Making the Internet more scalable and manageable

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“Human factors are responsible

for 50% to 80% of network outages”

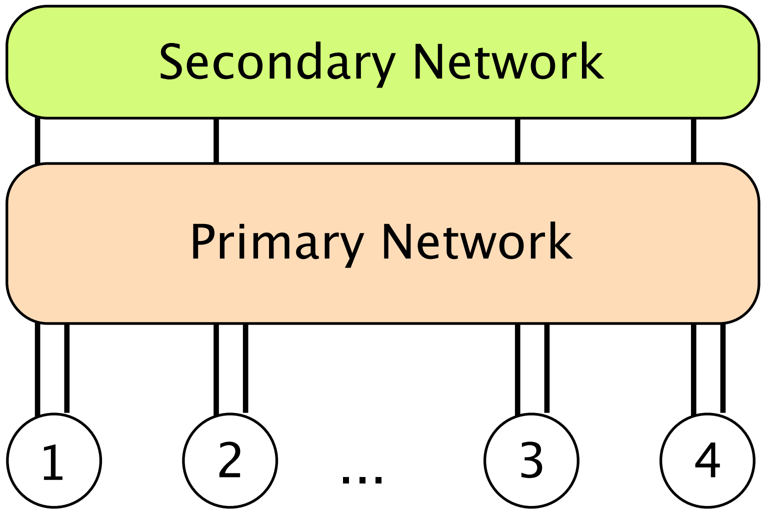
Juniper Networks, What’s Behind Network Downtime?, 2008

"Cost per network outage
can be as high as 750 000$"

Smart Management for Robust Carrier Network Health
and Reduced TCO!, NANOG54, 2012

At 12:47 AM PDT on April 21st 2011, a network change was performed as part of our normal scaling activities…

During the change, one of the steps is to shift traffic off of one of the redundant routers…

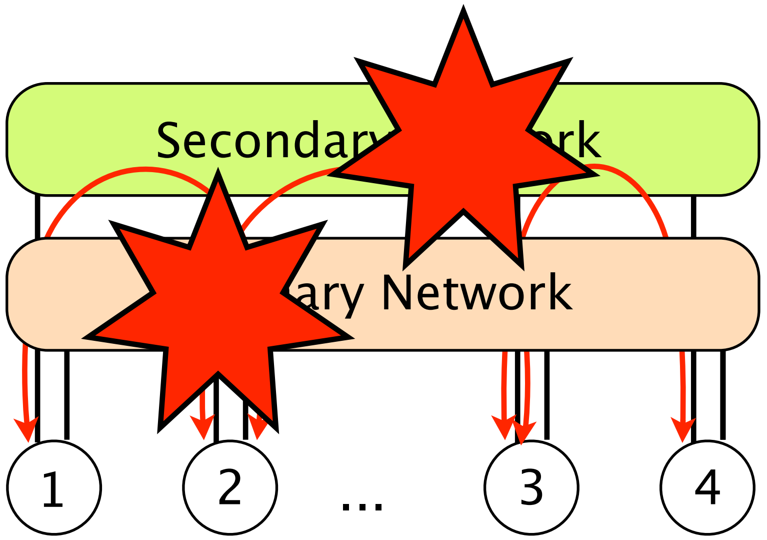


At 12:47 AM PDT on April 21st 2011, a network change was performed as part of our normal scaling activities…

During the change, one of the steps is to shift traffic off of one of the redundant routers…

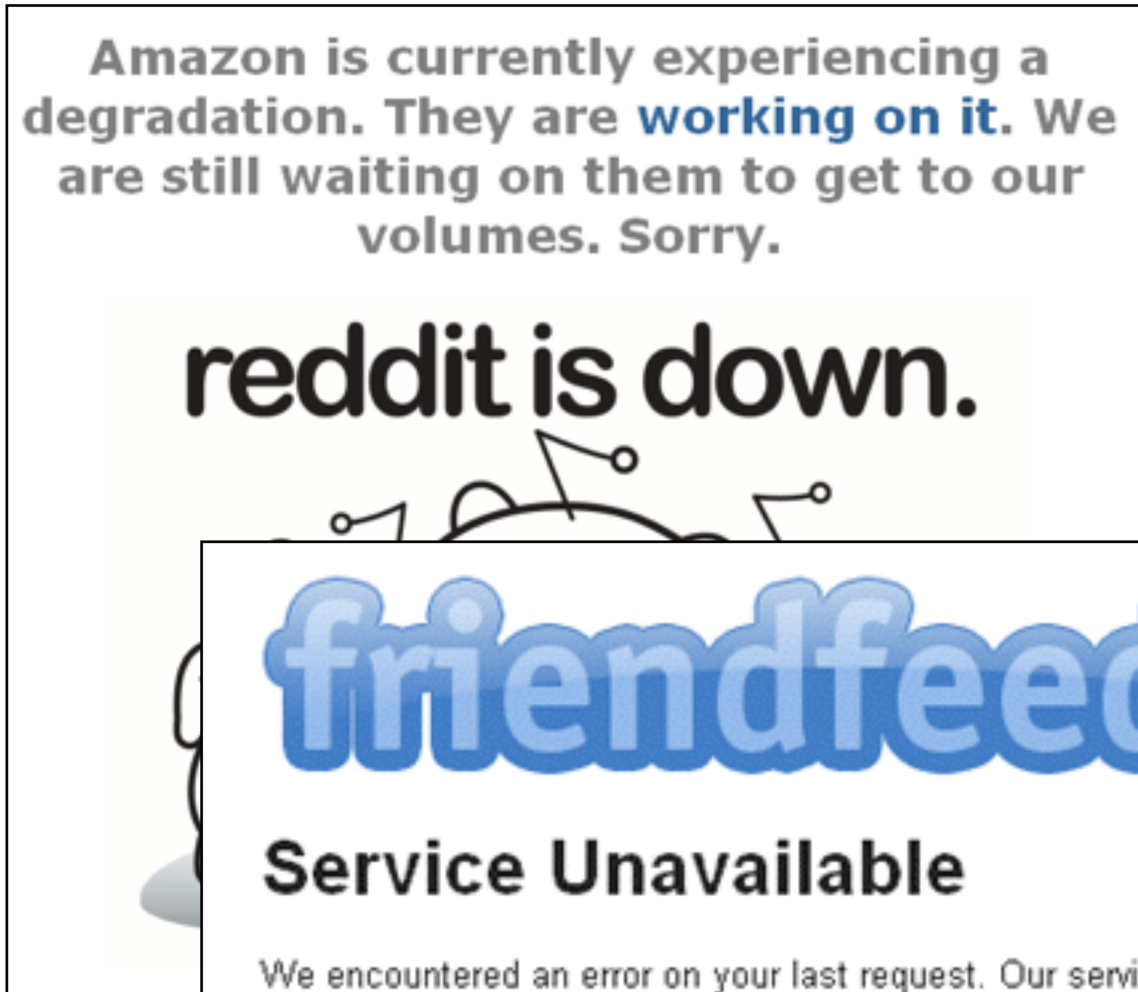
The traffic shift was executed incorrectly and the traffic was routed onto the lower capacity redundant network.

This change disconnected both the primary and secondary network simultaneously…



amazon webservices™


Amazon is currently experiencing a degradation. They are working on it. We are still waiting on them to get to our volumes. Sorry.
reddit is down.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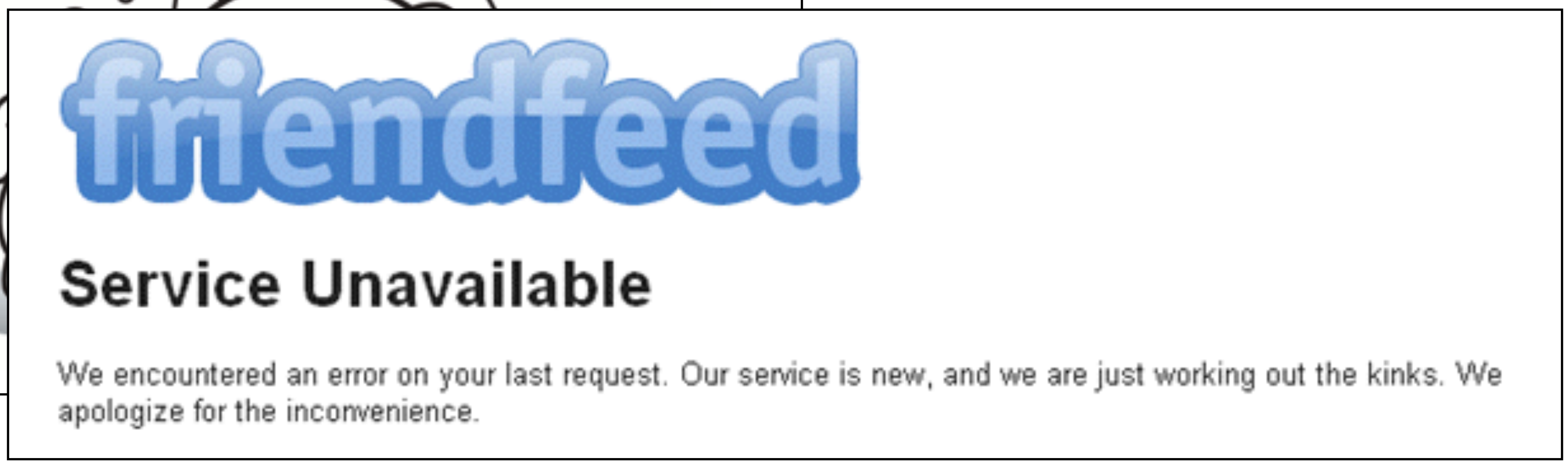
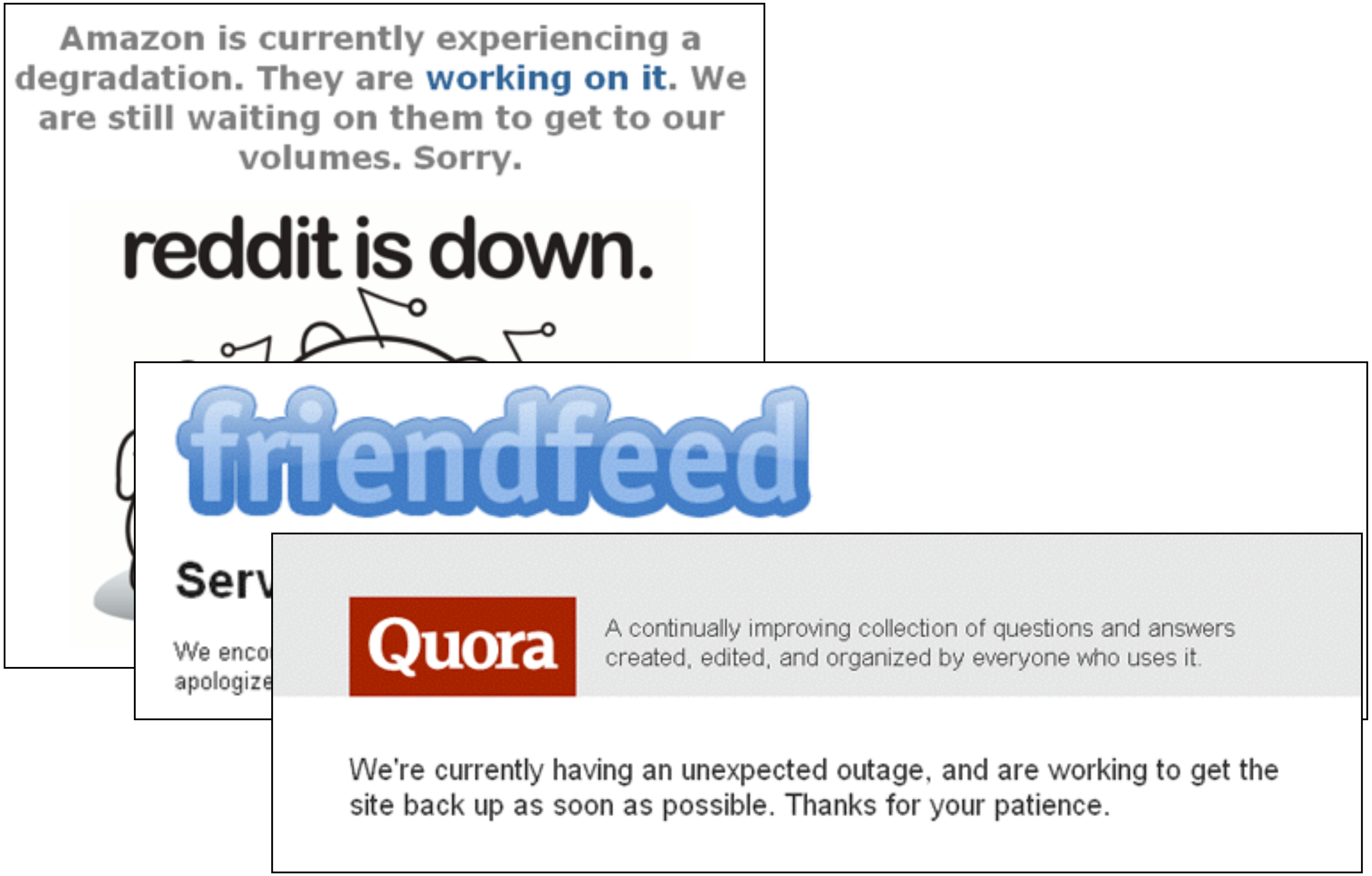
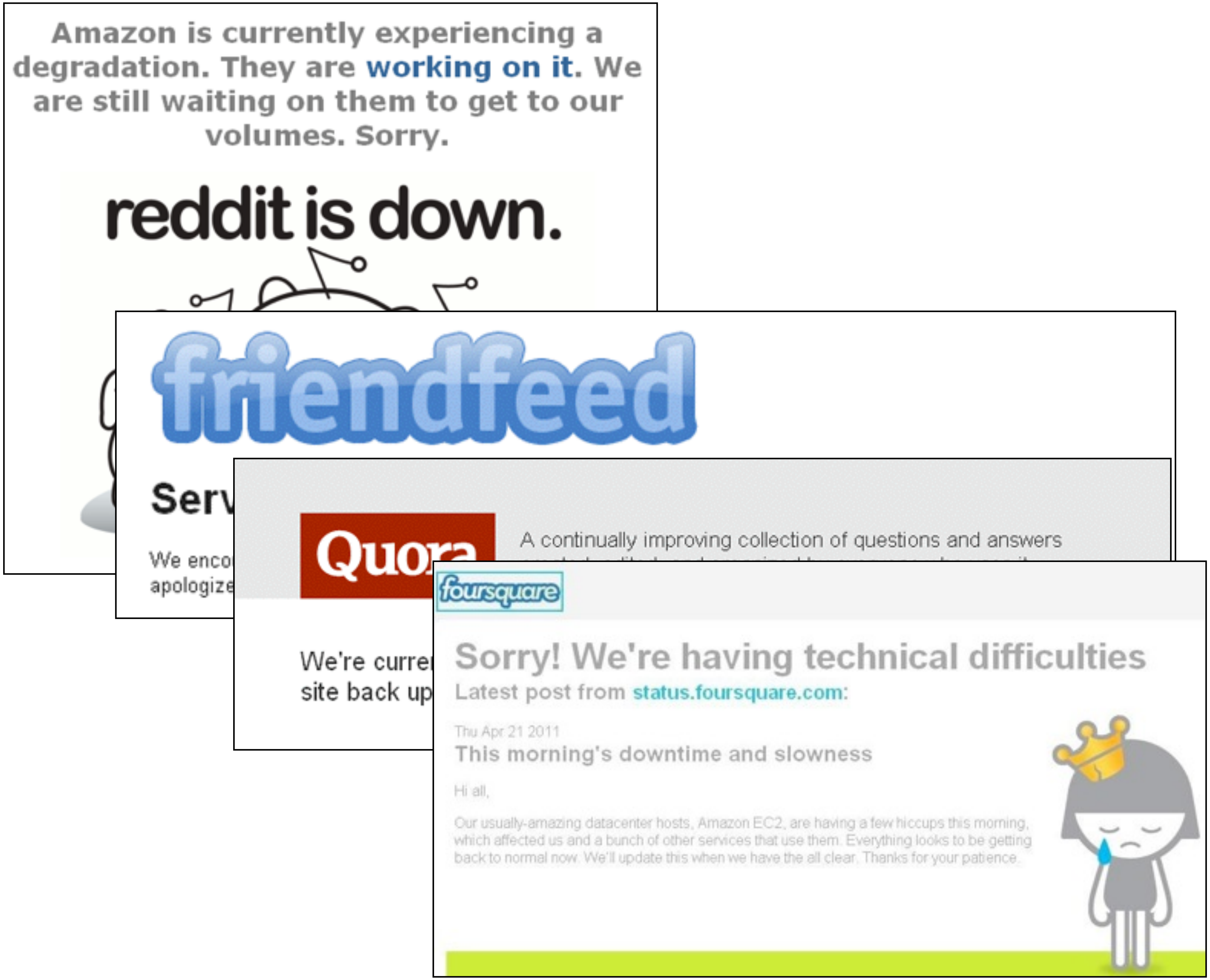

friendfeed
Service Unavailable
We encountered an error on your last request. Our service is new, and we are just working out the kinks. We apologize for the inconvenience.


Amazon is currently experiencing a degradation. They are working on it. We are still waiting on them to get to our volumes. Sorry.
reddit is down.
friendfeed
Quora
A continually improving collection of questions and answers created, edited, and organized by everyone who uses it.
We're currently having an unexpected outage, and are working to get the site back up as soon as possible. Thanks for your patience.


Amazon is currently experiencing a degradation. They are working on it. We are still waiting on them to get to our volumes. Sorry.
reddit is down.
friendfeed
Serv
We enco
apologize
Quora
A continually improving collection of questions and answers
We're curre
site back up
foursquare
Sorry! We're having technical difficulties
Latest post from status.foursquare.com:
Thu Apr 21 2011
This morning's downtime and slowness
Hi all,
Our usually-amazing datacenter hosts, Amazon EC2, are having a few hiccups this morning, which affected us and a bunch of other services that use them. Everything looks to be getting back to normal now. We'll update this when we have the all clear. Thanks for your patience.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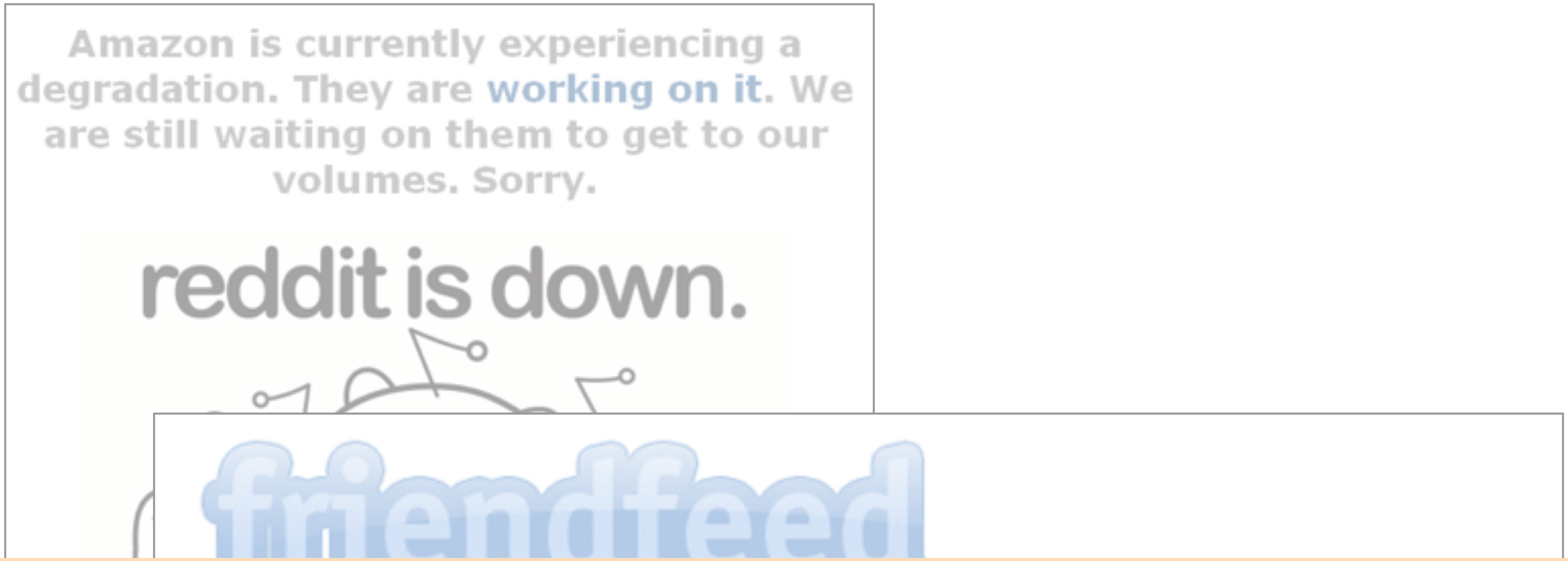
reddit is down.
friendfeed
Quora
A continually improving collection of questions and answers
foursquare
Thu Apr 21 2011
Hi all,
Owls need a break sometimes too
We'll be back in action shortly -- in the meantime go outside and flap your arms around, you may find that flying ain't very easy.
In the meantime, if you can't wait to send a Tweet, head over to Twitter web to share your 140 character musings.
フクロウはときどき休まないといけないのです。
hootsuite



The trigger for this event was a poorly executed network update

Internet

Internet

Internet

routing system

Internet

Border Gateway Protocol (BGP)

2 fundamental properties of a good routing system

scalability

tolerate growth

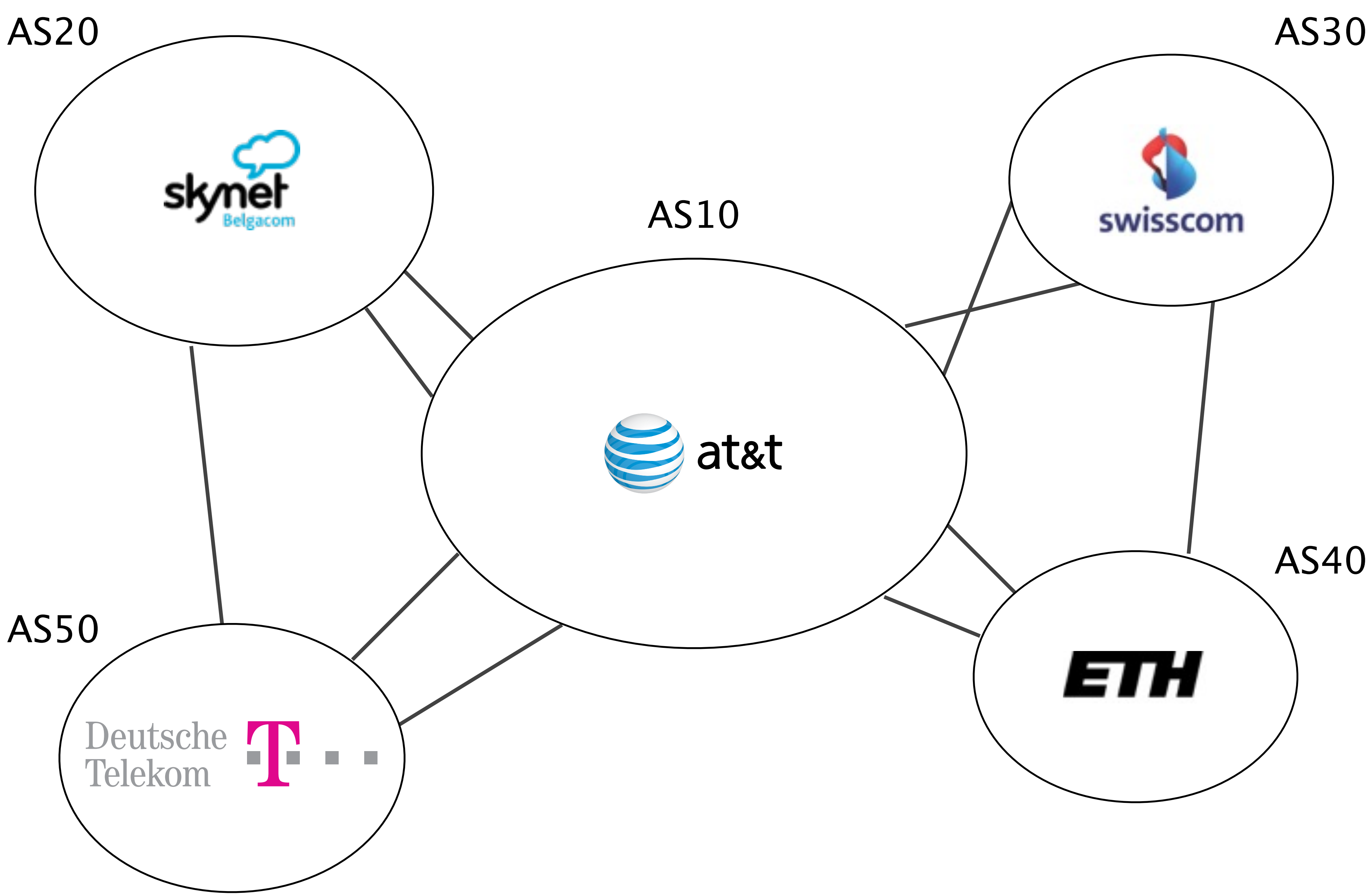
flexibility

routing policies

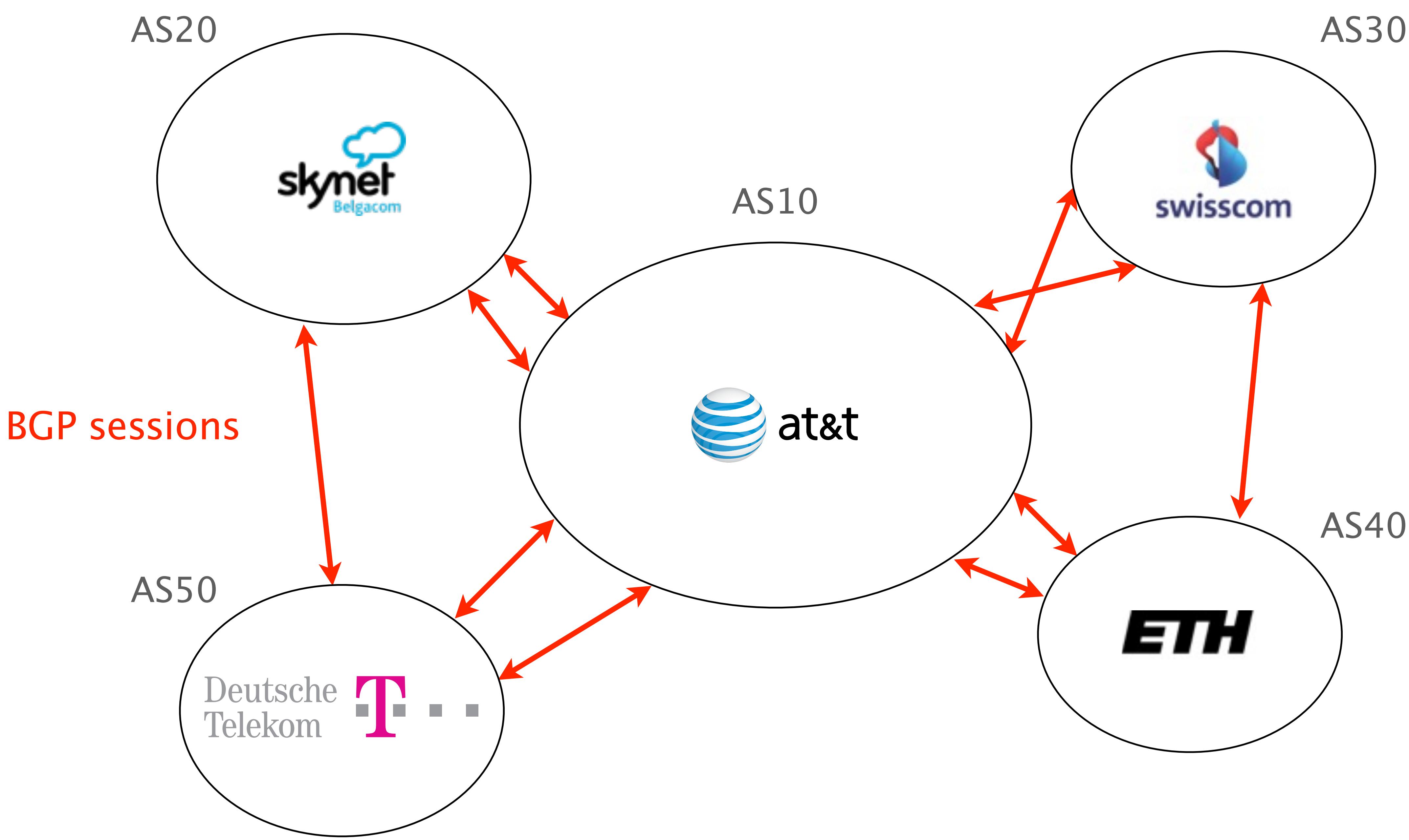
2 fundamental properties... not met by BGP

scalability	flexibility
tolerate growth	routing policies
keep track of too much state	low-level management device-by-device

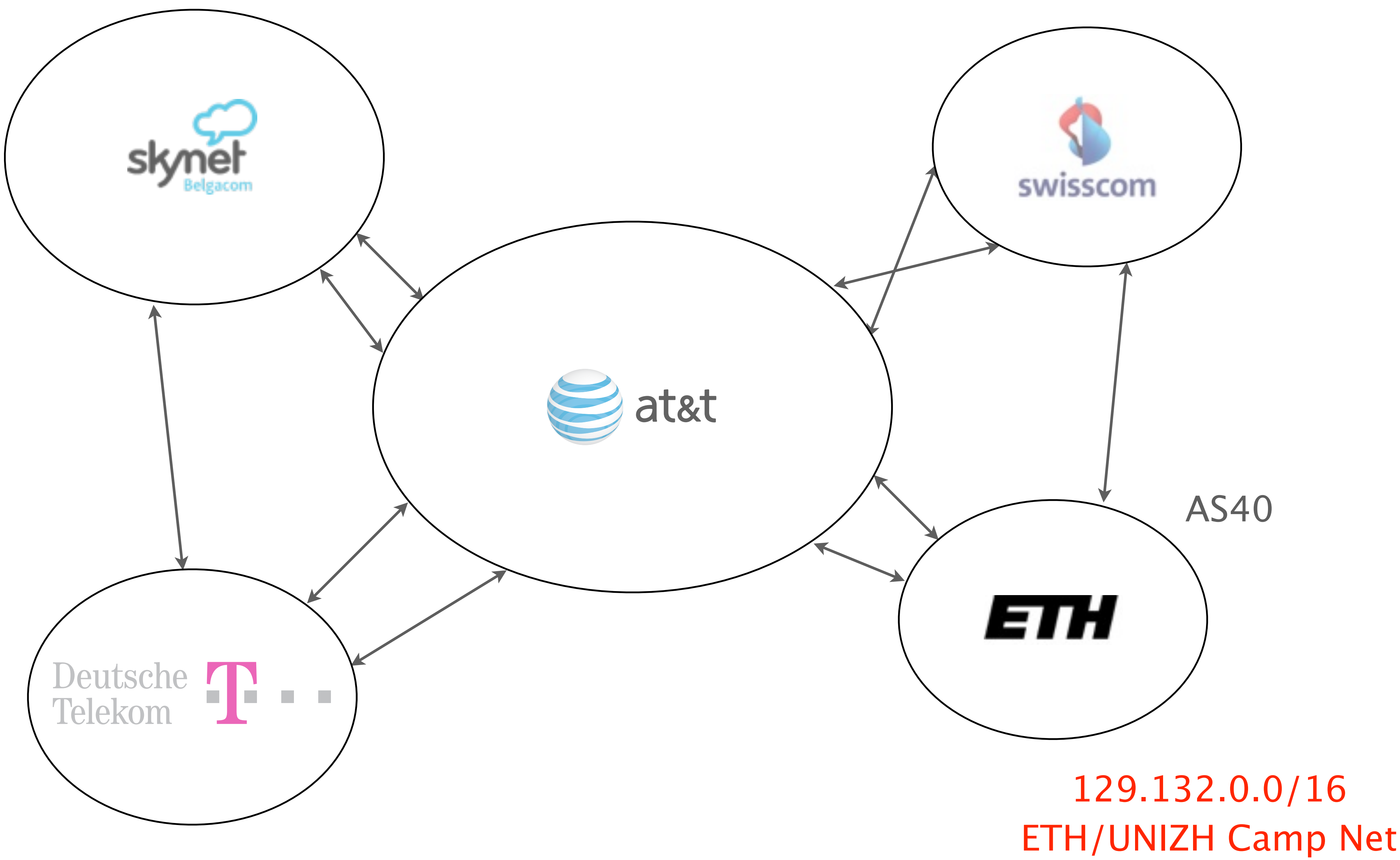
The Internet is a network of networks, referred to as Autonomous Systems (AS)



BGP is the routing protocol "glueing" the Internet together



ASes exchange information about the IP prefixes they can reach



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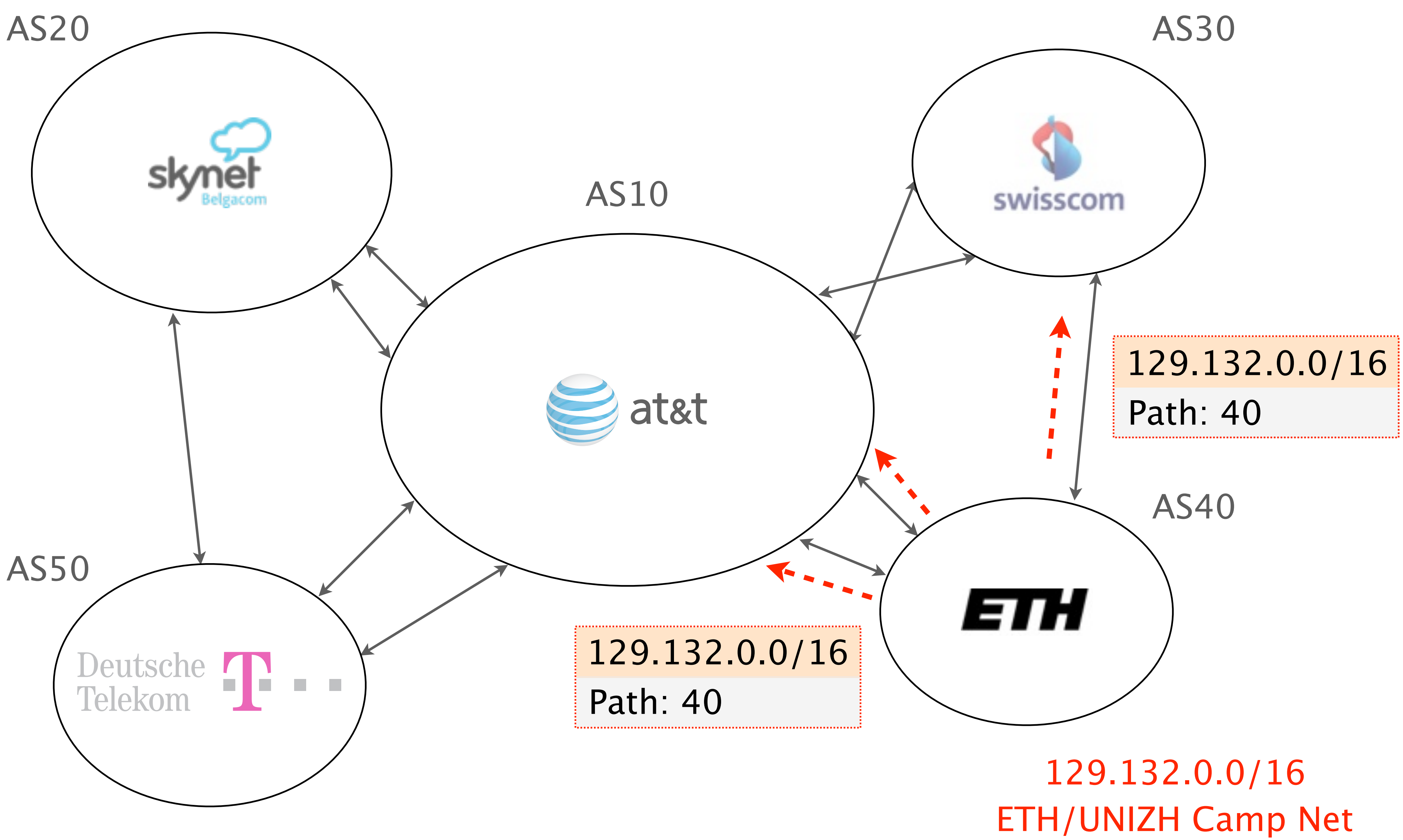
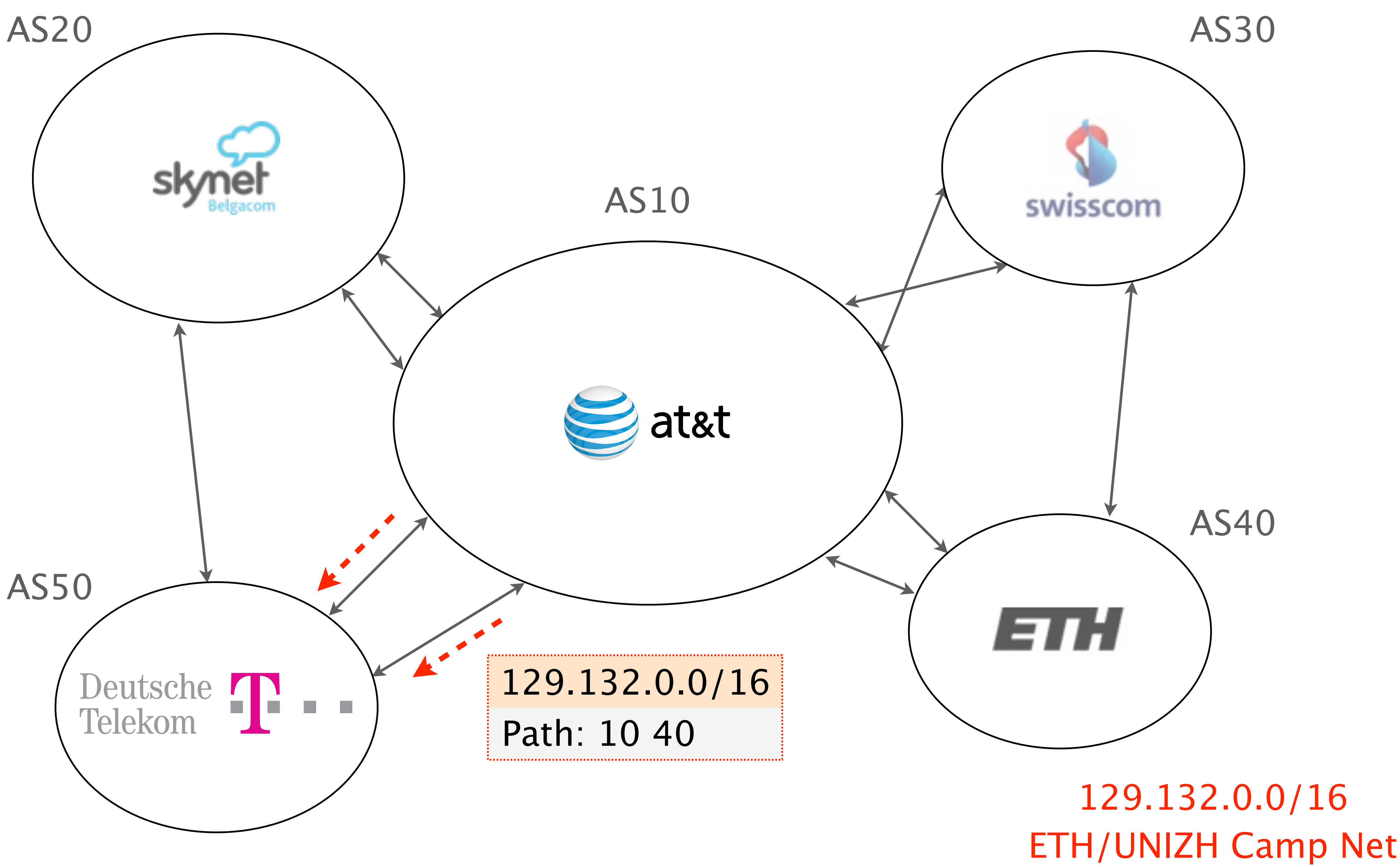


Reachability information is propagated hop-by-hop



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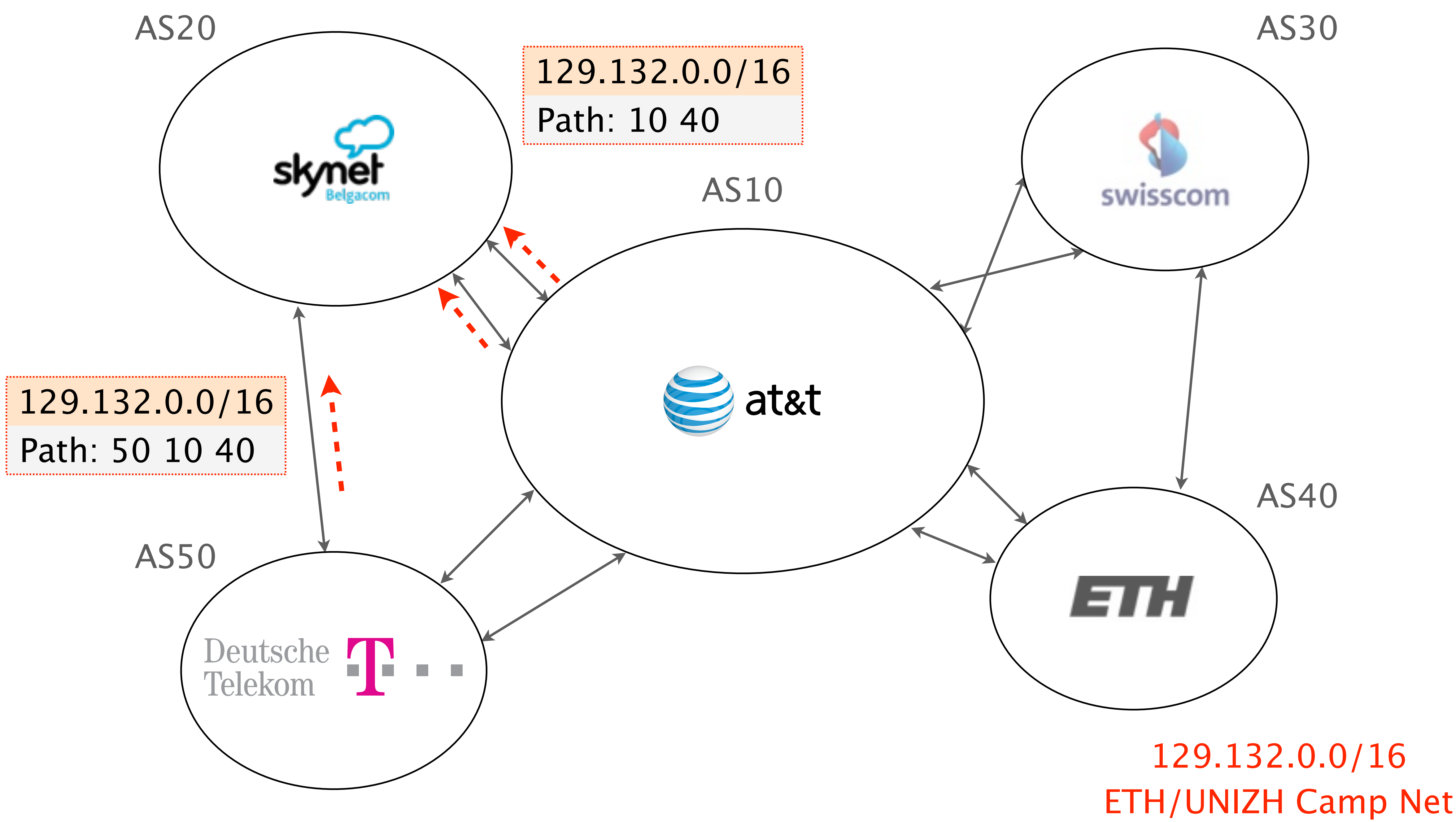


Life of a BGP router is made of three consecutive steps

while true:

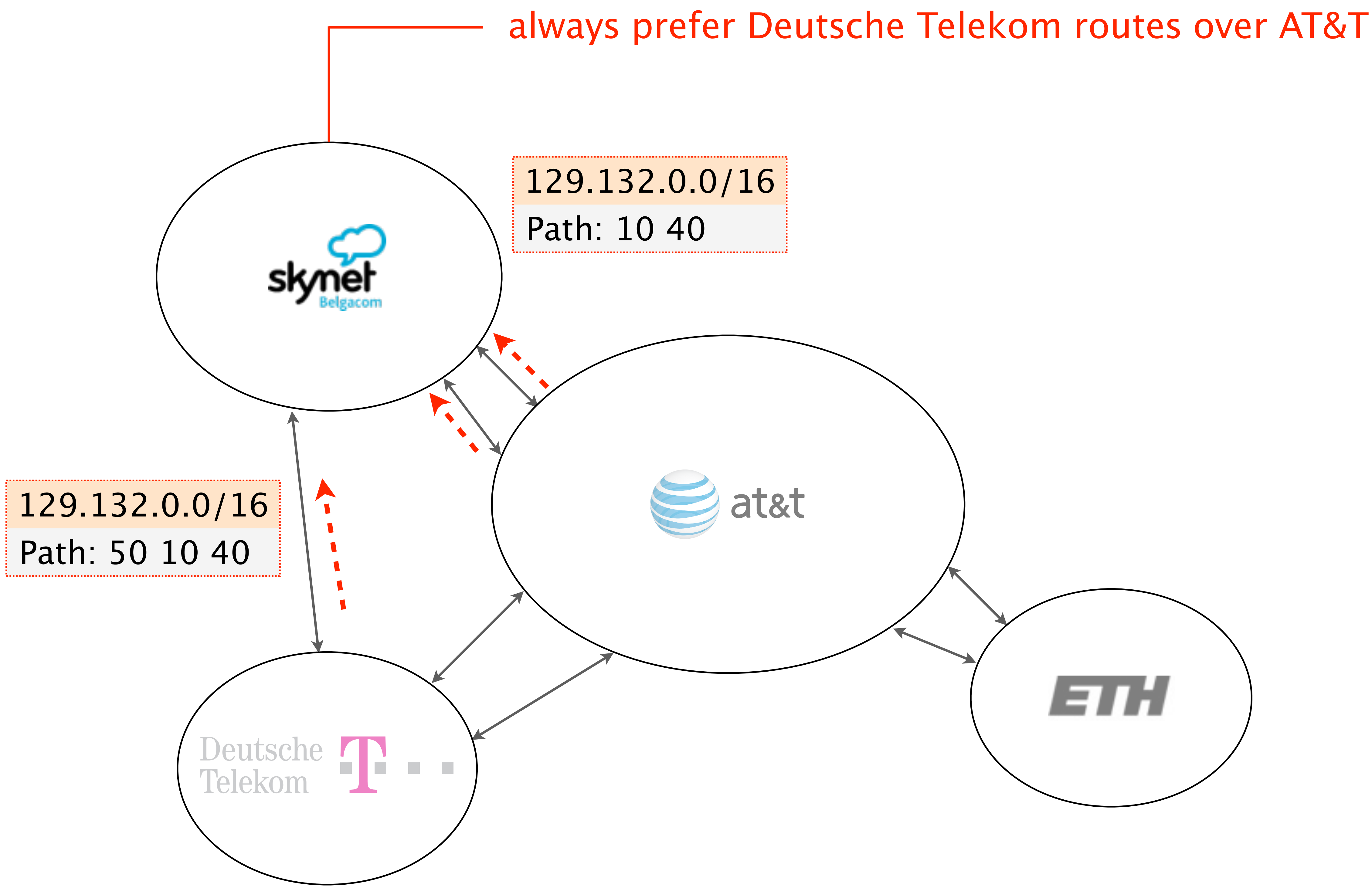
- receives routes from my neighbors
- select one best route for each prefix
- export the best route to my neighbors

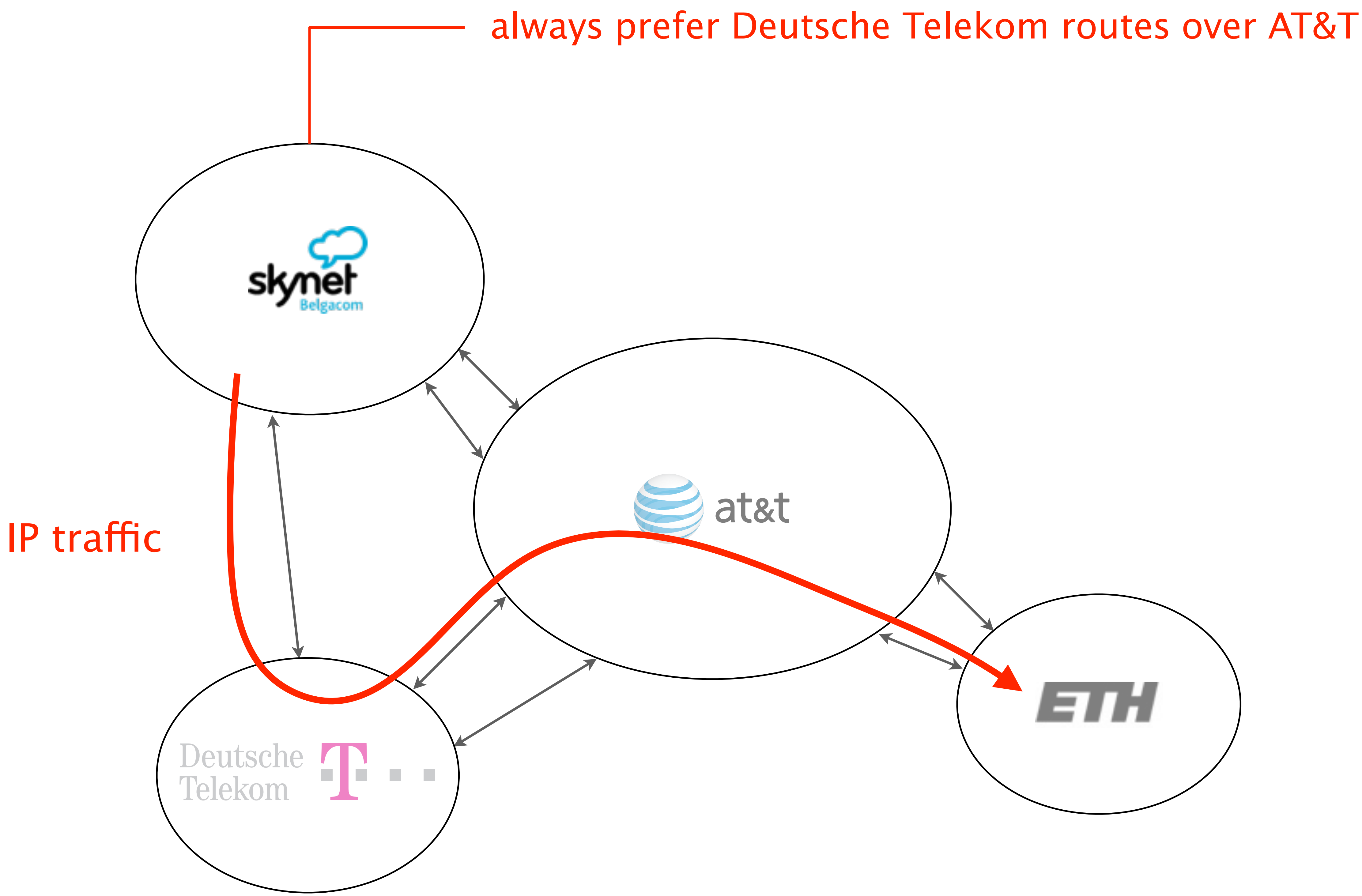
Each AS can apply local routing policies

Each AS is free to

- select and use any path

  preferably, the cheapest one


always prefer Deutsche Telekom routes over AT&T
129.132.0.0/16
Path: 10 40
129.132.0.0/16
Path: 50 10 40
skynet
Belgacom
at&t
Deutsche
Telekom
ETH


always prefer Deutsche Telekom routes over AT&T
skynet
Belgacom
at&t
IP traffic
Deutsche
Telekom
ETH

Each AS can apply local routing policies

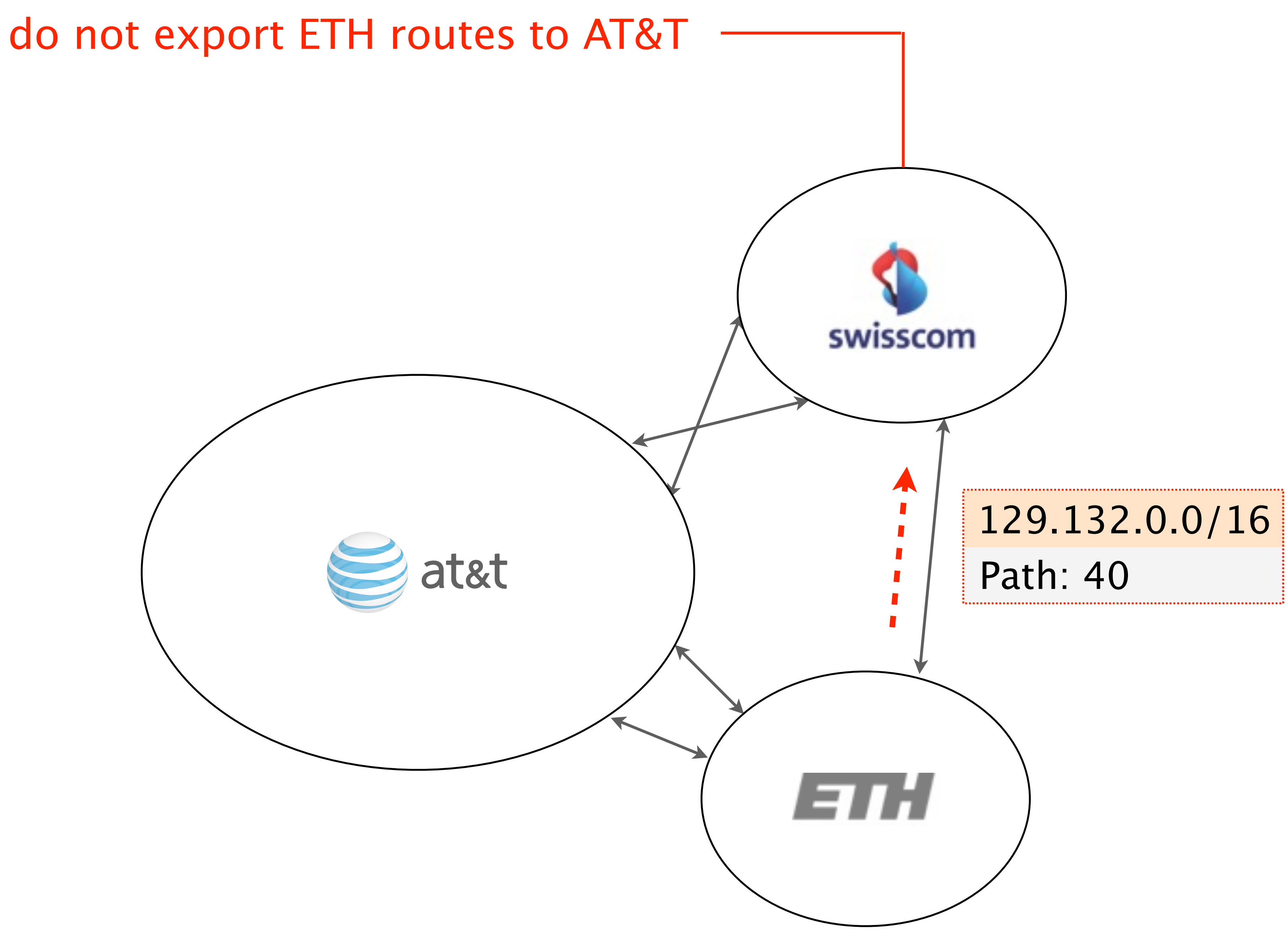
Each AS is free to

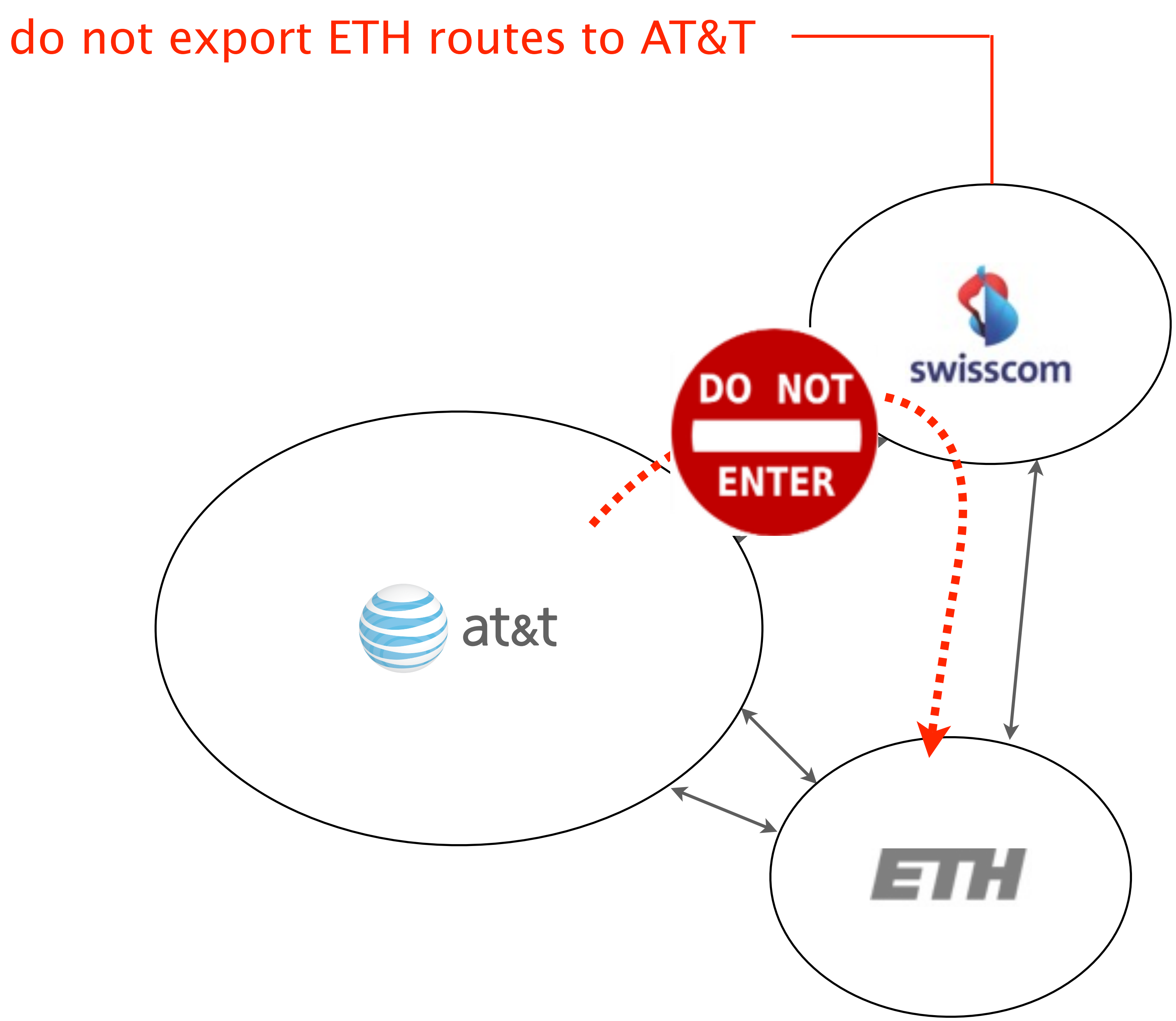
- select and use any path

  preferably, the cheapest one

- decide which path to export (if any) to which neighbor

  preferably, none to minimize carried traffic


do not export ETH routes to AT&T
swisscom
at&t
129.132.0.0/16
Path: 40
ETH



do not export ETH routes to AT&T
swisscom
DO NOT
ENTER
at&t
ETH

2 fundamental properties of a good routing system

scalability

tolerate growth

keep track of
too much state

flexibility

routing policies

Scalable routing systems maintain

- detailed information about nearby destination
- coarse-grained information about far-away destination

BGP maintains detailed information about every destination (i.e., network)

Sign Post Forest, Watson Lake, Yukon

The problem is that the number of devices connected to the Internet increases rapidly

mobile

Internet of things

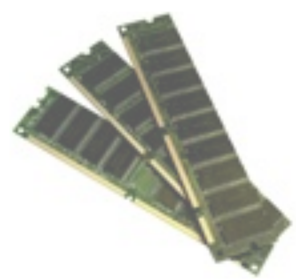
sensors

virtual machines

BGP routers must also maintain routes for IPv6 networks in addition of IPv4 networks

IPv6 ramping up could easily double the size of the Internet routing table

The growth of the number of destinations has serious consequences for the Internet

memory  routing and forwarding table size

time  convergence time after a failure

boot time for a router, session, …

security  cost of signing & verifying BGP route

DRAGON: Distributed Route AGgregatiON

Joint work with: João Luís Sobrinoh, Franck Le and Jennifer Rexford

1 **Background**
Route aggregation 101

2 **Distributed filtering**
preserving consistency

3 **Performance**
up to 80% of filtering efficiency

DRAGON: Distributed Route AGgregatiON

1 **Background**

Route aggregation 101

Distributed filtering

preserving consistency

Performance

up to 80% of filtering efficiency

How do you maintain less

routing and/or forwarding information?

You make use of the IP prefix hierarchy to remove redundant information

Routing Table

IP prefix	Output Interface
...	
129.0.0.0/8	IF#2
129.132.1.0/24	IF#2
129.132.2.0/24	IF#2
129.133.0.0/16	IF#3
...	

An IP prefix identifies a set of IP addresses

Routing Table

IP prefix	Output Interface
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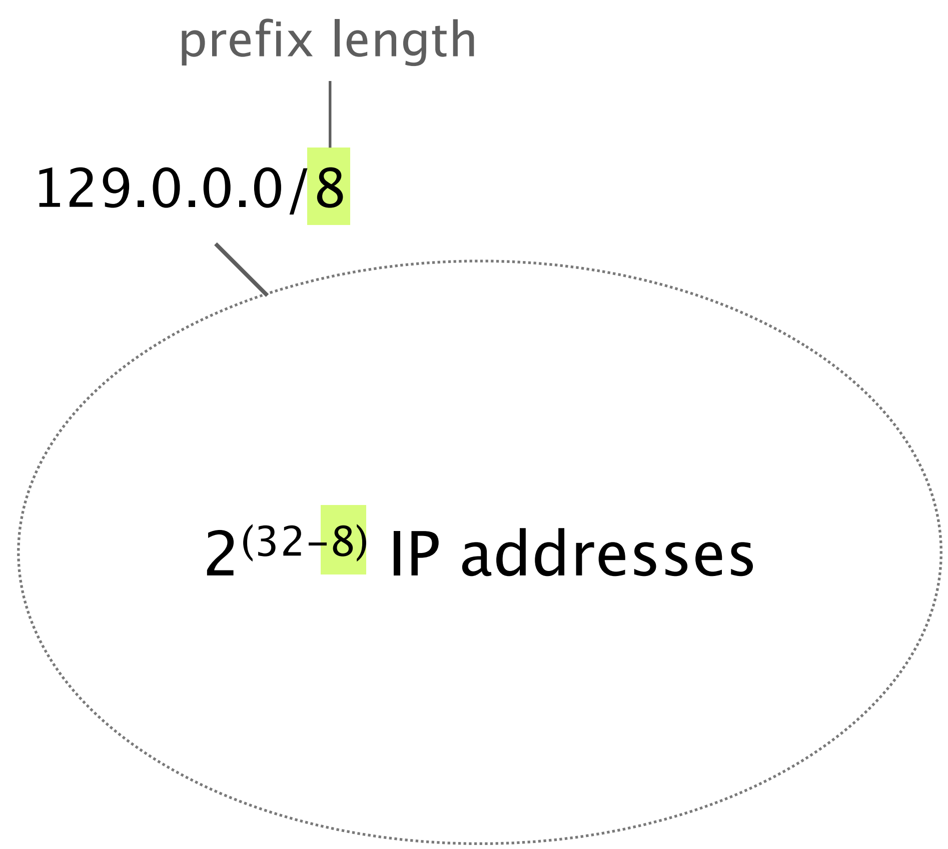
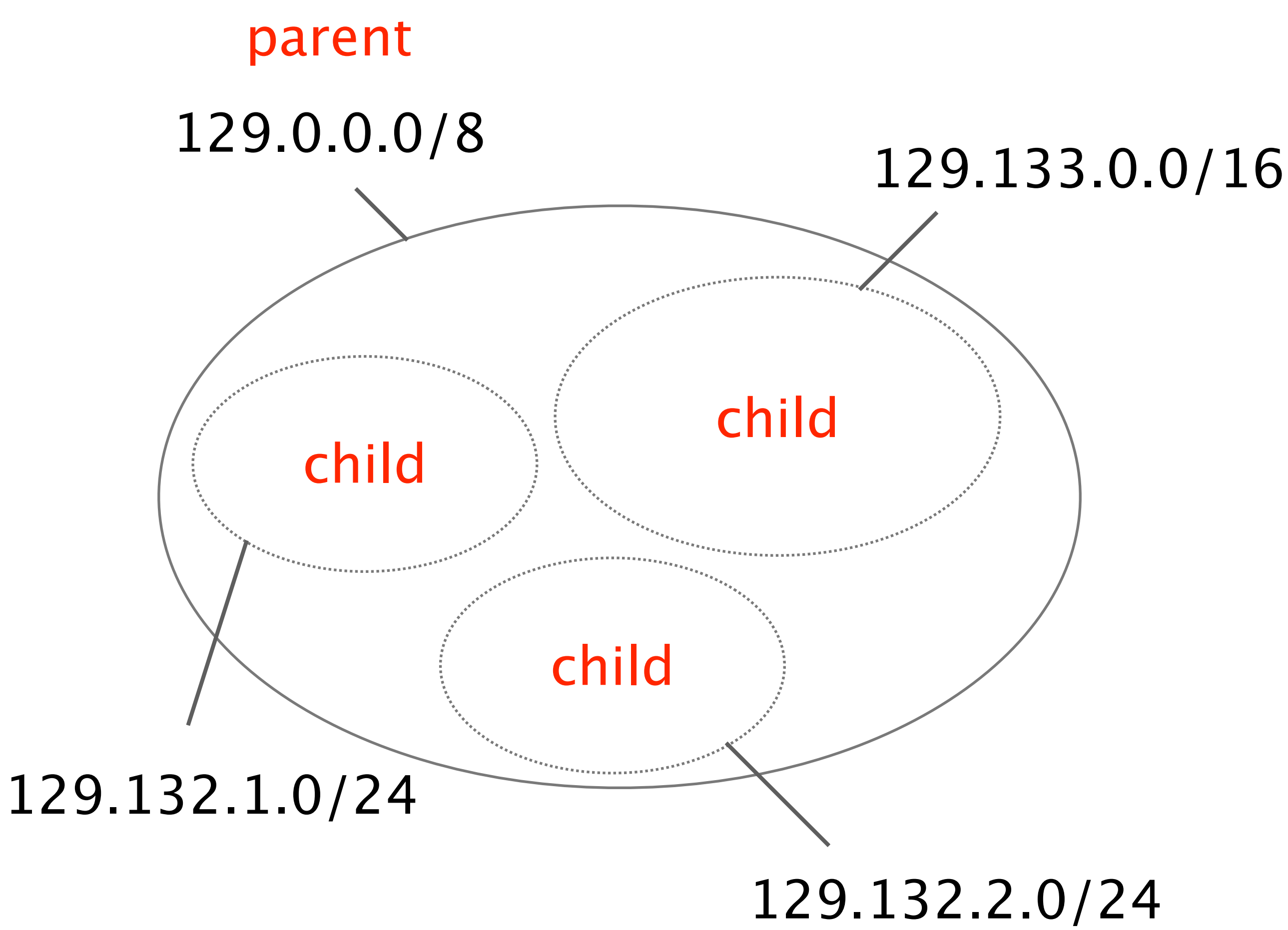
…	



An IP prefix identifies a set of IP addresses
which can be included into another one

Routing Table

IP prefix	Output Interface
...	
129.0.0.0/8	IF#2
129.132.1.0/24	IF#2
129.132.2.0/24	IF#2
129.133.0.0/16	IF#3
...	



Forwarding is done along the most specific prefix, i.e., the smallest set containing the IP address

Routing Table

IP prefix	Output Interface
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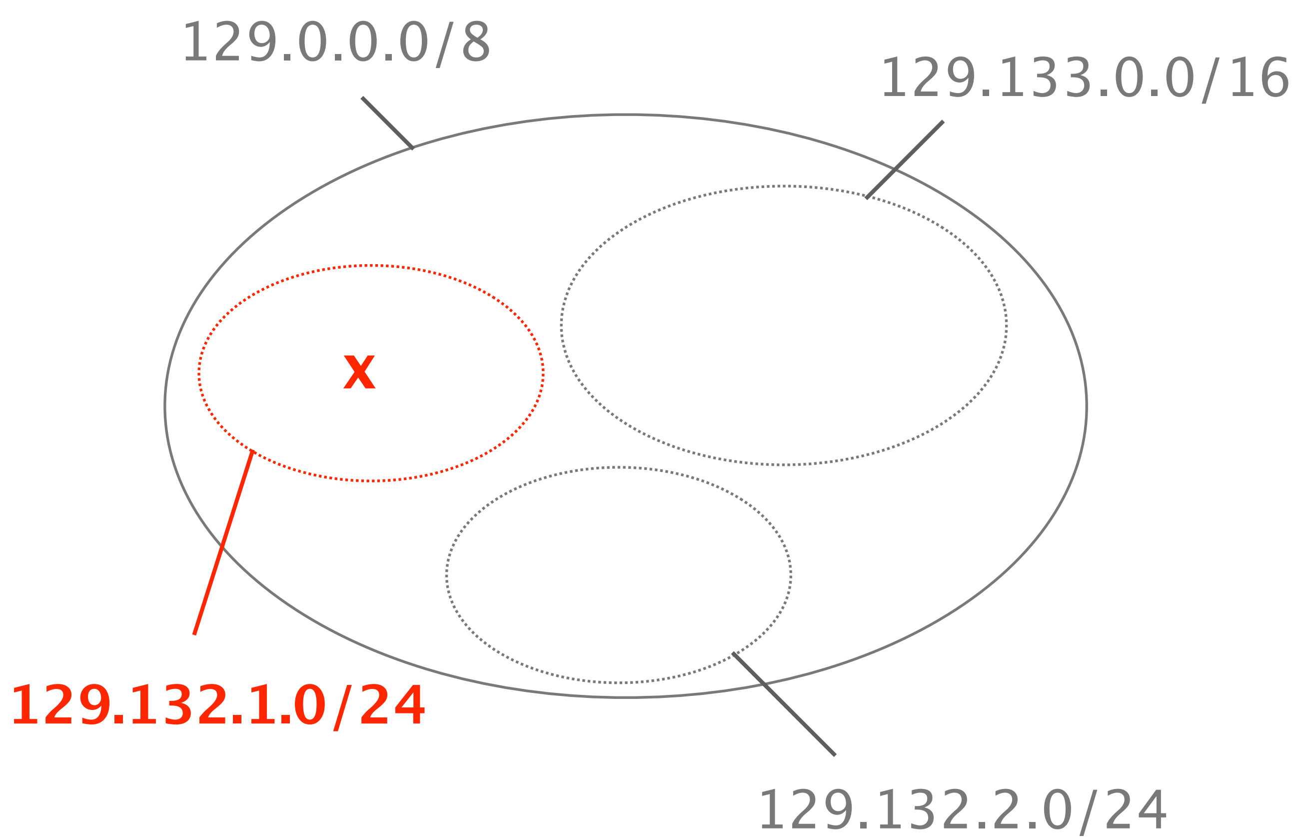
129.0.0.0/8	IF#2
129.132.1.0/24	**IF#2**
129.132.2.0/24	IF#2
129.133.0.0/16	IF#3
...	

Input packet: 129.132.1.1



A child prefix can be filtered whenever it shares the same output interface as its parent

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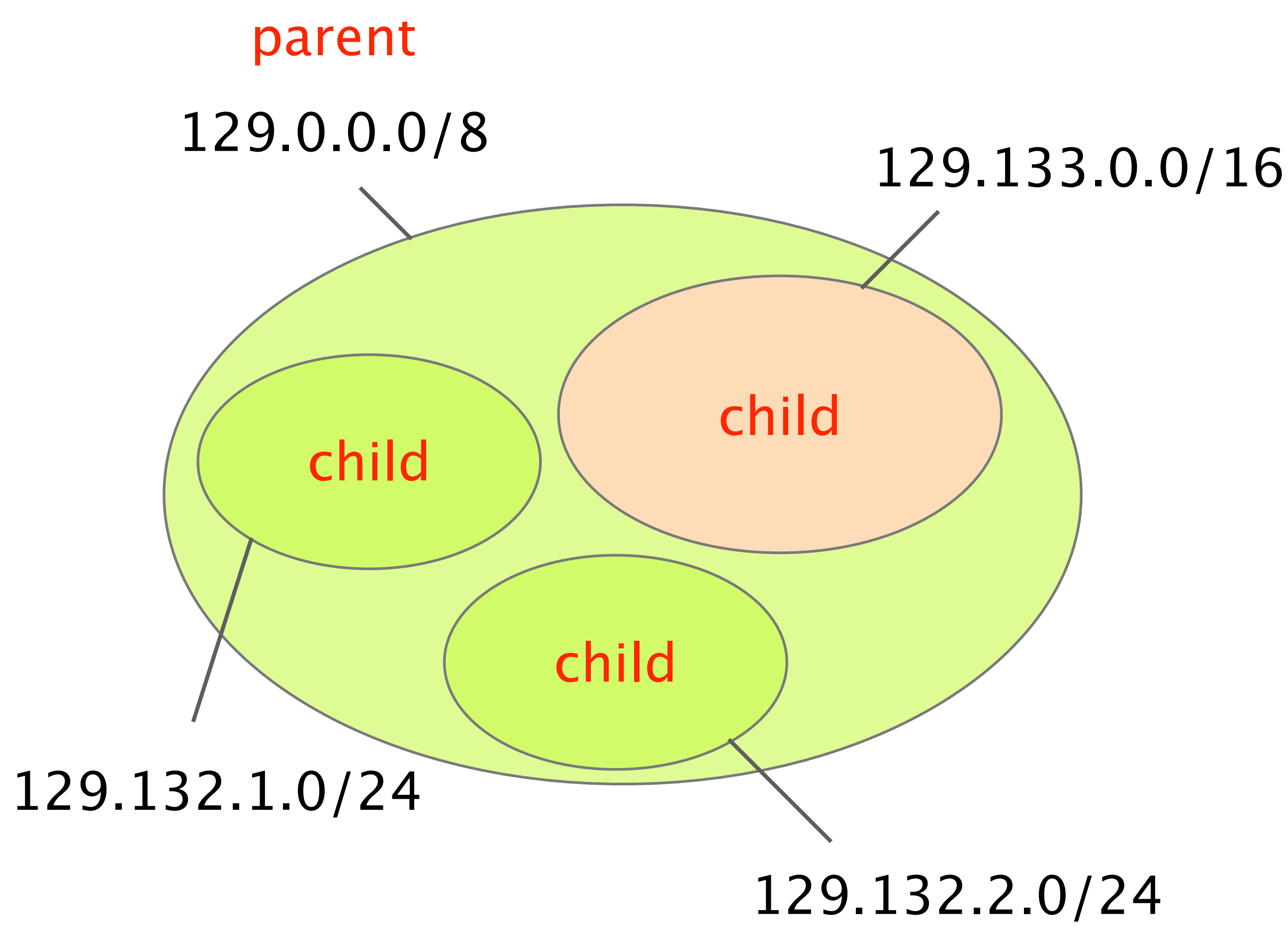

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Routing Table

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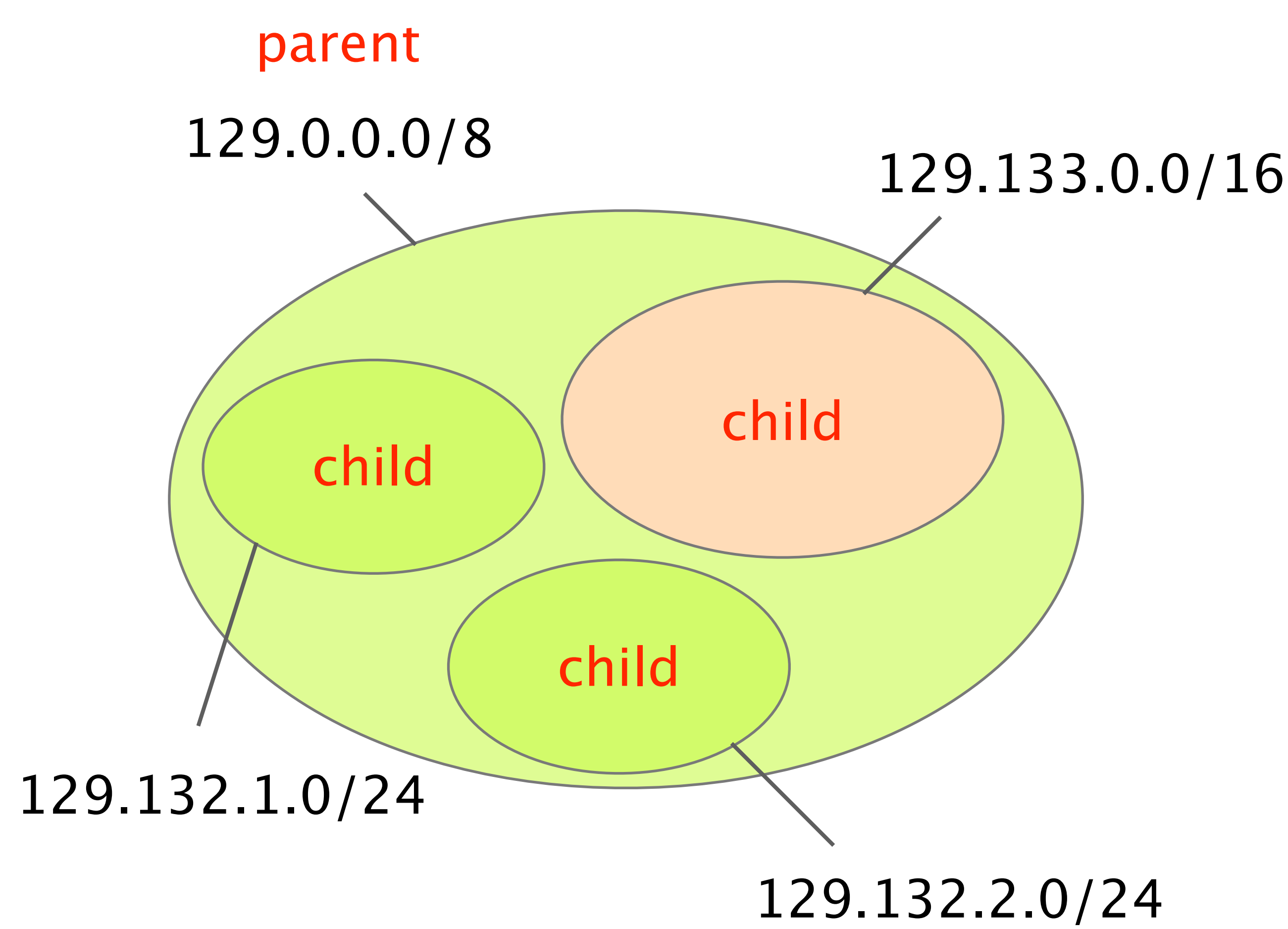
~~129.132.1.0/24~~	~~IF#2~~
~~129.132.2.0/24~~	~~IF#2~~
129.133.0.0/16	IF#3
...	



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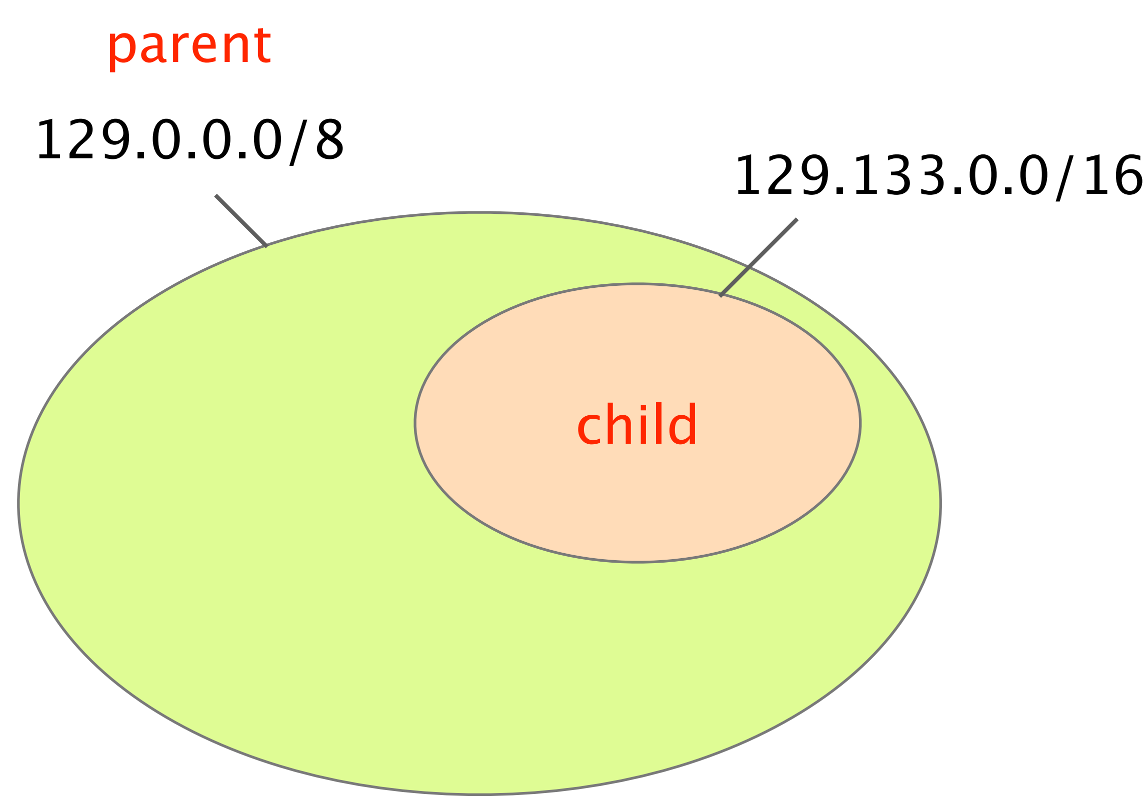

Exactly the same forwarding as before

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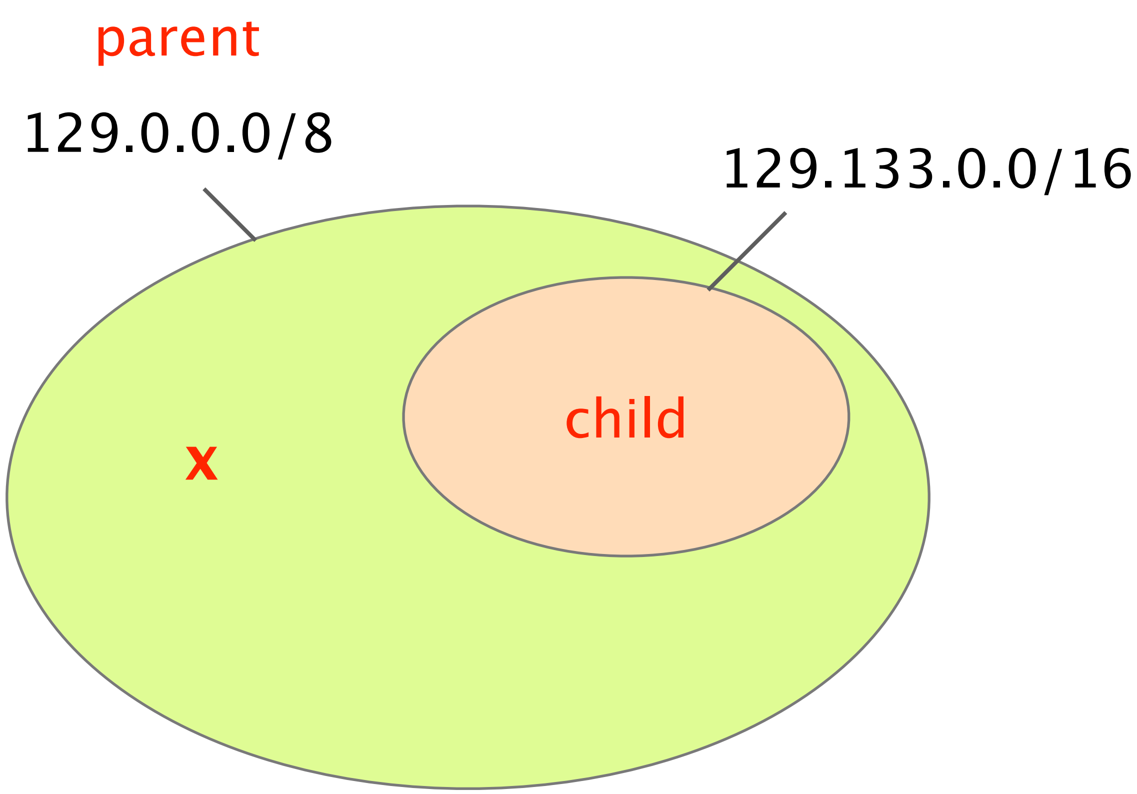

Exactly the same forwarding as before

Numerous previous works have studied this problem

2013	(Rétvári, SIGCOMM); (Rottenstreich, INFOCOM)
2012	(Karpilovsky, IEEE TNSM)
2011	(Li, INFOCOM); (Uzmi, CoNEXT)
2010	(Zhao, INFOCOM); (Liu, GLOBECOM)
2009	(Ballani, NDSI)
…	…
1999	(Draves, INFOCOM)

The problem is that they only provide local gain

local gain

router or network

(Rétvári, SIGCOMM); (Rottenstreich, INFOCOM)

(Karpilovsky, IEEE TNSM)

(Li, INFOCOM); (Uzmi, CoNEXT)

(Zhao, INFOCOM); (Liu, GLOBECOM)

(Ballani, NDSI)

…

(Draves, INFOCOM)

Others proposed clean-slate approach to improve scalability, but none of them is incrementally deployable

	(Rétvári, SIGCOMM); (Rottenstreich, INFOCOM)
	(Karpilovsky, IEEE TNSM)
local gain router or network	(Li, INFOCOM); (Uzmi, CoNEXT)
	(Zhao, INFOCOM); (Liu, GLOBECOM)
	(Ballani, NDSI)
	…
	(Draves, INFOCOM)
clean-slate hard to deploy	(Godfrey, SIGCOMM), (Andersen, SIGCOMM)
	(Subramanian, SIGCOMM)

DRAGON provides both Internet-wide gain and incremental deployability

existing	DRAGON
local gain router or network	global gain Internet-wide
clean-slate hard to deploy	works with BGP incrementally deployable

DRAGON: Distributed Route AGgregatiON

Background

Route aggregation 101

2 Distributed filtering

preserving consistency

Performance

up to 80% of filtering efficiency

DRAGON is distributed route-aggregation technique where routers “think globally, but act locally”

Main result

By comparing routes for different prefixes,
a router can locally compute which routes it
can filter and not export while preserving
routing & forwarding decisions globally

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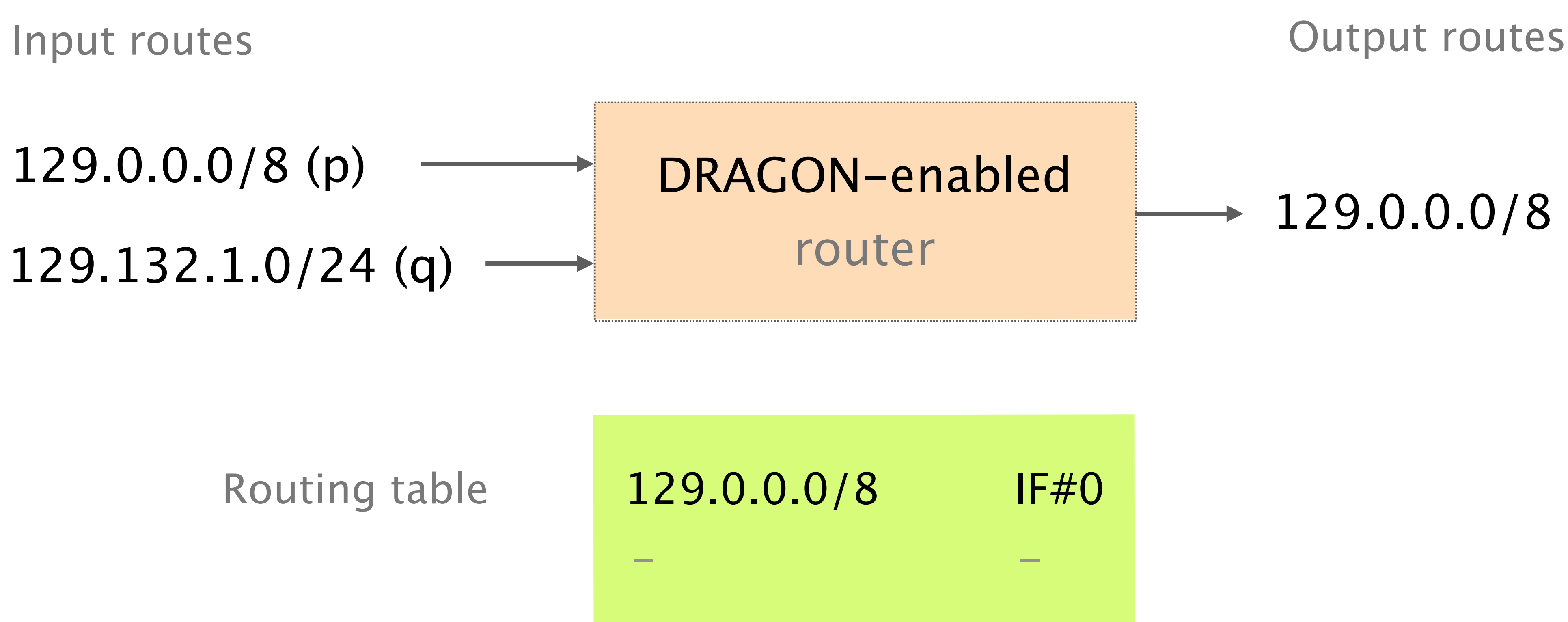
Main result

By comparing routes for different prefixes, a router can locally compute which routes it can filter and not export while preserving routing & forwarding decisions globally

When a router filters q, it does not create any forwarding entry for q and does not export q to any neighbor



DRAGON is distributed route-aggregation technique where routers "think globally, but act locally"

Main result

By comparing routes for different prefixes, a router can locally compute which routes it can filter and not export while preserving routing & forwarding decisions globally

DRAGON filters routing information,
preserving the flow of data traffic

Somewhere in Belgium…

DRAGON guarantees network-wide routing and/or forwarding consistency post-filtering

	Routing consistency	Forwarding consistency
preserved property at every node for each data packet	route attribute	forwarding neighbors

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	Routing consistency	Forwarding consistency
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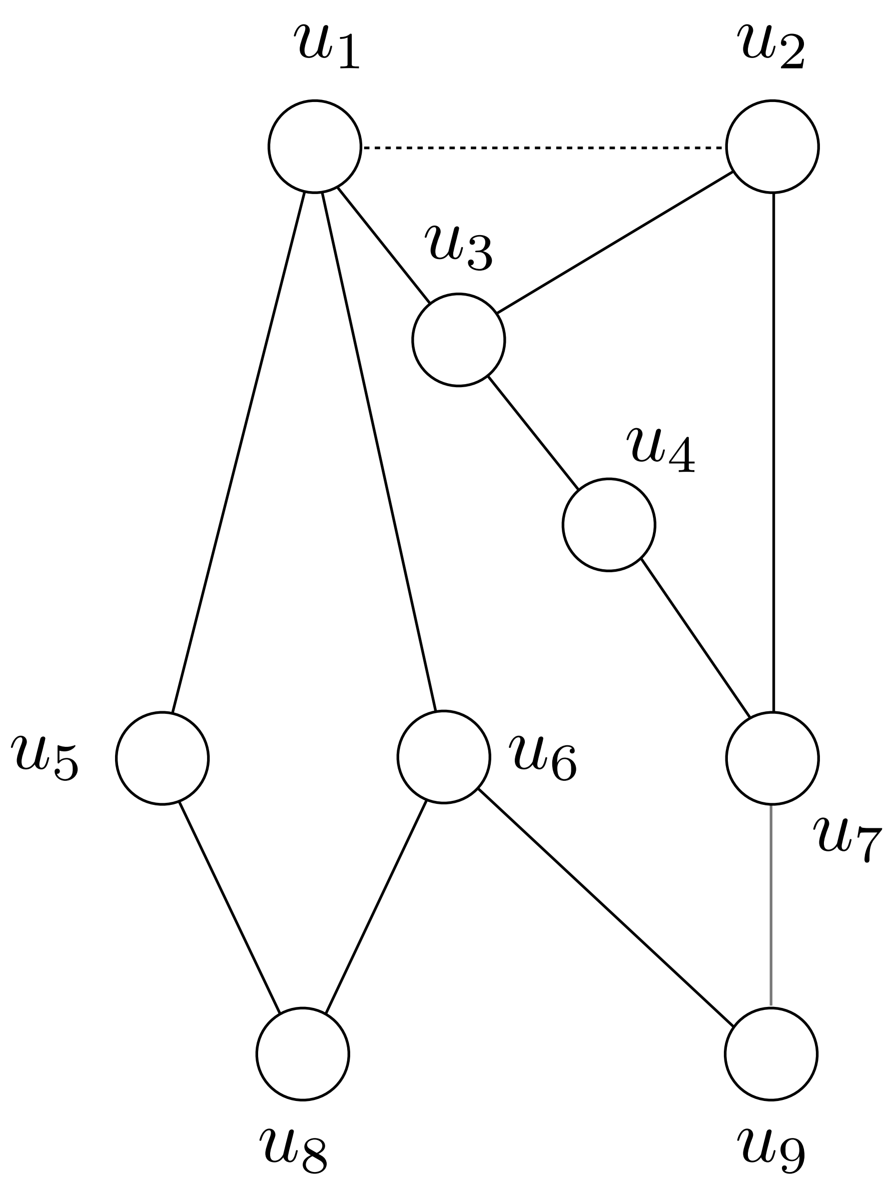
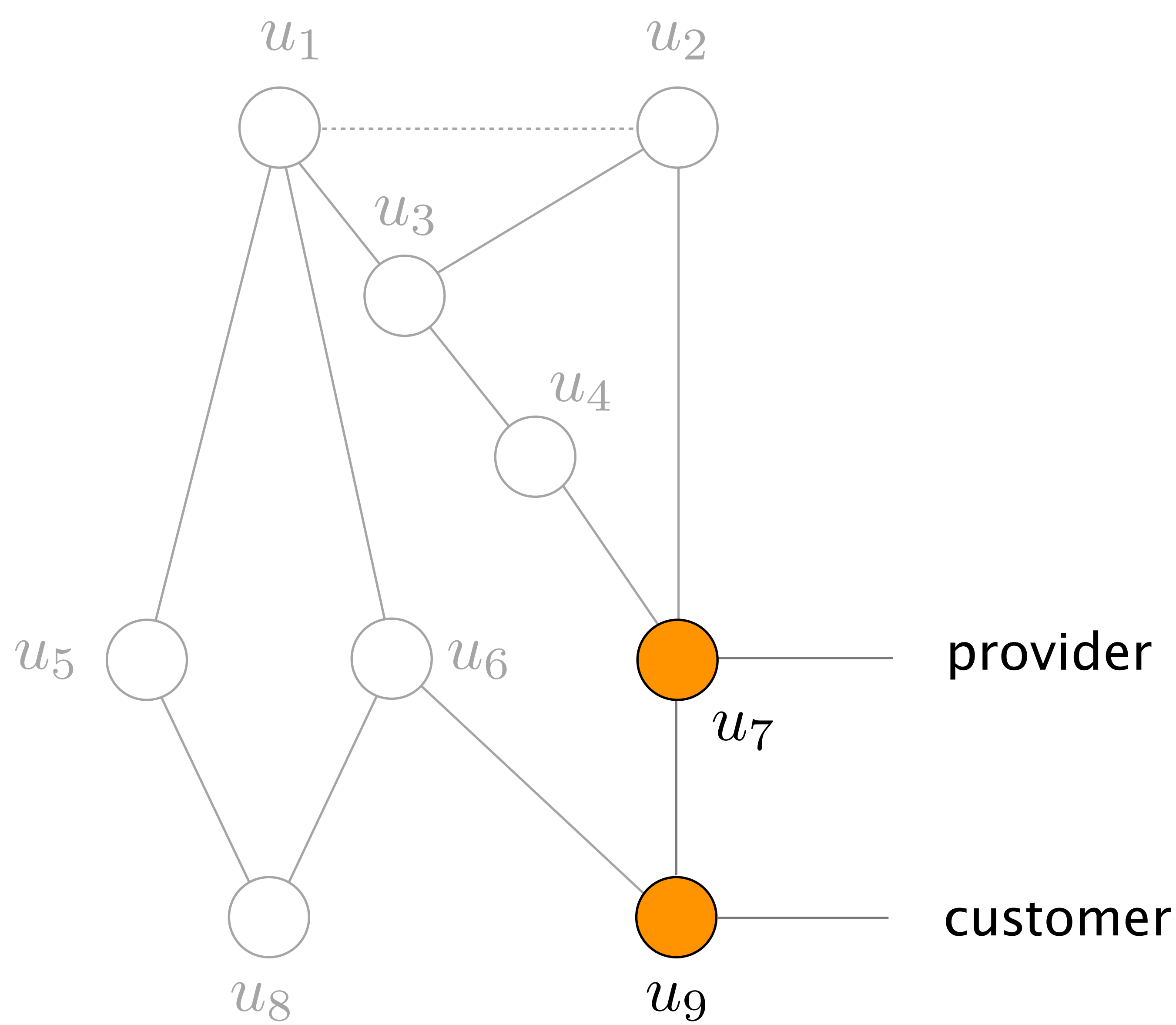
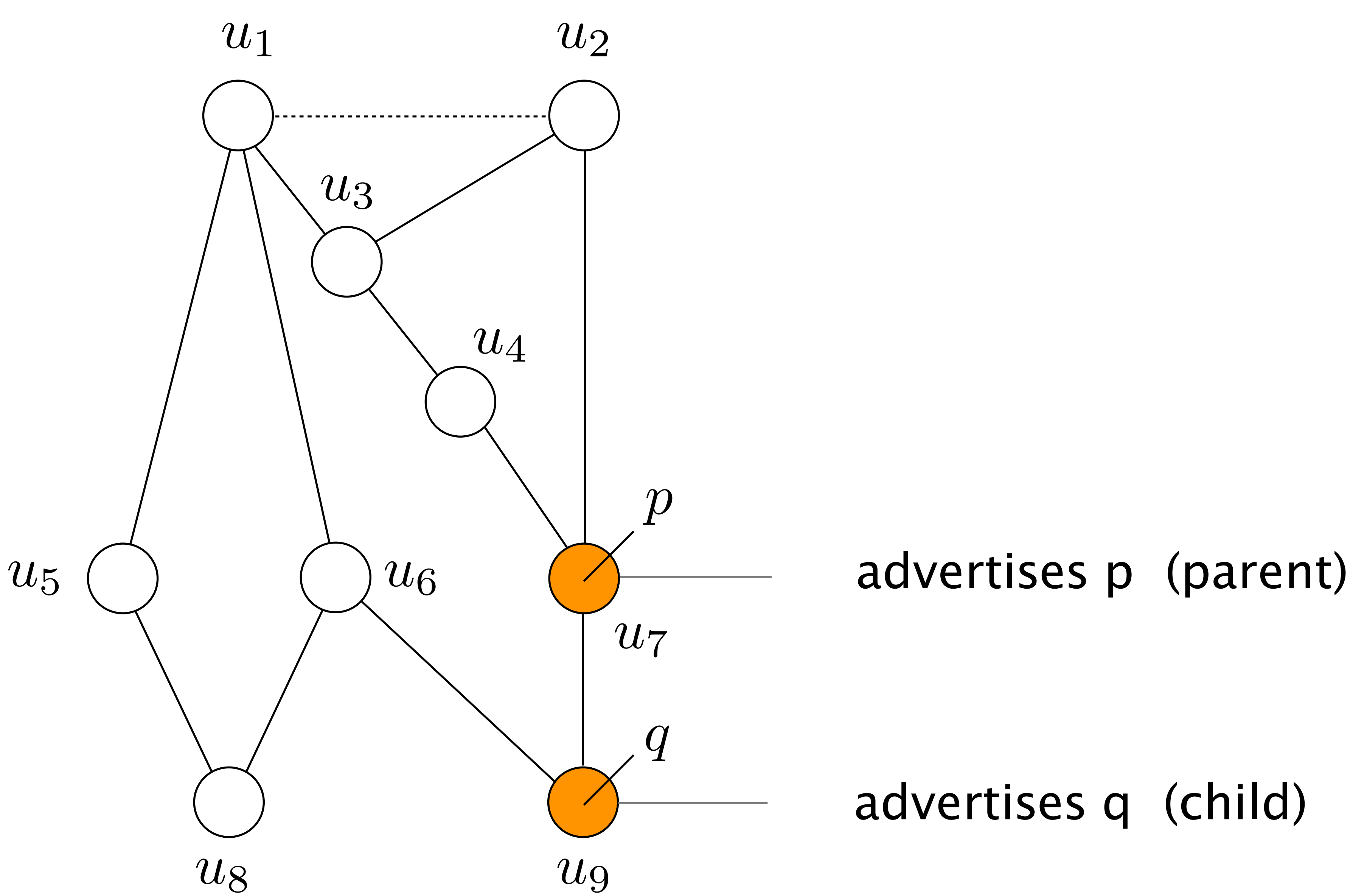
	This talk	

Let's consider a mini-Internet using simplified routing policies

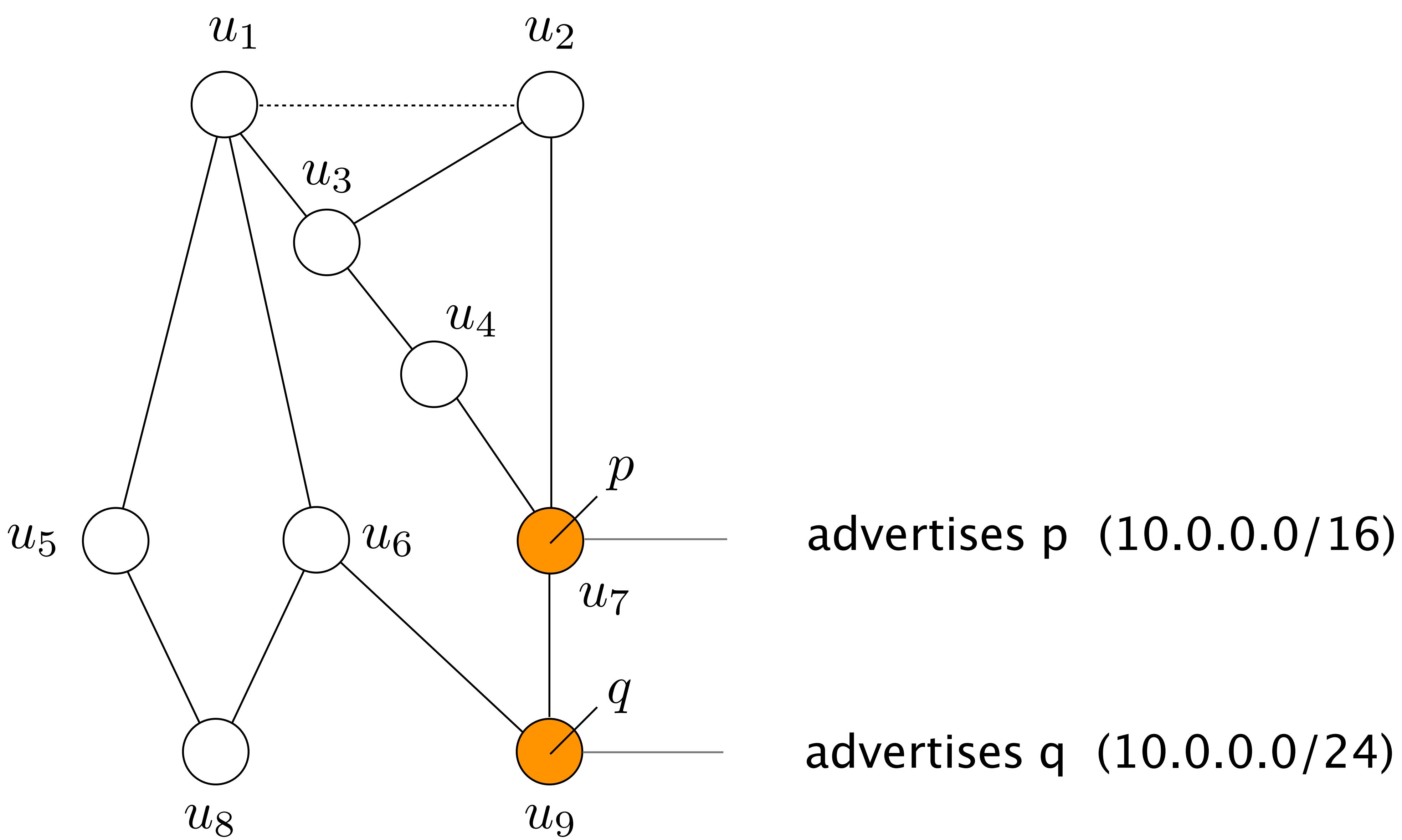


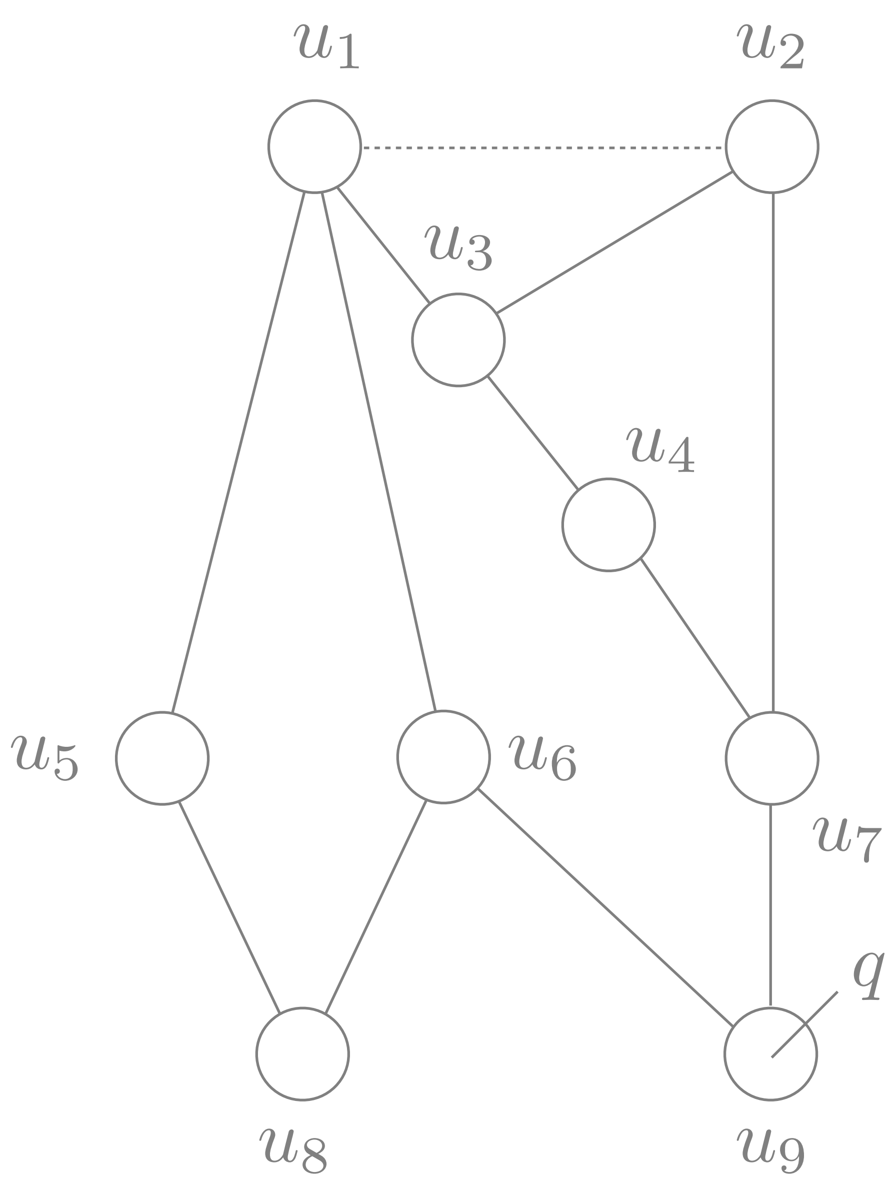
Solid lines join a provider and a customer, with the provider drawn above the customer





u_1
u_2
u_3
u_4
u_5
u_6
u_7
u_8
u_9
p
q
advertises p (parent)
advertises q (child)


u_1
u_2
u_3
u_4
u_5
u_6
u_7
u_8
u_9
p
q
advertises p (10.0.0.0/16)
advertises q (10.0.0.0/24)



2 route attributes

learned from customer

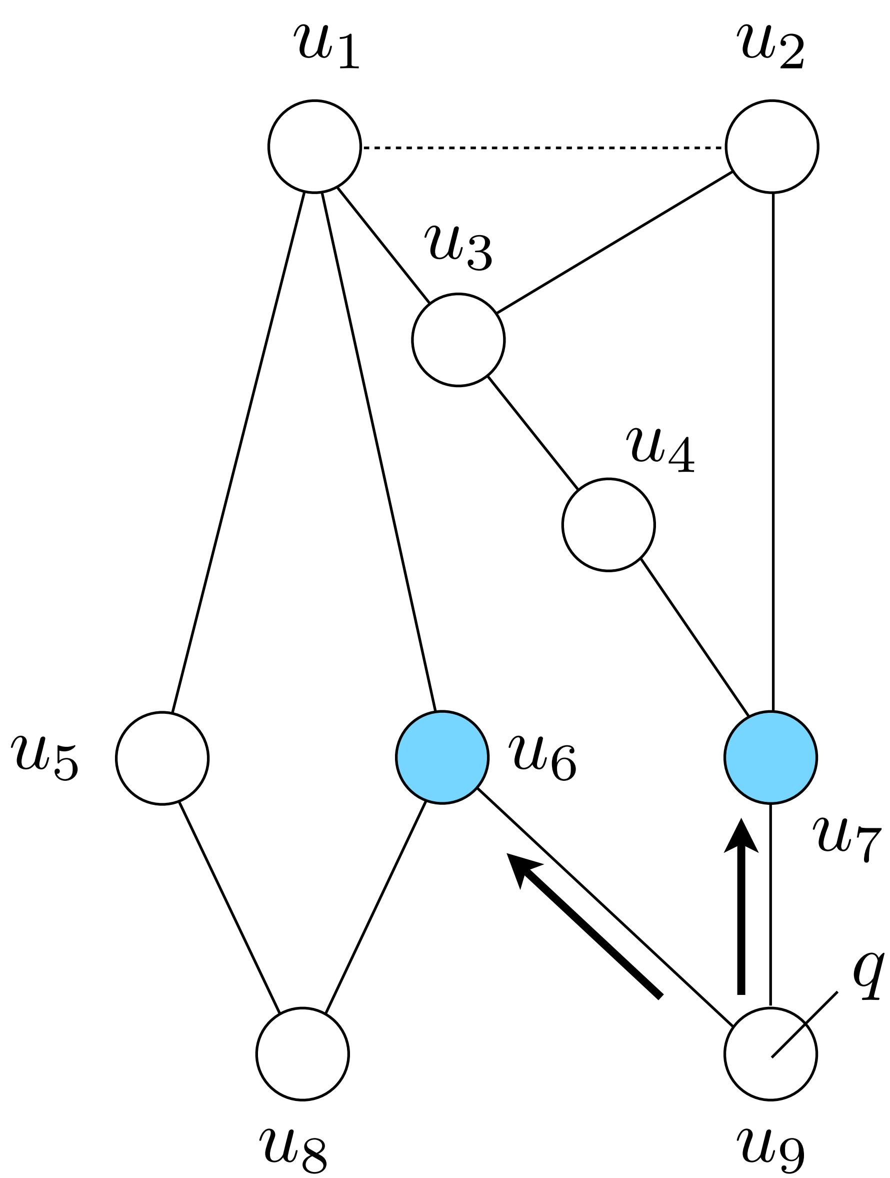
learned from provider

preference

2 exportation rules

- customer routes to every neighbor
- provider routes to customers

Current routing state for q



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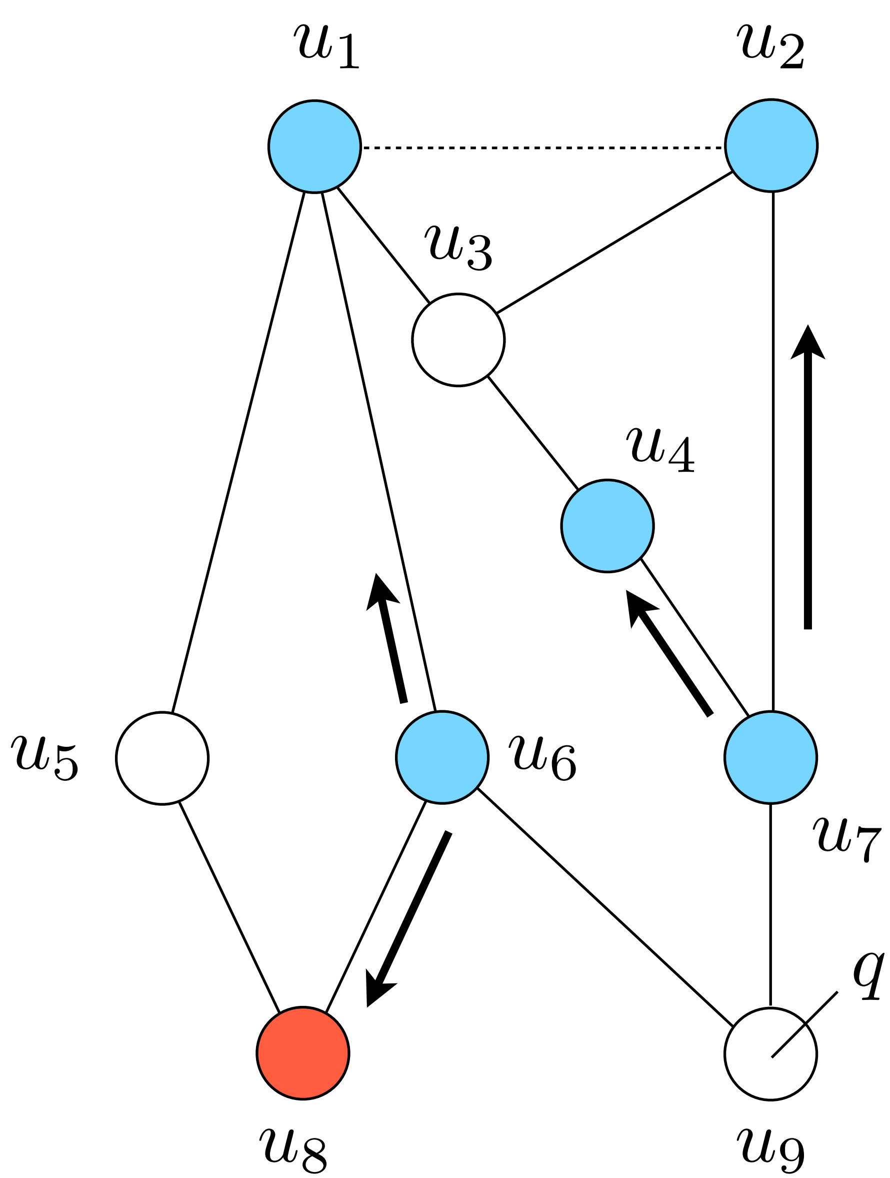

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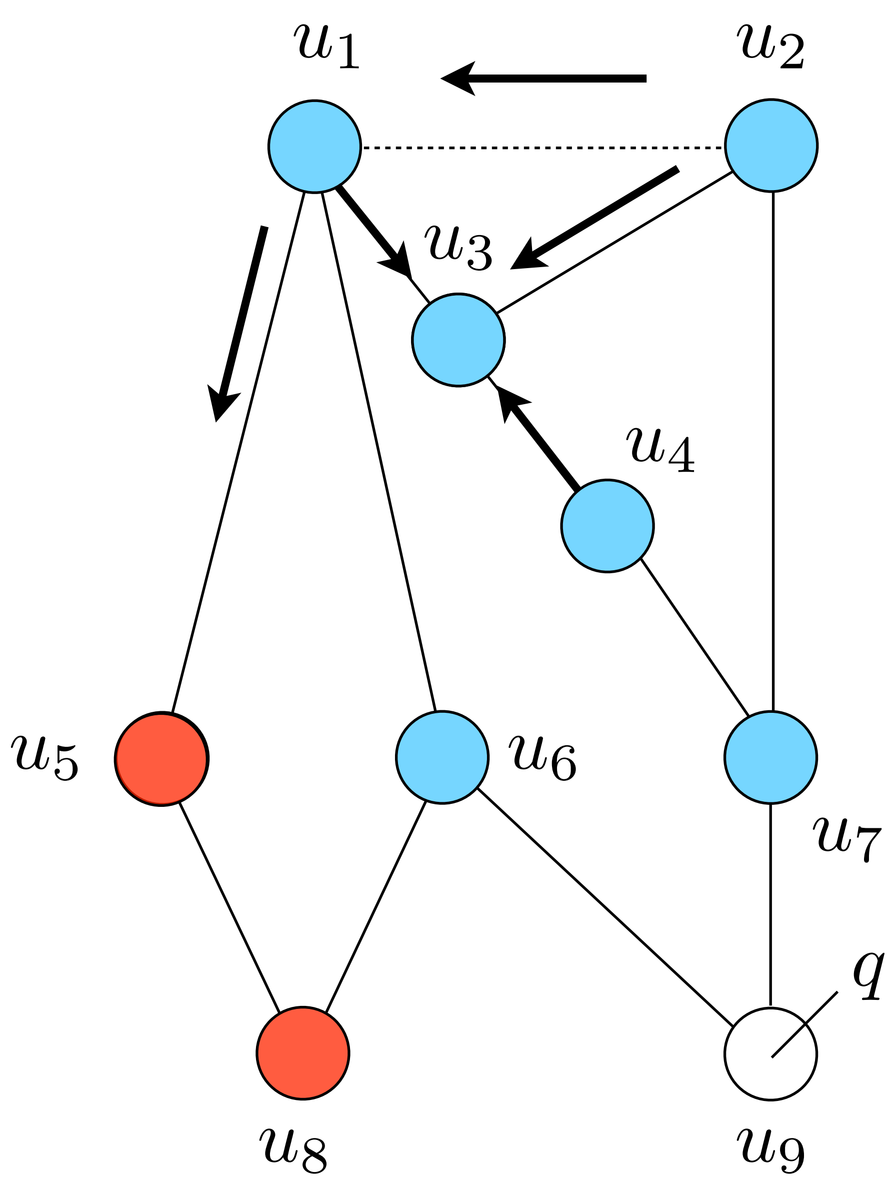

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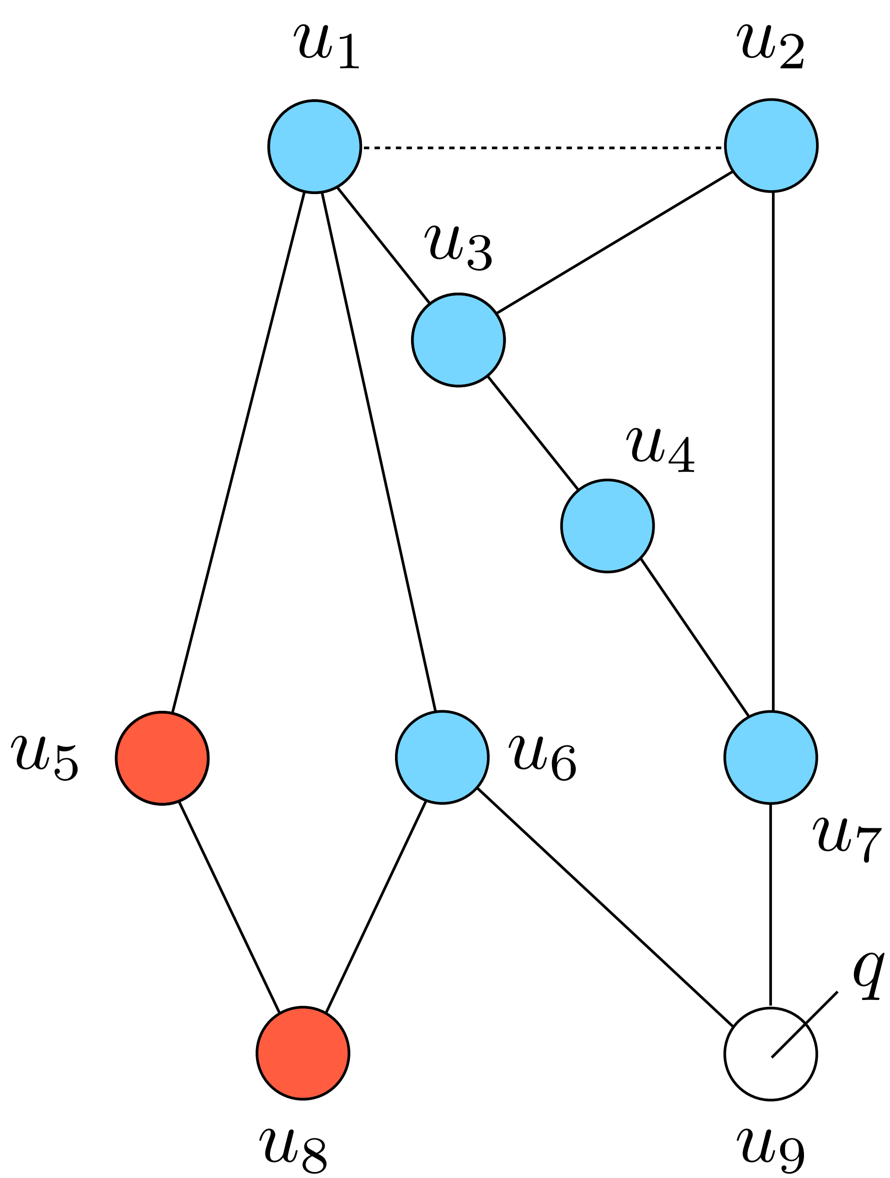
Final routing state for q



2 route attributes

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Current routing state for p

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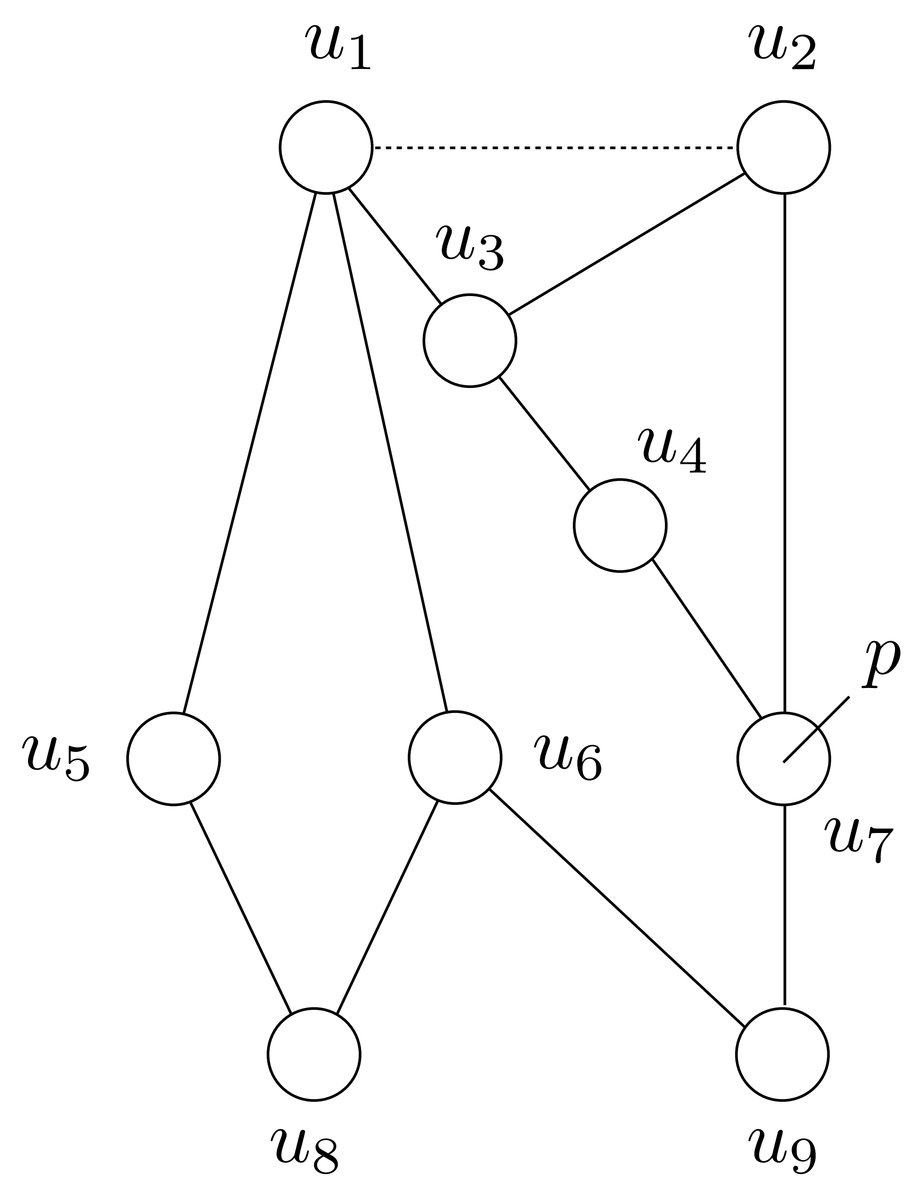

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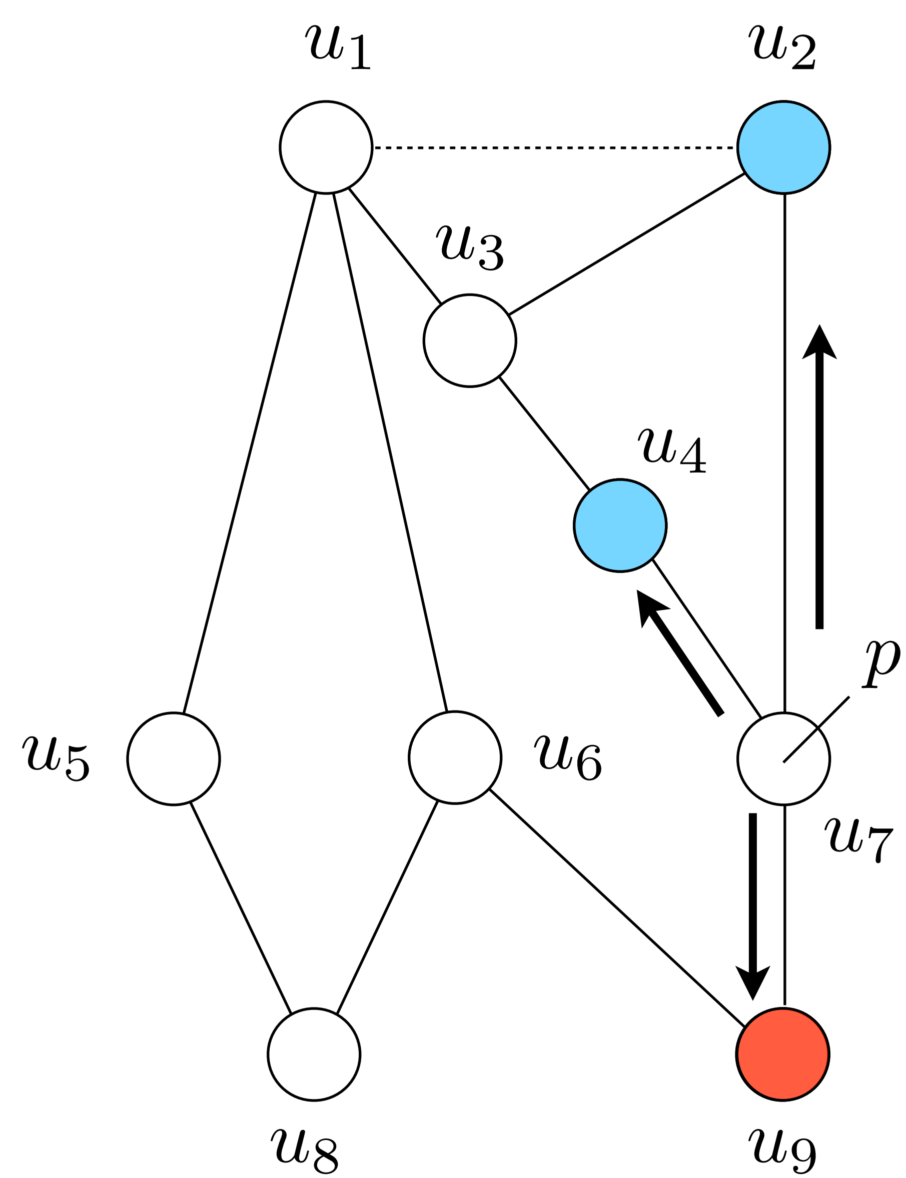

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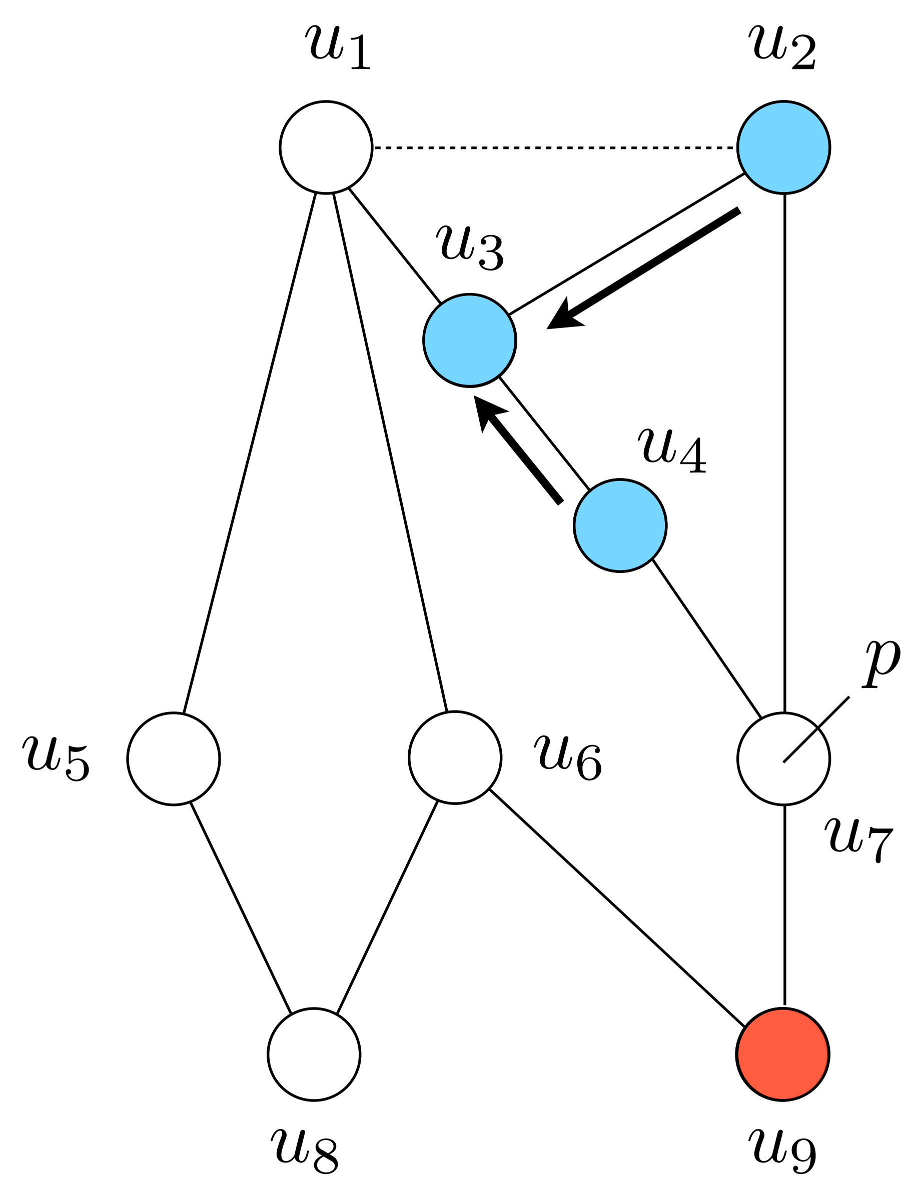

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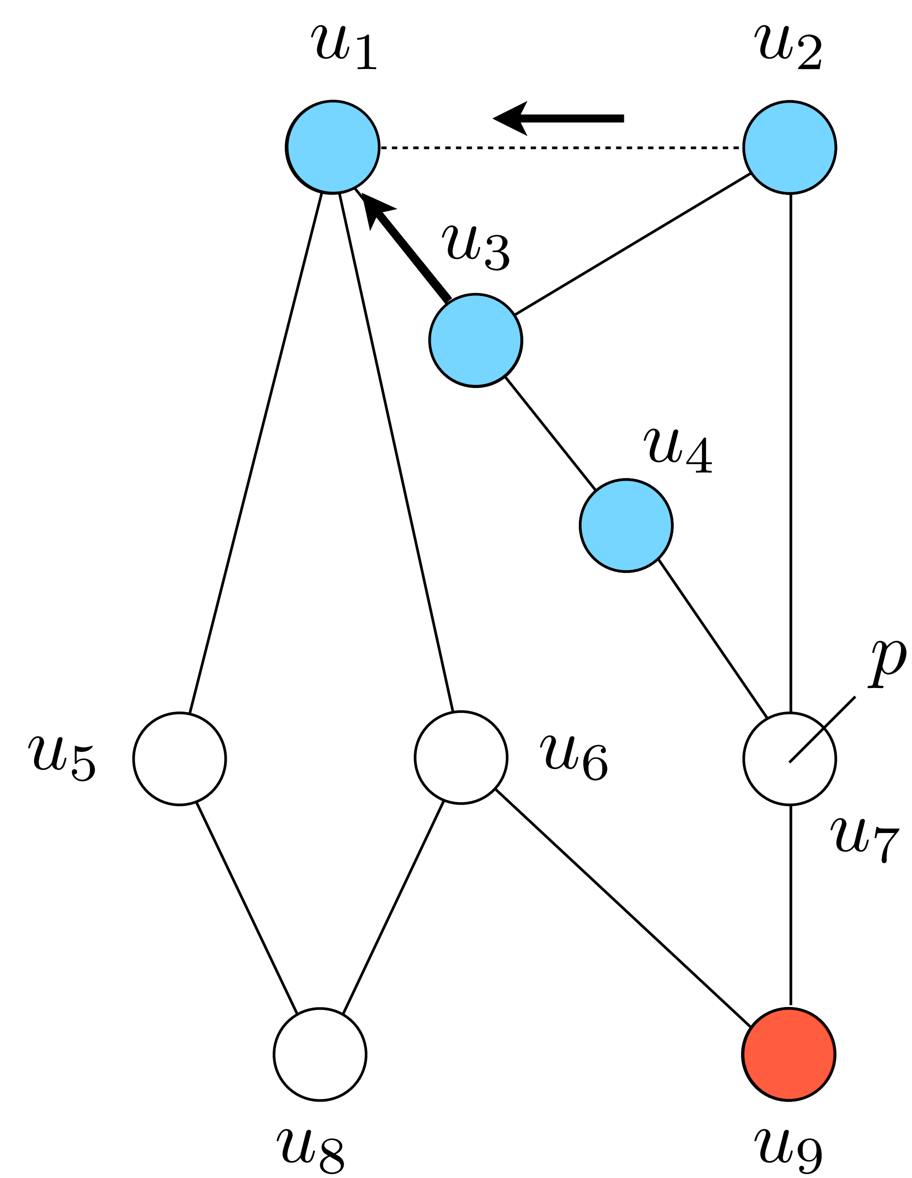

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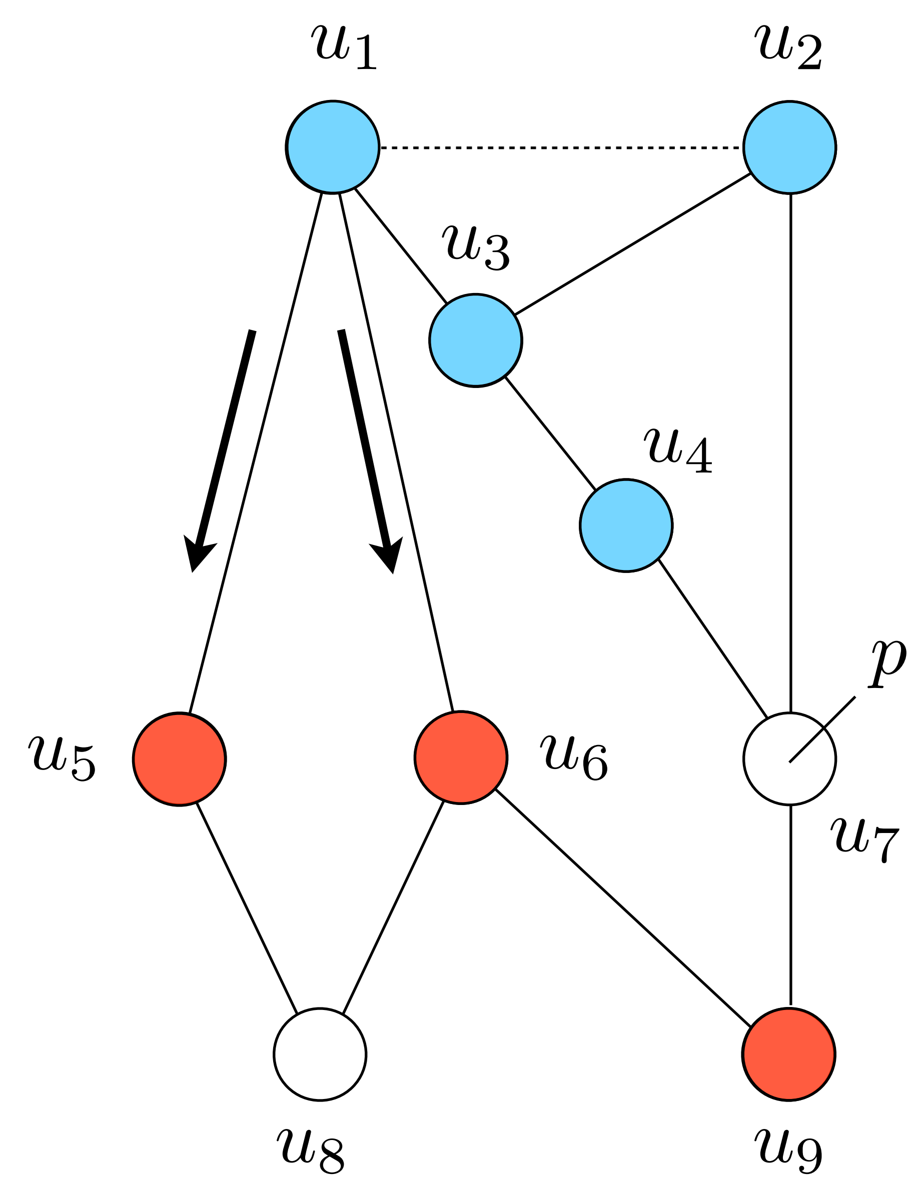

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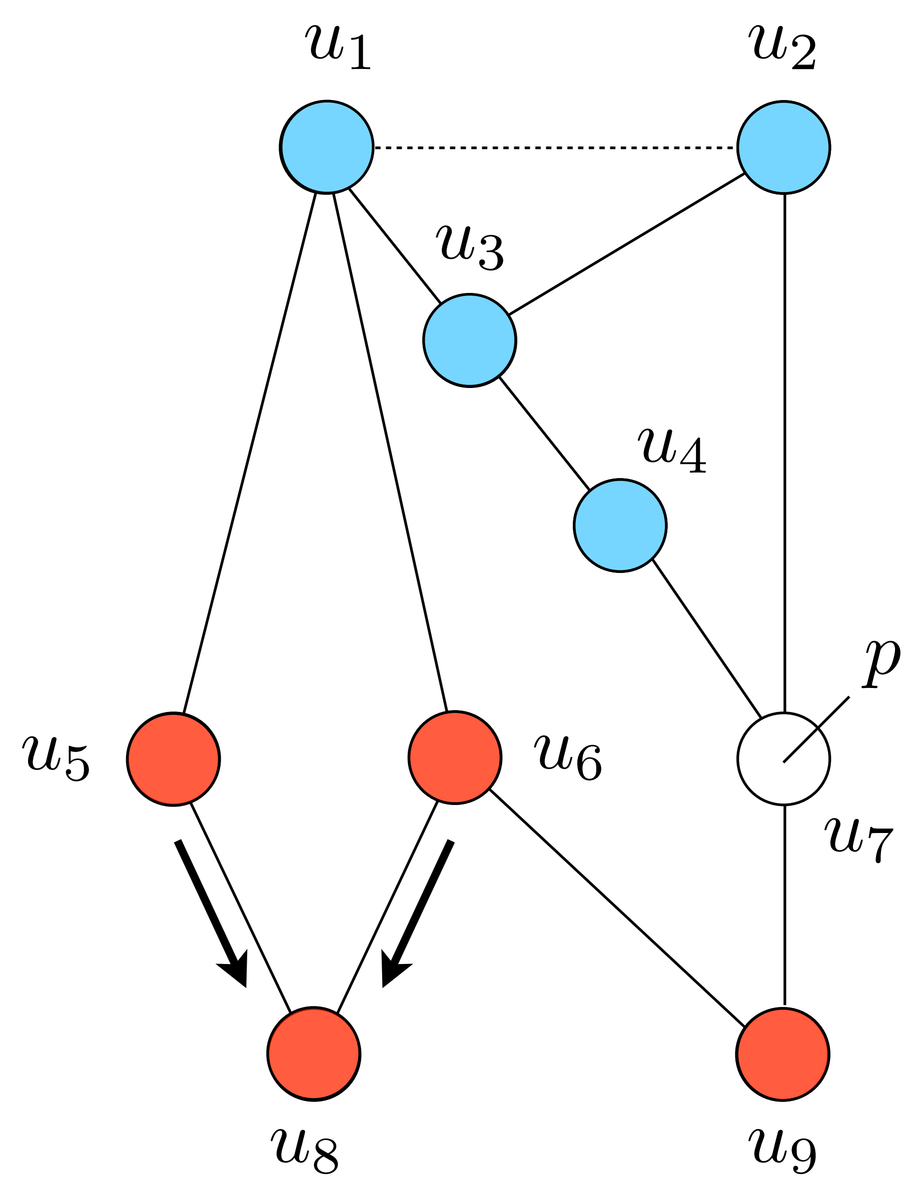
- customer routes to every neighbor
- provider routes to customers



Final routing state for p

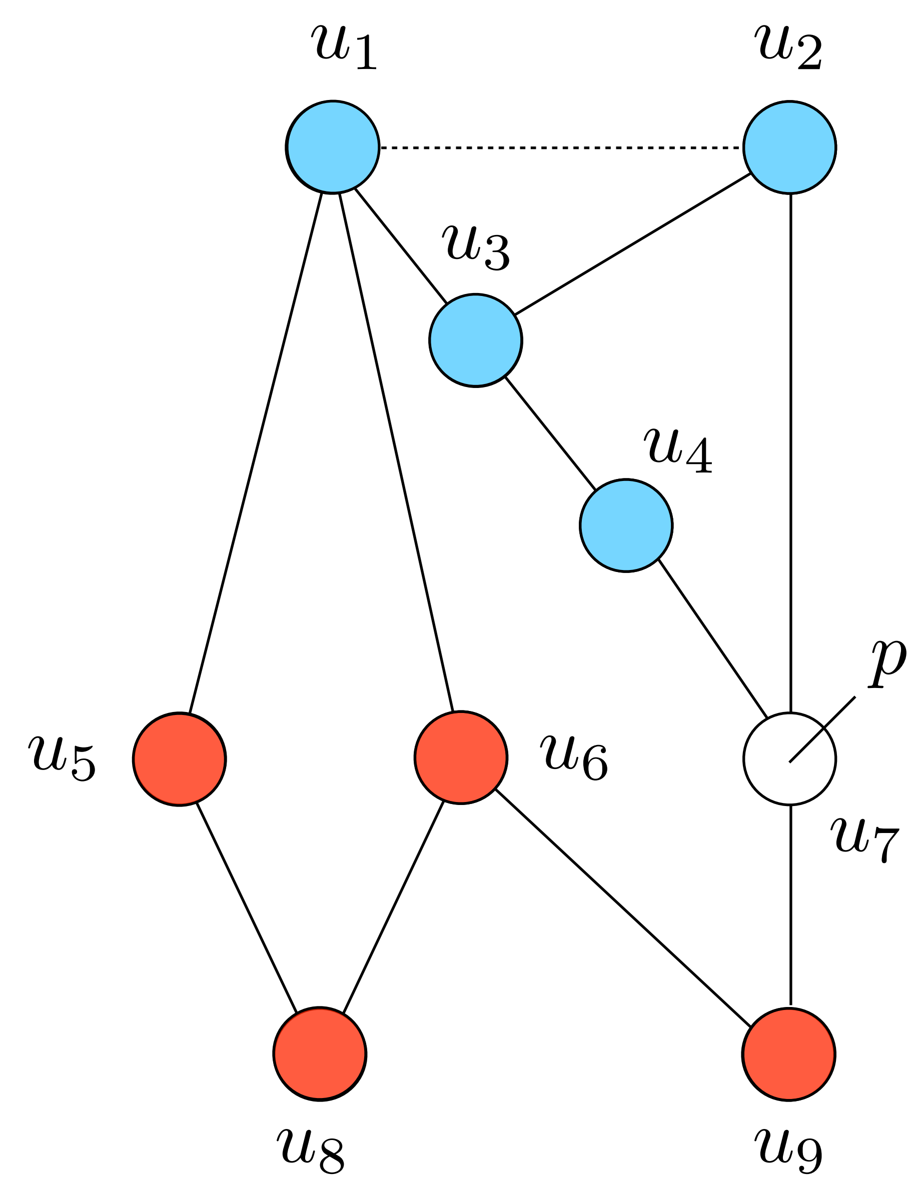
2 route attributes

learned from customer

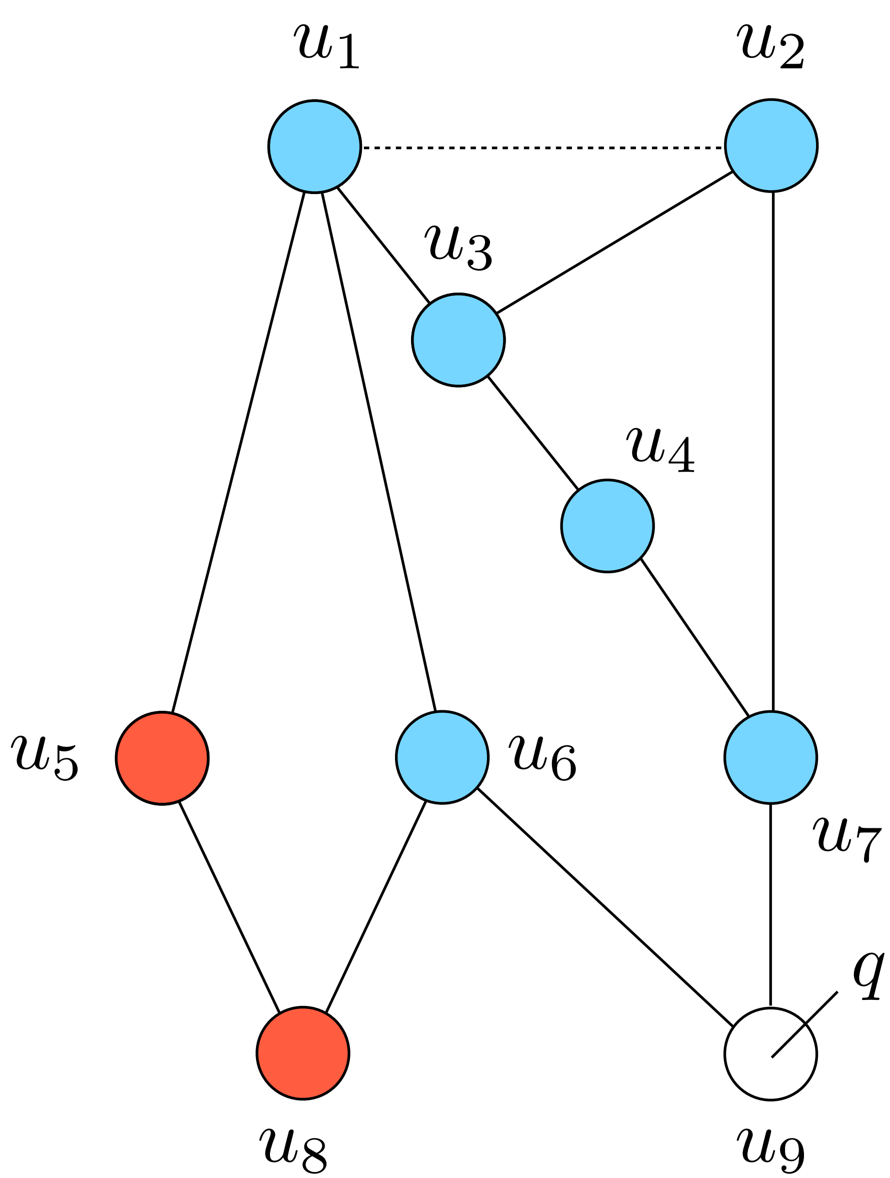
learned from provider

2 exportation rules

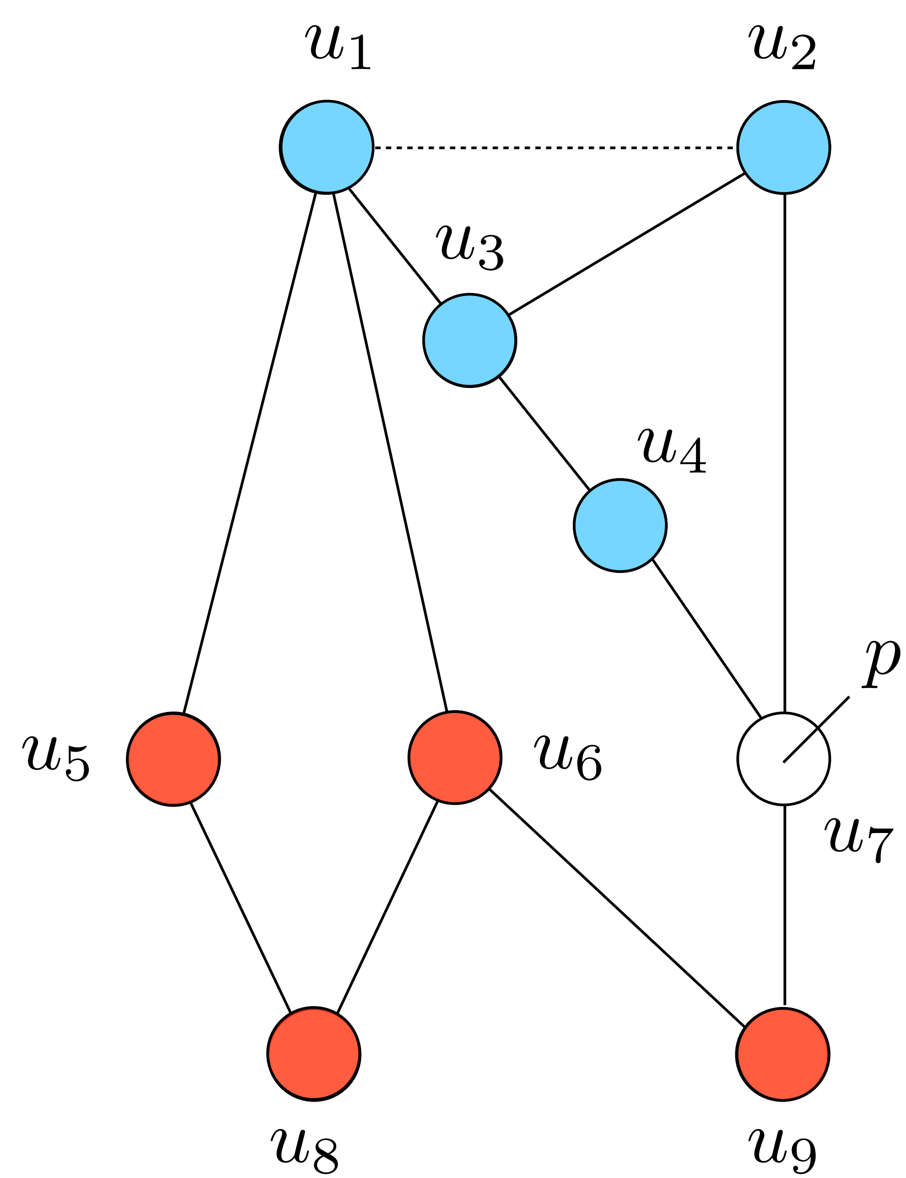
- customer routes to every neighbor
- provider routes to customers



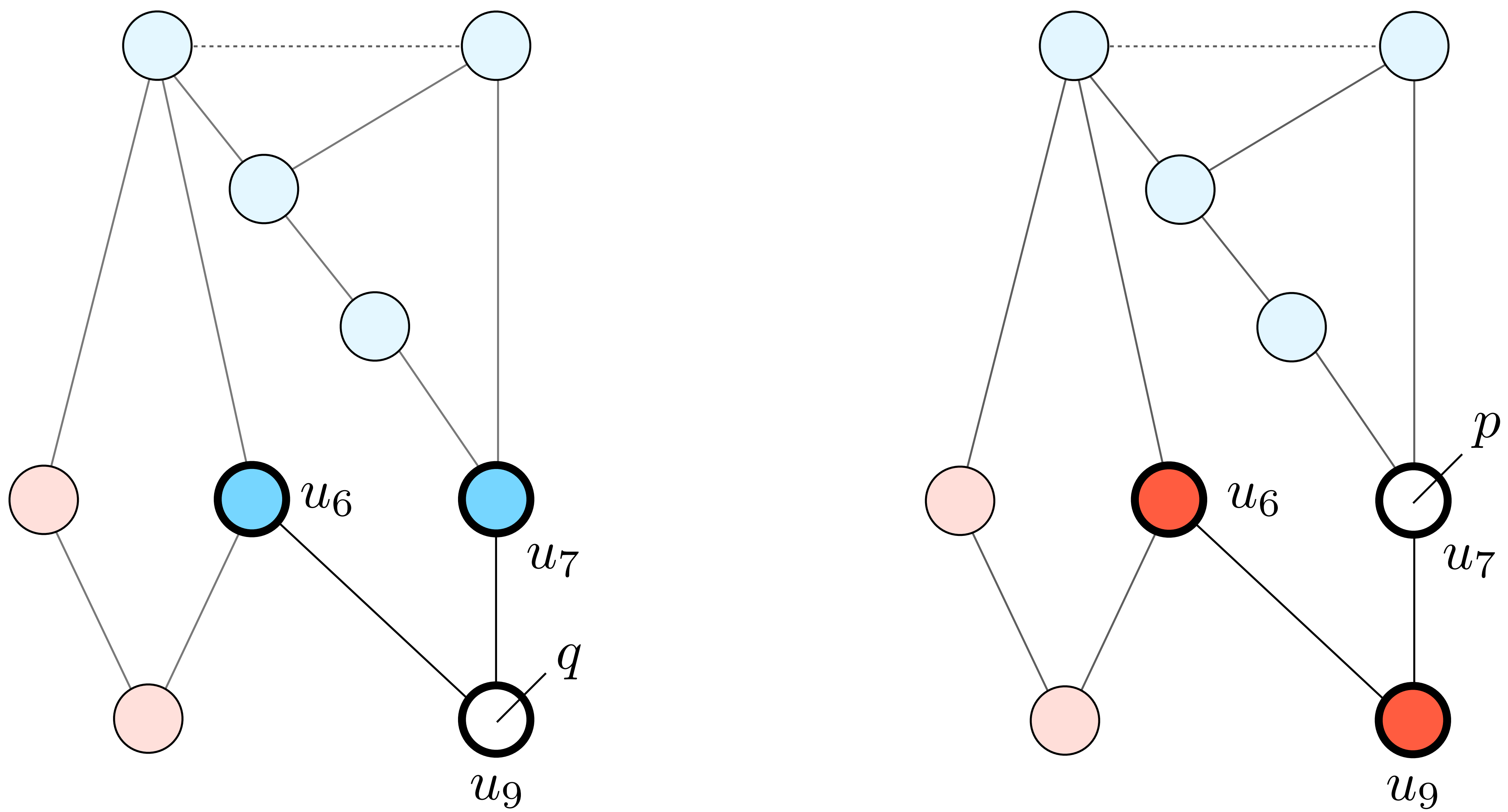
Final routing state for **q**



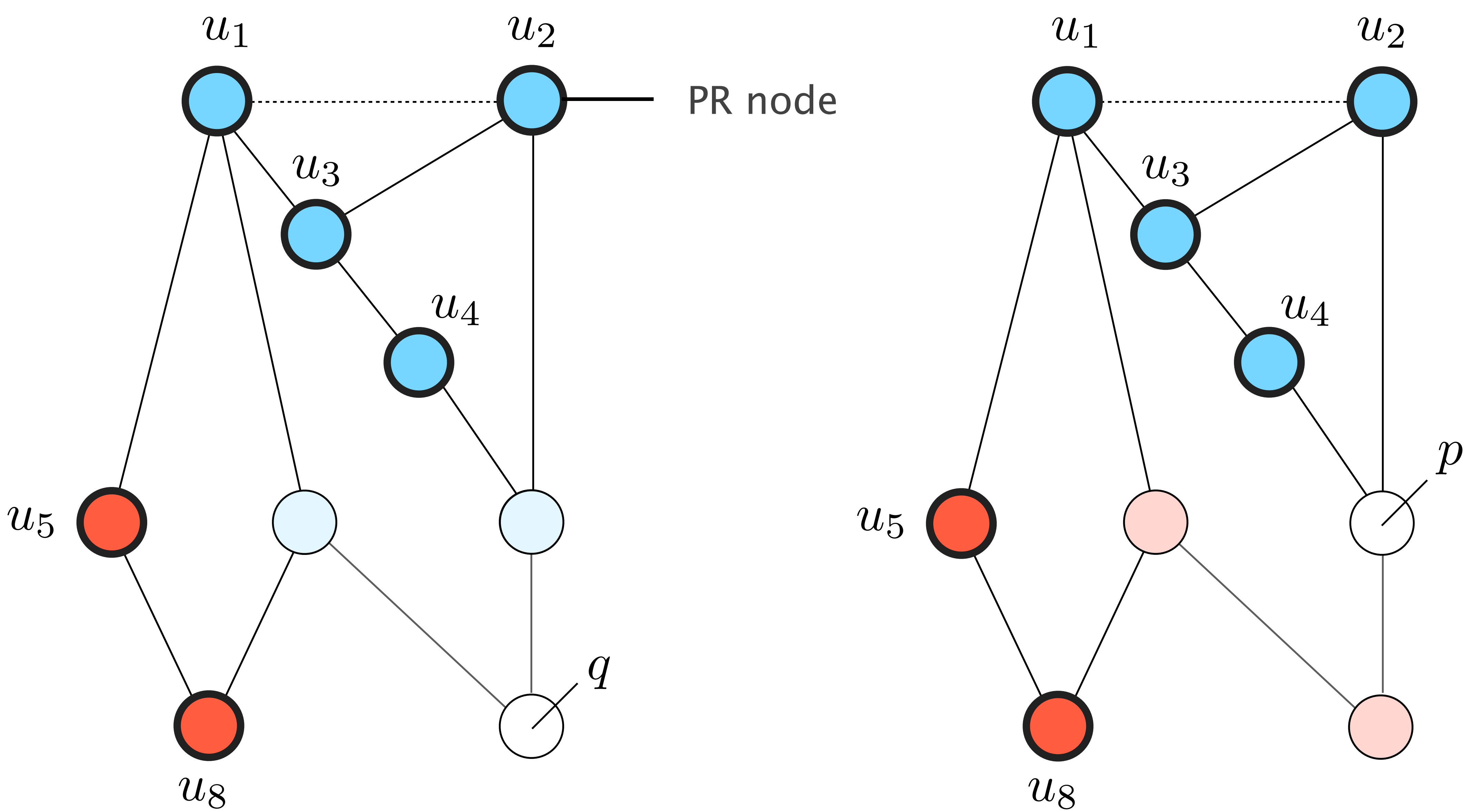
Final routing state for **p**



These three node elect different attribute for both q and p. They cannot filter.

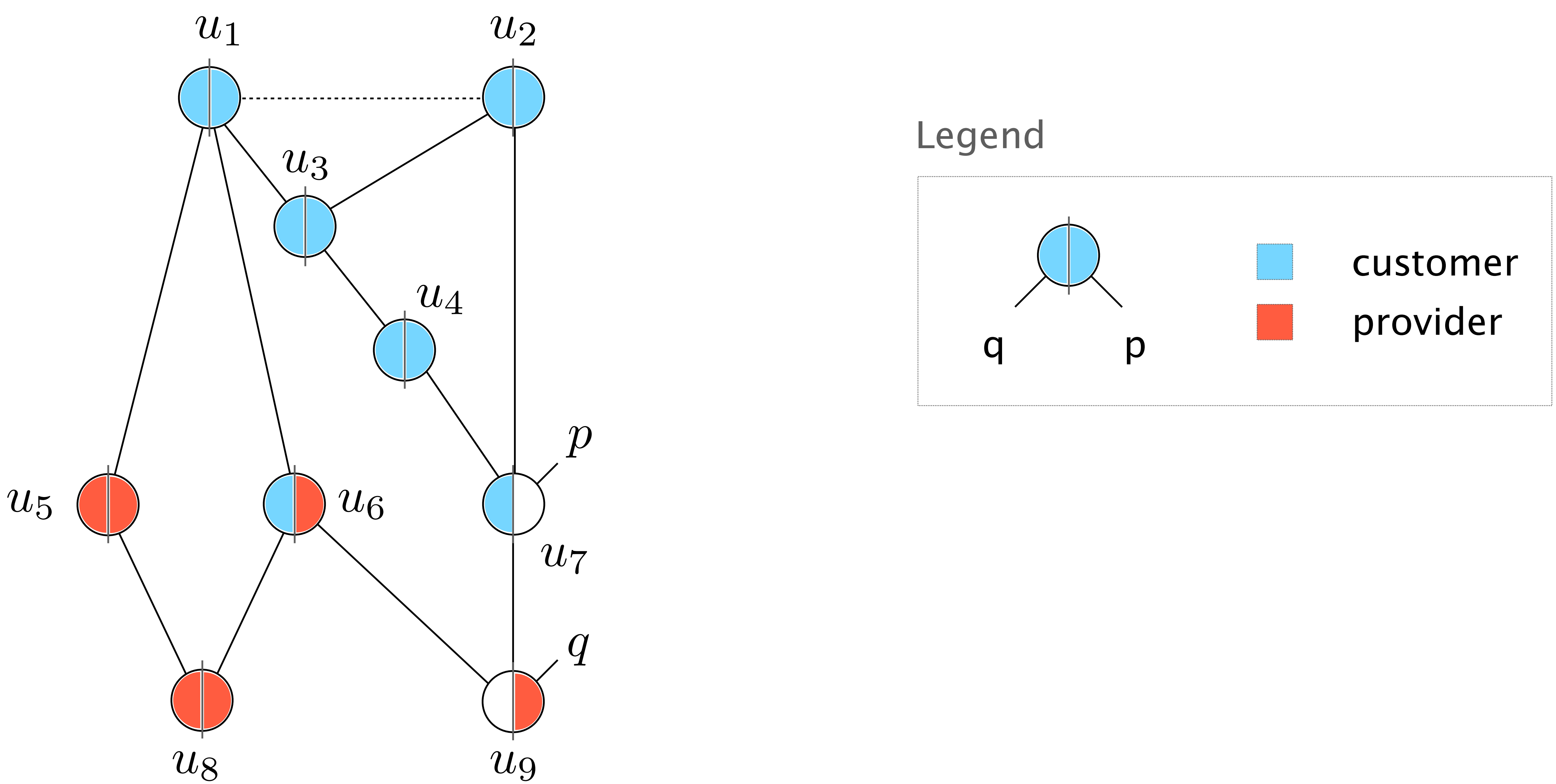


These node elect the same attribute for q and p. They are of type PR.

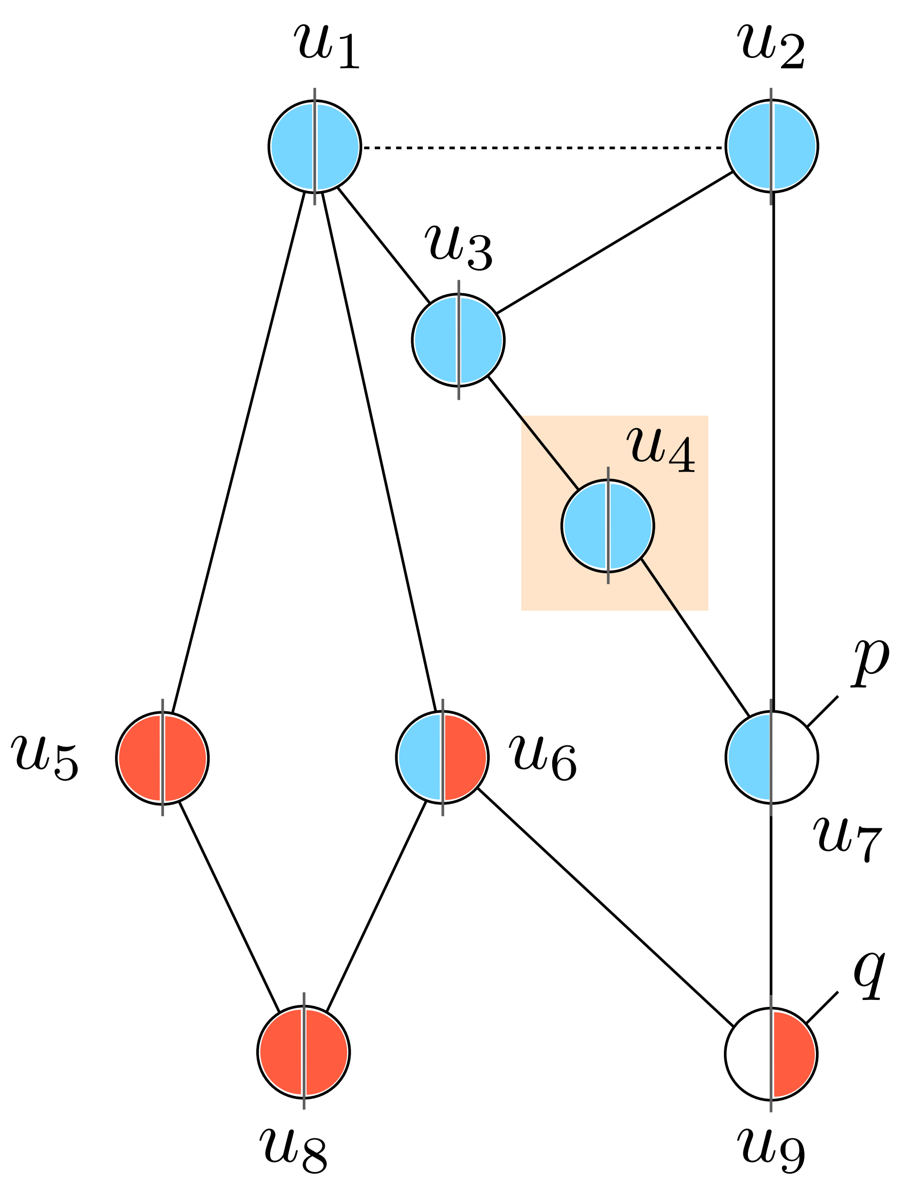


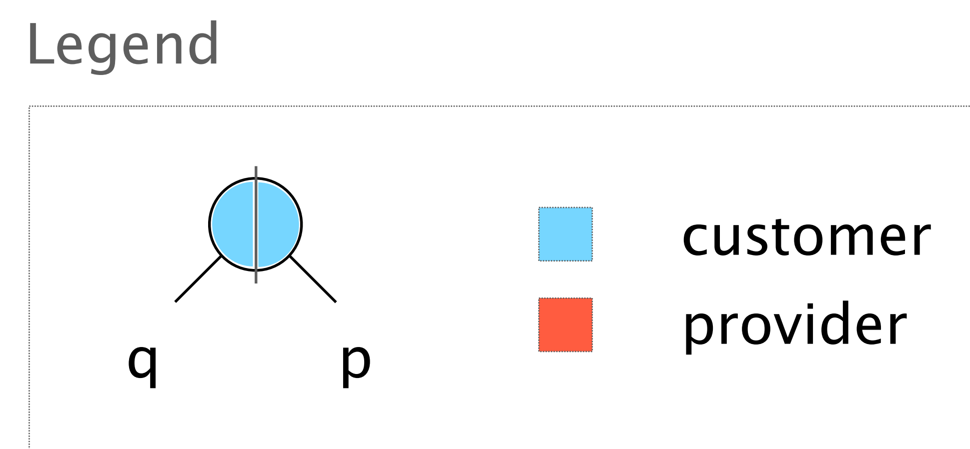
What if PR nodes filter?

Combined routing state

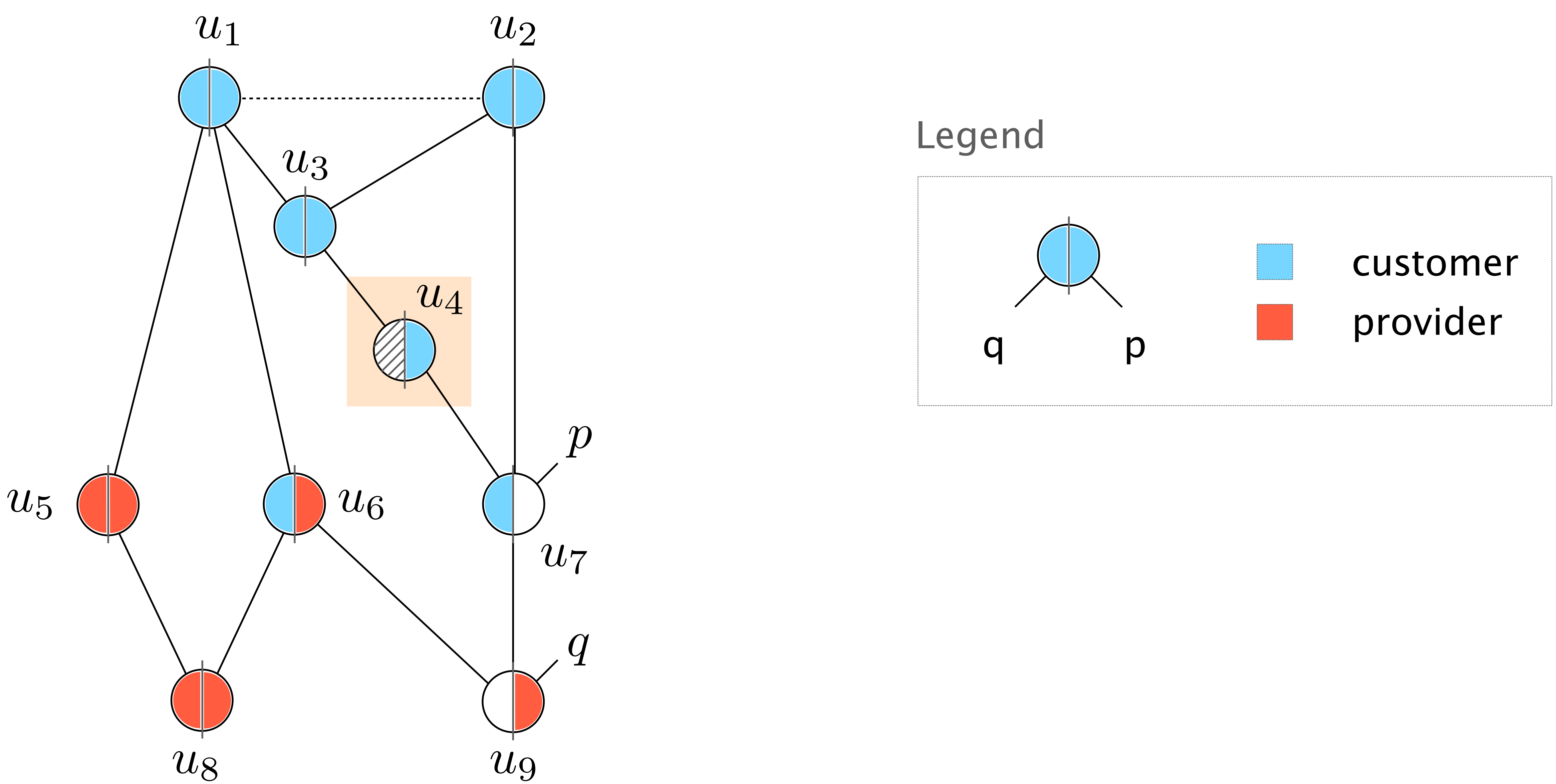


u4 filters q and stops propagating it to u3

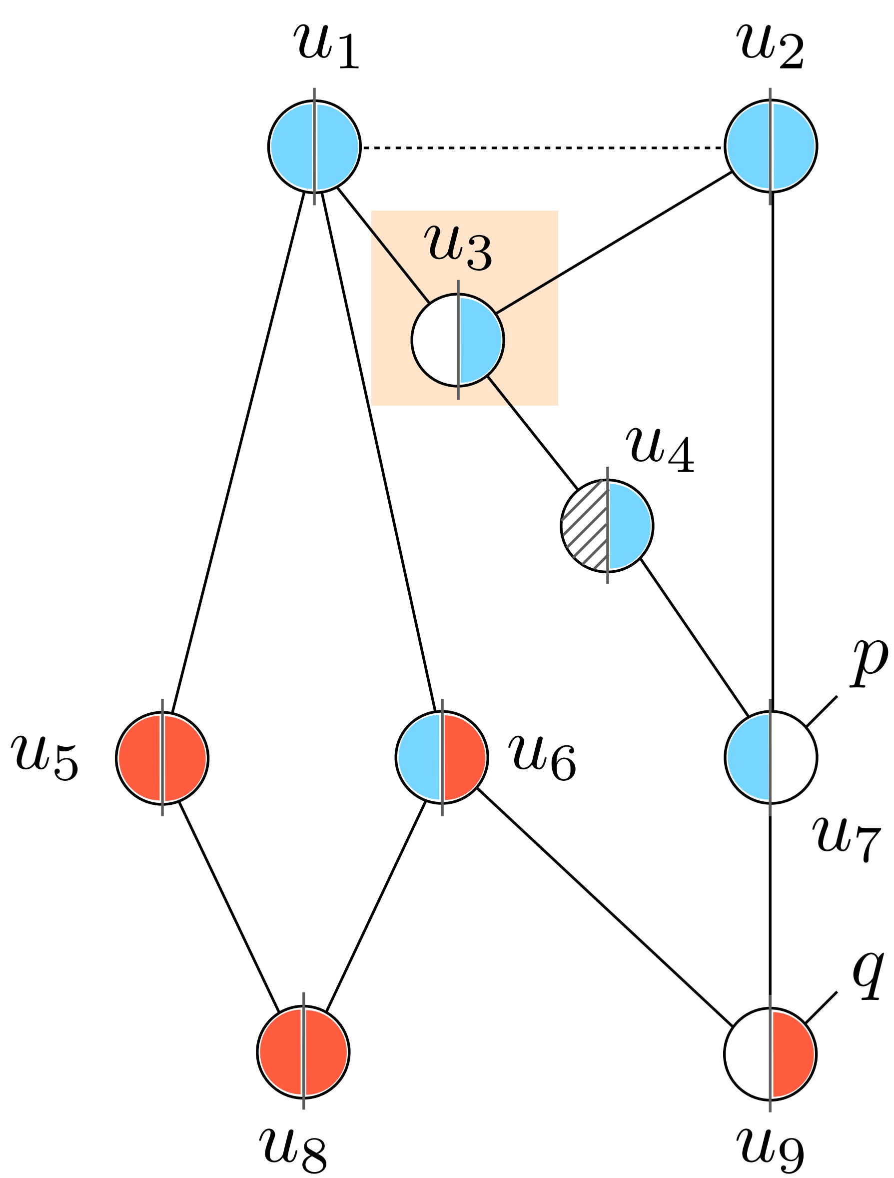


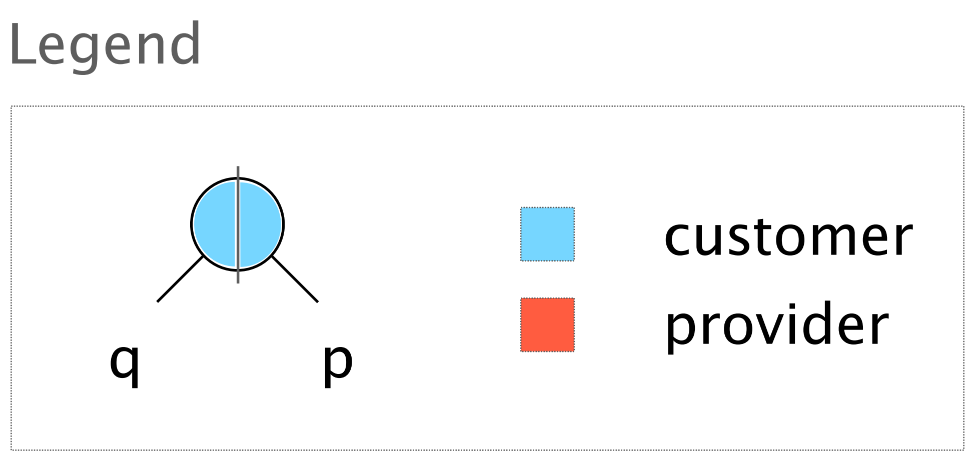


u_4 filters q and stops propagating it to u_3

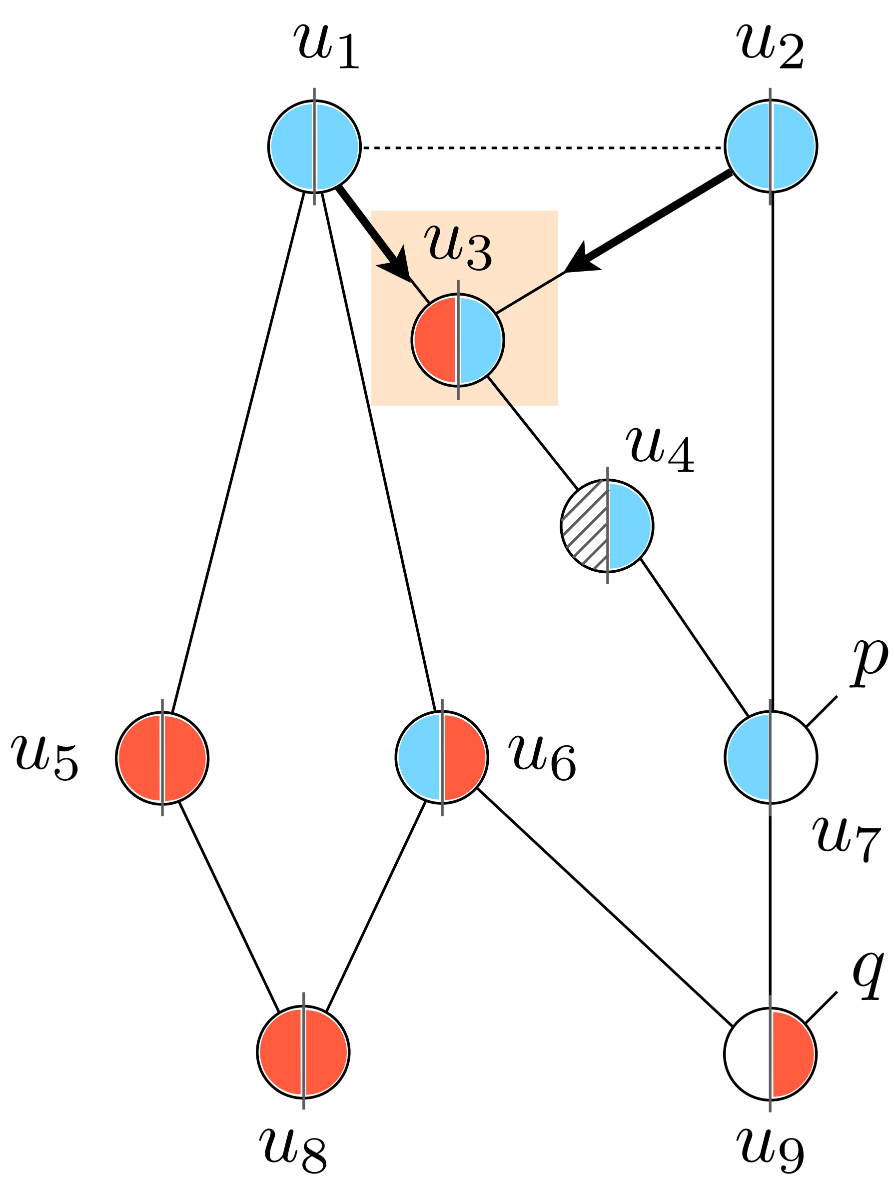


u₃ looses its only customer route to q

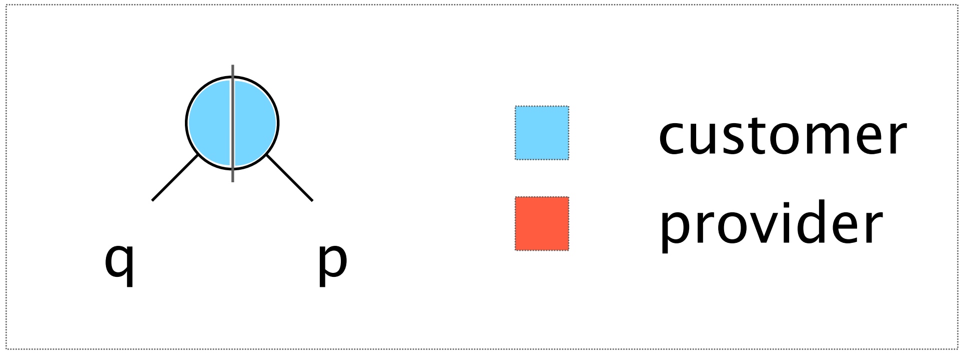




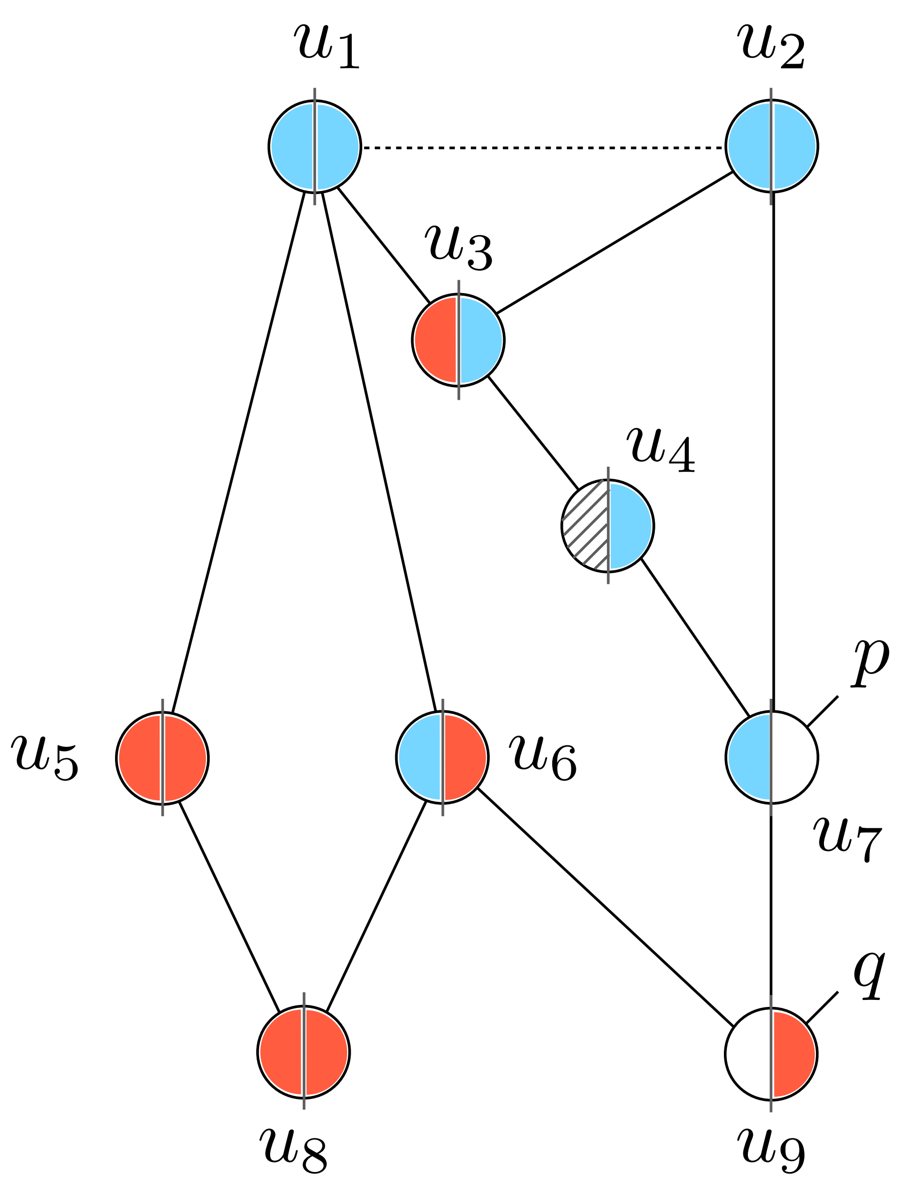
u3 starts using a provider route for q

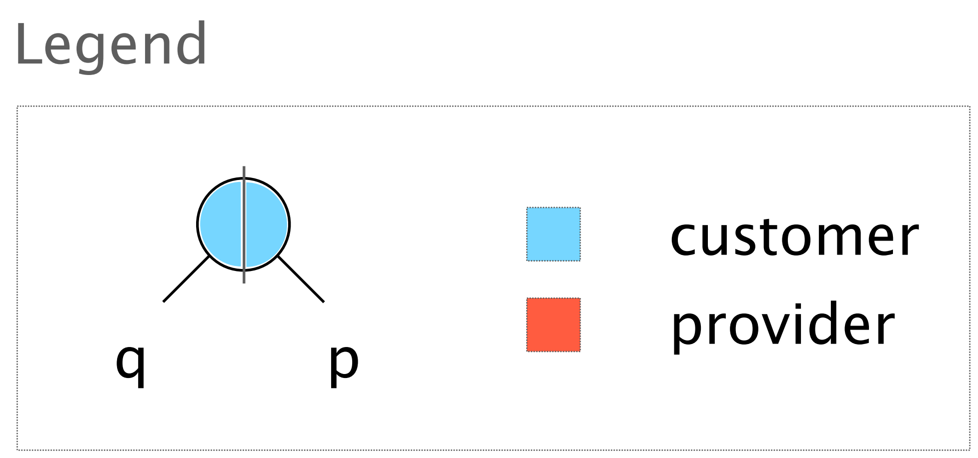


Legend

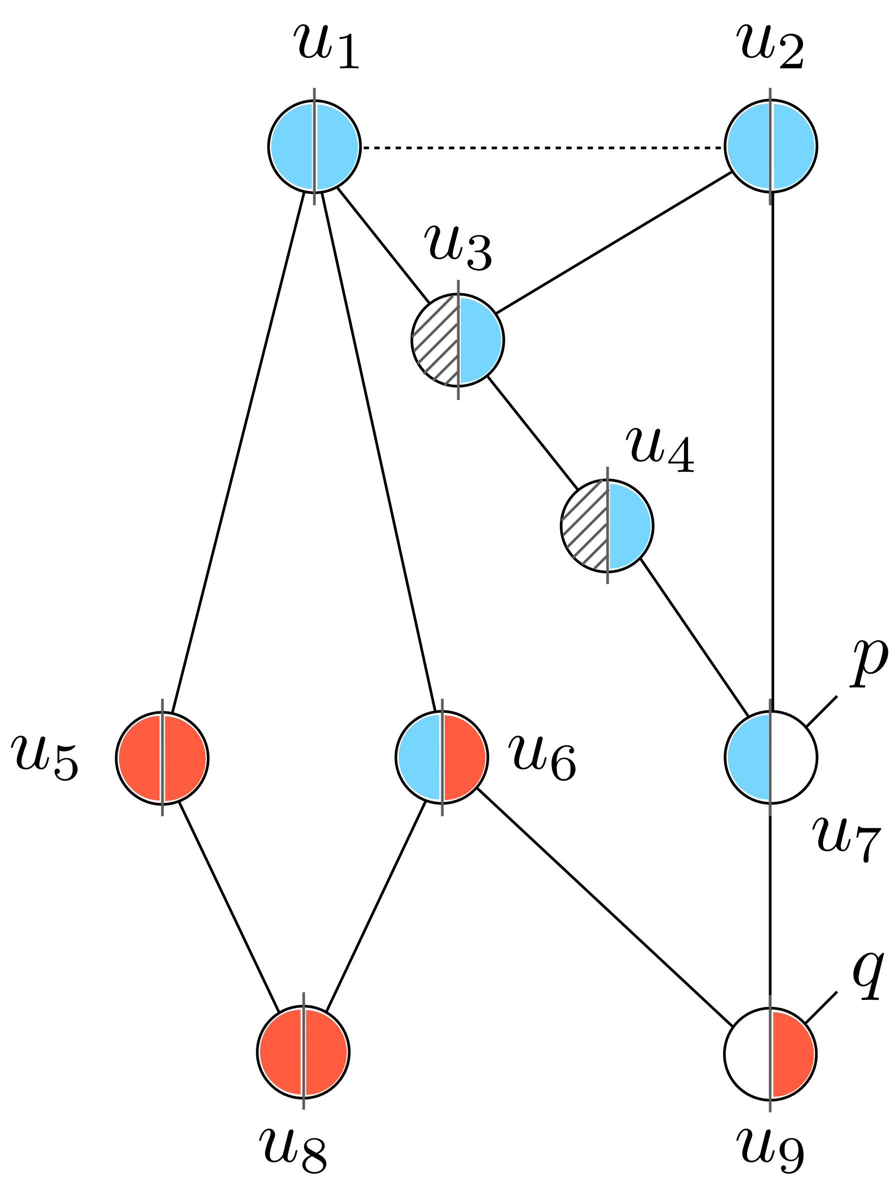


But what if u_3 filters?





if u_3 filters, it uses a customer route again for forwarding q



… and it saves space!

All PR nodes filtering is a Nash Equilibrium

Any node has two incentives to filter q-routes:

- retrieve a better route to forward traffic
- gain space in its routing and forwarding tables

with no node having an unilateral incentive to move away

Simple route consistent algorithm

Considering a node u,

a child prefix q,

its parent prefix p,

Simple route consistent algorithm

Considering a node u,

a child prefix q,

its parent prefix p,

Algorithm

If u is not the destination for q and

If elected q-route ≥ elected p-route

then u filters q-routes

The algorithm is provably correct

Theorem 3 No matter the order in which node runs the algorithm, a route consistent state is eventually reached

The algorithm is provably correct

Theorem 1

For every node u, the elected q-route can only worsen when an arbitrary set of nodes filter q-routes

Theorem 3

No matter the order in which node runs the algorithm, a route consistent state is eventually reached

The algorithm is provably correct

Theorem 1 — For every node u, the elected q-route can only worsen when an arbitrary set of nodes filter q-routes

Theorem 2 — The elected q-route at a node u for which the elected q-route < elected p-route is not affected if an arbitrary set of nodes filters

Theorem 3 — No matter the order in which node runs the algorithm, a route consistent state is eventually reached

The algorithm is provably correct

Theorem 1

For every node u, the elected q-route can only worsen when an arbitrary set of nodes filter q-routes

Theorem 2

The elected q-route at a node u for which the elected q-route < elected p-route is not affected if an arbitrary set of nodes filters

Theorem 3

No matter the order in which node runs the algorithm, a route consistent state is eventually reached

DRAGON relies on isotonicity, a property which characterizes the combined policies of two neighbors

Isotonicity

If an AS u prefers one route over another, a neighboring AS does not have the opposite preference

Observation

required for optimality, not correctness

verified in a lot of actual routing policies

DRAGON: Distributed Route AGgregatiON

Background

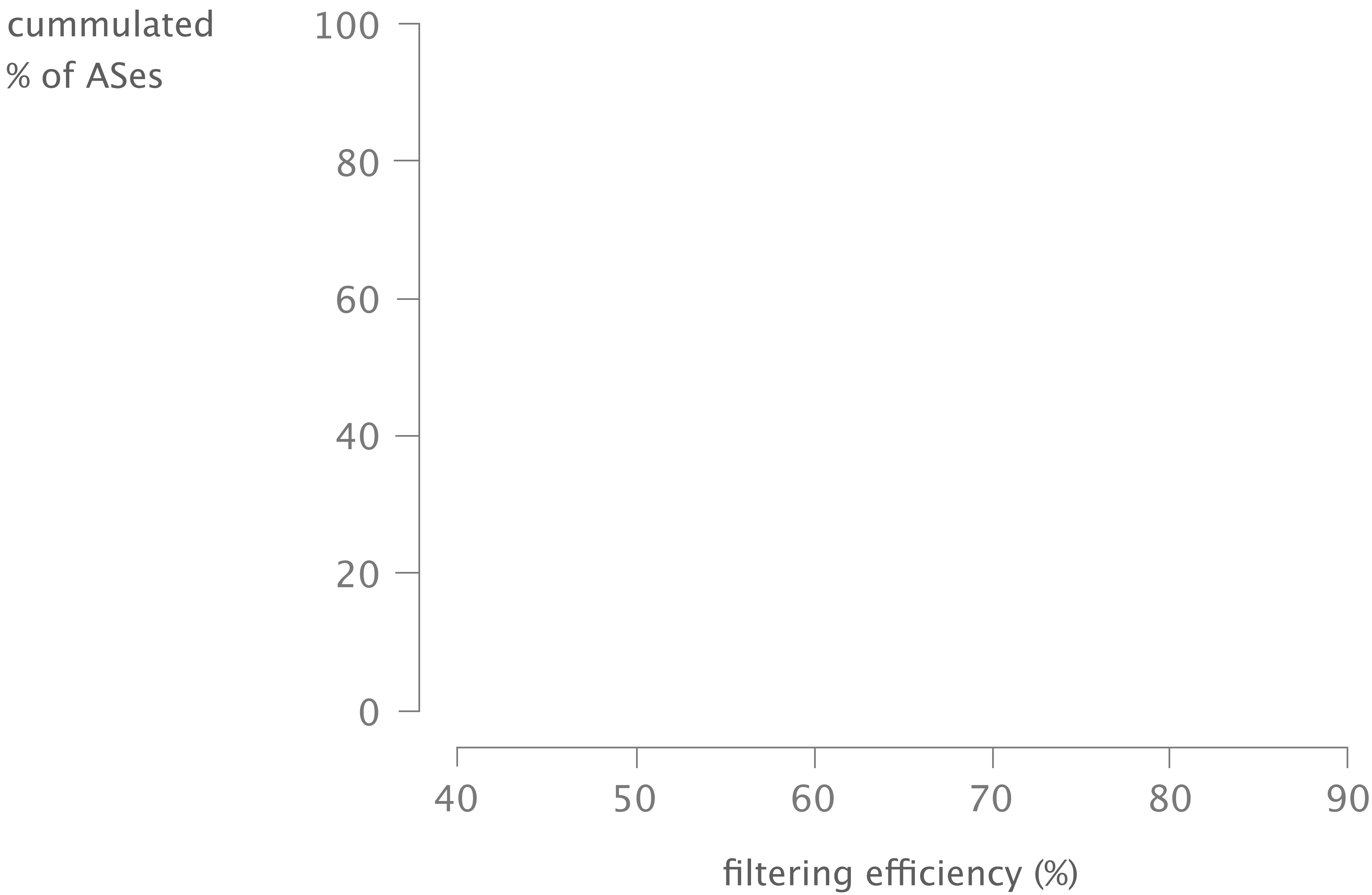
Route aggregation 101

Distributed filtering

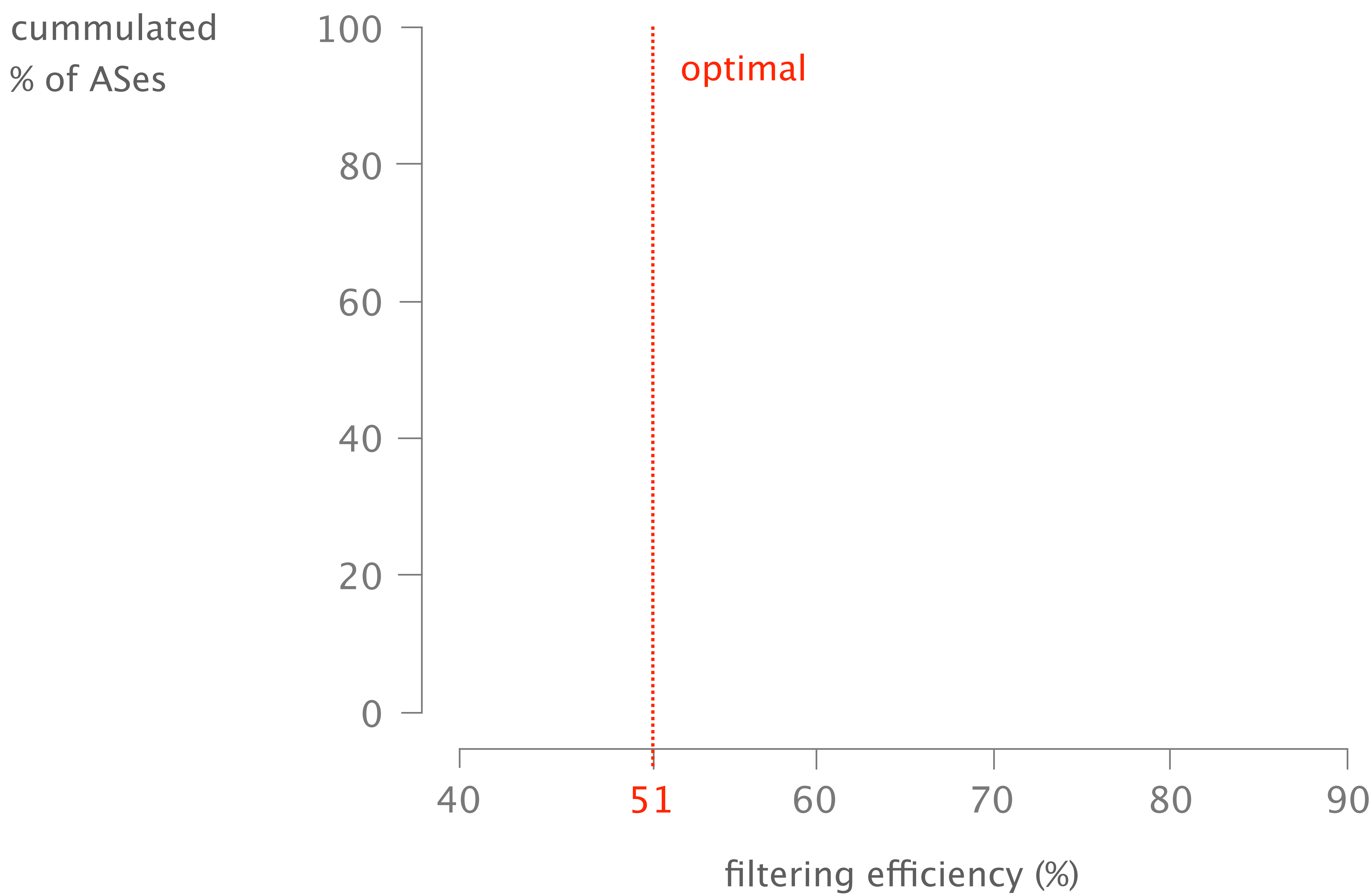
preserving consistency

3 Performance

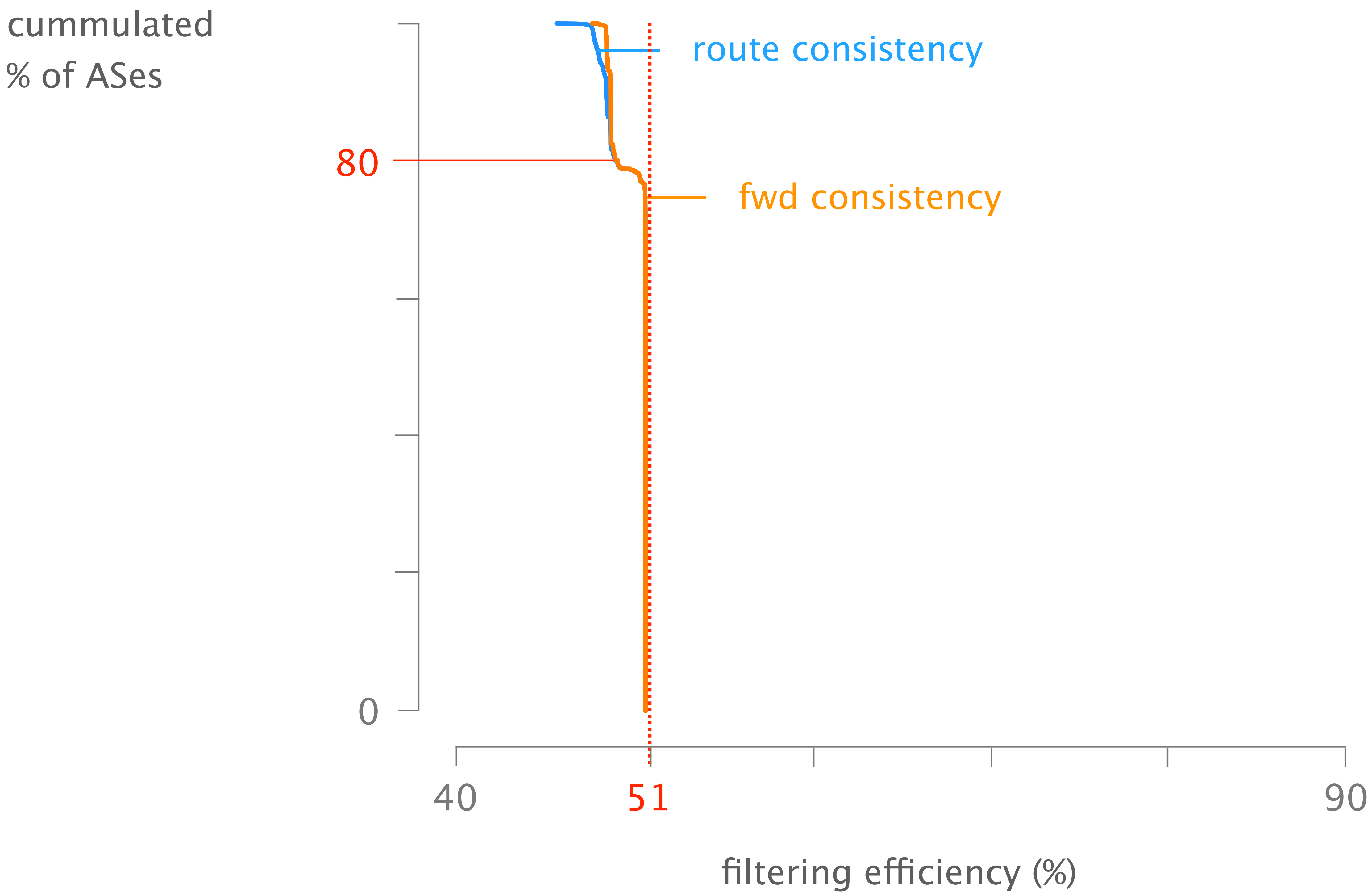
up to 80% of filtering efficiency


cummulated
% of ASes
100
80
60
40
20
0
40
50
60
70
80
90
filtering efficiency (%)

In today's Internet, optimal filtering is ~50% as half of the Internet prefixes are parentless



~80% of the ASes reaches optimal filtering efficiency



DRAGON node can automatically introduce aggregation prefix to filter prefixes without parent

Node can autonomously announce aggregation prefixes

based on local computation and preserving consistency

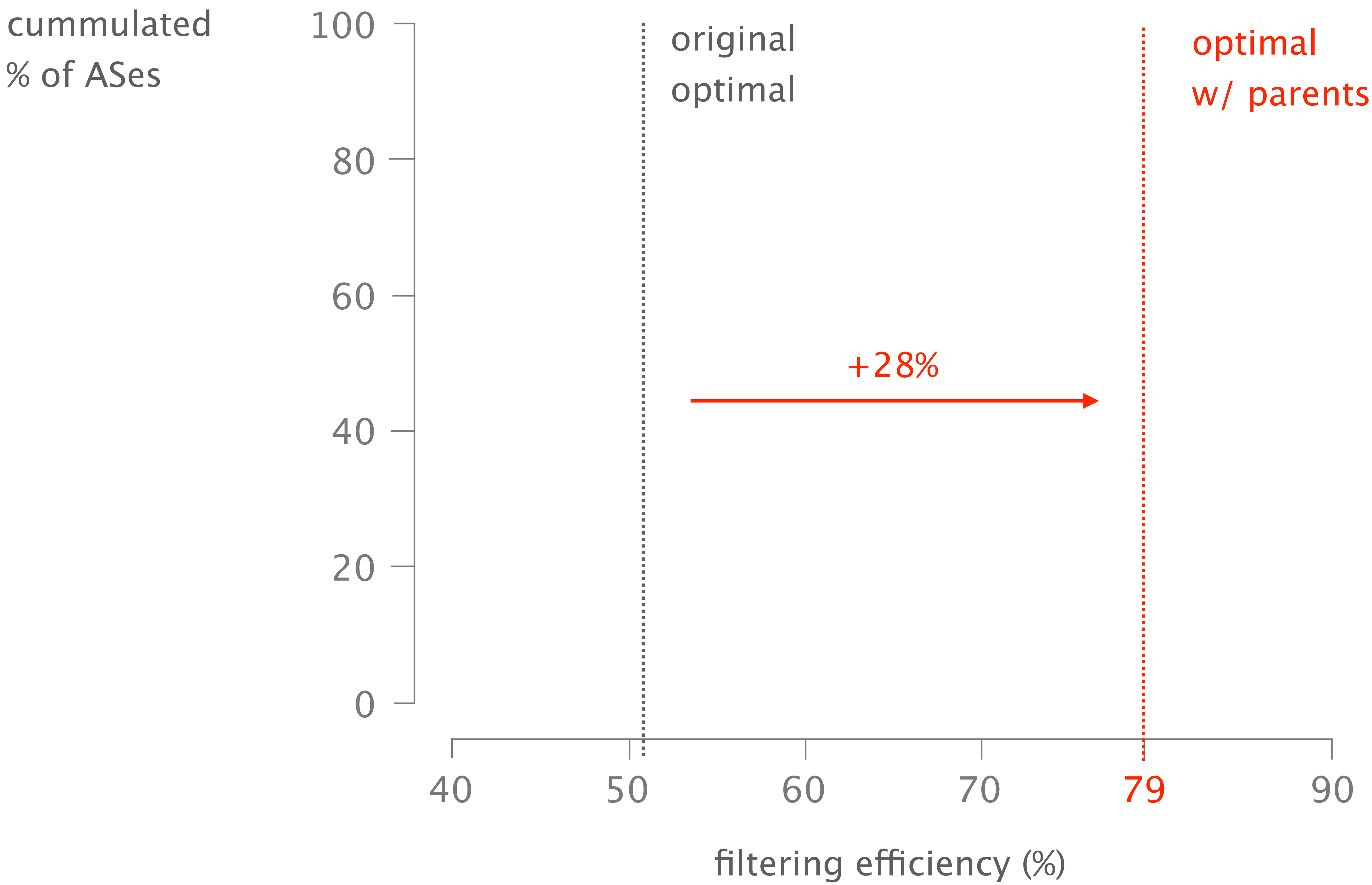
Routing system self-organizes itself in case of conflict

when more than one node announce the same parent prefix

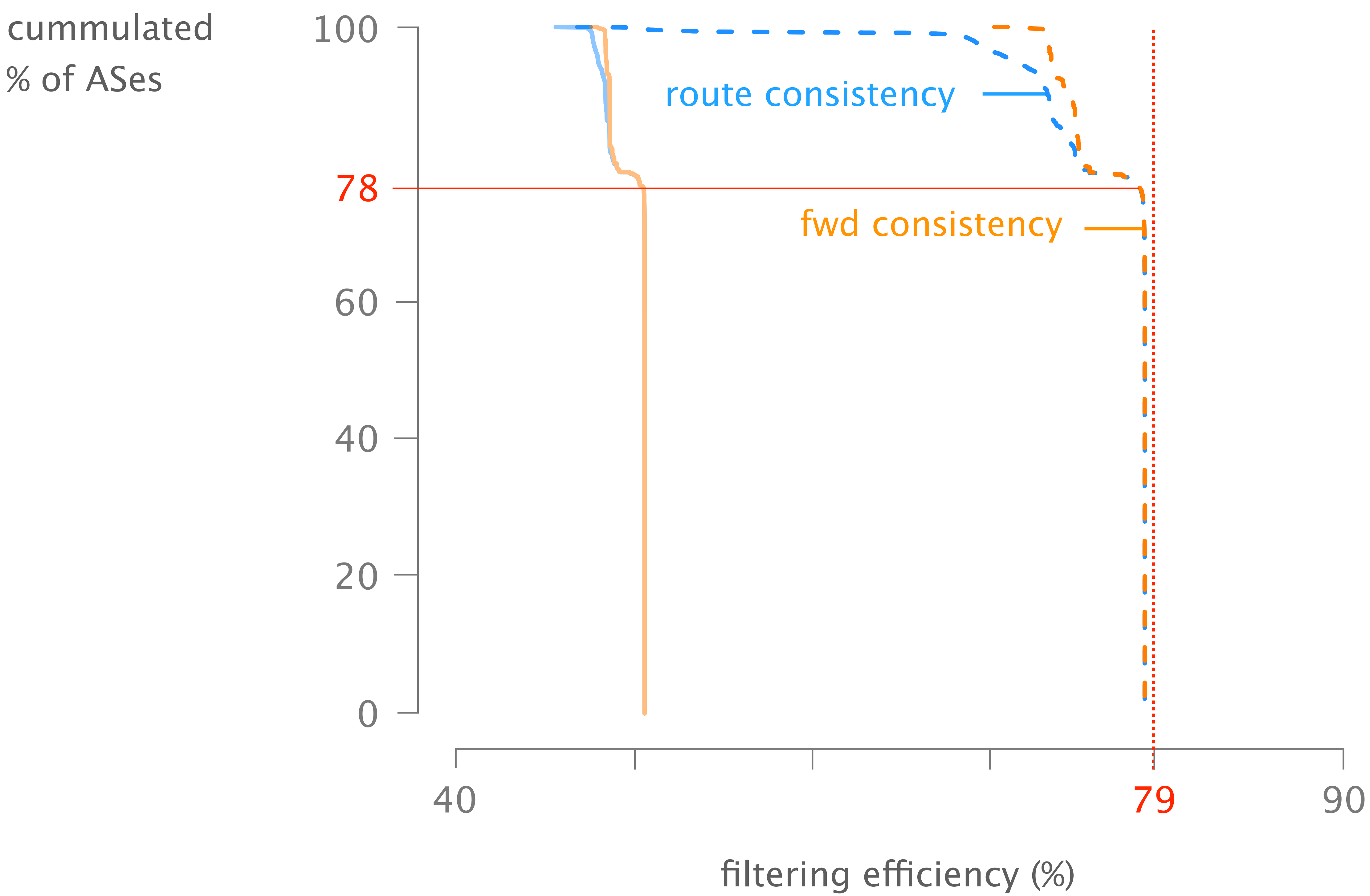
Number of aggregation prefixes introduced can be tuned

e.g., maximum prefix length or minimum # covered children

Introducing <10% of parent prefixes boosts the optimal efficiency to 79%



Again, ~80% of the ASes reaches optimal filtering efficiency



DRAGON: Distributed Route AGgregatiON

Background

Route aggregation 101

Distributed filtering

preserving consistency

Performance

up to 80% of filtering efficiency

DRAGON is a distributed route-aggregation algorithm which automatically harnesses any aggregation potential

DRAGON works on today's routers

only require a software update and offers incentives to do it

DRAGON preserves routing and forwarding decision

leveraging the isotonicity properties of Internet policies

DRAGON is more general than BGP

shortest-path, ad-hoc networks, etc.

2 fundamental properties of a good routing system

scalability

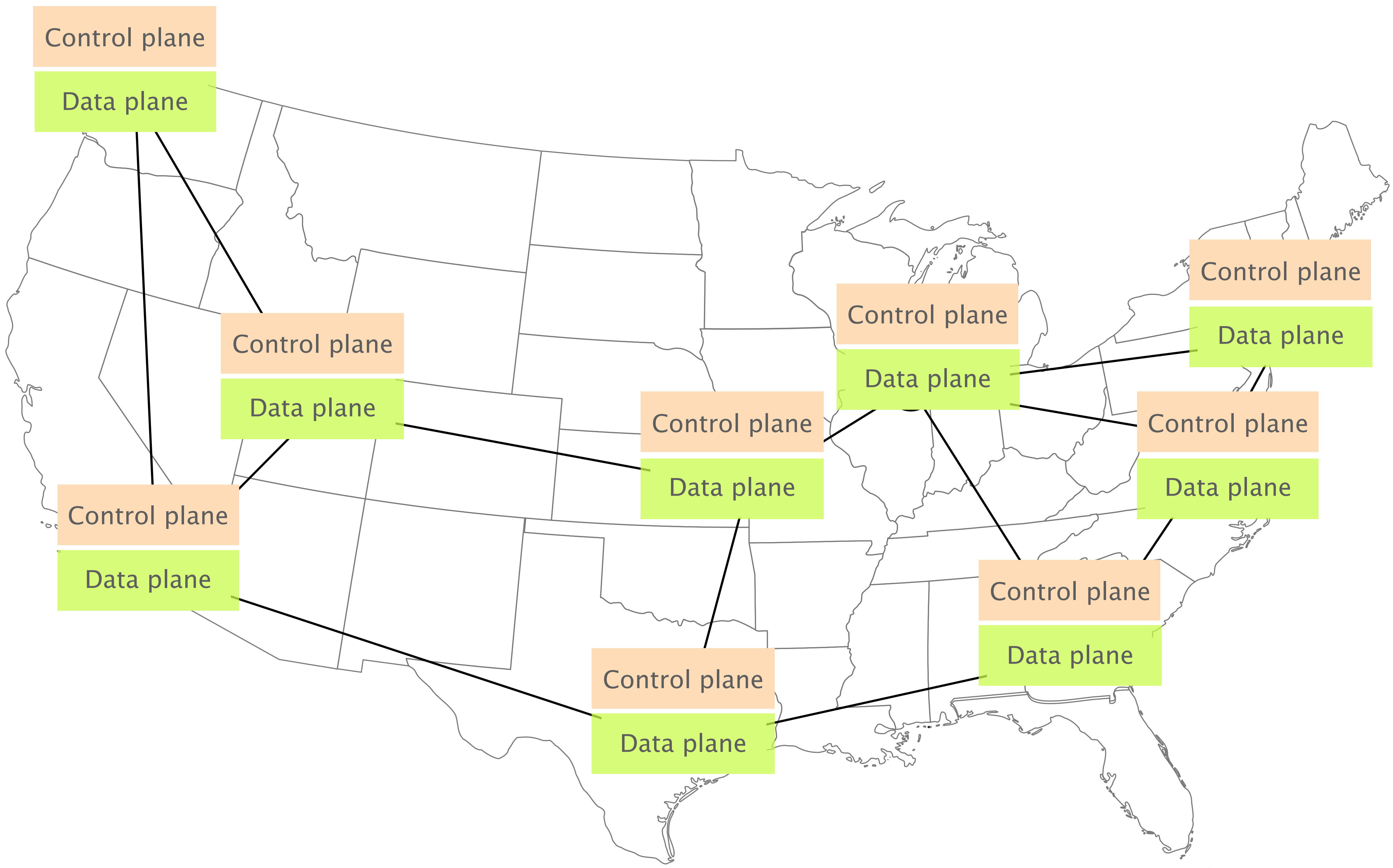
tolerate growth

flexibility

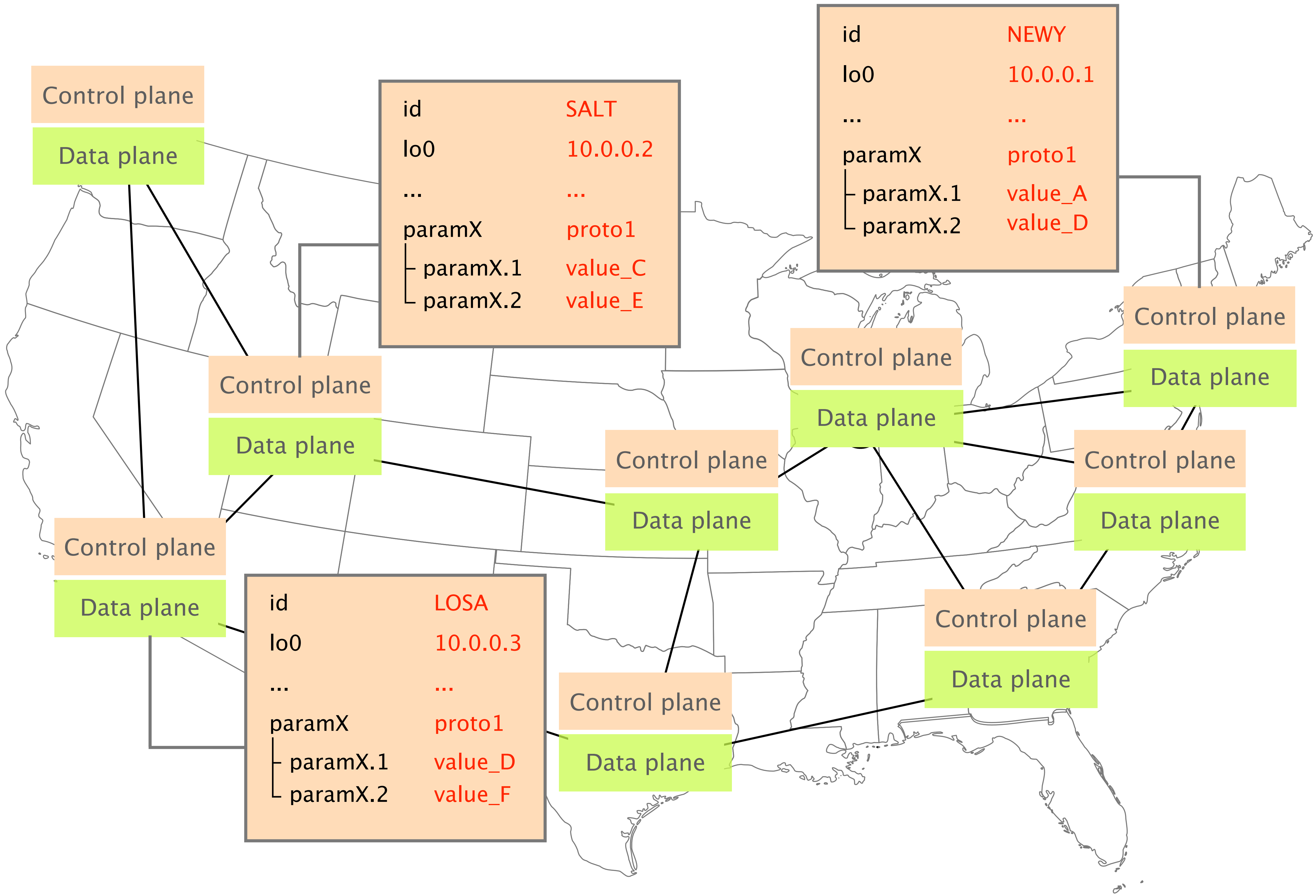
routing policies

low-level management
device-by-device

A network is a distributed system which requires each element to be configured properly

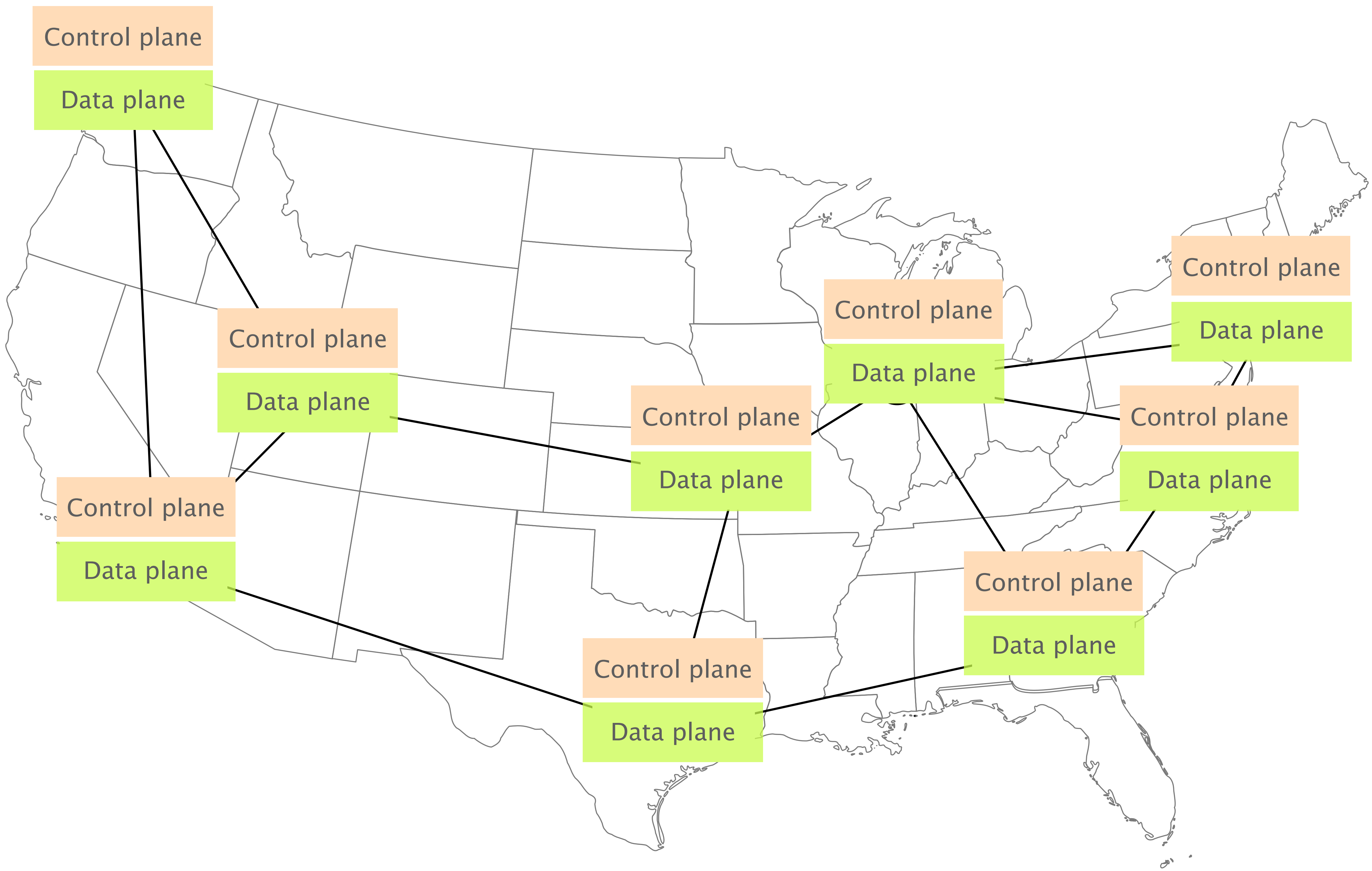


Configuring a distributed system is error-prone & time consuming (especially if done manually!)

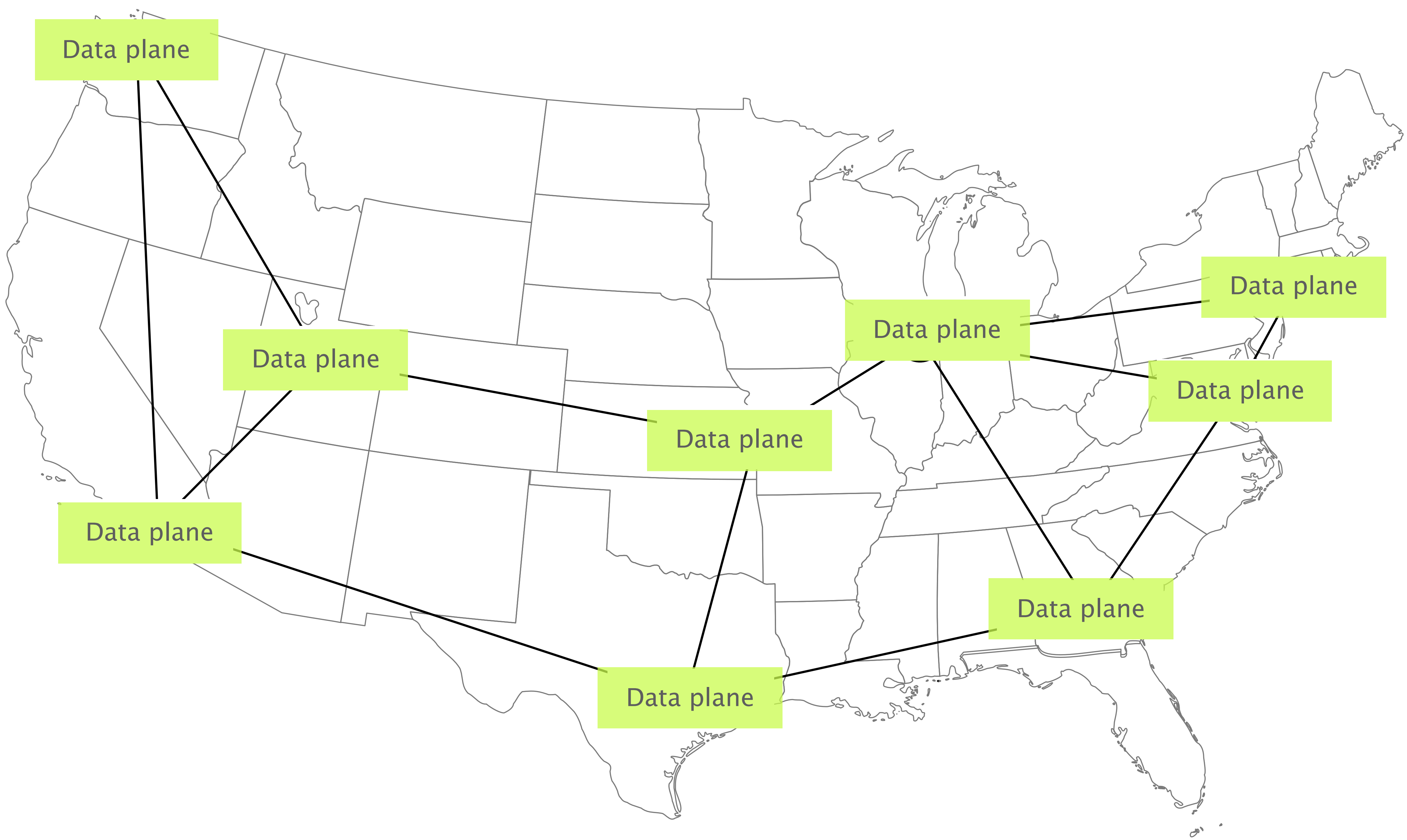


In contrast, SDN simplifies network management…

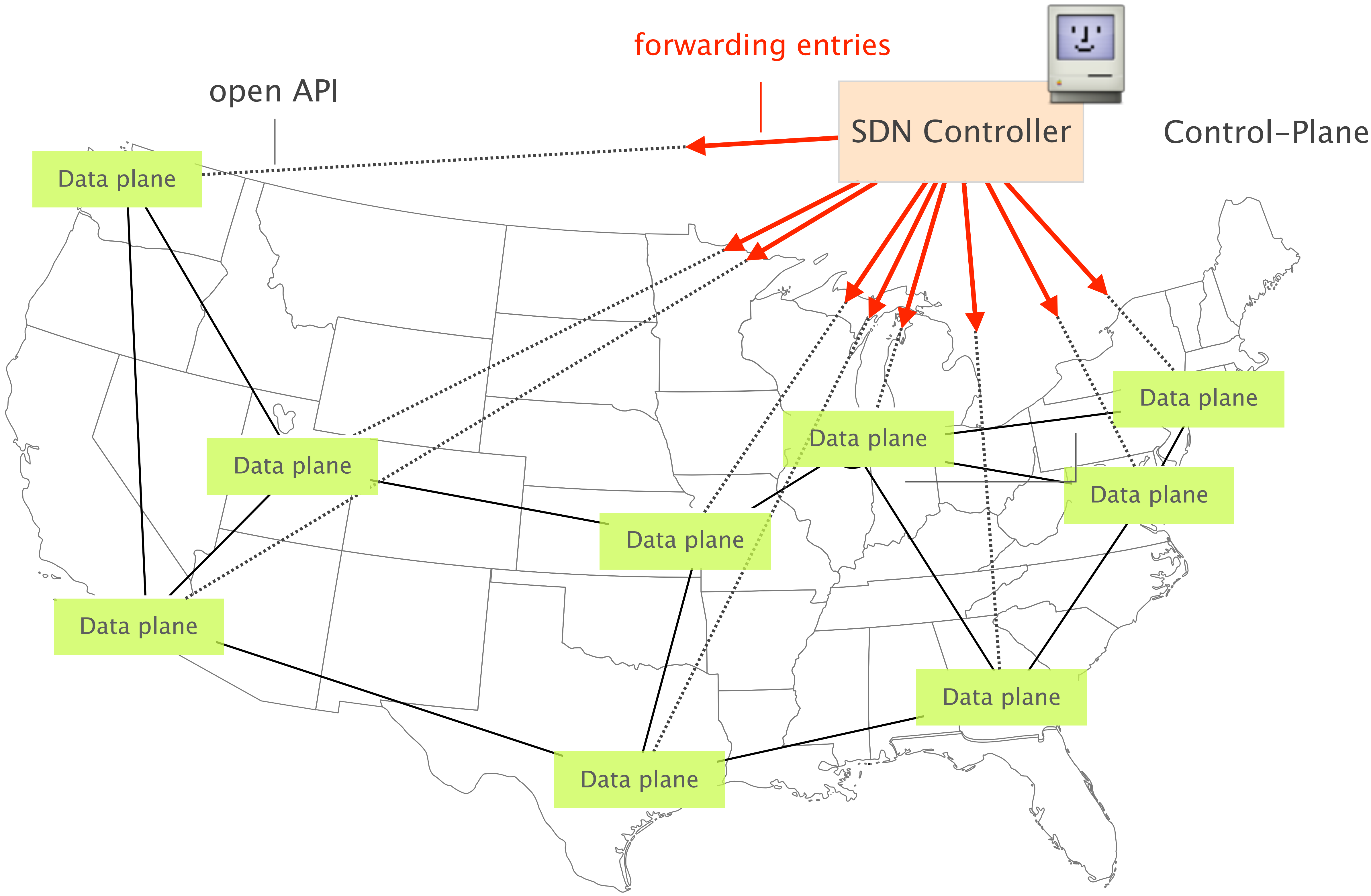
… by removing the intelligence from the routers



… by removing the intelligence from the routers

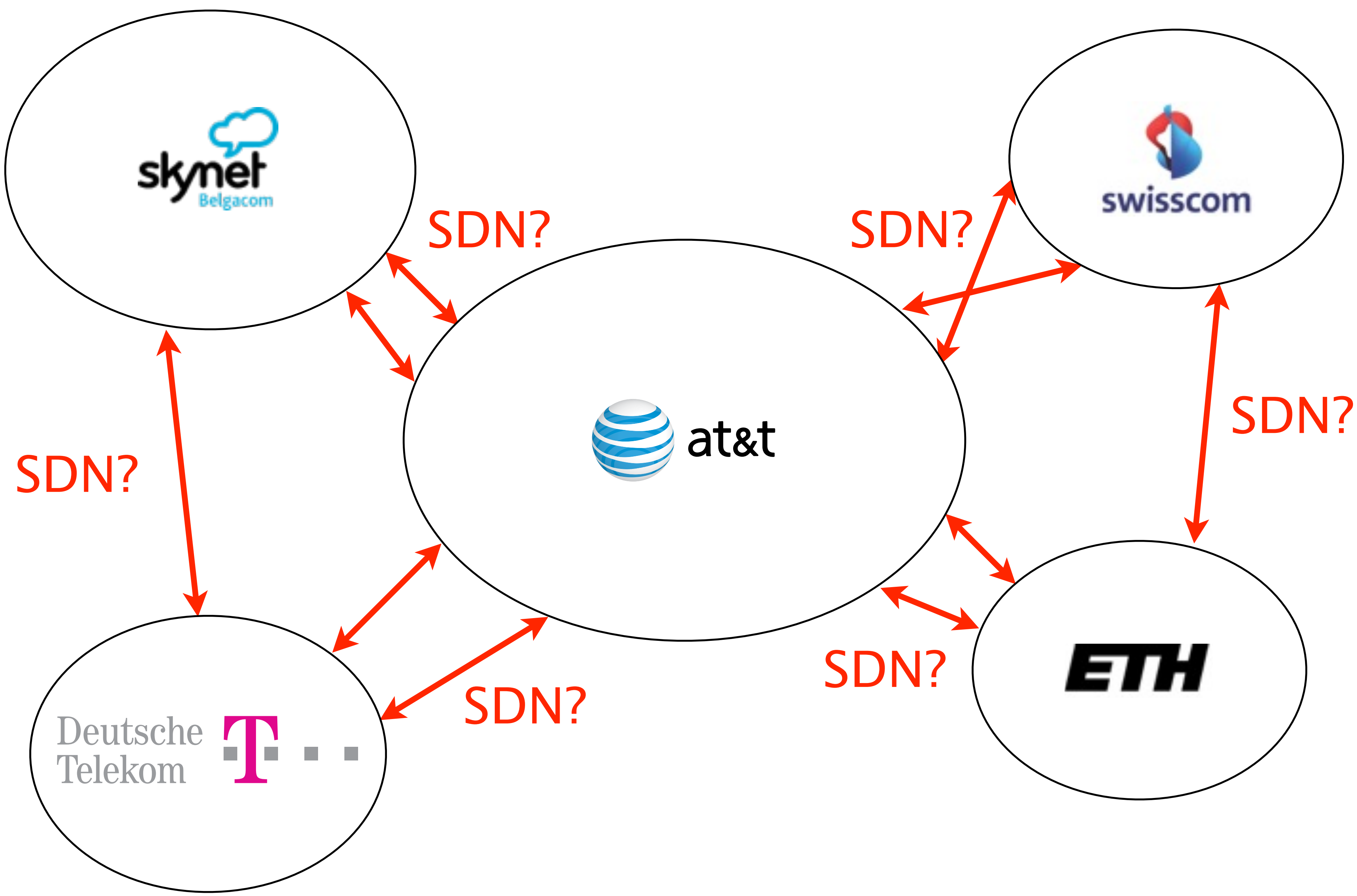


…and program forwarding entries, from logically-centralized controller



So far, SDN has mostly been applied within a network…

… but managing BGP between networks is notoriously difficult and inflexible



How do you deploy SDN in a network composed of 50,000 subnetworks?

How do you deploy SDN in a network composed of 50,000 subnetworks?

Well, you don't …

Instead, you aim at finding locations where deploying SDN can have the most impact

Instead, you aim at finding locations where deploying SDN can have the most impact

Deploy SDN in locations that

- connect a large number of networks
- carry a large amount of traffic
- are opened to innovation

Internet eXchange Points (IXP) meet all the criteria

Deploy SDN in locations that

- connect a **large number of networks**
- carry a **large amount of traffic**
- are **opened to innovation**

AMS-IX

650 networks
2.7 Tb/s (peak)
BGP Route Server Mobile peering Open peering…

https://www.ams-ix.net

A single deployment can have a large impact

Deploy SDN in locations that

- connect a large number of networks
- carry a large amount of traffic
- are opened to innovation

AMS-IX

650 networks

2.7 Tb/s (peak)

BGP Route Server

Mobile peering

Open peering…

https://www.ams-ix.net

SDX = SDN + IXP

Joint work with: Arpit Gupta, Muhammad Shahbaz, Russ Clark,

E. Katz-Bassett, Nick Feamster, Jennifer Rexford and Scott Shenker

SDX = SDN + IXP

Augment the IXP data-plane with SDN capabilities

keeping default forwarding and routing behavior

Enable fine-grained inter domain policies

bringing new features while simplifying operations

SDX = SDN + IXP

Augment the IXP data-plane with SDN capabilities

keeping default forwarding and routing behavior

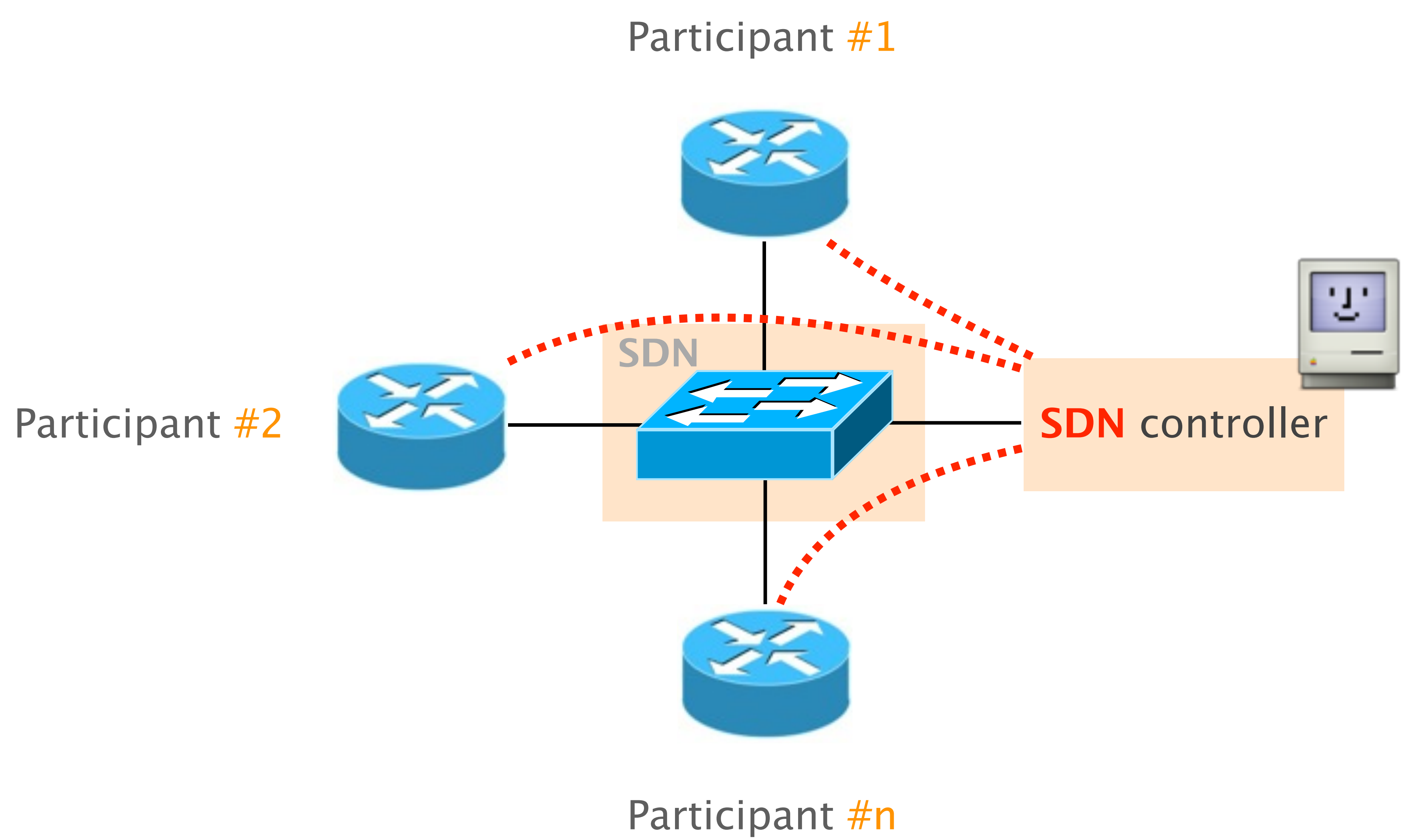
Enable fine-grained inter domain policies

bringing new features while simplifying operations

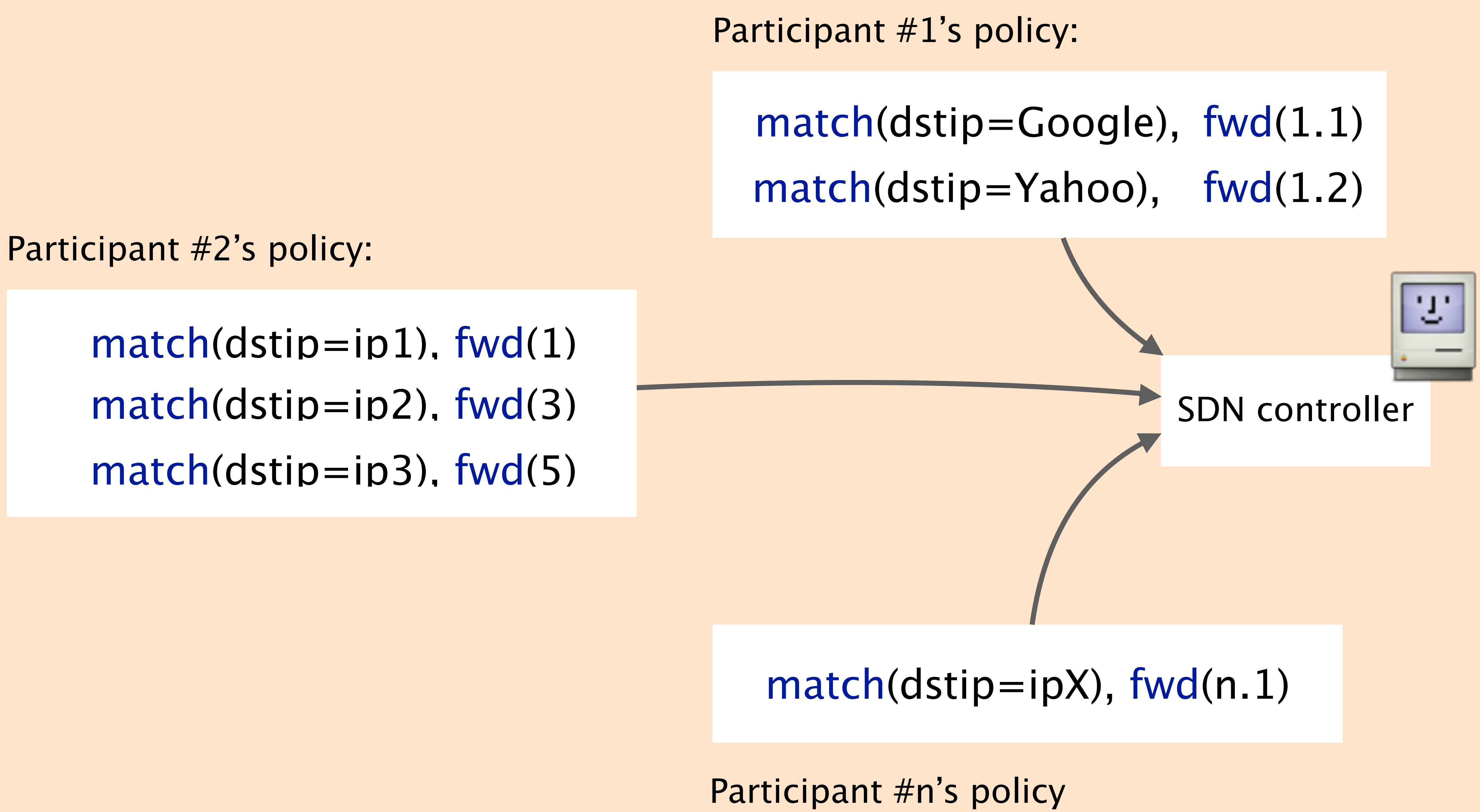
… with scalability and correctness in mind

supporting the load of a large IXP and resolving conflicts

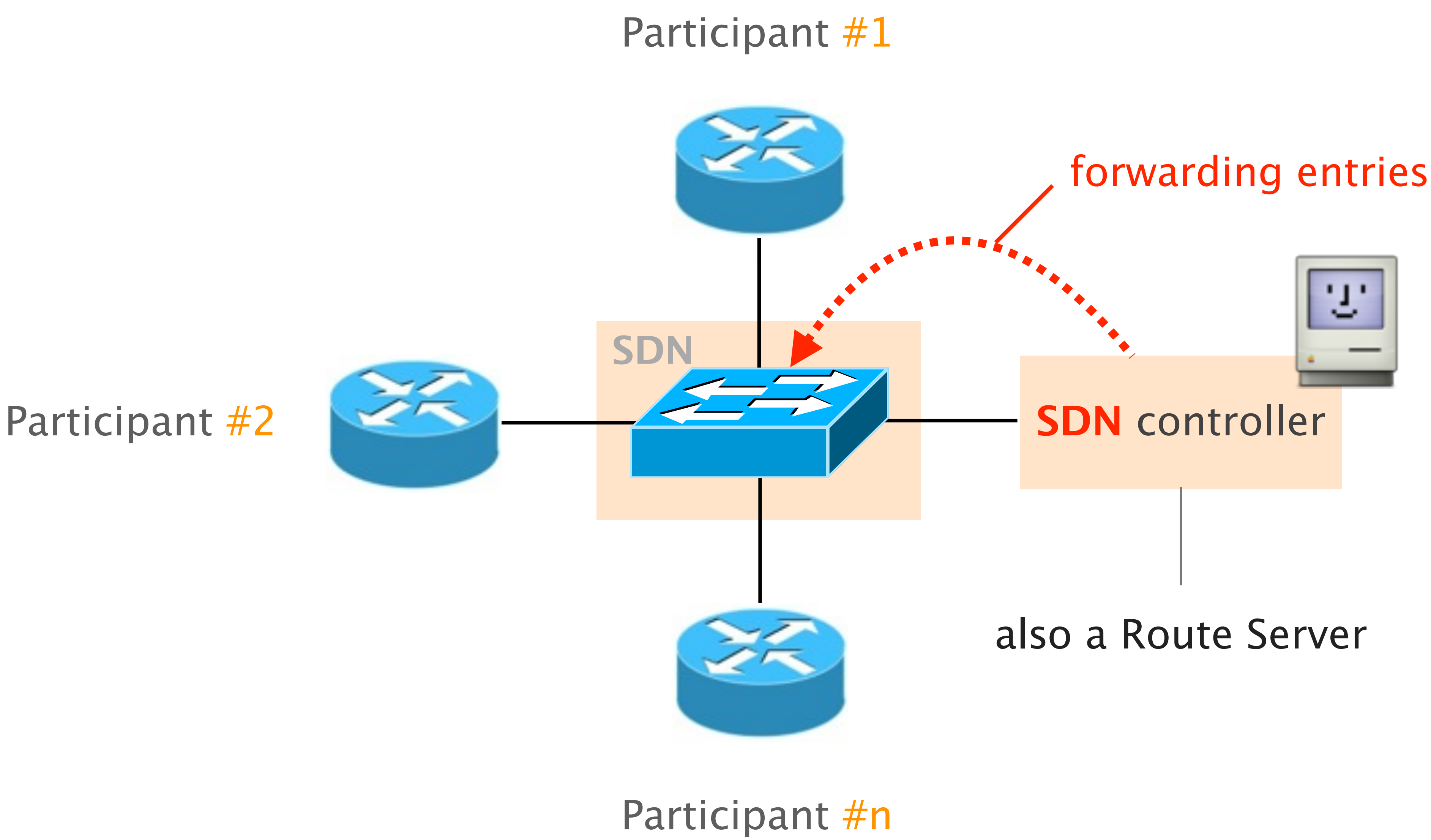
In a SDX, each participant connects its edge router(s) to a shared SDN-enabled network



Each participant writes policies independently in a high-level language and transmits them to the controller



The SDX controller compiles policies to forwarding entries ensuring isolation, scalability and avoiding conflicts



SDX enables a wide range of novel applications

security	Prevent/block policy violation
	Prevent participants communication
	Upstream blocking of DoS attacks
forwarding optimization	Middlebox traffic steering
	Traffic offloading
	Inbound Traffic Engineering
	Fast convergence
peering	Application-specific peering
remote-control	Influence BGP path selection
	Wide-area load balancing

SDX works today!

We have running code (*)

controller and BGP daemon

We have a first deployment

@Telx Internet Exchange in Atlanta

Many interested parties

including AMS-IX, LINX, Amazon, Facebook & Google

(*) https://github.com/agupta13/sdx-optimized

2 fundamental properties of a good routing system

scalability
tolerate growth

manageability
enable flexibility

This talk

DRAGON

distributed filtering

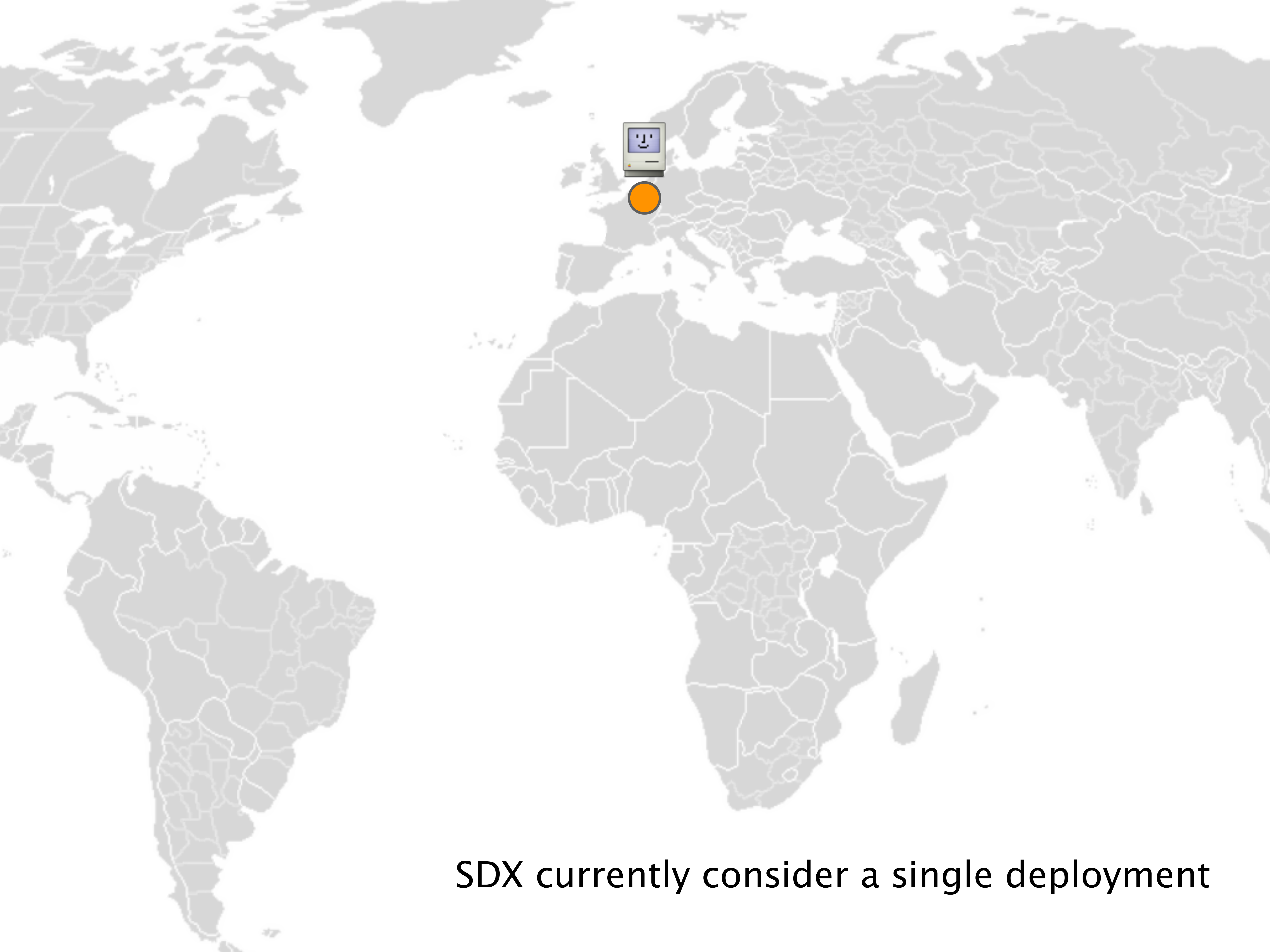
SDX

flexible policies

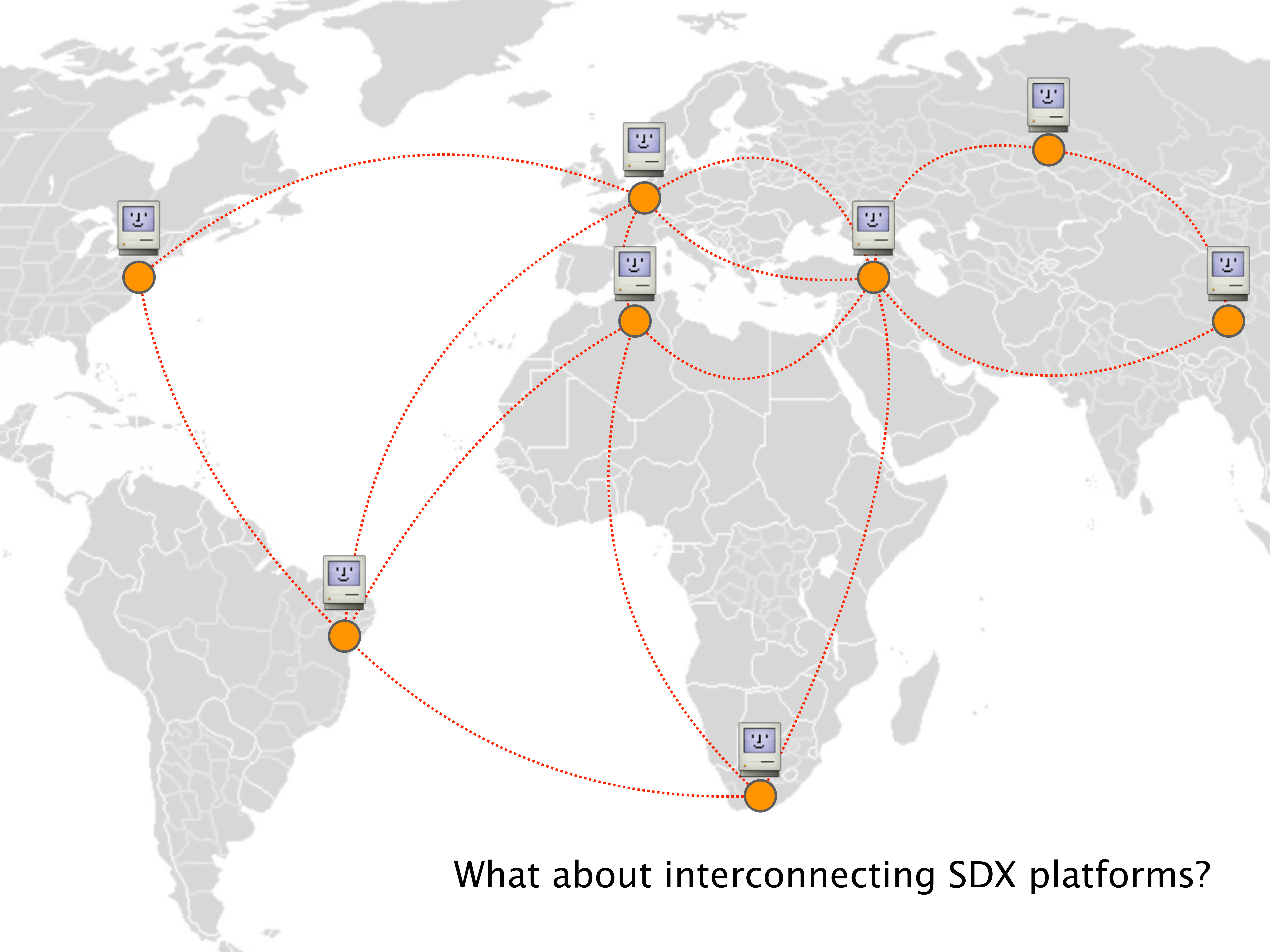
What’s next?

Internet ♥ SDN

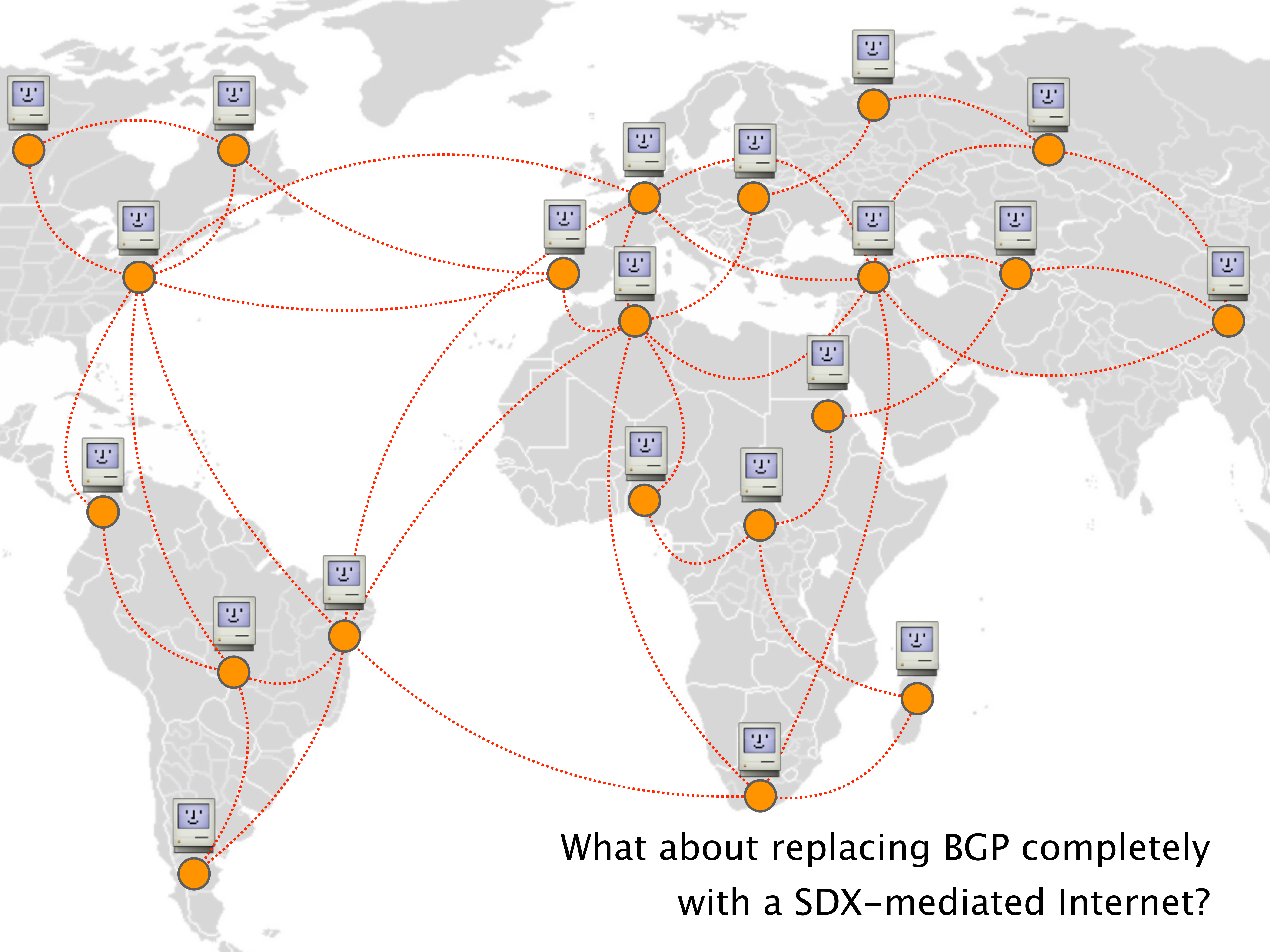
Part I: A SDX-mediated Internet



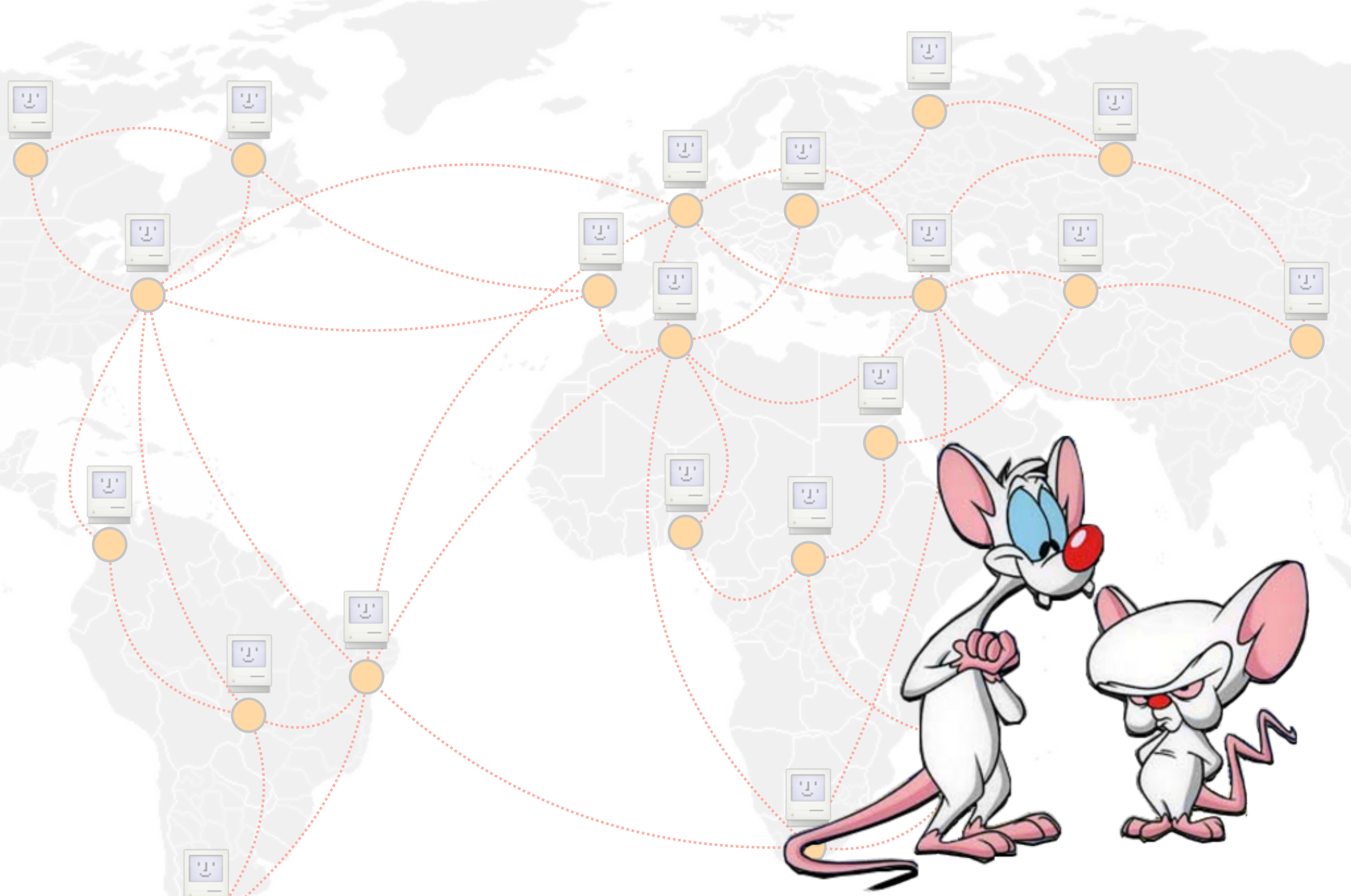
SDX currently consider a single deployment



What about interconnecting SDX platforms?



What about replacing BGP completely
with a SDX-mediated Internet?



“Let’s take over the world”

Towards a SDX-mediated Internet

New endpoint peering paradigm

more flexible, tailored to the traffic exchanged

Simple, scalable & policy neutral Internet core

SDX-to-SDX only, just carry bits

In-synch with the current Internet ecosystem

content consumer vs content provider vs transit network

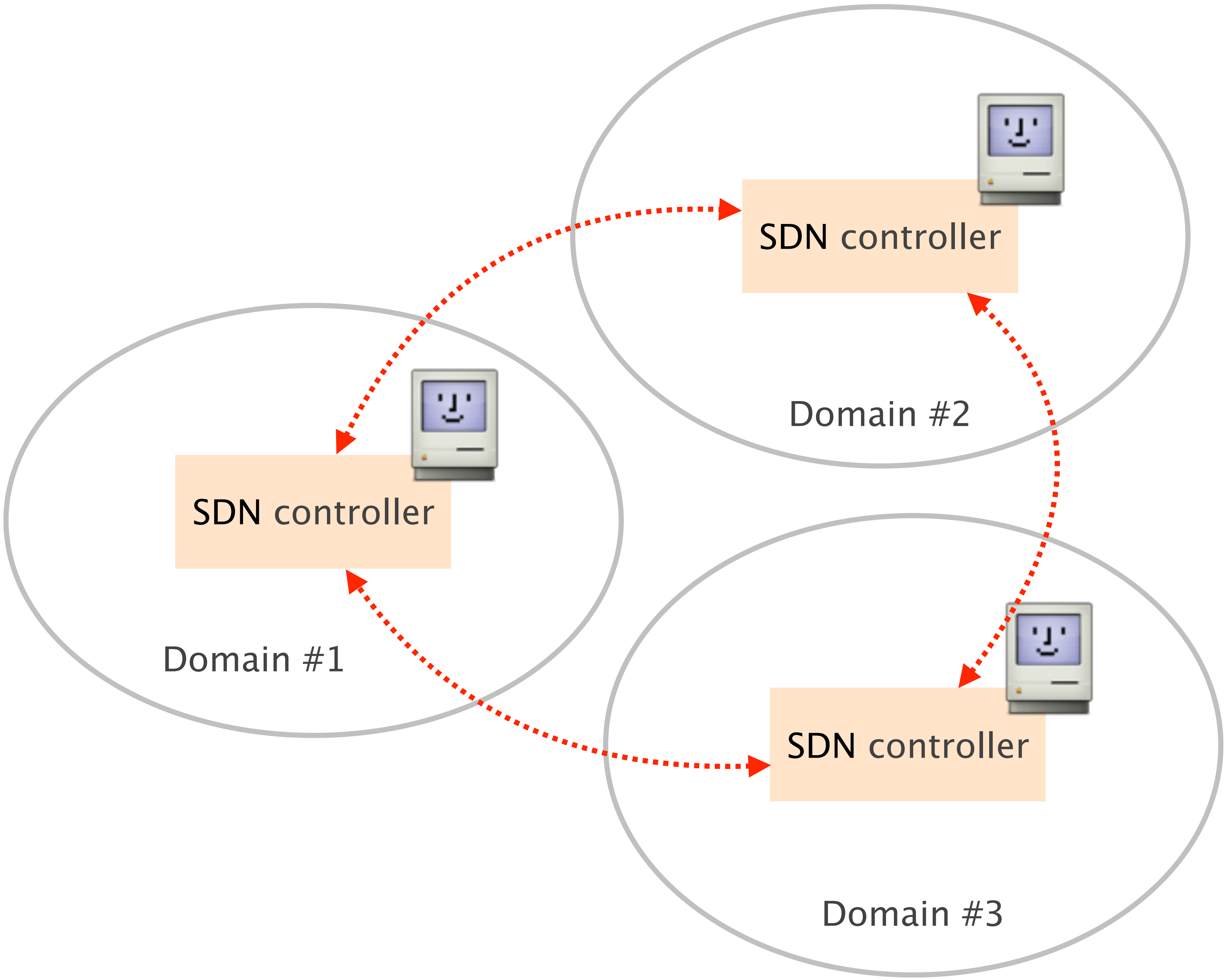
Many novel research questions!

policy analysis?	New endpoint peering paradigm more flexible, tailored to the traffic exchanged
routing mechanism?	Simple, scalable & policy neutral Internet core SDX-to-SDX only, just carry bits
new provider type?	In-synch with the current Internet ecosystem content consumer vs content provider vs transit network

Internet ❤ SDN

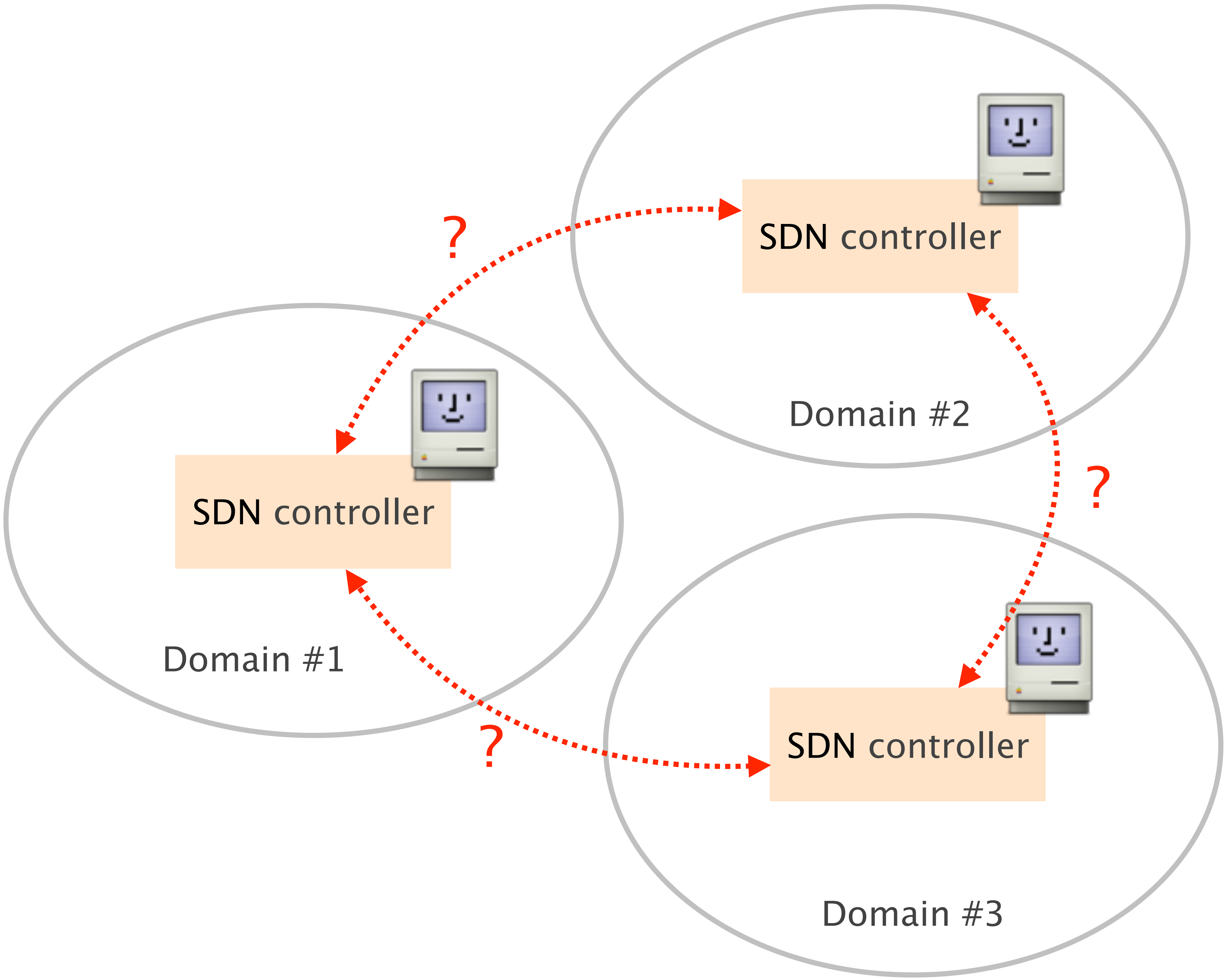
Part II: Rethinking inter-domain routing

SDN controllers sitting in different domains will have to exchange reachability information…

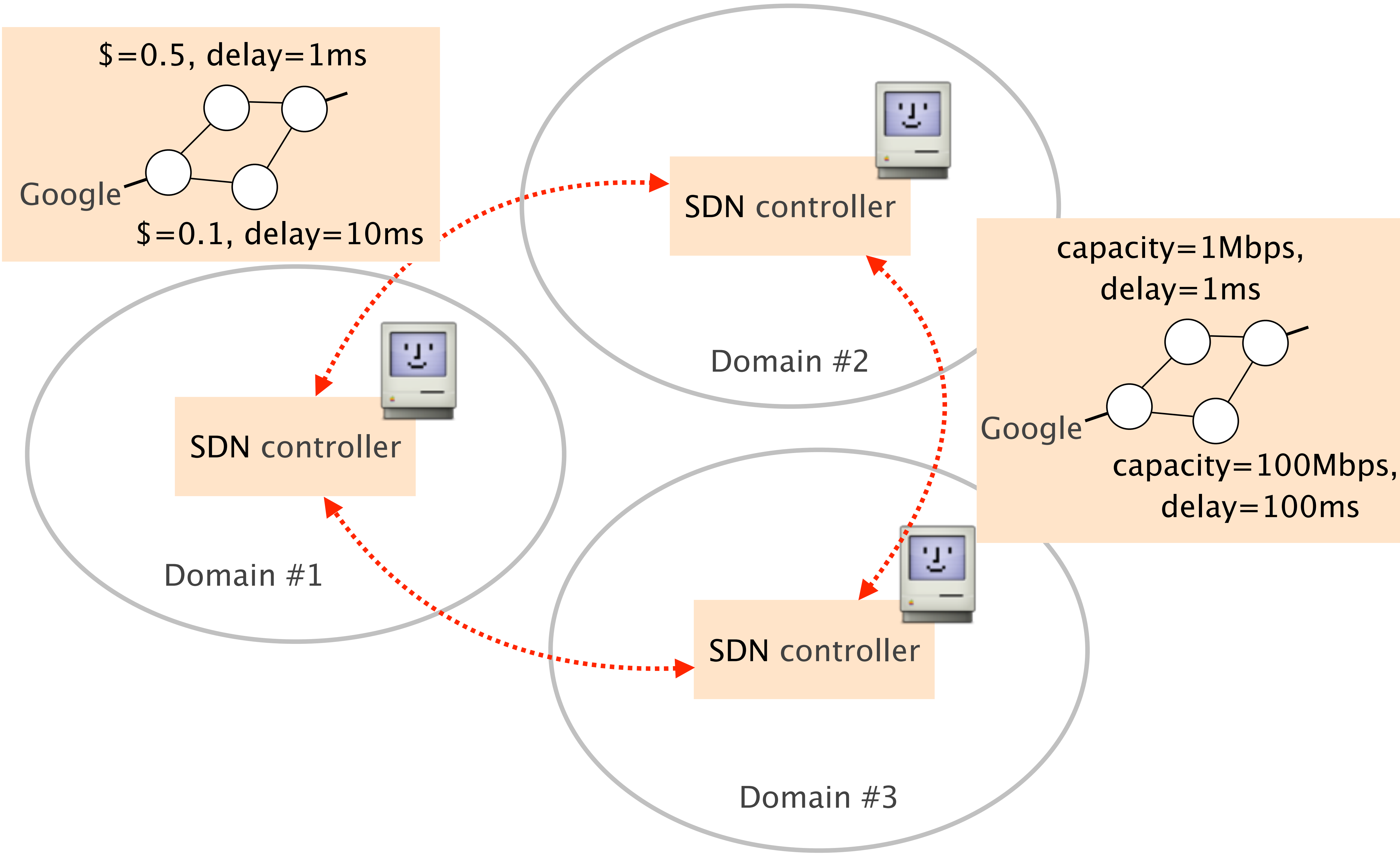


What protocol shall they use?

hint: not BGP!



Instead of just exchanging destination, what about transmitting abstract annotated graphs?



Annotated graphs reveal more information about paths while still letting each AS implements local policies

Announcing network can hide information using abstraction

e.g., hide internal topology, more costly exit points…

Receiving network composes the graph with its own topology

then use its own objective function to compute path

BGP is just a special case in which each graph is a “node”

support partial deployment in the Internet

Many novel research questions!

abstraction operator?	Announcing network can hide information using abstraction e.g., hide internal topology, more costly exit points…
composition mechanism? correctness?	Receiving network composes the graph with its own topology then use its own objective function to compute path
data-plane realization?	BGP is just a special case in which each graph is a “node” support partial deployment in the Internet

Making the Internet more scalable and manageable

Laurent Vanbever

www.vanbever.eu

ETH Zürich

March, 17 2014