A Policy Framework for a Secure Future Internet

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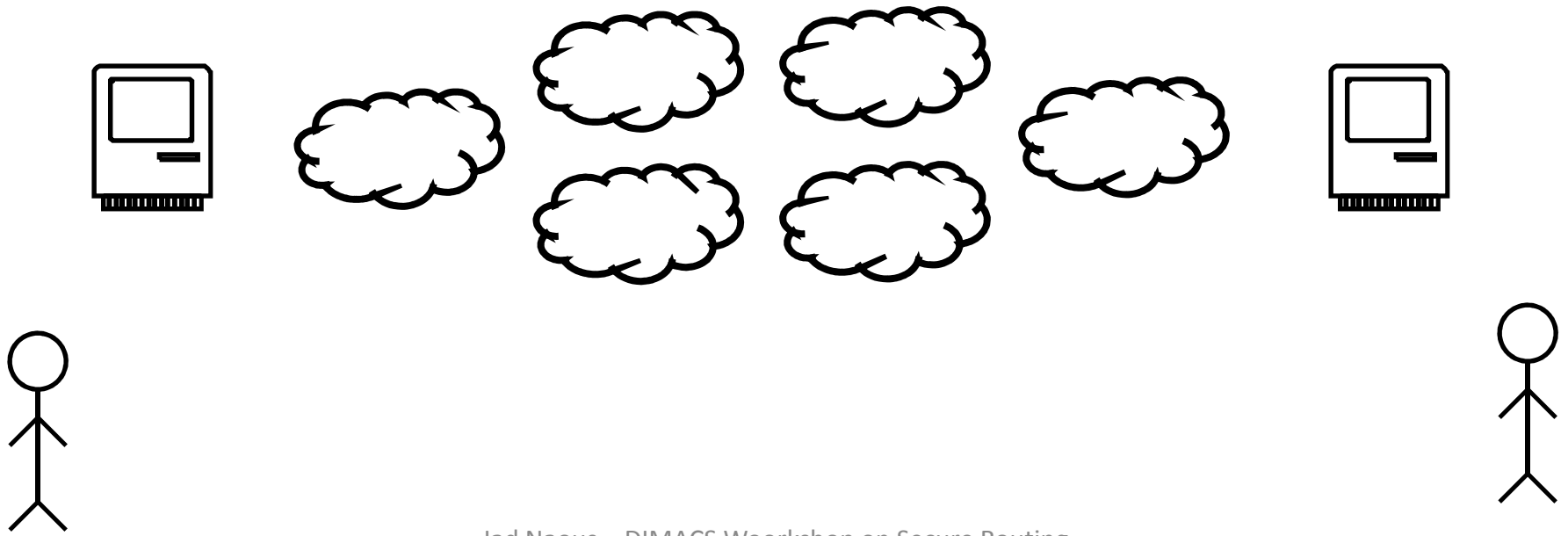
What do we want from the network?

Conflicting requirements

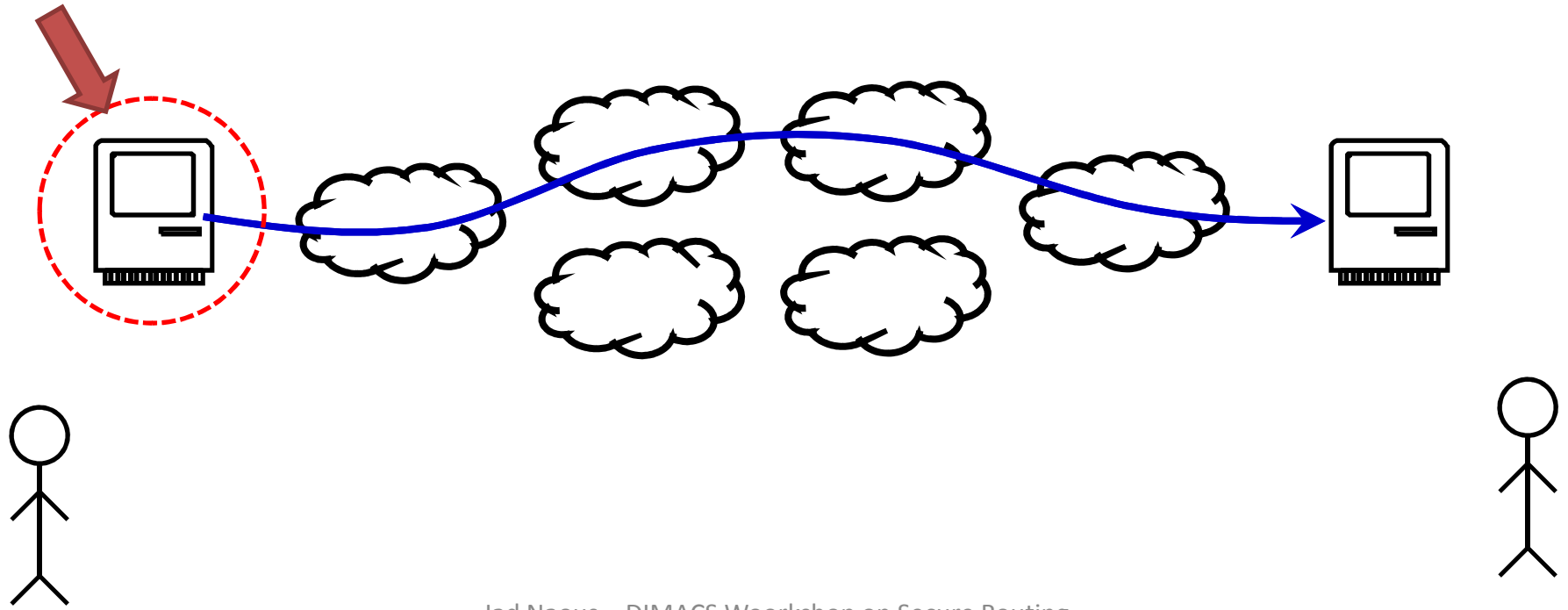
from many stakeholders



Network Policies

Conflicting requirements

from many stakeholders



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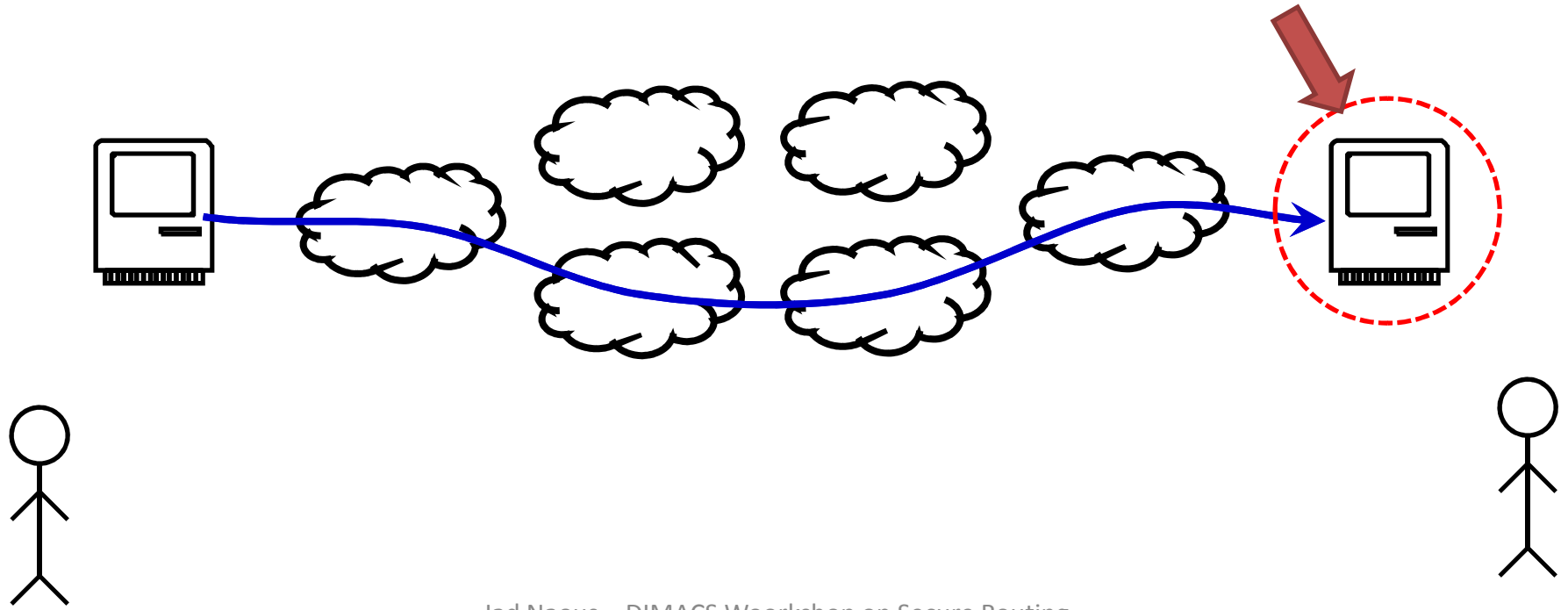

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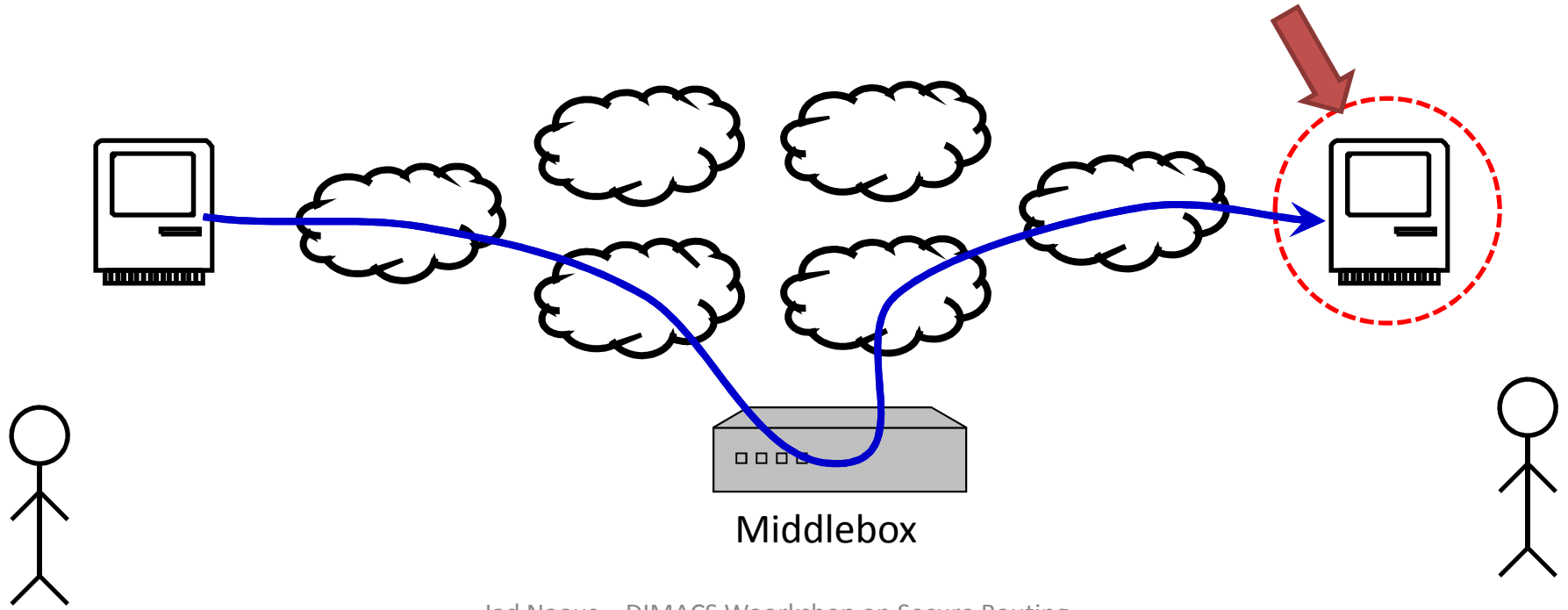

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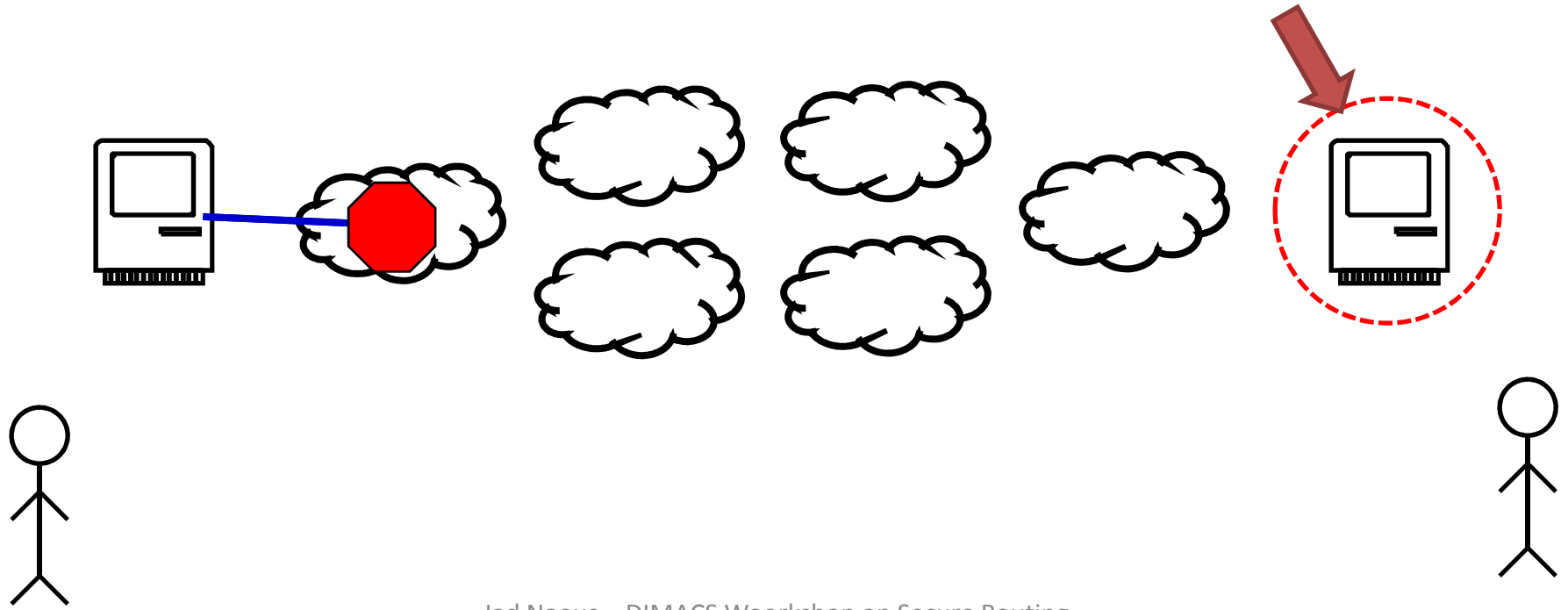

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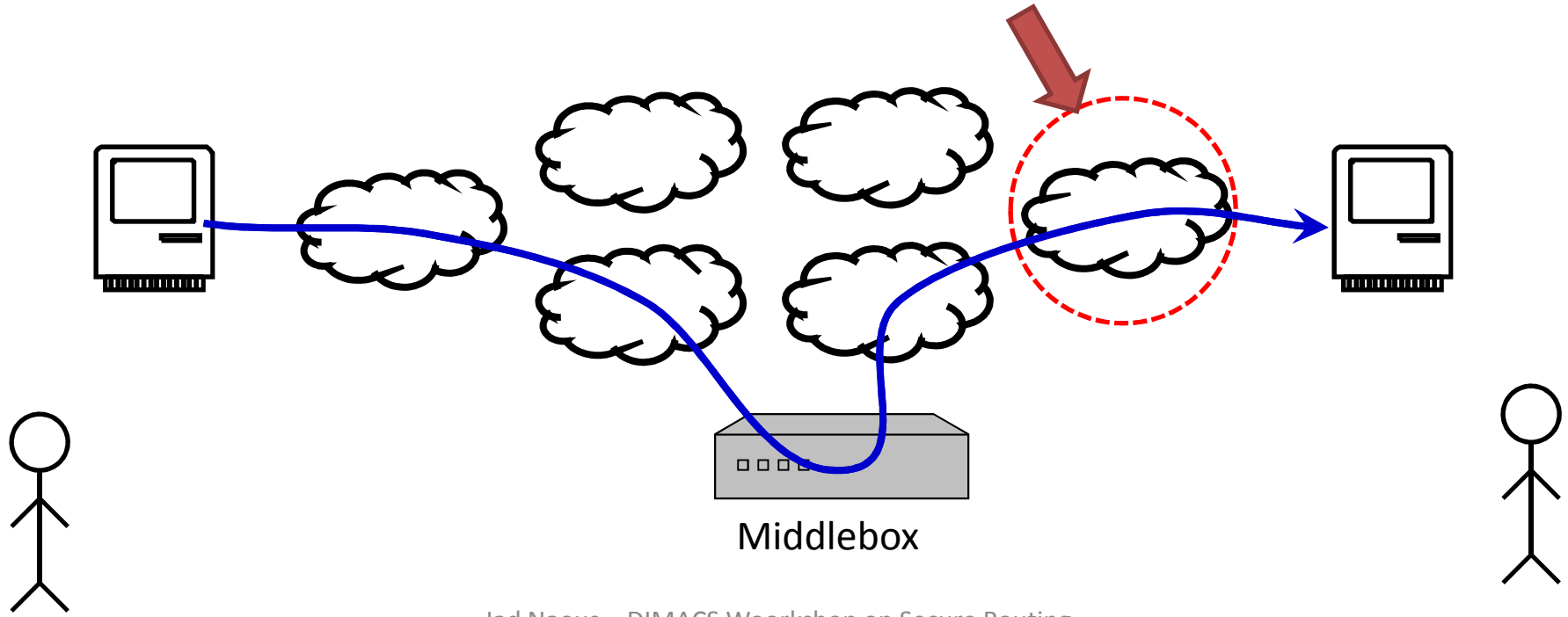

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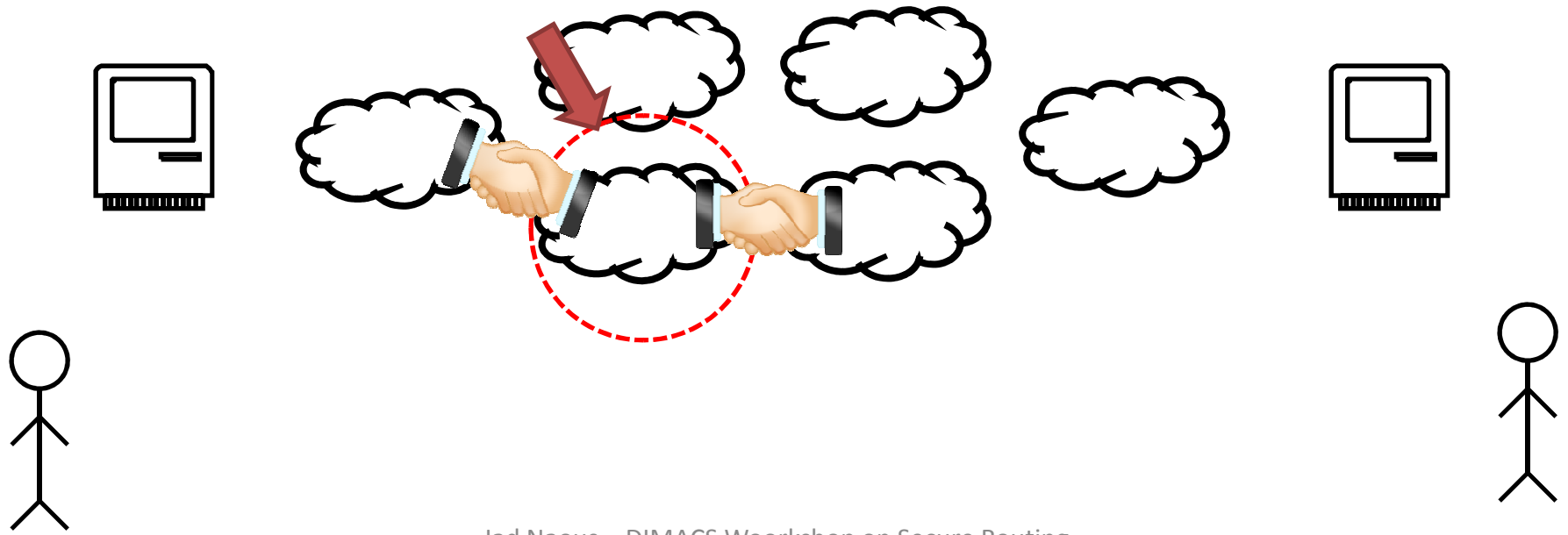

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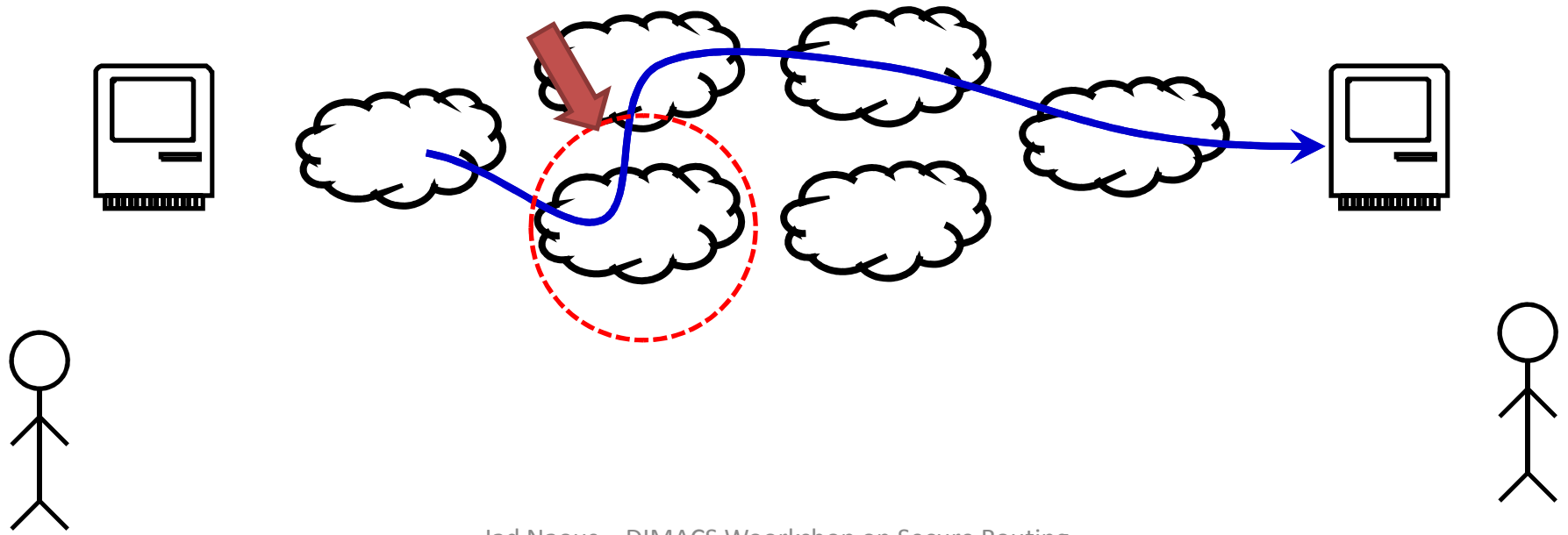

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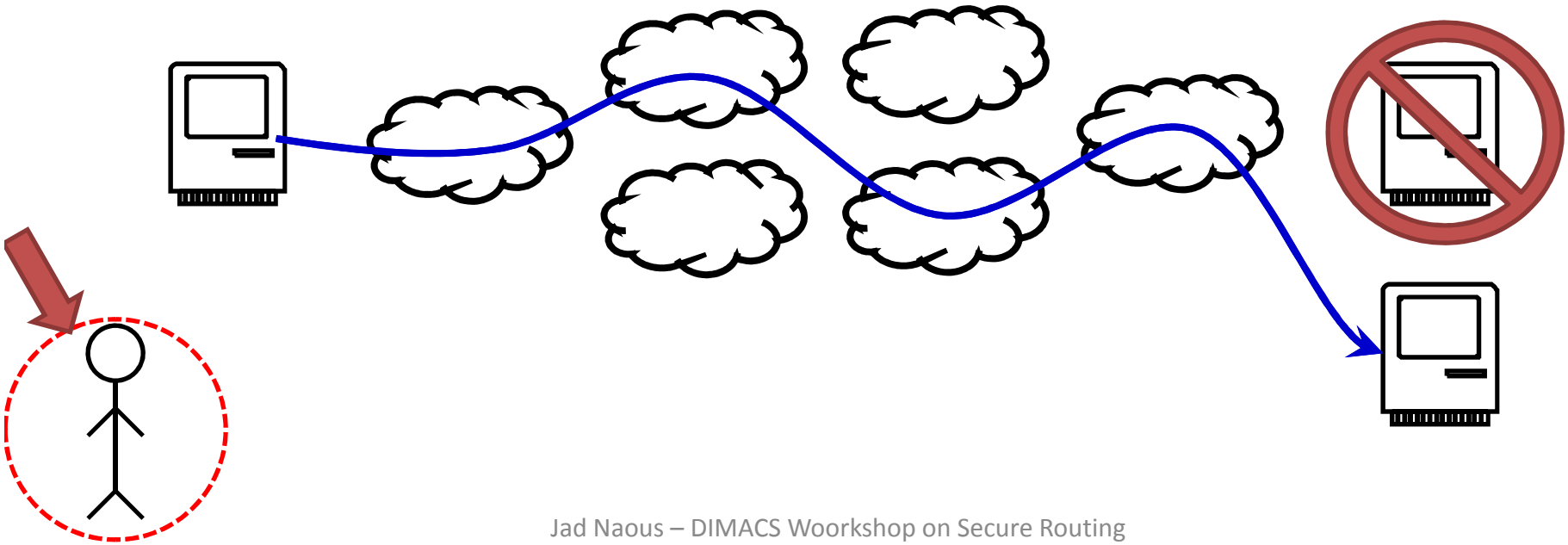


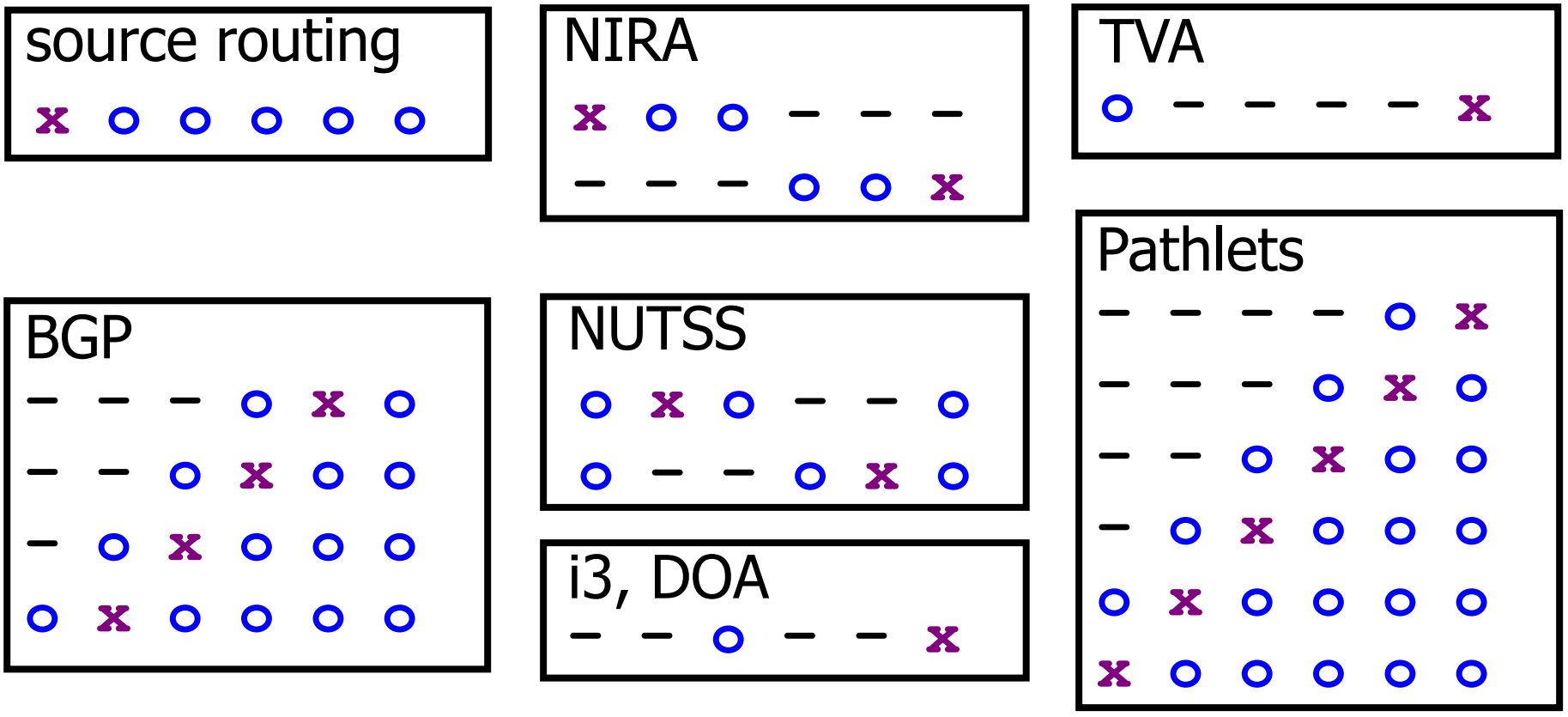
Network Policies

There are many stakeholders:

senders, receivers, enterprises that are both senders and receivers (e.g. data centers), service providers, security middlemen (à la Prolexic), governments, data owners, …

Each has many valid policy goals, and they might conflict.

Prior proposals:
Large union, small intersection



[legend: x exerts control over o's]

Prior Proposals

Incomplete or insufficient

Incompatible

What Types of Policies for the Future Internet?

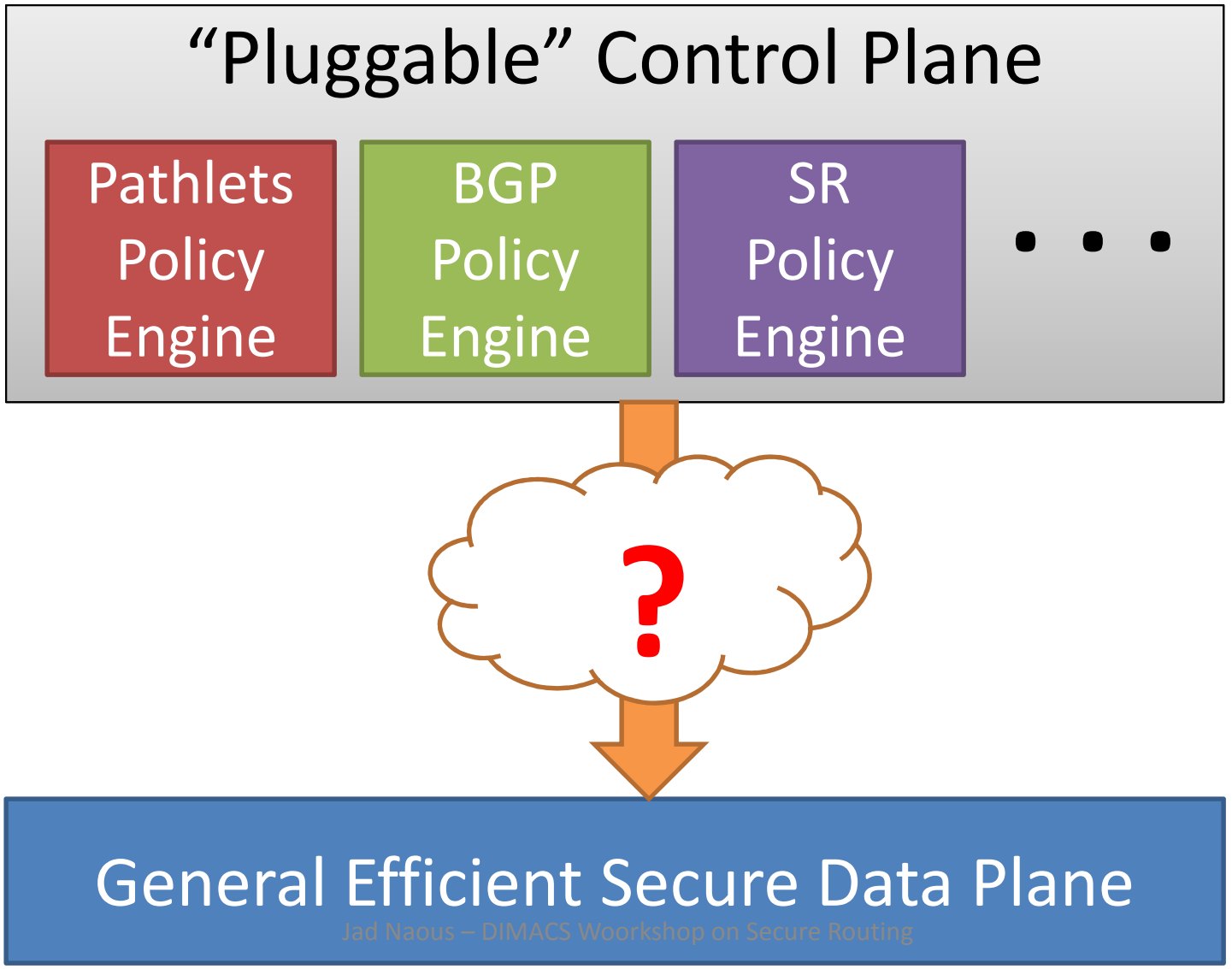
Three choices:

1. Embrace the status quo: *Do nothing.*
   Unsatisfactory.
2. Make a hard choice: *Select the "right" subset.*
   A high-stakes gamble.
3. Choose "all of the above": *Take union of controls.*
   Preserve all options; no picking winners/losers.

“All of the above” brings challenges:

1. How do we enable all these different policies?
2. How do we enforce all of them efficiently?

The ICING Policy Framework



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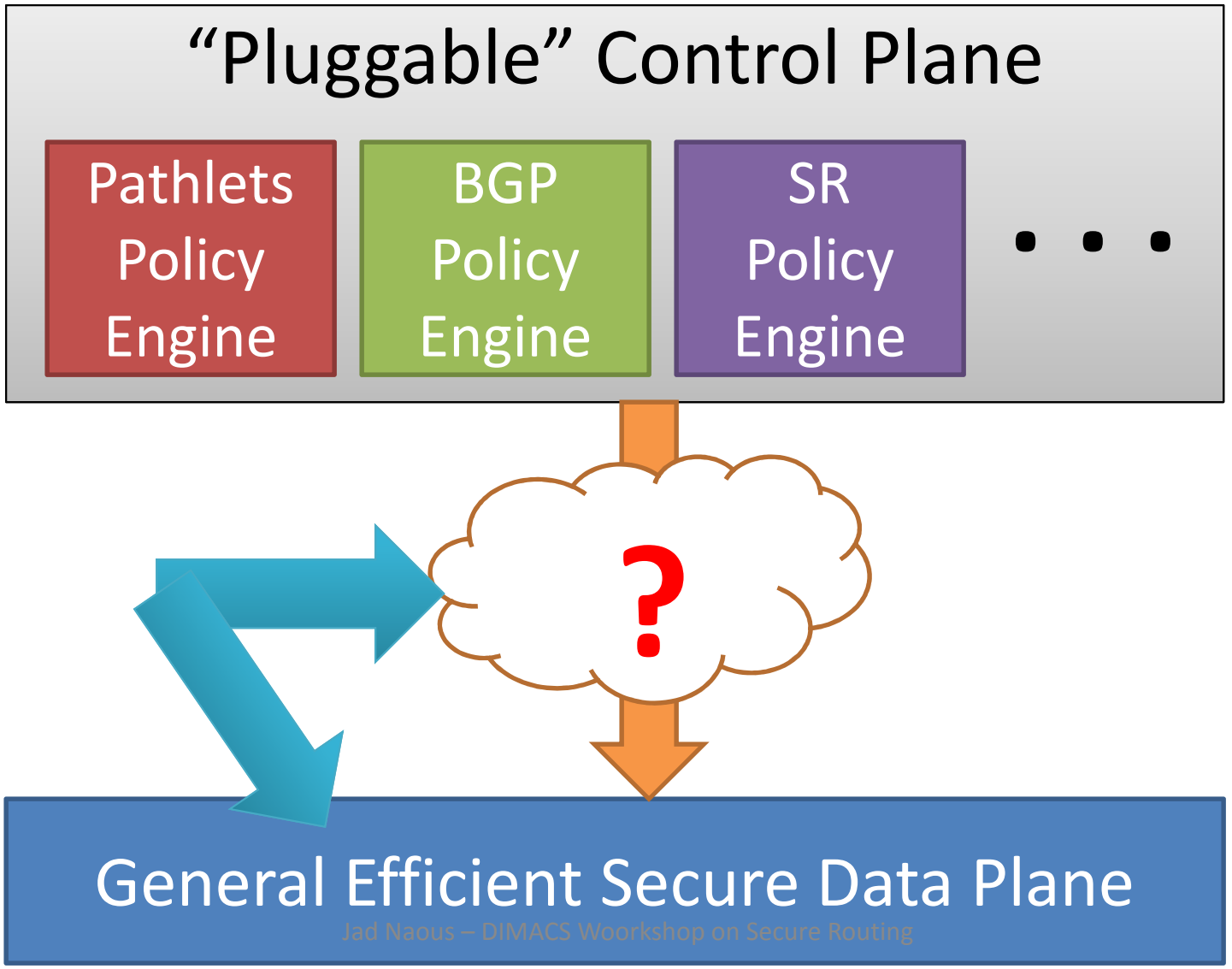

Outline

- How general is general?
  (What is the control? Who gets control? How can it be used?)
- How do we enforce policy decisions in the data plane?
- What is the control/data plane interface and how can it be used?

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Control over what?

Policy requirements

$\Rightarrow$ Who handles the packets and how

$\Rightarrow$The path or parts of it (interdomain-level)

Control over what?

Policy requirements

$\Rightarrow$ Who handles packets they send/receive/transit and how

$\Rightarrow$ The path or parts of it (interdomain-level)

For most flexibility:

Give control over full path

Who gets control?

Three principles:

1. Entities whose network resources are consumed.
2. Entities that are consuming network resources.
3. Entities should be within a single layer – the network layer.

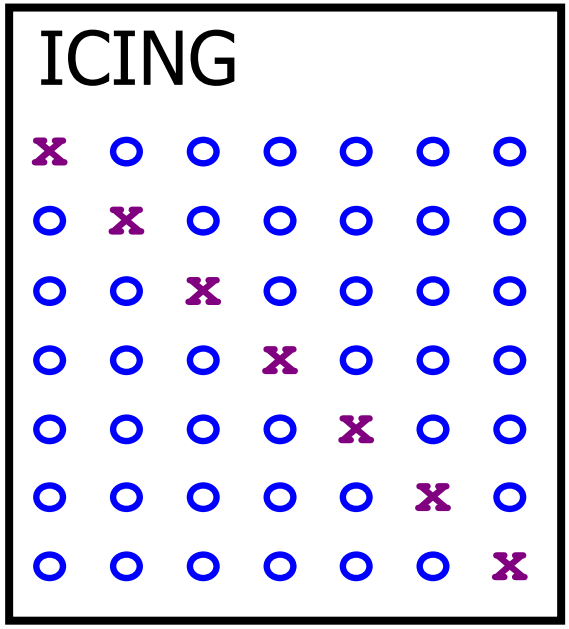
Who gets control?

The three principles

$\Rightarrow$ Give control to all entities on the path.

Other stakeholders use other layers or external power of authority (e.g. laws).

ICING's Policy Principle



A path is legal if and only if
all participants on the path approve of the path.

Architecture enforces that only legal paths are used.

How general are policies?

- Provider: Allow use of high speed links from 5pm to 8am only
- Internet2: Only carry traffic between universities
- Sender: Only use paths that my neighbor is using.

=> Policies can be arbitrary.

For flexibility and evolvability:

Allow arbitrary policies

For accuracy:

Provide sufficient information

What are policy decisions based on?

1. The path

2. Consumed resources:
   - Long/short haul, high/low speed, transit/delivery, …

3. Arbitrary external information:
   - Billing status, costs, time of day
   - Does everyone else consent?

Checkpoint Summary

- There are many stakeholders in a communication, and we give control to all network-level participants.
- For most flexibility and to satisfy the largest number of requirements we need to give them control over the full path.
- For evolvability and flexibility, allow arbitrary policies and provide sufficient information

Outline

- How general is general?
  (What is the control? Who gets control? How can it be used?)
- How do we enforce policy decisions in the data plane?
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Secure Routing Insufficient

Data packets today do not necessarily follow BGP-given routes

i.e. Data plane does not necessarily conform to the control plane.

Challenges

Many challenges:

- Enabling arbitrary informed policies
- Enforcing policy decisions at line-rate
- Handling errors and network failures in a locked-down Internet
- Delegating access
- Bootstrapping

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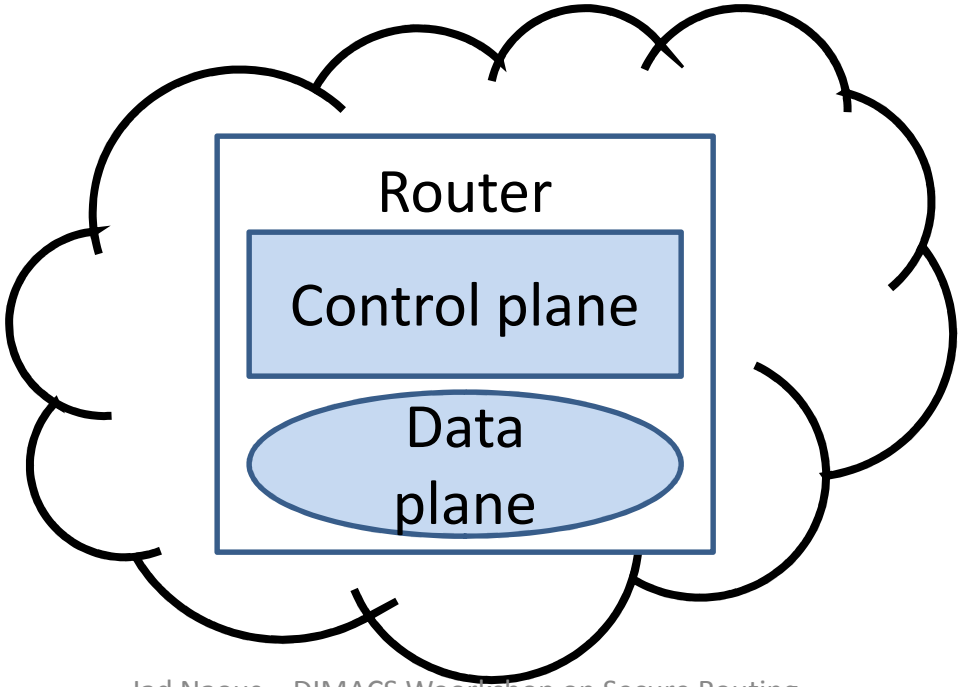
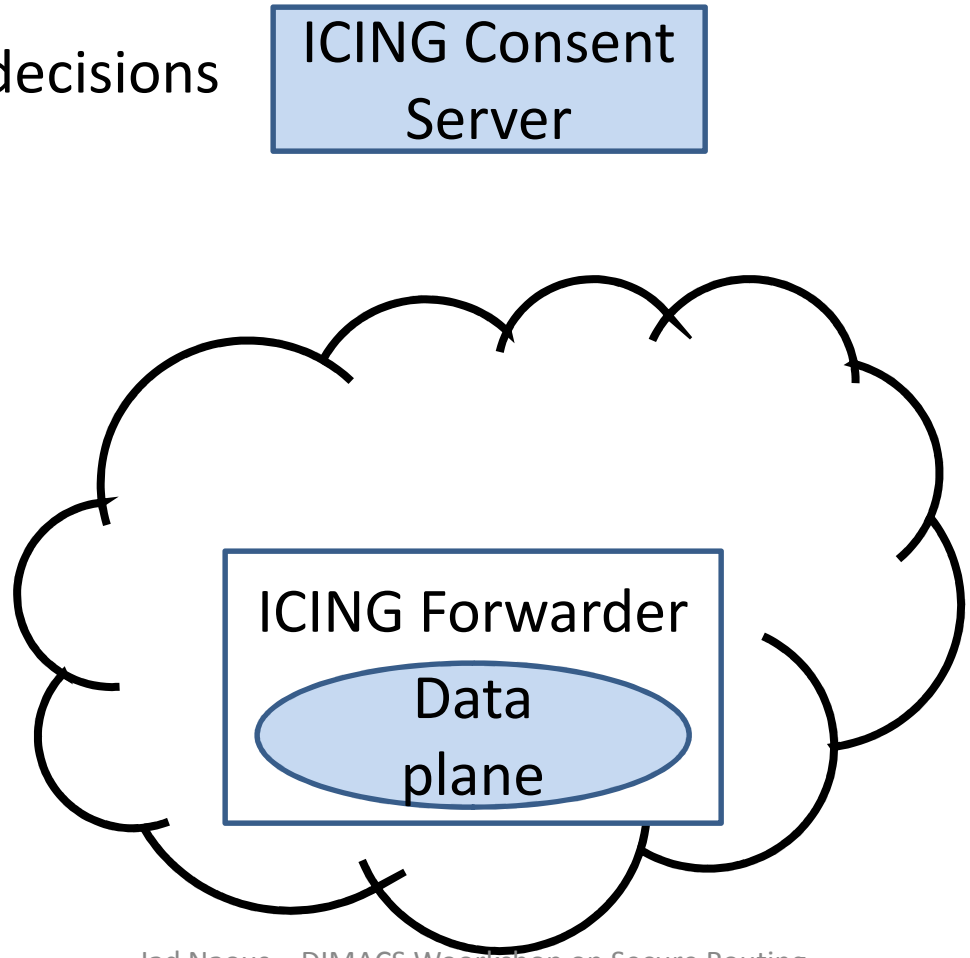
Enabling arbitrary informed policies



Challenge:
Enabling arbitrary informed policies

Makes all policy decisions



Enforces policy decisions

Challenge:
Enforcing policy decisions at line-rate

1. Make sure that the path is legal

2. Make sure that the path is followed

Challenge:
Enforcing policy decisions at line-rate

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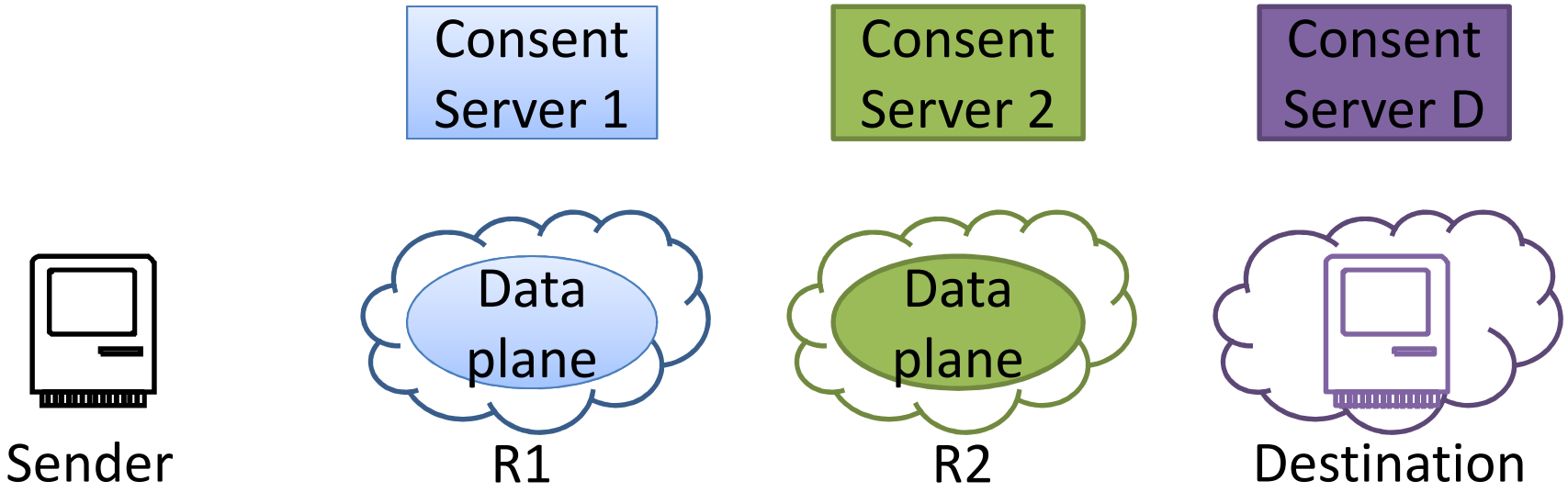

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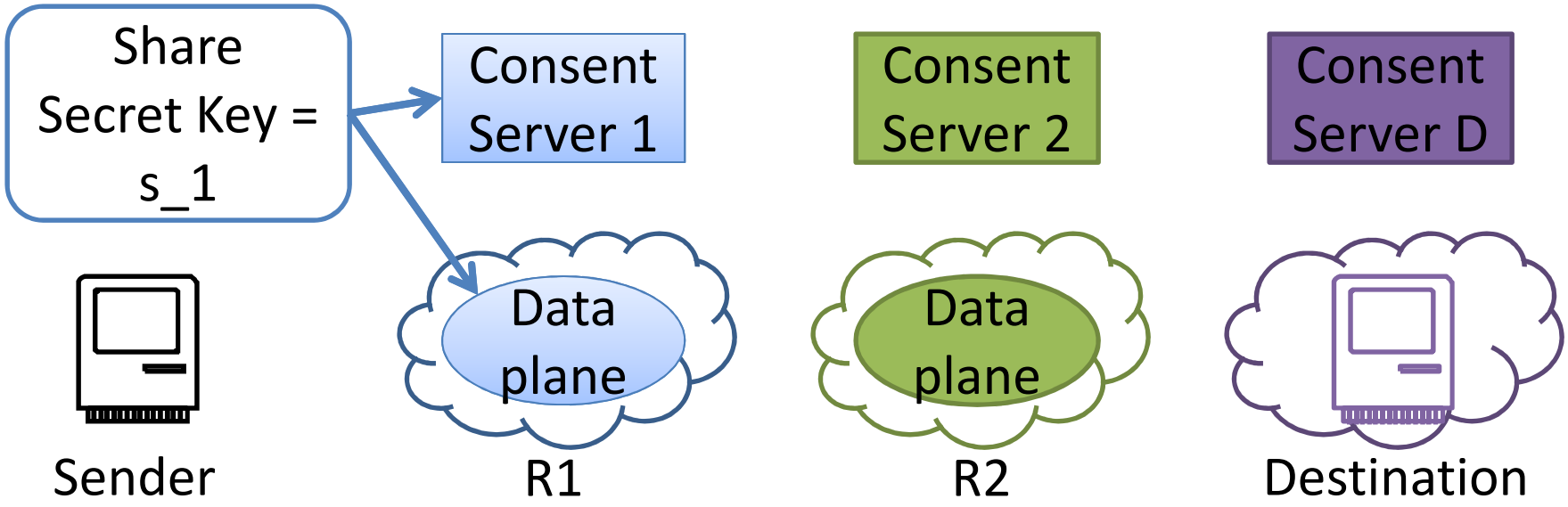

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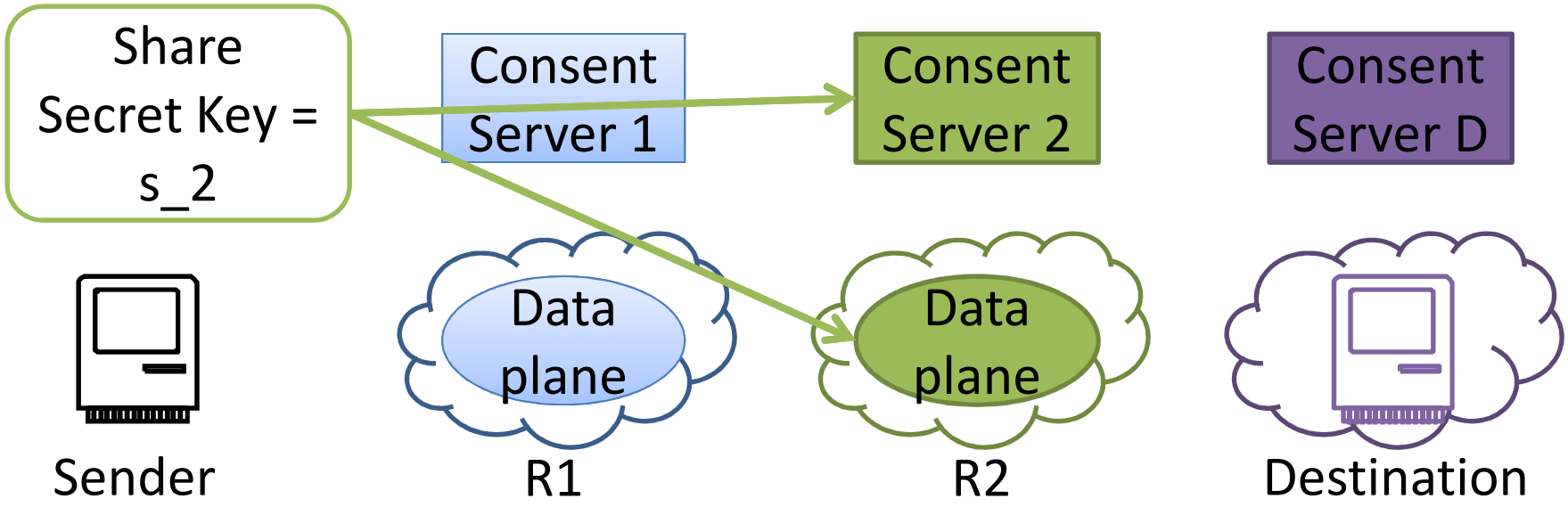

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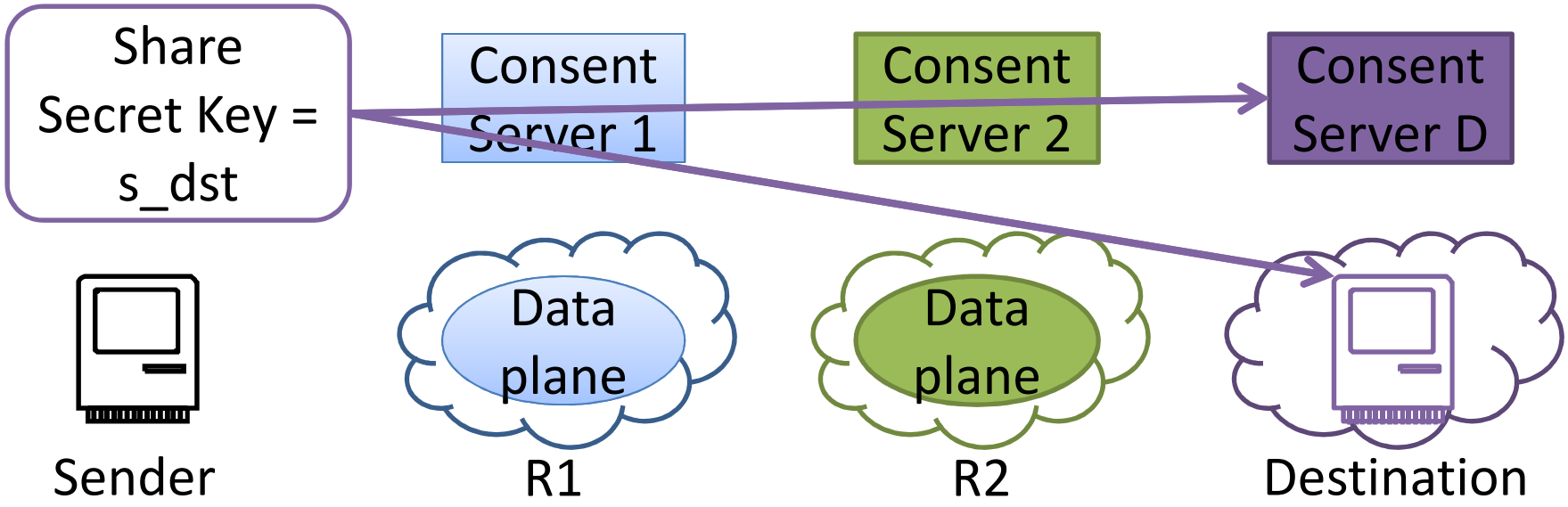

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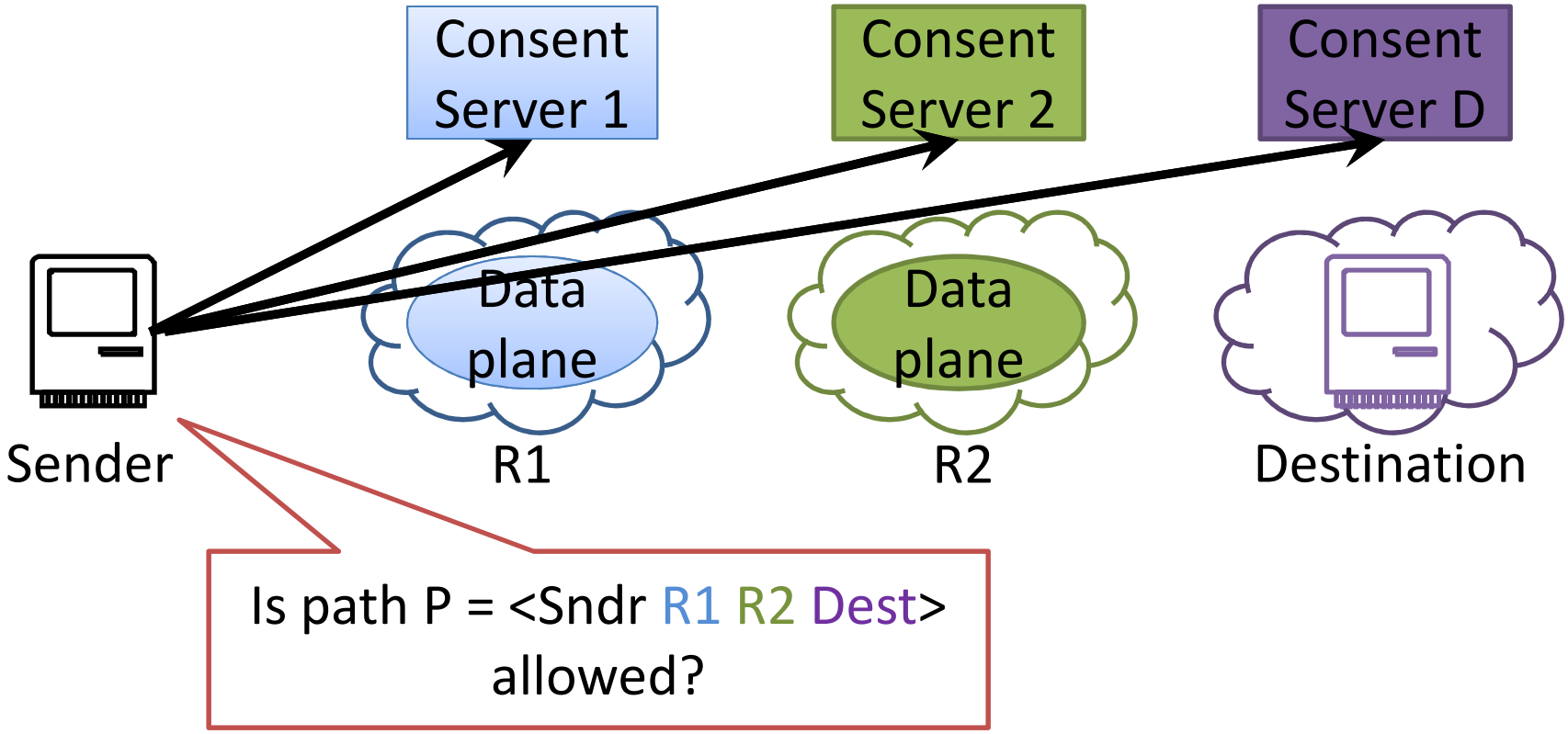

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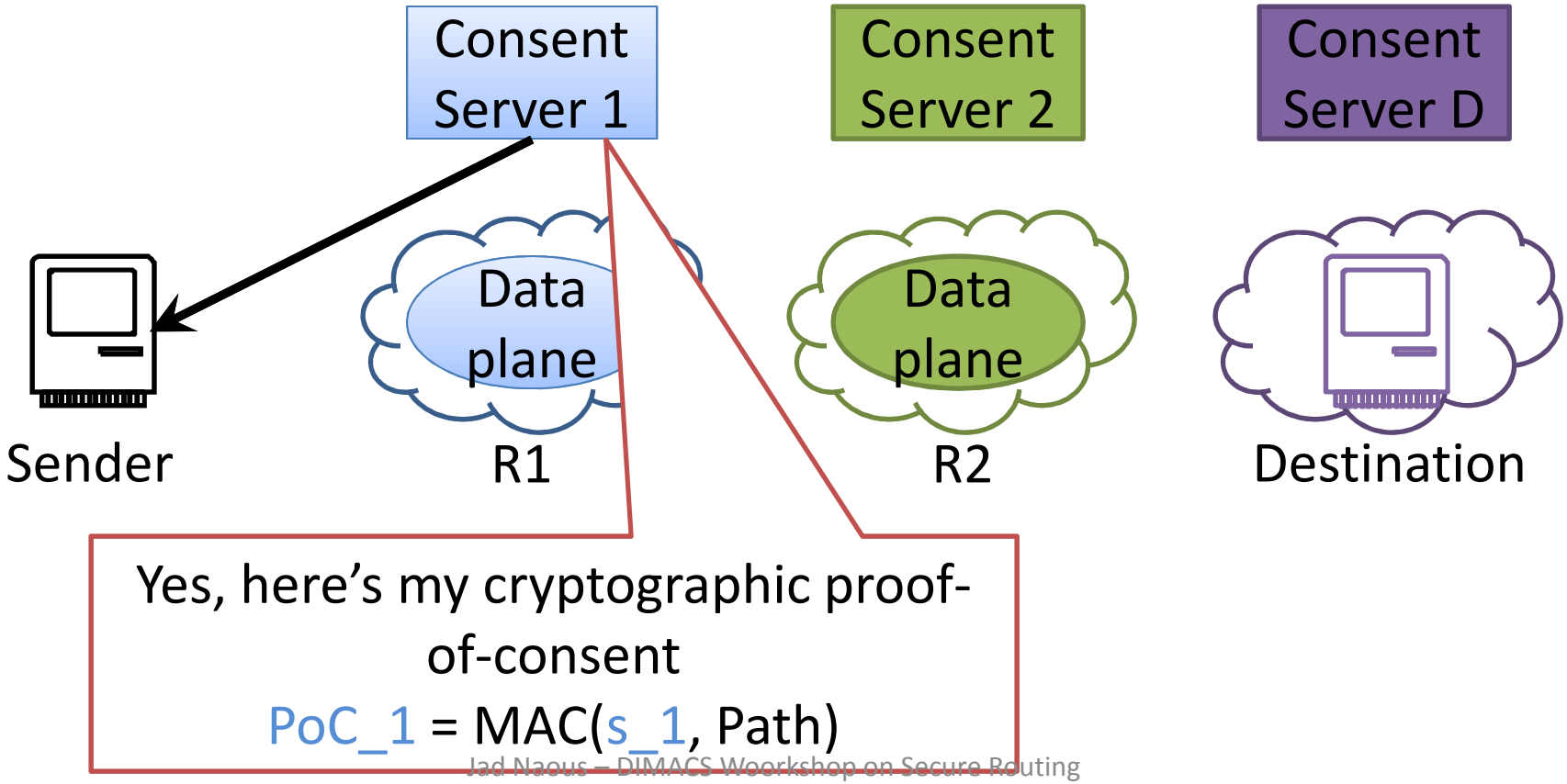

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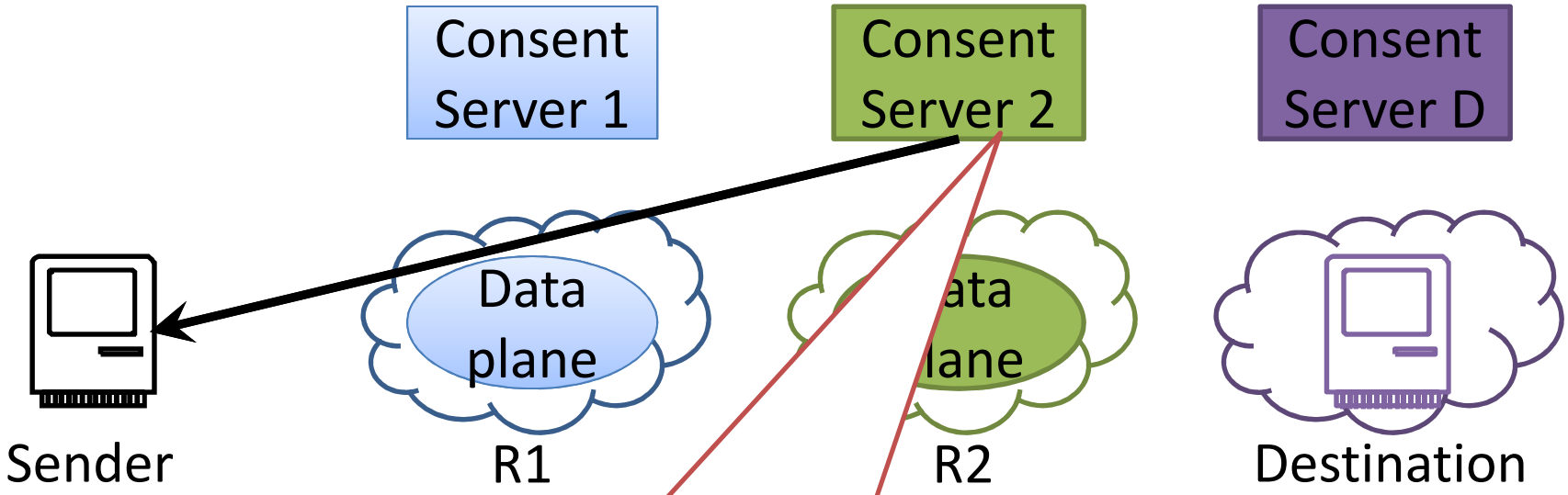

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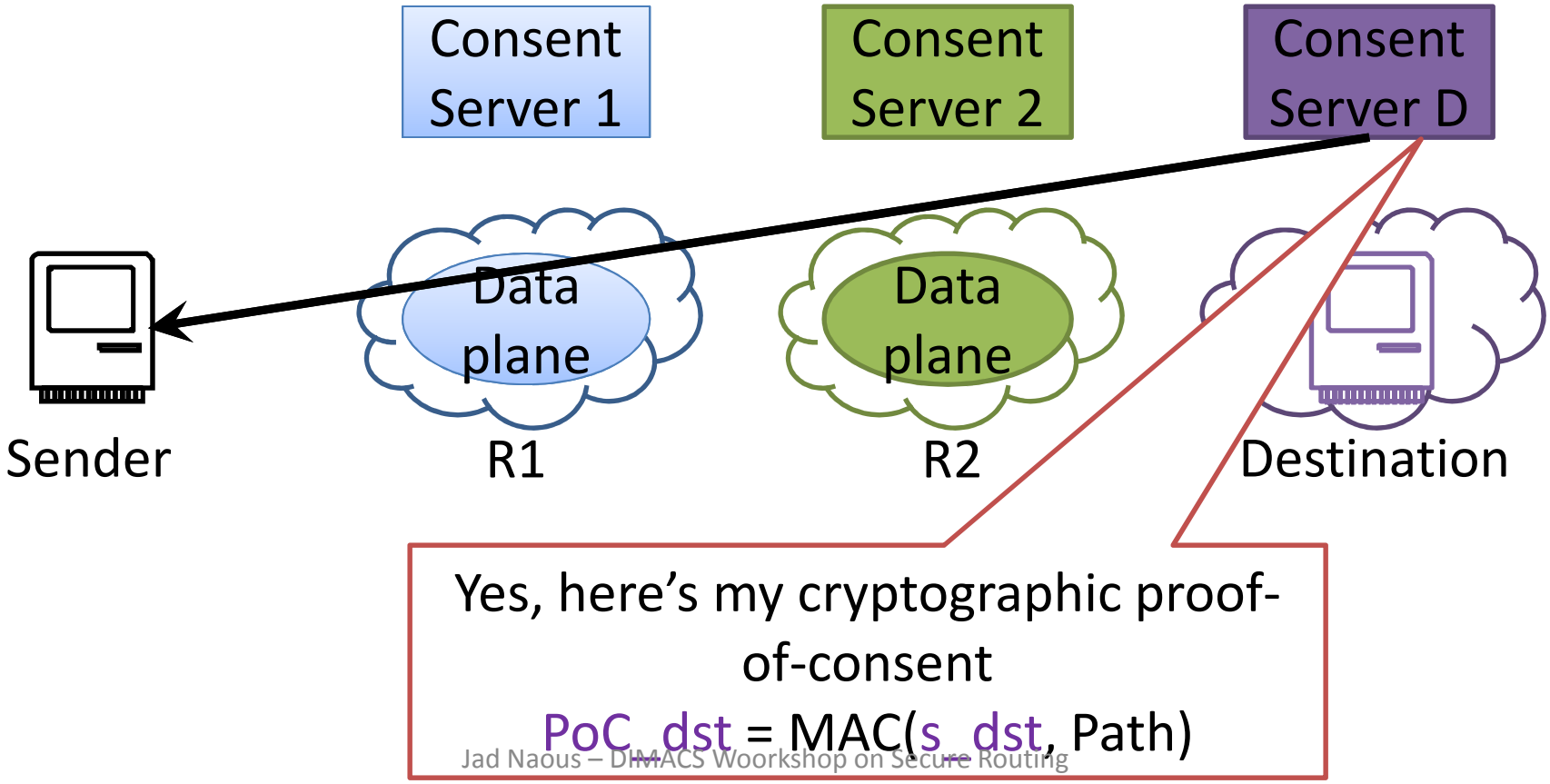

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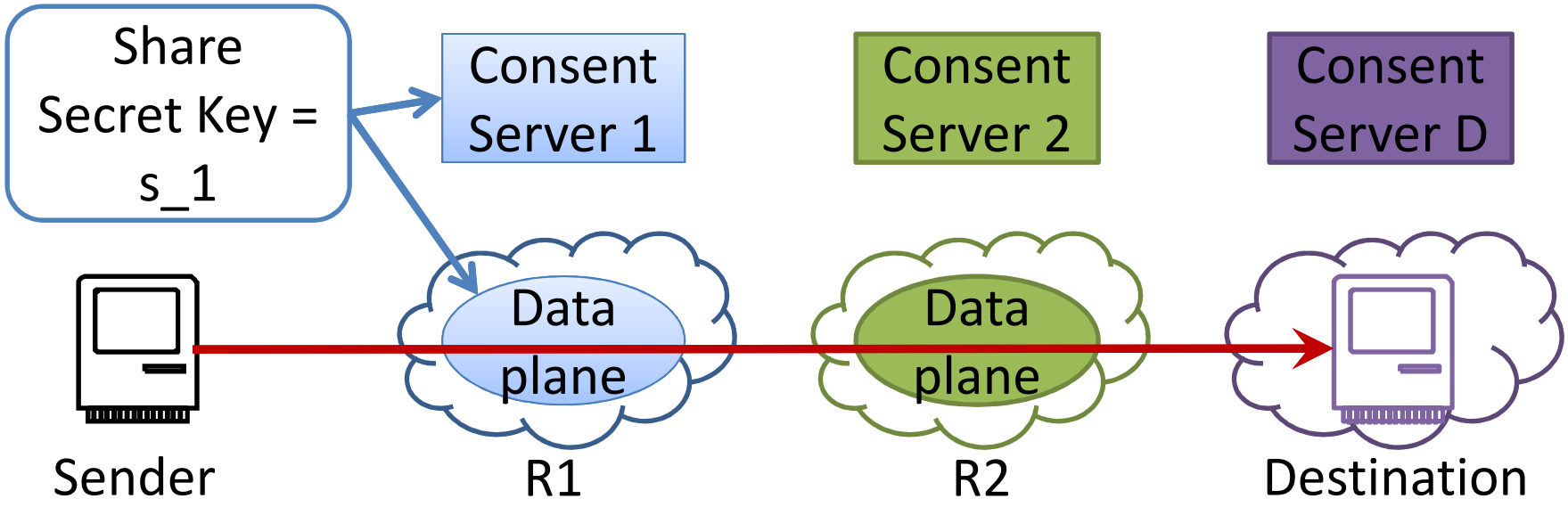


Packet =
<Path, PoC_1, PoC_2, PoC_dst, data>
PoCs verifiable by data plane using
Shared secret keys s_1, s_2, s_dst

Challenge:
Enforcing policy decisions at line-rate

Notes:

1. Policy decisions made off the critical path
   - Once per path
     (not per-packet, not even per flow)
   - Before packet flow
2. Decision is encoded in cryptographic proof of consent using shared symmetric key.
3. Forwarders can verify that the consent server had approved of the path.

Challenge:
Enforcing policy decisions at line-rate

1. Make sure that the path is legal

2. Make sure that the path is followed

Challenge:
Enforcing policy decisions at line-rate

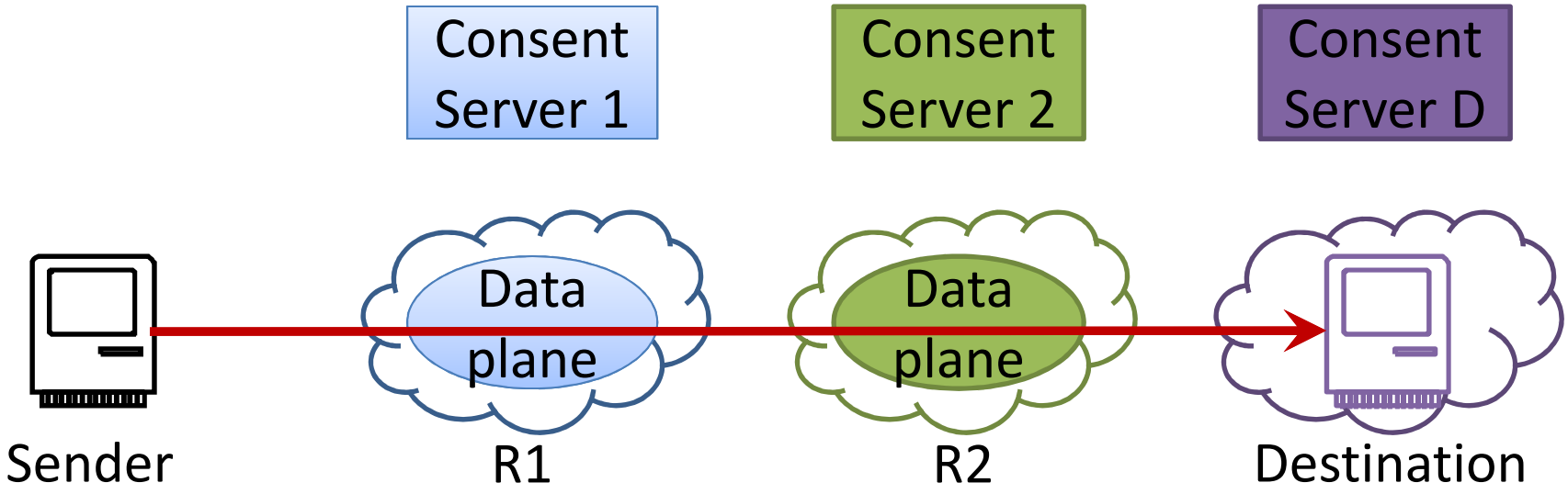
Step 2: Make sure the path is followed

- Problems:
  - Backbone speeds preclude digital signatures or public key crypto on the fast path.
  - Federated nature of the Internet precludes central root of trust, pre-configured shared secrets, etc…

- ICING overcomes these hurdles with new packet authentication techniques.

Challenge:
Enforcing policy decisions at line-rate

Step 2: Make sure the path is followed



Packet =
<Path, PoC_1, PoC_2, PoC_dst, V_1, V_2, V_dst, data>
V_i proves to Realm i that everyone before it has seen the packet.

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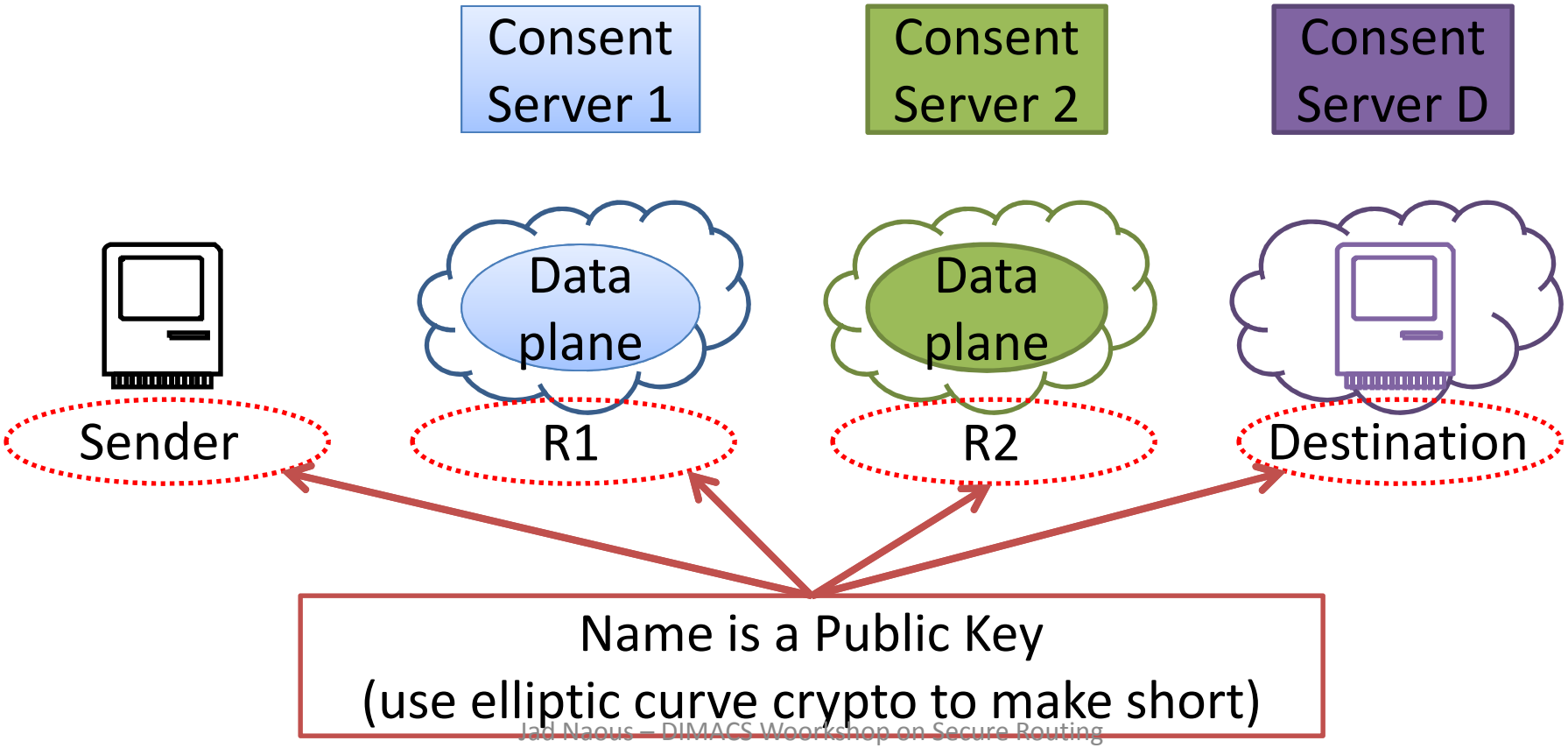

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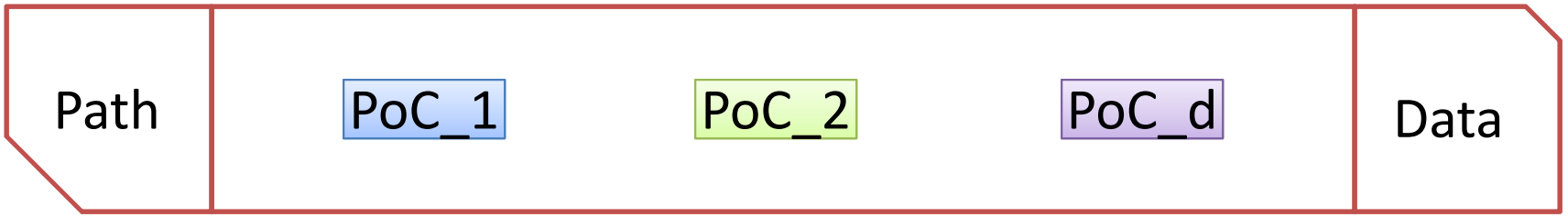
Step 2: Make sure the path is followed

1. Verify consent & provenance
2. Prove provenance



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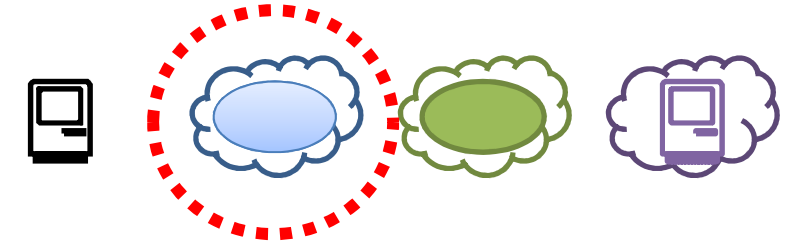

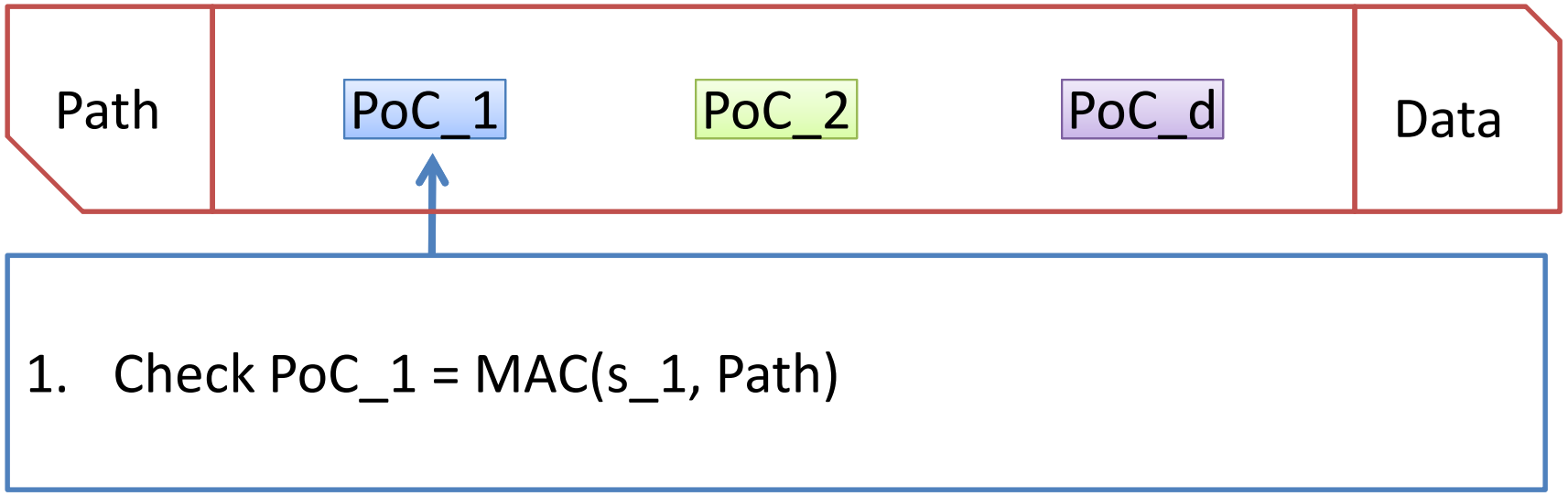

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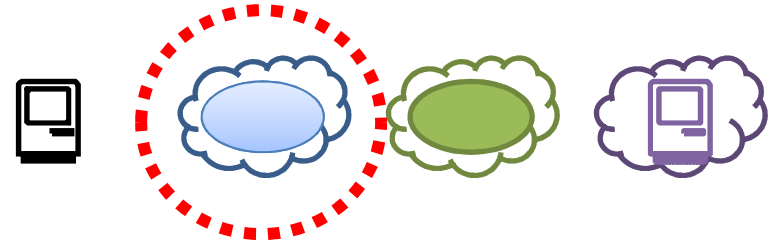

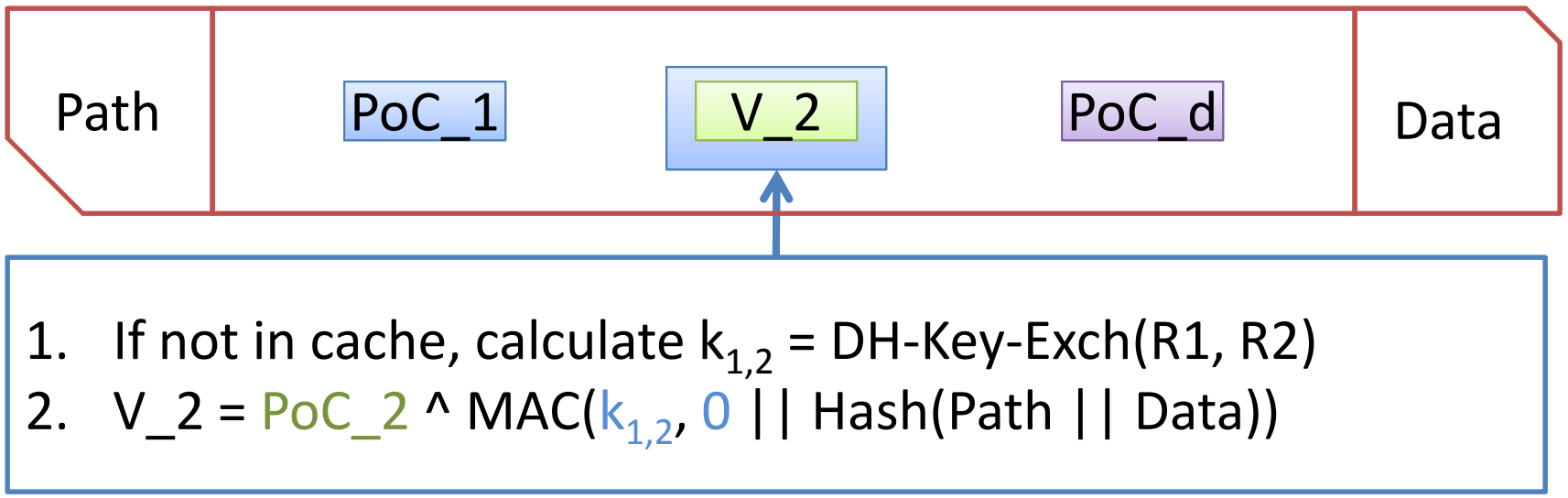

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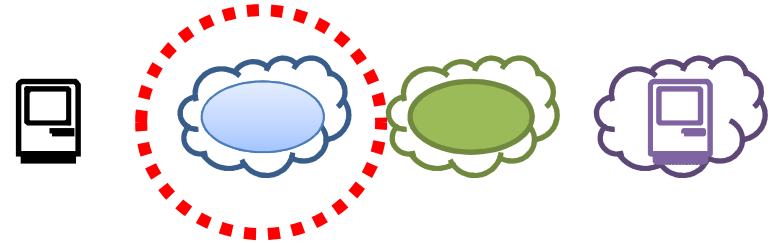

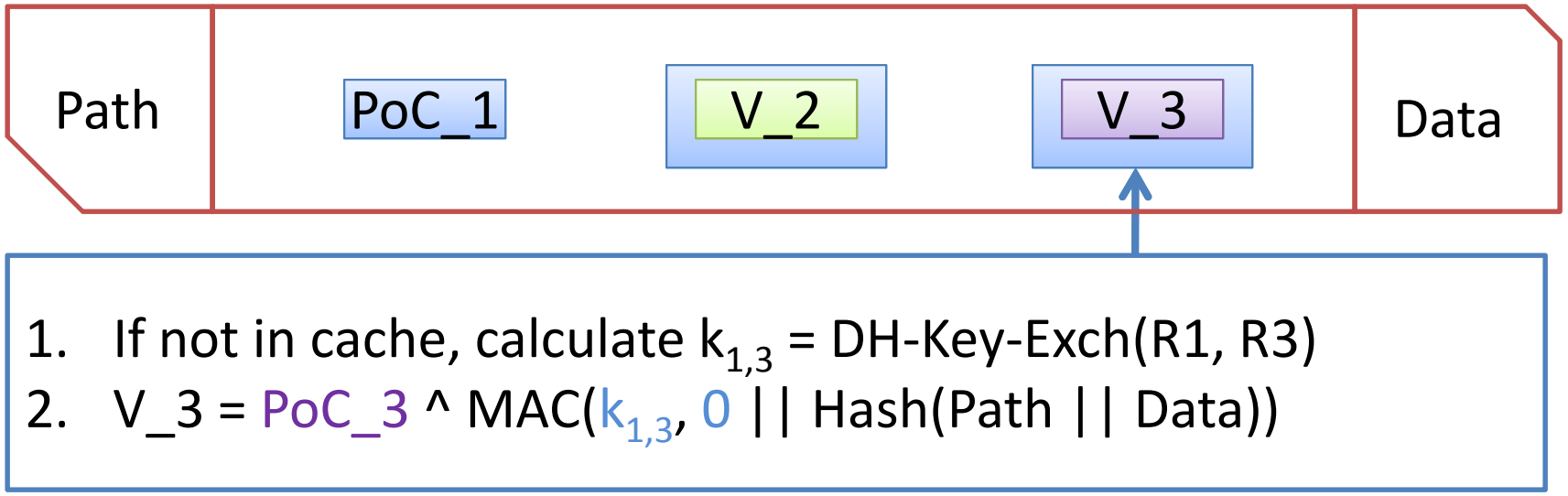

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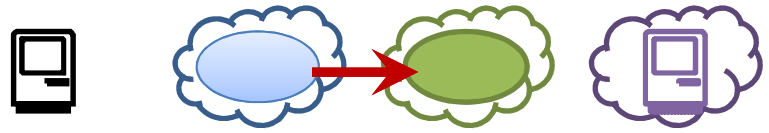

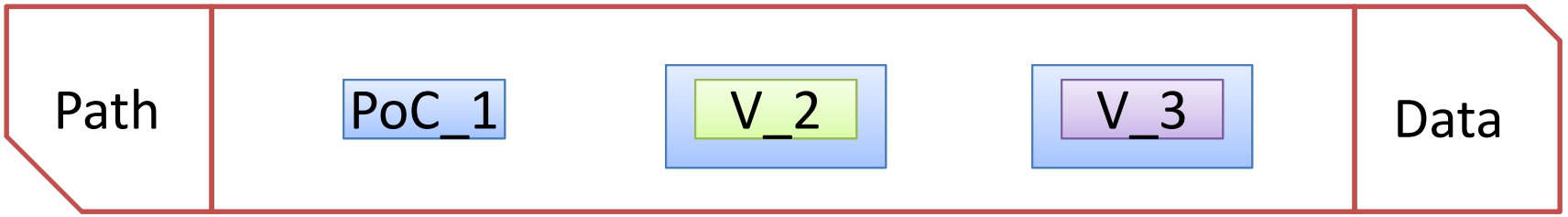

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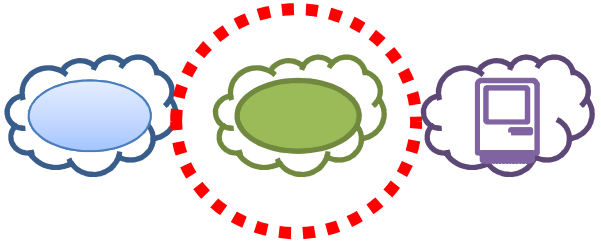

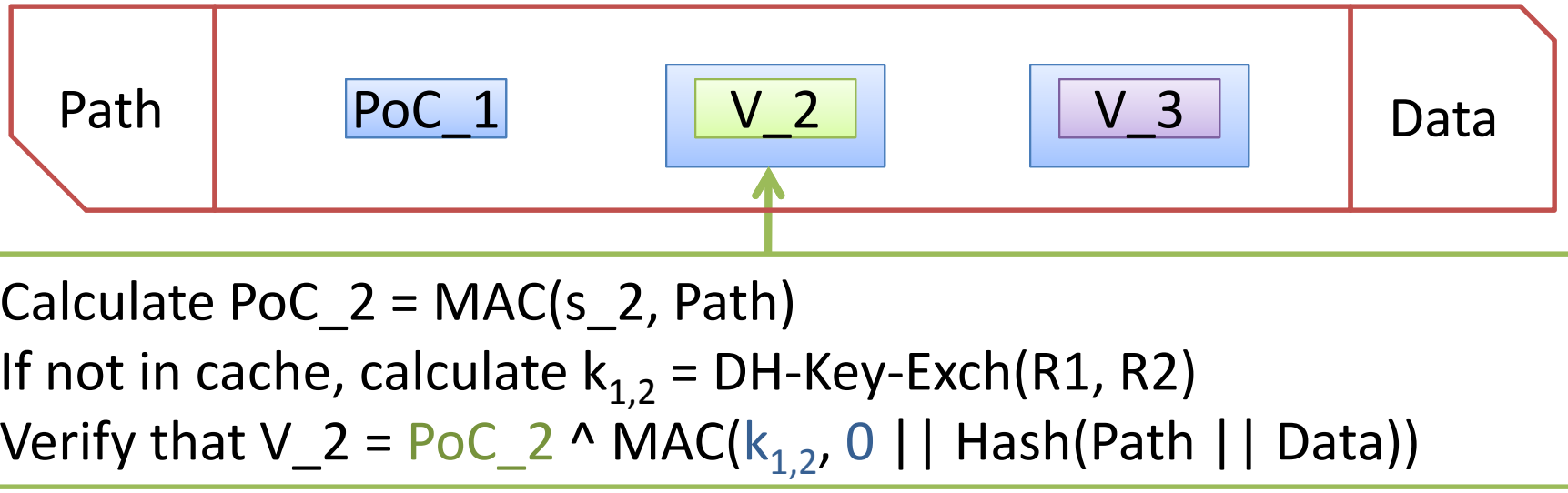

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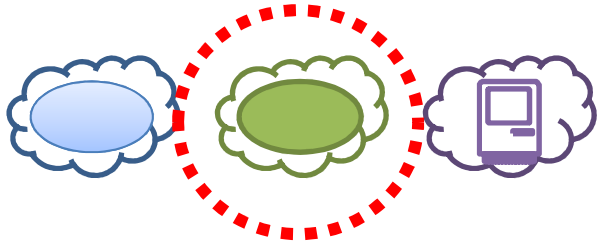

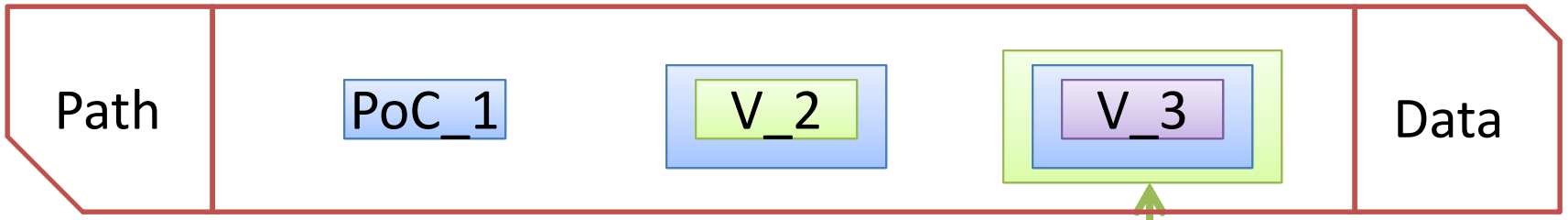

1. If not in cache, calculate $k_{2,3}$ = DH-Key-Exch(R1, R2)
2. Set V_3 = V_3 ^ MAC($k_{2,3}$, 1 || Hash(Path || Data))

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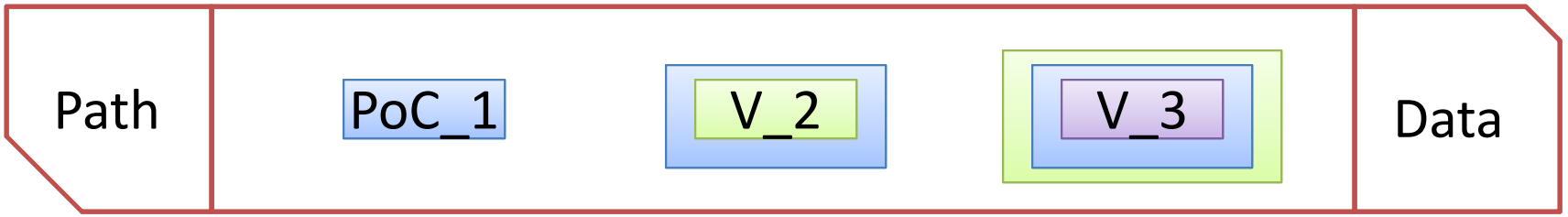
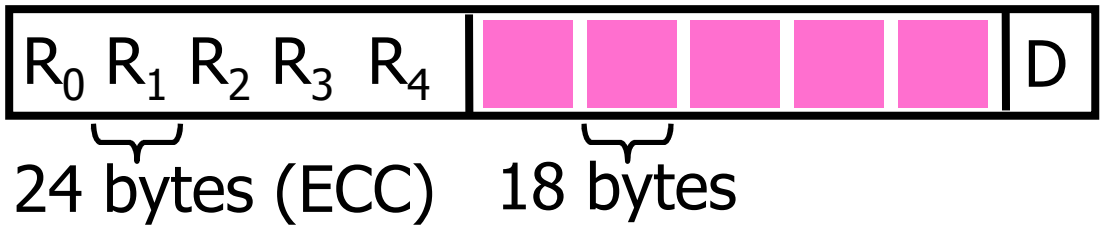


ICING's data plane in a nutshell

- Binds a packet to its path
  - Packet carries path (list of public keys), verifiers
  - Realms use $k_{i,j}$ to transform verifiers
  - R_i verifies provenance through upstream realms R_j using $k_{j,i}$
  - R_i proves provenance to downstream realms R_j using $k_{i,j}$
- No key distribution: R_i derives $k_{i,j}$ from R_j's name
- Resists attack: forgery, injection, short-circuiting, …
- Feasibility: is required space, computation tolerable?

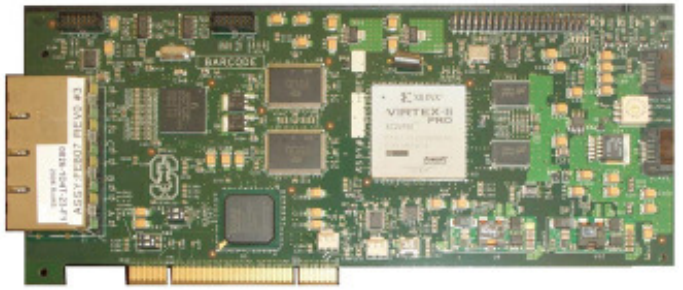
ICING is feasible

Space overhead?



- Average ICING header: ~250 bytes
- Average packet size: ~1300 bytes [CAIDA]
- So, total overhead from ICING: ~20% more space

ICING is feasible



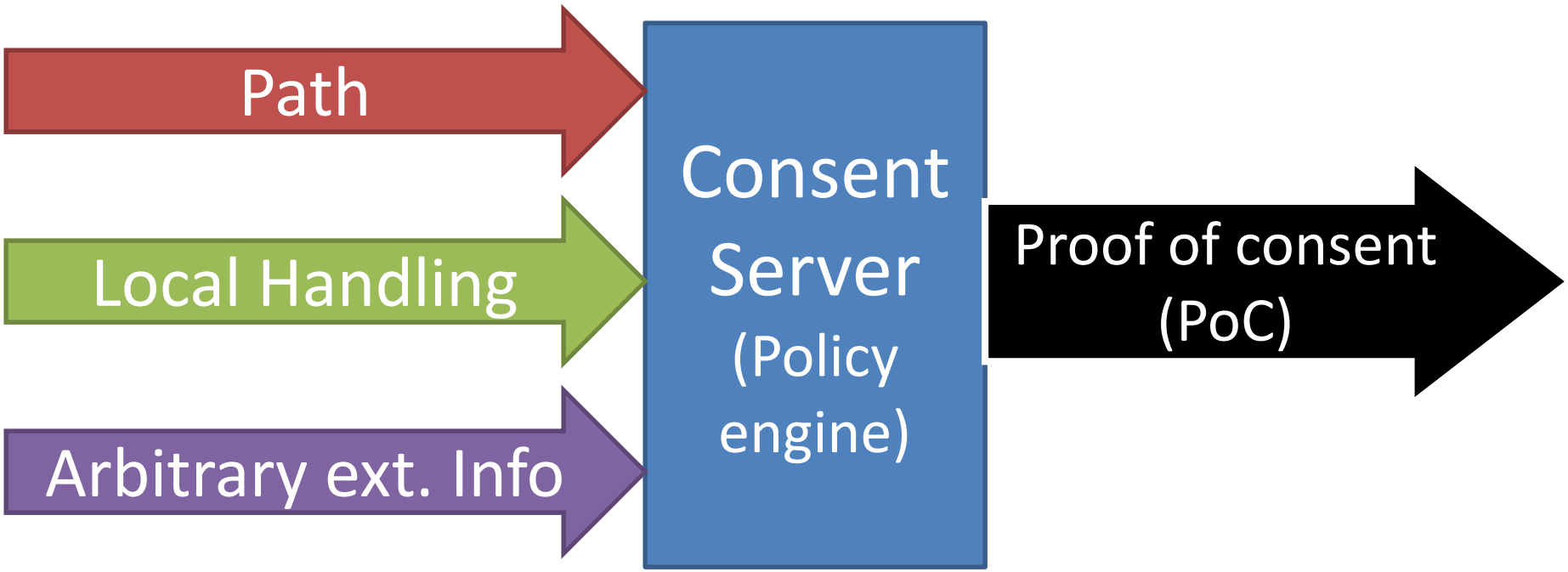
- What is the hardware cost?
  - NetFPGA gate counts: ICING is 13.4 M, IP is 8.7 M
  - NetFPGA forwarding speed: ICING is ~80% of IP
  - ICING vs. simple IP in gates/(Gbits/sec): ~2x
- Bandwidth and computation increasing faster than crypto costs

Outline

- How general is general?
  (What is the control? Who gets control? How can it be used?)
- How do we enforce policy decisions in the data plane?
- What is the control/data plane interface and how can it be used?

Control/Data Plane Interface

1. Allow/Deny Decisions



Control/Data Plane Interface

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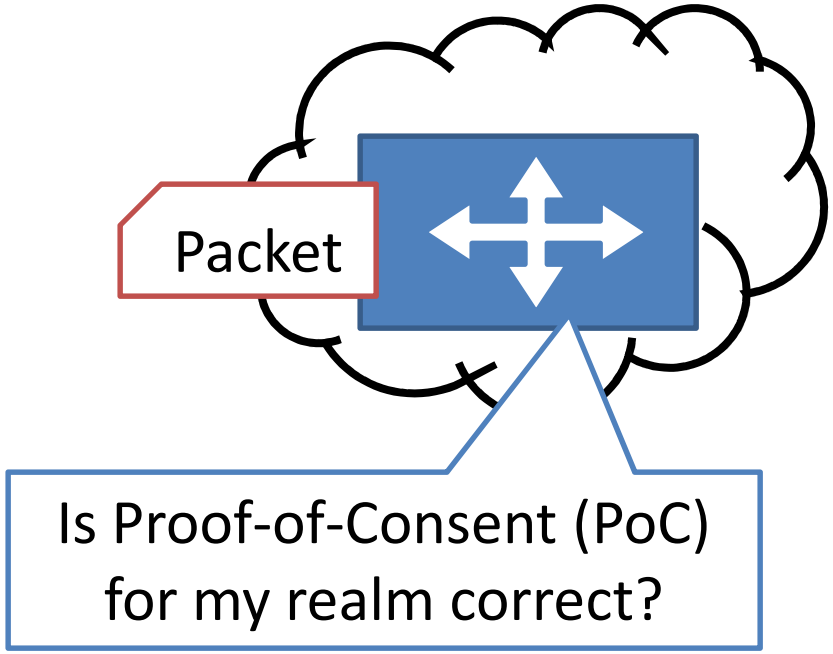
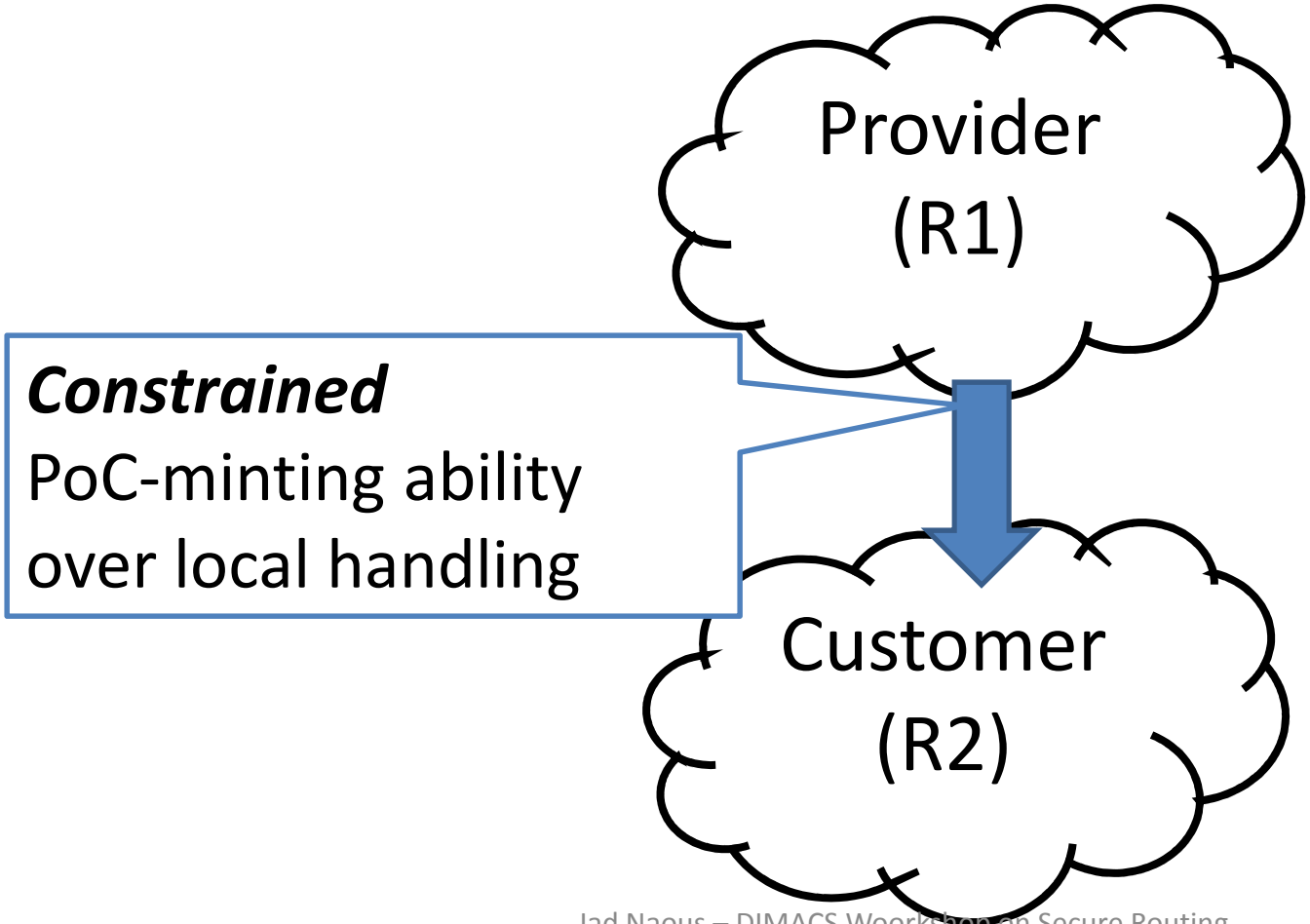


Control/Data Plane Interface

2. Allow/Deny Decision Delegation



Control/Data Plane Interface

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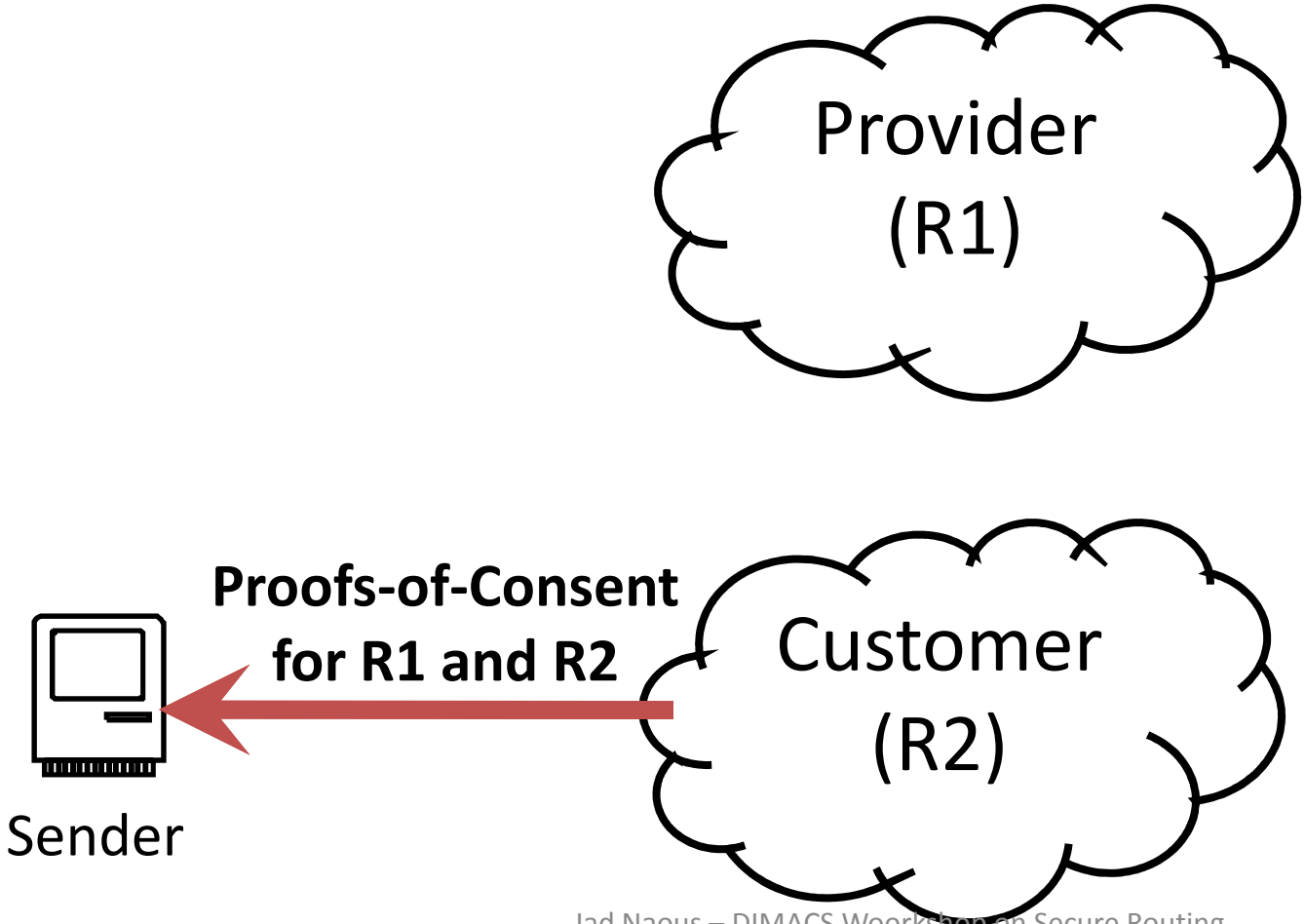
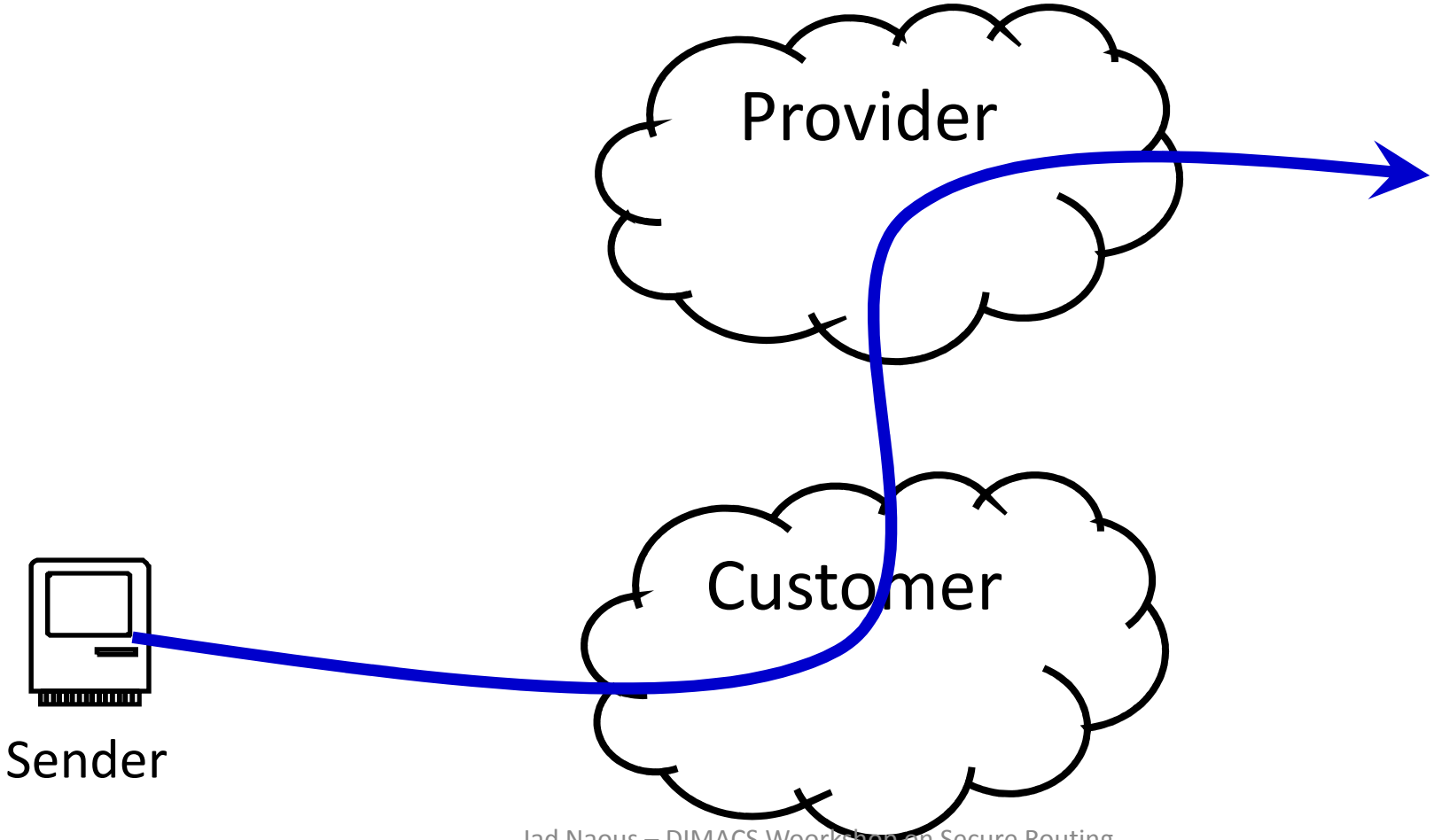
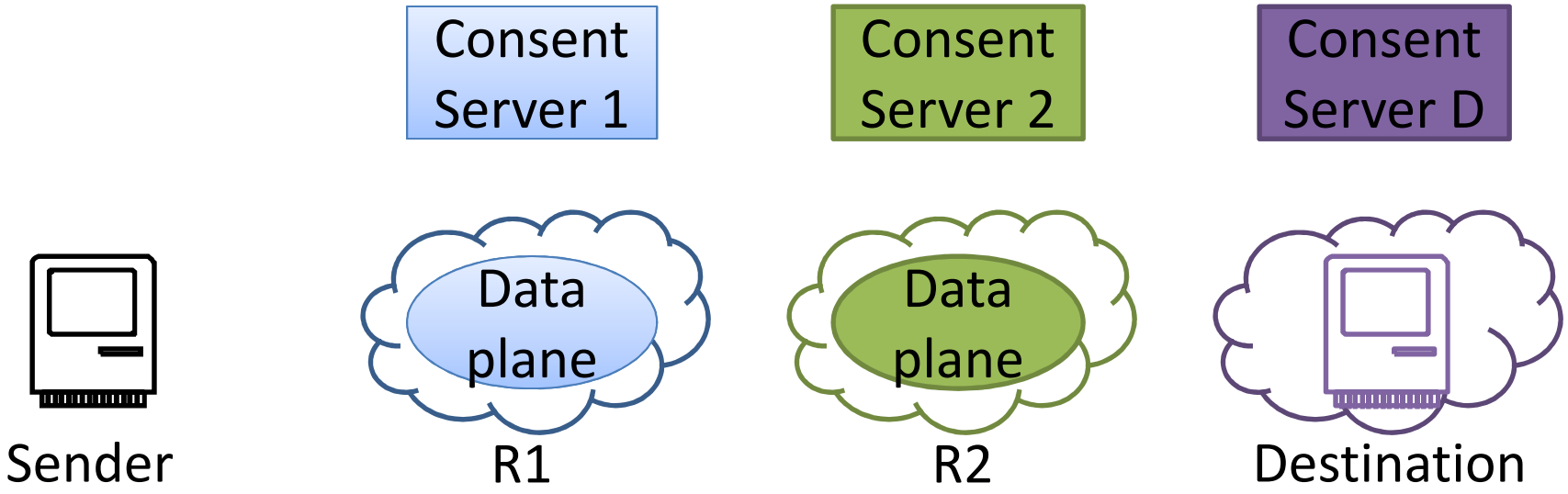


Control Plane “Knobs”

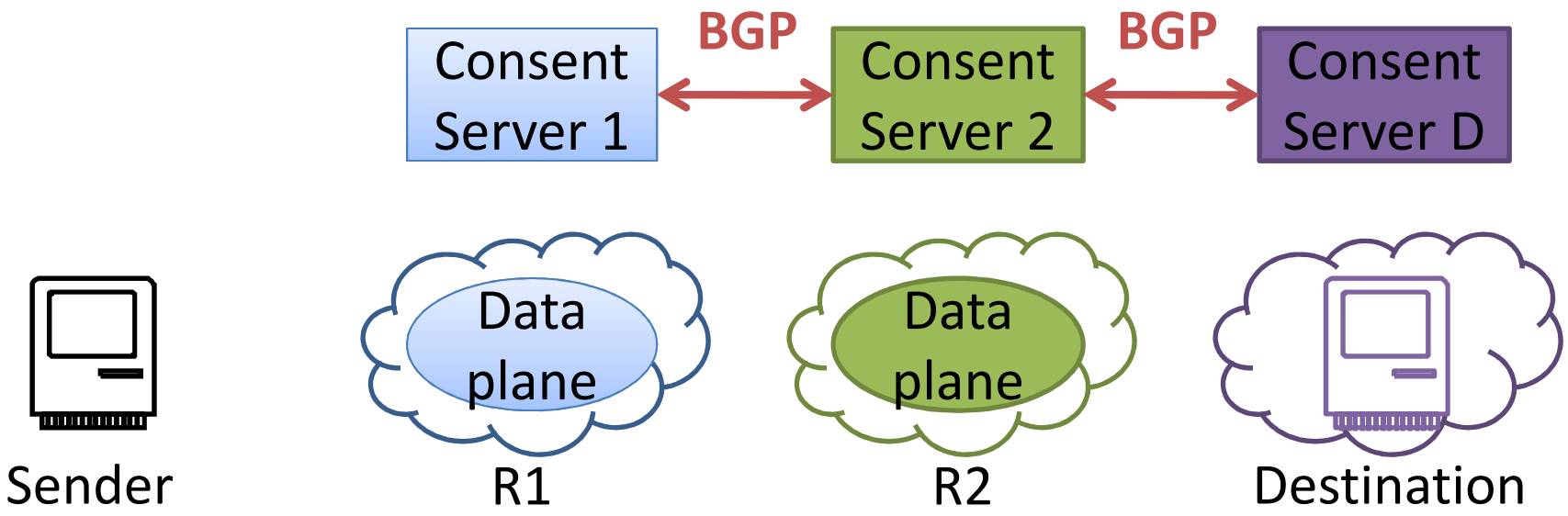
2. Allow/Deny Decision Delegation



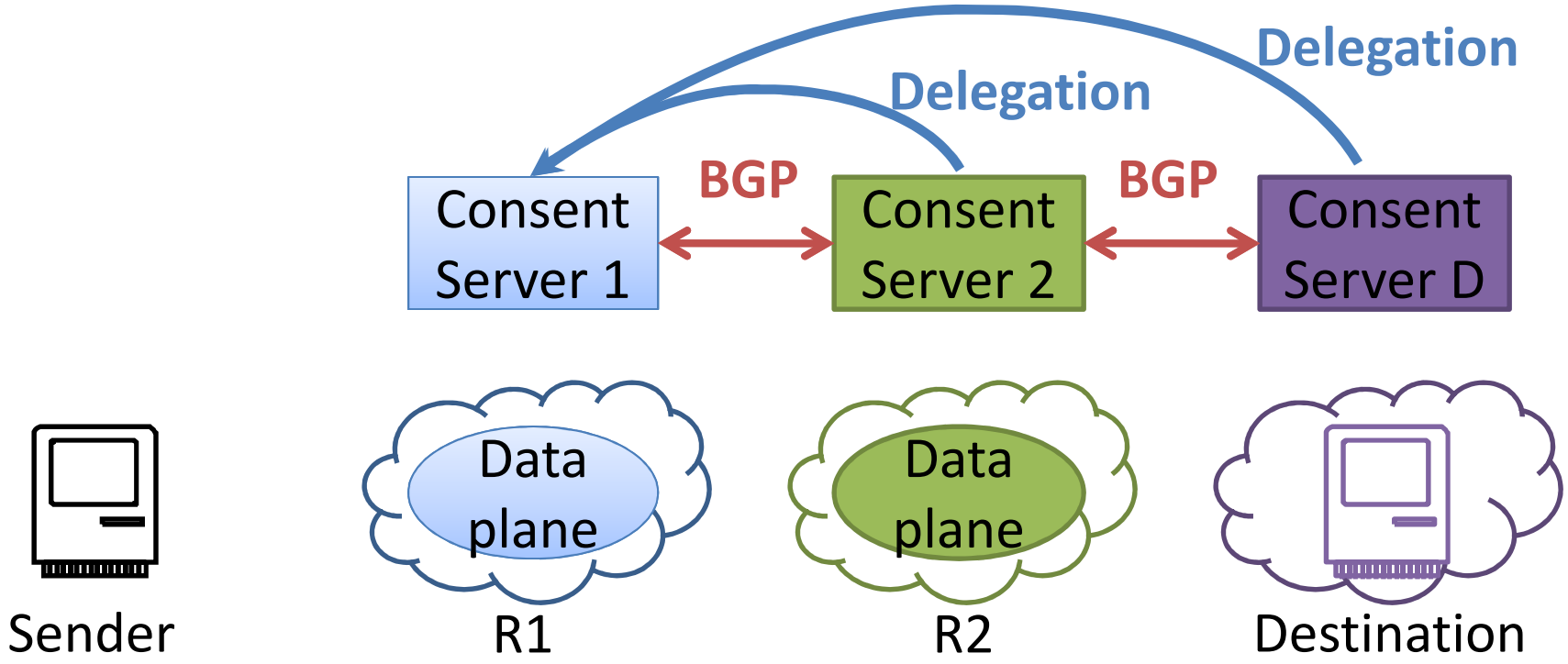
Example:
BGP with Enforcement



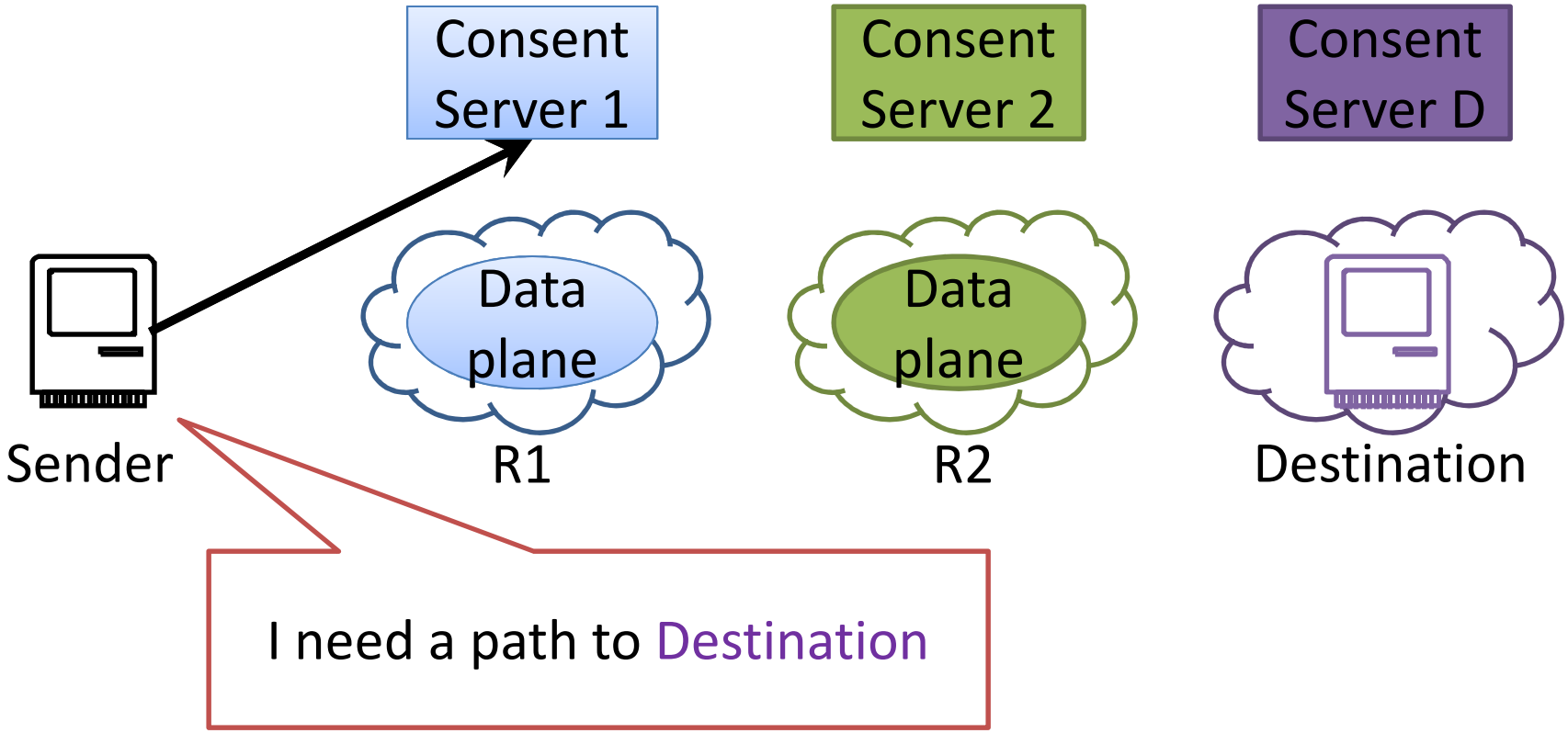
Example:
BGP with Enforcement



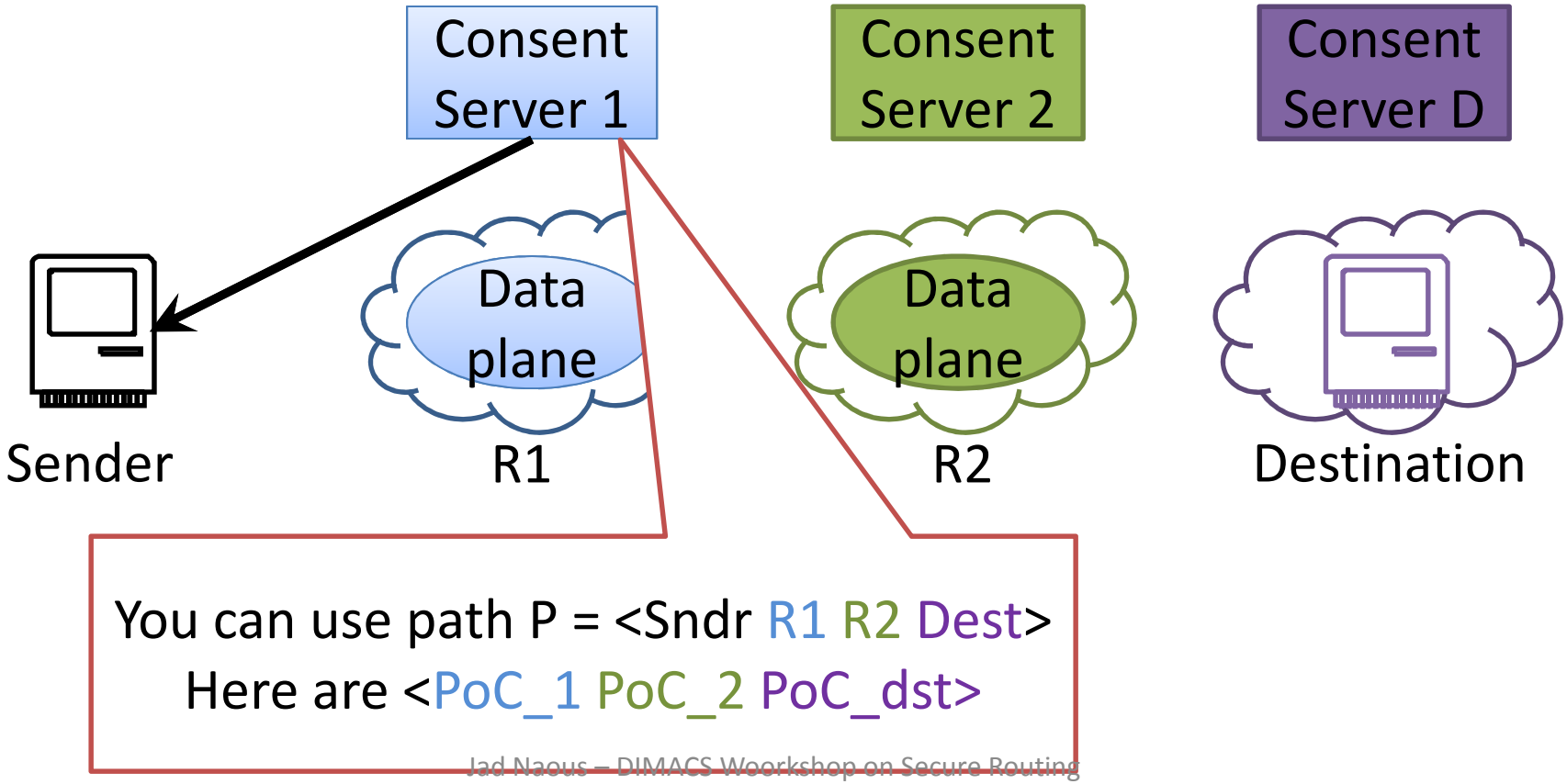
Example:
BGP with Enforcement



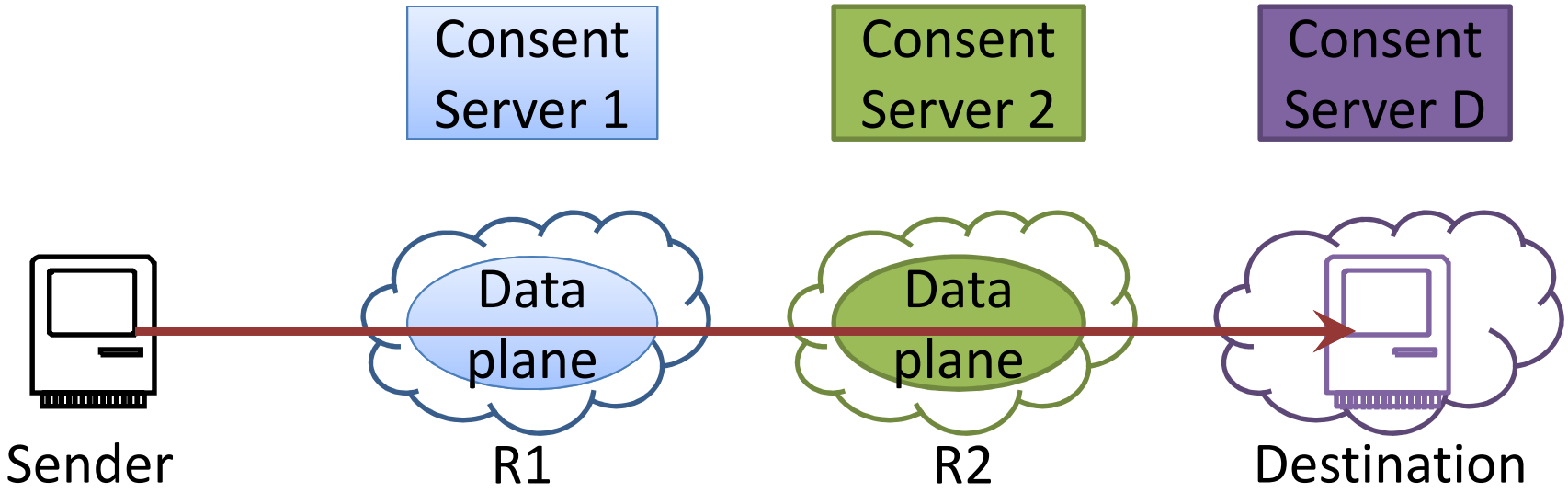
Example:
BGP with Enforcement



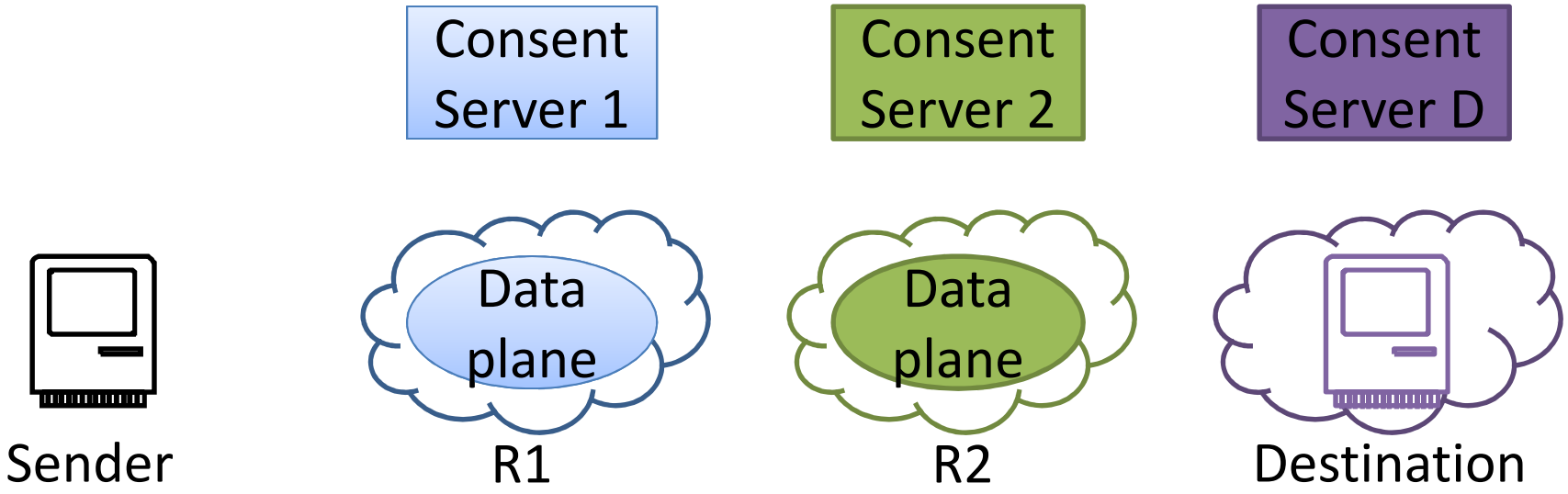
Example:
BGP with Enforcement



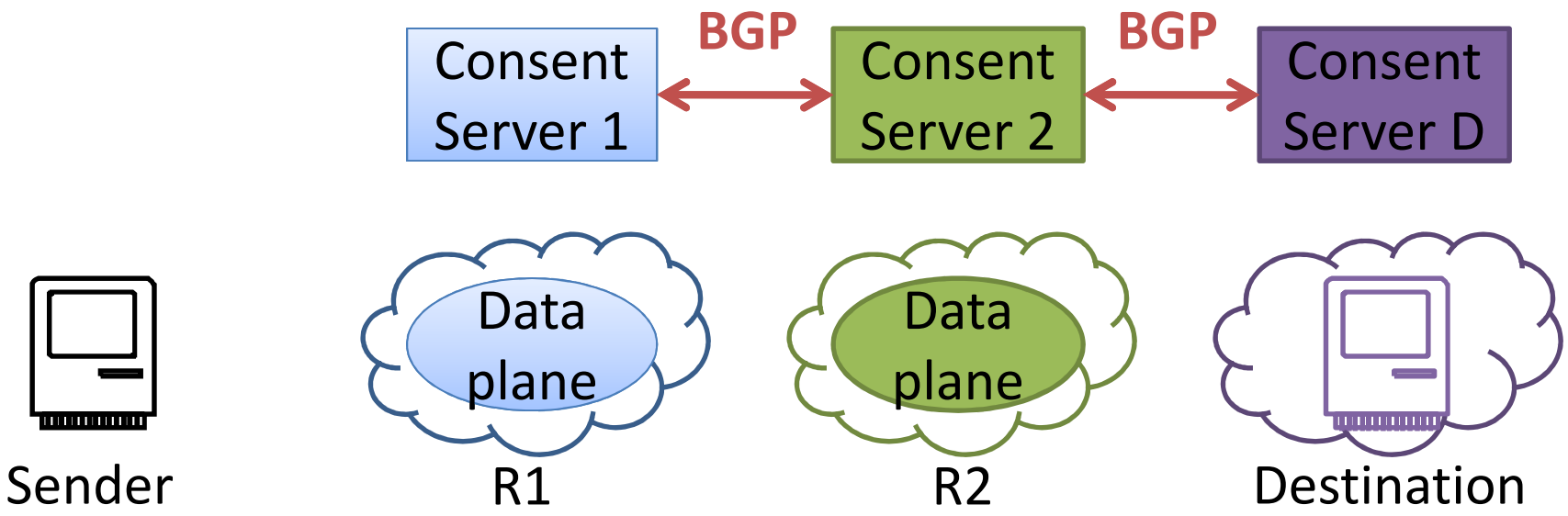
Example:
BGP with Enforcement



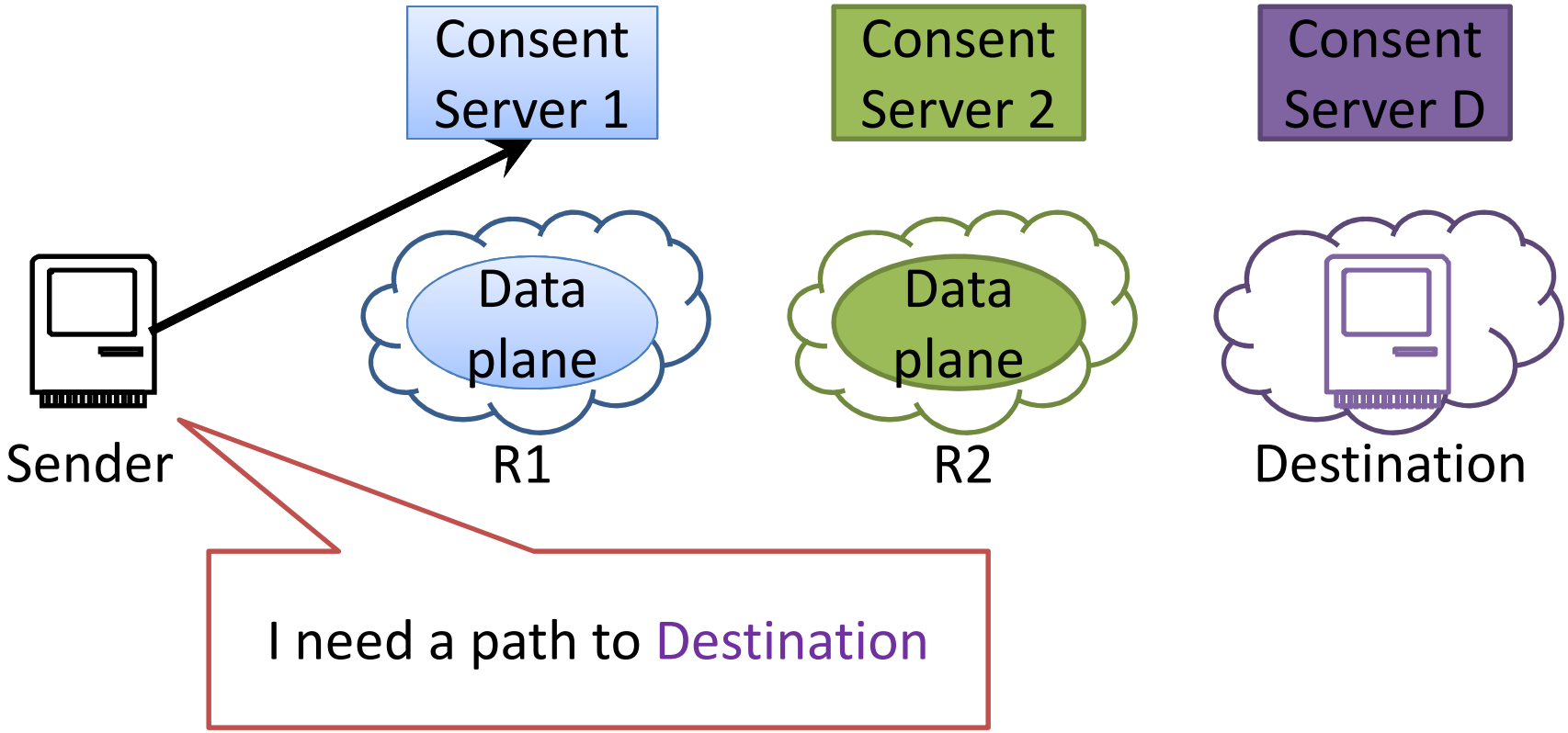
Example:
TVA and default-off



Example:
TVA and default-off



Example:
BGP with Enforcement



Example:
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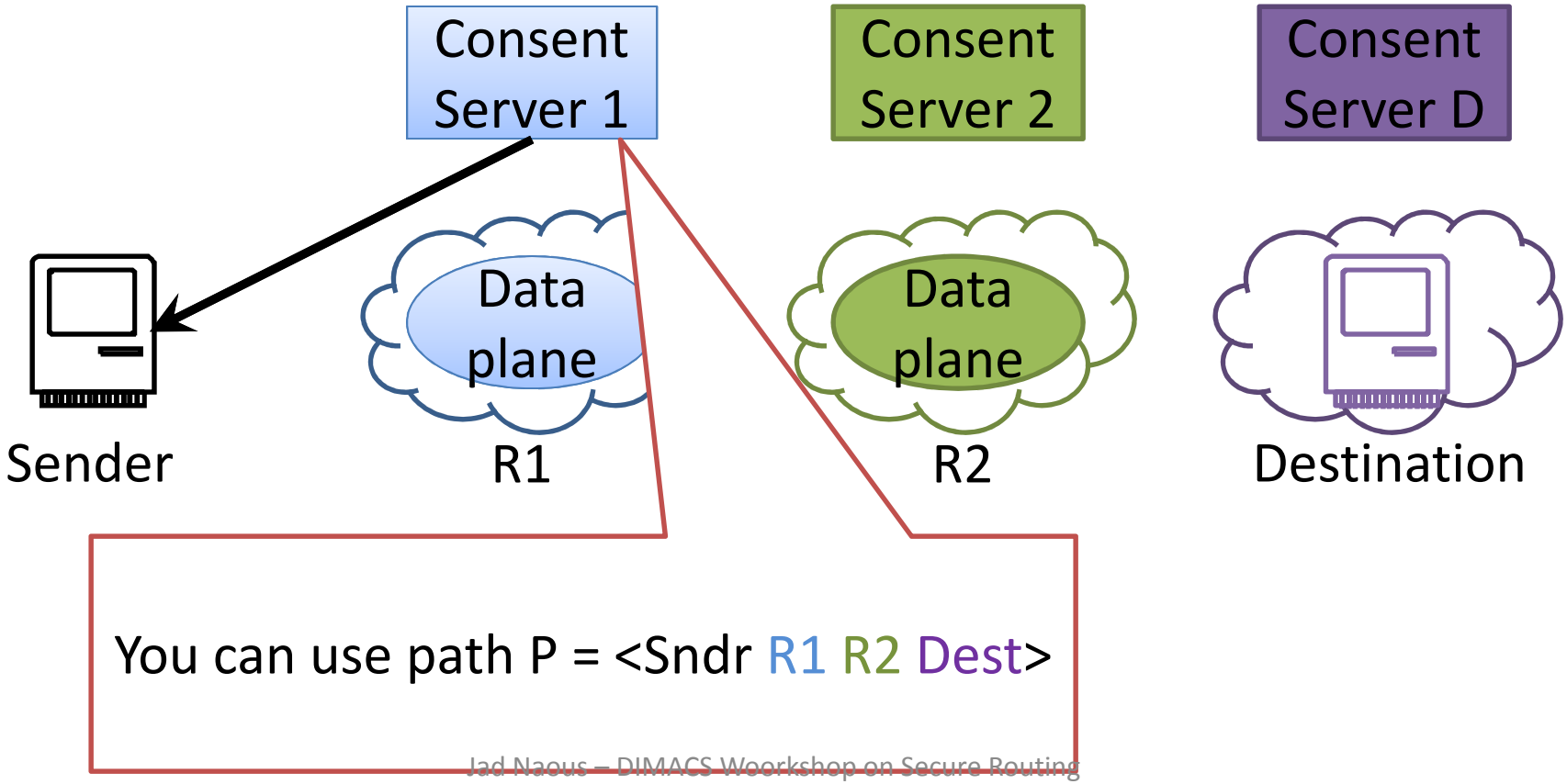
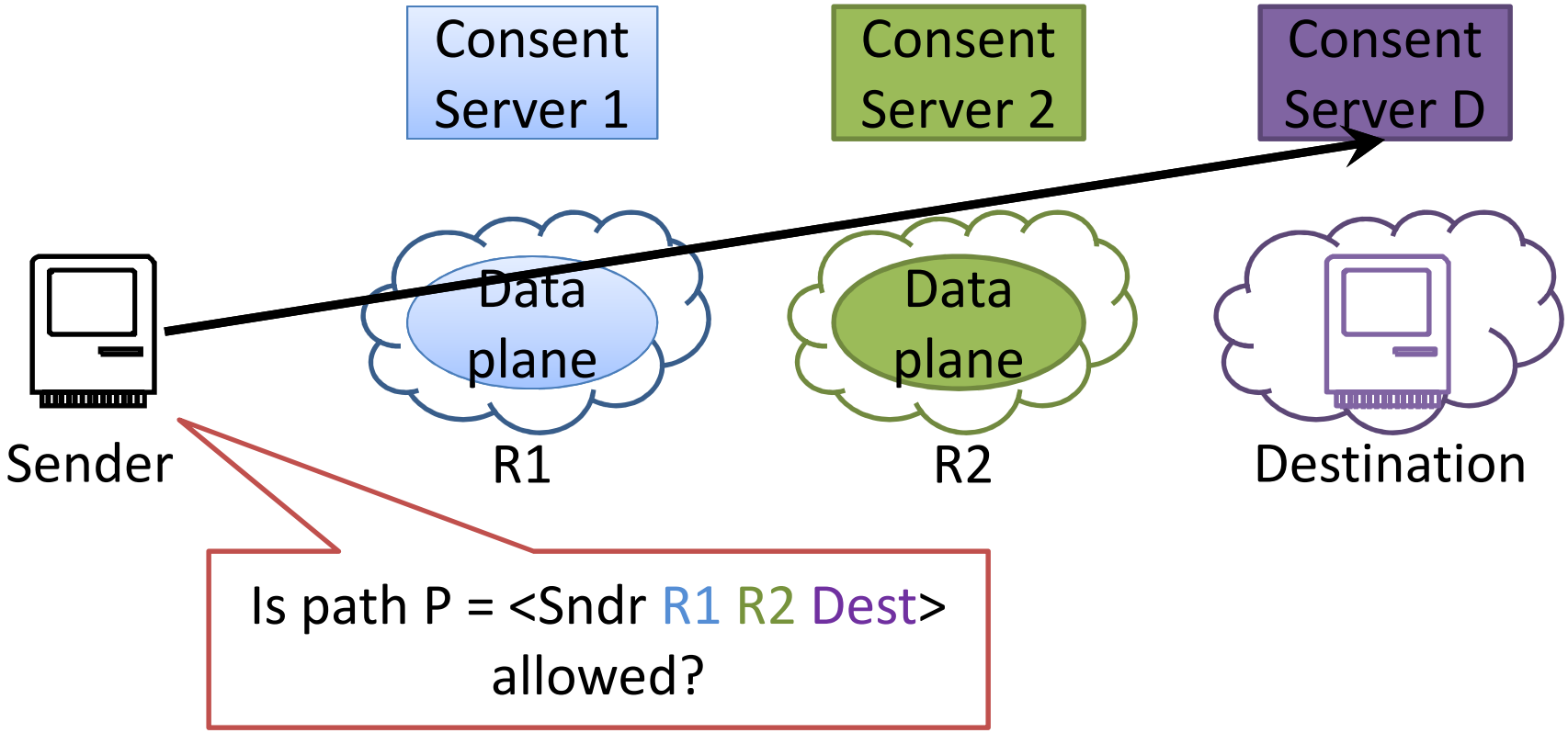
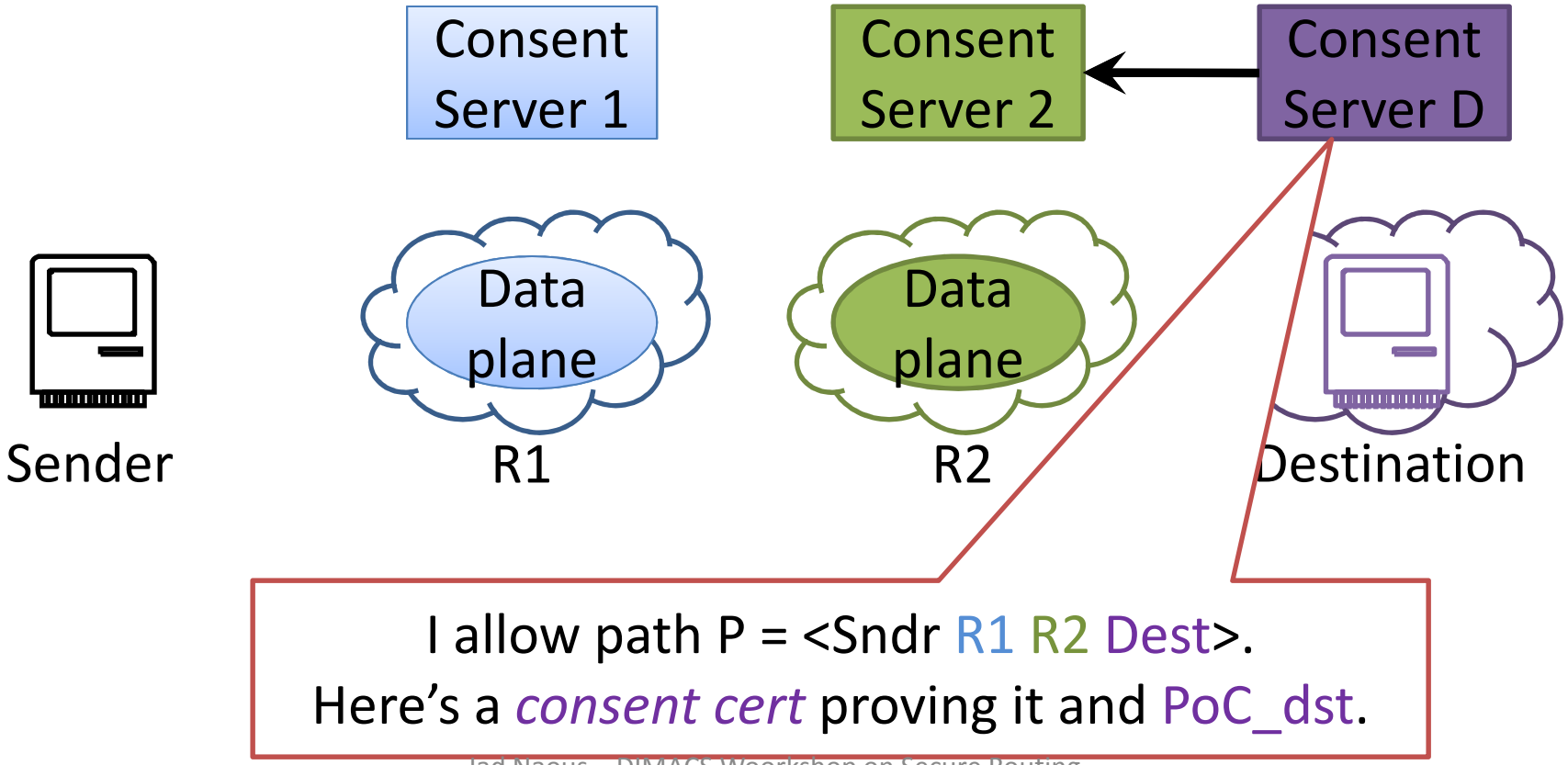


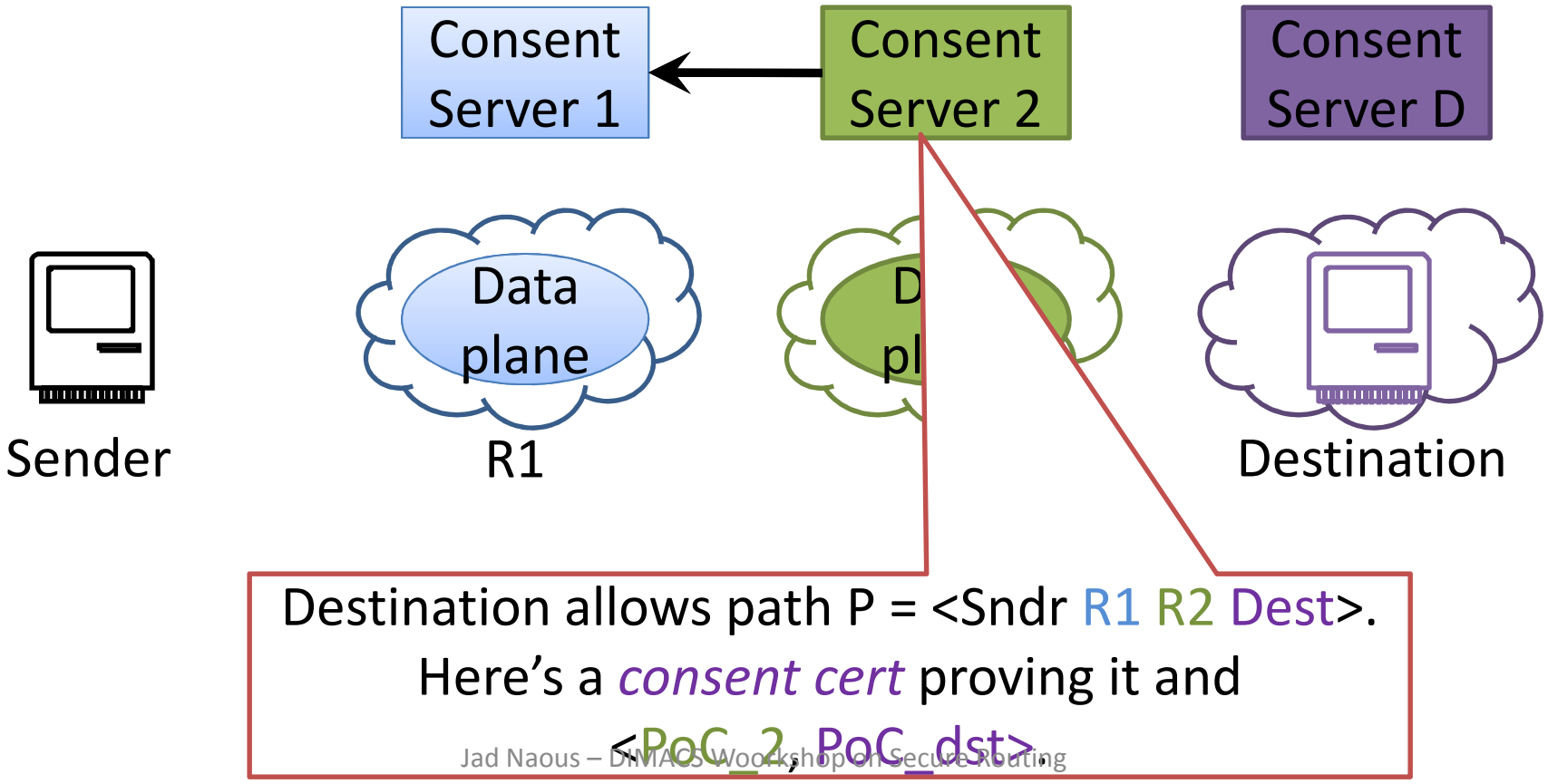
Example:
TVA and default-off



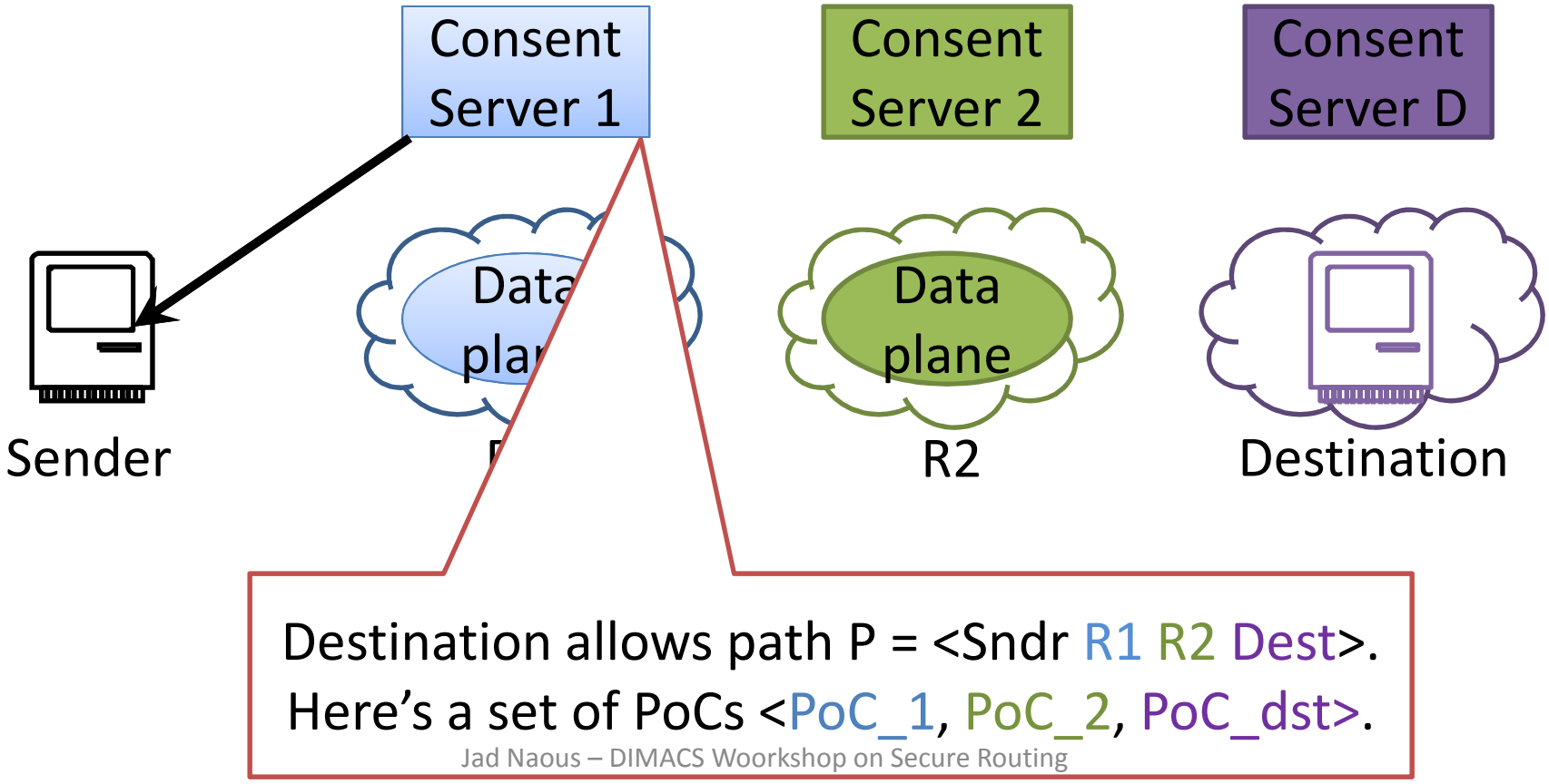
Example:
TVA and default-off



Example:
TVA and default-off



Example:
TVA and default-off

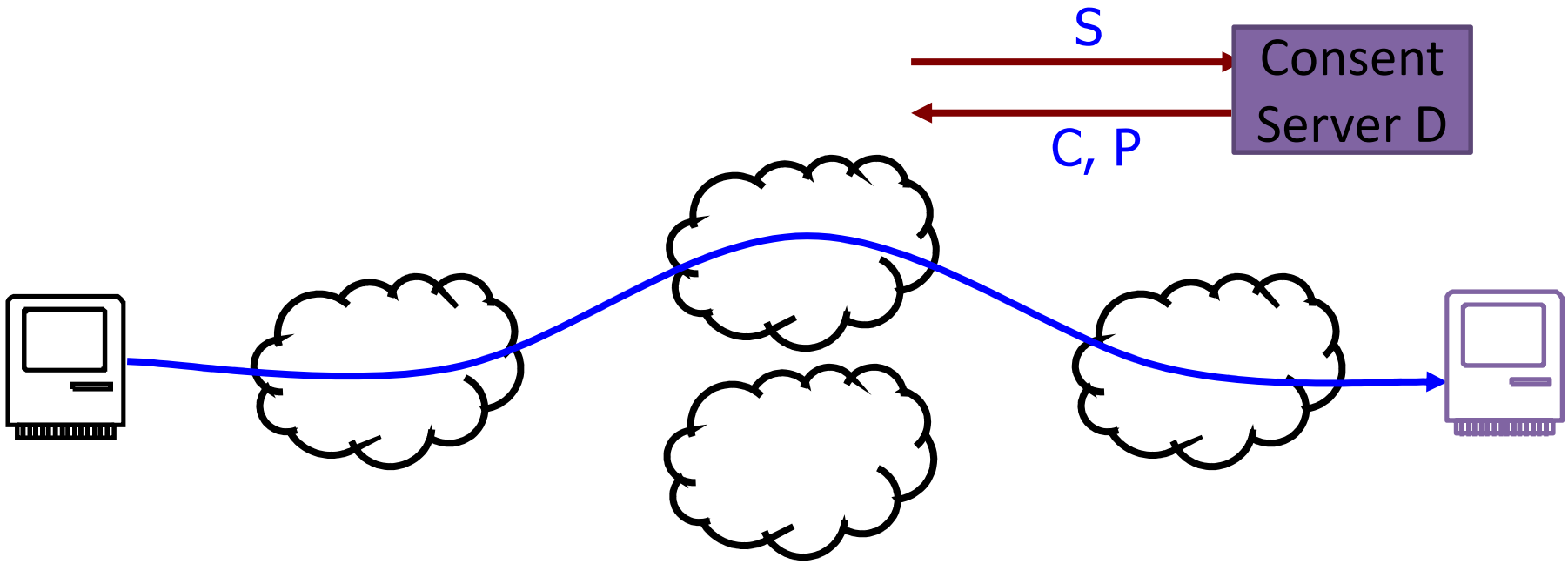


Others

Can emulate other proposals: NIRA, Pathlets, Source Routing, LSRR, …

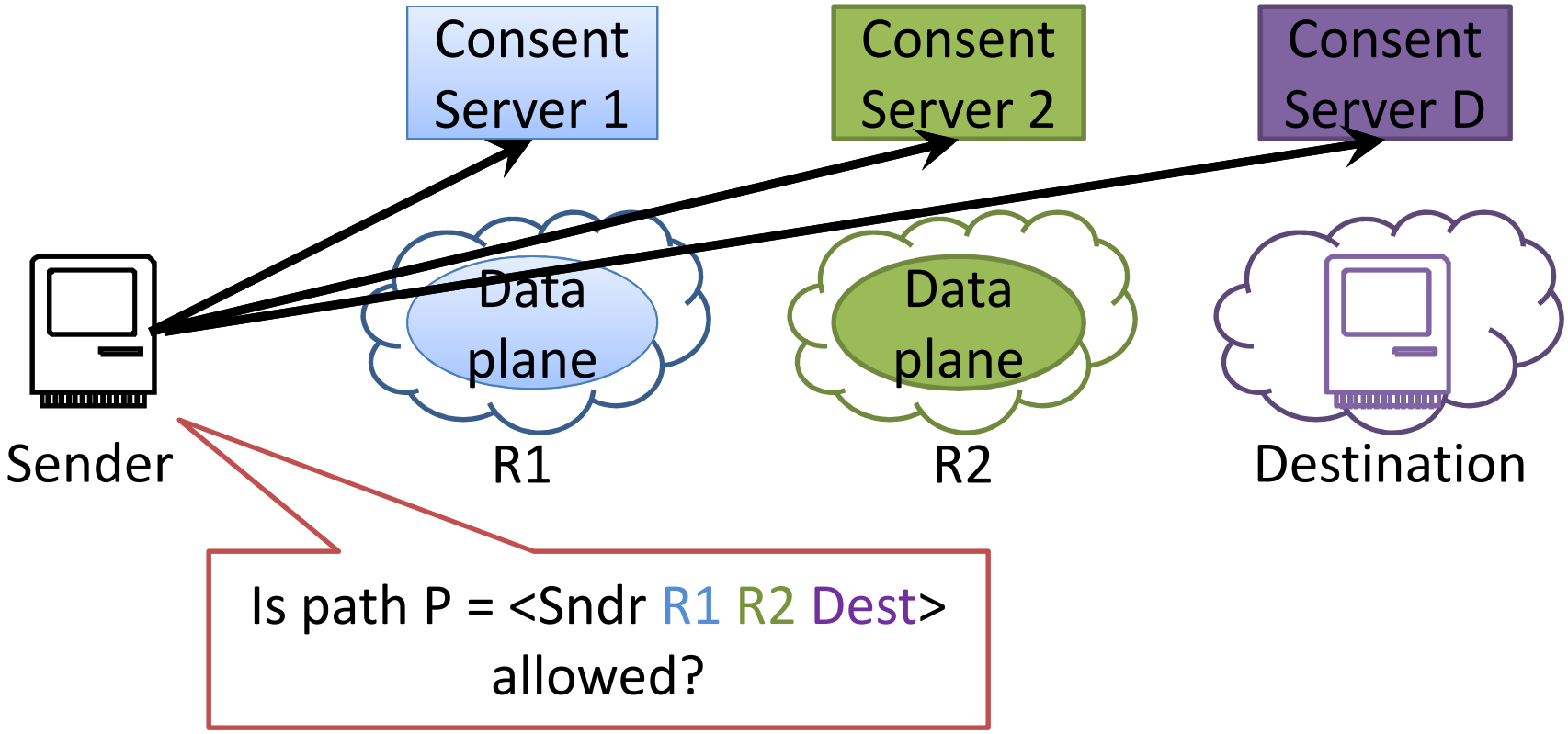
New policy engines with more features.

Example: choosing trustworthy providers through sink routing

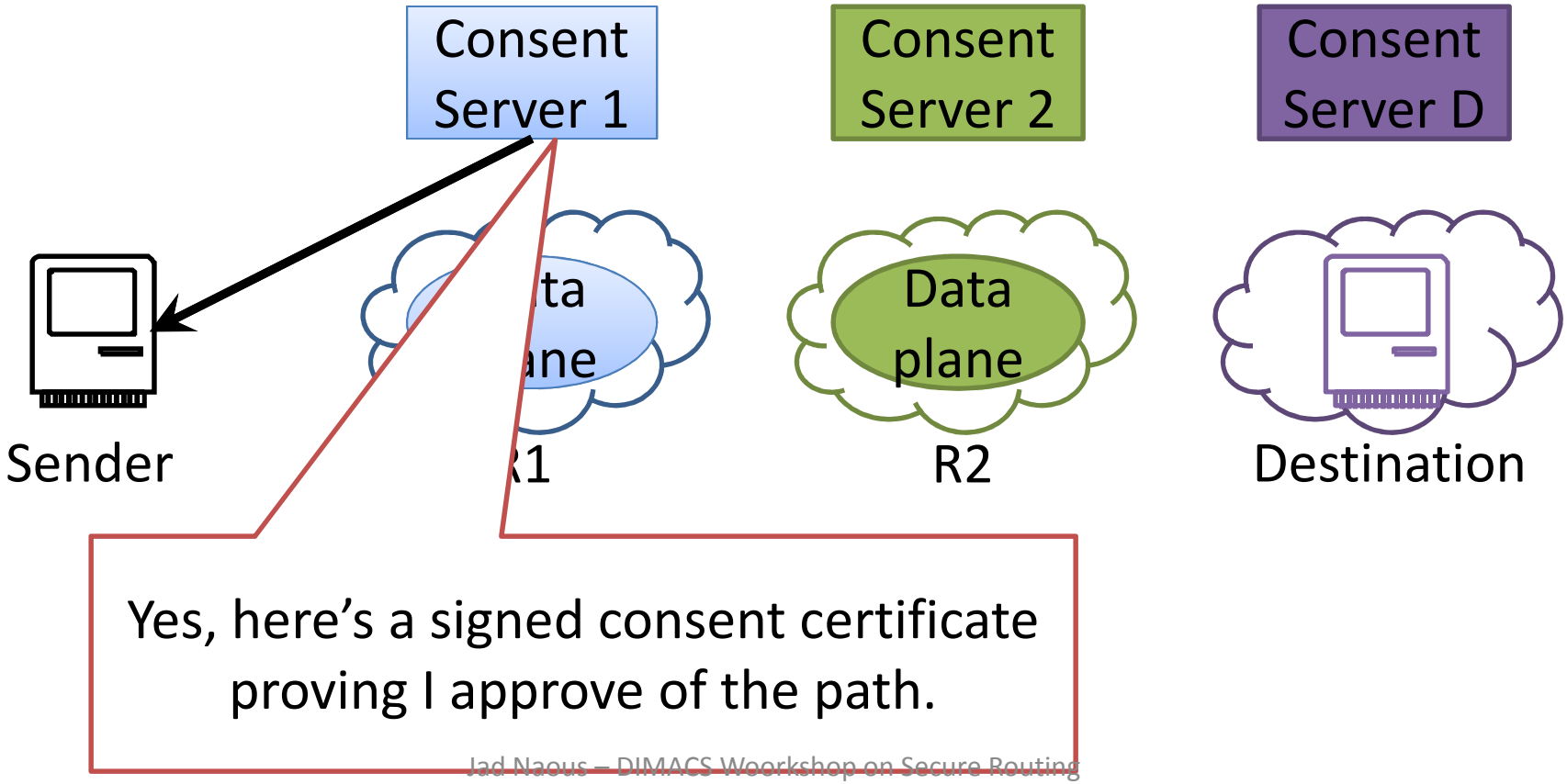


- This is analog of well-known source routing
- Sender requests consent; gives its own id (S)
- Receiver specifies path toward itself
  - Useful for organizations handling sensitive data

Example:
Early blocking of illegal packets



Example:
Early blocking of illegal packets



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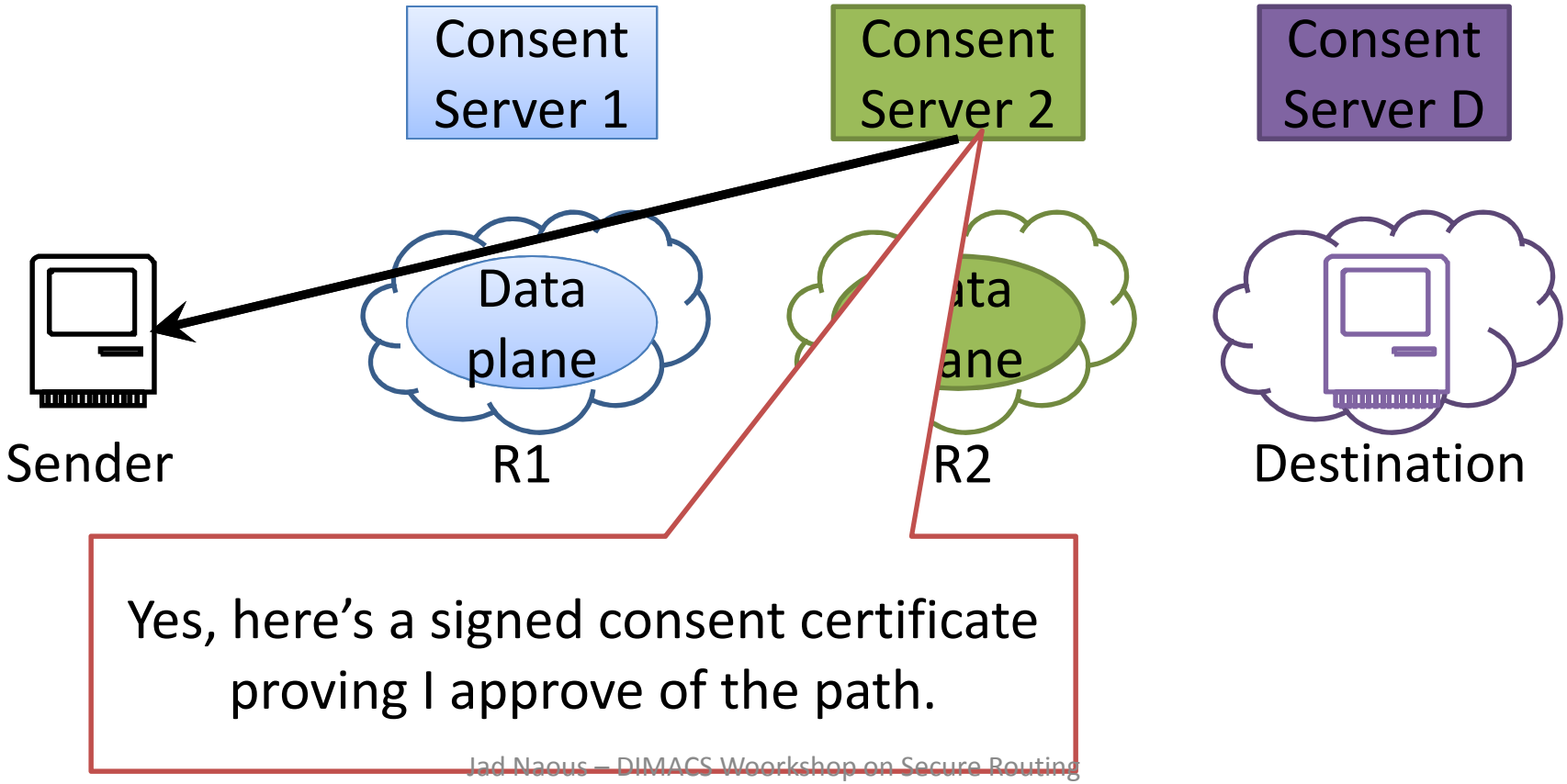

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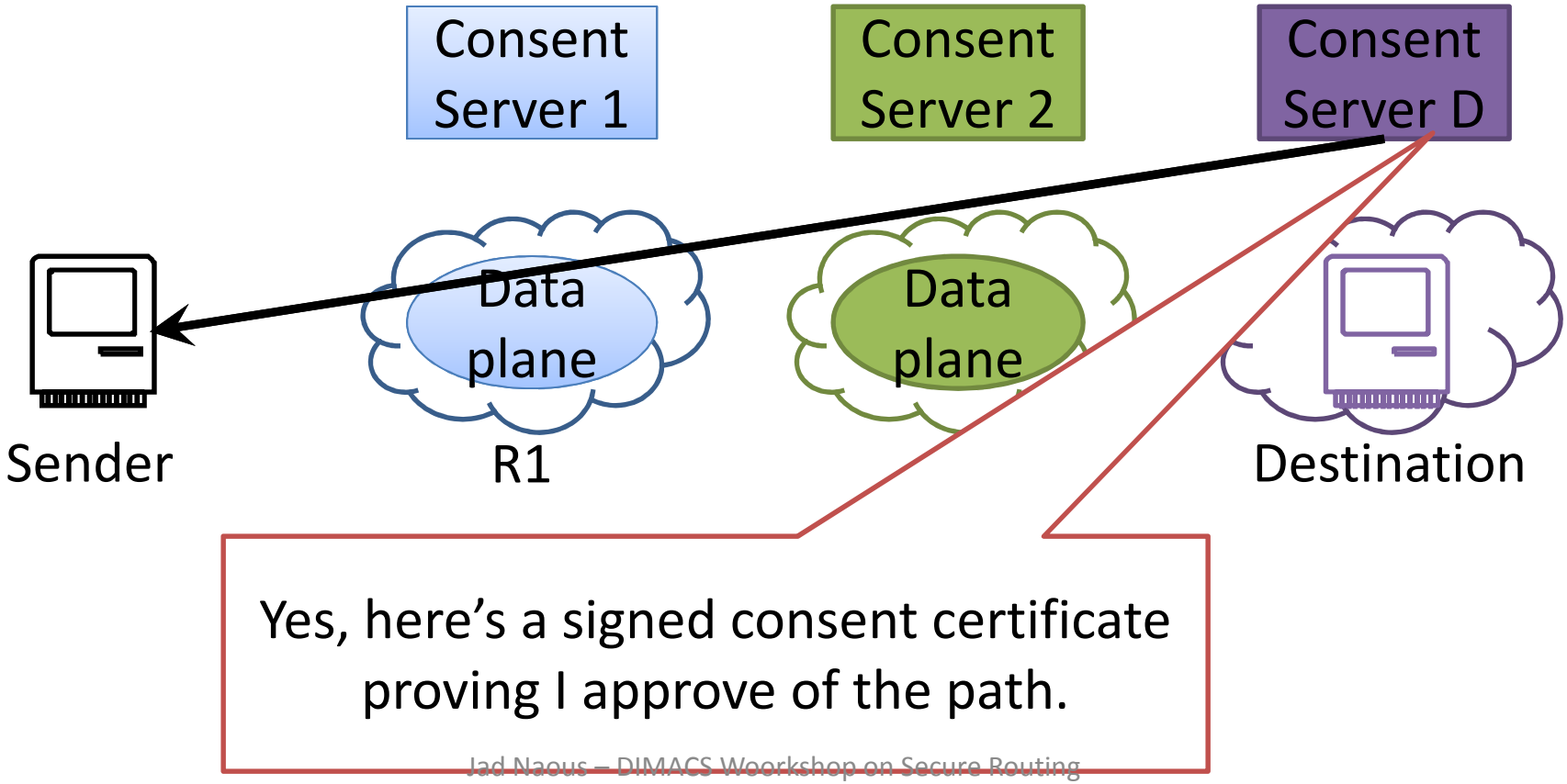

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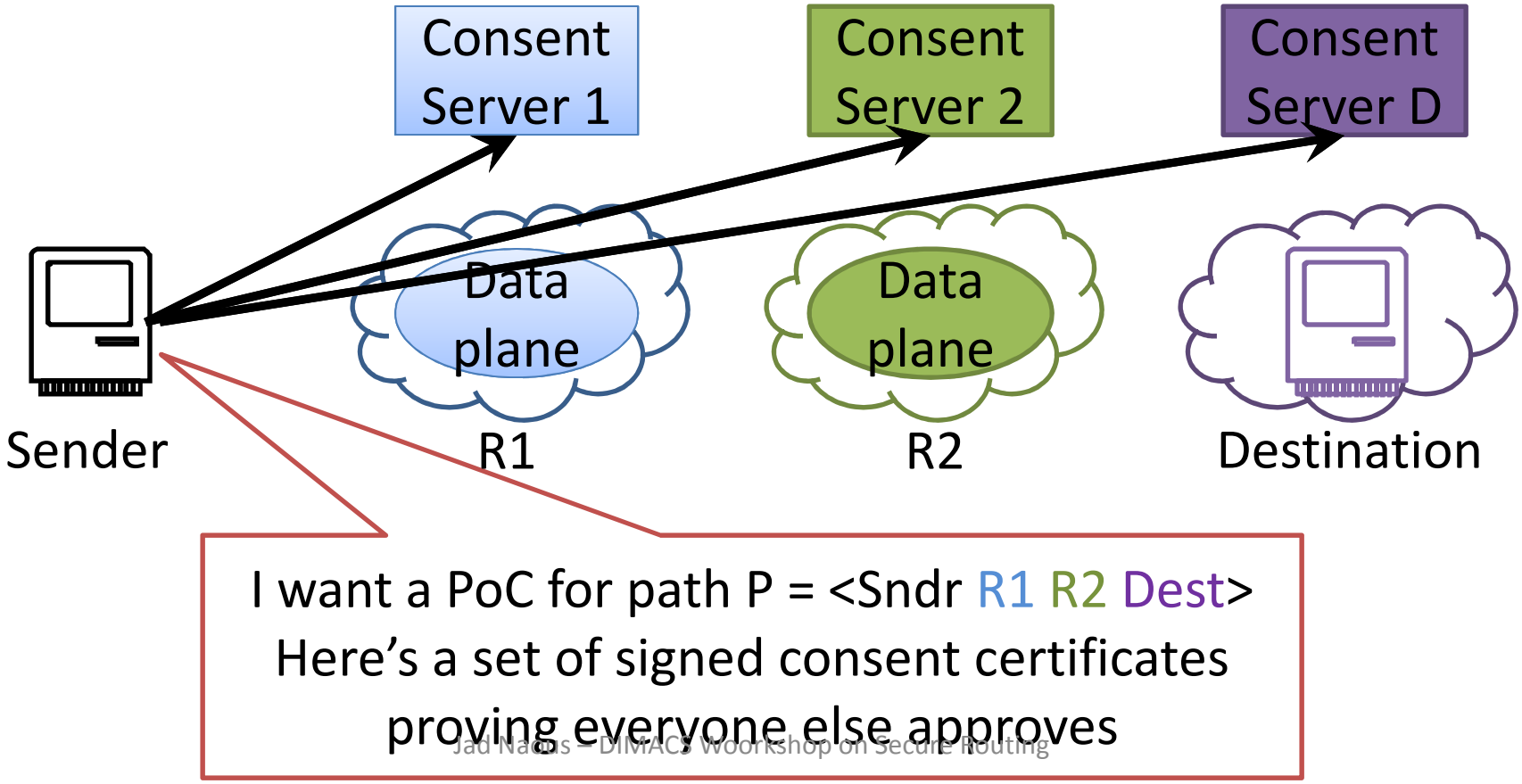

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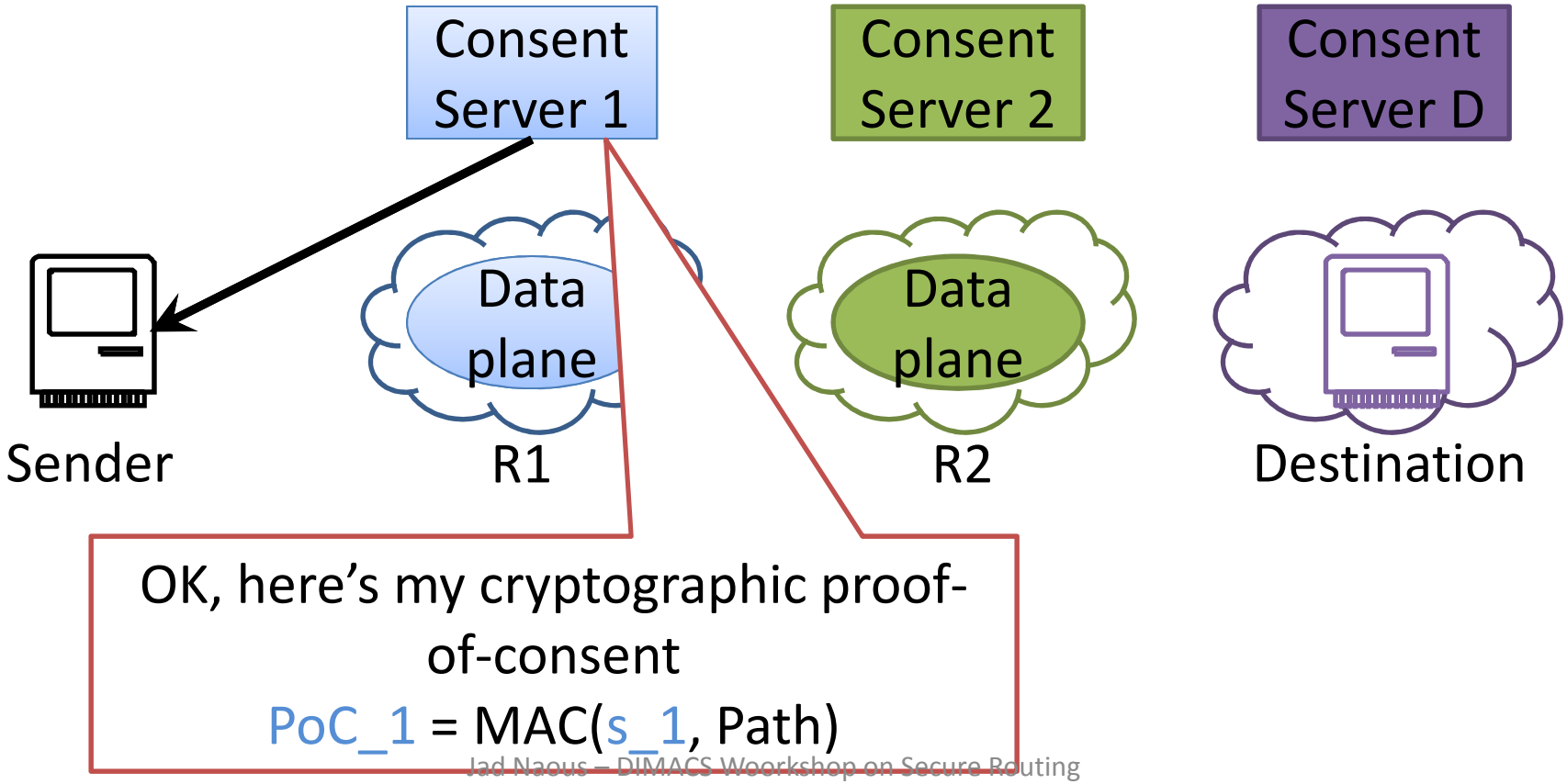

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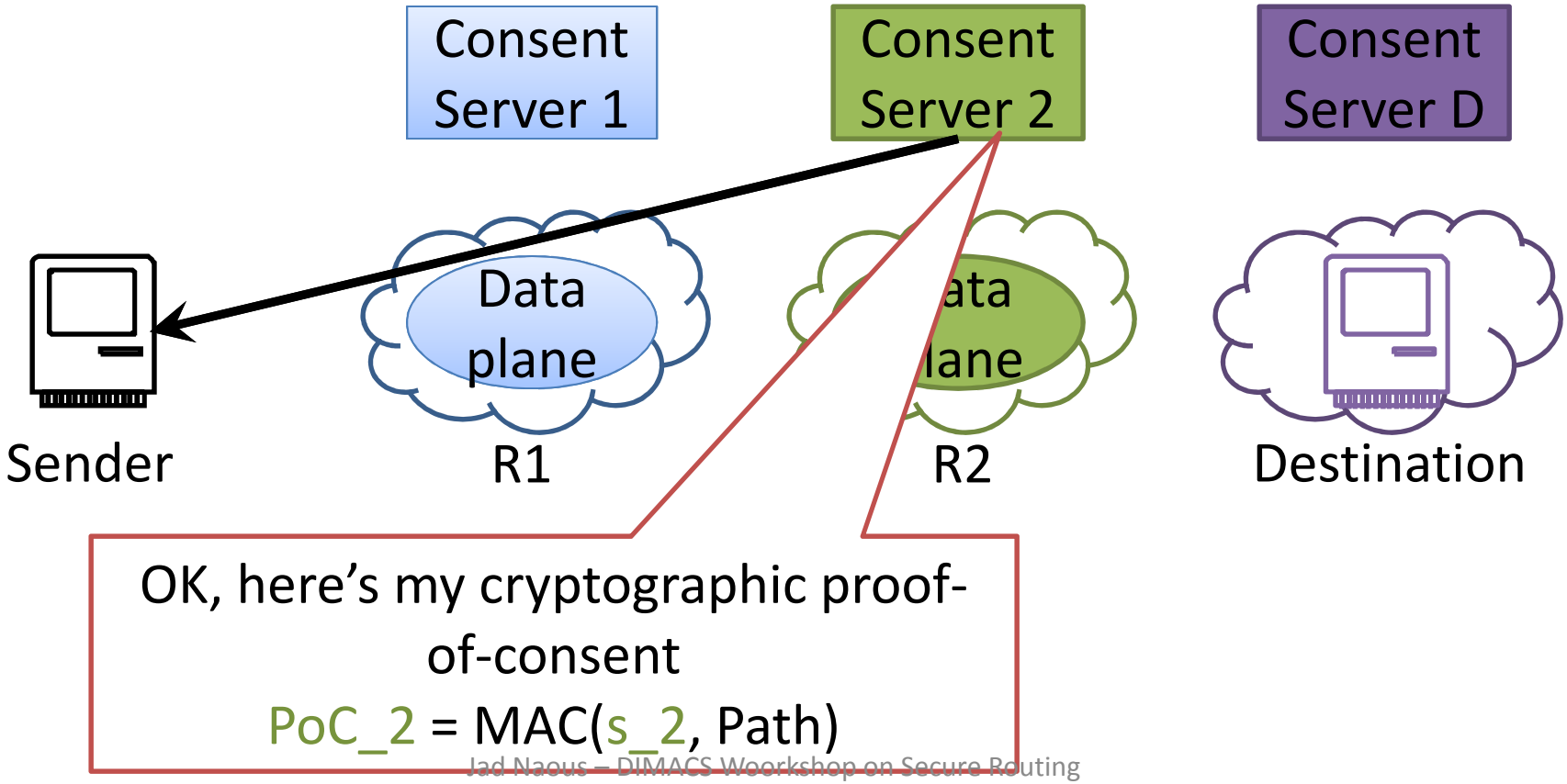

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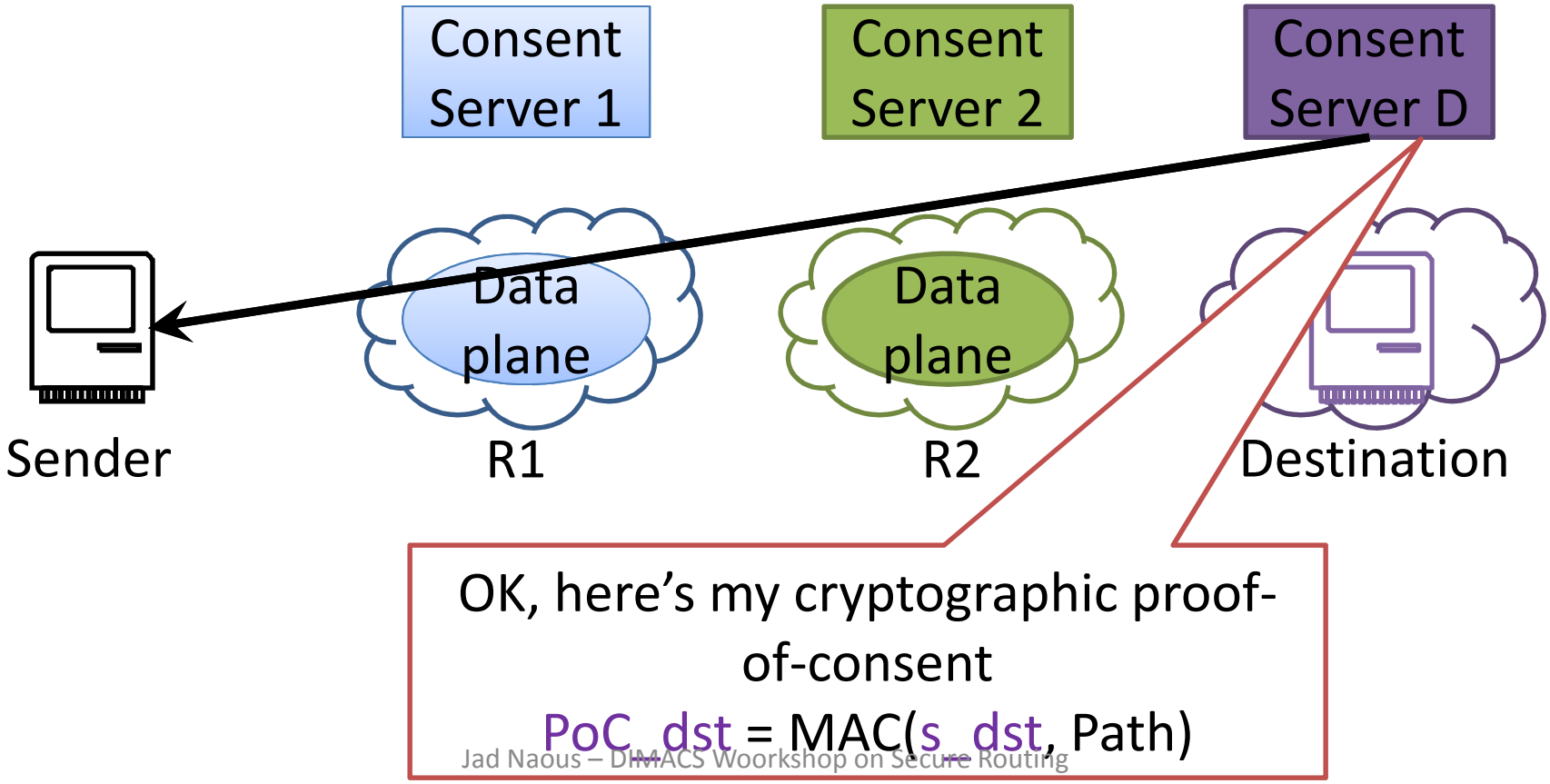

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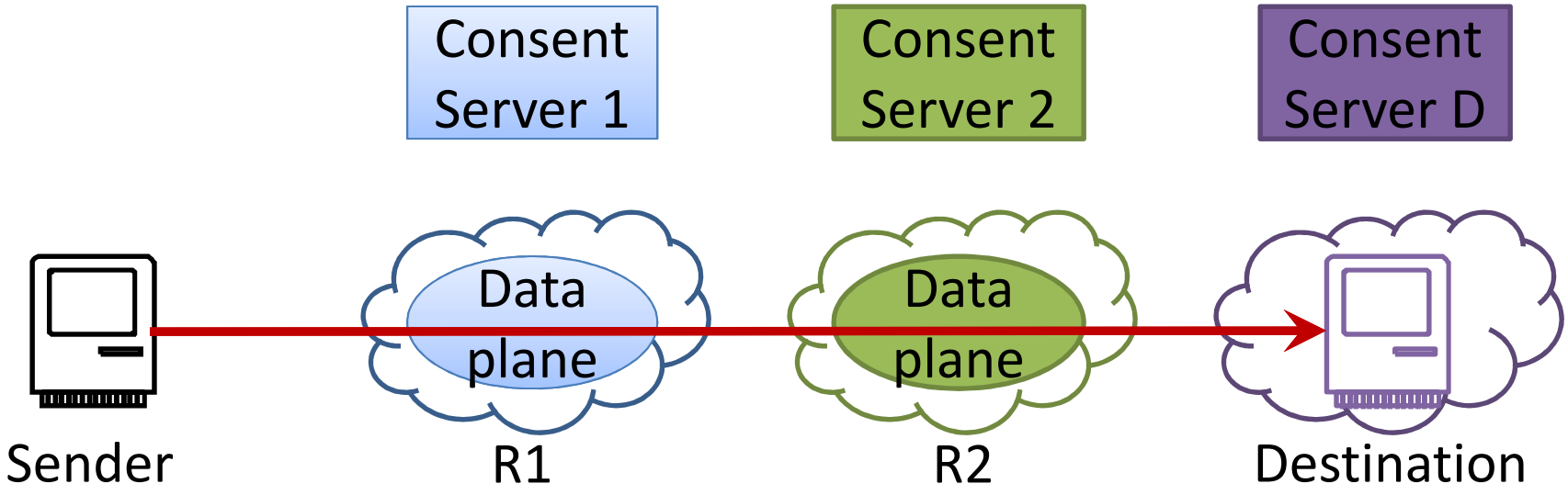
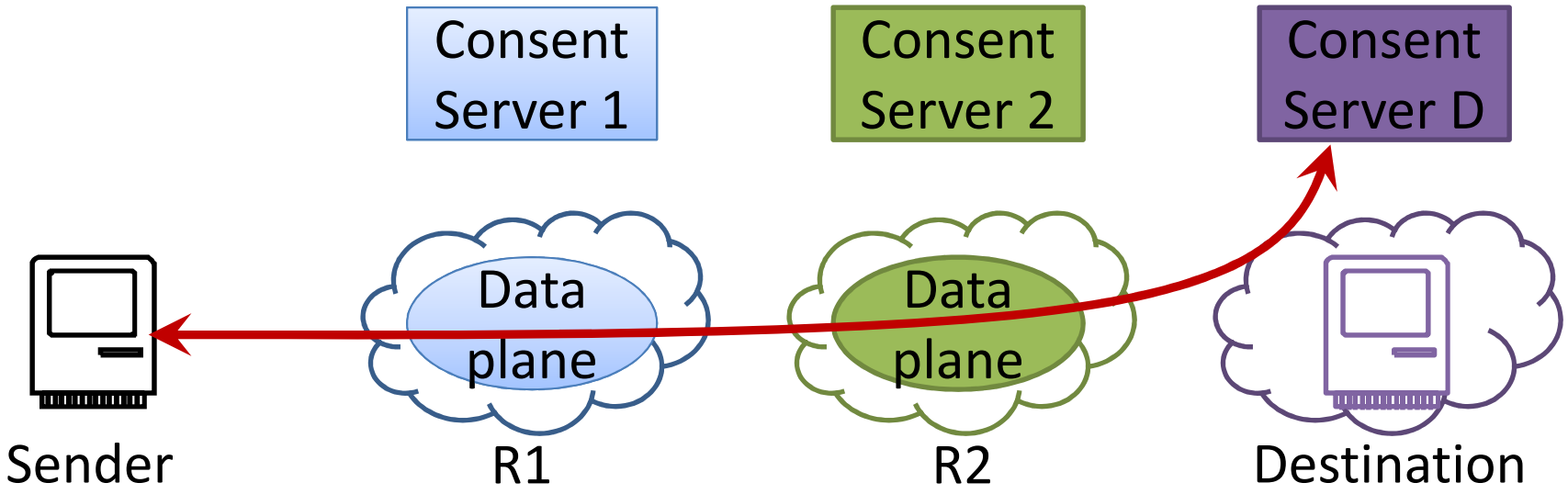
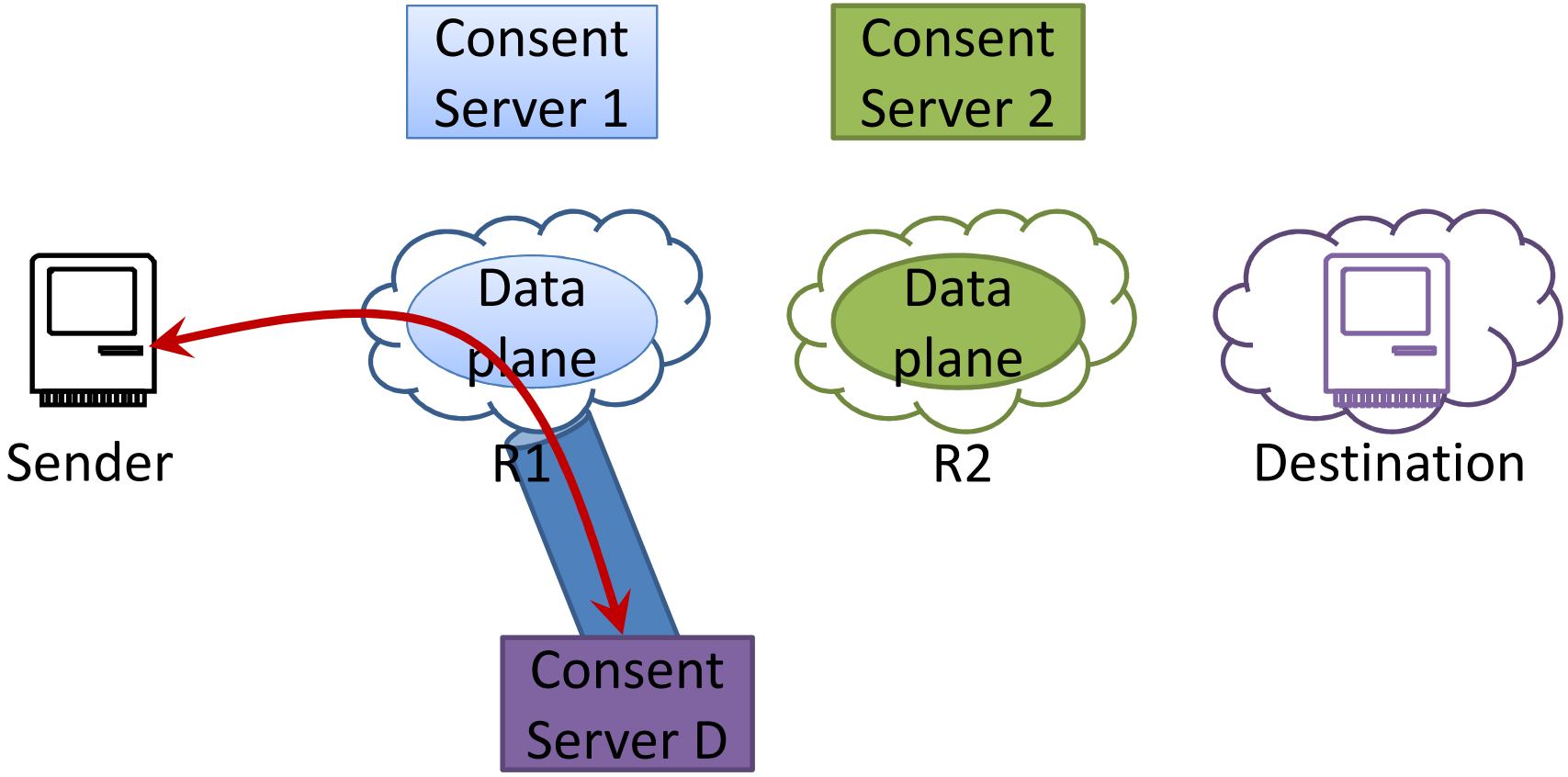


Packet =
<Path, PoC_1, PoC_2, PoC_dst, data>
PoCs verifiable by data plane using
Shared secret keys s_1, s_2, s_dst

Example use: preventing denial-of-service



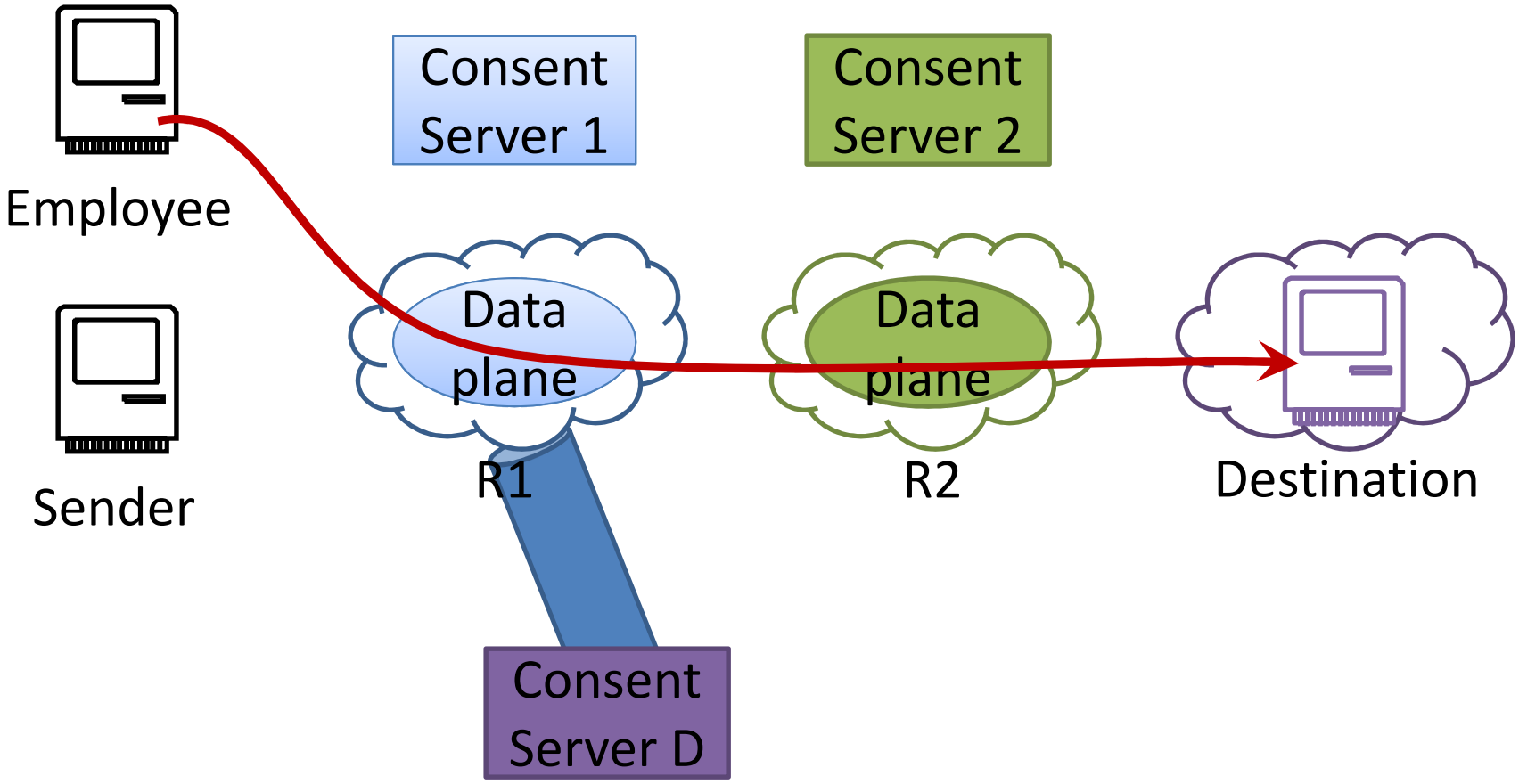
Example use: preventing denial-of-service



Consent server can be moved to where bandwidth is plentiful

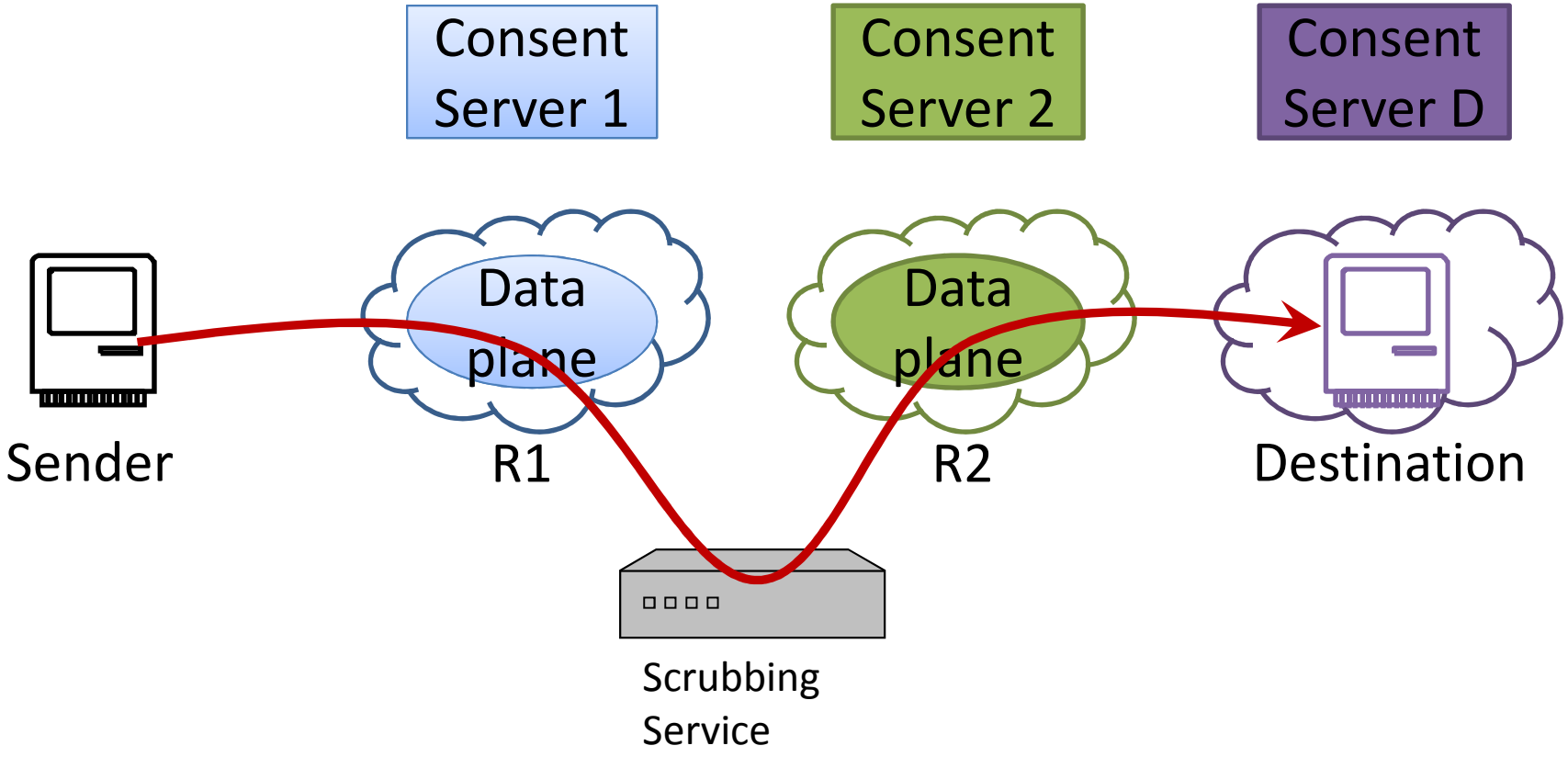
e.g. DoS prevention specialist

Example use: preventing denial-of-service



Employees can be given special keys to mint their own PoCs and not have to access a consent server

Example use: Off-site scrubbing service



- Consent is only granted if path goes through middlebox
- First honest realm drops the packet if middlebox not actually passed

Other uses

- Multipath
- QoS
- Billing support
- Access delegation
- …

Beyond this talk

- More data plane issues:
  - Bootstrapping (consent to get consent)
  - Key management/expiry/compromises
  - Network failures
  - Crypto details
- Pluggable control plane
  - Finding legal paths (routing)
  - Control delegation details
- Other issues:
  - Incremental deployment/benefit

Further Work

- More general and powerful policy engines
- Replay attacks
- Corner case attacks:
  - Putting legal full path in packet but only using prefix of the path.
- Route dissemination and other control plane overheads
- New business and economic models

Summary

- Policy framework for future Internet
- Principle of consent: Give all entities along a path control over path.
- ICING enables pluggable policy engines
- ICING is flexible, evolvable, and general