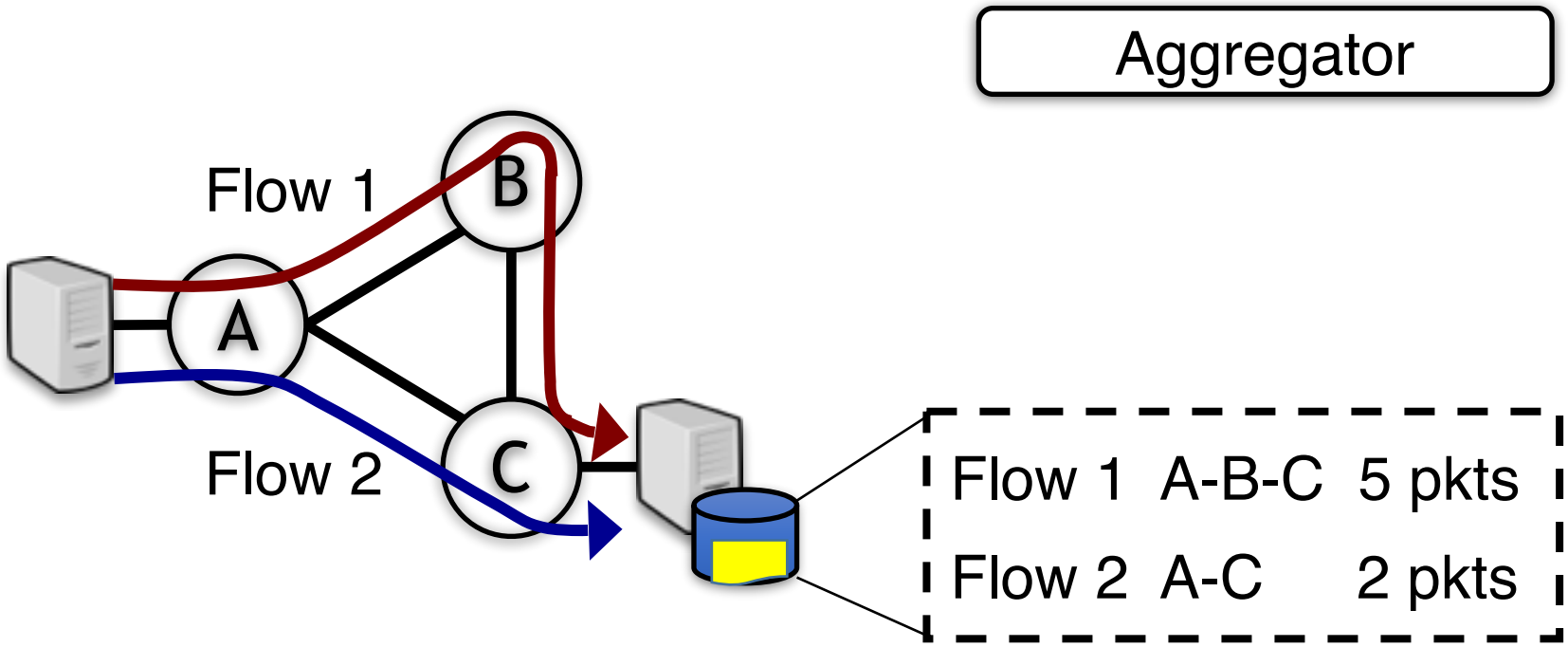

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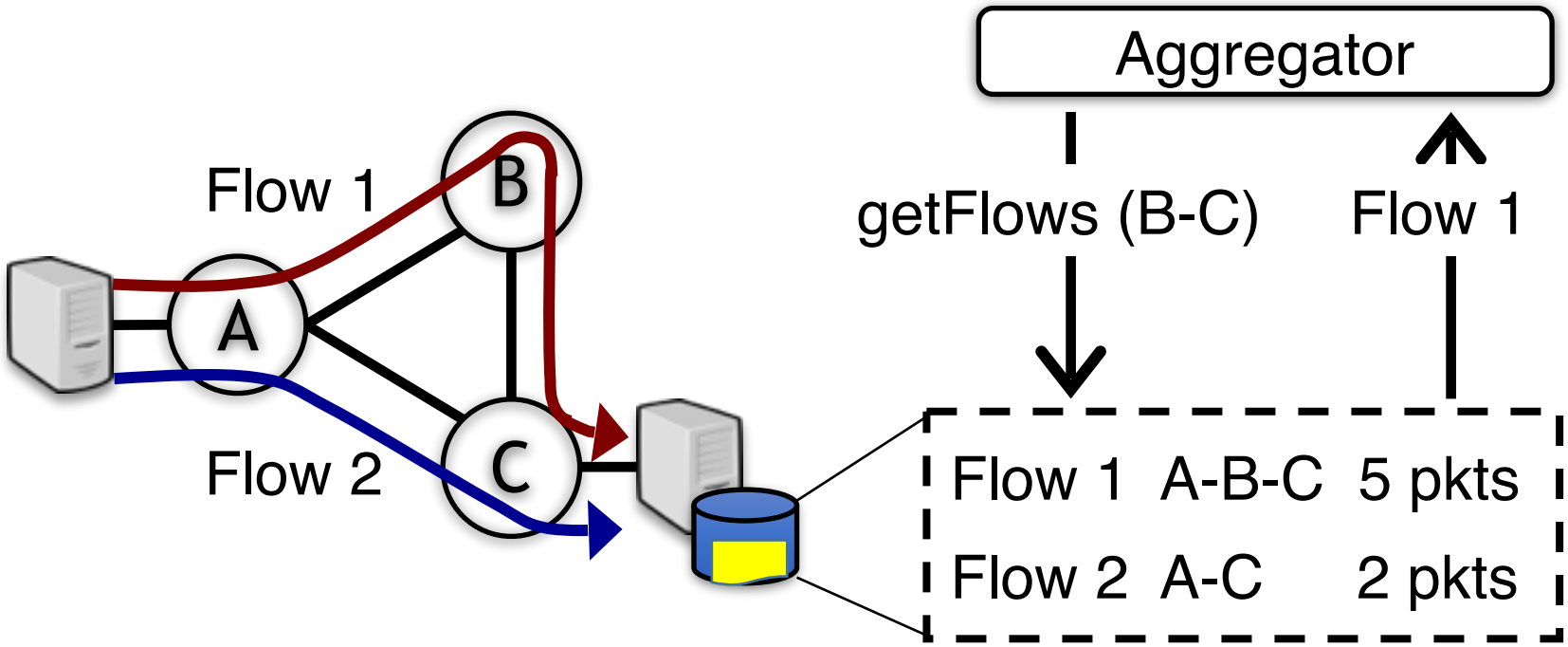

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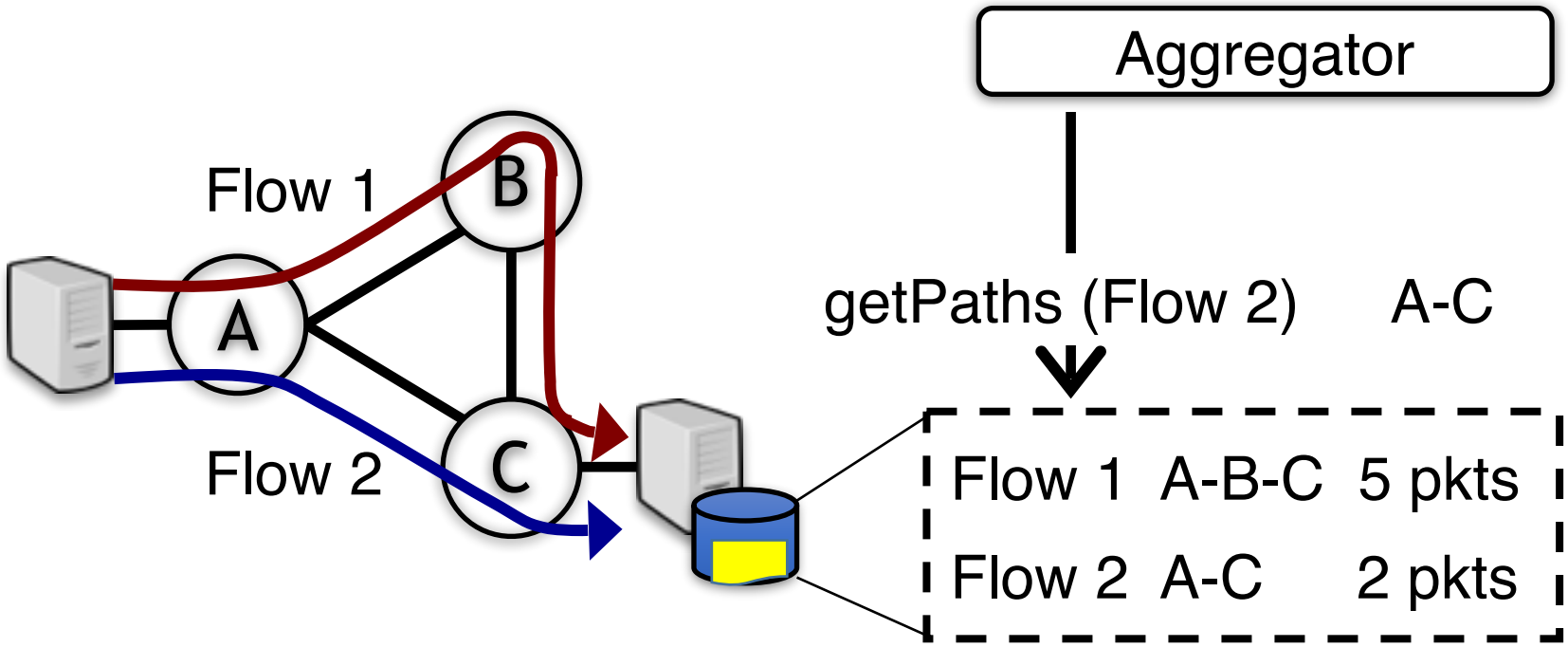

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Example 1: Path conformance

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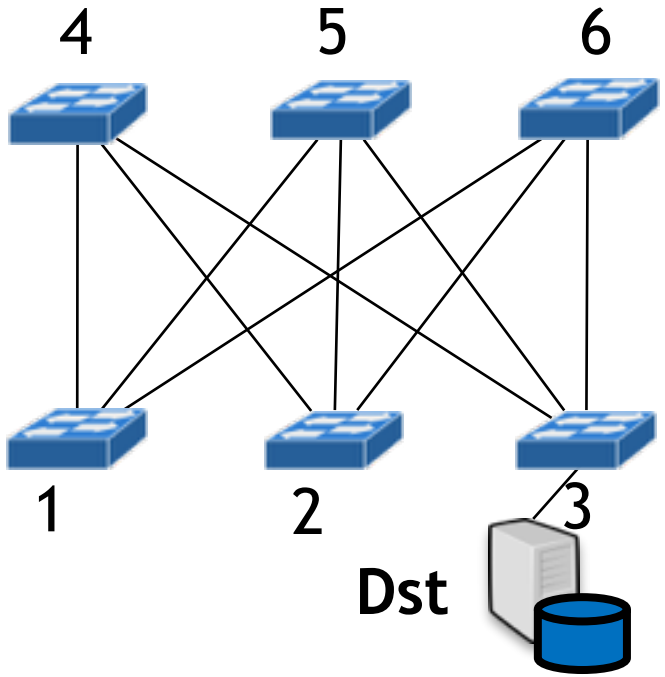
Check if actual forwarding path != network policy

- May occur due to switch faults or network state change

Policy: Packet must avoid switch 4



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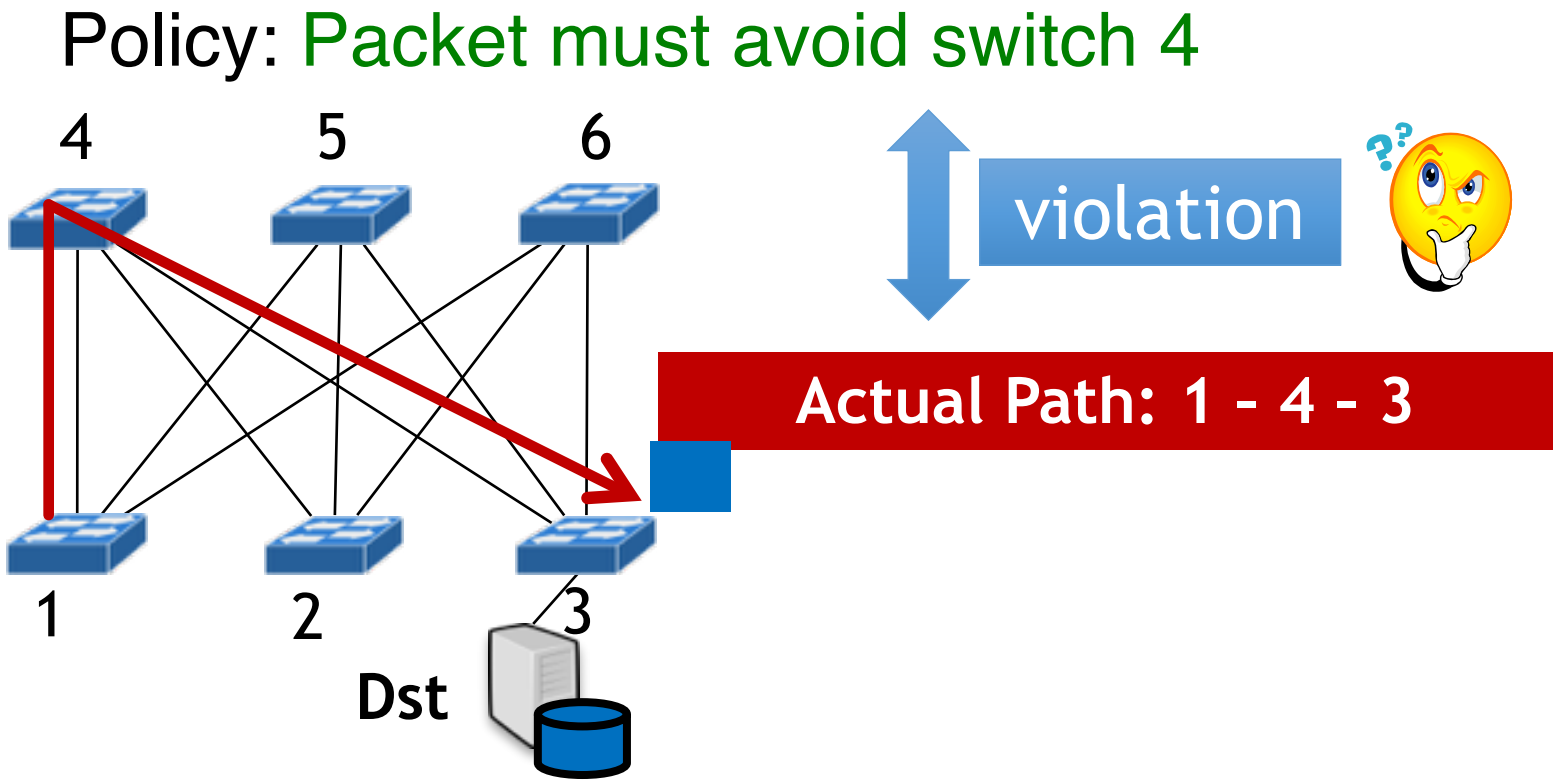


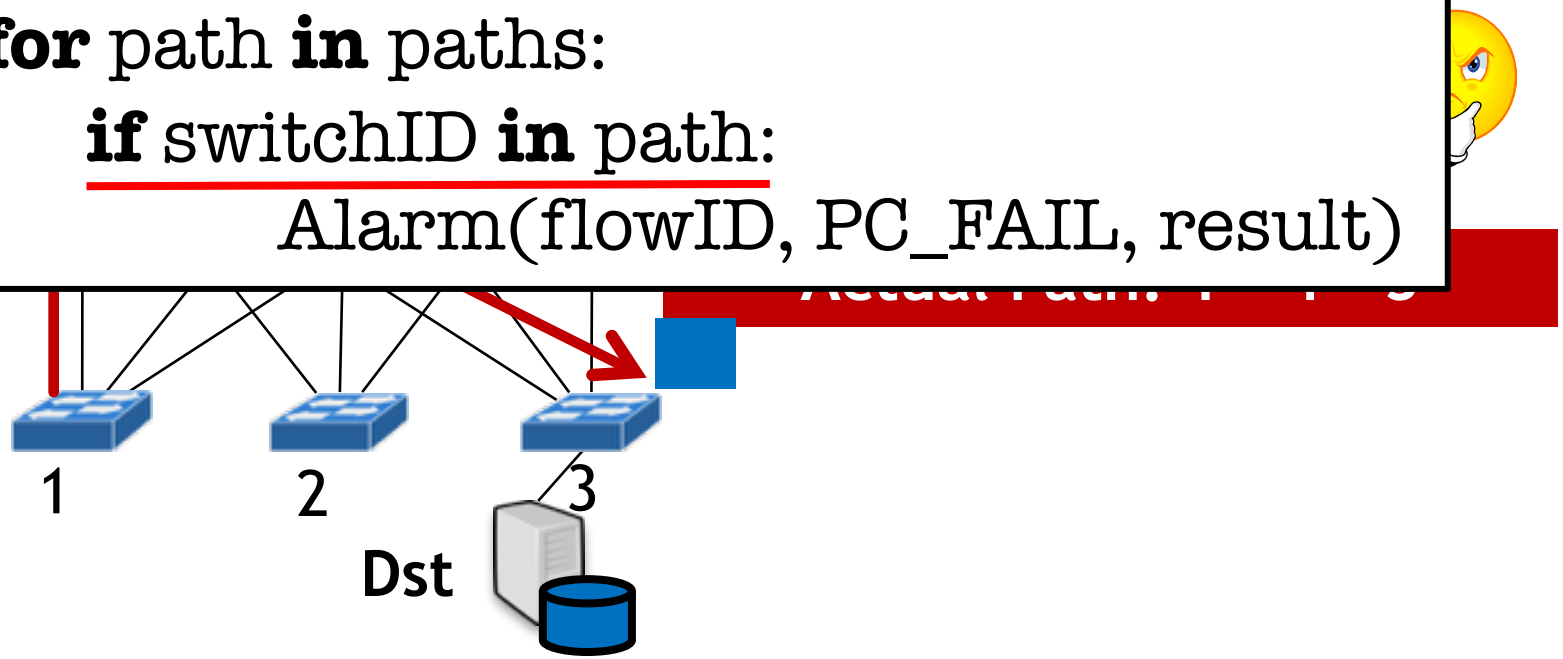
Example 1: Path conformance

Check if actual forwarding path != network policy

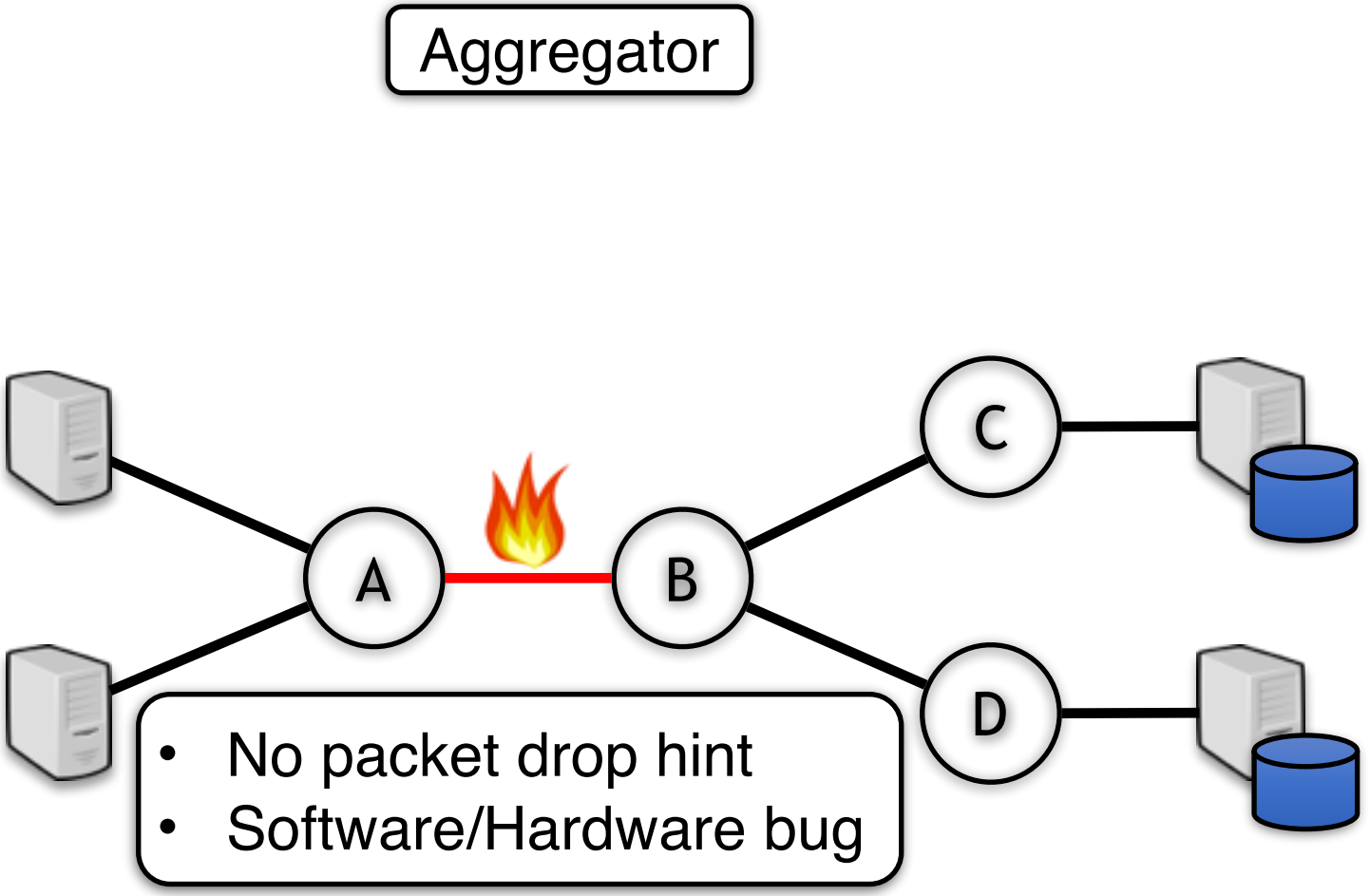
- May occur due to switch faults or network state change

```
# Given flowID, paths, switchID

1: for path in paths:
2:     if switchID in path:
3:         Alarm(flowID, PC_FAIL, result)
```



Example 2: Silent random packet drop diagnosis



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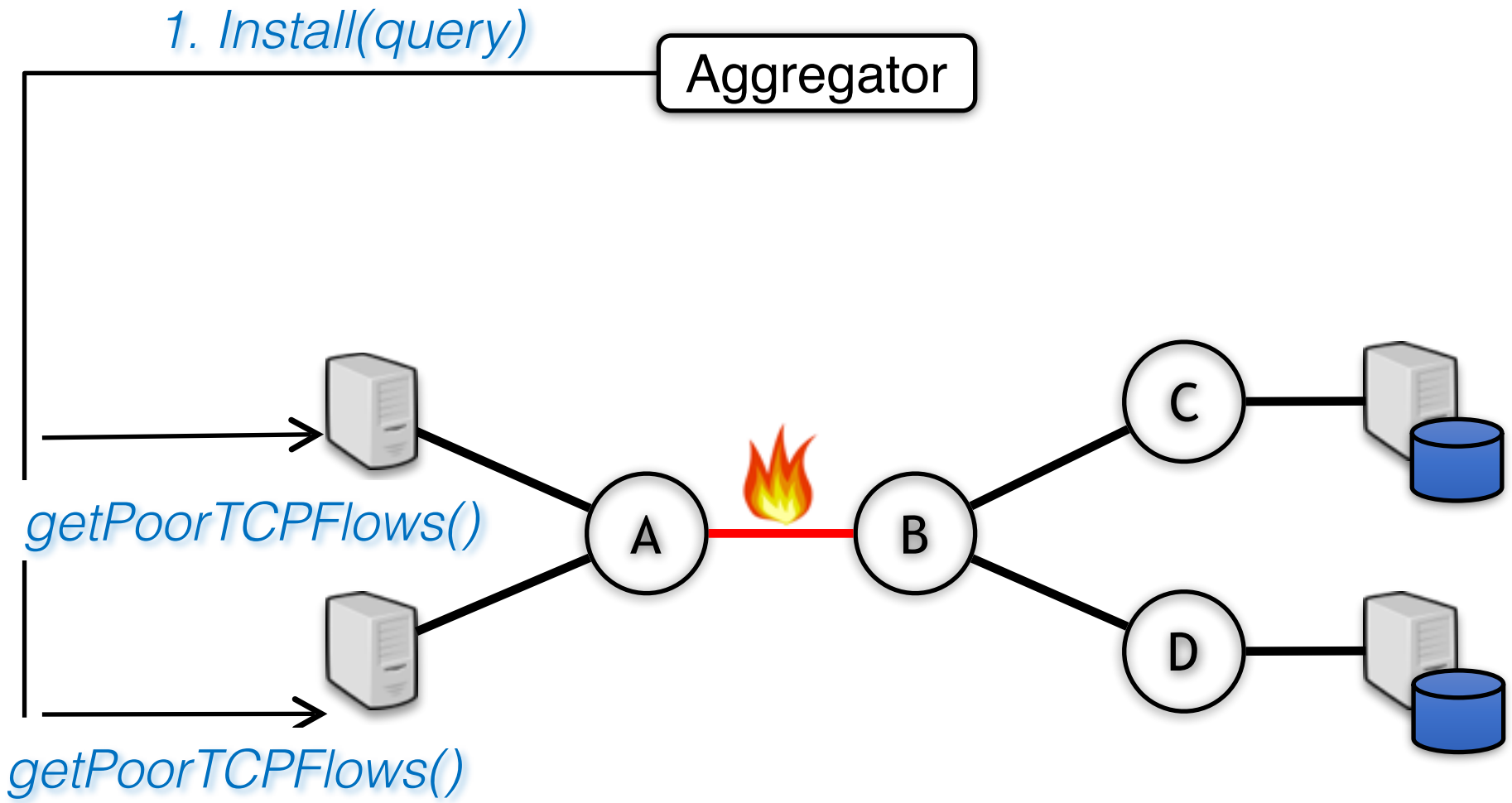

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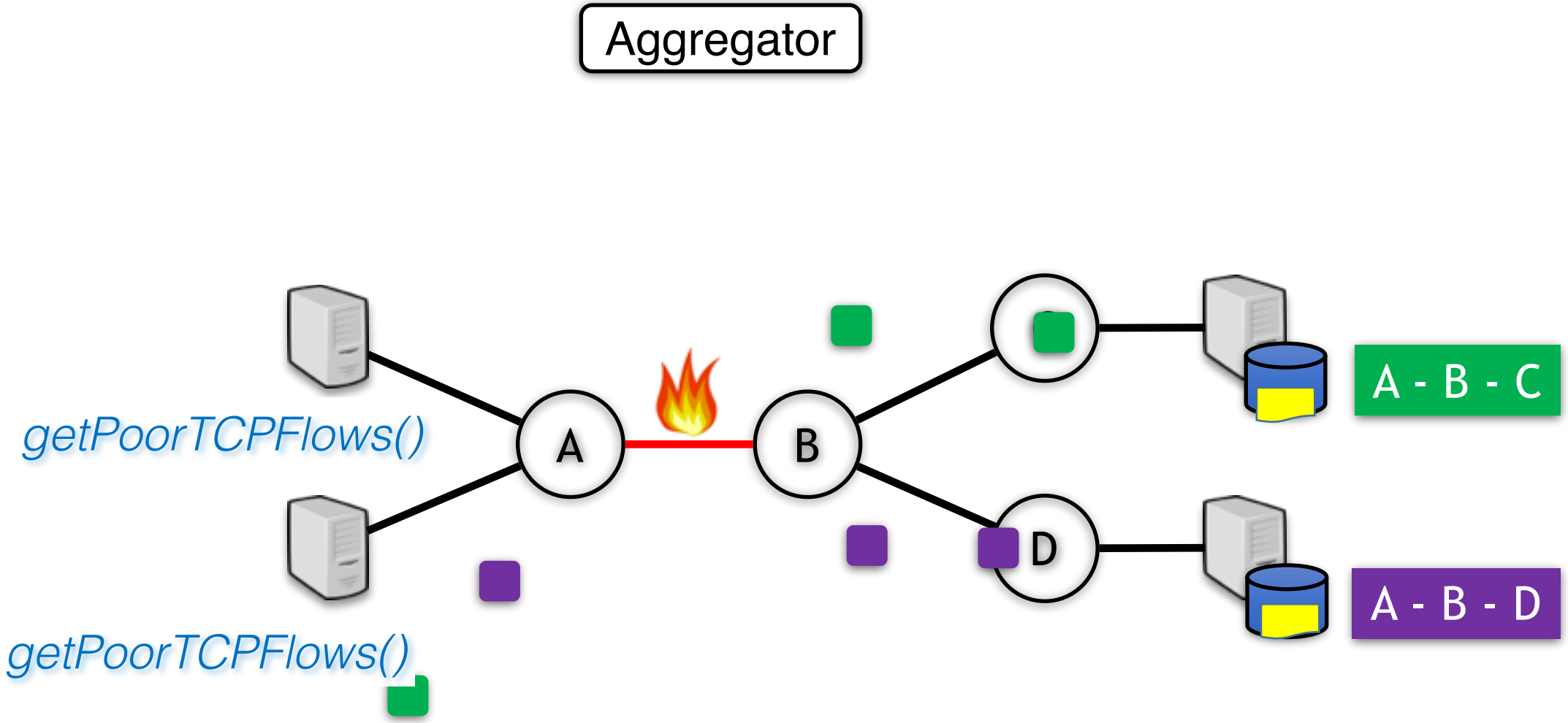

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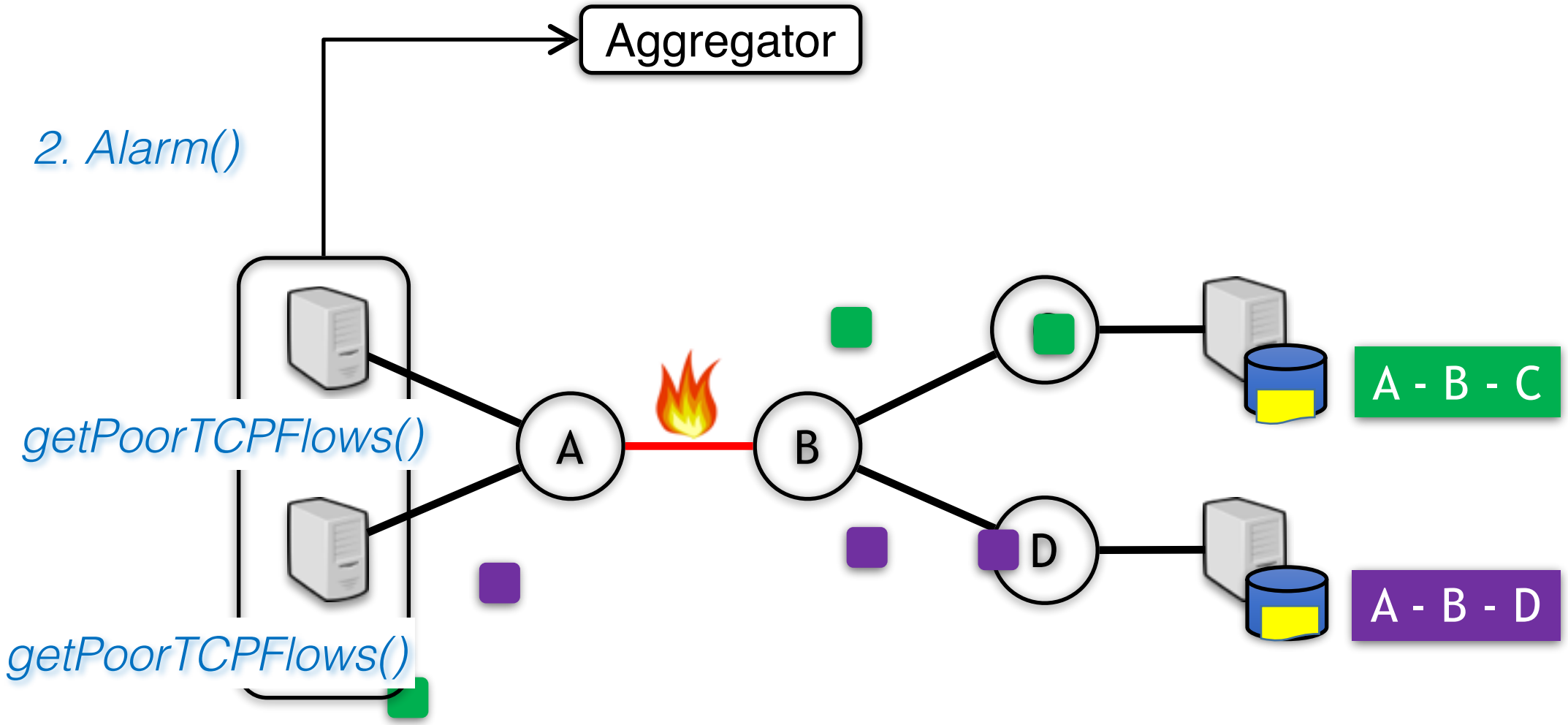

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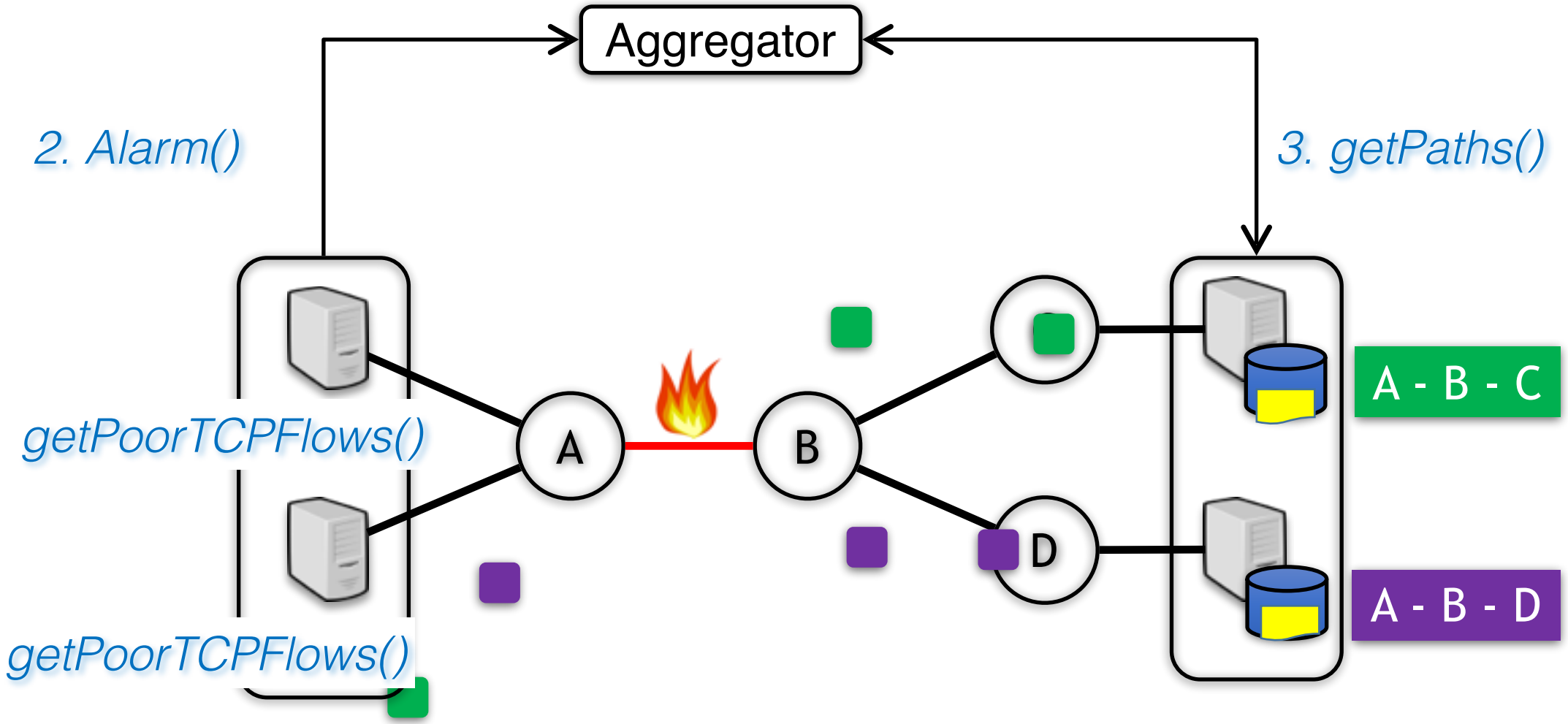

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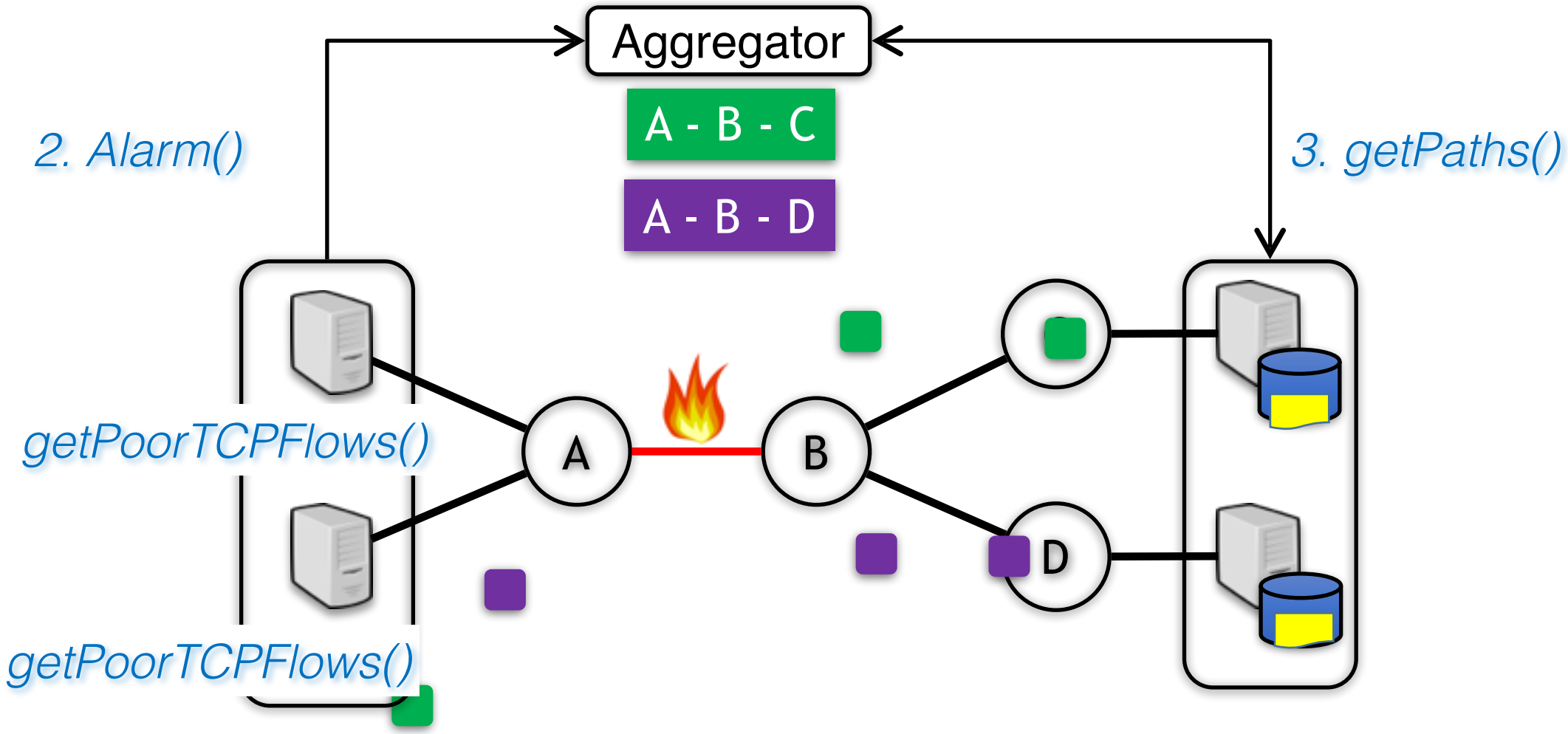

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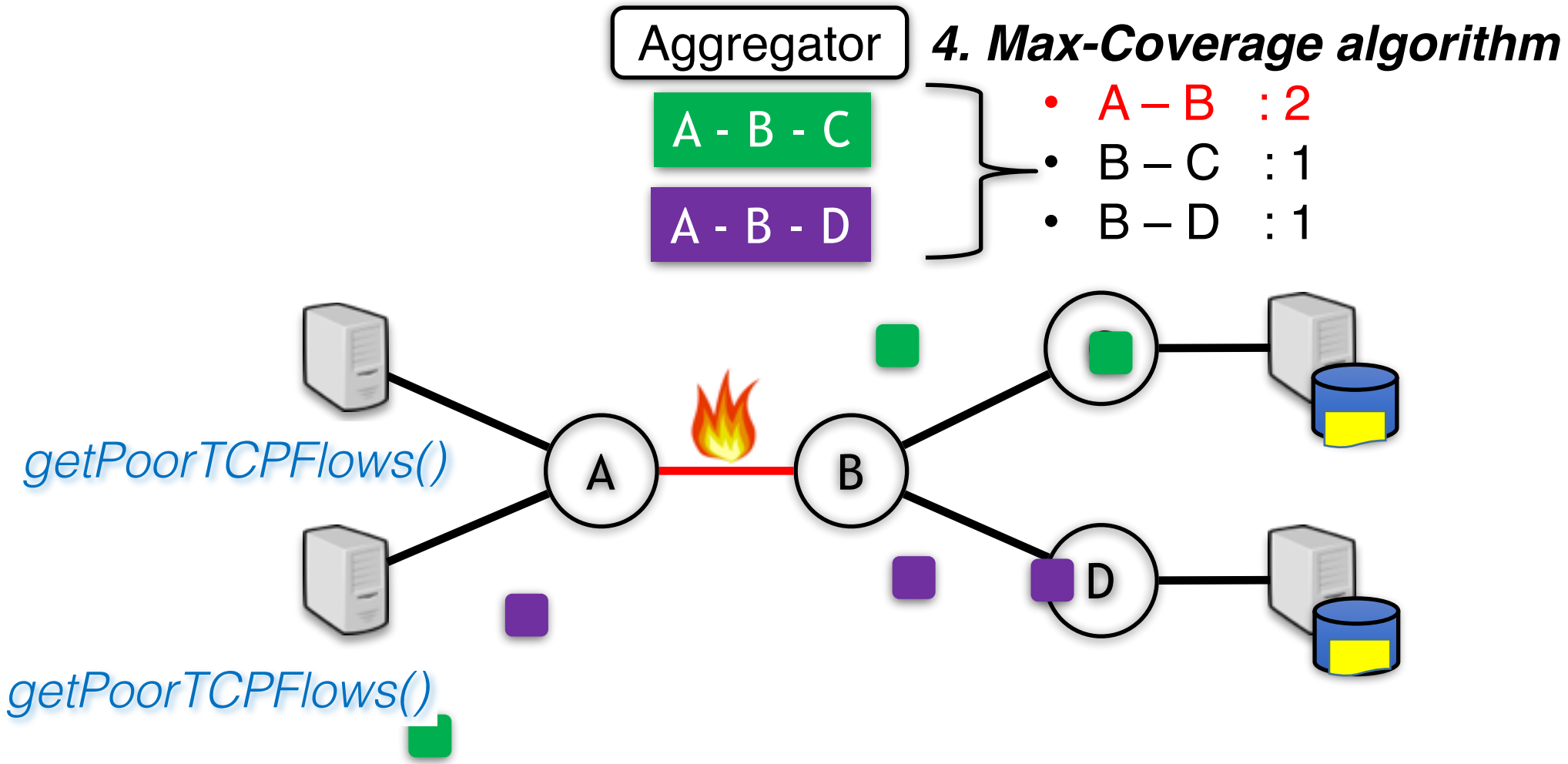

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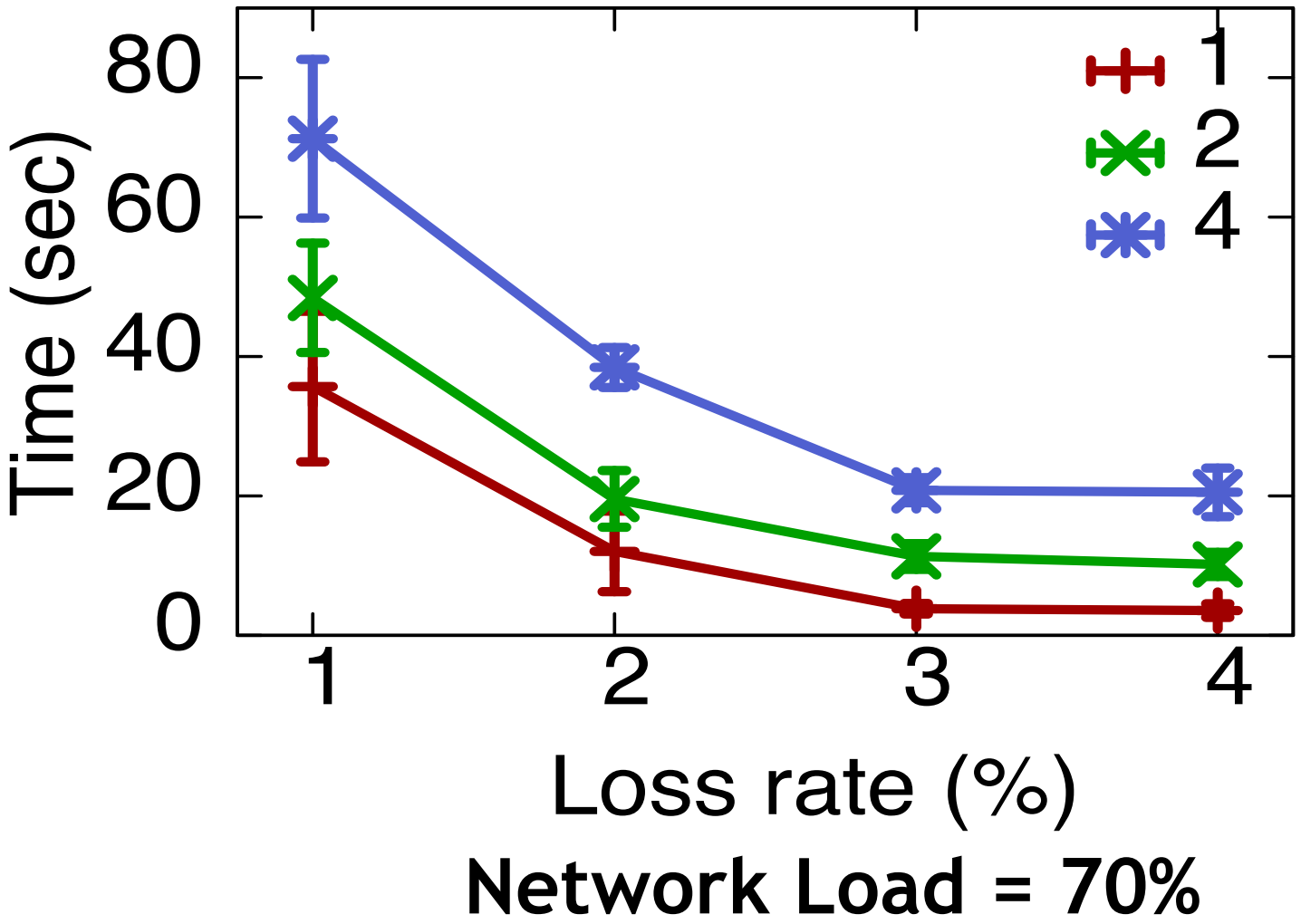

Lab setup

- 4-ary fat-tree topology
- Web-traffic model

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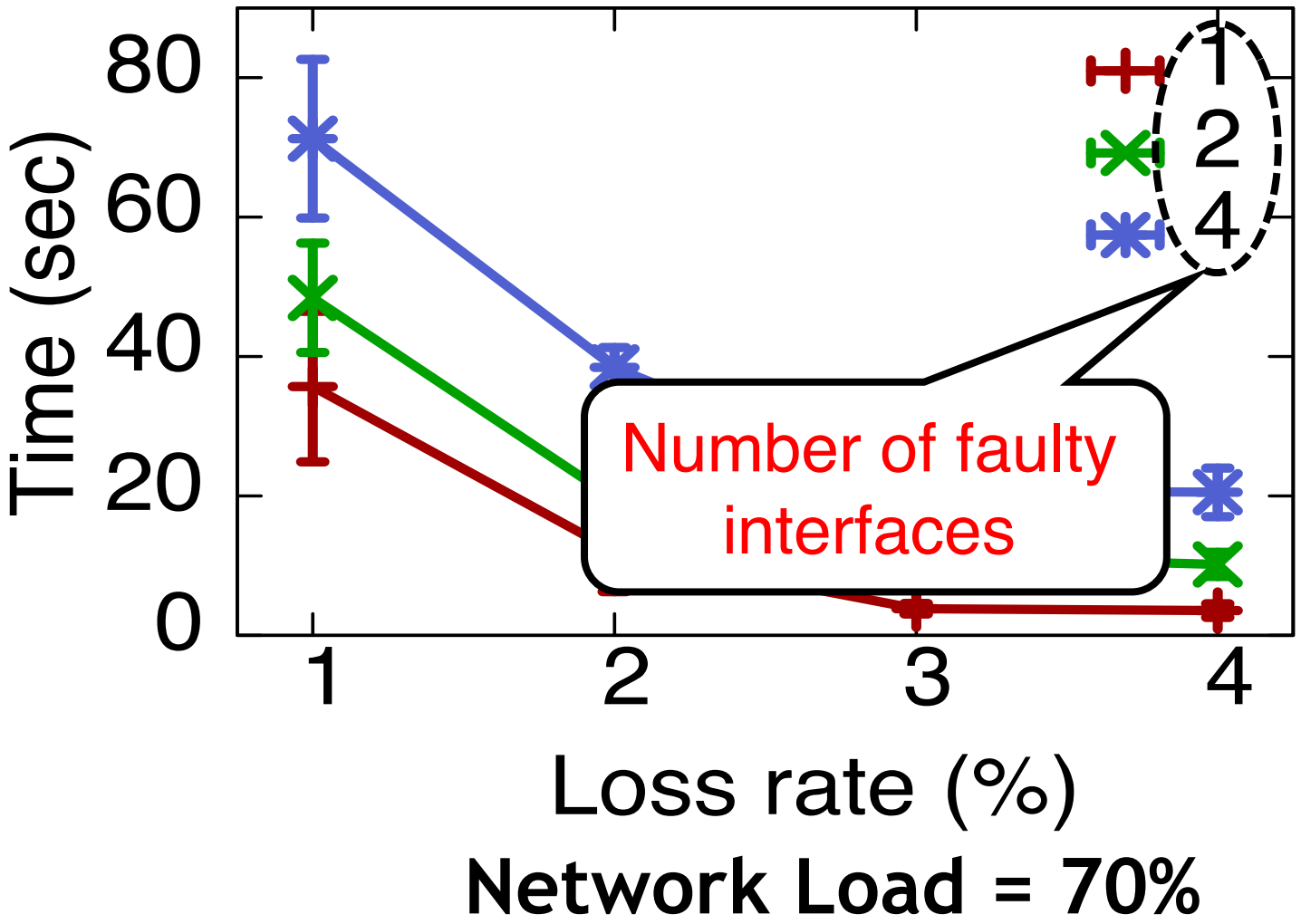

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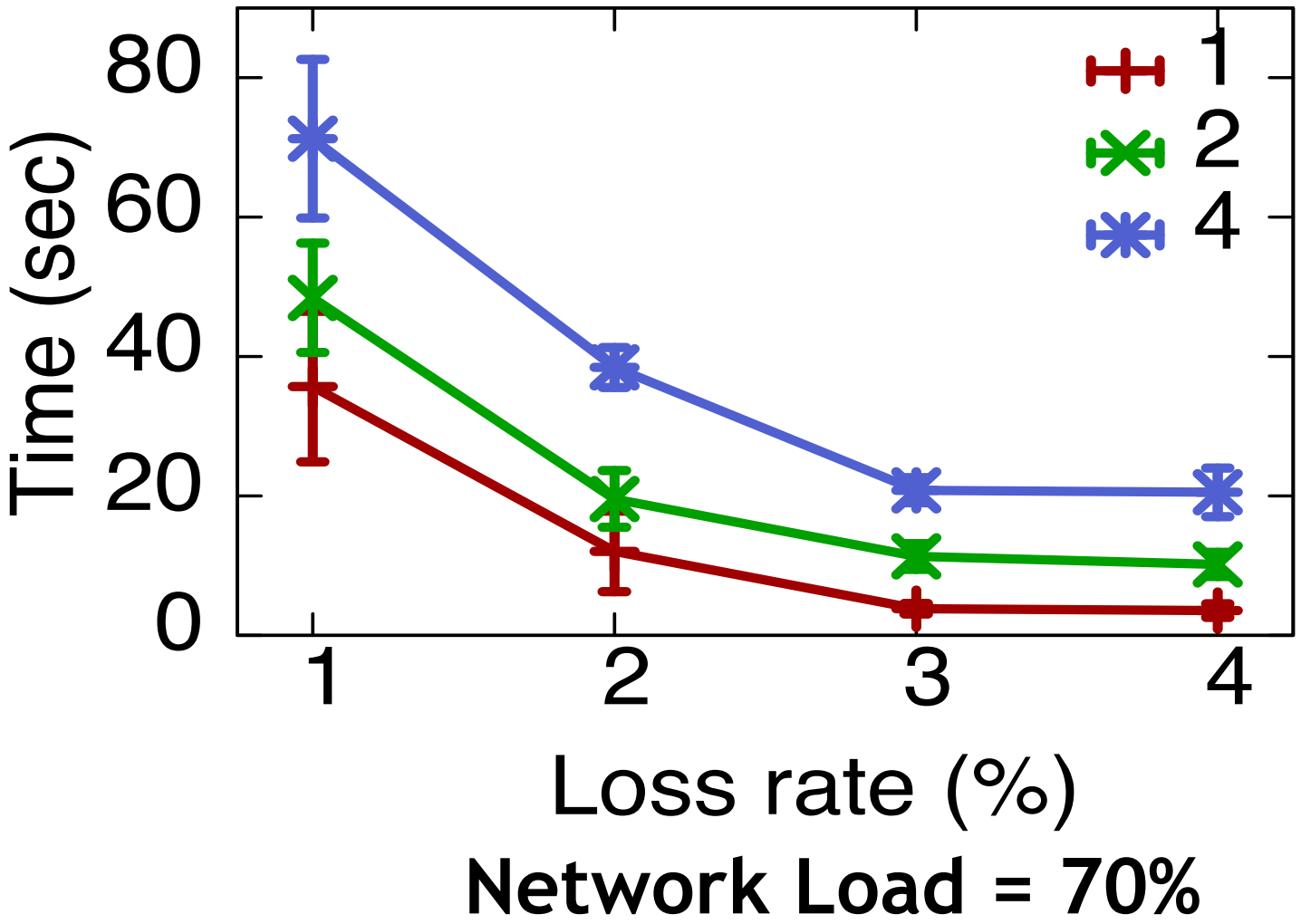

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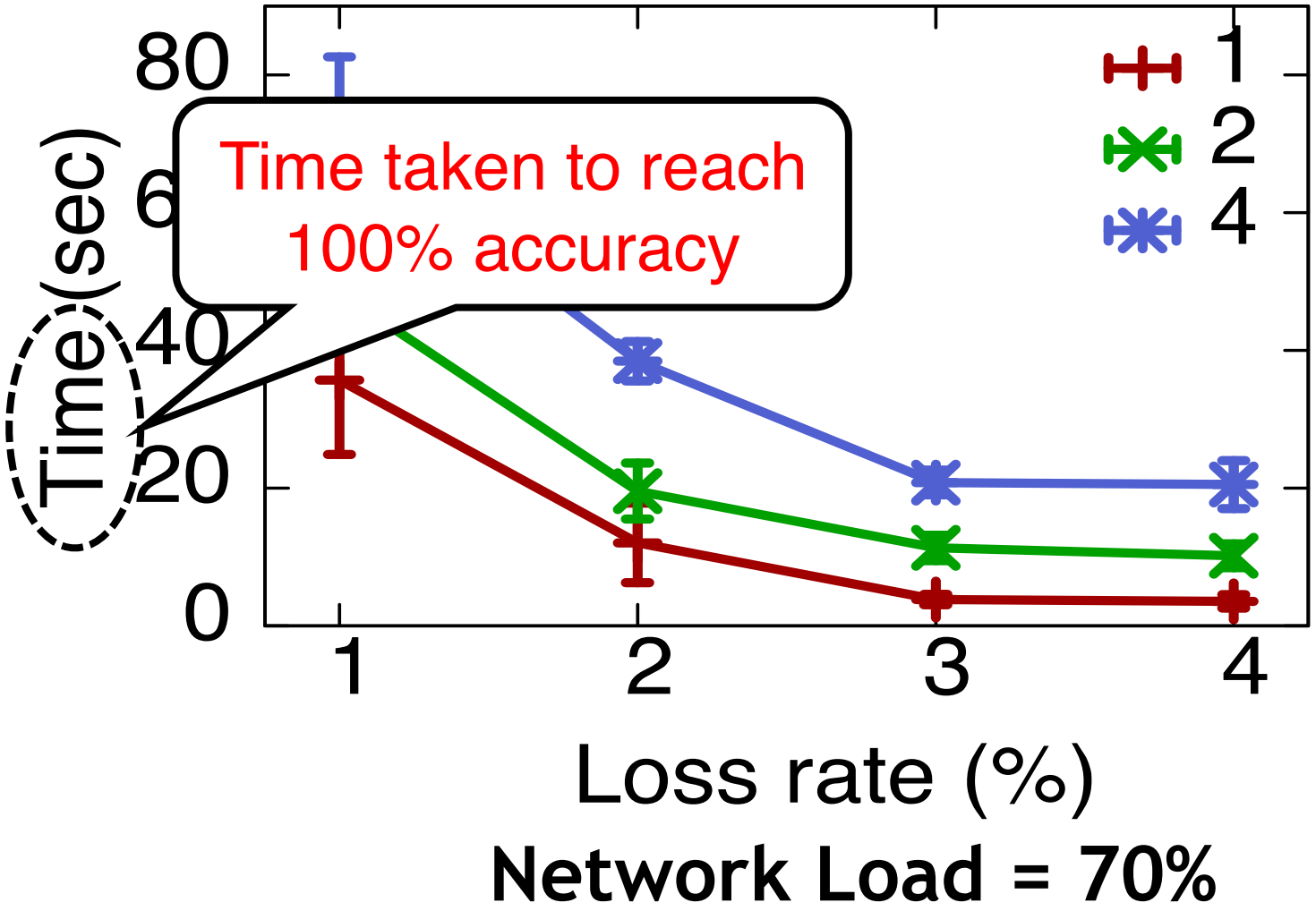

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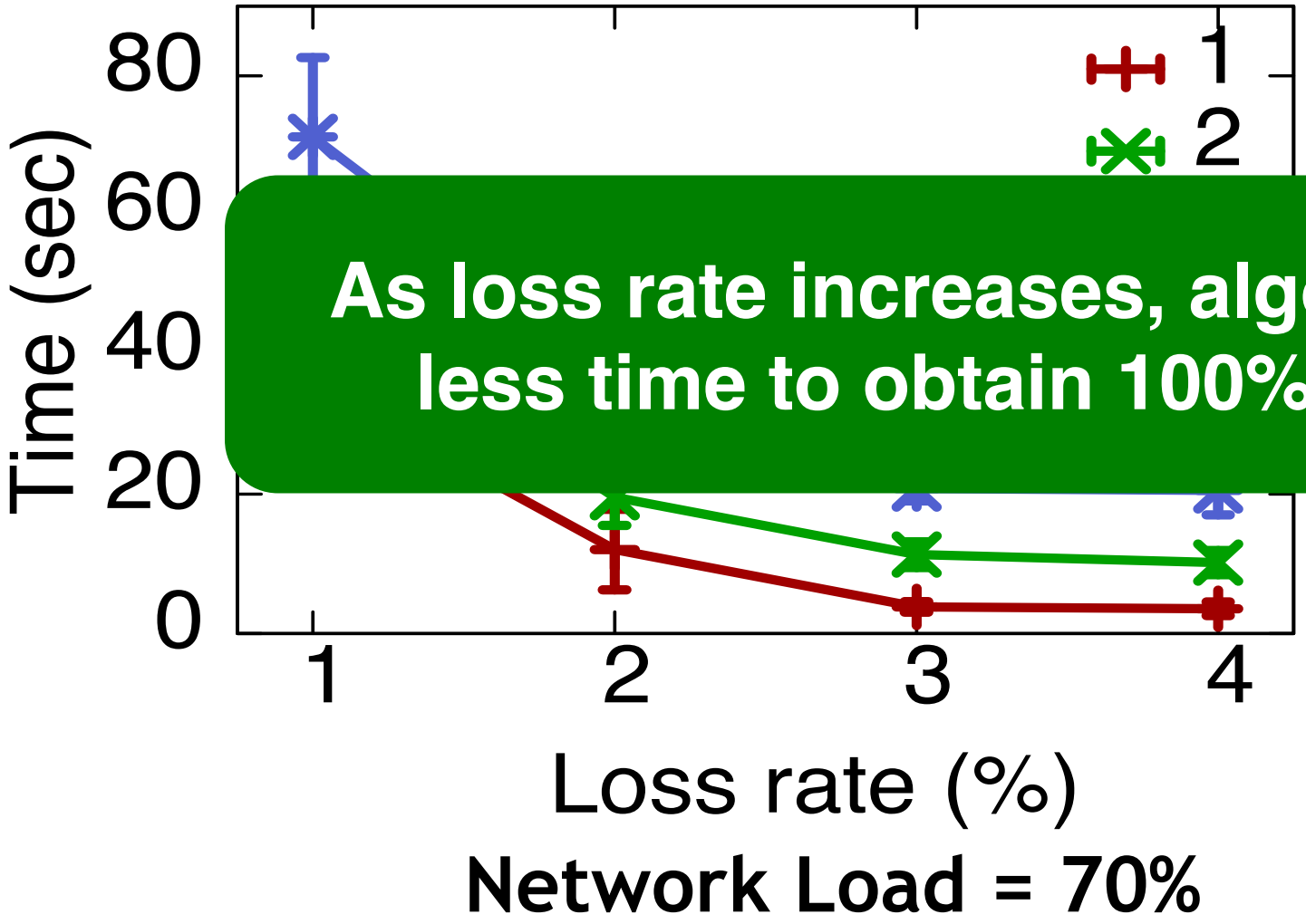


Network Load = 70%

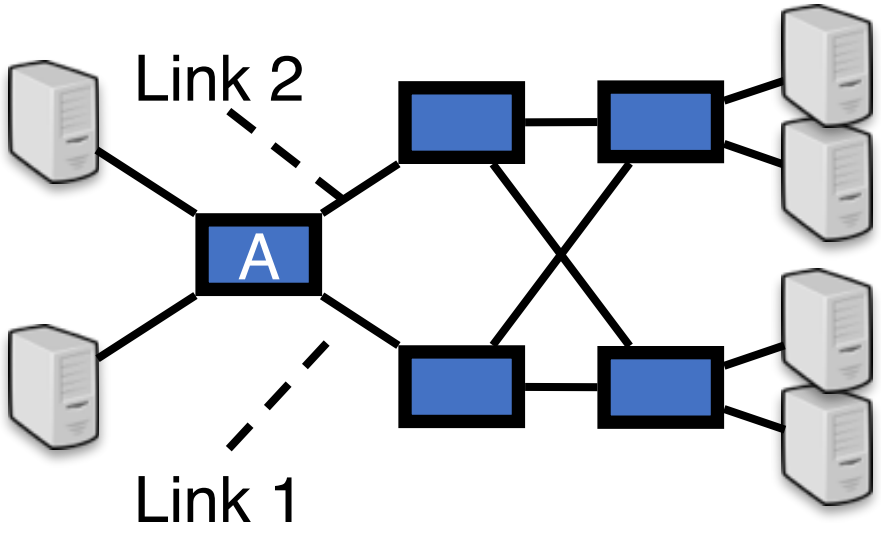
Lab setup

- 4-ary fat-tree topology
- del

As loss rate increases, algorithm takes less time to obtain 100% accuracy

Example 3: Load imbalance diagnosis

Aggregator



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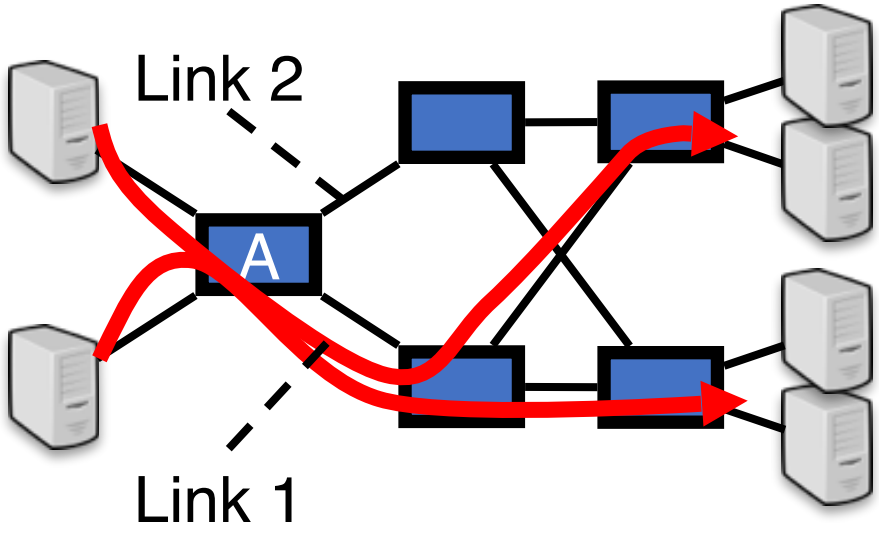
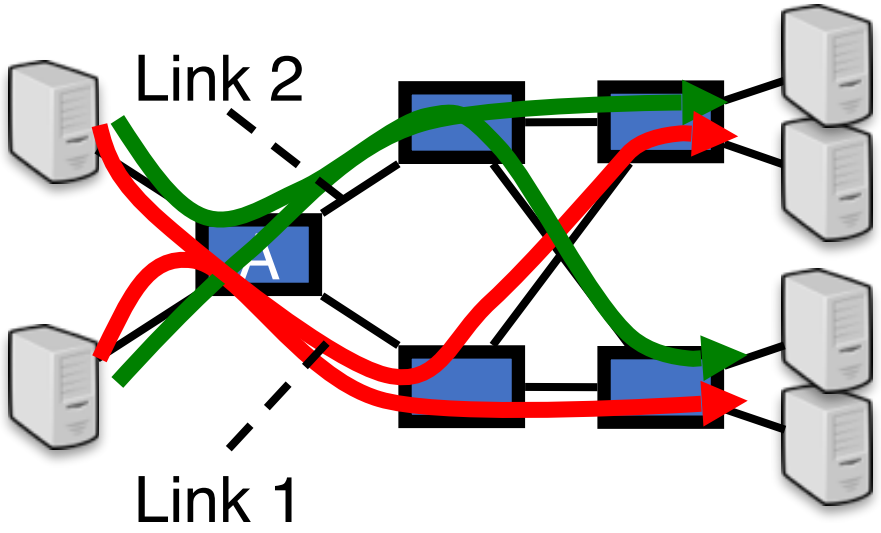


If flow >= 1 MB ➔ Link 1

Example 3: Load imbalance diagnosis

Aggregator

If flow < 1 MB ➔ Link 2



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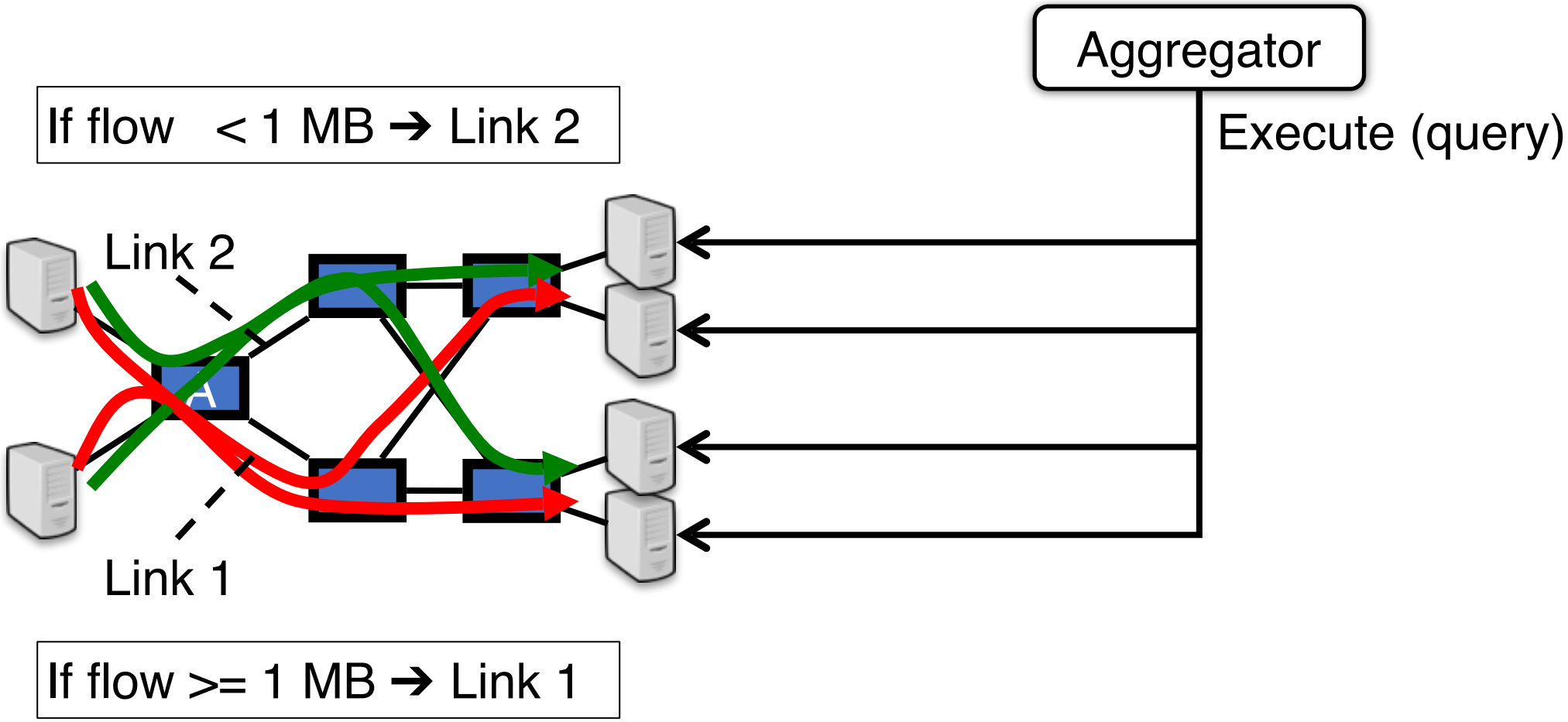

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Aggregator

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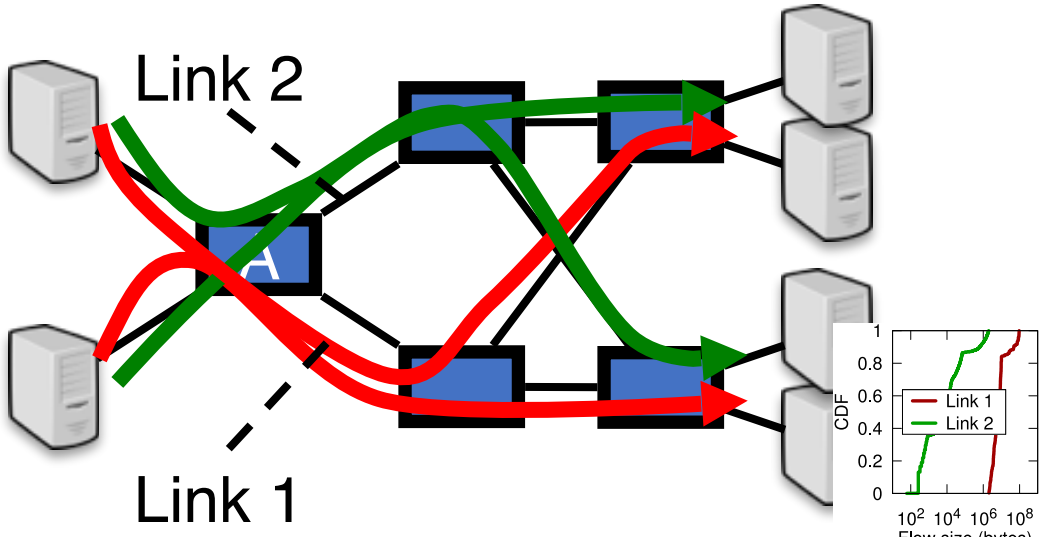
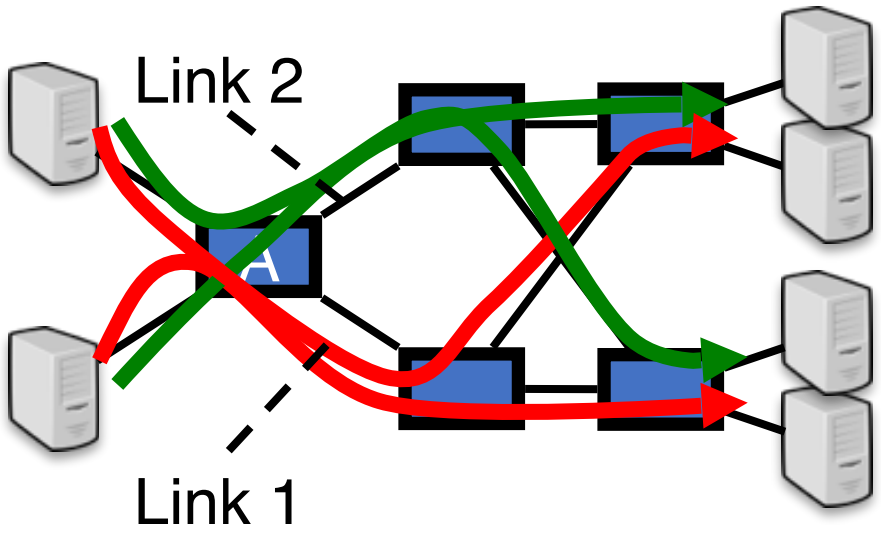


If flow >= 1 MB ➔ Link 1

Local flow size distribution

Example 3: Load imbalance diagnosis

If flow < 1 MB ➔ Link 2



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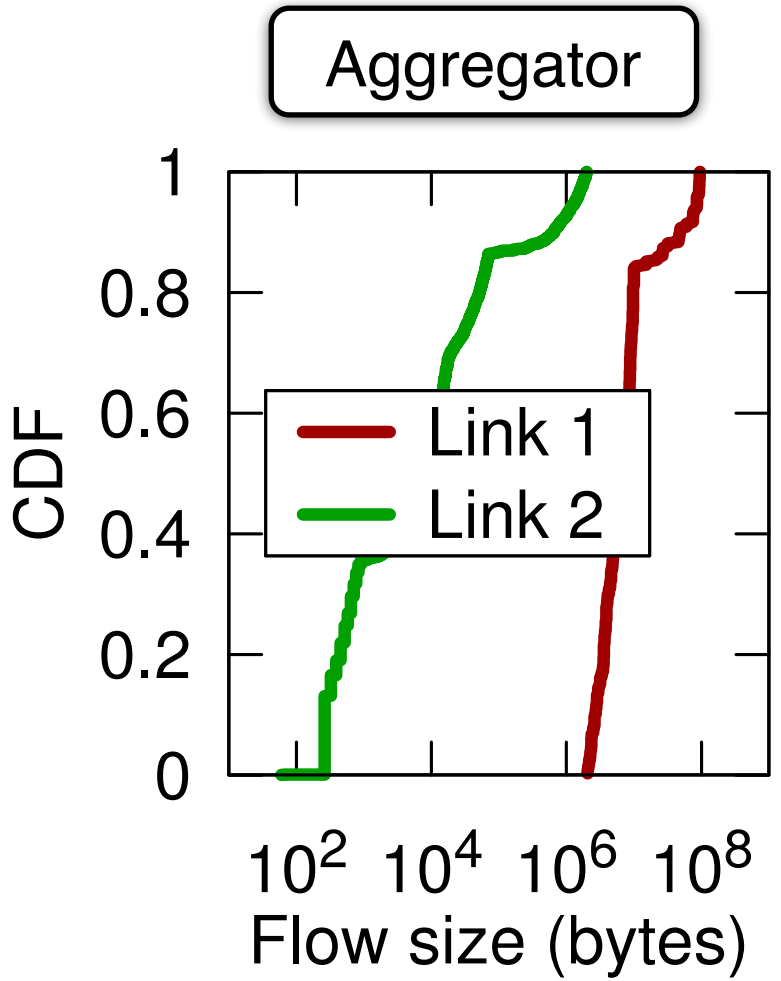

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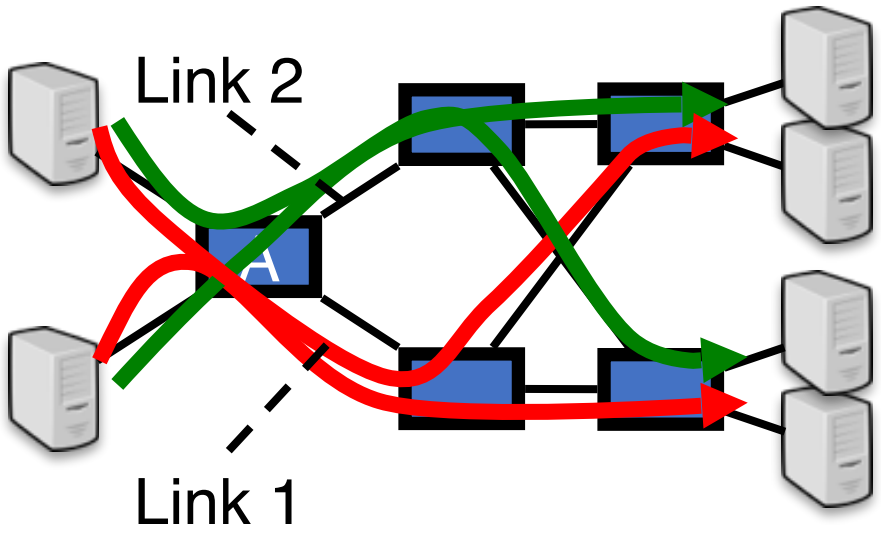

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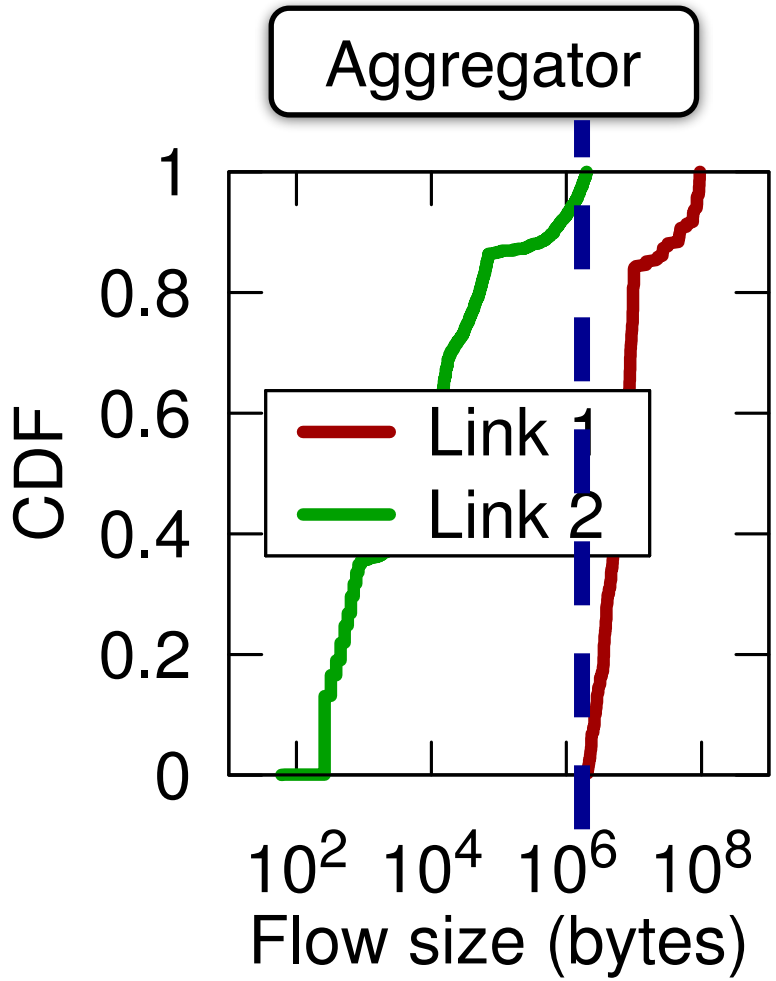
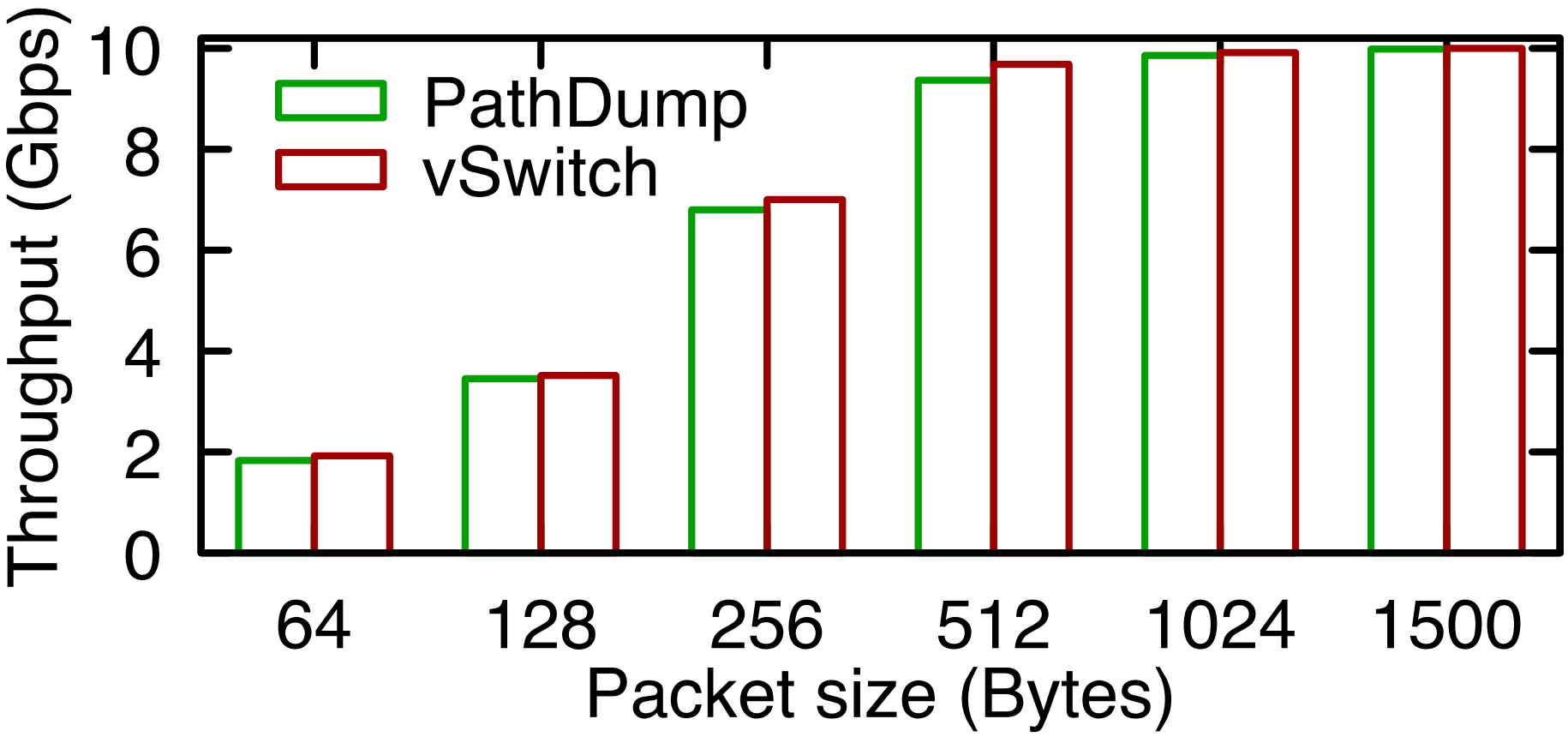


Other debugging applications

- Real-time routing loop detection
- Blackhole diagnosis
- TCP performance anomaly diagnosis
  - TCP incast and outcast
- Traffic measurement
  - Traffic matrix, heavy-hitter detection, etc.

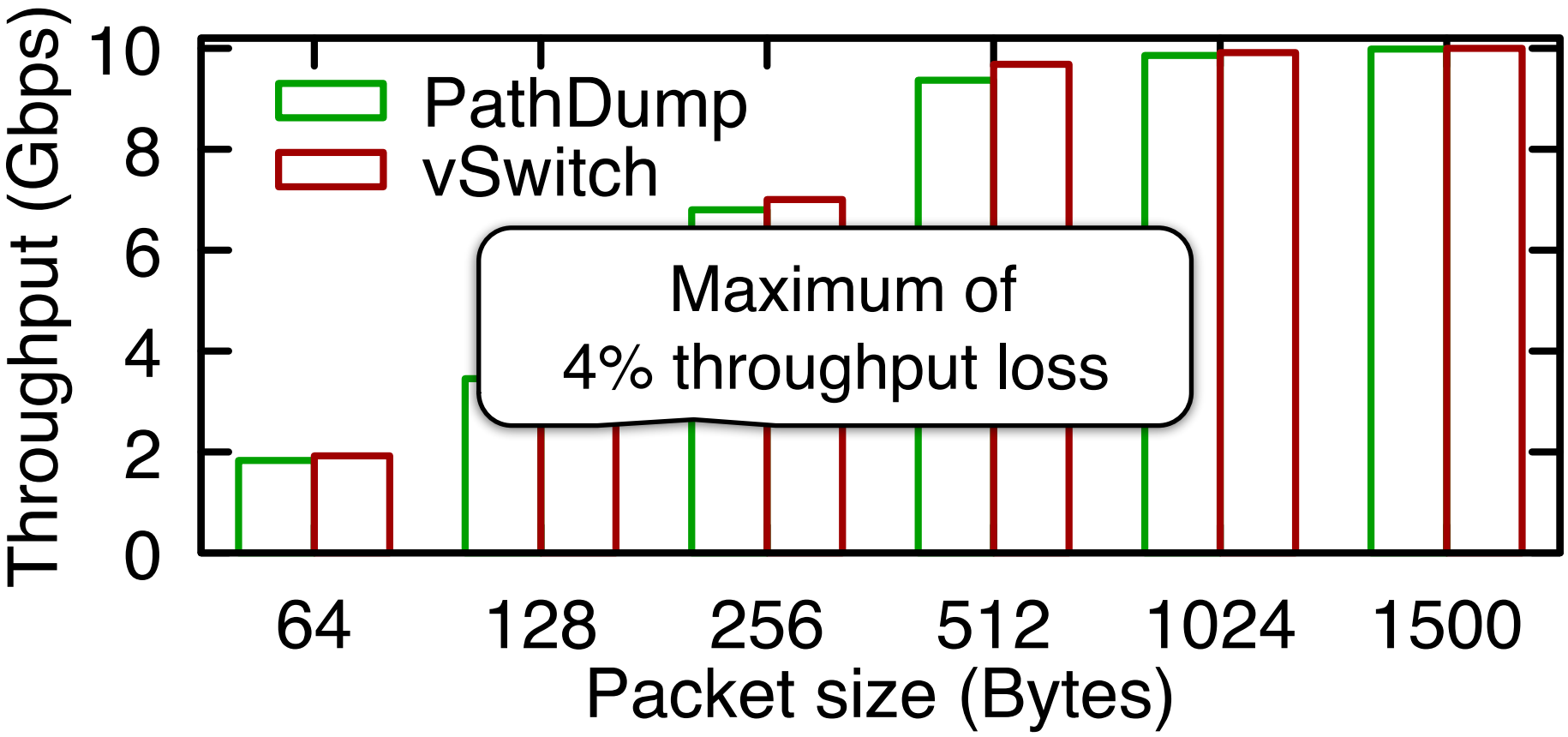
More details in our paper

Packet processing overhead at end-host



Packet processing overhead at end-host

Minimal packet processing overhead atop Open vSwitch



More details (In the paper)

- Distributed query mechanism
- Supported network debugging problems
- Implementation details
- Evaluation over real testbed(s)

Conclusion

- DCNs are complex; and their debuggers are even more complex
- Design and implement PathDump, a simple debugger
- Keeps network switches simple
  - No complex operations in network switches
- Executes debugging queries in a distributed manner
- Consumes small amount of data plane and end-host resources
- Debugs a large class of network problems

https://github.com/PathDump

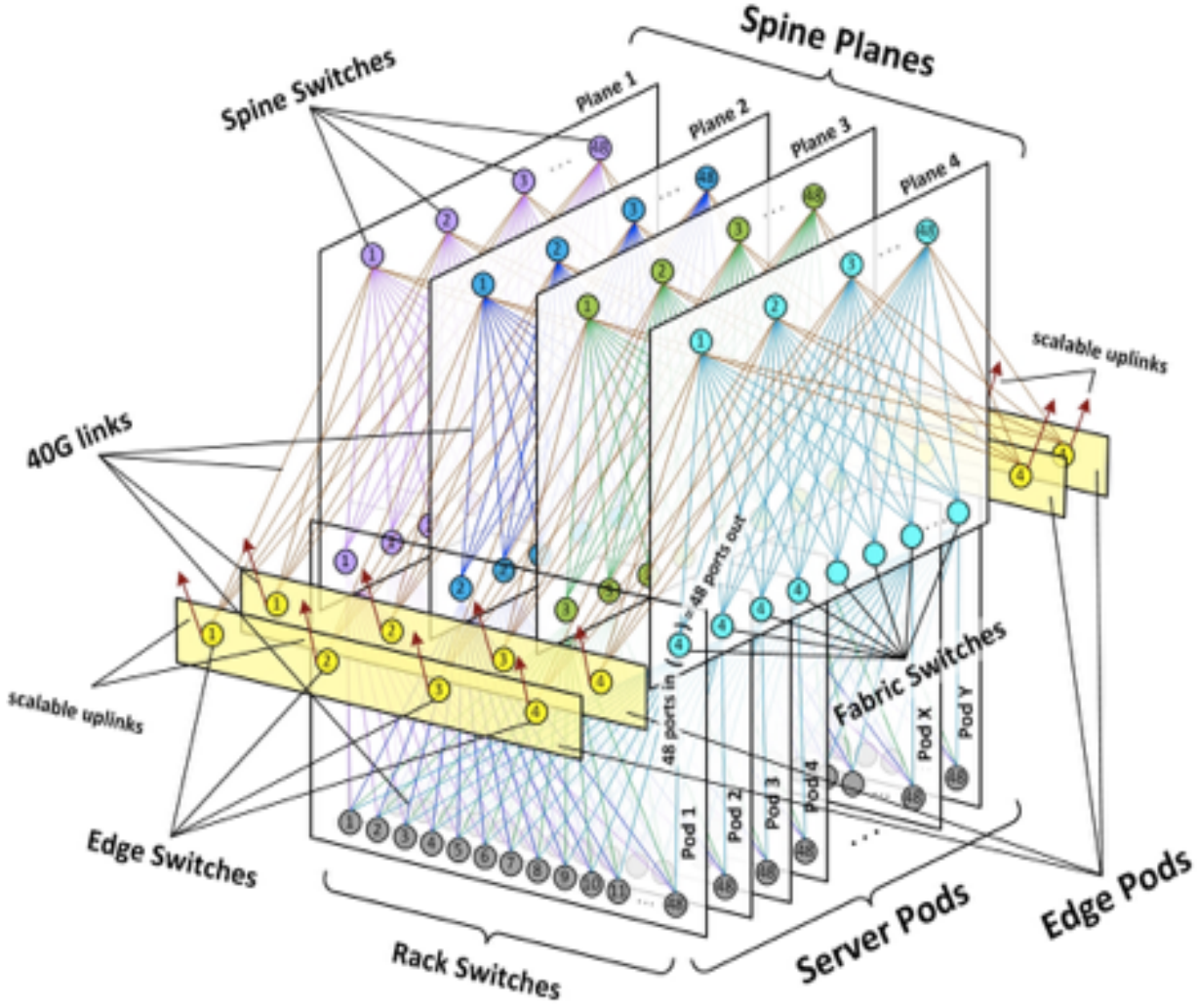
Datacenter networks are complex(*remove slide)

- Complexity due to need for
  - High availability
  - High performance

Latency matters. Amazon found every 100ms of latency cost them 1% in sales.

Google found an extra .5 seconds in search page generation time dropped traffic by 20%.

--source: The Gigaspaces blog



--source: TechRepublic.com

PathDump interface

Simple 9 APIs enables a variety of debugging applications

Host API

```
getFlows(linkID, timeRange)
getPaths(flowID, linkID, timeRange)
getCount(flow, timeRange)
getDuration(flow, timeRange)
getPoorTCPFlows(threshold)
Alarm(flowID, reason, paths)
```

Aggregator API

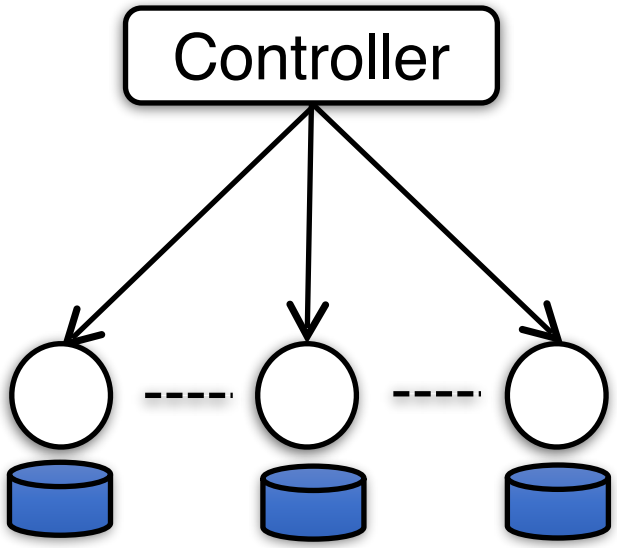
```
execute(list<hostID>, query)
install(list<hostID>, query, Period)
uninstall(list<hostID>, query)
```

✓ Write a query using host API

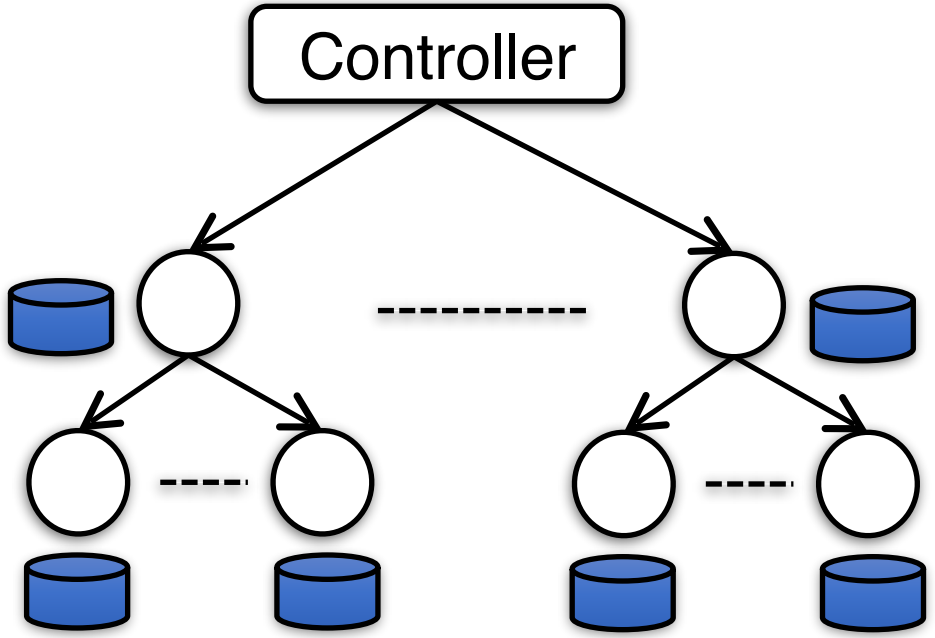
✓ Install(), execute() or uninstall() with Aggregator API

Query processing

Direct query

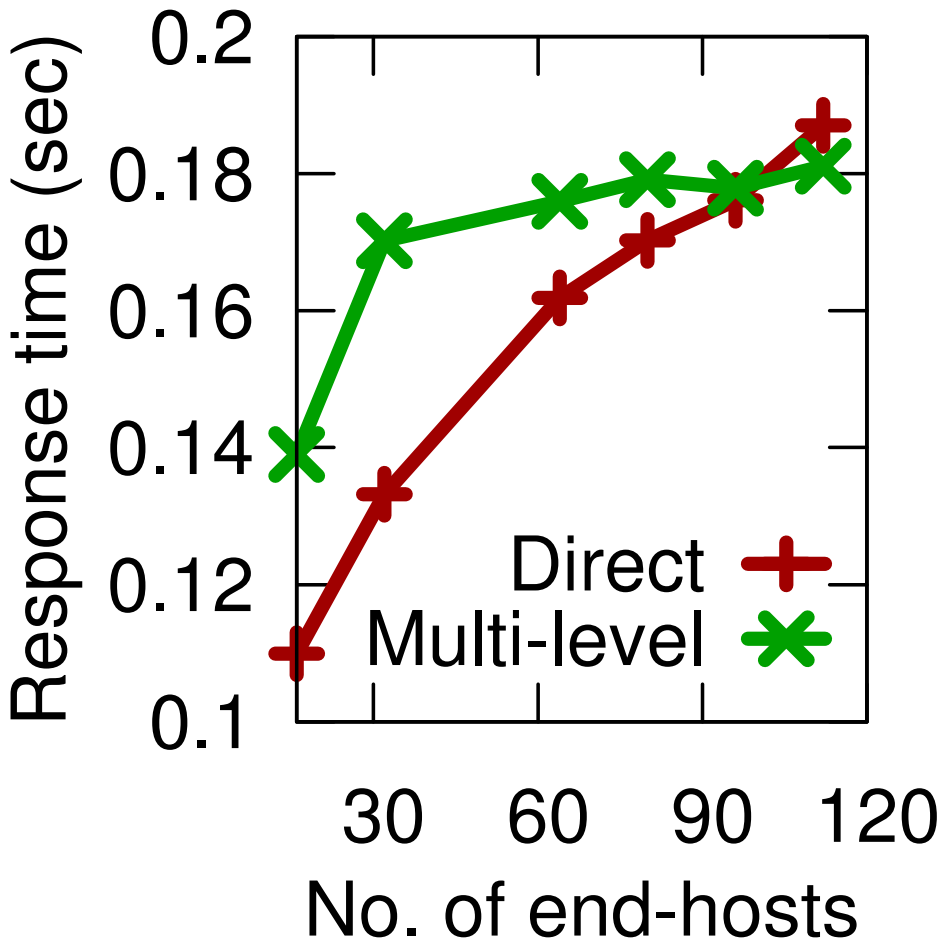


Multi level query



Query processing

Flow size distribution query



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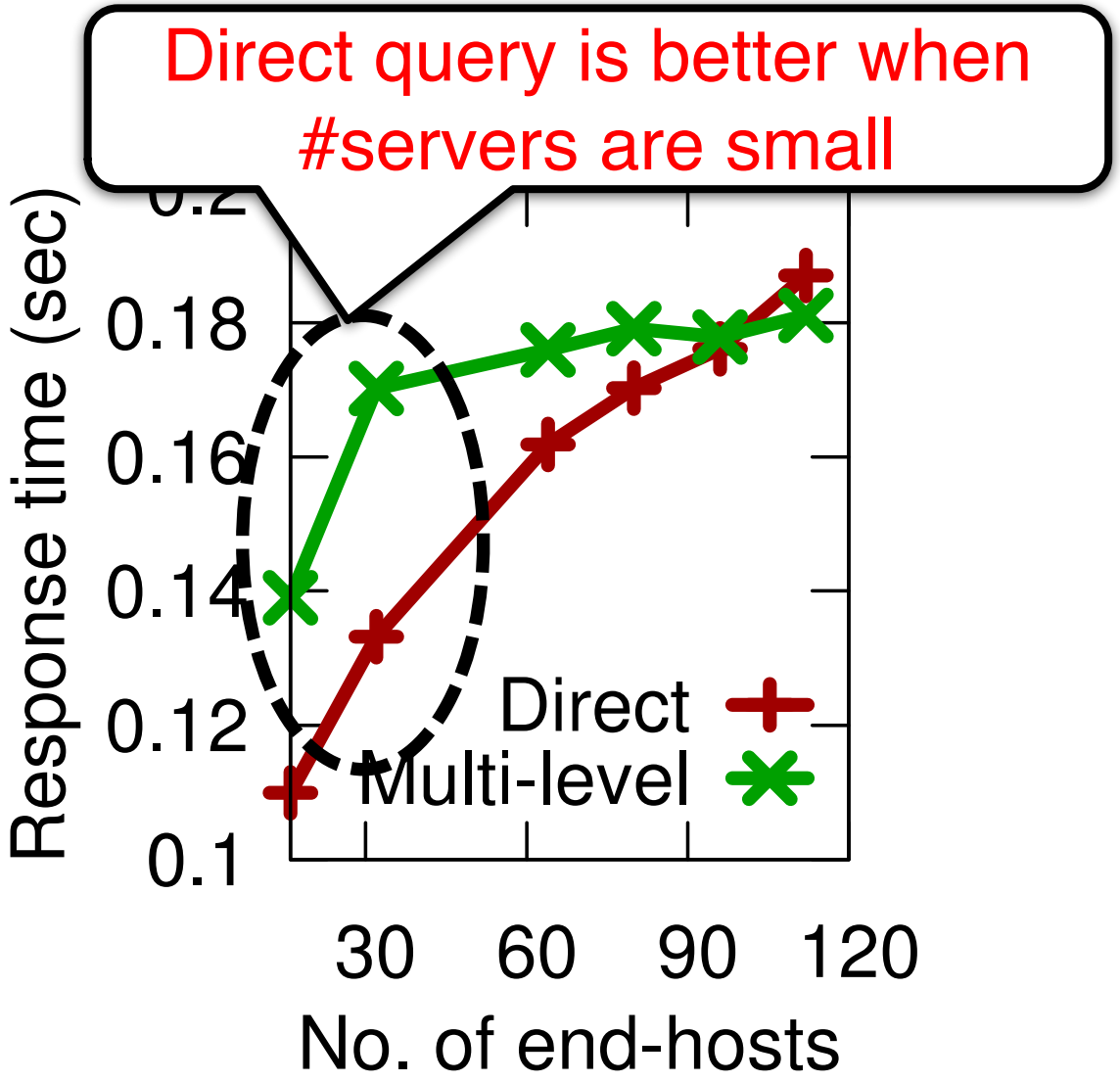
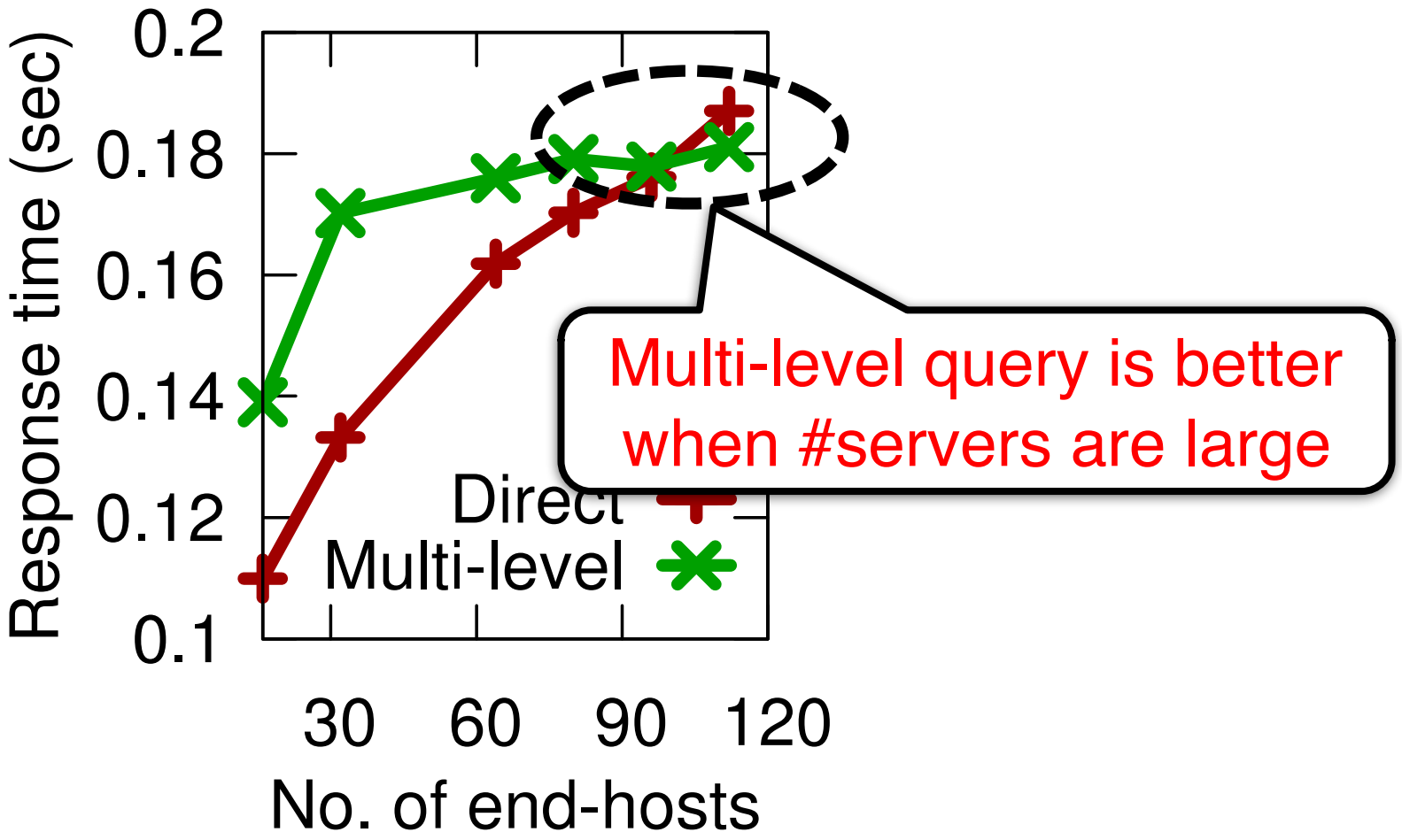


Query processing

Flow size distribution query



Query processing

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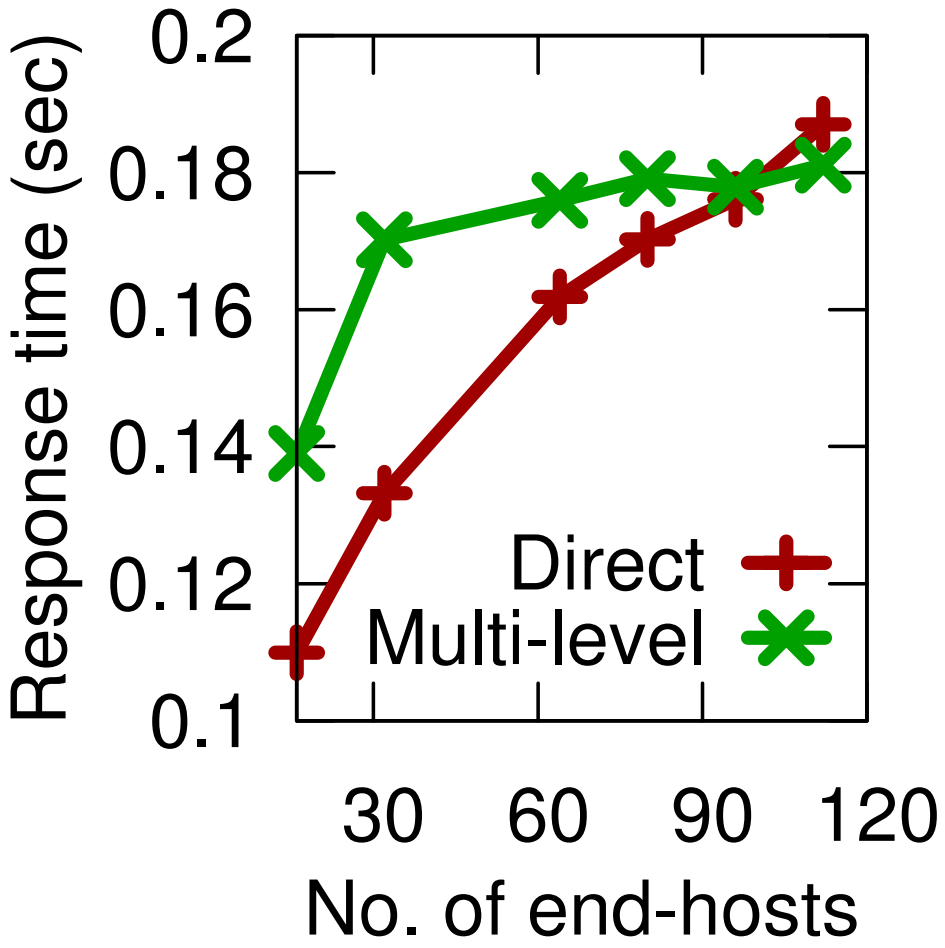
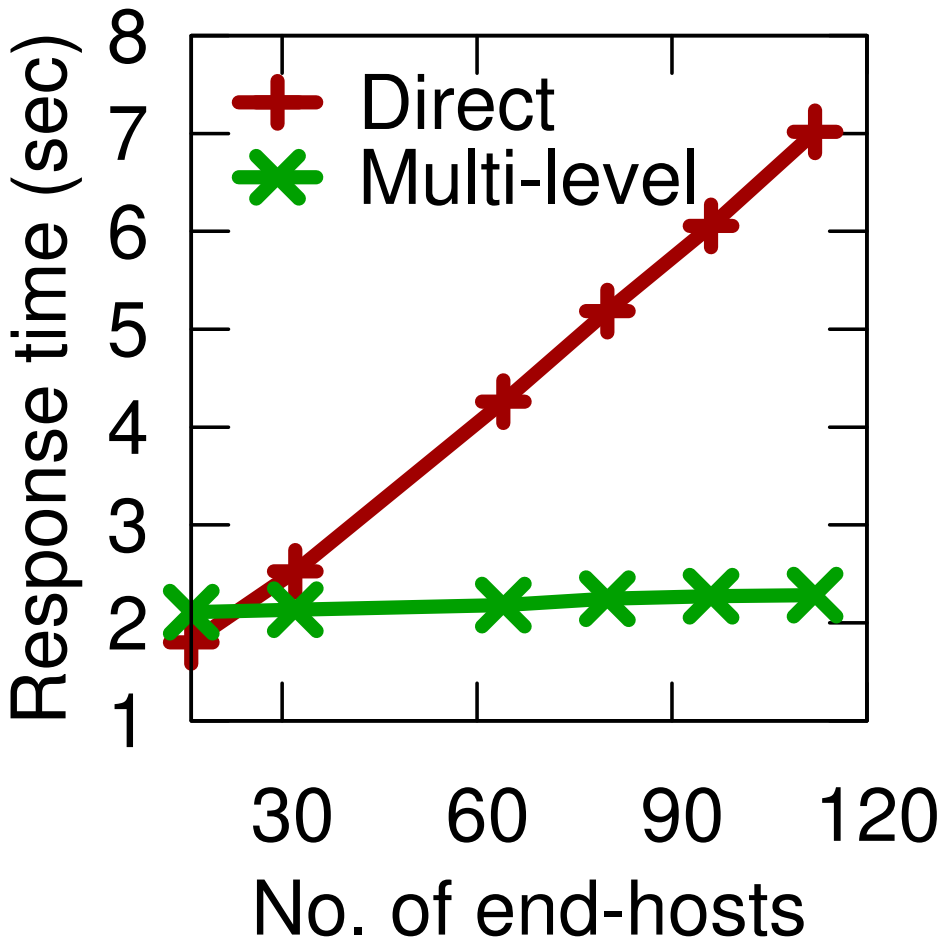


Top-k flows query



Query processing

Flow size distribution query

Top-k flows query