Communication Networks

Spring 2019

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April 1 2019

Materials inspired from Scott Shenker & Jennifer Rexford

Internet Hackathon

This Thursday @6pm in ETZ hall + ETZ E6

2016 edition

No exercise session this Thursday

Q&A session today (April 1)

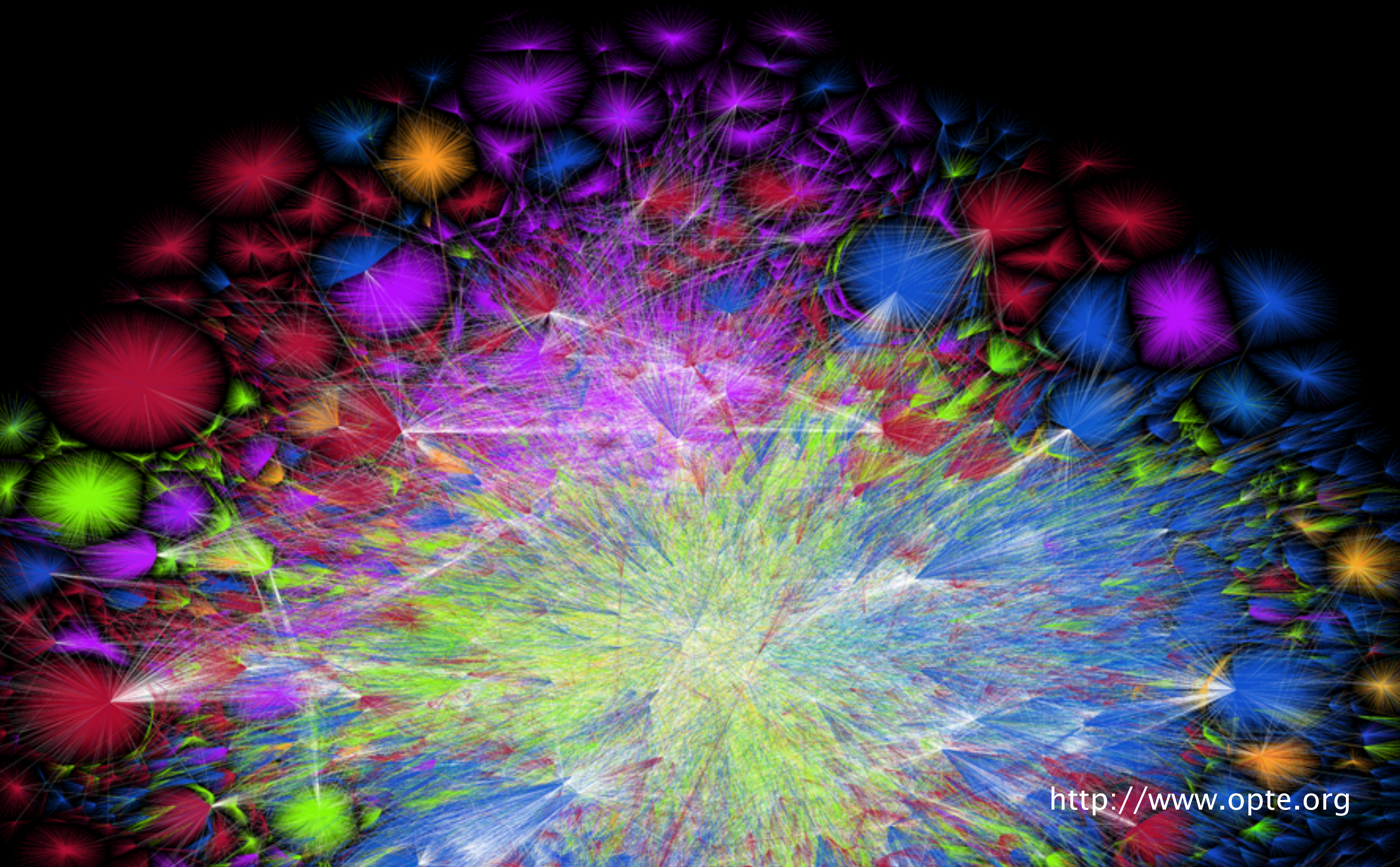
3pm to 5pm in ETZ G71.2

and online on #routing_project

Last week on

Communication Networks

Internet routing



http://www.opte.org

Internet routing

from here to there, and back

1 **Intra-domain routing**

- Link-state protocols
- Distance-vector protocols

2 **Inter-domain routing**

- Path-vector protocols

Internet routing

from here to there, and back

1 **Intra-domain routing**

Link-state protocols

Distance-vector protocols

Inter-domain routing

Path-vector protocols

In Link-State routing, routers build a precise map of the network by flooding local views to everyone

Each router keeps track of its incident links and cost

as well as whether it is up or down

Each router broadcast its own links state

to give every router a complete view of the graph

Routers run Dijkstra on the corresponding graph

to compute their shortest-paths and forwarding tables

Distance-vector protocols are based on Bellman-Ford algorithm

Let $d_x(y)$ be the cost of the least-cost path known by x to reach y

Each node bundles these distances into one message (called a vector) that it repeatedly sends to all its neighbors

until convergence

Each node updates its distances based on neighbors' vectors:

$$d_x(y) = \min\{ c(x,v) + d_v(y) \}$$ over all neighbors v

Internet routing

from here to there, and back

Intra-domain routing

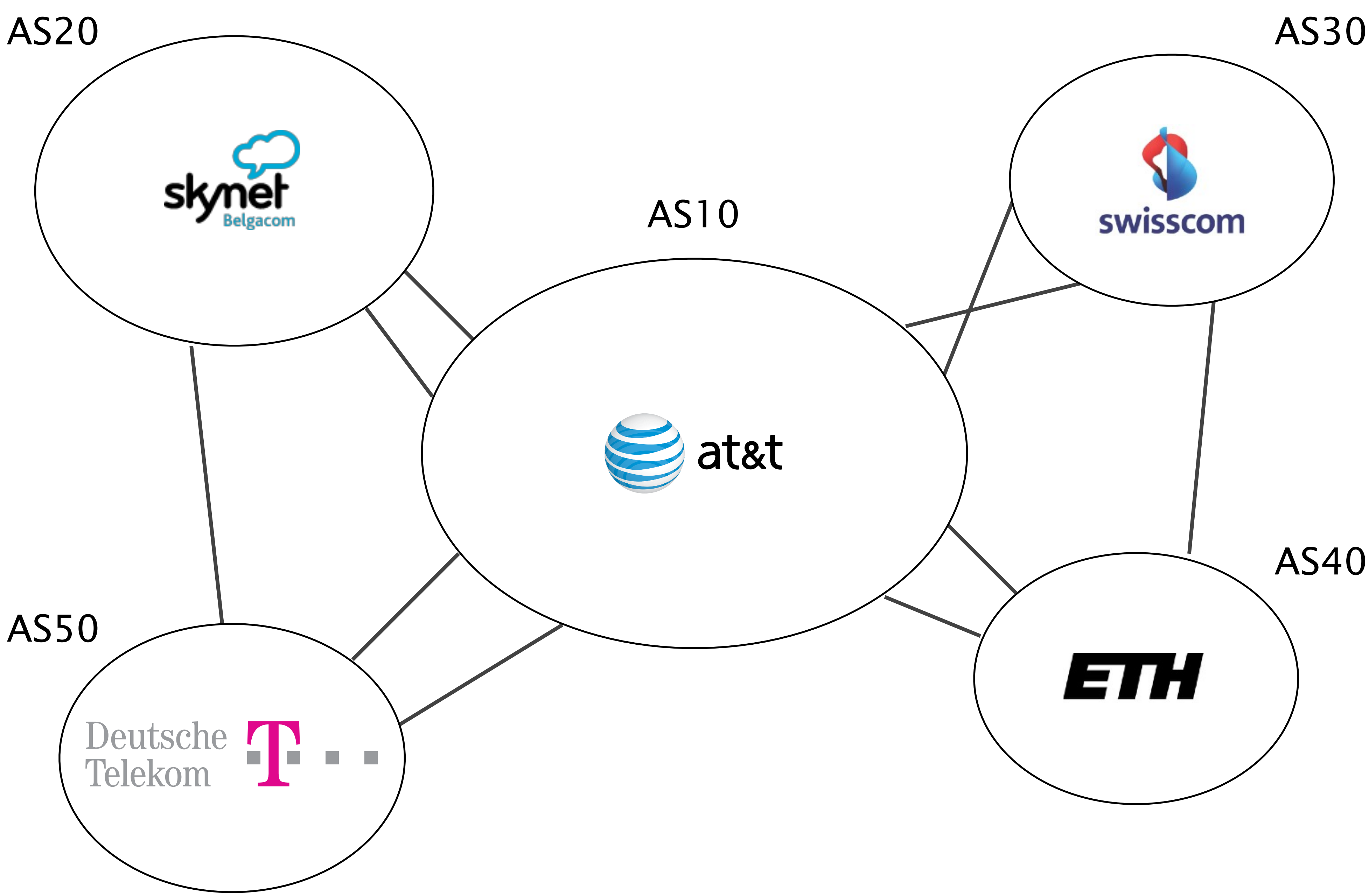
Link-state protocols

Distance-vector protocols

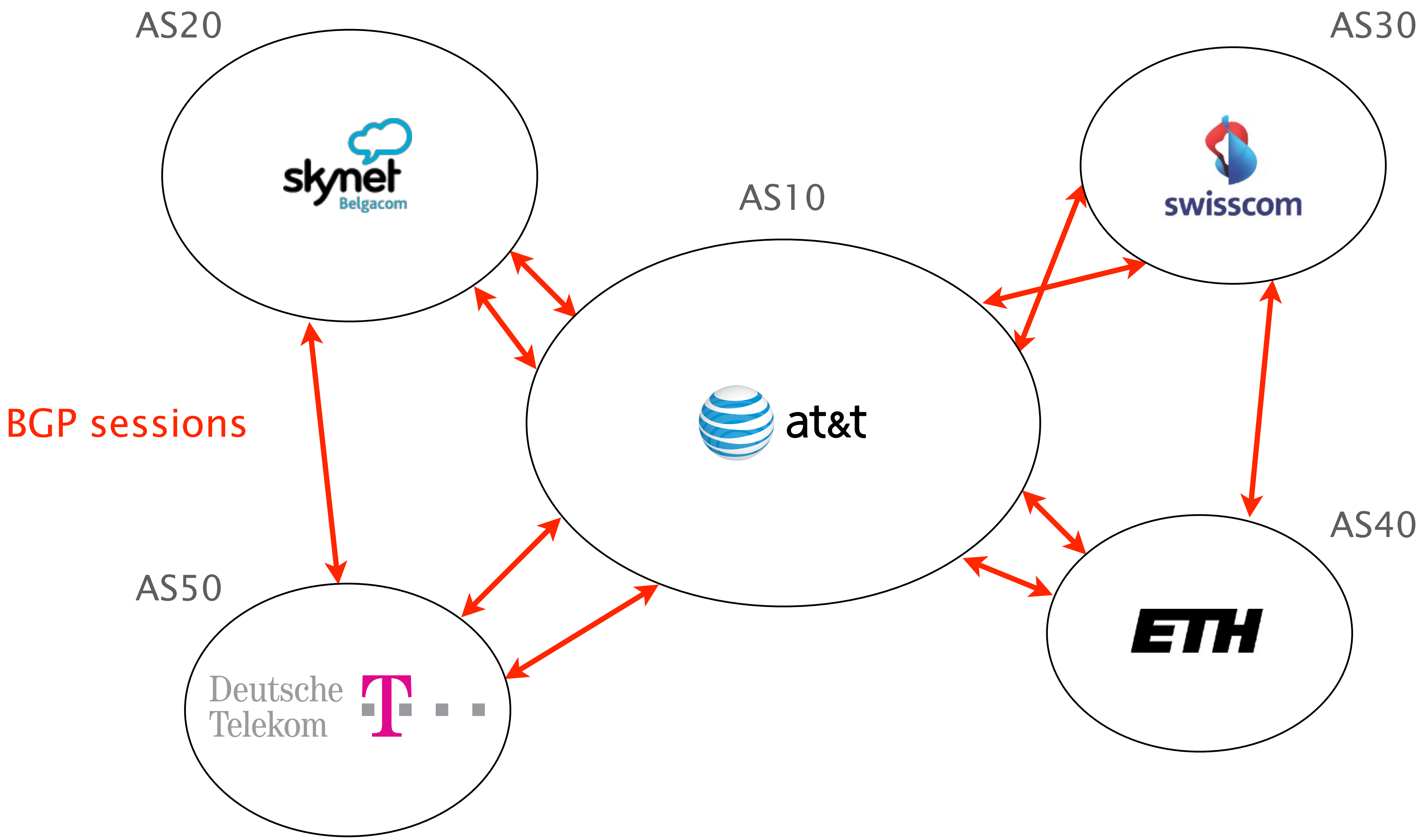
2 Inter-domain routing

Path-vector protocols

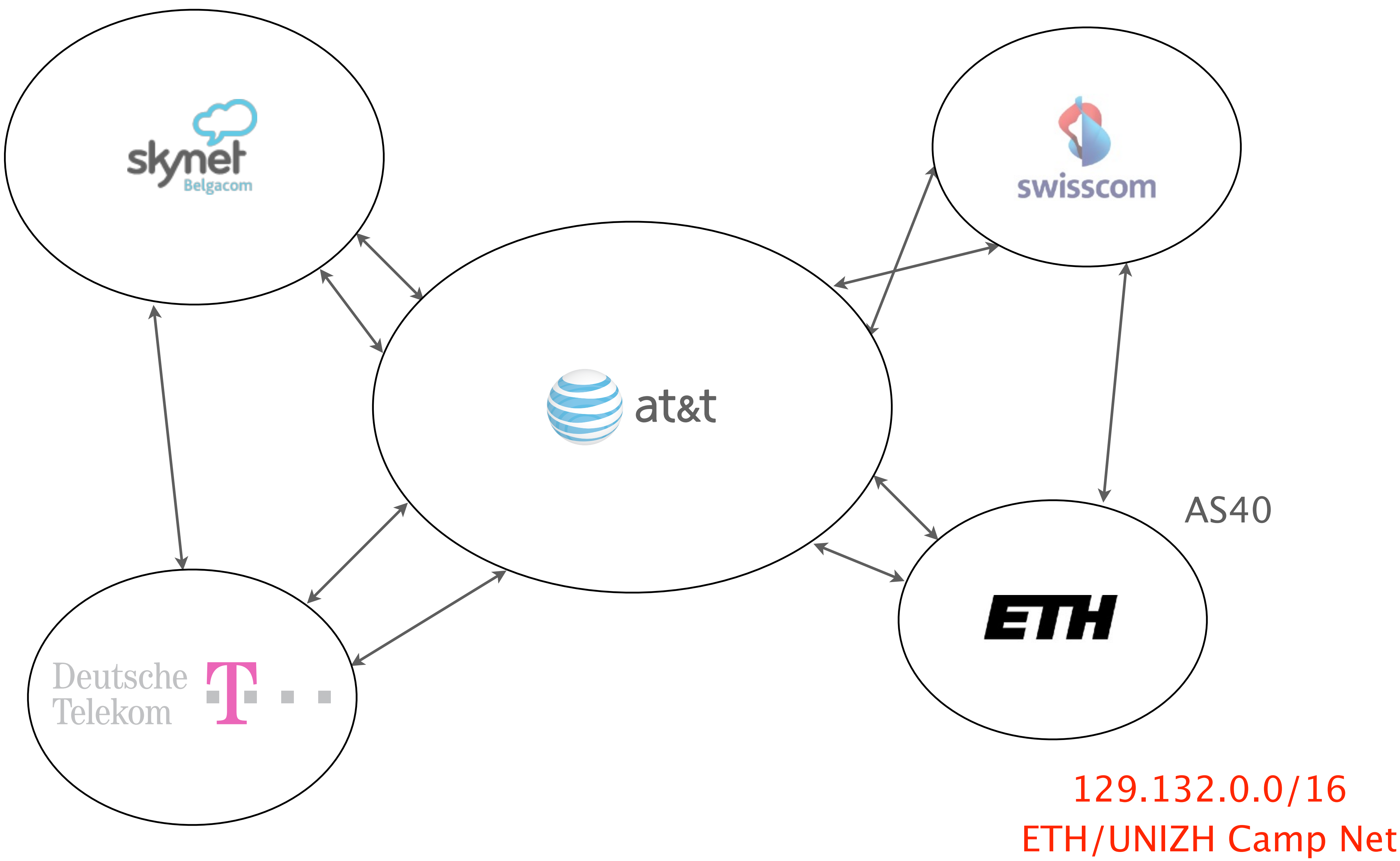
The Internet is a network of networks, referred to as Autonomous Systems (AS)



BGP is the routing protocol "glueing" the Internet together



Using BGP, ASes exchange information about the IP prefixes they can reach, directly or indirectly



BGP needs to solve three key challenges: scalability, privacy and policy enforcement

There is a huge # of networks and prefixes

700k prefixes, >50,000 networks, millions (!) of routers

Networks don't want to divulge internal topologies

or their business relationships

Networks needs to control where to send and receive traffic

without an Internet-wide notion of a link cost metric

Link-State routing does not solve these challenges

Floods topology information

high processing overhead

Requires each node to compute the entire path

high processing overhead

Minimizes some notion of total distance

works only if the policy is shared and uniform

Distance-Vector routing is on the right track

pros	Hide details of the network topology
	nodes determine only “next-hop” for each destination

Distance-Vector routing is on the right track, but not really there yet…

pros

Hide details of the network topology

nodes determine only “next-hop” for each destination

cons

It still minimizes some common distance

impossible to achieve in an inter domain setting

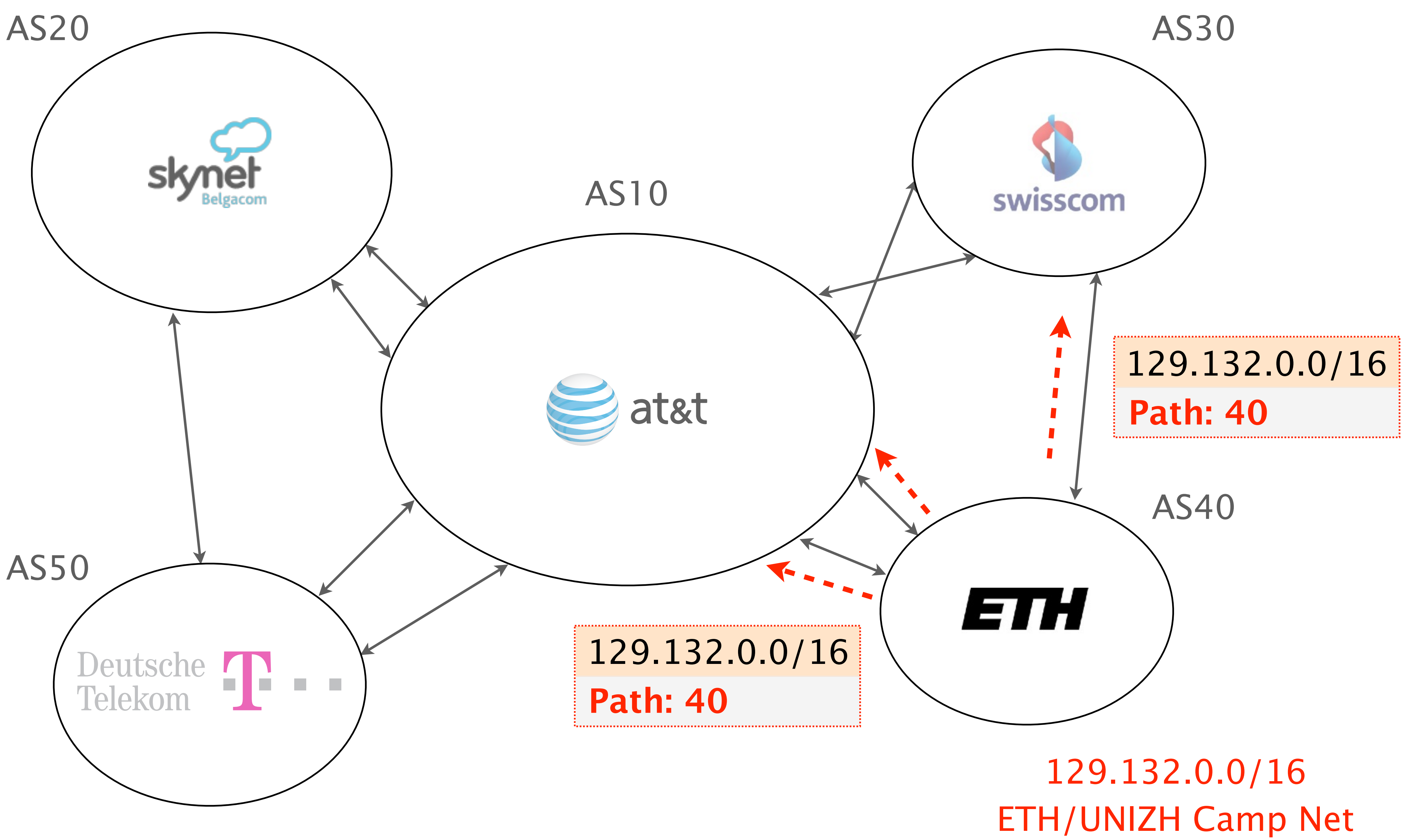
It converges slowly

counting-to-infinity problem

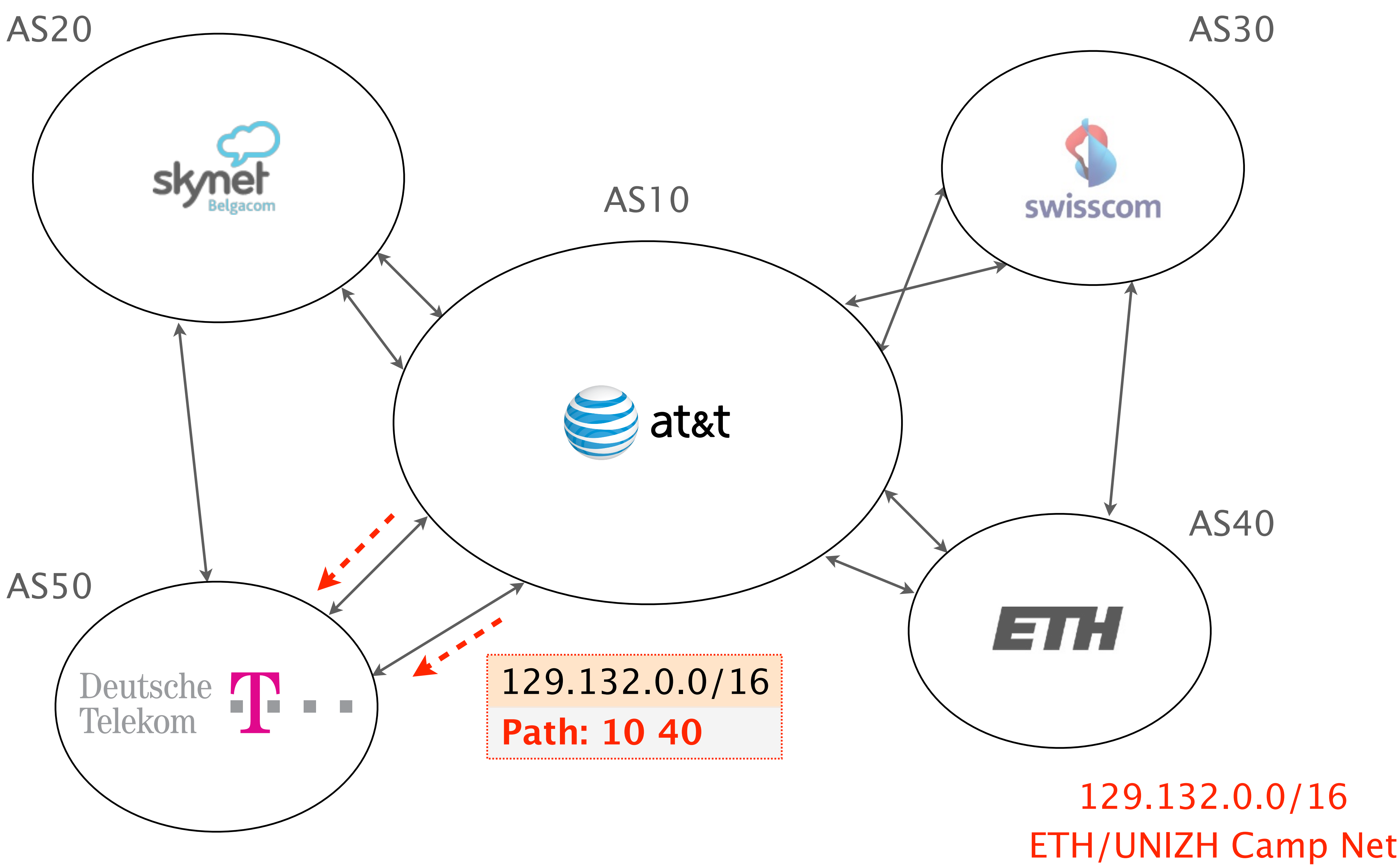
BGP relies on path-vector routing to support flexible routing policies and avoid count-to-infinity

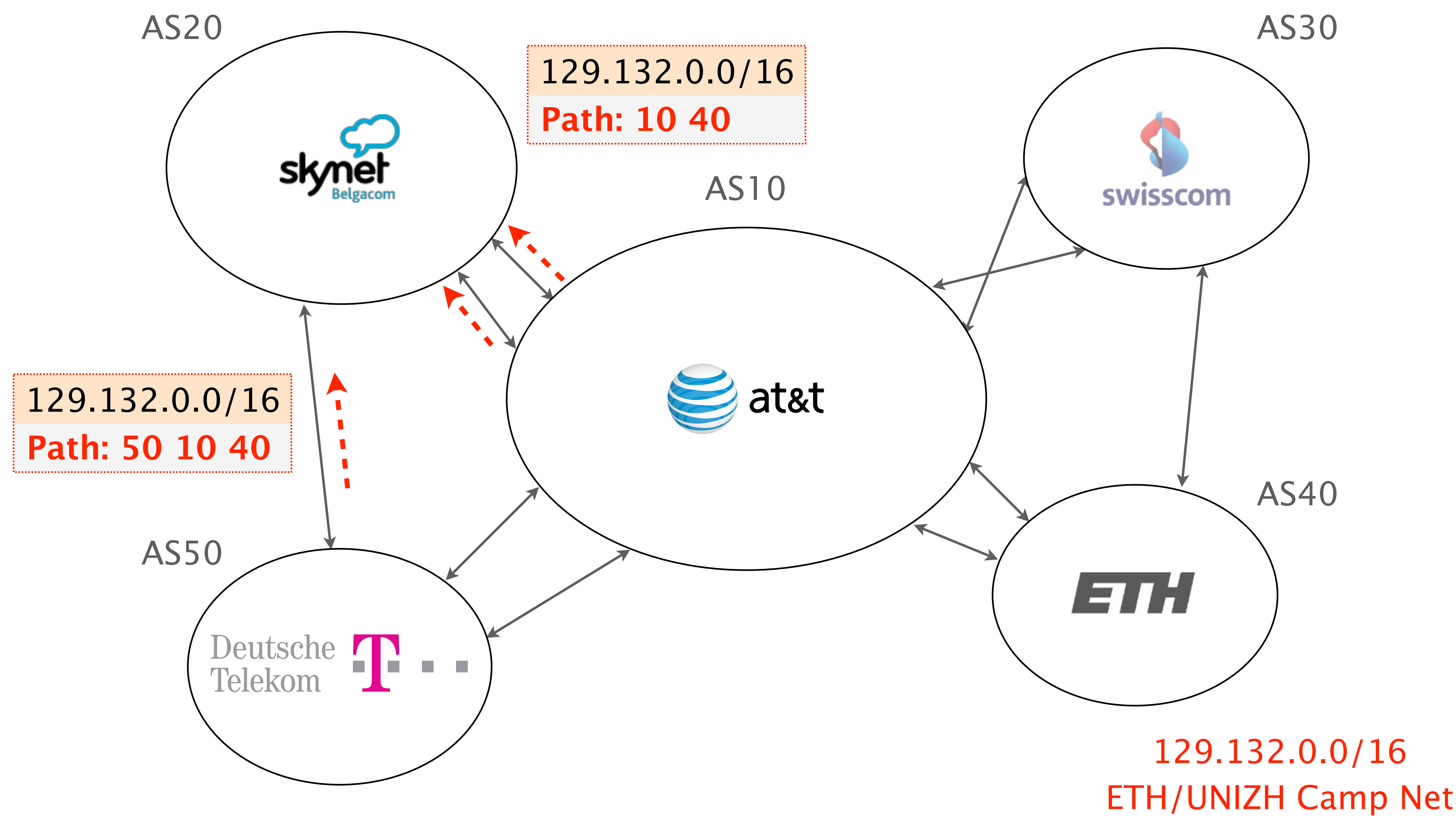
key idea advertise the entire path instead of distances

BGP announcements carry complete path information instead of distances



Each AS appends itself to the path when it propagates announcements





AS20
129.132.0.0/16
Path: 10 40
AS30
AS10
129.132.0.0/16
Path: 50 10 40
AS40
AS50
129.132.0.0/16
ETH/UNIZH Camp Net

This week on

Communication Networks

Border Gateway Protocol

policies and more

1 **BGP Policies**

Follow the Money

2 **Protocol**

How does it work?

3 **Problems**

security, performance, …

Border Gateway Protocol

policies and more

1 **BGP Policies**

Follow the Money

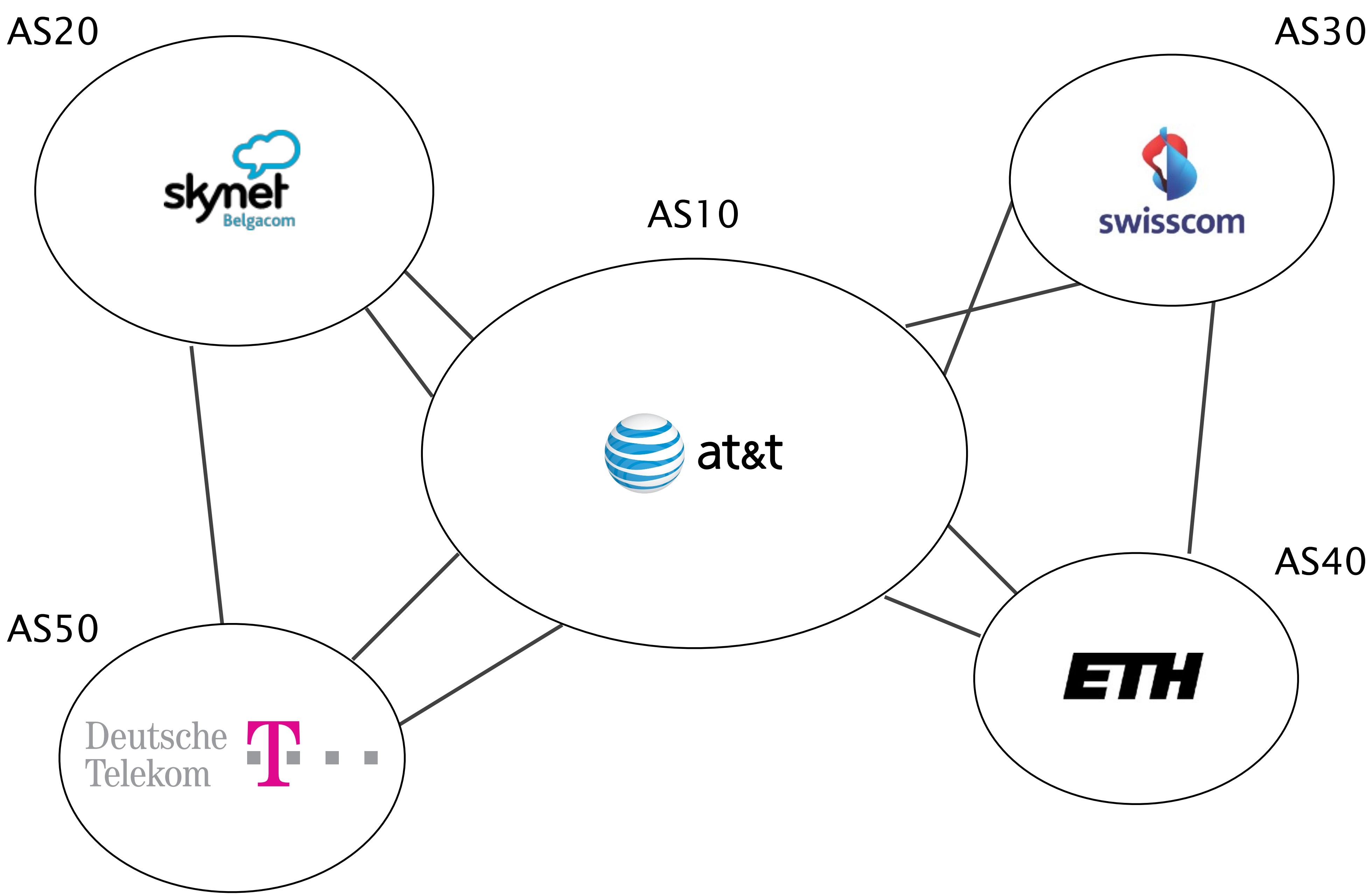
Protocol

How does it work?

Problems

security, performance, …

The Internet topology is shaped according to business relationships



Intuition

2 ASes connect only if they have a business relationship

BGP is a "follow the money" protocol

There are 2 main business relationships today:

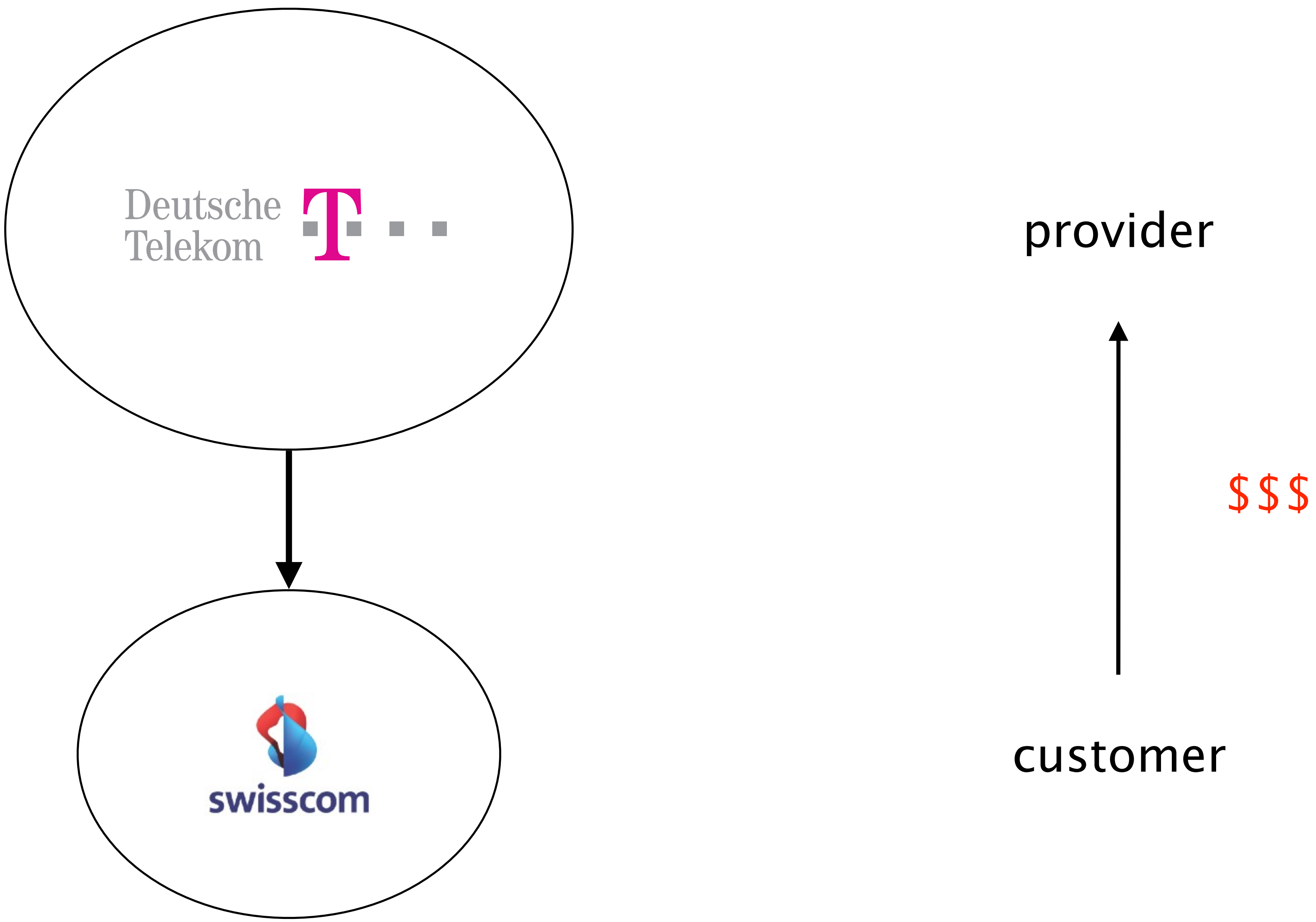
- customer/provider
- peer/peer

many less important ones (siblings, backups,...)

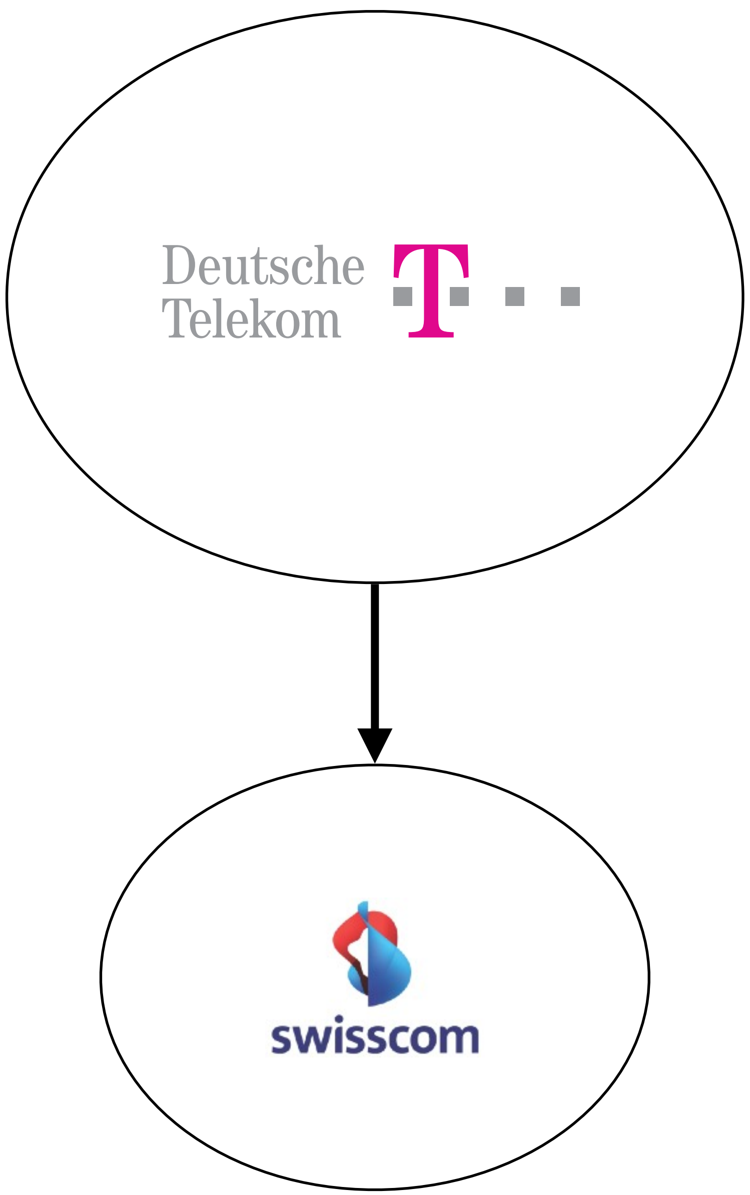
There are 2 main business relationships today:

- customer/provider
- peer/peer

Customers pay providers
to get Internet connectivity



The amount paid is based on peak usage, usually according to the 95th percentile rule



Every 5 minutes, DT

records the # of bytes sent/received

At the end of the month, DT

- sorts all values in decreasing order
- removes the top 5% values
- bills wrt highest remaining value

Most ISPs discounts traffic unit price when pre-committing to certain volume

commit		unit price ($)	Minimum monthly bill ($/month)
10	Mbps	12	120
100	Mbps	5	500
1	Gbps	3.50	3,500
10	Gbps	1.20	12,000
100	Gbps	0.70	70,000

Examples taken from The 2014 Internet Peering Playbook

Internet Transit Prices have been continuously declining during the last 20 years

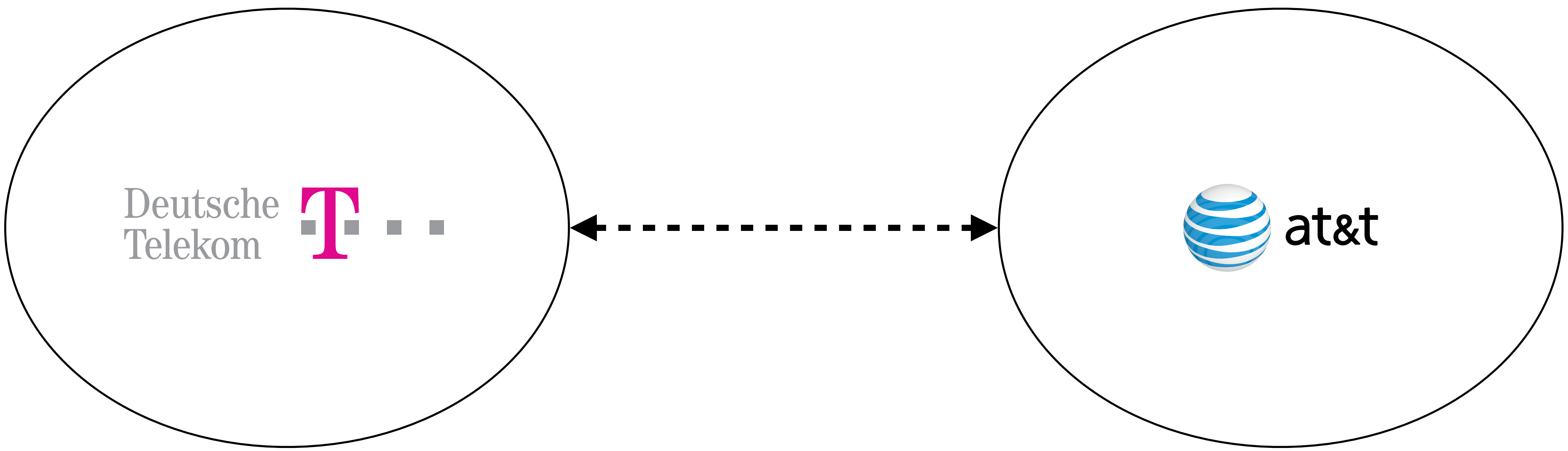
Internet Transit Pricing (1998-2015)			
Source: http://DrPeering.net			
Year	**Internet Transit Price**		**% decline**
1998	$1,200.00	per Mbps	
1999	$800.00	per Mbps	33%
2000	$675.00	per Mbps	16%
2001	$400.00	per Mbps	41%
2002	$200.00	per Mbps	50%
2003	$120.00	per Mbps	40%
2004	$90.00	per Mbps	25%
2005	$75.00	per Mbps	17%
2006	$50.00	per Mbps	33%
2007	$25.00	per Mbps	50%
2008	$12.00	per Mbps	52%
2009	$9.00	per Mbps	25%
2010	$5.00	per Mbps	44%
2011	$3.25	per Mbps	35%
2012	$2.34	per Mbps	28%
2013	$1.57	per Mbps	33%
2014	$0.94	per Mbps	40%
2015	$0.63	per Mbps	33%

The reason? Internet commoditization & competition

There are 2 main business relationships today:

- customer/provider
- peer/peer

Peers don’t pay each other for connectivity,
they do it *out of common interest*

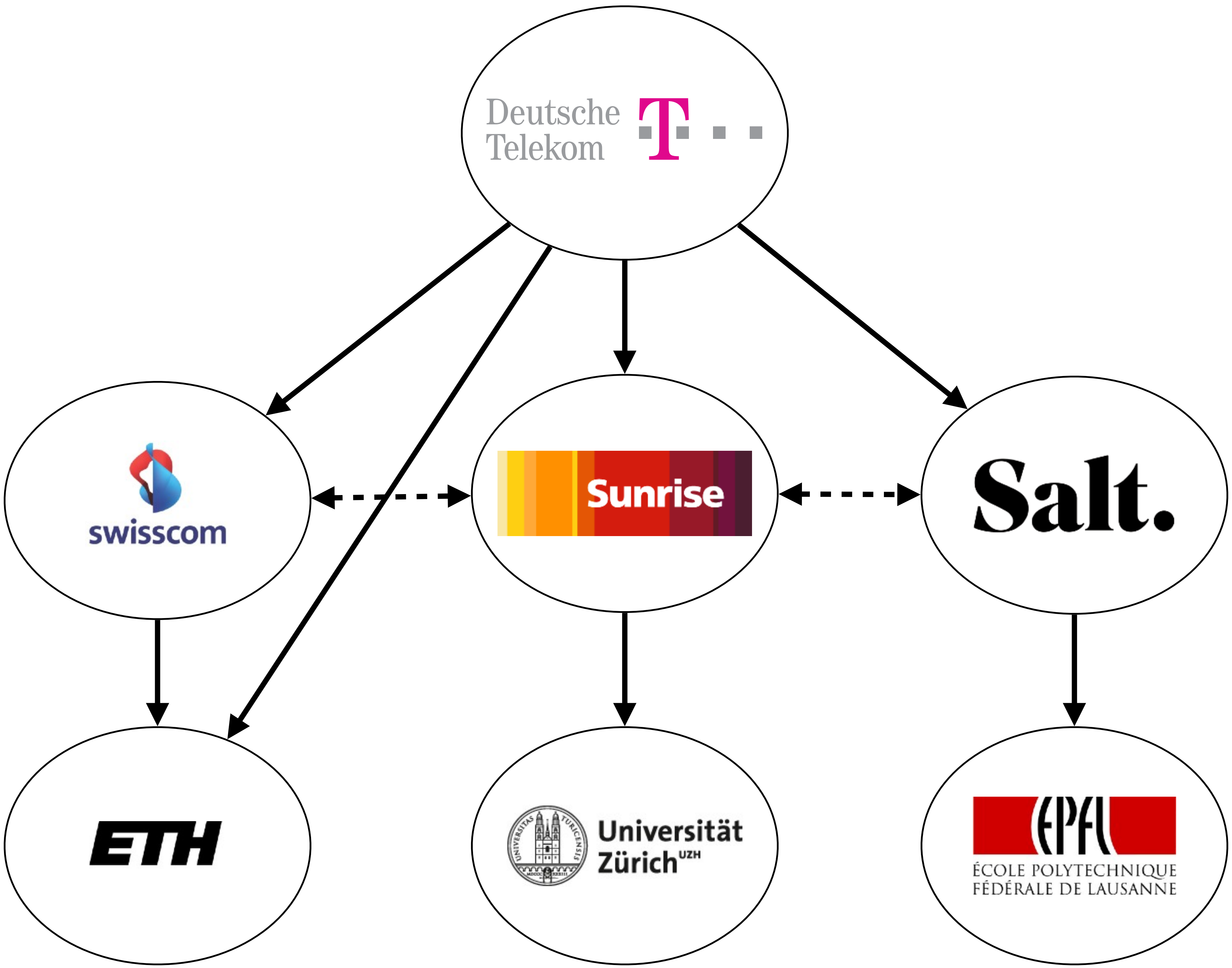


peer peer

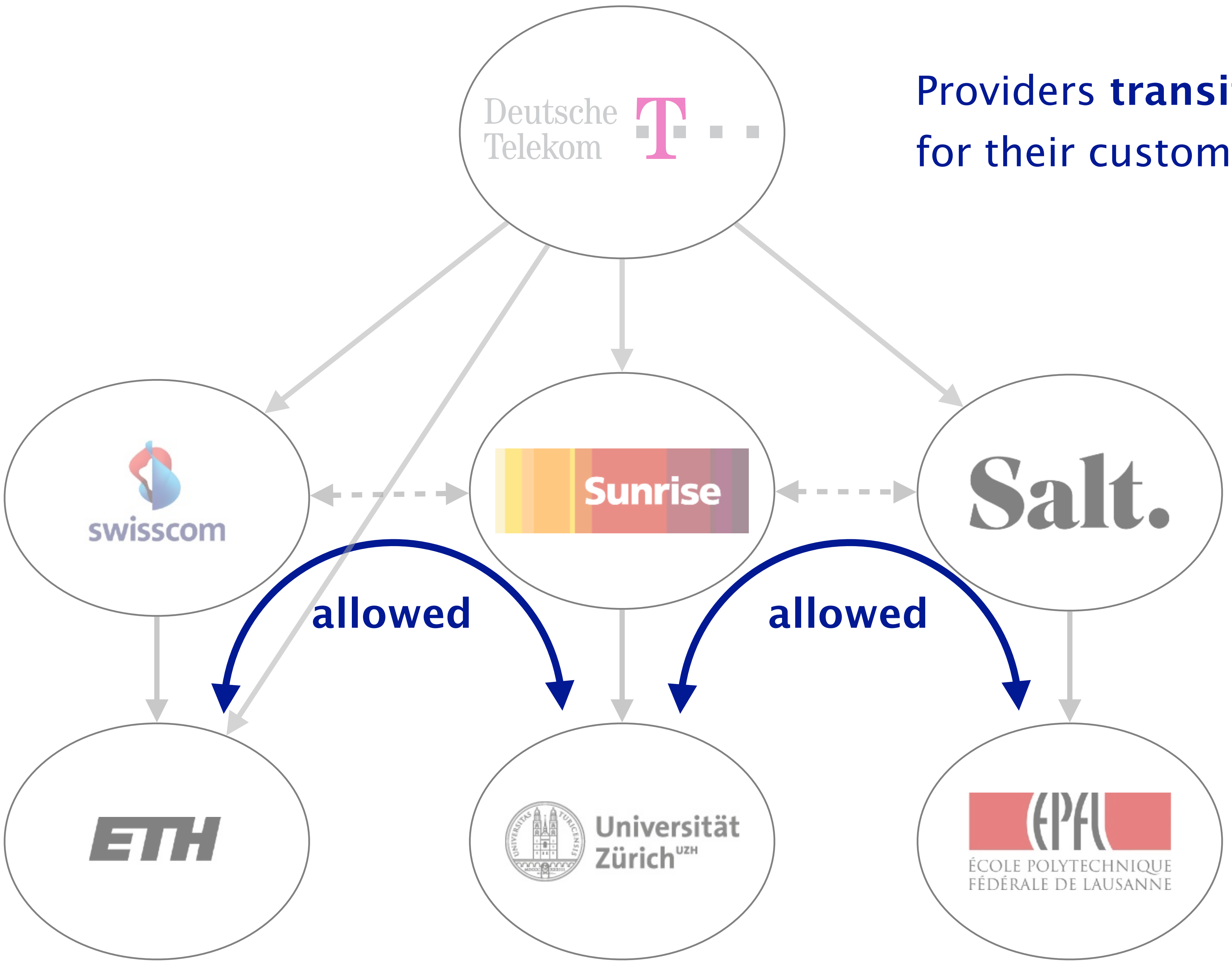
DT and ATT exchange *tons* of traffic.
they save money by directly connecting to each other

To understand Internet routing,

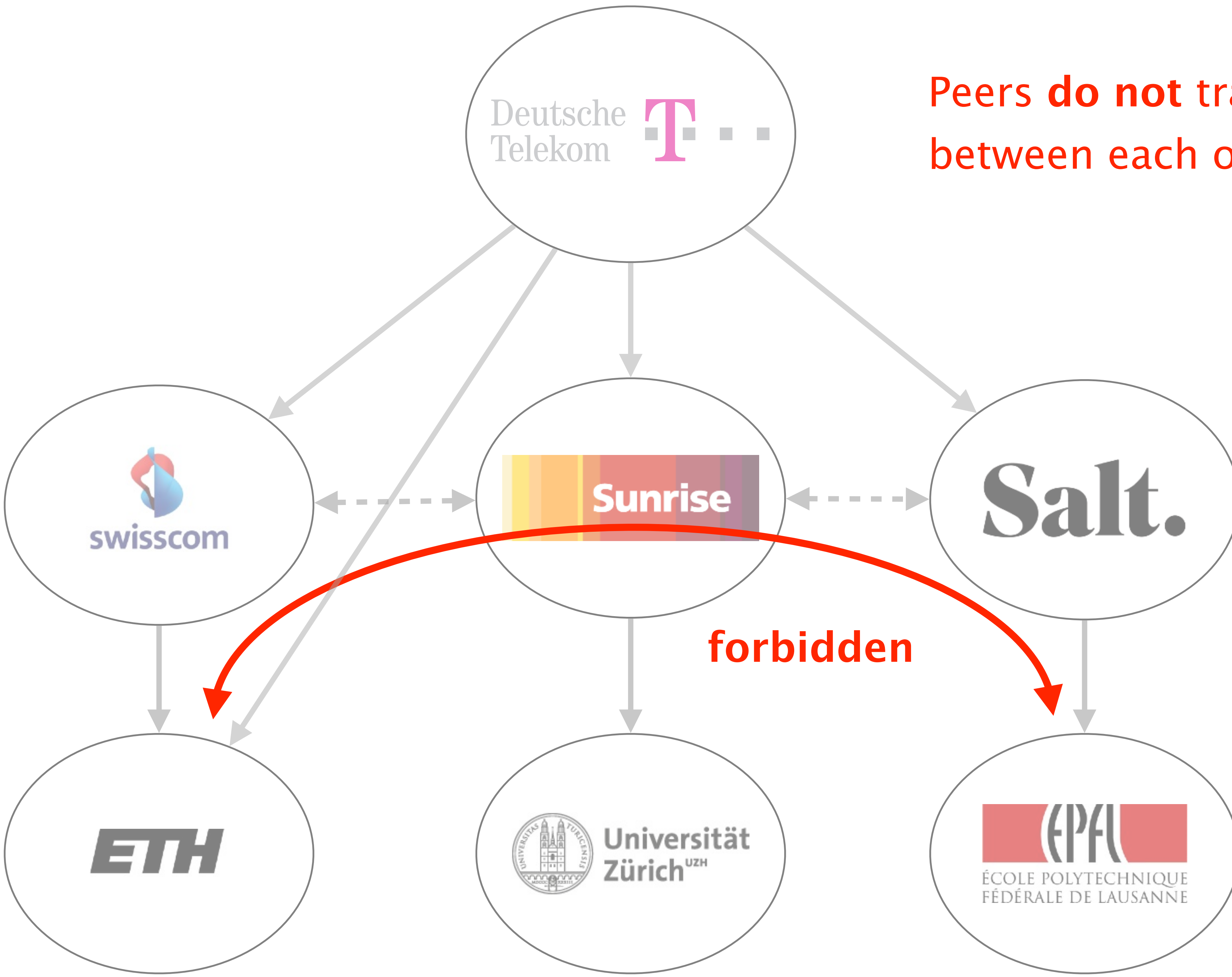
follow the money


Deutsche Telekom
swisscom
Sunrise
Salt.
ETH
Universität Zürich UZH
EPFL
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

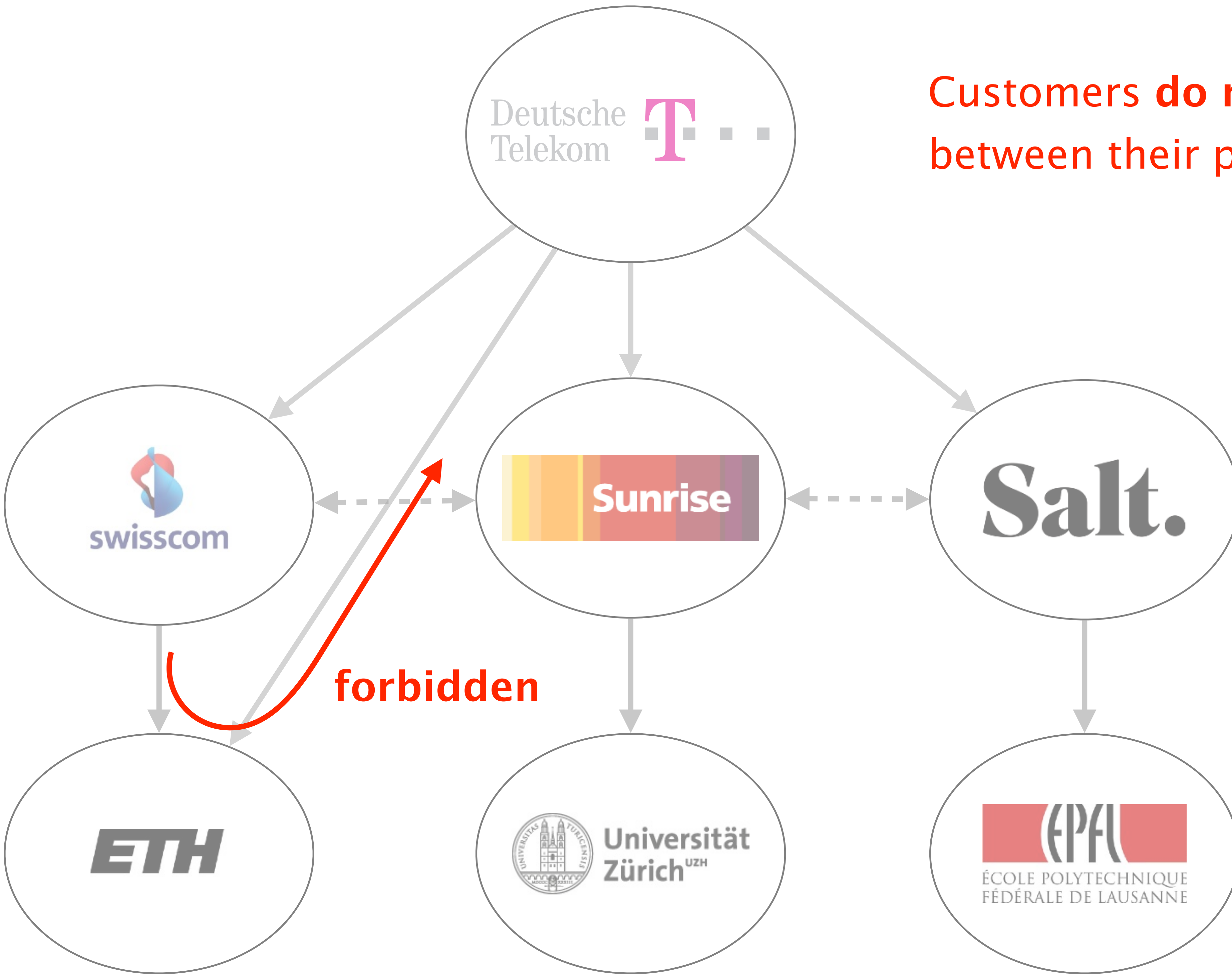
Providers **transit** traffic for their customers



Peers **do not** transit traffic between each other



Customers **do not** transit traffic between their providers



These policies are defined by constraining which BGP routes are *selected* and *exported*

Selection

Export

which path to use?

which path to advertise?

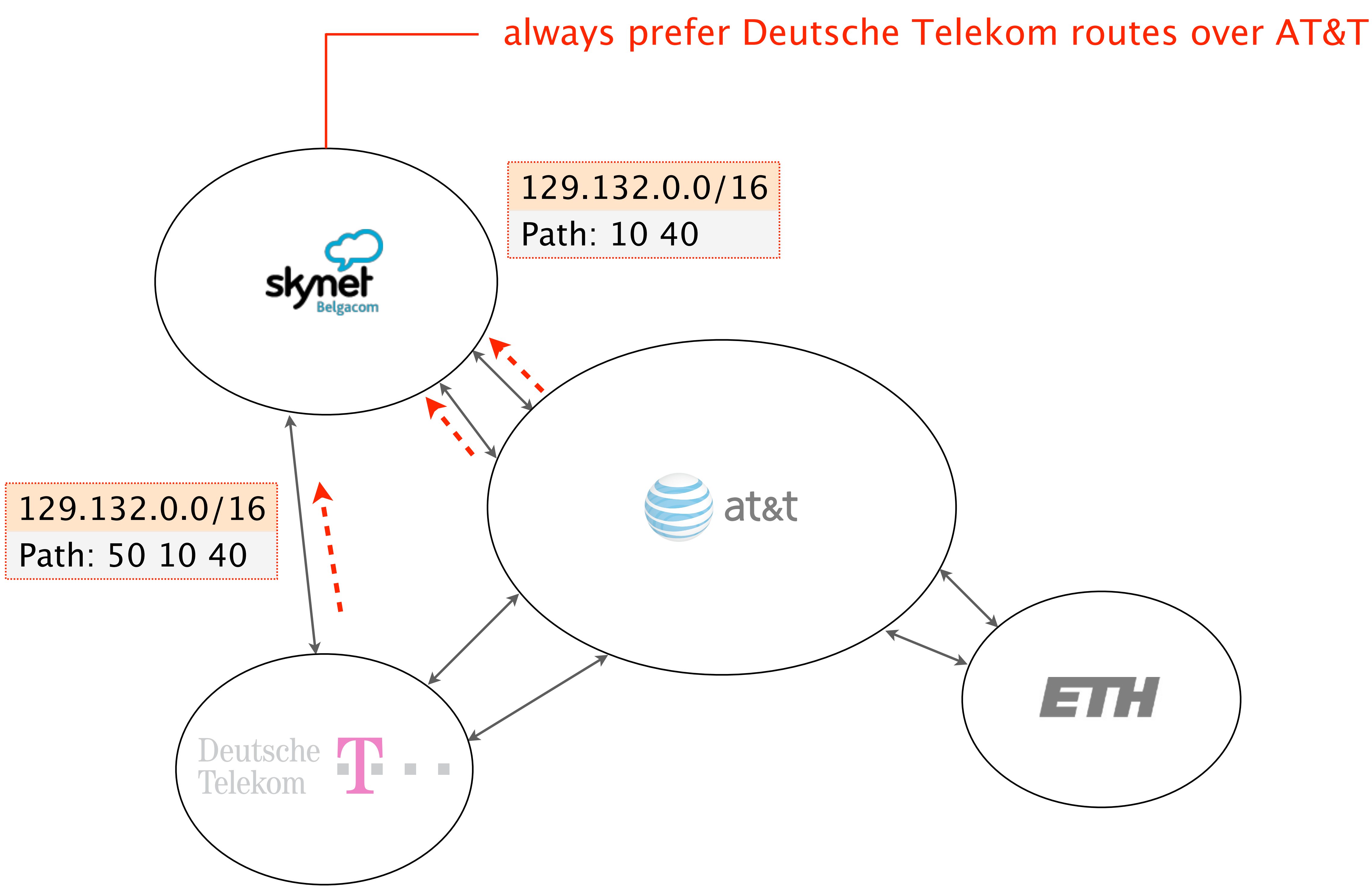
Selection

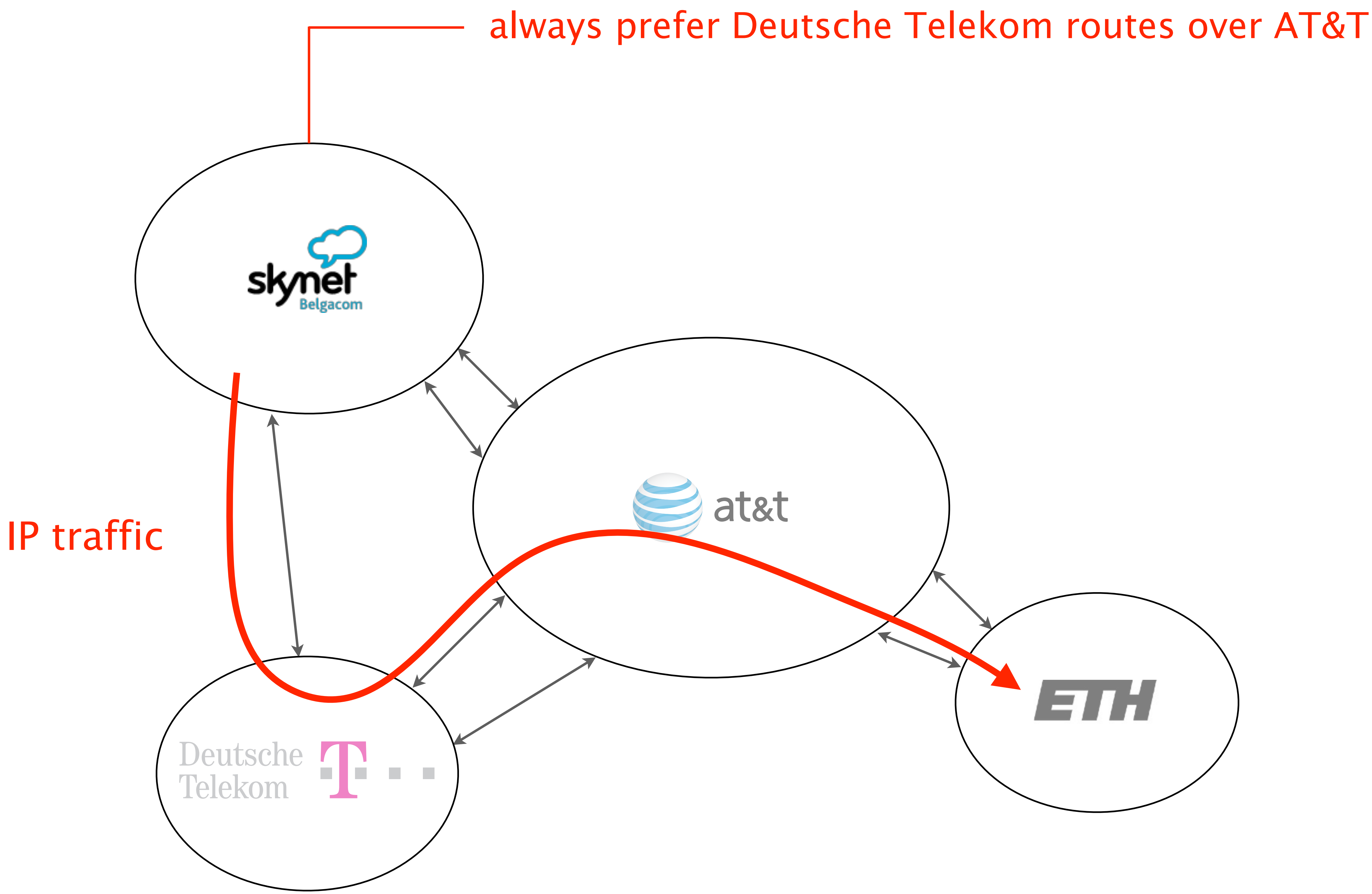
Export

which path to use?

which path to advertise?

control outbound traffic


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
T
ETH


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

Business relationships conditions
route selection

For a destination p, prefer routes coming from

- customers over
- peers over
- providers

route type

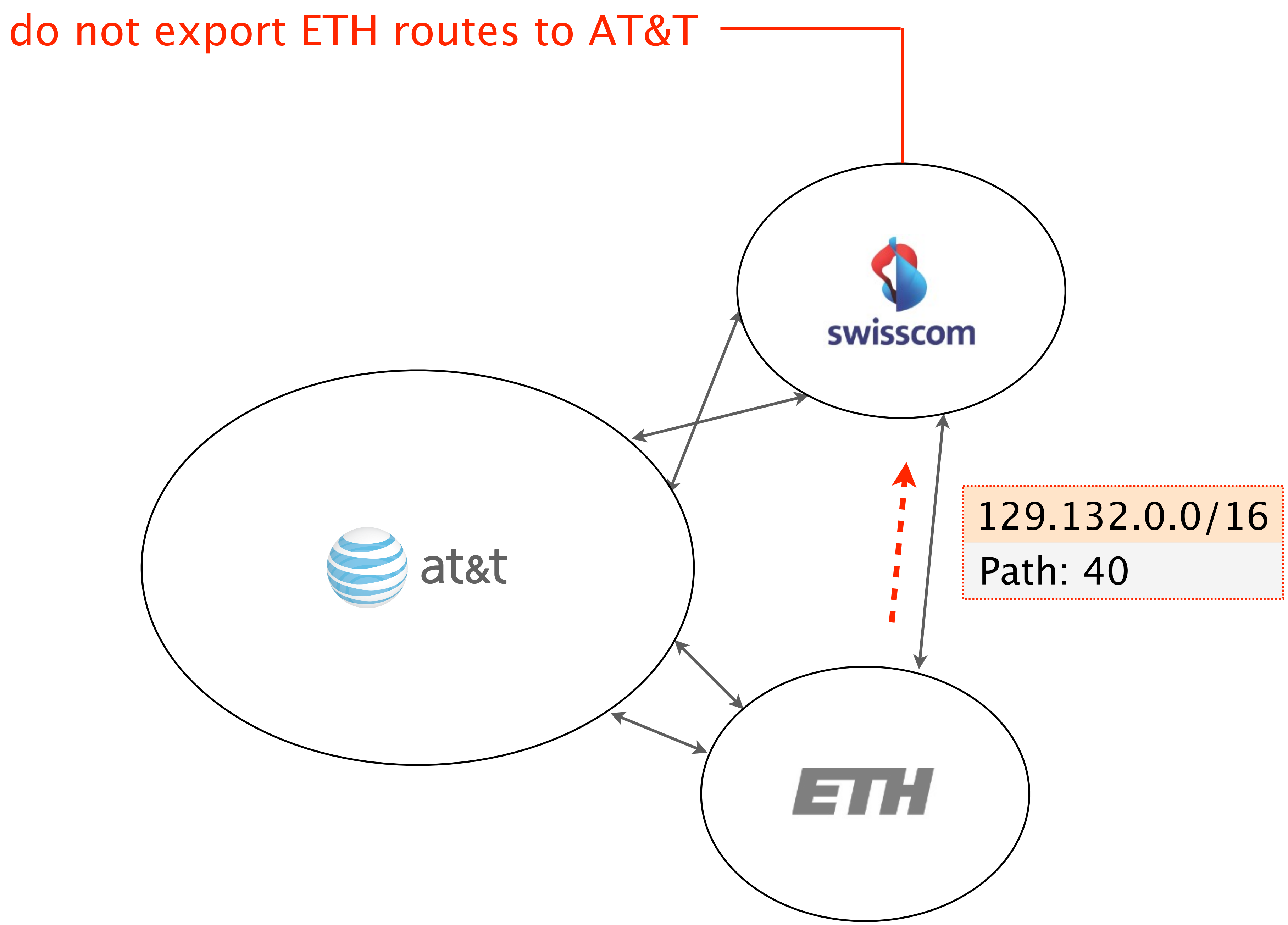
Selection

Export

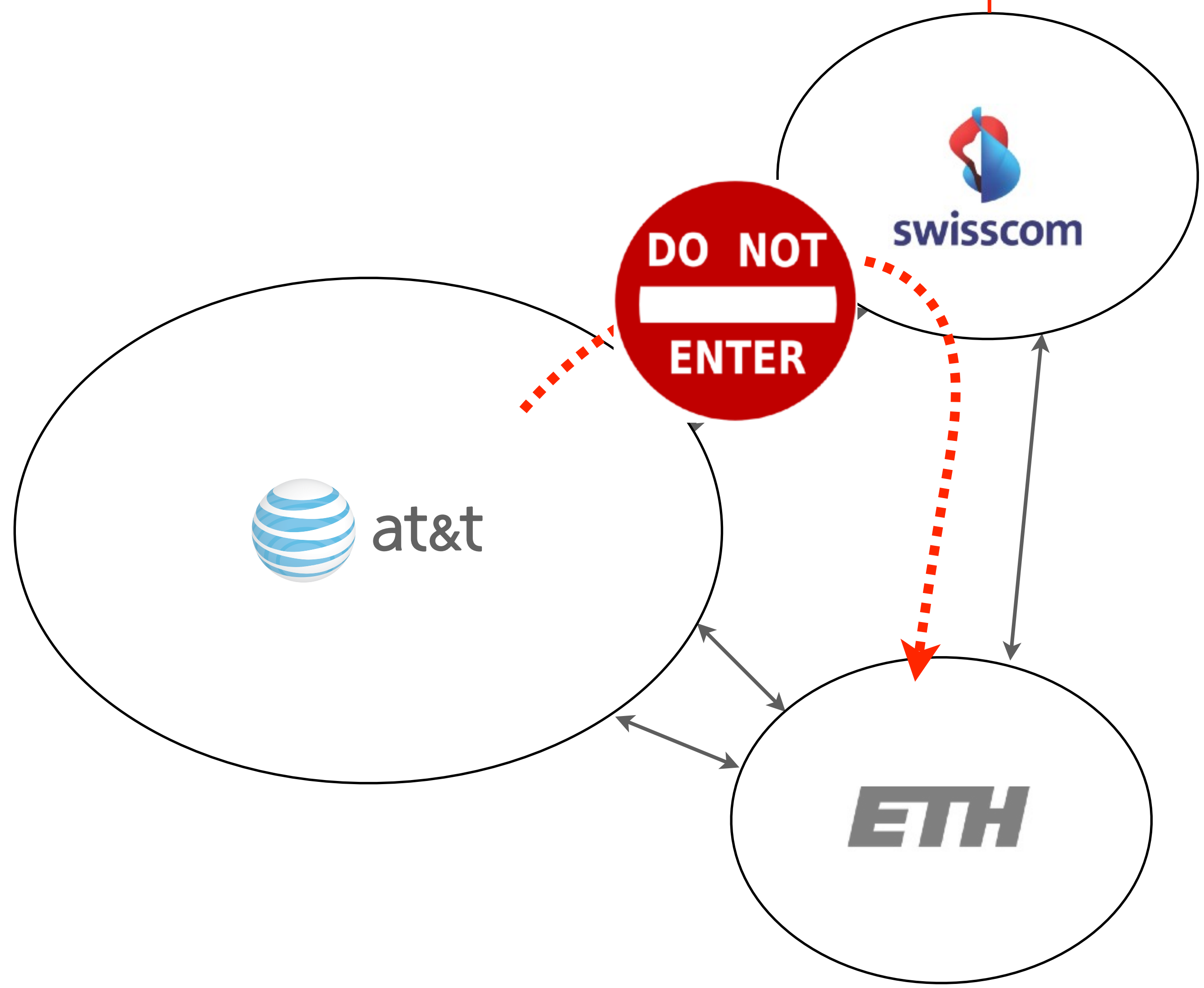
which path to use?

which path to advertise?

control inbound 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



Business relationships conditions

route exportation

		send to		
		customer	peer	provider
	customer			
from	peer			
	provider			

Routes coming from customers are propagated to everyone else

		send to		
		customer	peer	provider
from	customer	✓	✓	✓
	peer			
	provider			

Routes coming from peers and providers are only propagated to customers

		send to		
		customer	peer	provider
	customer	✓	✓	✓
from	peer	✓	-	-
	provider	✓	-	-

Selection

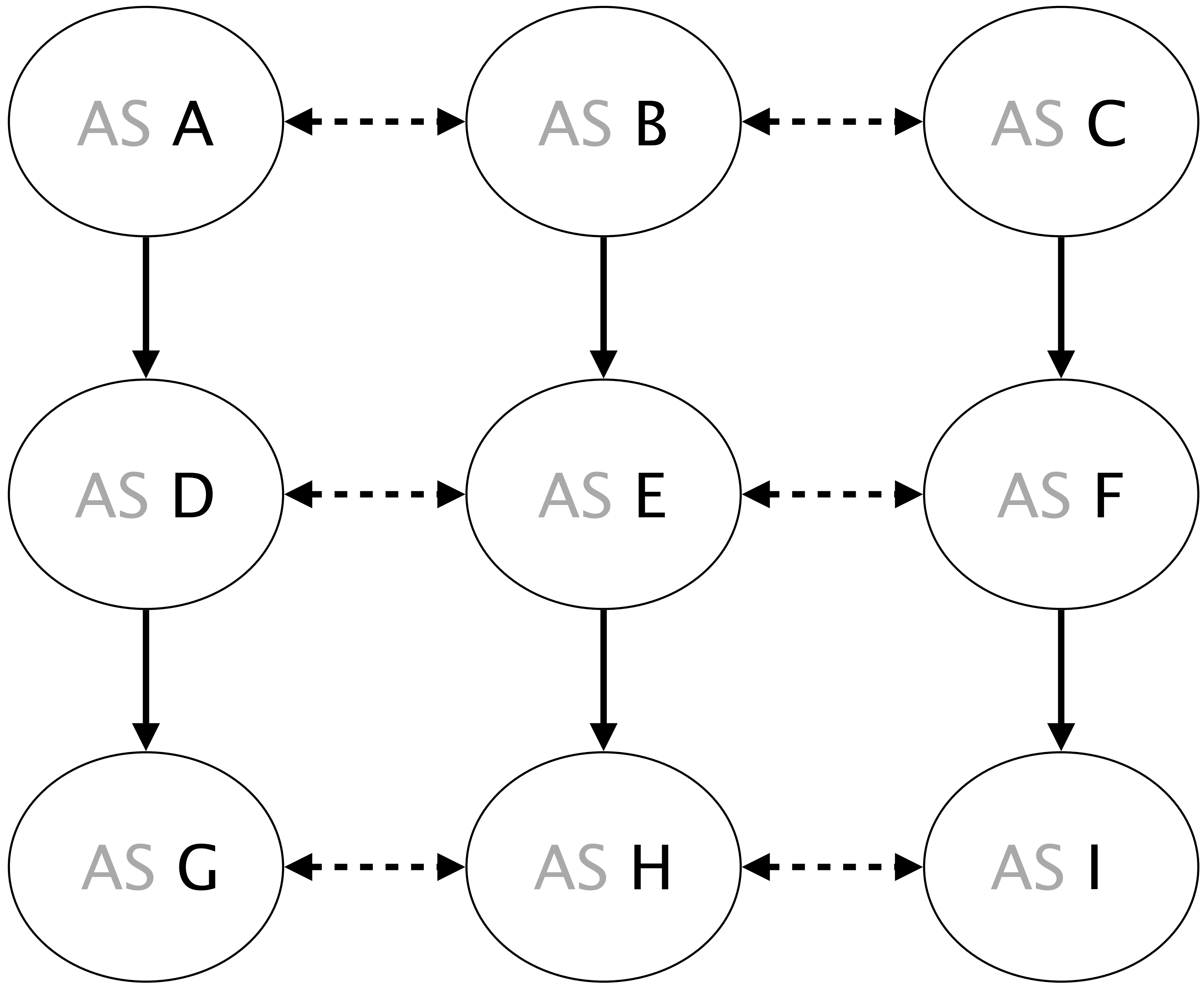
which path to use?

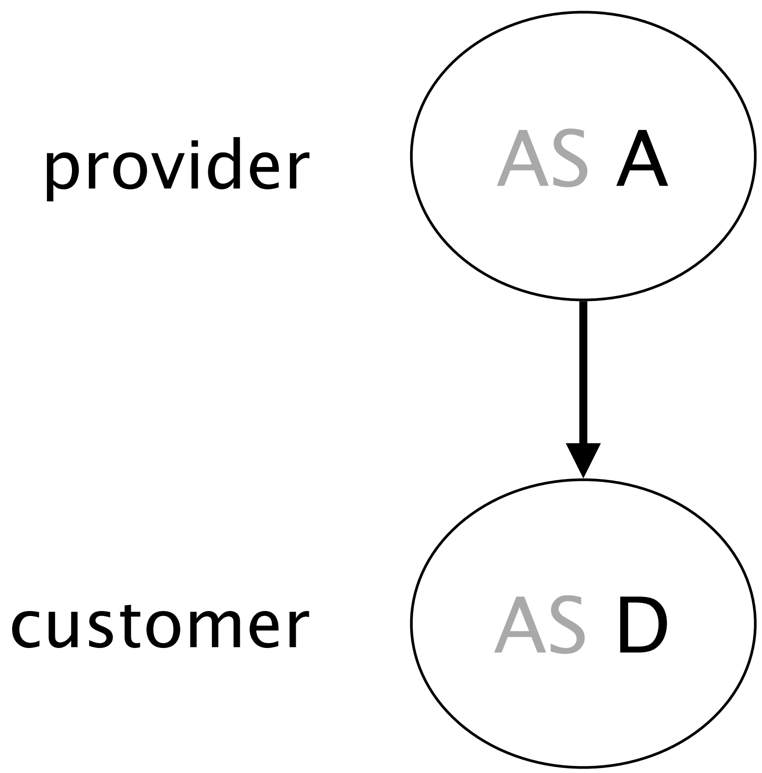
control outbound traffic

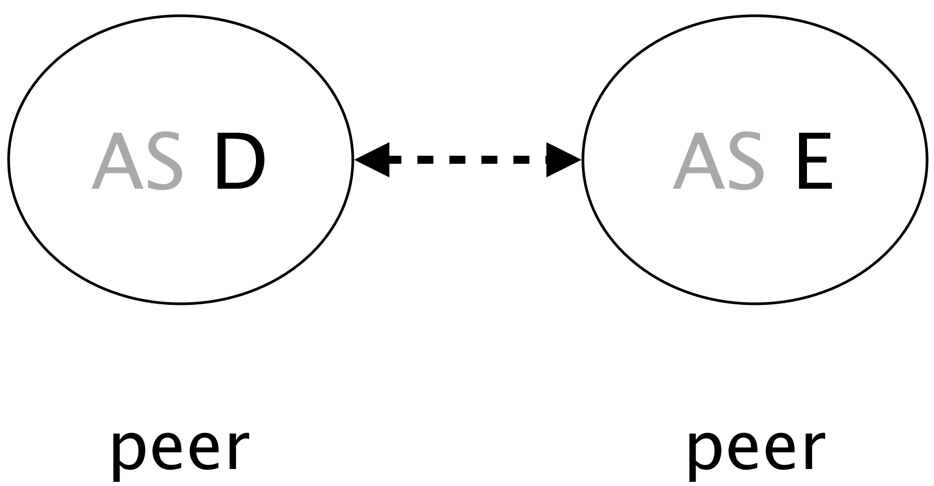
Export

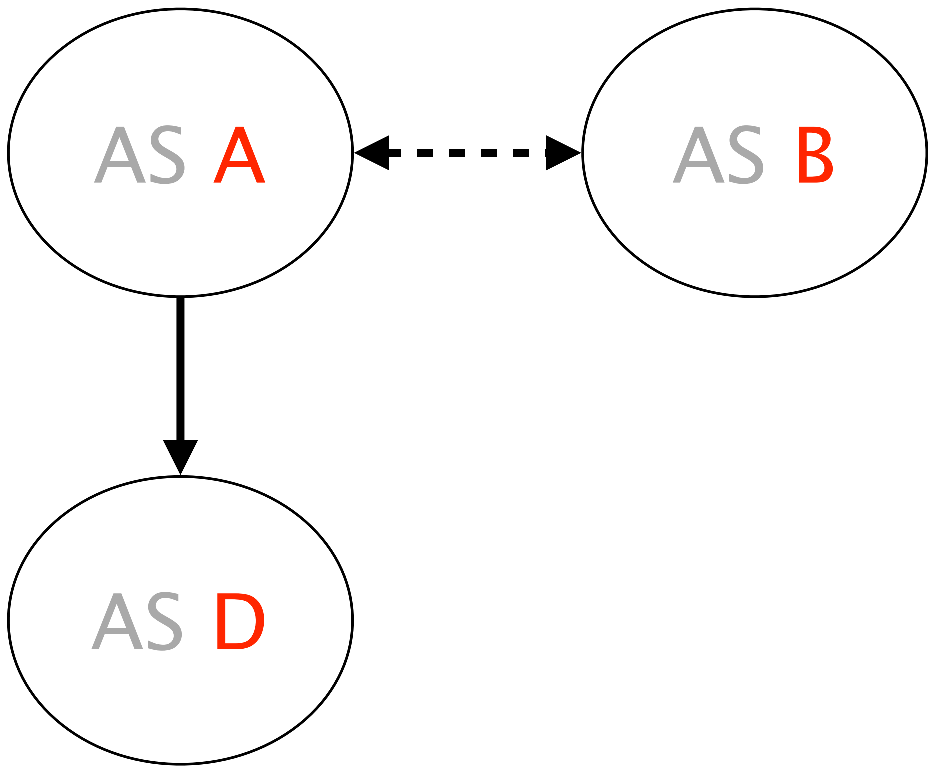
which path to advertise?

control inbound traffic

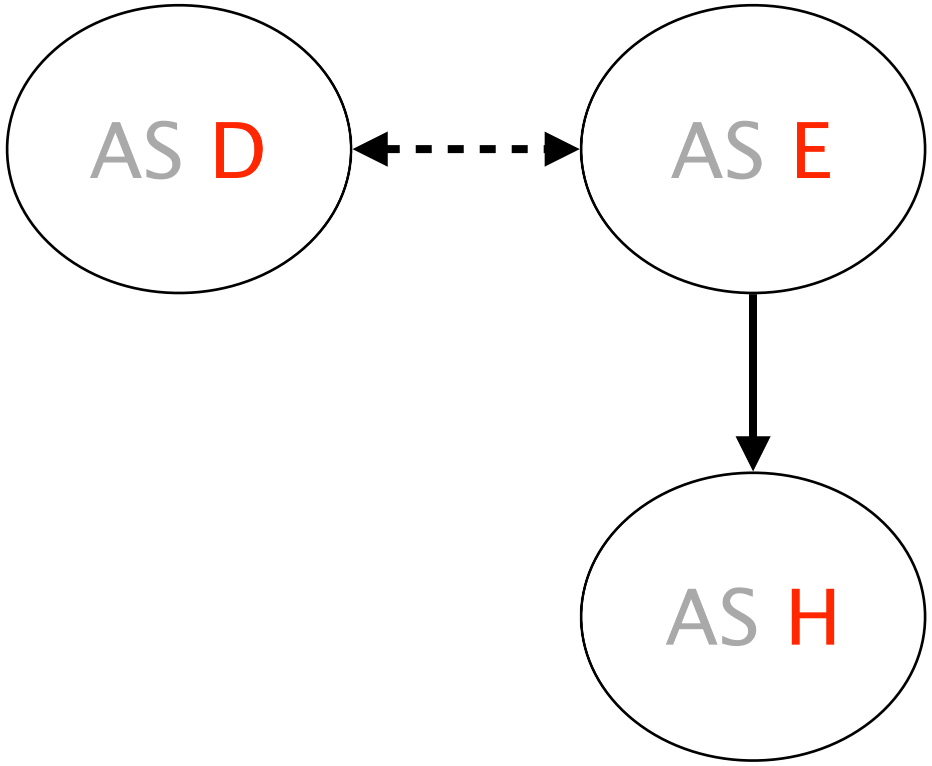

AS A
AS B
AS C
AS D
AS E
AS F
AS G
AS H
AS I


provider
AS A
customer
AS D

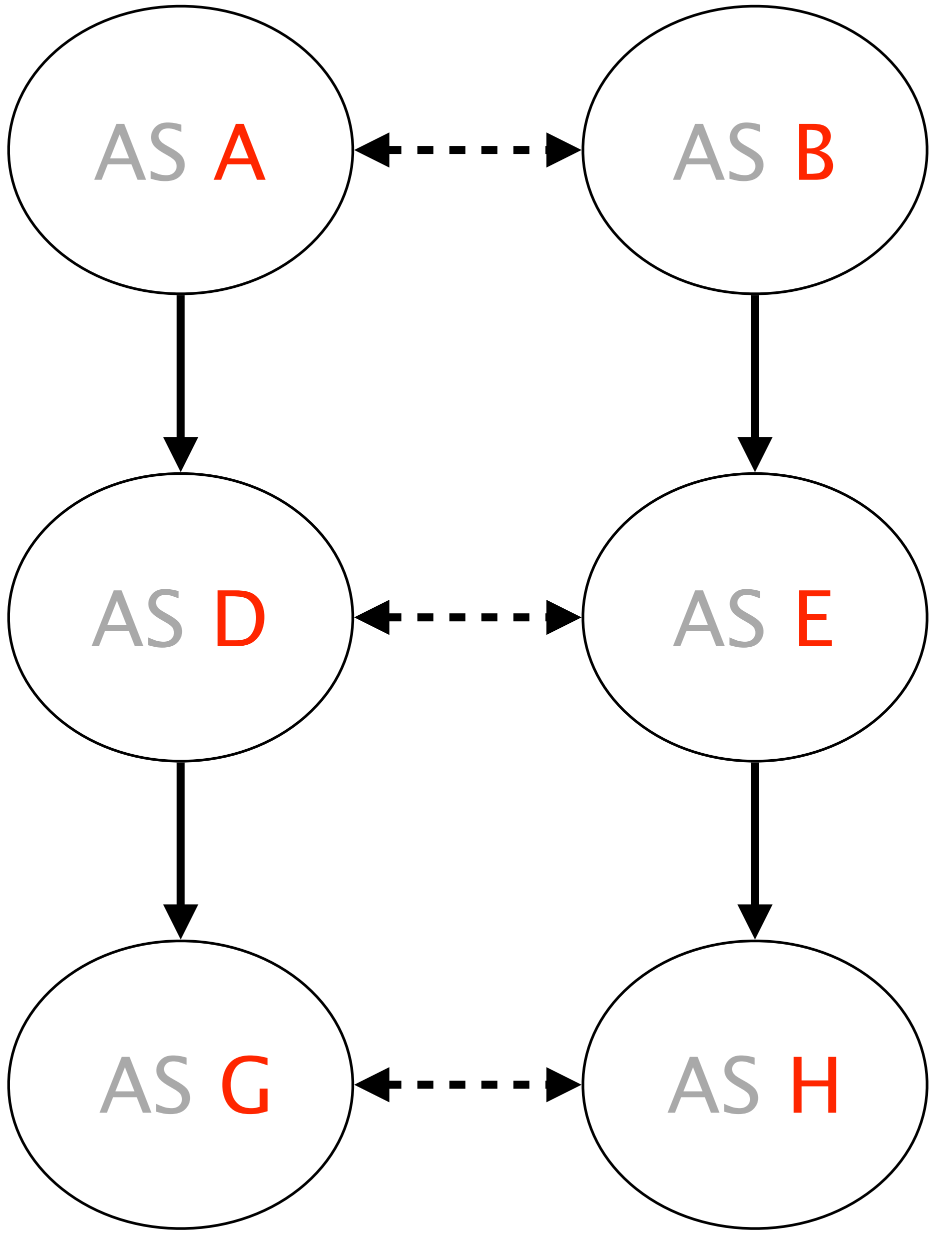

AS D
AS E
peer
peer



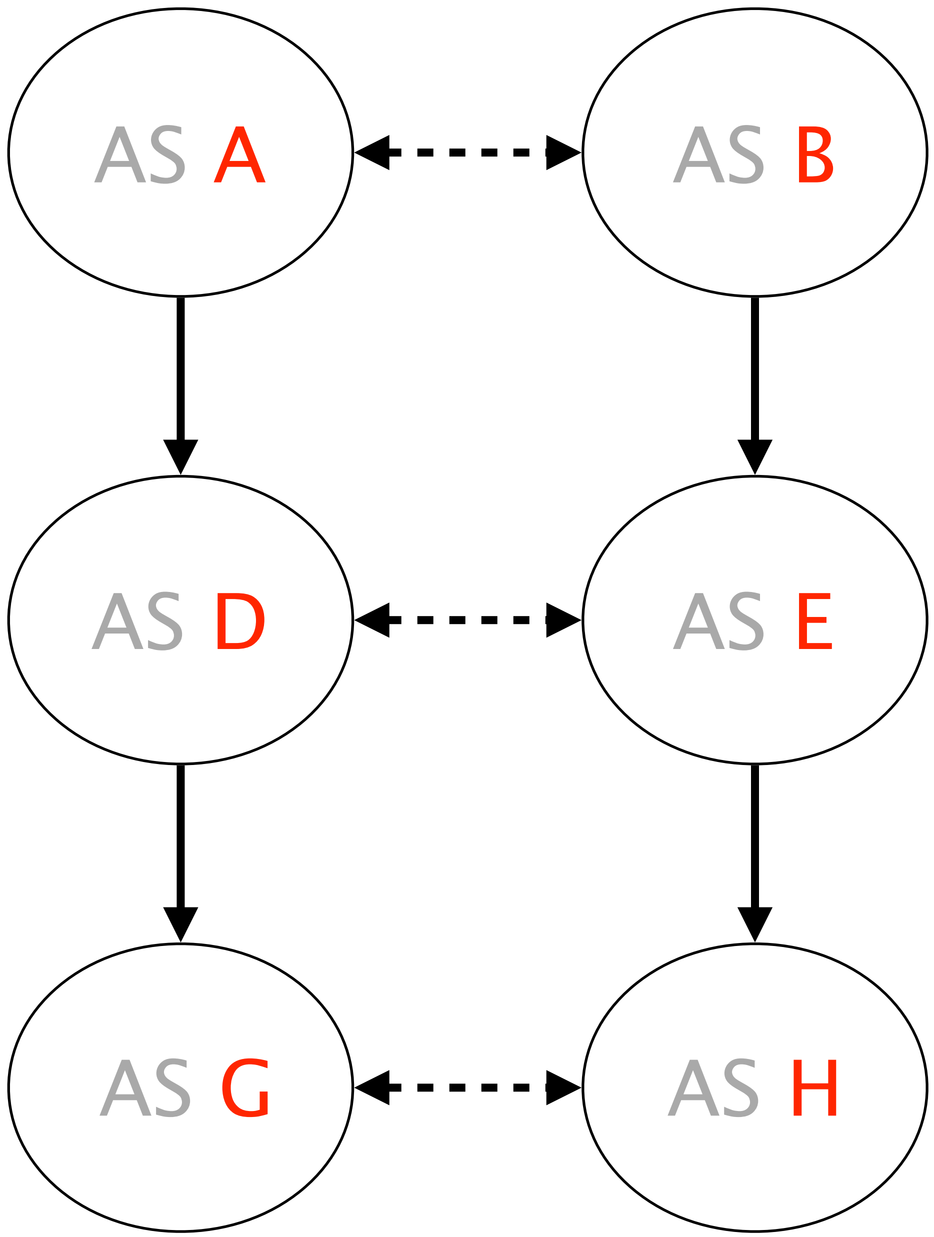
Is (B, A, D) a valid path? Yes/No



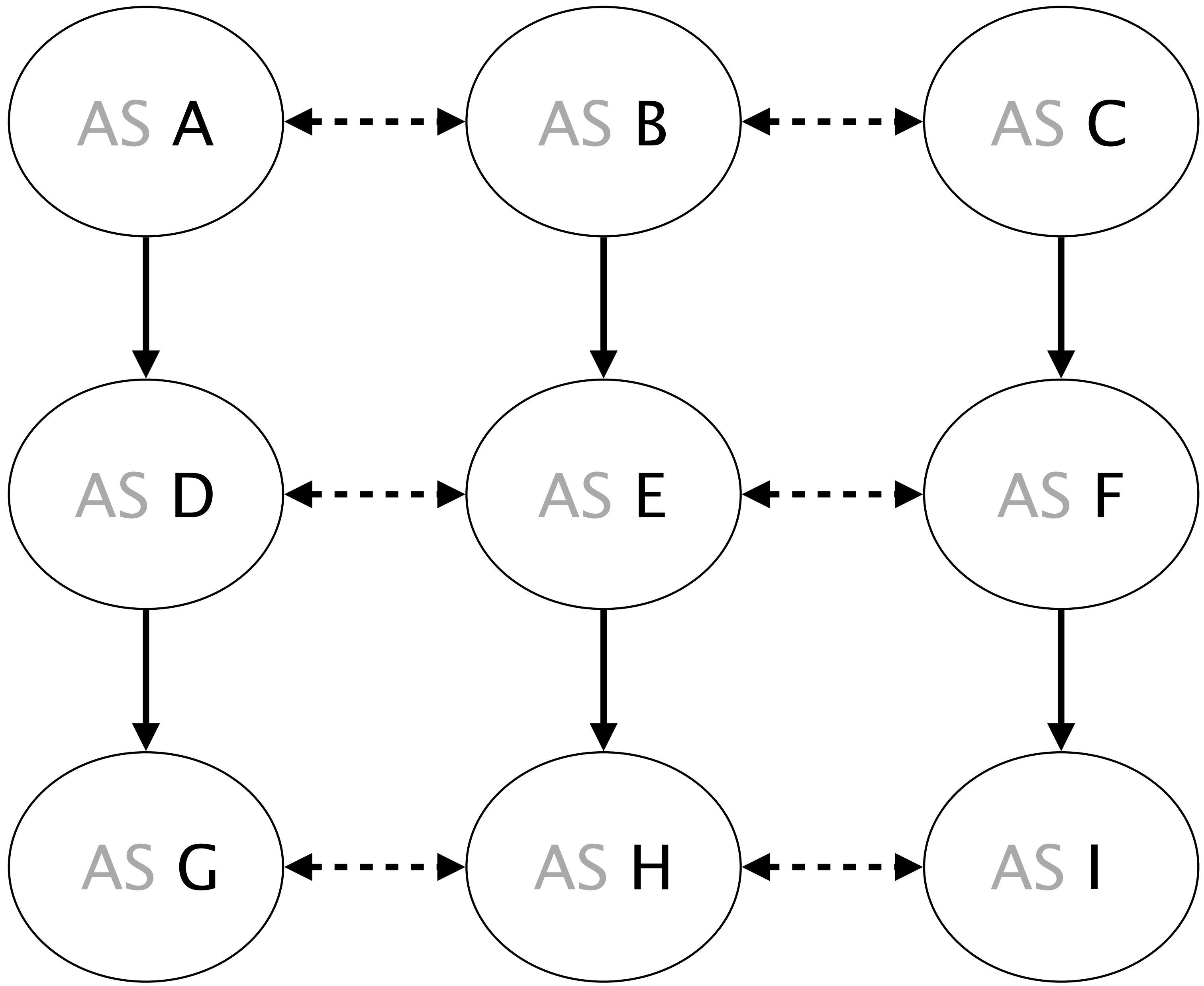
Is (H, E, D) a valid path? Yes/No



Is (G,D,A,B,E,H) a valid path? Yes/No



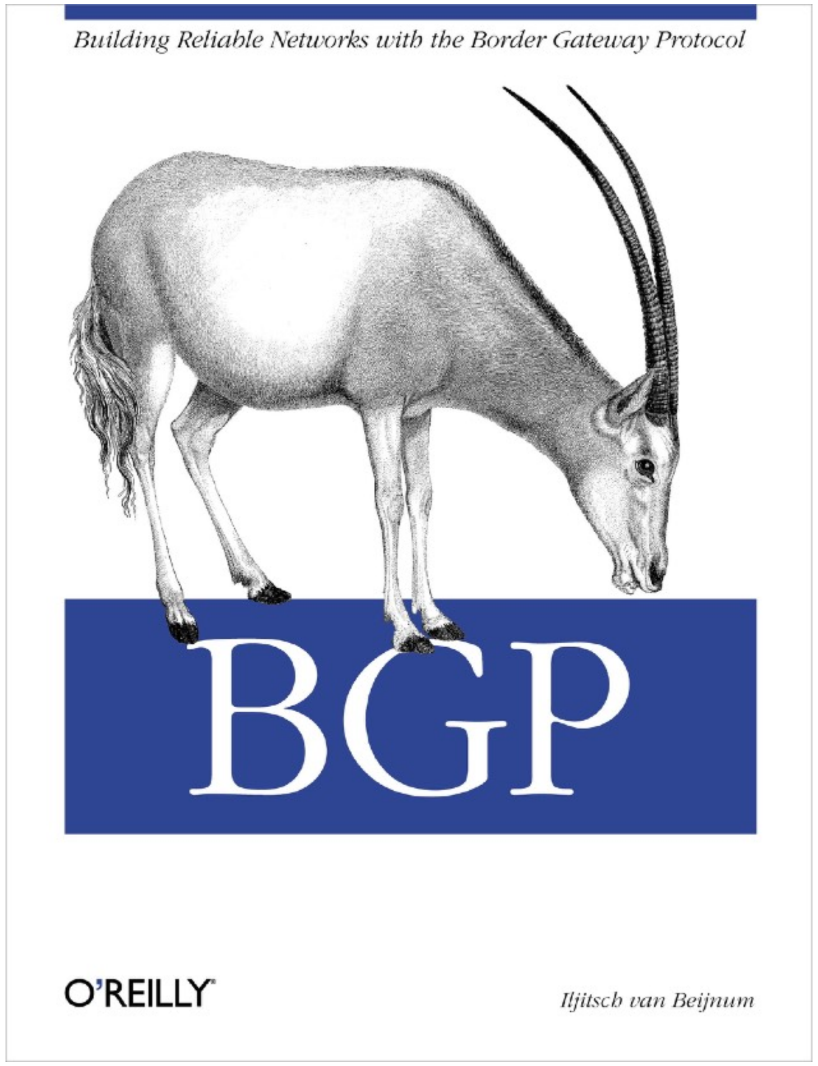
Will (G,D,A,B,E,H) actually see packets? Yes/No



What’s a valid path between G and I?

Border Gateway Protocol

policies and more



BGP Policies

Follow the Money

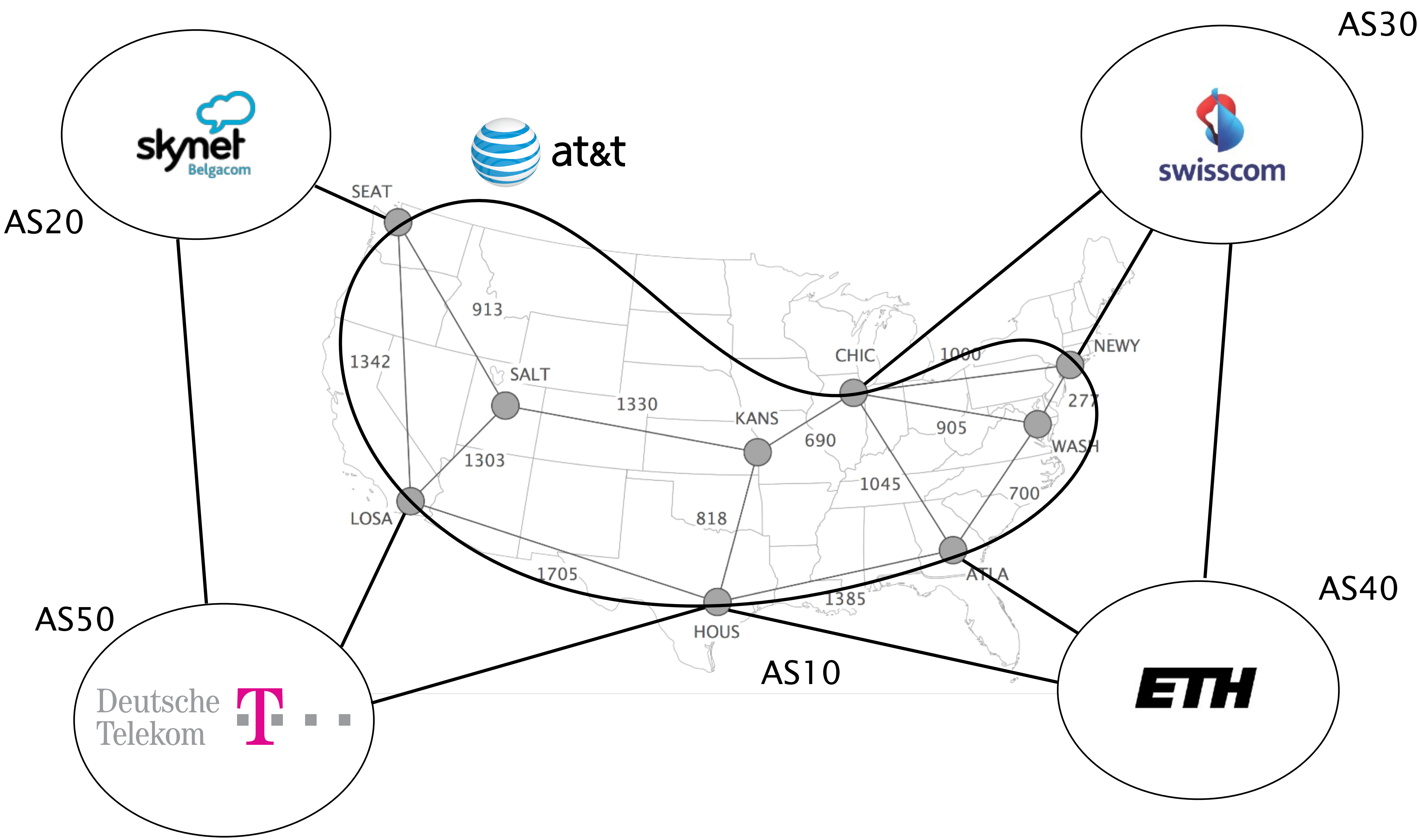
2 Protocol

How does it work?

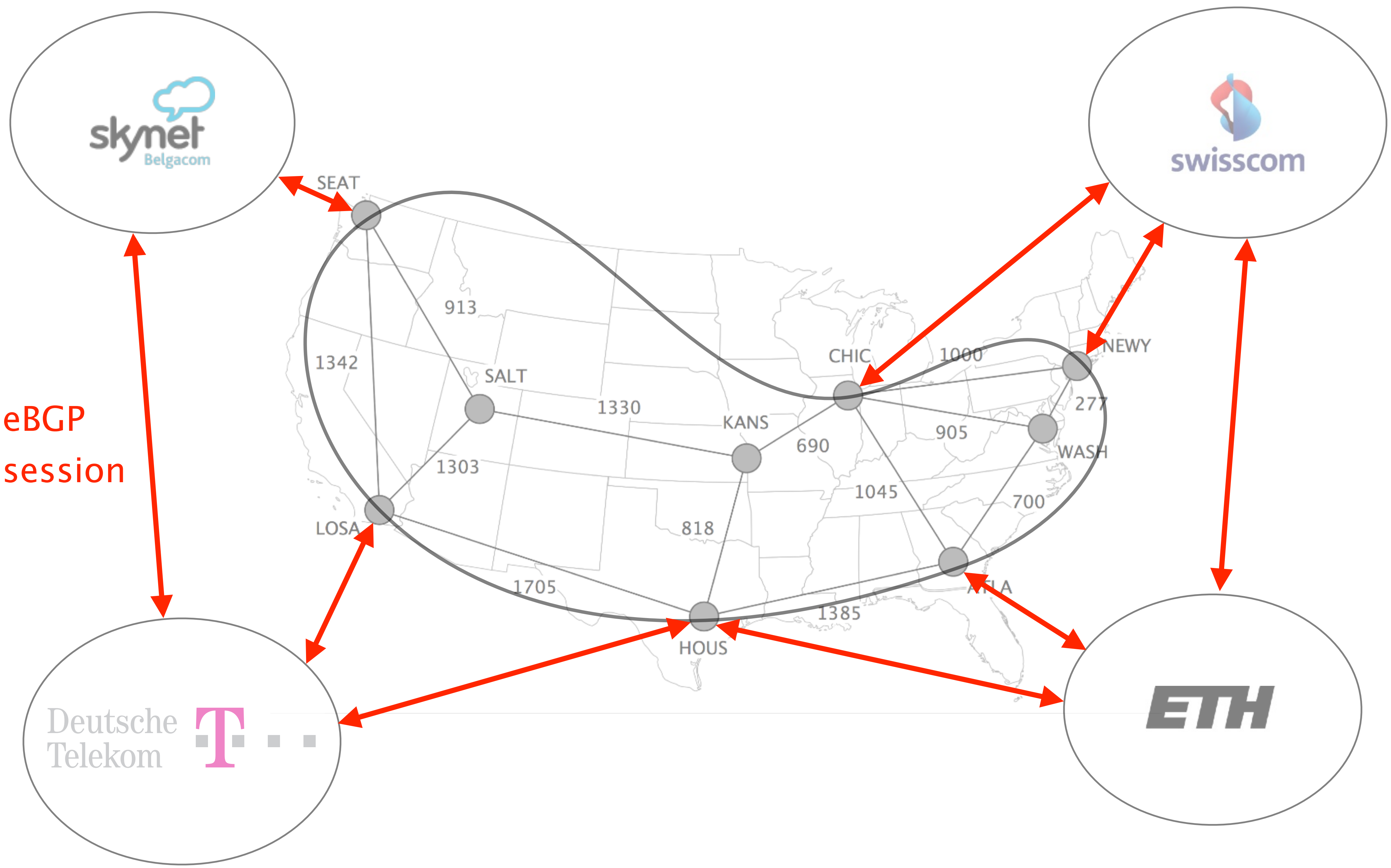
Problems

security, performance, …

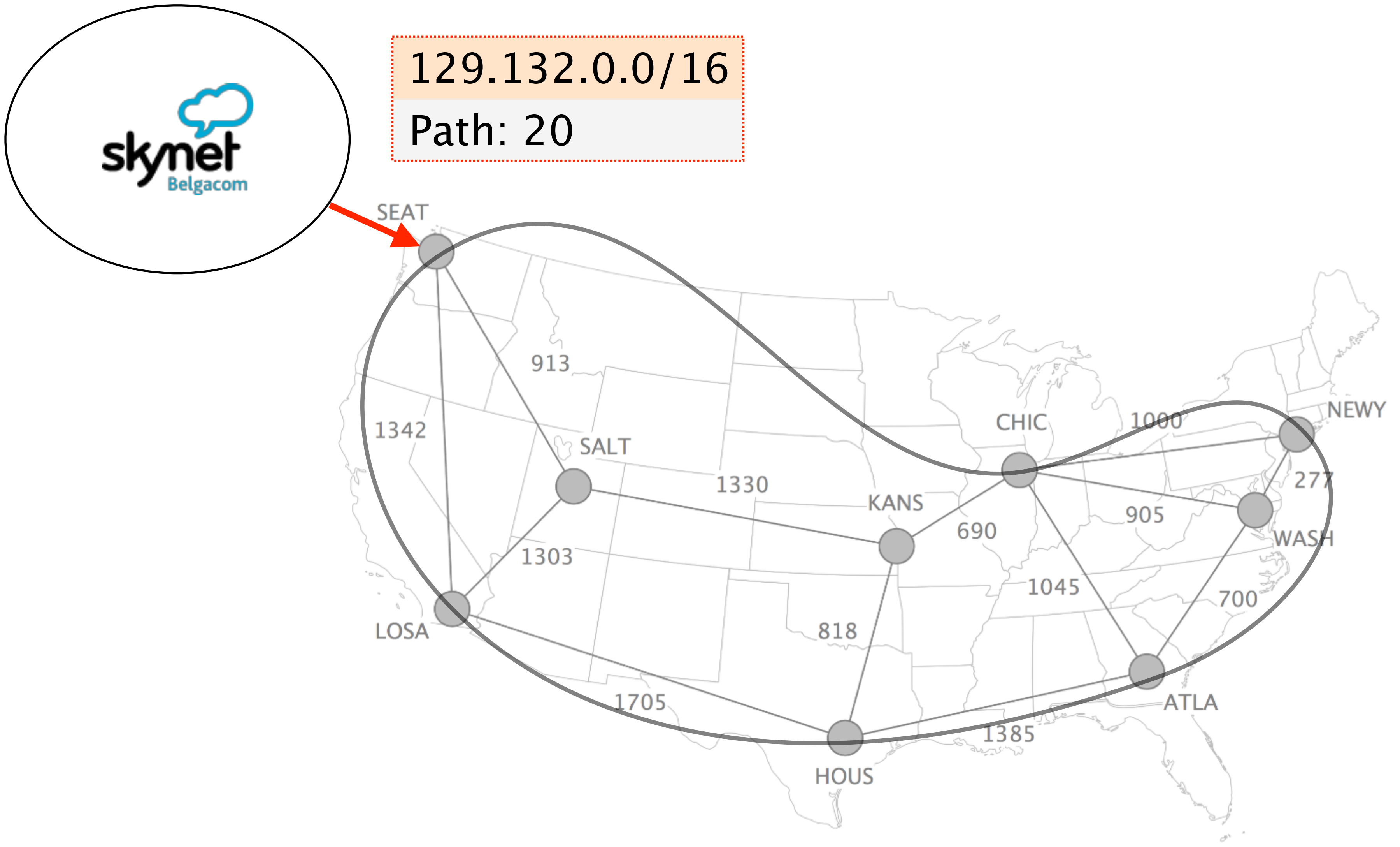
BGP sessions come in two flavors



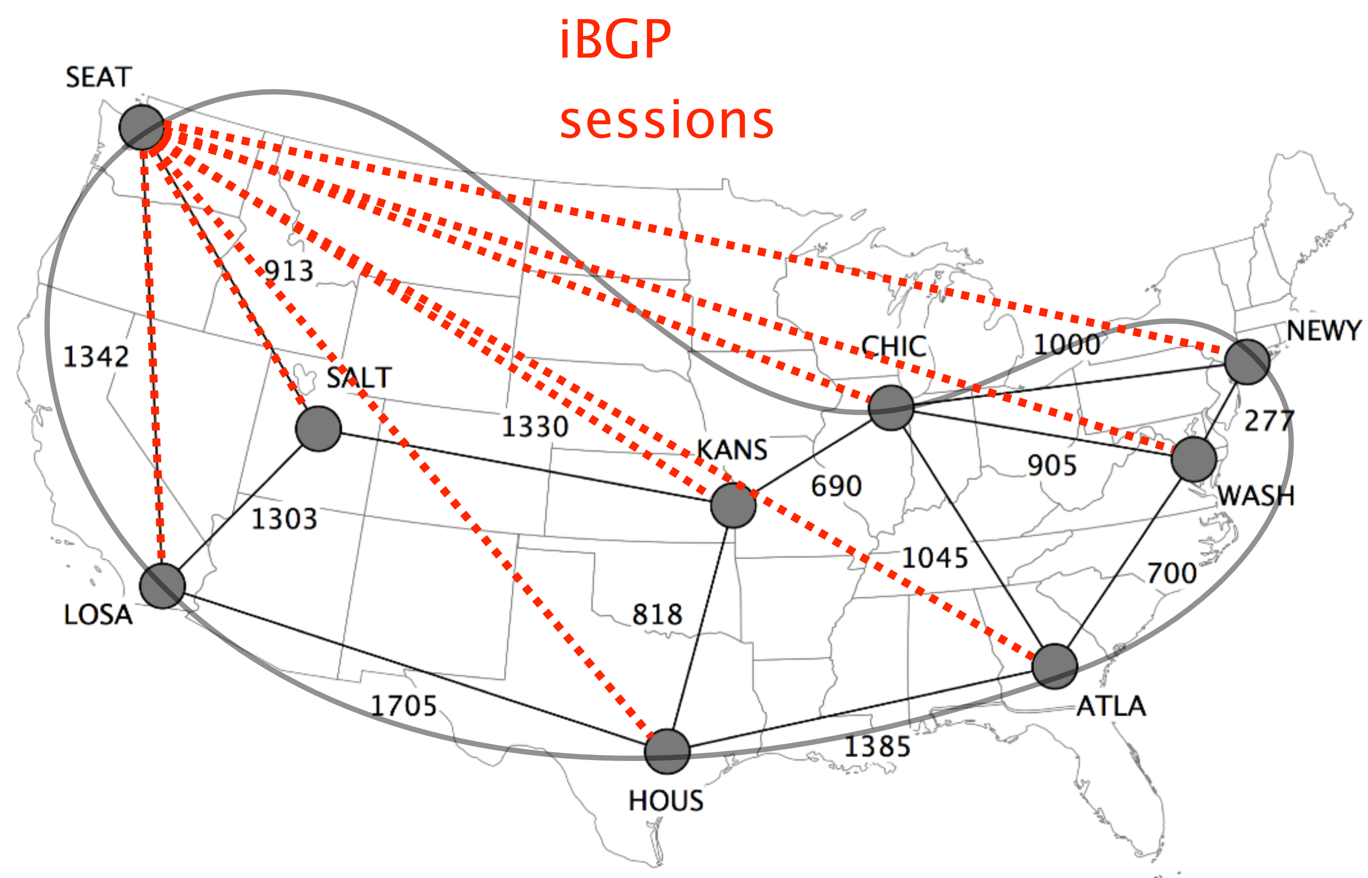
external BGP (eBGP) sessions
connect border routers in different ASes



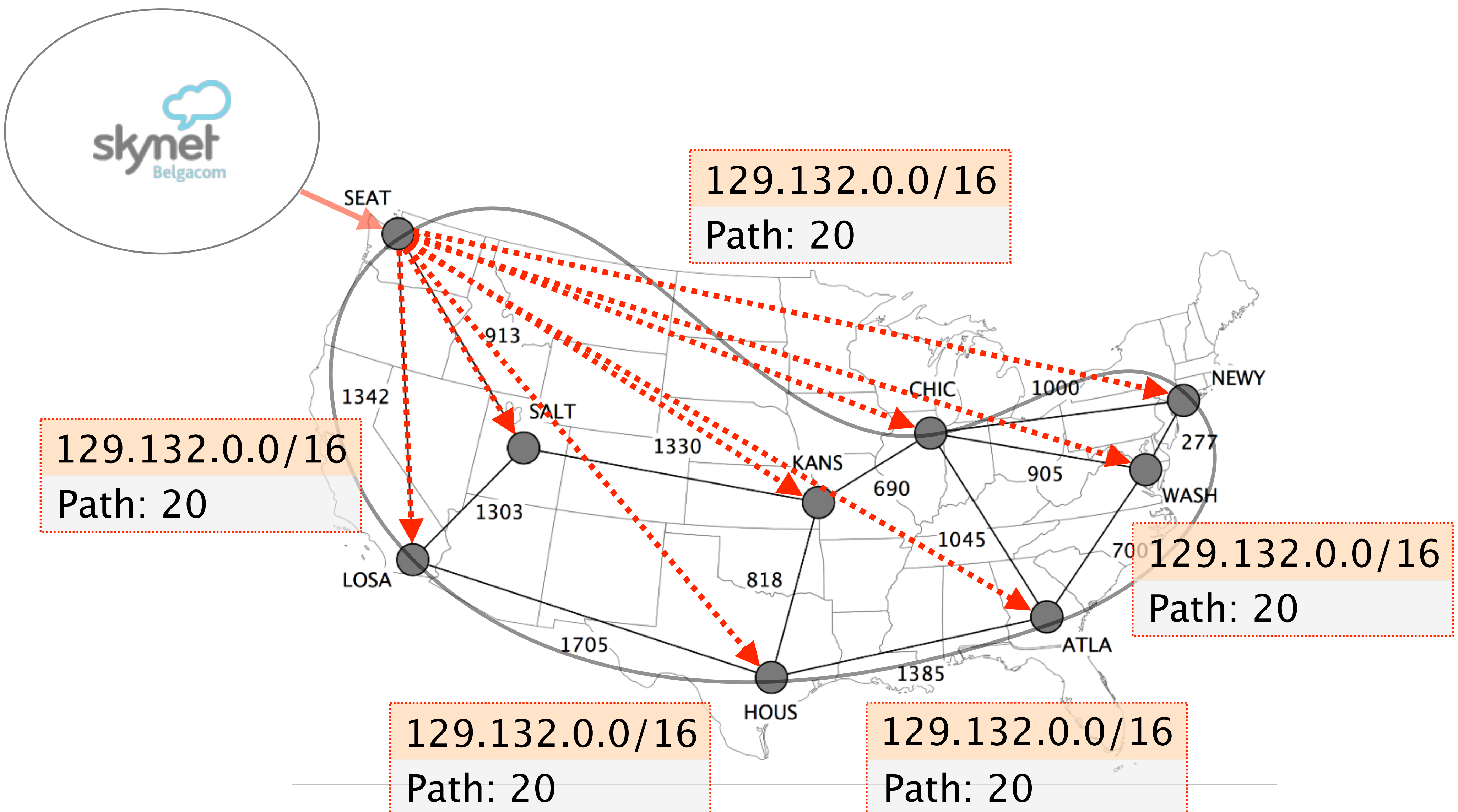
eBGP sessions are used to learn routes to external destinations

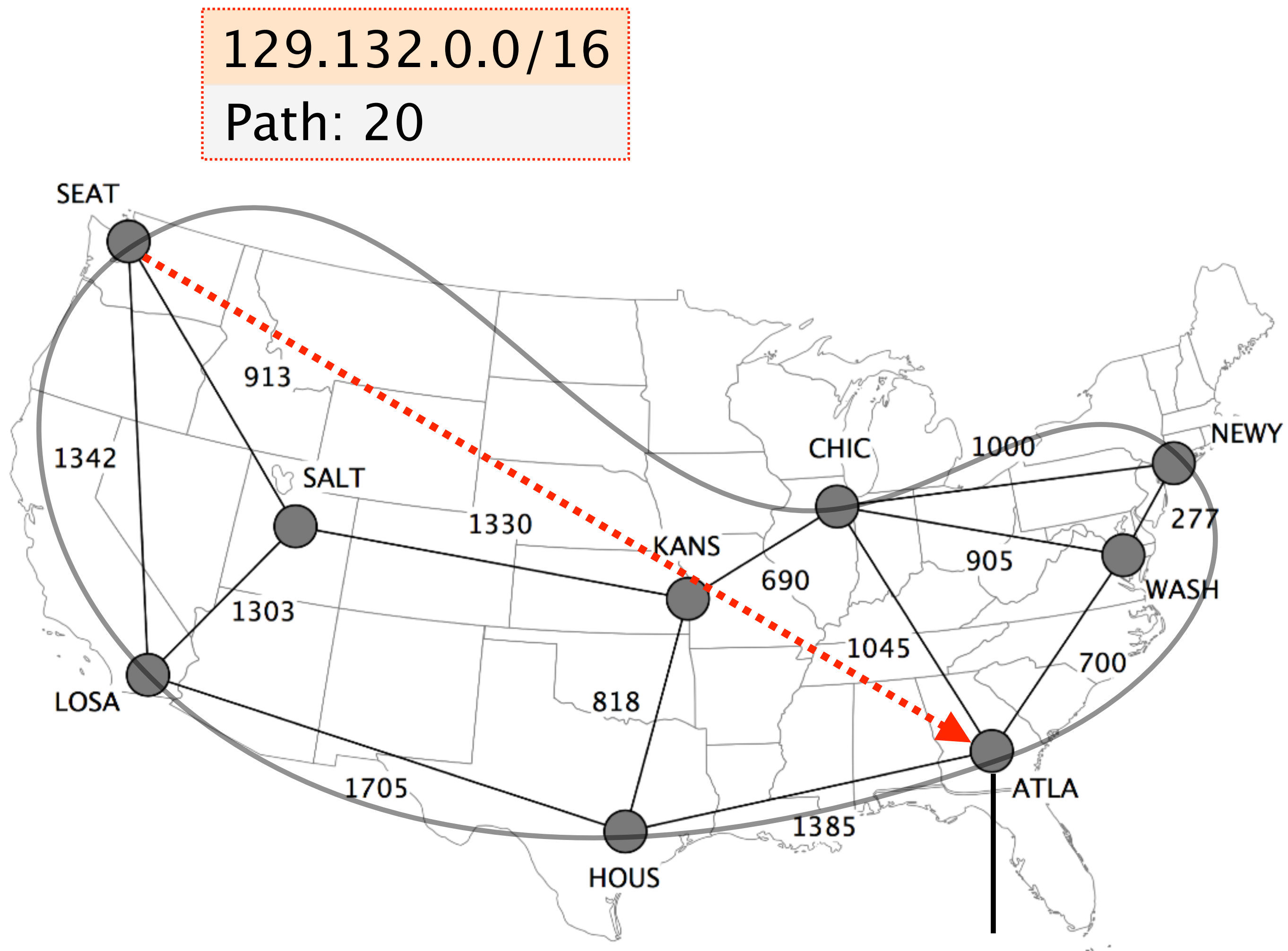


internal BGP (iBGP) sessions connect the routers in the same AS



iBGP sessions are used to disseminate externally-learned routes internally

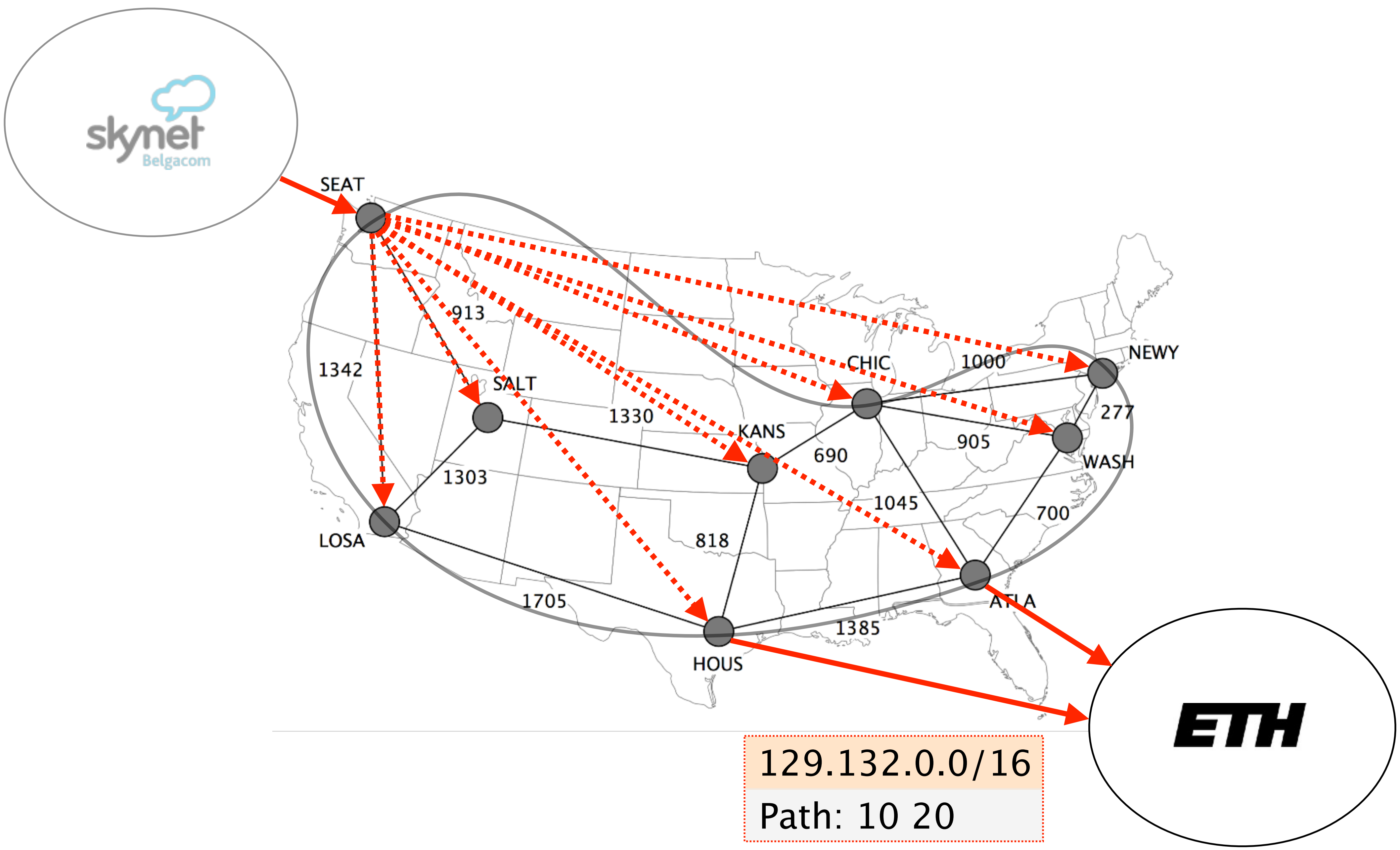




I can reach “129.132/16” via SEAT,
internal NH is CHIC

learned via IGP (*e.g.*, OSPF)

Routes disseminated internally are then announced externally again, using eBGP sessions



On the wire, BGP is a rather simple protocol composed of four basic messages

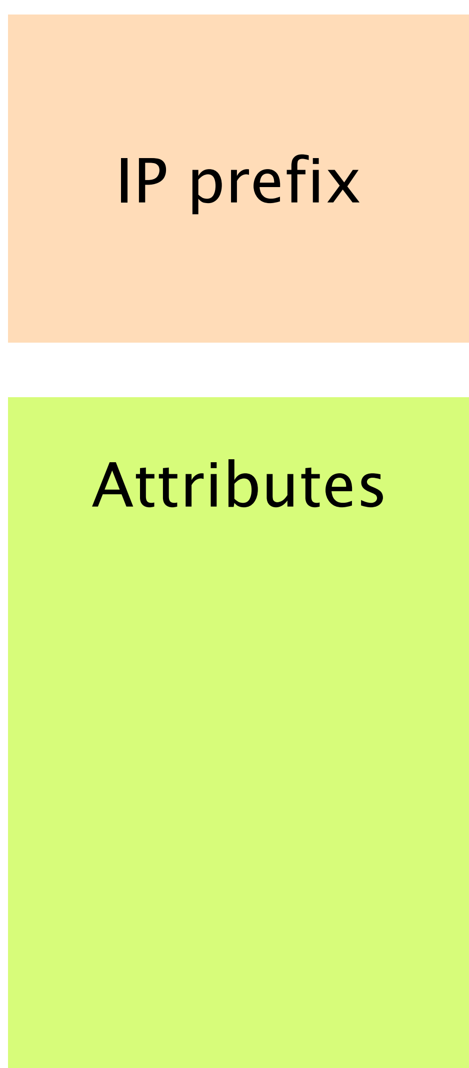
type	used to…
OPEN	establish TCP-based BGP sessions
NOTIFICATION	report unusual conditions
UPDATE	inform neighbor of a new best route a change in the best route the removal of the best route
KEEPALIVE	inform neighbor that the connection is alive

UPDATE inform neighbor of a new best route

a change in the best route

the removal of the best route

BGP UPDATEs carry an IP prefix together with a set of attributes



BGP UPDATEs carry an IP prefix together with a set of attributes

IP prefix

Attributes

Describe route properties

used in route selection/exportation decisions

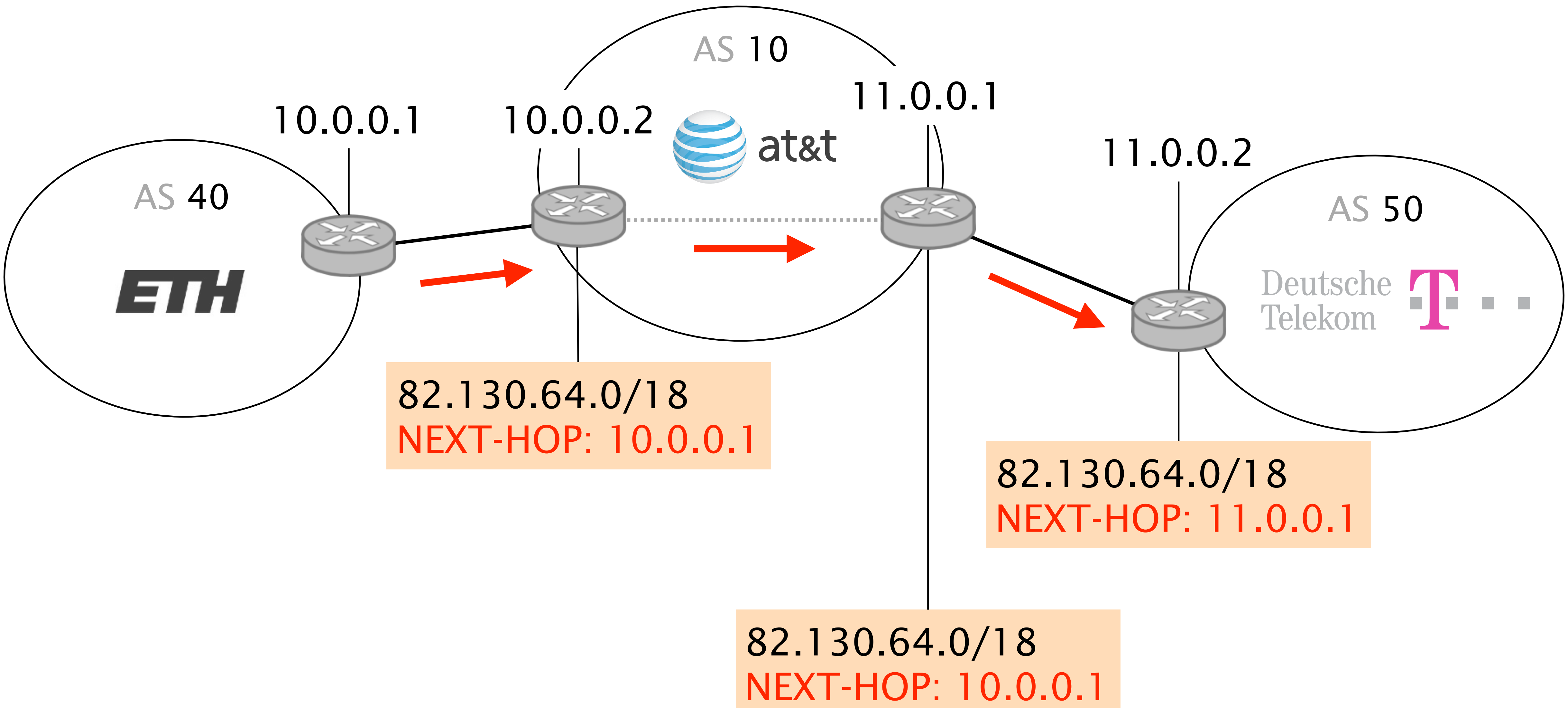
are either local (*only* seen on iBGP)

or global (seen on iBGP *and* eBGP)

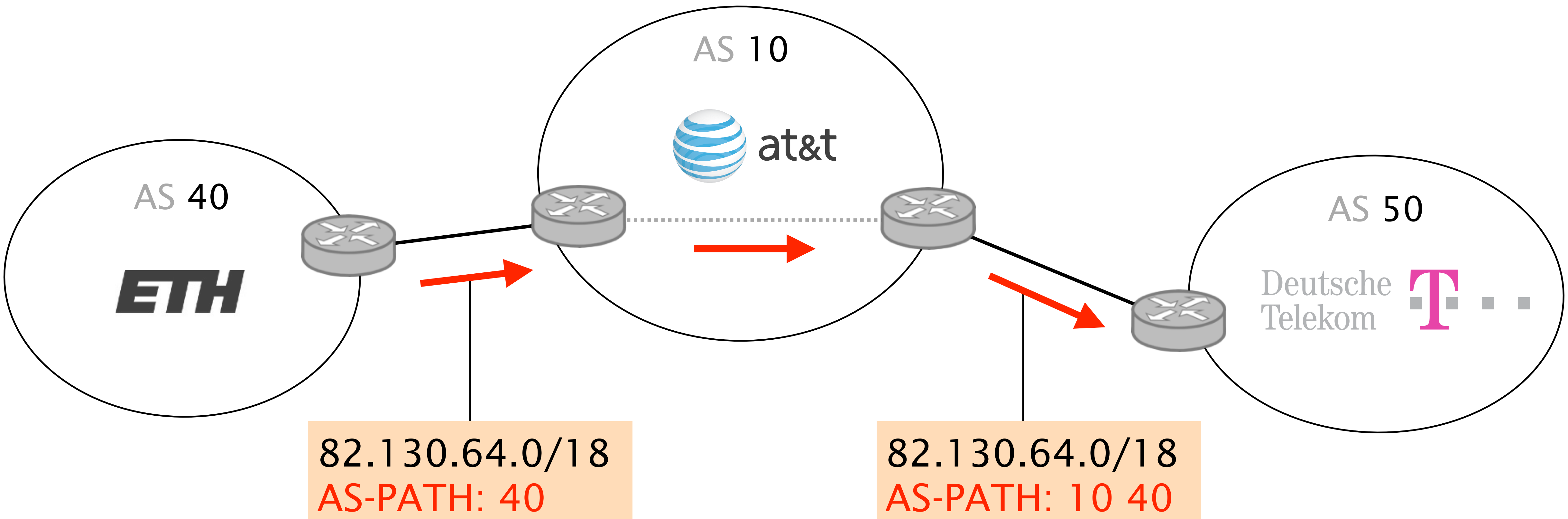
Attributes	Usage
NEXT-HOP	egress point identification
AS-PATH	loop avoidance outbound traffic control inbound traffic control
LOCAL-PREF	outbound traffic control
MED	inbound traffic control

The NEXT-HOP is a global attribute which indicates where to send the traffic next

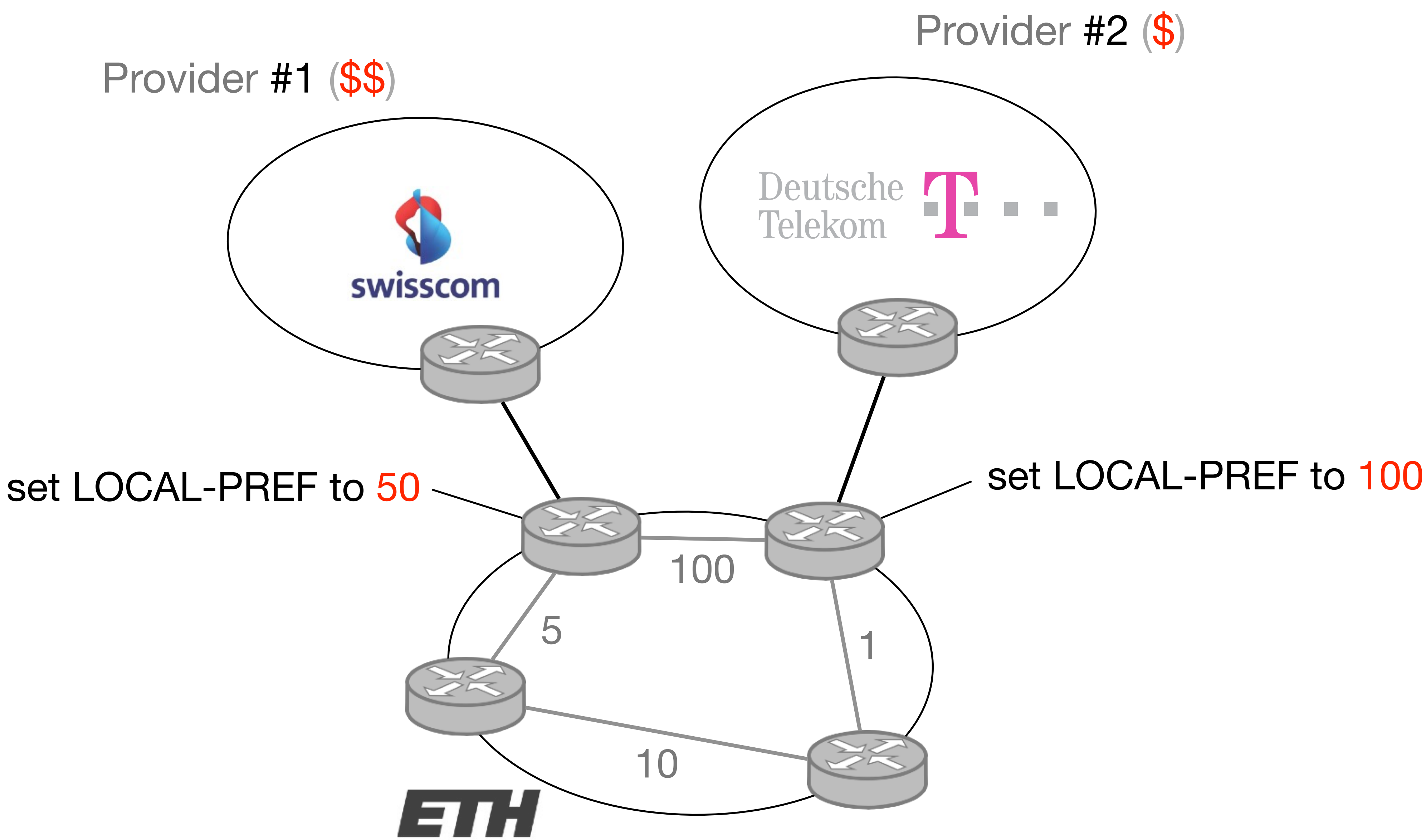
The NEXT-HOP is set when the route enters an AS, it does not change within the AS



The AS-PATH is a global attribute that lists all the ASes a route has traversed (in reverse order)


AS 10
at&t
AS 40
ETH
AS 50
Deutsche Telekom
82.130.64.0/18
AS-PATH: 40
82.130.64.0/18
AS-PATH: 10 40

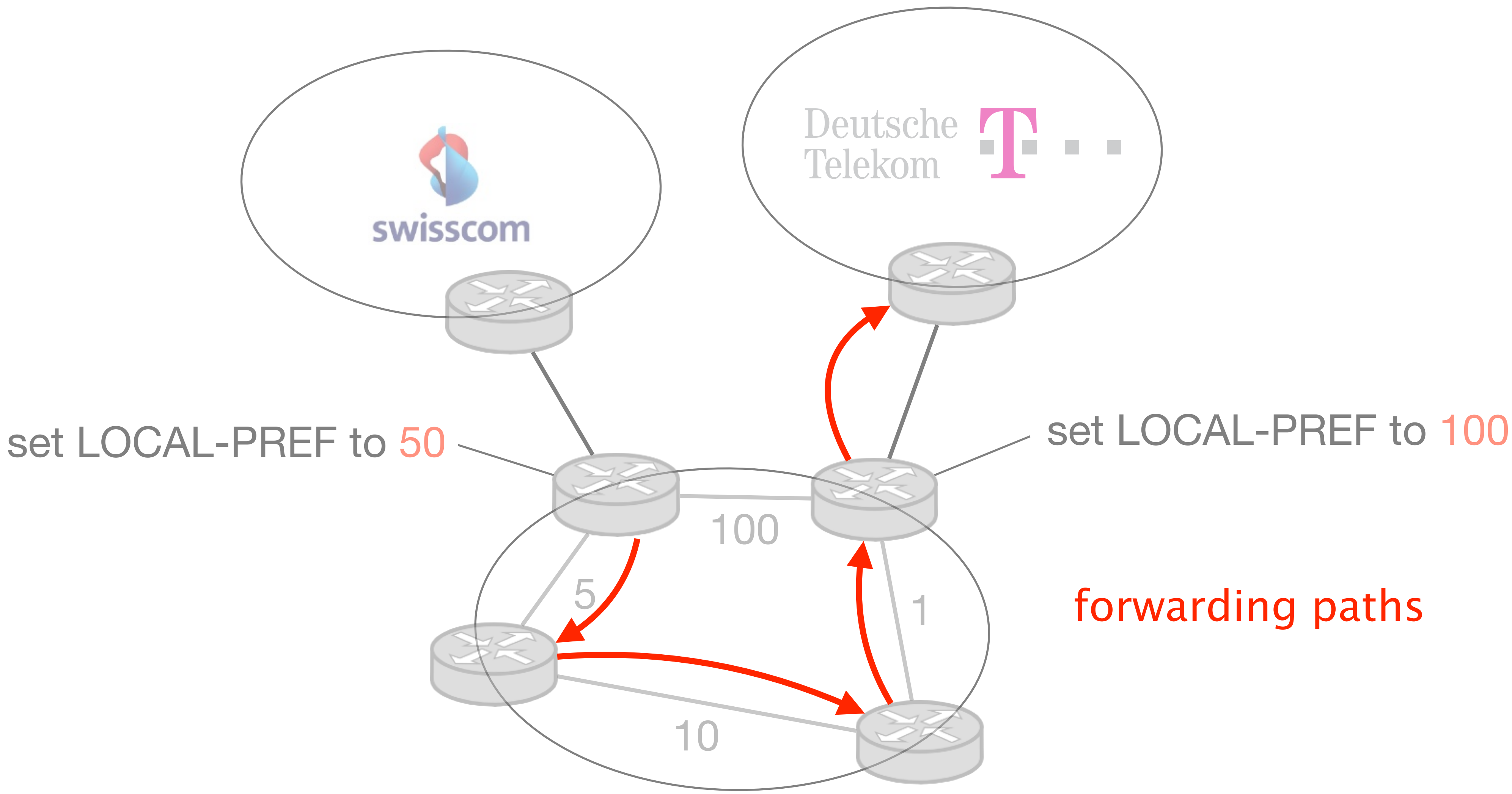
The LOCAL-PREF is a *local* attribute set at the border, it represents how "preferred" a route is


Provider #1 ($$)
swisscom
Provider #2 ($)
Deutsche Telekom
set LOCAL-PREF to 50
set LOCAL-PREF to 100
100
5
1
10
ETH

By setting a higher LOCAL-PREF,

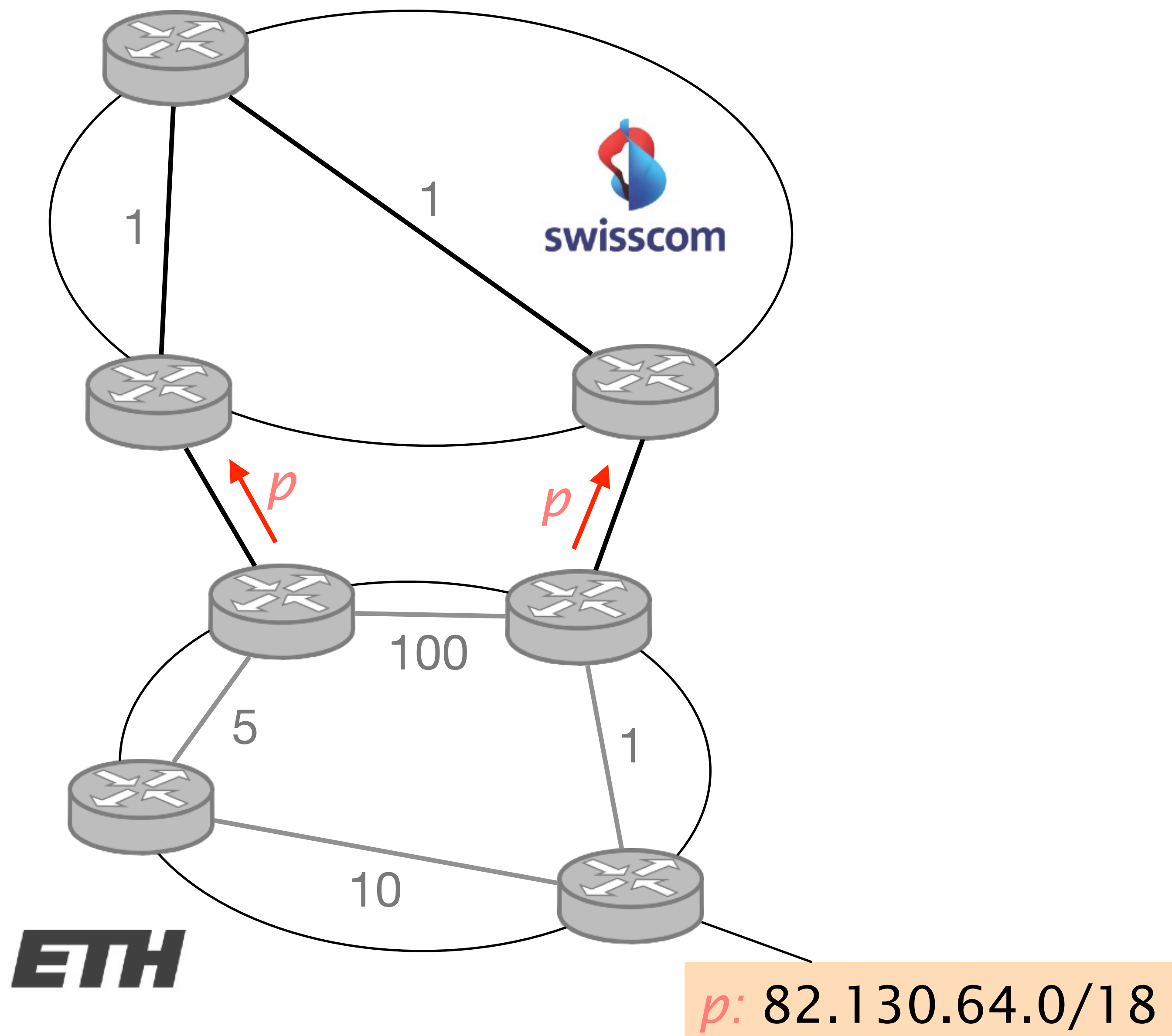
all routers end up using DT to reach any external prefixes,

even if they are closer (IGP-wise) to the Swisscom egress



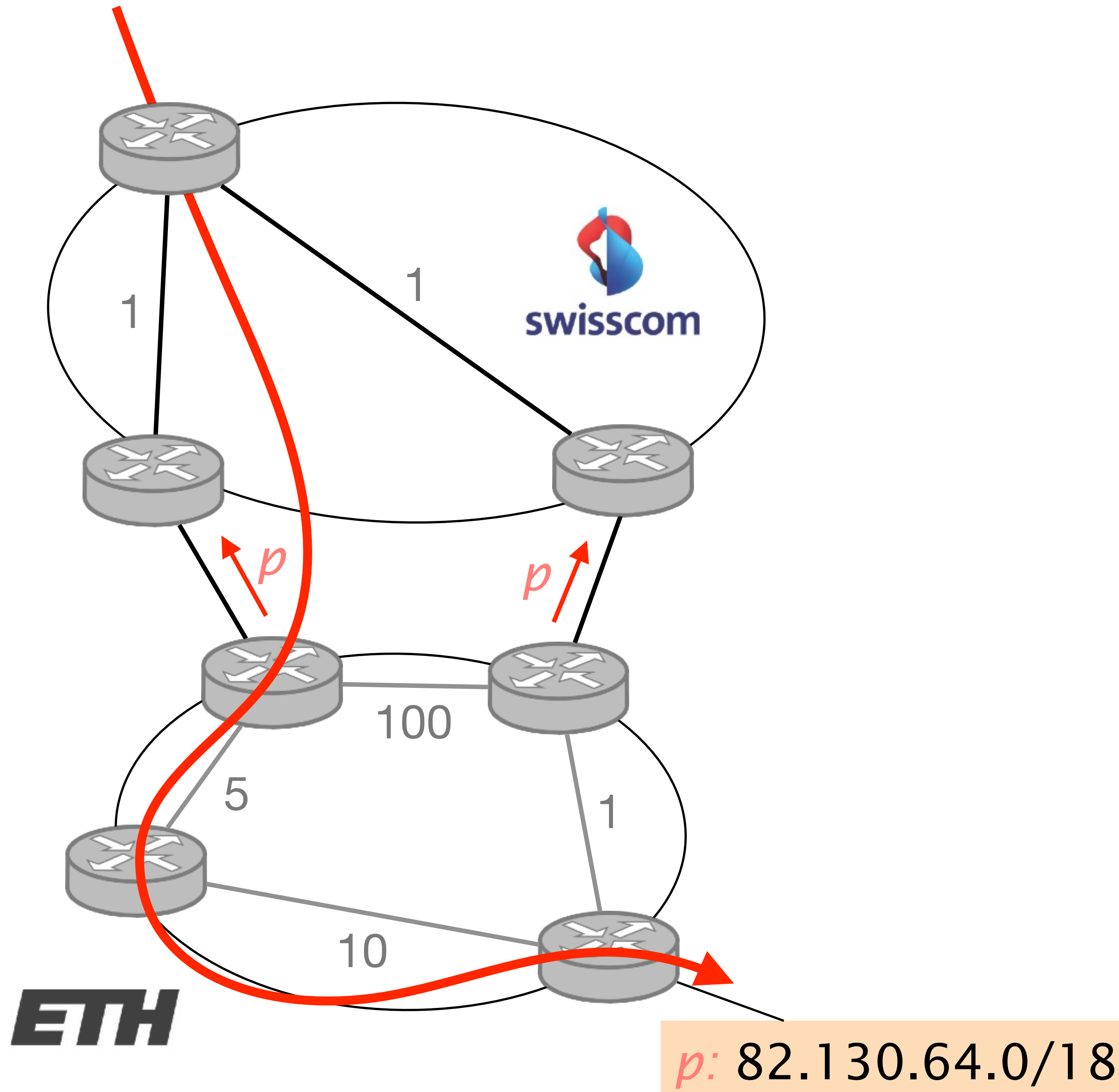
The MED is a *global* attribute which encodes
the relative “proximity” of a prefix wrt to the announcer

Swisscom receives two routes to reach *p*

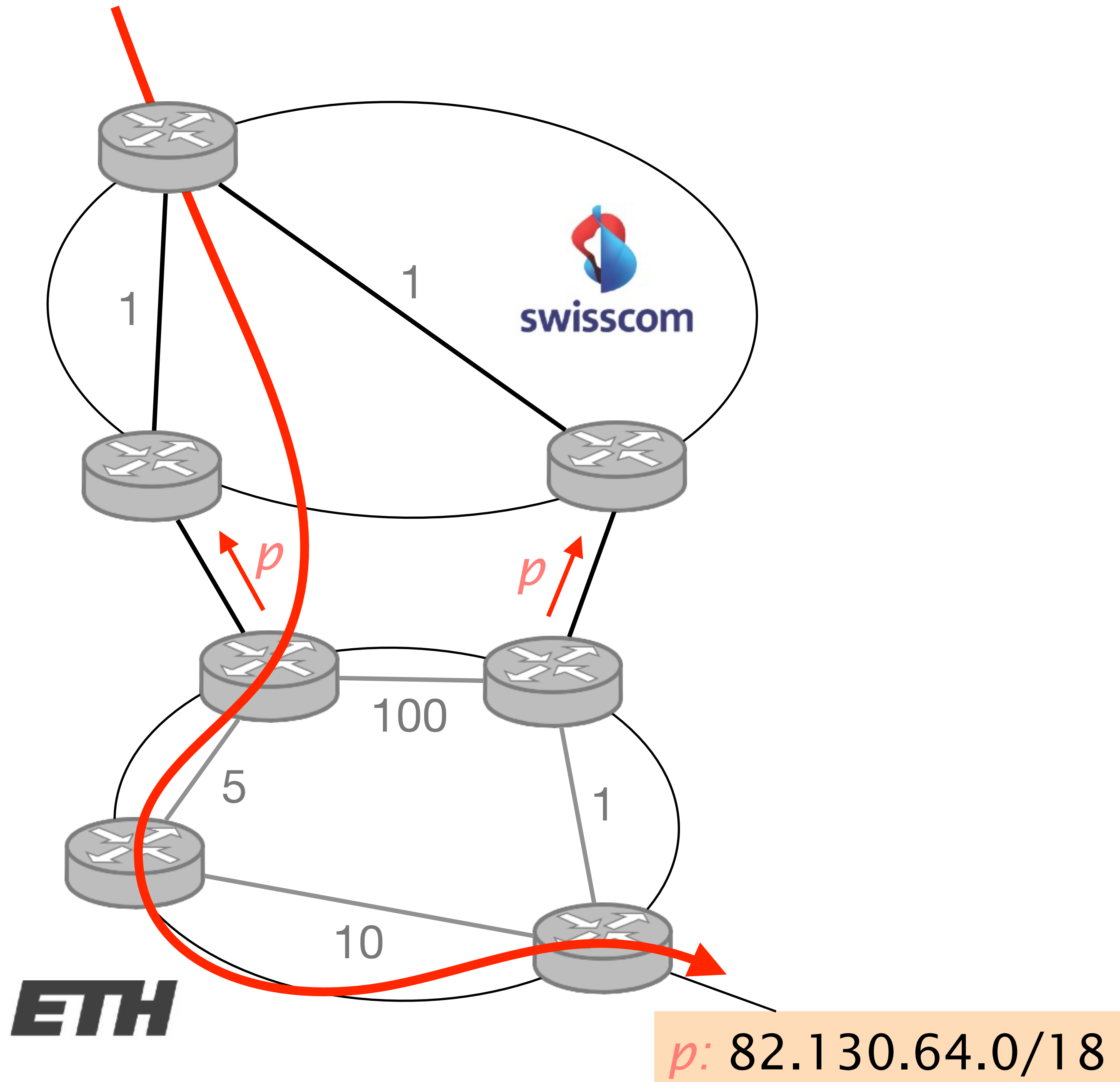


Swisscom receives two routes to reach p

and chooses (arbitrarily) its left router as egress

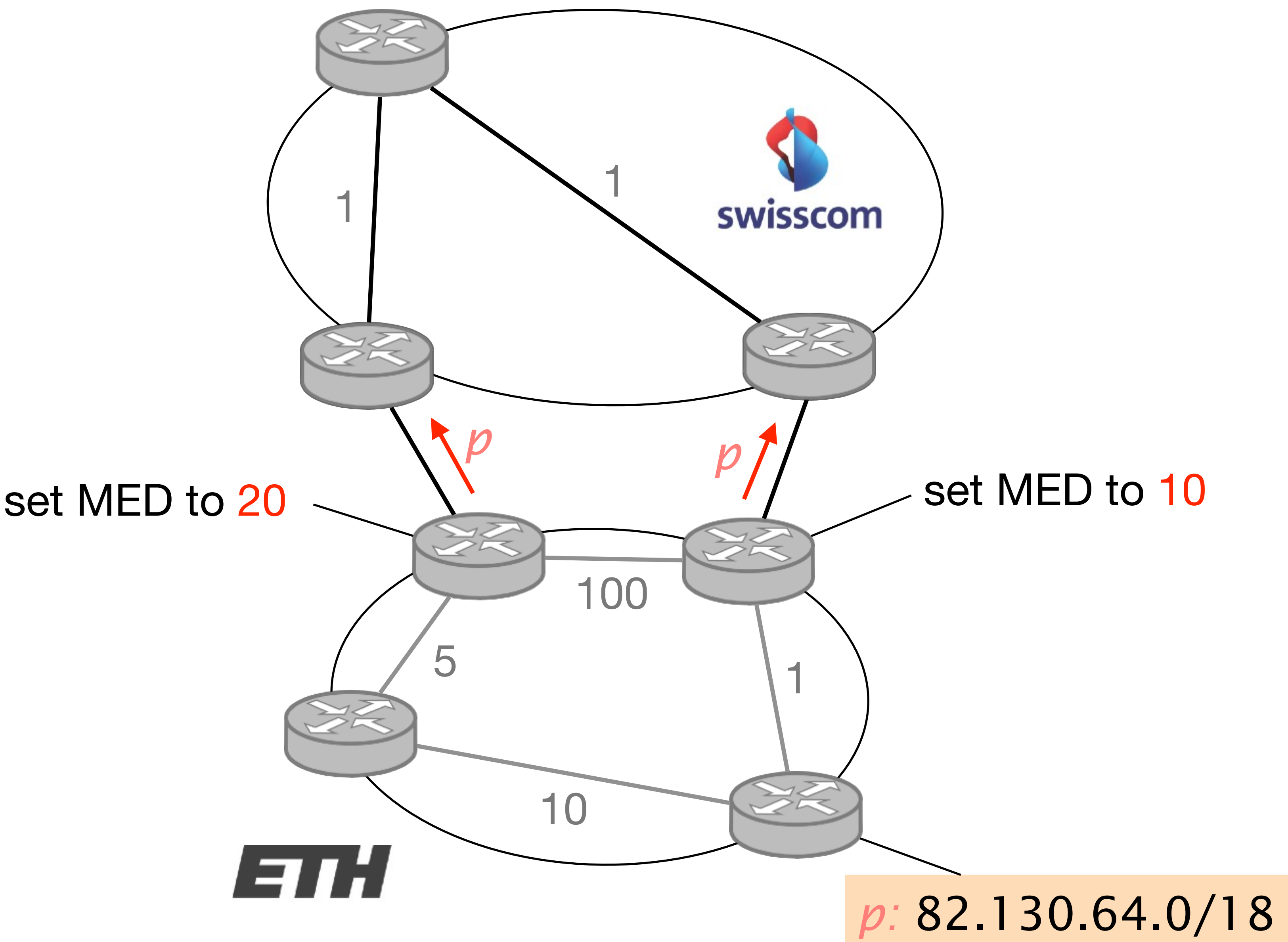


Yet, ETH would prefer to receive traffic for *p*
on its right border router which is closer to the actual destination

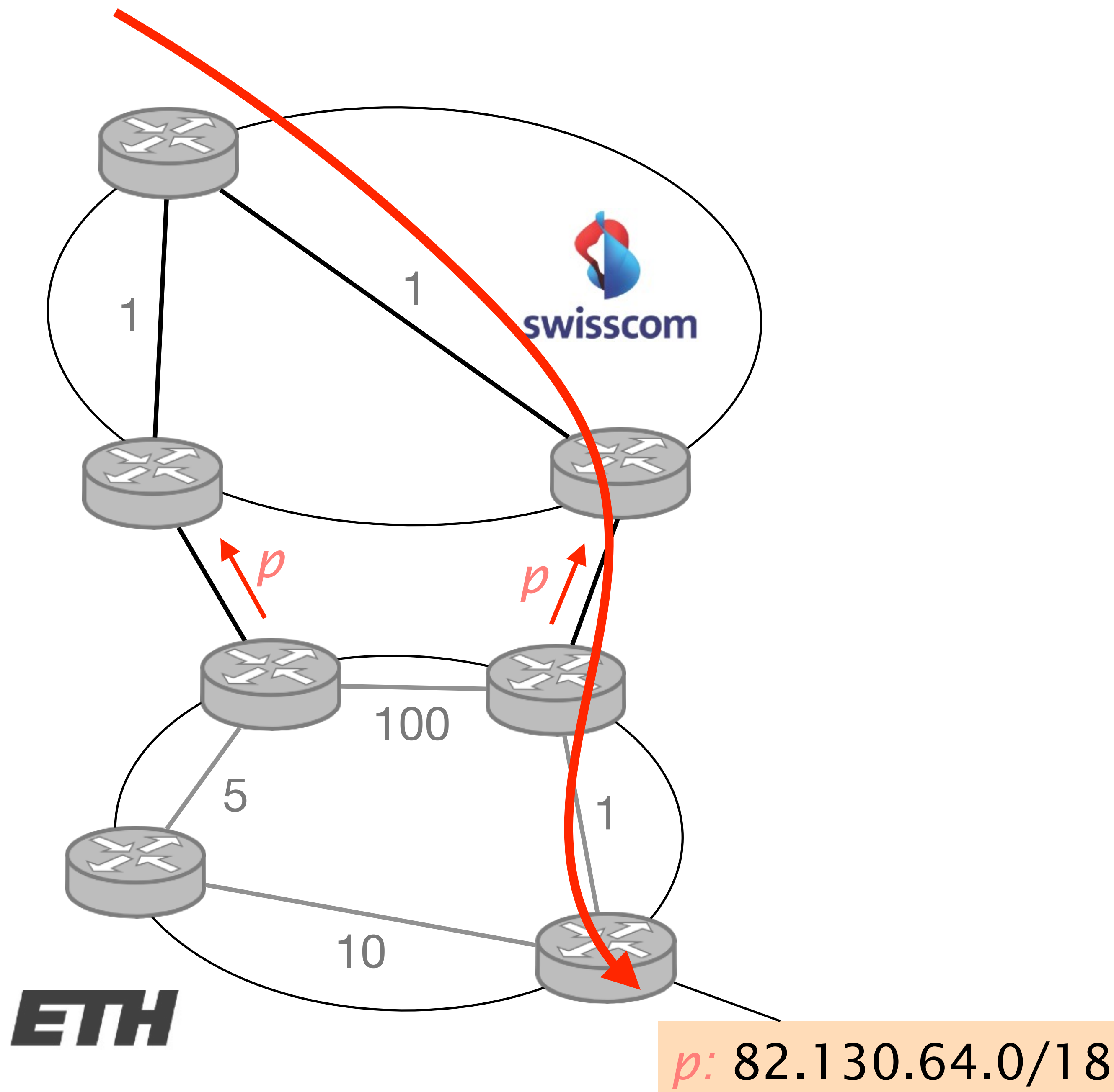


ETH can communicate that preferences to Swisscom

by setting a higher MED on *p* when announced from the left



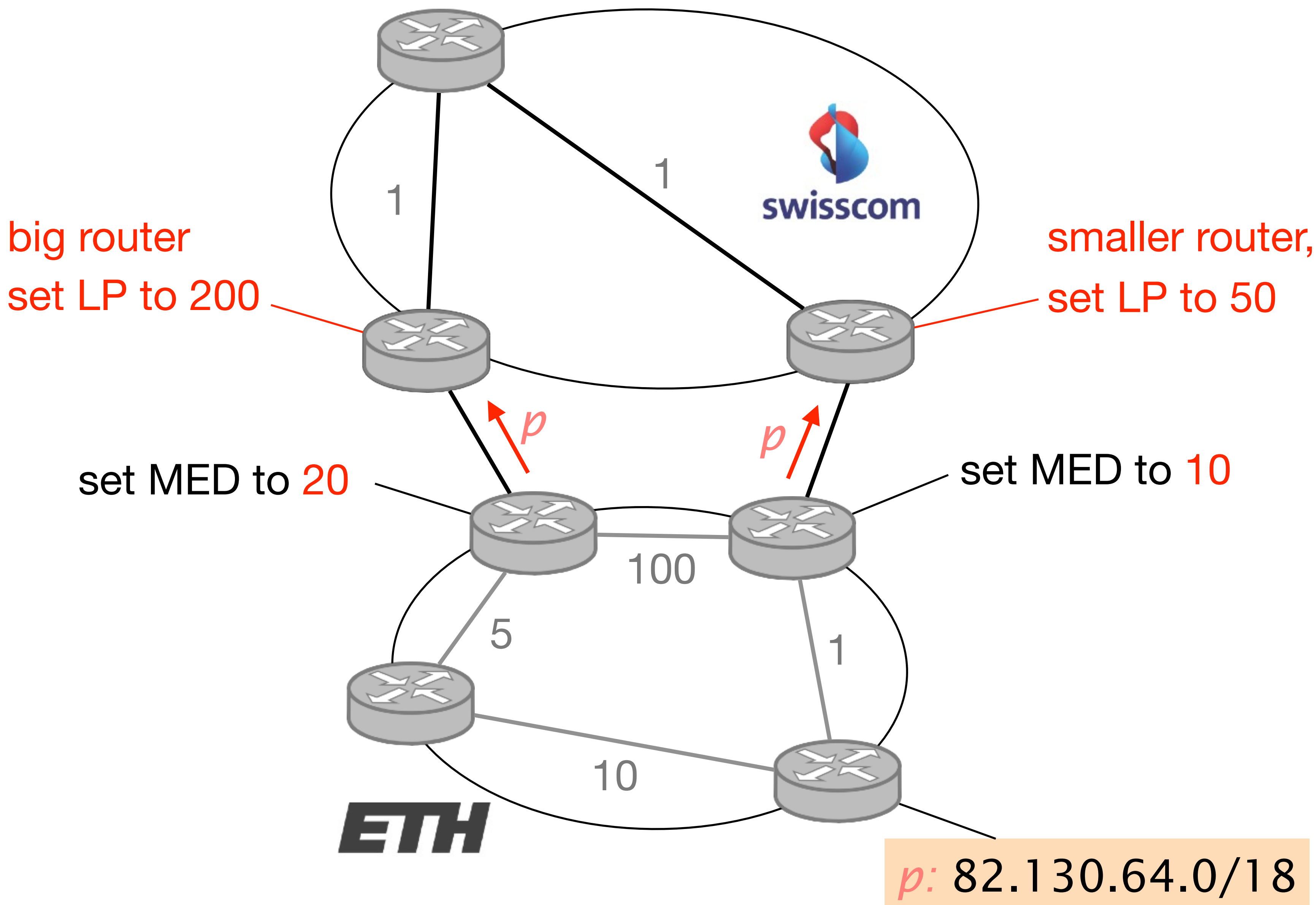
Swisscom receives two routes to reach *p*
and, *given it does not cost it anything more*,
chooses its right router as egress



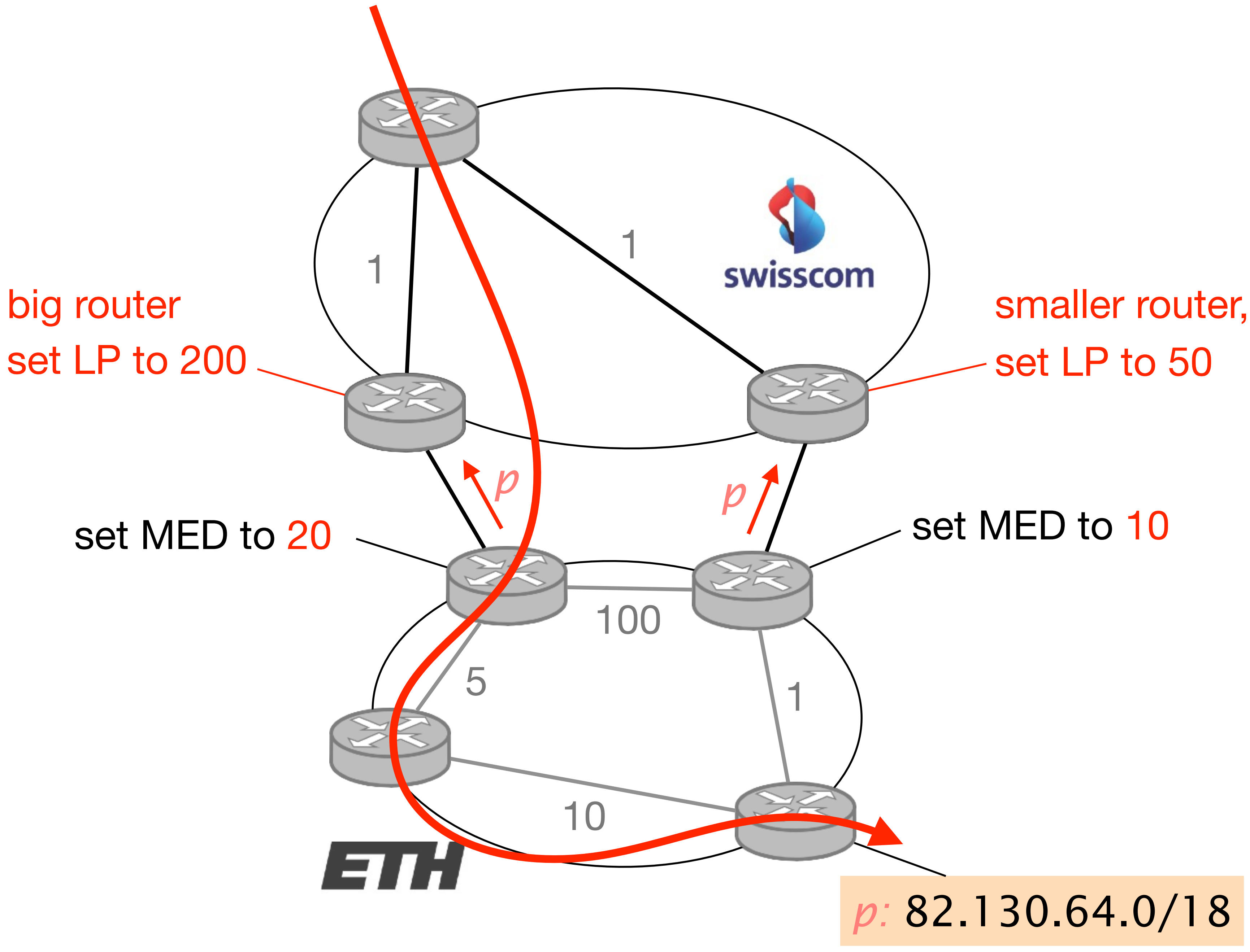
Swisscom receives two routes to reach *p* and, *given it does not cost it anything more*, chooses its right router as egress

But what if it does?

Consider that Swisscom always prefer to send traffic via its left egress point (bigger router, less costly)



In this case, Swisscom will not care about the MED value and still push the traffic via its left router



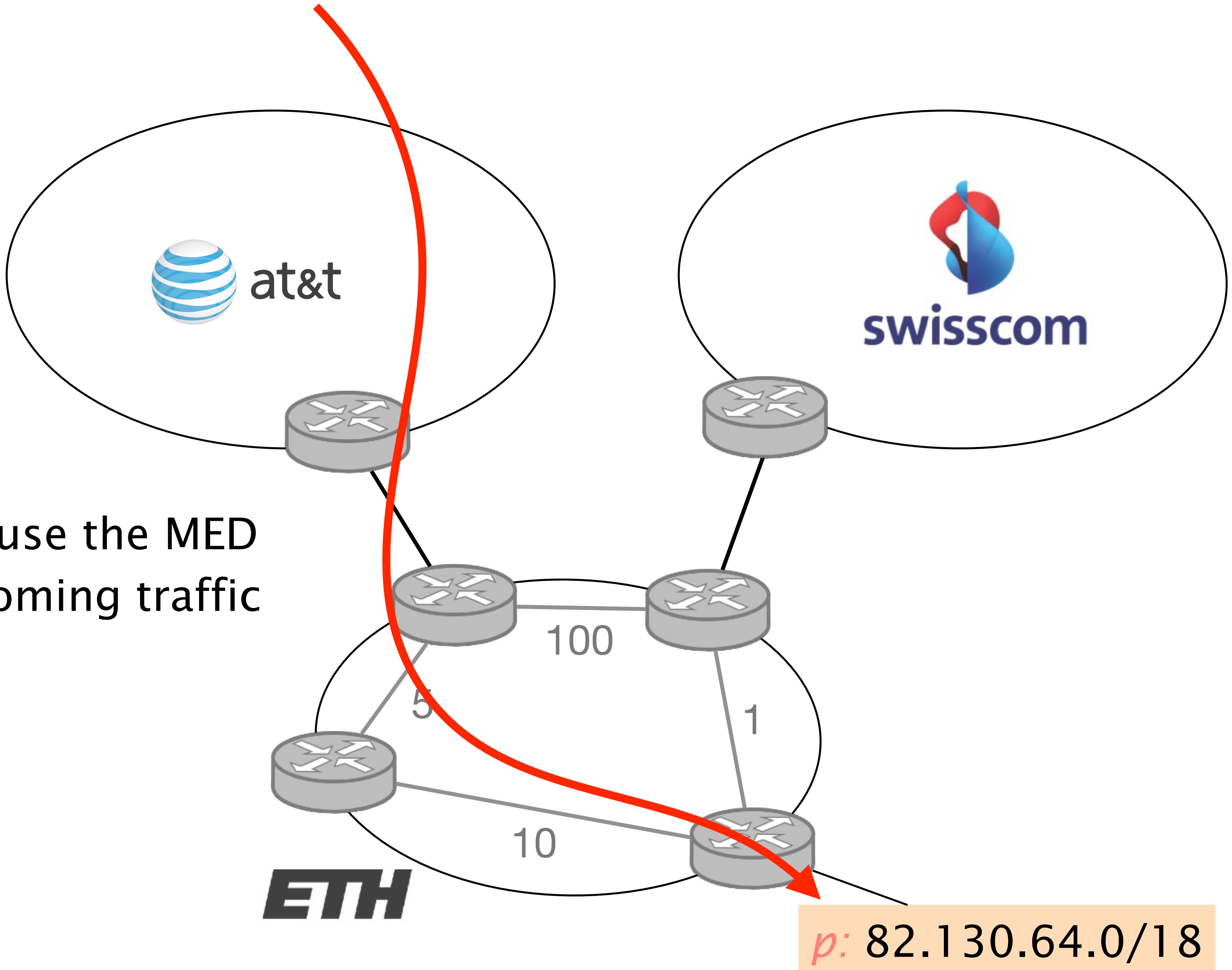
Lesson

The network which is sending the traffic always has the final word when it comes to deciding where to forward

Corollary

The network which is receiving the traffic can just influence remote decision, not control them

With the MED, an AS can influence its inbound traffic between multiple connection towards the same AS



ETH cannot use the MED to move incoming traffic to Swisscom

BGP UPDATEs carry an IP prefix together with a set of attributes

IP prefix

Attributes

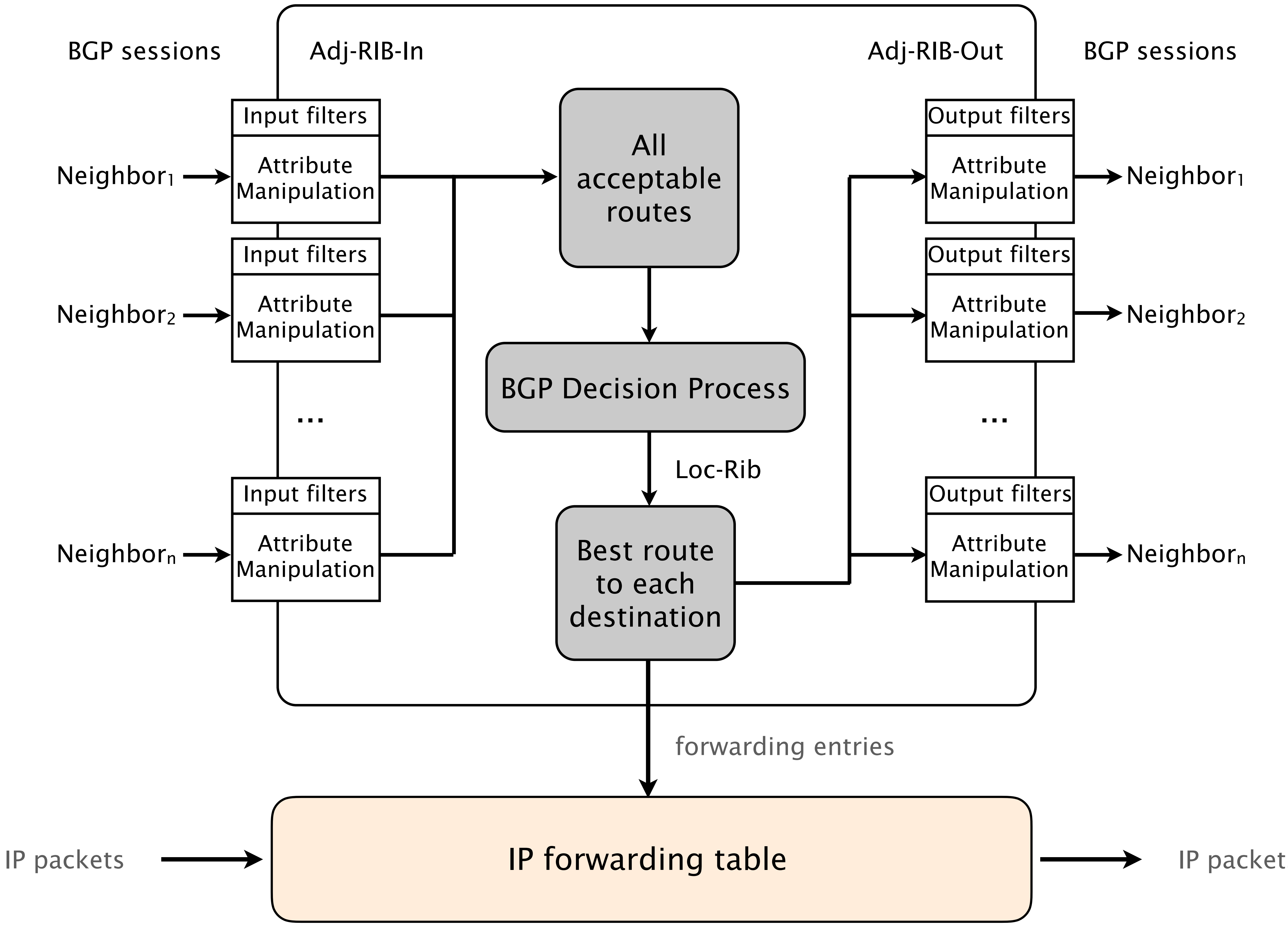
Describe route properties

used in route selection/exportation decisions

are either local (*only* seen on iBGP)

or global (seen on iBGP *and* eBGP)

Each BGP router processes UPDATEs according to a precise pipeline


BGP sessions
Adj-RIB-In
Adj-RIB-Out
BGP sessions
Input filters
Attribute Manipulation
Neighbor1
All acceptable routes
Output filters
Attribute Manipulation
Neighbor1
Input filters
Attribute Manipulation
Neighbor2
Output filters
Attribute Manipulation
Neighbor2
BGP Decision Process
...
...
Loc-Rib
Input filters
Attribute Manipulation
Neighborn
Best route to each destination
Output filters
Attribute Manipulation
Neighborn
forwarding entries
IP packets
IP forwarding table
IP packets

Given the set of all acceptable routes for each prefix, the BGP Decision process elects a single route

BGP is often referred to as a single path protocol

Prefer routes…

with higher LOCAL-PREF

with shorter AS-PATH length

with lower MED

learned via eBGP instead of iBGP

with lower IGP metric to the next-hop

with smaller egress IP address (tie-break) learned via eBGP instead of iBGP

with lower IGP metric to the next-hop

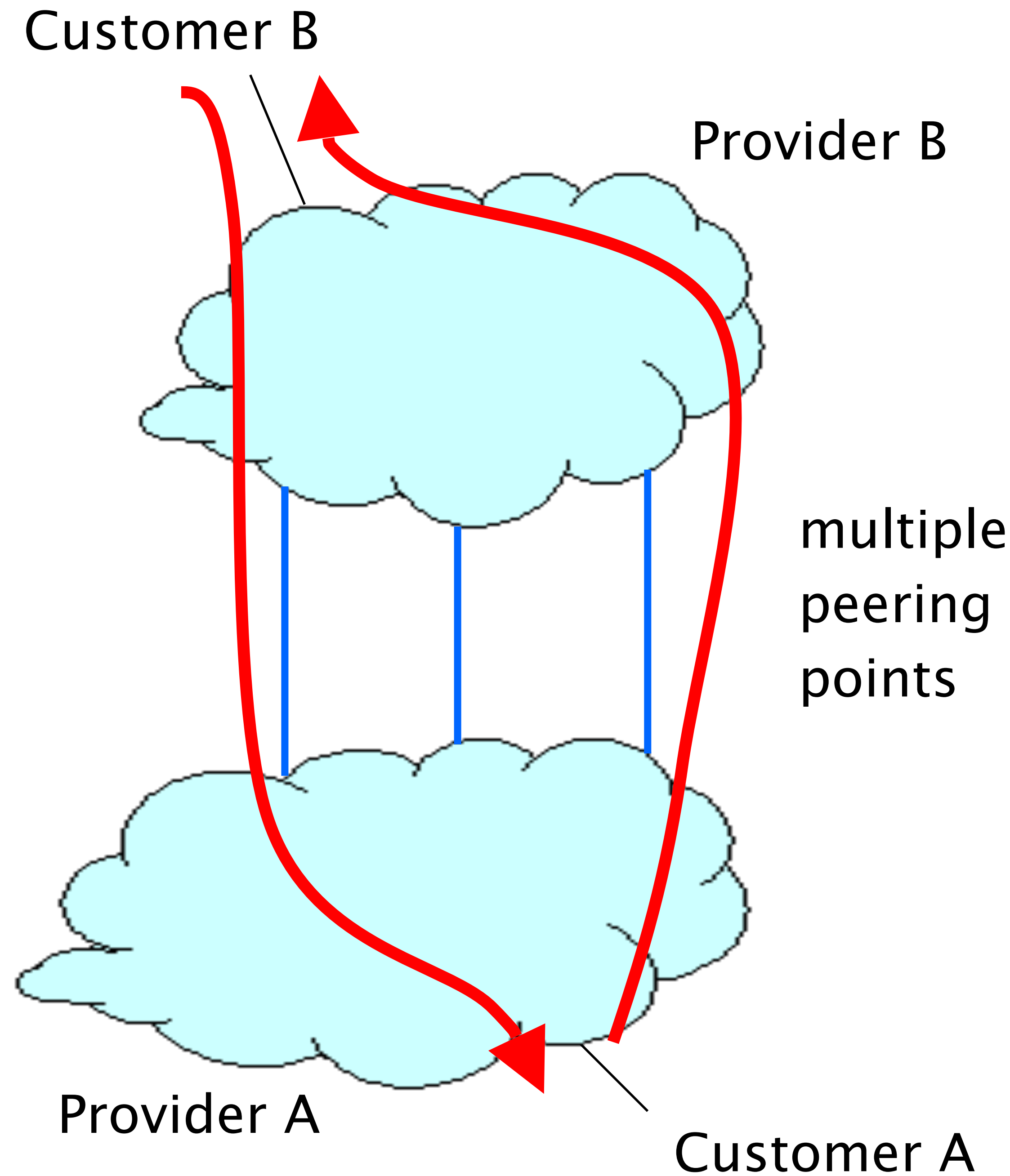
These two steps aim at directing traffic
as quickly as possible out of the AS (early exit routing)

ASes are selfish

They dump traffic
as soon as possible
to someone else

This leads to asymmetric routing

Traffic does not flow on
the same path
in both directions



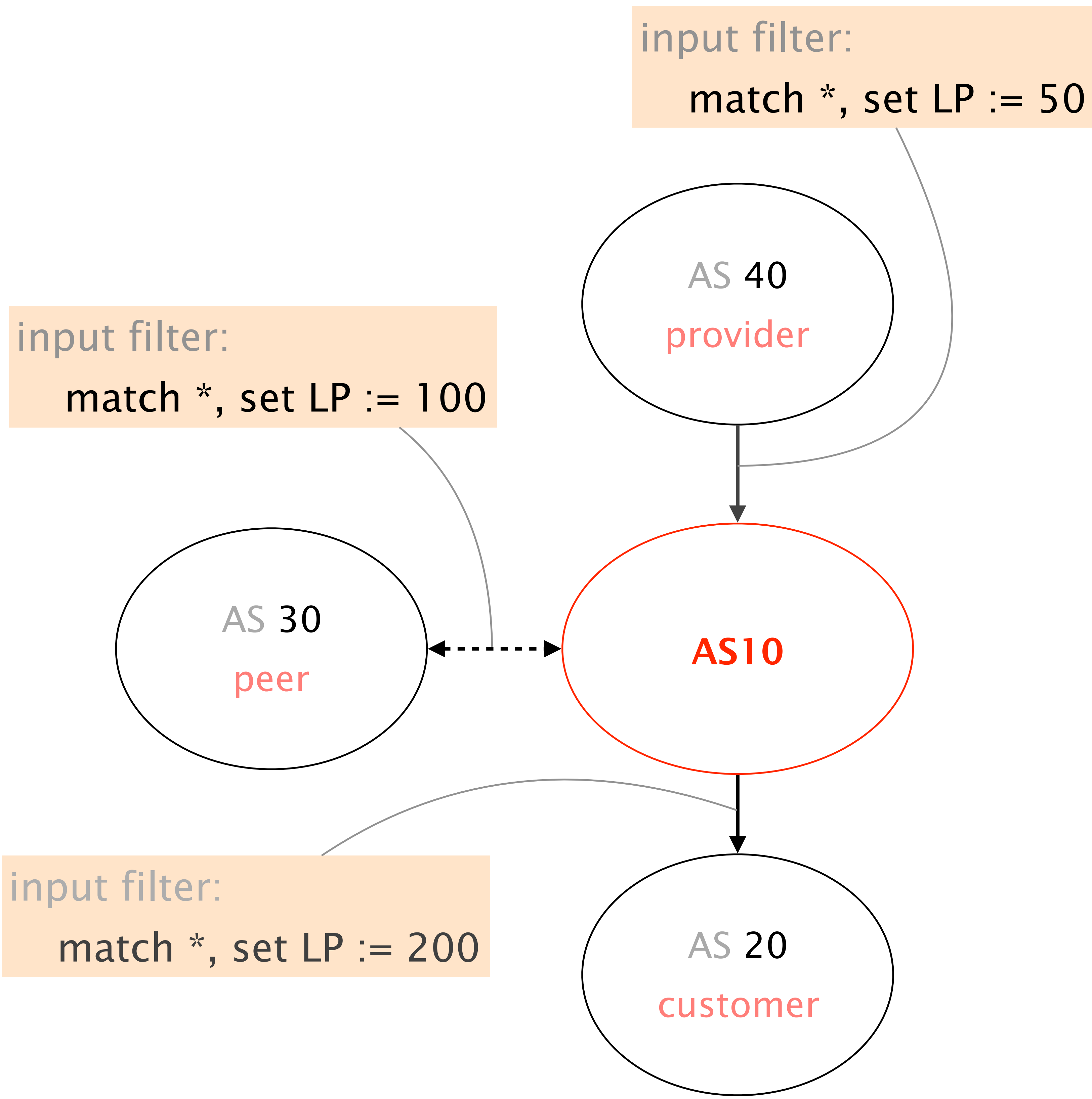
Let's look at how operators implement customer/provider and peer policies in practice

To implement their selection policy, operators define input filters which manipulates the LOCAL-PREF

For a destination *p*, prefer routes coming from

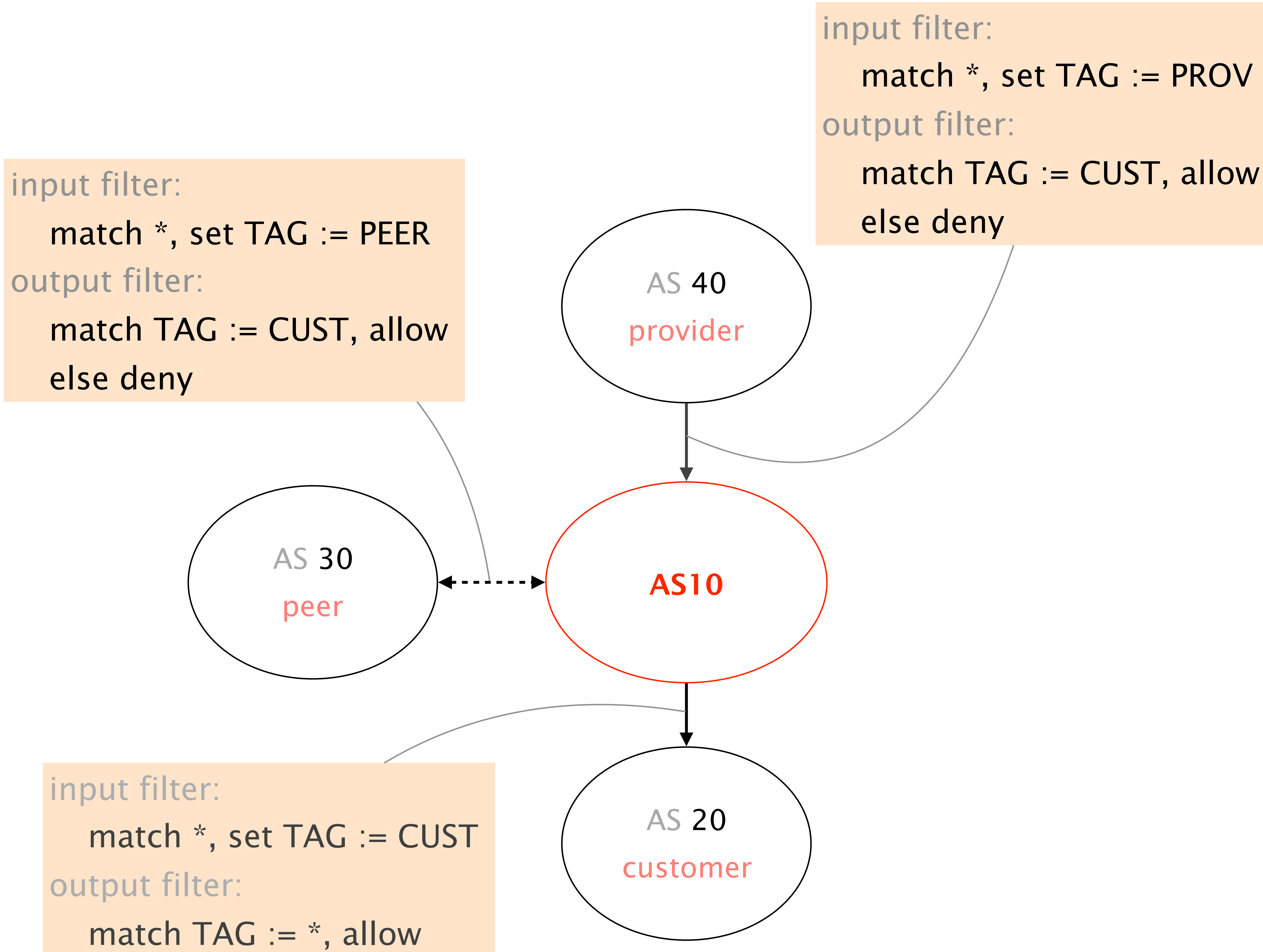
- customers over
- peers over
- providers

route type


input filter:
match *, set LP := 50
AS 40
provider
input filter:
match *, set LP := 100
AS 30
peer
AS10
input filter:
match *, set LP := 200
AS 20
customer

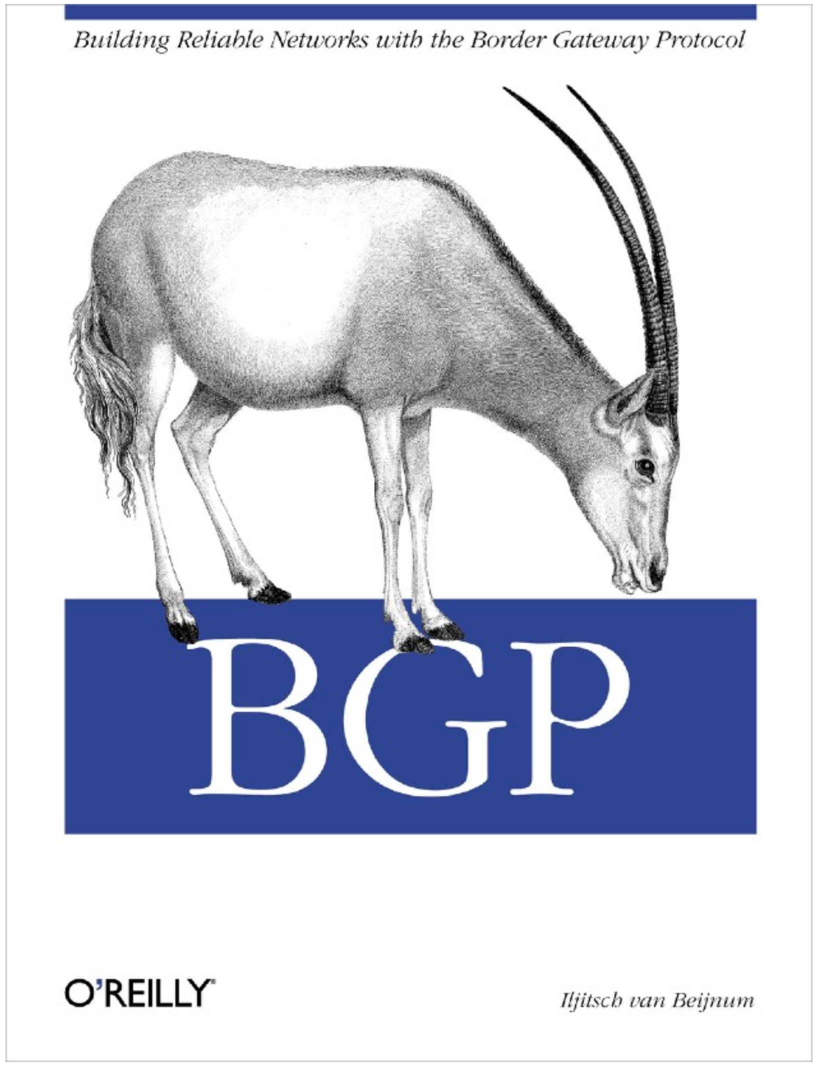
To implement their exportation rules,
operators use a mix of import and export filters

		send to		
		customer	peer	provider
	customer	✓	✓	✓
from	peer	✓	-	-
	provider	✓	-	-


input filter:
match *, set TAG := PROV
output filter:
match TAG := CUST, allow
else deny
input filter:
match *, set TAG := PEER
output filter:
match TAG := CUST, allow
else deny
AS 40
provider
AS 30
peer
AS10
AS 20
customer
input filter:
match *, set TAG := CUST
output filter:
match TAG := *, allow

Border Gateway Protocol

policies and more



BGP Policies

Follow the Money

Protocol

How does it work?

3 **Problems**

security, performance, …

BGP suffers from many rampant problems

Problems	Reachability
	Security
	Convergence
	Performance
	Anomalies
	Relevance

Problems

Reachability

Security

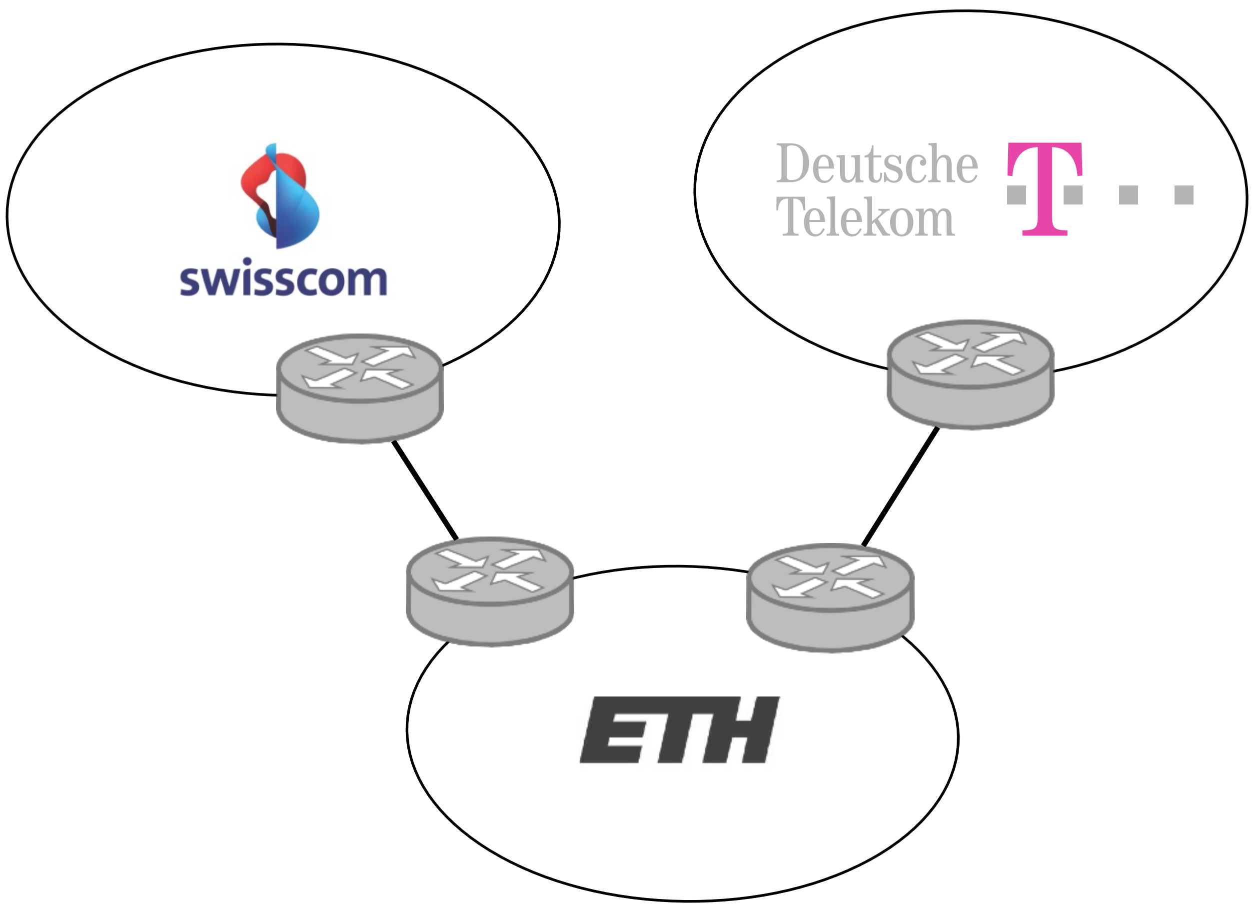
Convergence

Performance

Anomalies

Relevance

Unlike normal routing, policy routing does not guarantee reachability even if the graph is connected



Because of policies,

Swisscom cannot reach DT

even if the graph is connected

Problems

Reachability

Security

Convergence

Performance

Anomalies

Relevance

Many security considerations are simply absent from BGP specifications

ASes can advertise any prefixes

even if they don't own them!

ASes can arbitrarily modify route content

e.g., change the content of the AS-PATH

ASes can forward traffic along different paths

than the advertised one

BGP (lack of) security

#1	BGP does not validate the origin of advertisements
#2	BGP does not validate the content of advertisements

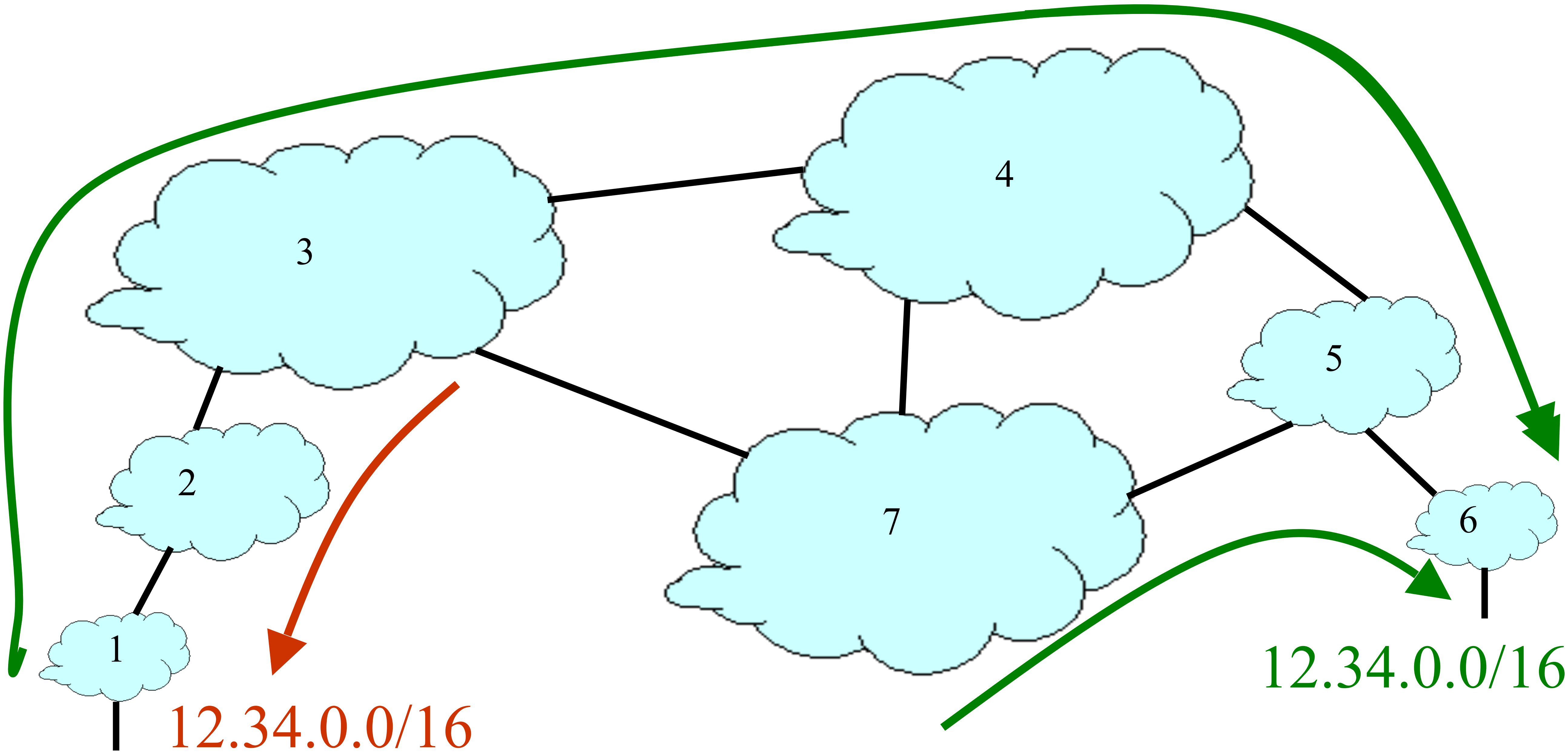
BGP (lack of) security

#1	BGP does not validate the origin of advertisements
#2	BGP does not validate the content of advertisements

IP Address Ownership and Hijacking

- IP address block assignment
  - Regional Internet Registries (ARIN, RIPE, APNIC)
  - Internet Service Providers
- Proper origination of a prefix into BGP
  - By the AS who owns the prefix
  - … or, by its upstream provider(s) in its behalf
- However, what's to stop someone else?
  - Prefix hijacking: another AS originates the prefix
  - BGP does not verify that the AS is authorized
  - Registries of prefix ownership are inaccurate

Prefix Hijacking

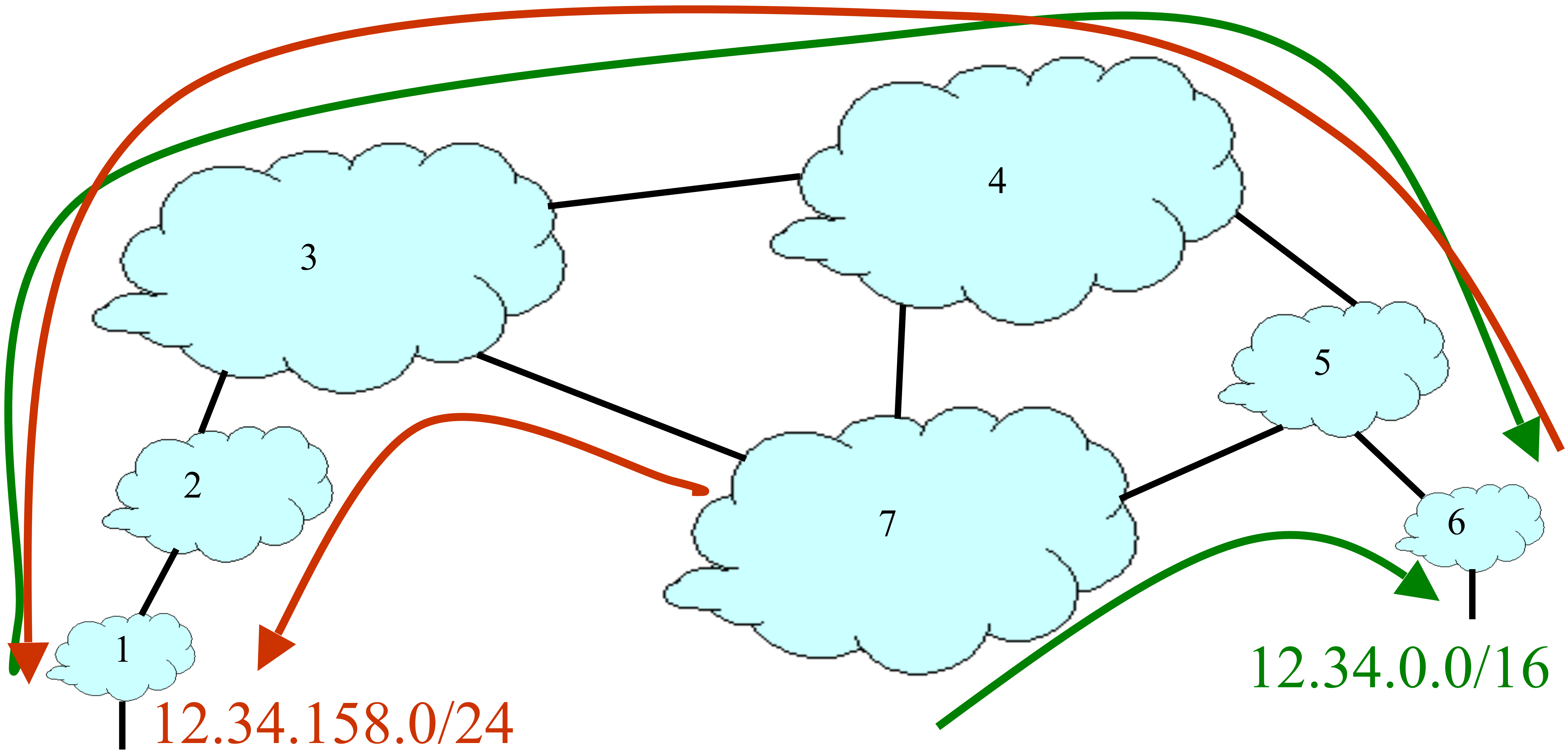


- Blackhole: data traffic is discarded
- Snooping: data traffic is inspected, then redirected
- Impersonation: traffic sent to bogus destinations

Hijacking is Hard to Debug

- The victim AS doesn't see the problem
  - Picks its own route, might not learn the bogus route
- May not cause loss of connectivity
  - Snooping, with minor performance degradation
- Or, loss of connectivity is isolated
  - E.g., only for sources in parts of the Internet
- Diagnosing prefix hijacking
  - Analyzing updates from many vantage points
  - Launching traceroute from many vantage points

Sub-Prefix Hijacking



- Originating a more-specific prefix
  - Every AS picks the bogus route for that prefix
  - Traffic follows the longest matching prefix

How to Hijack a Prefix

- The hijacking AS has
  - Router with BGP session(s)
  - Configured to originate the prefix
- Getting access to the router
  - Network operator makes configuration mistake
  - Disgruntled operator launches an attack
  - Outsider breaks in to the router and reconfigures
- Getting other ASes to believe bogus route
  - Neighbor ASes do not discard the bogus route
  - E.g., not doing protective filtering

YouTube Outage on Feb 24, 2008

- YouTube (AS 36561)
  - Web site www.youtube.com (208.65.152.0/22)
- Pakistan Telecom (AS 17557)
  - Government order to block access to YouTube
  - Announces 208.65.153.0/24 to PCCW (AS 3491)
  - All packets to YouTube get dropped on the floor
- Mistakes were made
  - AS 17557: announce to everyone, not just customers
  - AS 3491: not filtering routes announced by AS 17557
- Lasted 100 minutes for some, 2 hours for others

Timeline (UTC Time)

- 18:47:45
  - First evidence of hijacked /24 route in Asia
- 18:48:00
  - Several big trans-Pacific providers carrying the route
- 18:49:30
  - Bogus route fully propagated
- 20:07:25
  - YouTube starts advertising /24 to attract traffic back
- 20:08:30
  - Many (but not all) providers are using valid route

Timeline (UTC Time)

- 20:18:43
  - YouTube announces two more-specific /25 routes
- 20:19:37
  - Some more providers start using the /25 routes
- 20:50:59
  - AS 17557 starts prepending (“3491 17557 17557”)
- 20:59:39
  - AS 3491 disconnects AS 17557
- 21:00:00
  - Videos of cats flushing toilets are available again!

Another Example: Spammers

- Spammers sending spam
  - Form a (bidirectional) TCP connection to mail server
  - Send a bunch of spam e-mail, then disconnect
- But, best not to use your real IP address
  - Relatively easy to trace back to you
- Could hijack someone's address space
  - But you might not receive all the (TCP) return traffic
- How to evade detection
  - Hijack unused (i.e., unallocated) address block
  - Temporarily use the IP addresses to send your spam

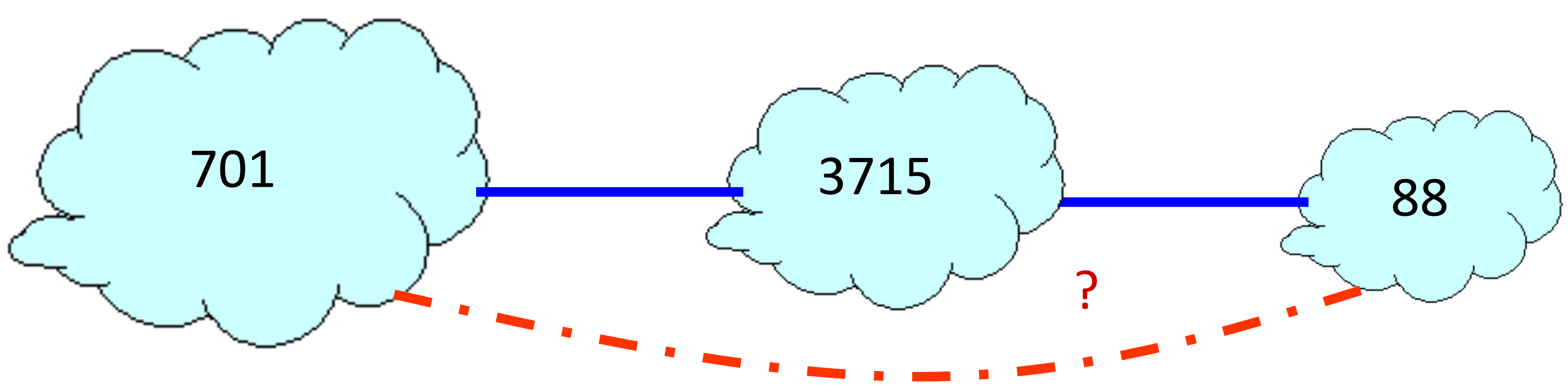
BGP (lack of) security

#1 BGP does not validate the origin of advertisements

#2 BGP does not validate the content of advertisements

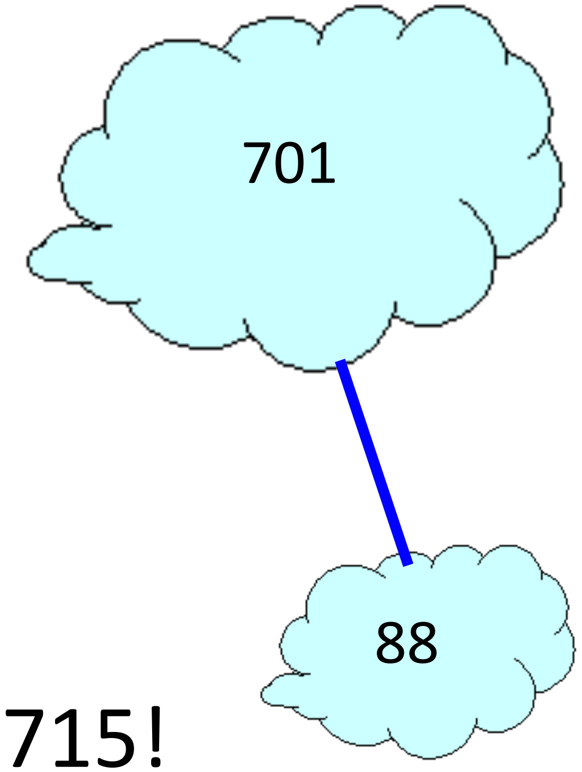
Bogus AS Paths

- Remove ASes from the AS path
  - E.g., turn “701 3715 88” into “701 88”
- Motivations
  - Attract sources that normally try to avoid AS 3715
  - Help AS 88 look like it is closer to the Internet’s core
- Who can tell that this AS path is a lie?
  - Maybe AS 88 *does* connect to AS 701 directly



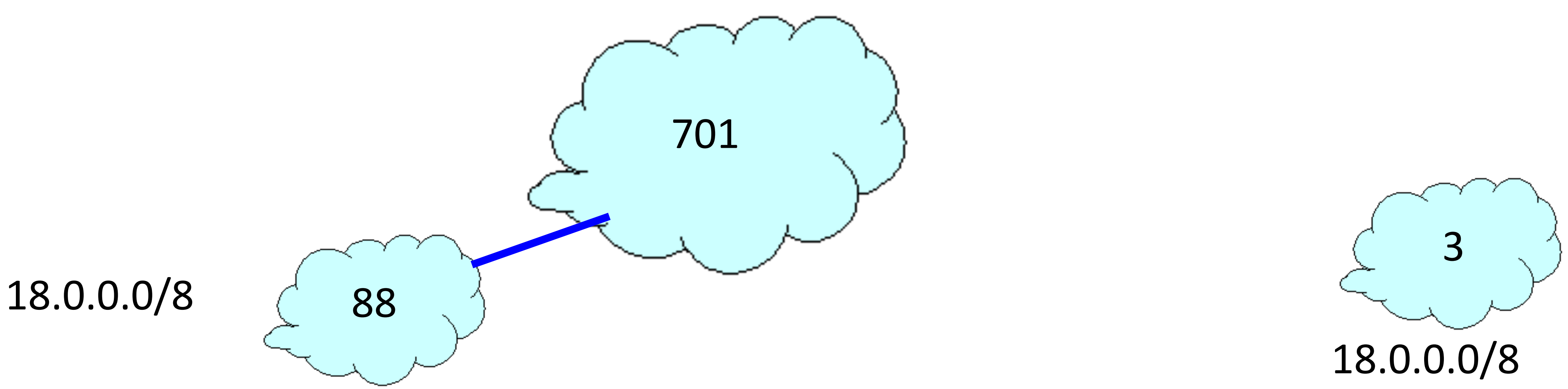
Bogus AS Paths

- Add ASes to the path
  - E.g., turn “701 88” into “701 3715 88”
- Motivations
  - Trigger loop detection in AS 3715
    - Denial-of-service attack on AS 3715
    - Or, blocking unwanted traffic coming from AS 3715!
  - Make your AS look like is has richer connectivity
- Who can tell the AS path is a lie?
  - AS 3715 could, if it could see the route
  - AS 88 could, but would it really care?



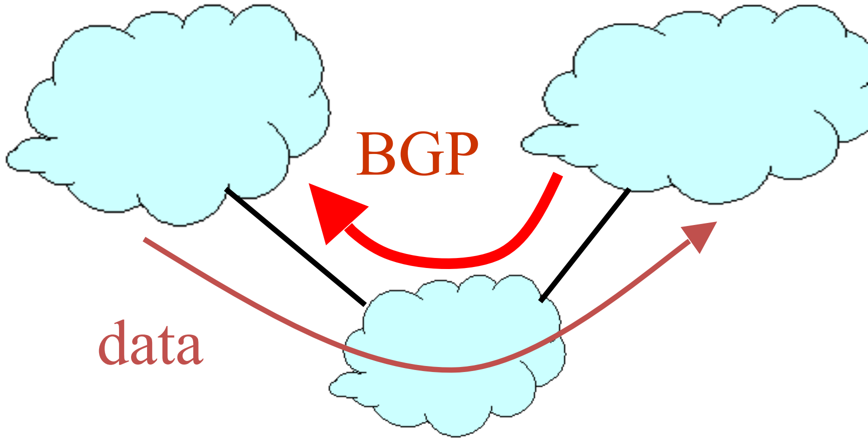
Bogus AS Paths

- Adds AS hop(s) at the end of the path
  - E.g., turns "701 88" into "701 88 3"
- Motivations
  - Evade detection for a bogus route
  - E.g., by adding the legitimate AS to the end
- Hard to tell that the AS path is bogus…
  - Even if other ASes filter based on prefix ownership



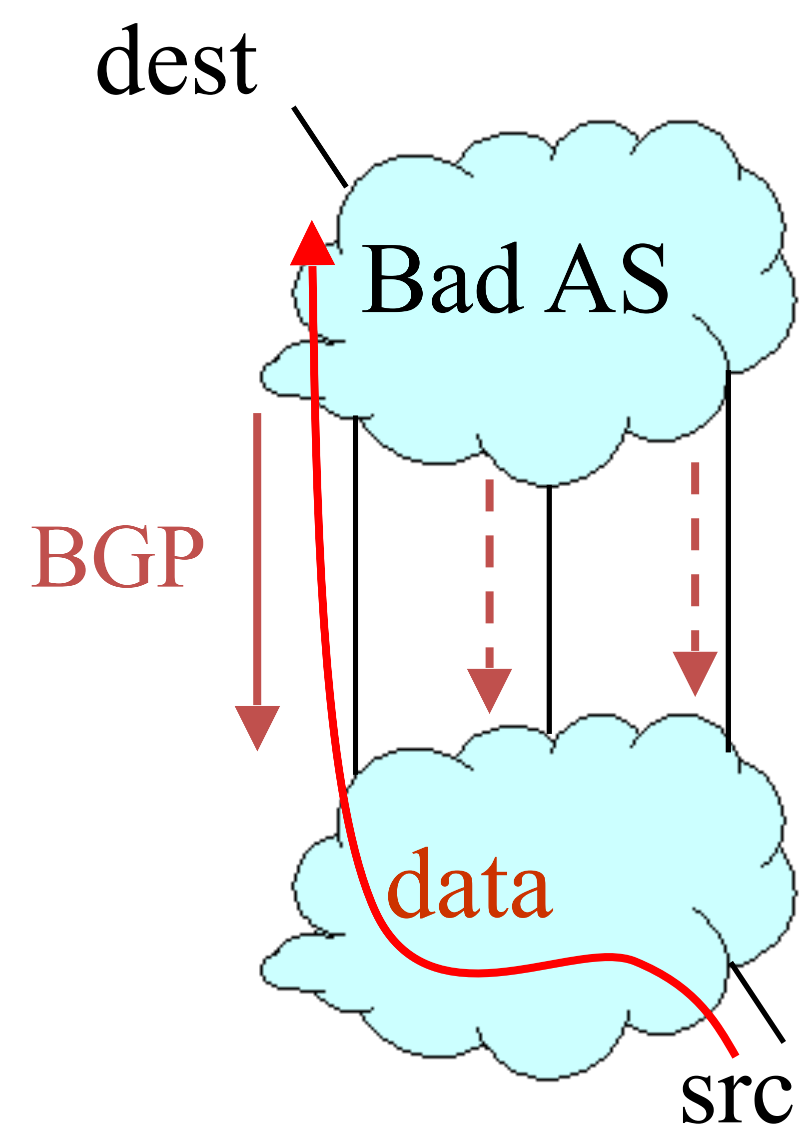
Invalid Paths

- AS exports a route it shouldn't
  - AS path is a valid sequence, but violated policy
- Example: customer misconfiguration
  - Exports routes from one provider to another
- Interacts with provider policy
  - Provider prefers customer routes
  - Directing all traffic through customer
- Main defense
  - Filtering routes based on prefixes and AS path



Missing/Inconsistent Routes

- Peers require consistent export
  - Prefix advertised at all peering points
  - Prefix advertised with same AS path length
- Reasons for violating the policy
  - Trick neighbor into "cold potato"
  - Configuration mistake
- Main defense
  - Analyzing BGP updates, or traffic,
  - … for signs of inconsistency



BGP Security Today

- Applying best common practices (BCPs)
  - Securing the session (authentication, encryption)
  - Filtering routes by prefix and AS path
  - Packet filters to block unexpected control traffic
- This is not good enough
  - Depends on vigilant application of BCPs
  - Doesn’t address fundamental problems
    - Can’t tell who owns the IP address block
    - Can’t tell if the AS path is bogus or invalid
    - Can’t be sure the data packets follow the chosen route

Routing attacks can be used to
de-anonymize Tor users

RAPTOR: Routing Attacks on Privacy in Tor

Yixin Sun — *Princeton University*
Anne Edmundson — *Princeton University*
Laurent Vanbever — *ETH Zurich*
Oscar Li — *Princeton University*
Jennifer Rexford — *Princeton University*
Mung Chiang — *Princeton University*
Prateek Mittal — *Princeton University*

Abstract

The Tor network is a widely used system for anonymous communication. However, Tor is known to be vulnerable to attackers who can observe traffic at both ends of the communication path. In this paper, we show that prior attacks are just the tip of the iceberg. We present a suite of new attacks, called Raptor, that can be launched by Autonomous Systems (ASes) to compromise user anonymity. First, AS-level adversaries can exploit the asymmetric nature of Internet routing to increase the chance of observing at least one direction of user traffic at both ends of the communication. Second, AS-level adversaries can exploit natural churn in Internet routing to lie on the BGP paths for more users over

specific Tor guard nodes) and interceptions (to perform traffic analysis). We demonstrate the feasibility of Rap-

journalists, businesses and ordinary citizens concerned about the privacy of their online communications [9].

Along with anonymity, Tor aims to provide low latency and, as such, does not obfuscate packet timings or sizes. Consequently, an adversary who is able to observe traffic on both segments of the Tor communication channel (*i.e.*, between the server and the Tor network, and between the Tor network and the client) can correlate packet sizes and packet timings to deanonymize Tor clients [45, 46].

There are essentially two ways for an adversary to gain visibility into Tor traffic, either by compromising (or owning enough) Tor relays or by manipulating the underlying network communications so as to put herself on the forwarding path for Tor traffic. Regarding net-

Internet Service Providers (ISPs) can easily eavesdrop on a portion of all links, and observe any unencrypted infor-

See http://vanbever.eu/pdfs/vanbever_raptor_usenix_security_2015.pdf

Routing attacks can be used to

partition the Bitcoin network

Hijacking Bitcoin: Routing Attacks on Cryptocurrencies

https://btc-hijack.ethz.ch

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***Abstract*—As the most successful cryptocurrency to date, Bitcoin constitutes a target of choice for attackers. While many attack vectors have already been uncovered, one important vector has been left out though: attacking the currency via the Internet routing infrastructure itself. Indeed, by manipulating routing advertisements (BGP hijacks) or by naturally intercepting traffic, Autonomous Systems (ASes) can intercept and manipulate a large fraction of Bitcoin traffic.**

This paper presents the first taxonomy of routing attacks and their impact on Bitcoin, considering both small-scale attacks, targeting individual nodes, and large-scale attacks, targeting the network as a whole. While challenging, we show that two key properties make routing attacks practical: *(i)* the efficiency of routing manipulation; and *(ii)* the significant centralization of Bitcoin in terms of mining and routing. Specifically, we find that any network attacker can hijack few (<100) BGP prefixes to isolate ~50% of the mining power—even when considering that mining pools are heavily multi-homed. We also show that on-path network attackers can considerably slow down block propagation by interfering with few key Bitcoin messages.

We demonstrate the feasibility of each attack against the deployed Bitcoin software. We also quantify their effectiveness on ... m a Bitcoin

See https://btc-hijack.ethz.ch

The potential damage to Bitcoin is worrying. By isolating parts of the network or delaying block propagation, attackers can cause

One important attack vector has been overlooked though: attacking Bitcoin via the Internet infrastructure using *routing attacks*. As Bitcoin connections are routed over the Internet—in clear text and without integrity checks—any third-party on the forwarding path can eavesdrop, drop, modify, inject, or delay Bitcoin messages such as blocks or transactions. Detecting such attackers is challenging as it requires inferring the exact forwarding paths taken by the Bitcoin traffic using measurements (e.g., traceroute) or routing data (BGP announcements), both of which can be forged [41]. Even ignoring detectability, mitigating network attacks is also hard as it is essentially a human-driven process consisting of filtering, routing around or disconnecting the attacker. As an illustration, it took Youtube close to 3 hours to locate and resolve rogue BGP announcements targeting its infrastructure in 2008 [6]. More recent examples of routing attacks such as [51] (resp. [52]) took 9 (resp. 2) hours to resolve in November (resp. June) 2015.

One of the reasons why routing attacks have been overlooked in Bitcoin is that they are often considered too challenging to be practical. Indeed, perturbing a vast peer-to-peer

Problems

Reachability

Security

Convergence

Performance

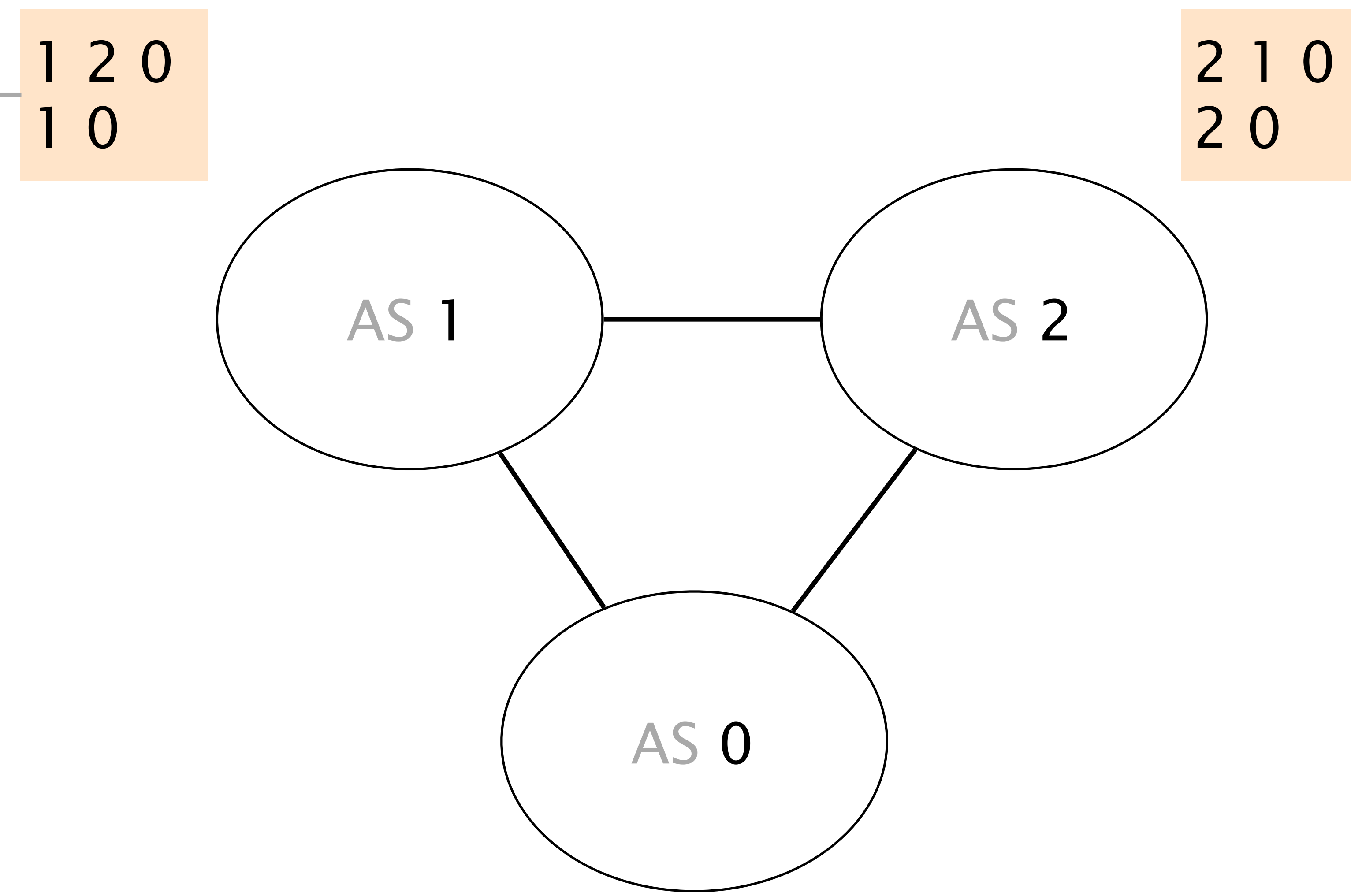
Anomalies

Relevance

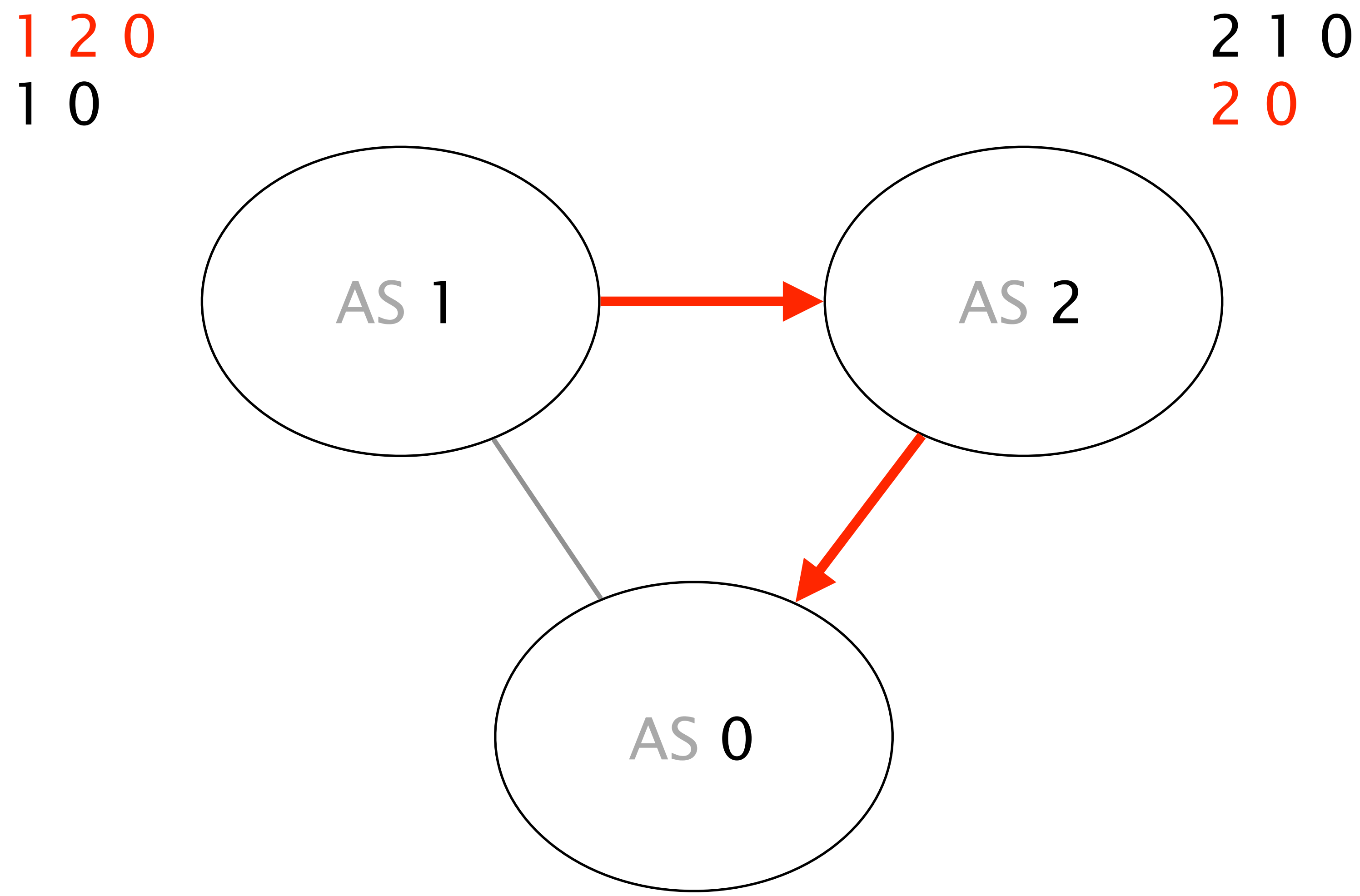
With arbitrary policies,
BGP may have multiple stable states

preference list

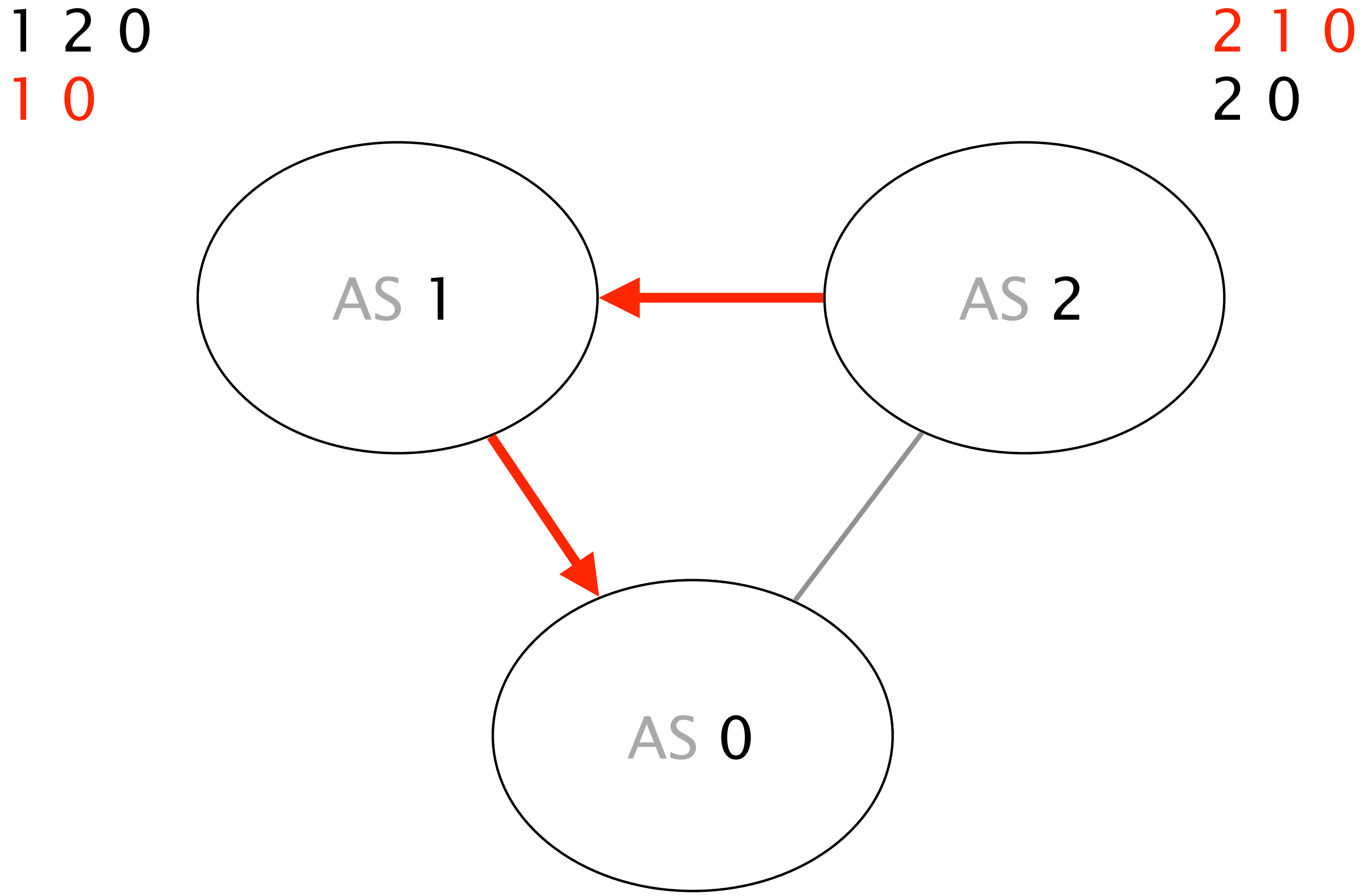
1 prefers to reach 0
via 2 rather than directly



If AS2 is the first to advertise 2 0,
the system stabilizes in a state where AS 1 is happy

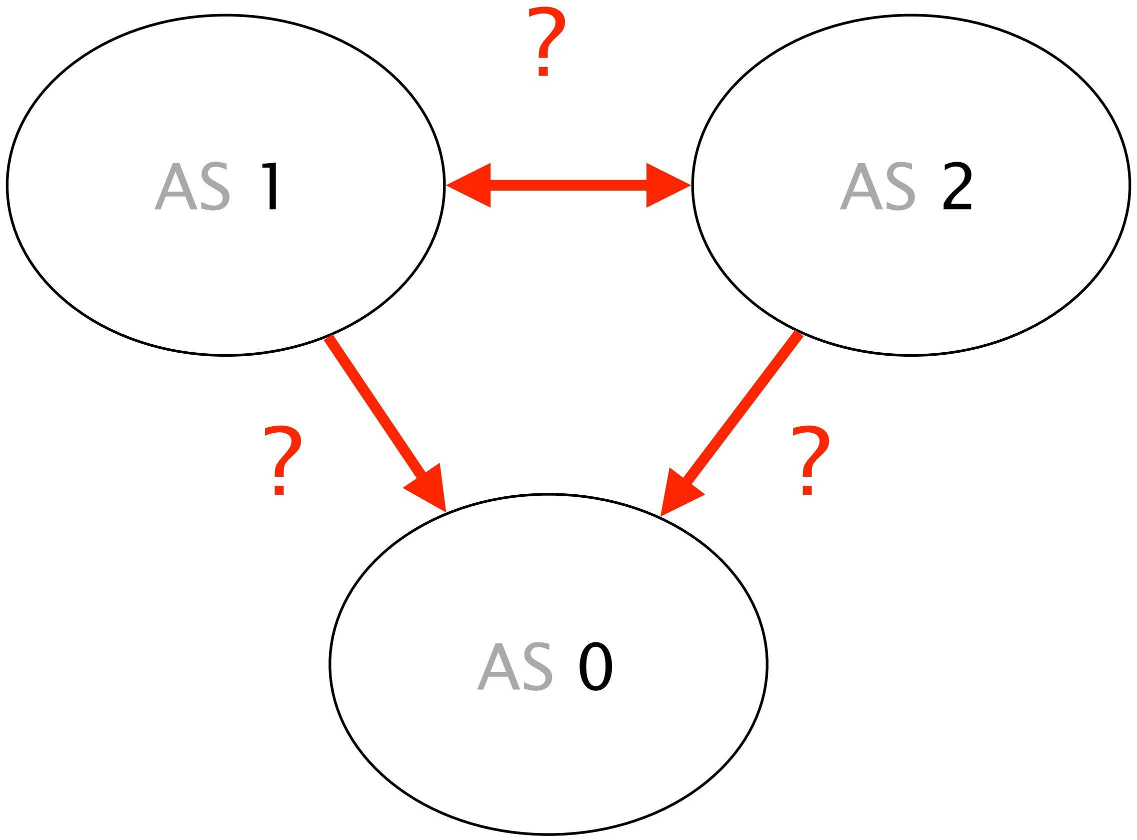


If AS1 is the first one to advertise 1 0,
the system stabilizes in a state where AS 2 is happy



The actual assignment depends on the ordering between the messages

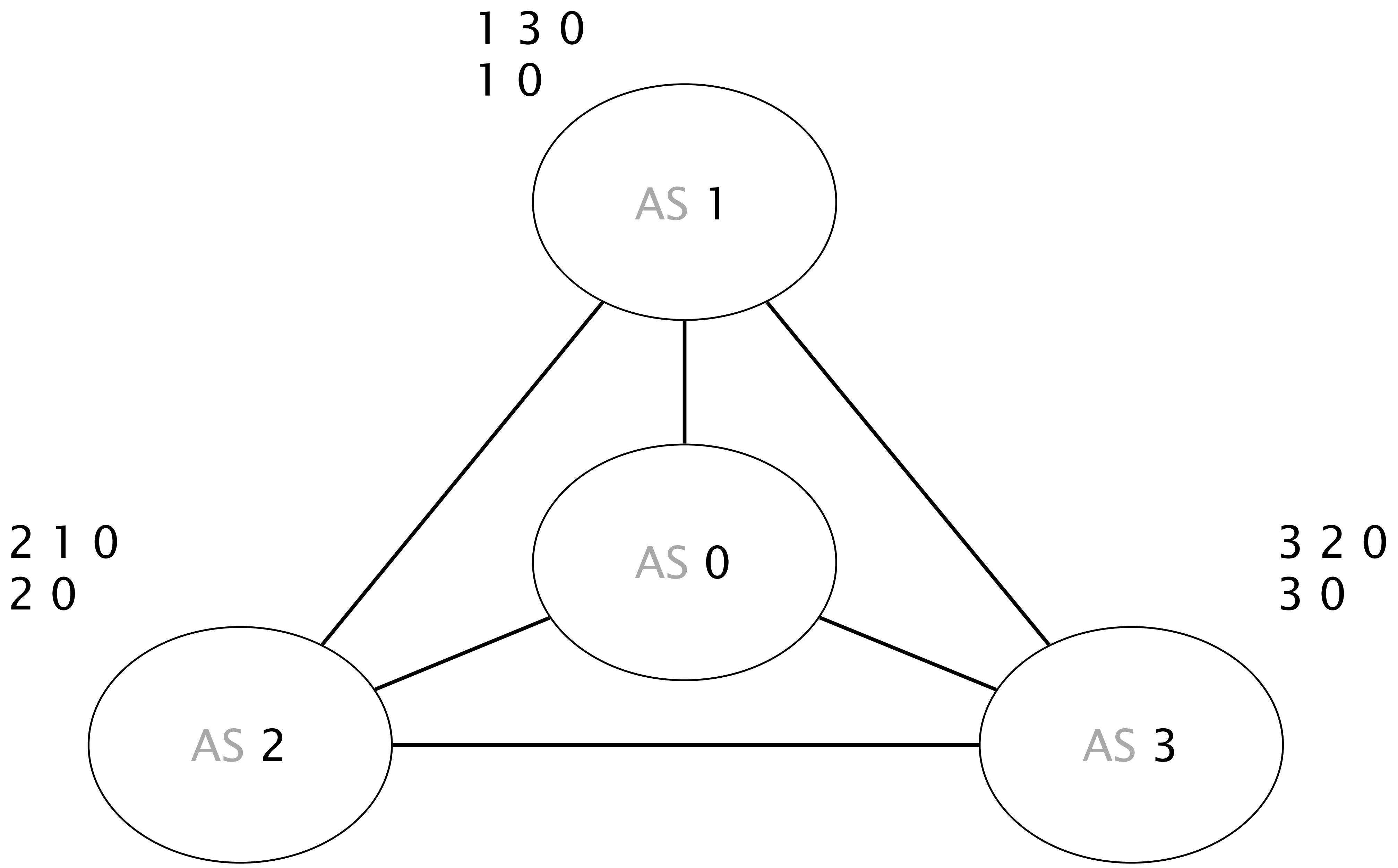
Note that AS1/AS2 could change the outcome by manual intervention

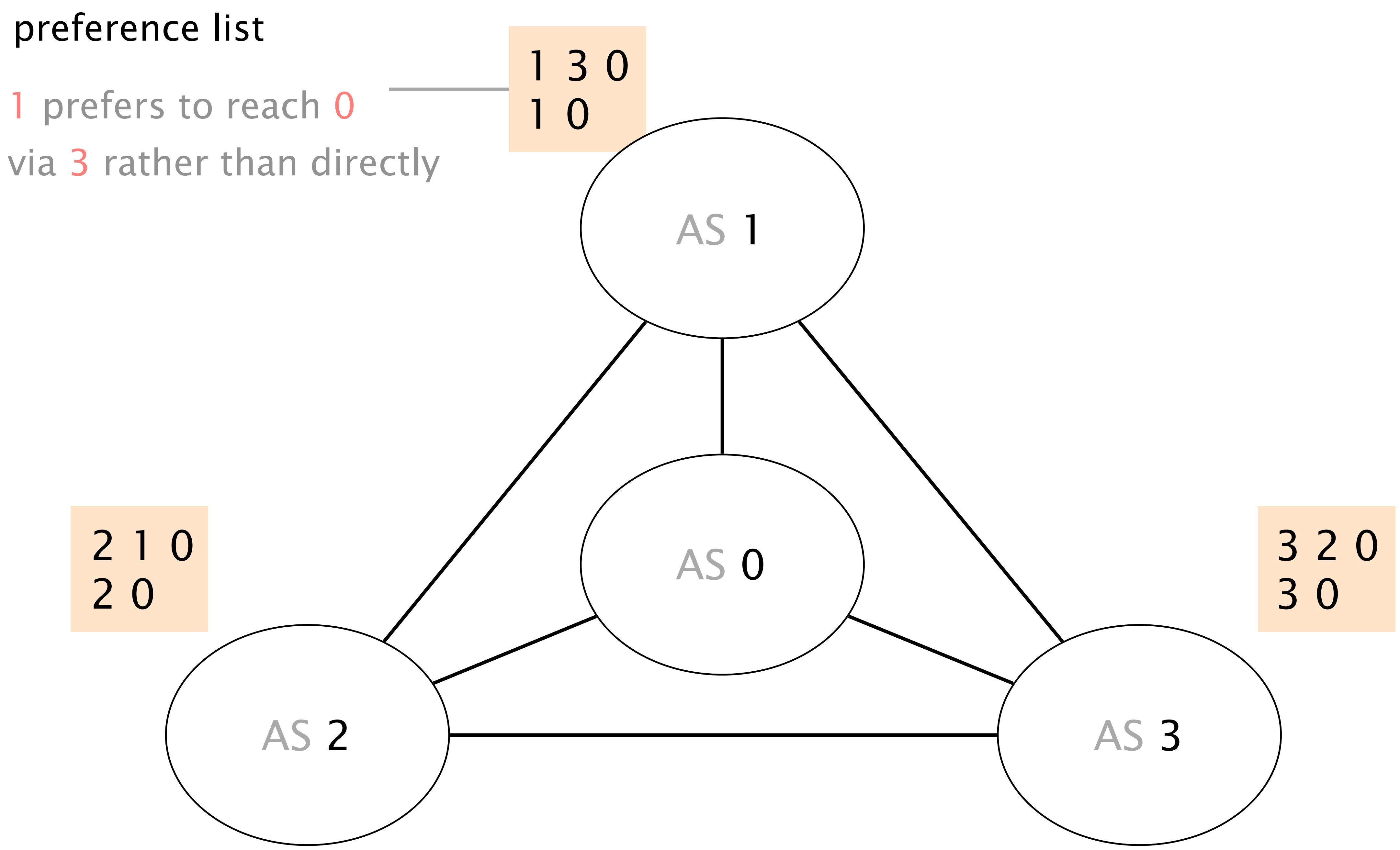


… this is not always possible *

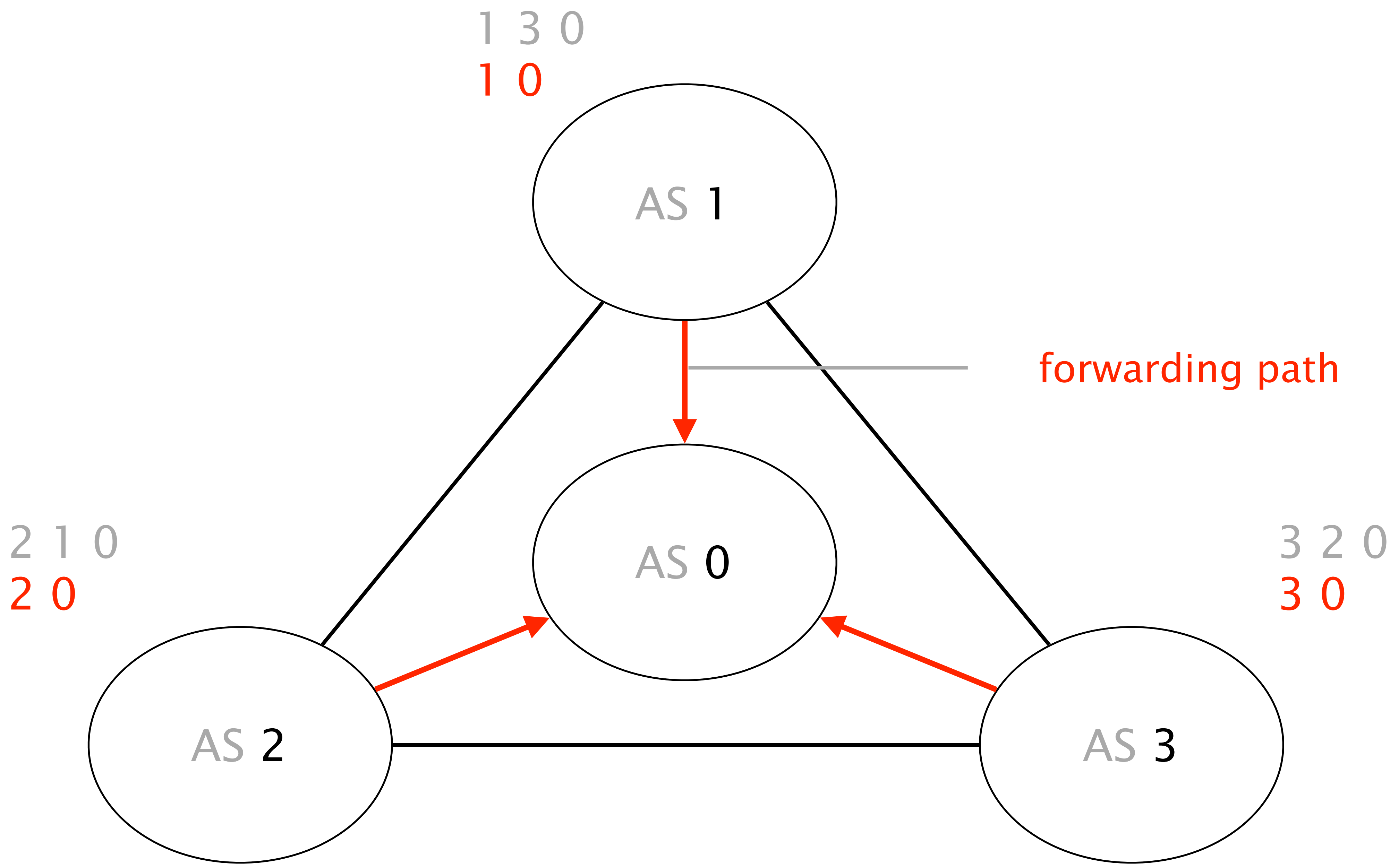
* https://www.nanog.org/meetings/nanog31/presentations/griffin.pdf

With arbitrary policies,
BGP may fail to converge

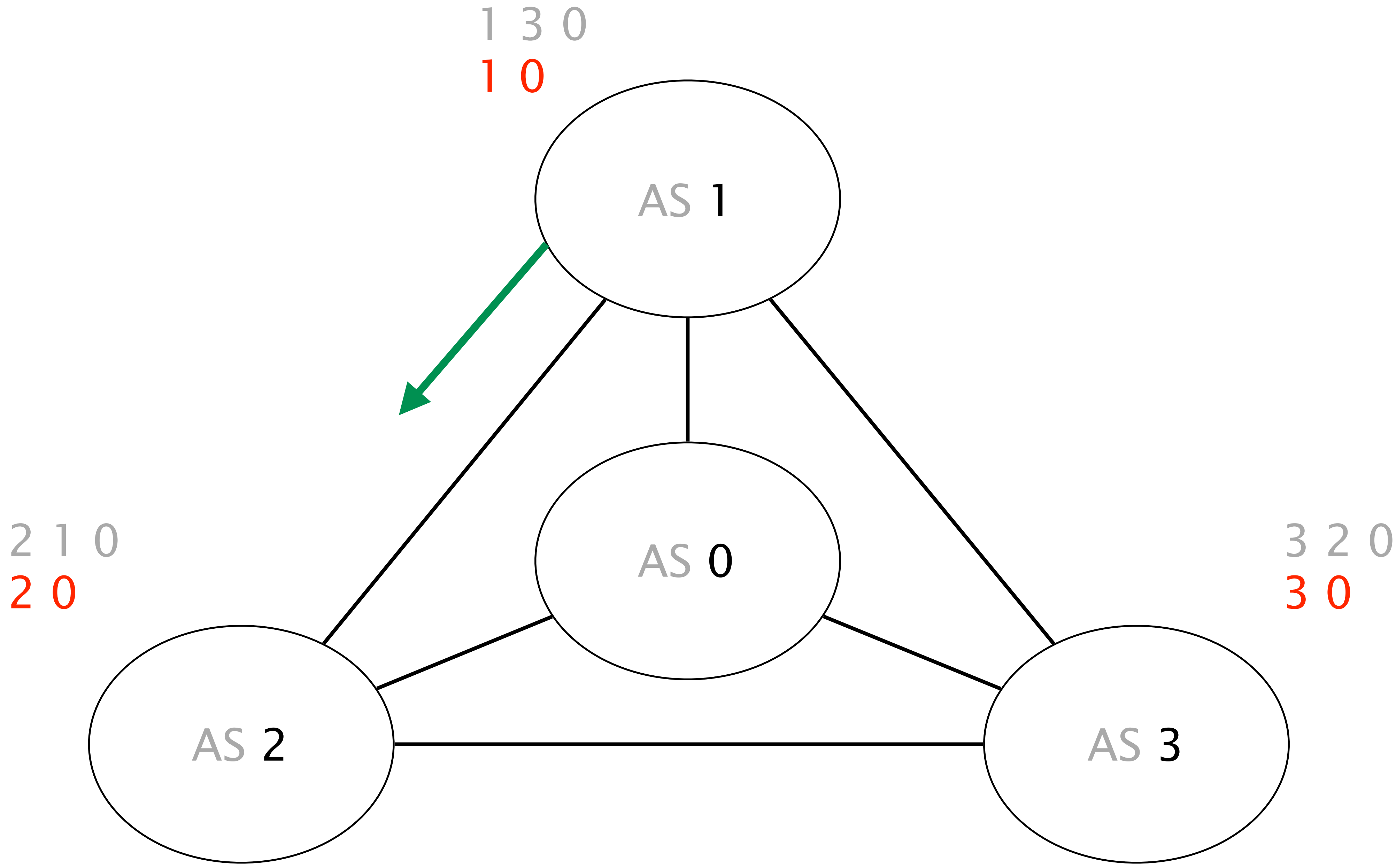

1 3 0
1 0
AS 1
2 1 0
2 0
AS 0
3 2 0
3 0
AS 2
AS 3


preference list
1 prefers to reach 0
via 3 rather than directly
1 3 0
1 0
AS 1
AS 0
2 1 0
2 0
3 2 0
3 0
AS 2
AS 3

Initially, all ASes only know the direct route to 0

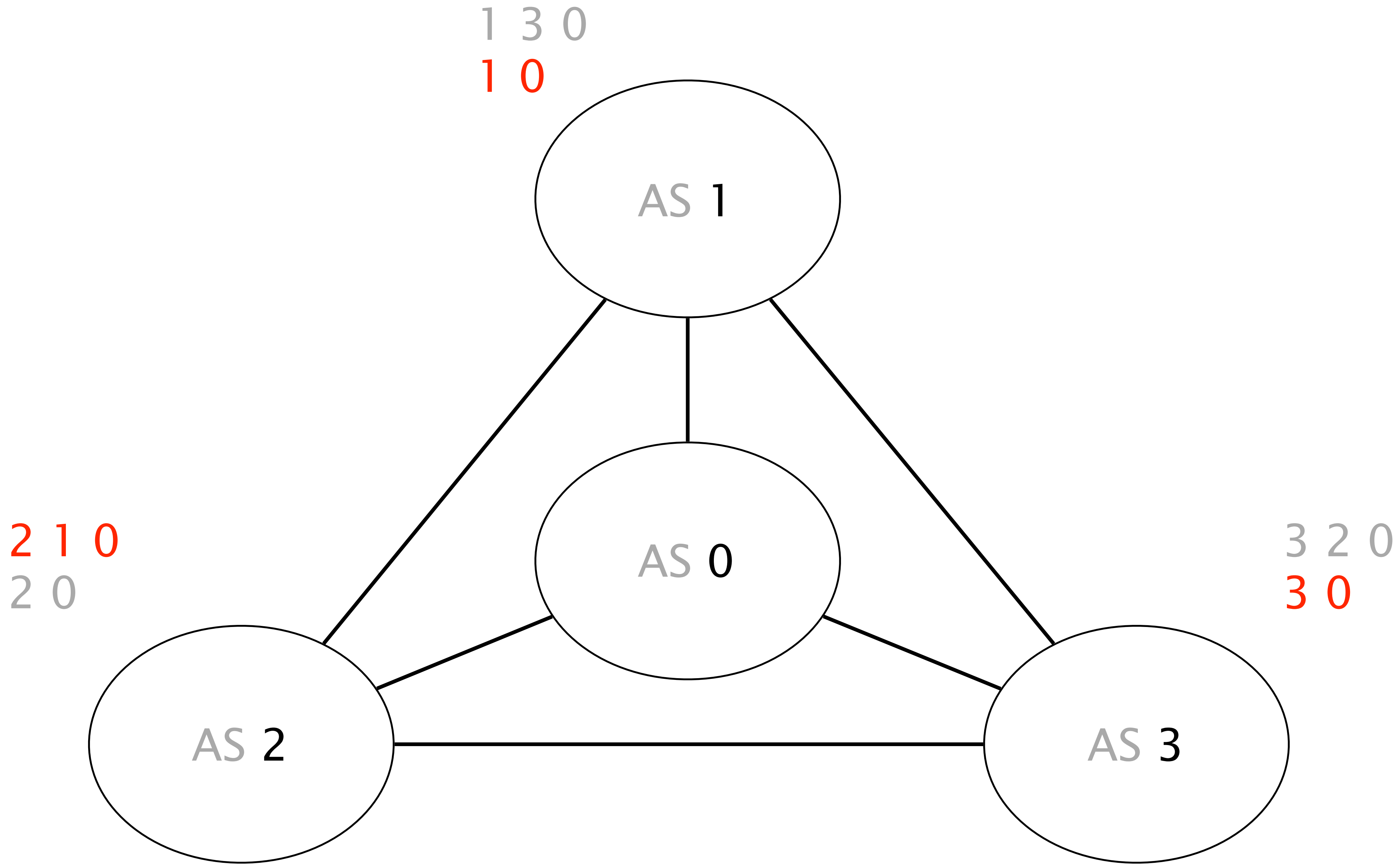


AS 1 advertises its path to AS 2

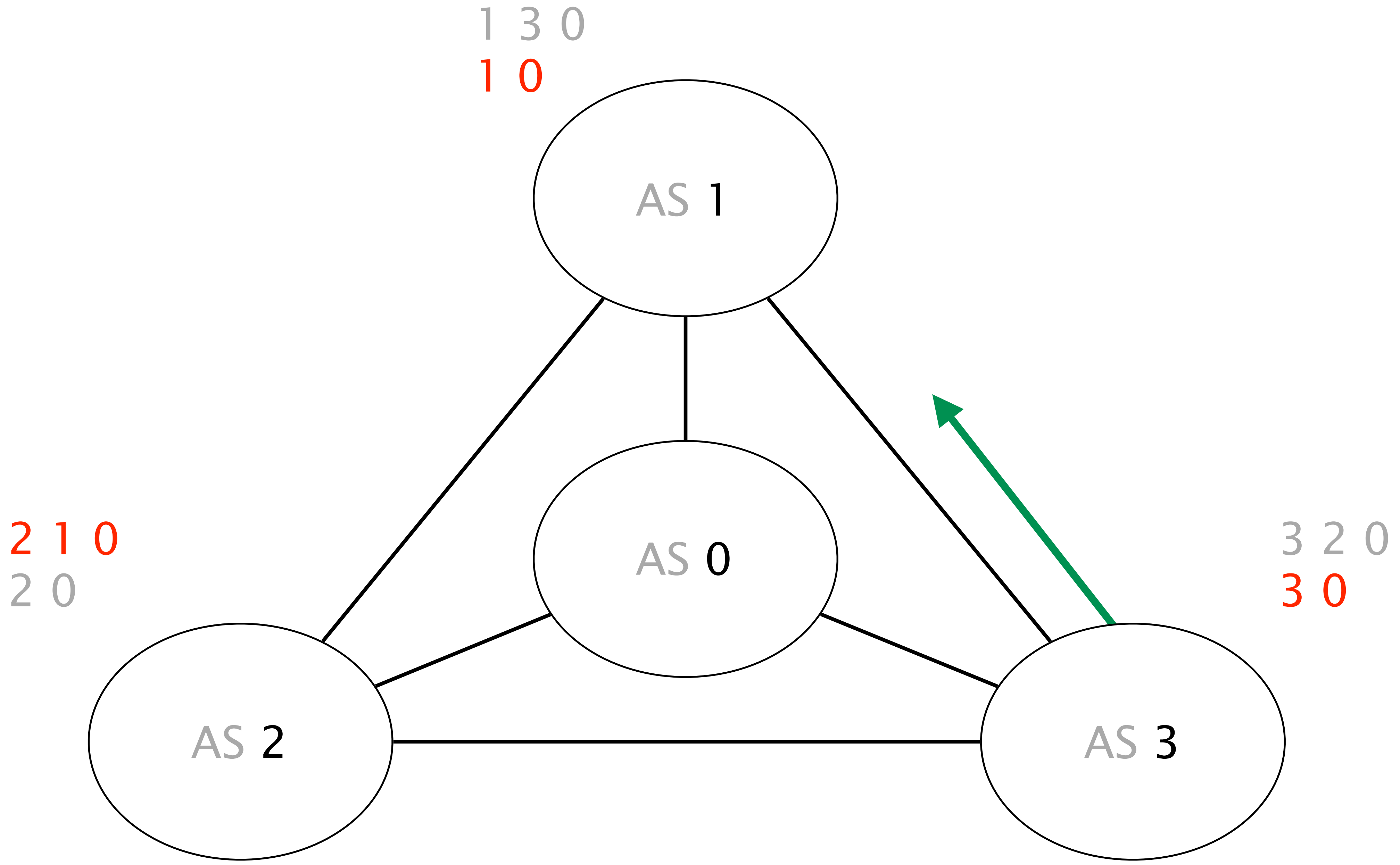


Upon reception,

AS 2 switches to 2 1 0 (preferred)

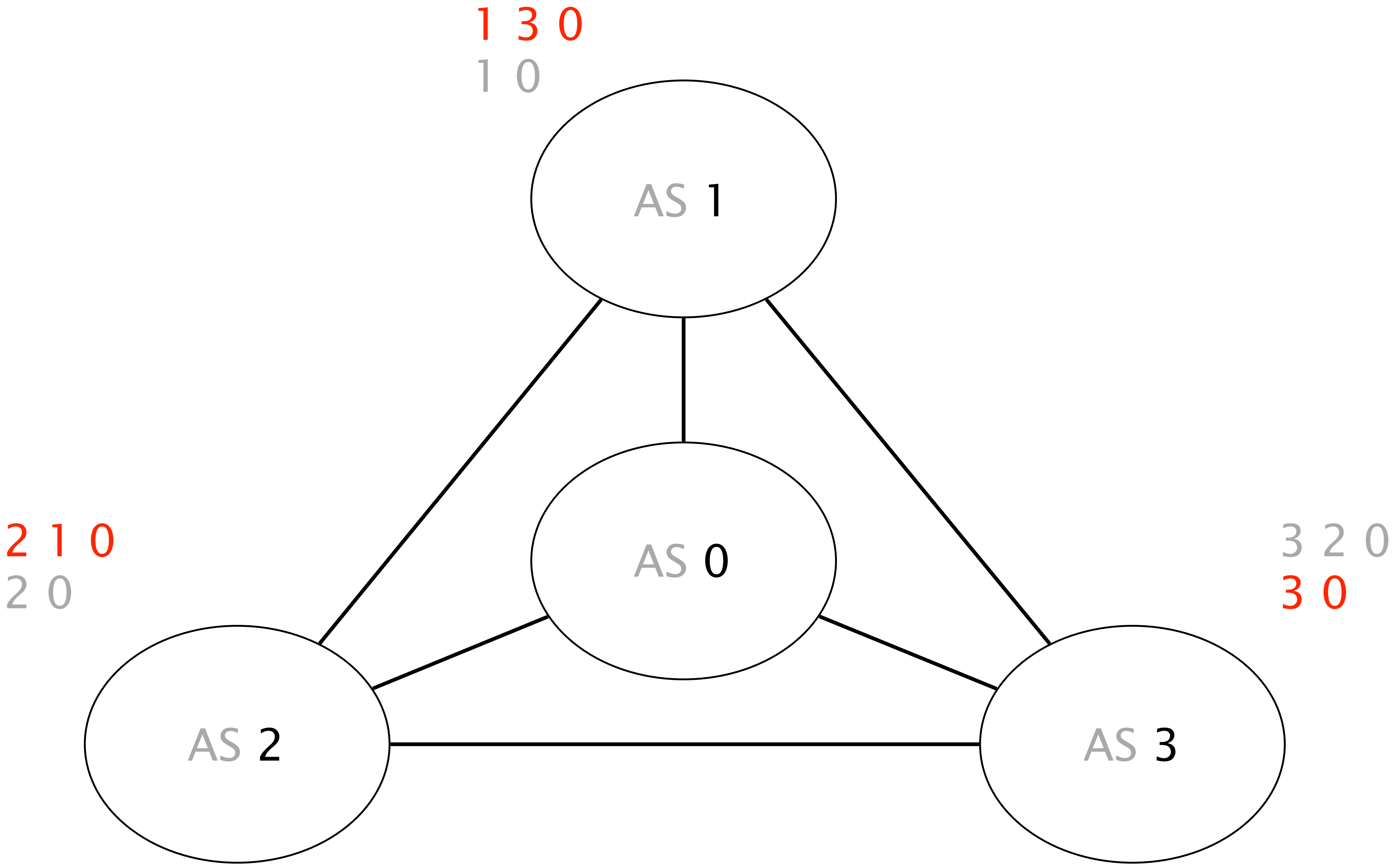


AS 3 advertises its path to AS 1

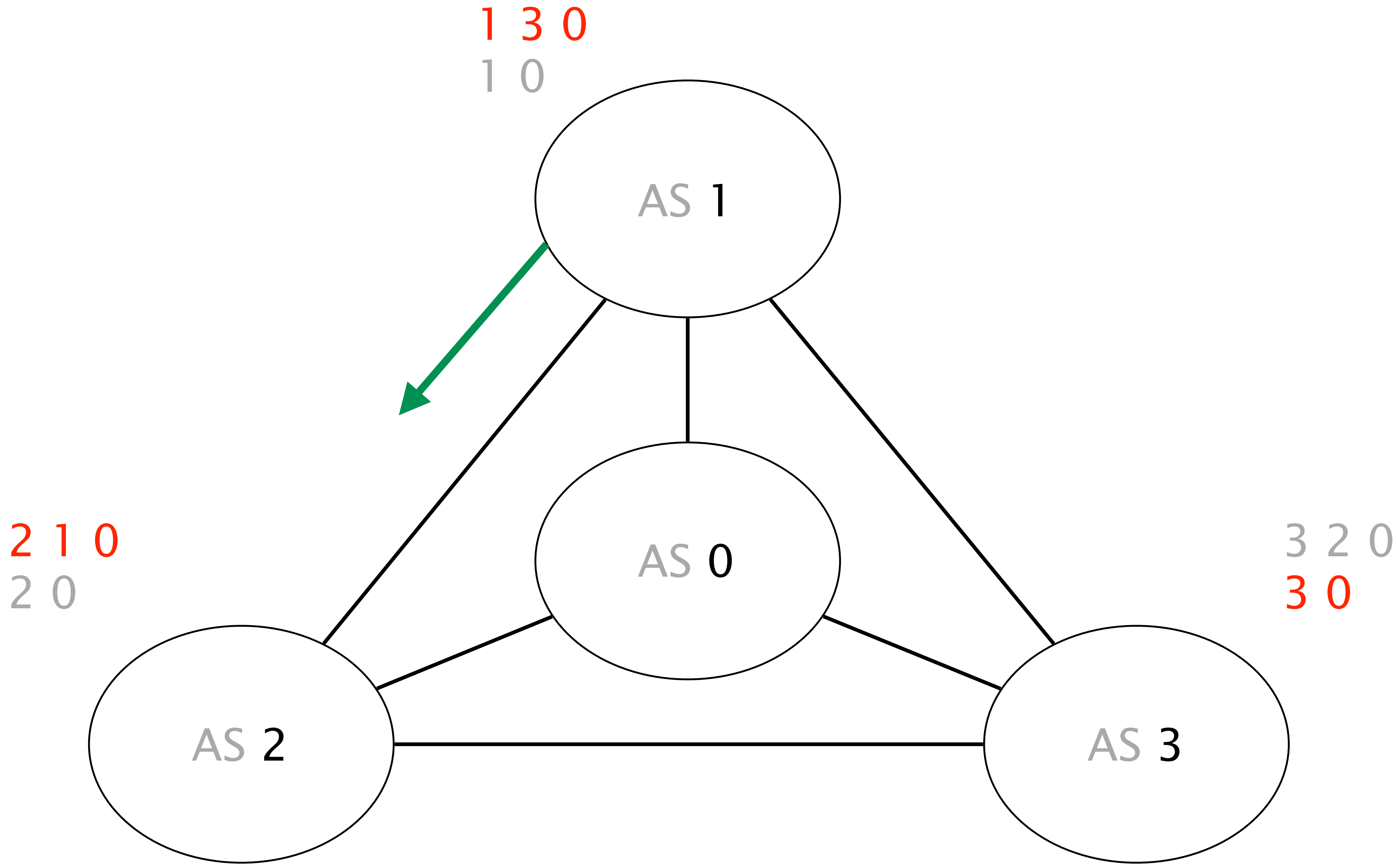


Upon reception,

AS 1 switches to 1 3 0 (preferred)

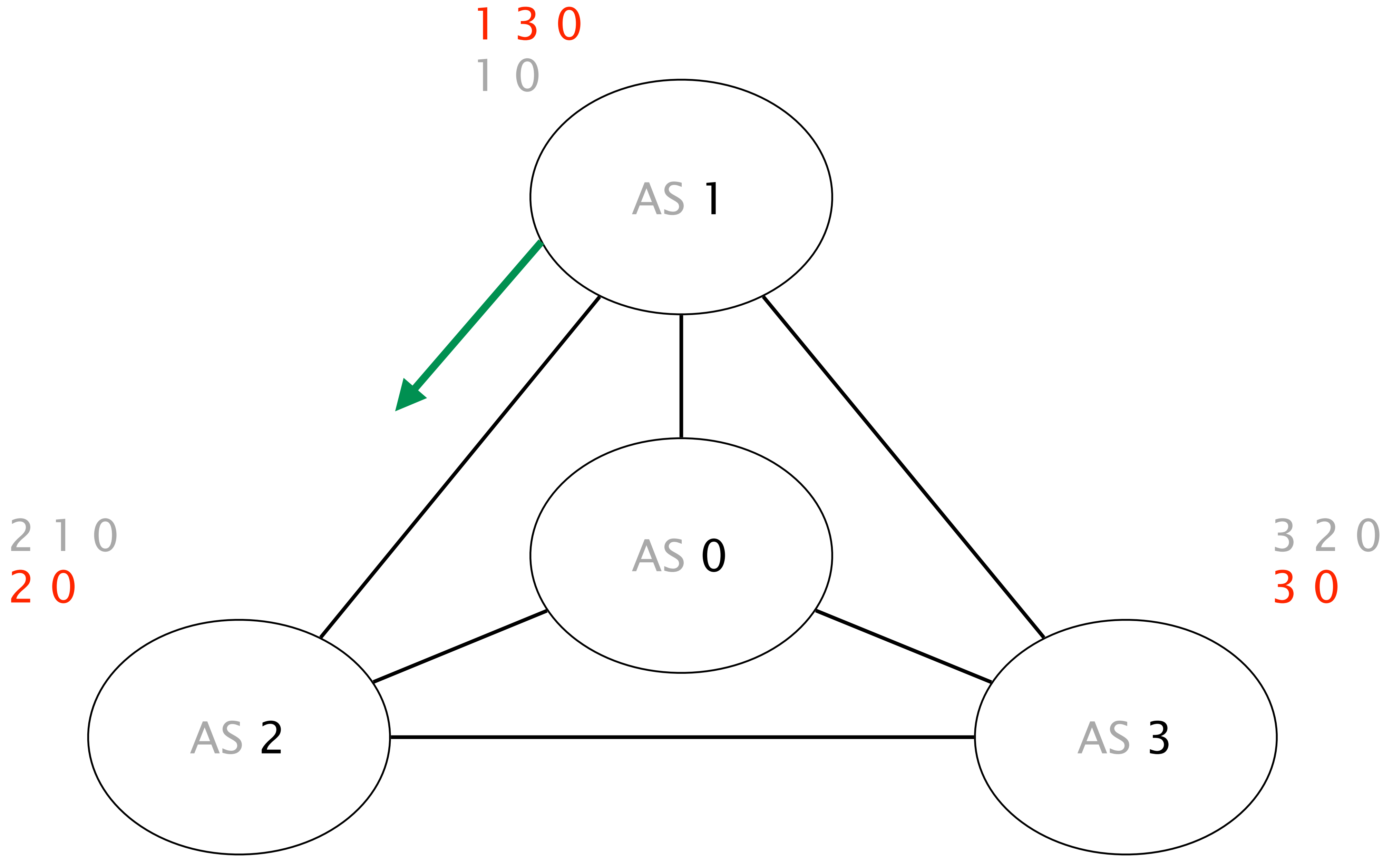


AS 1 advertises its new path 1 3 0 to AS 2

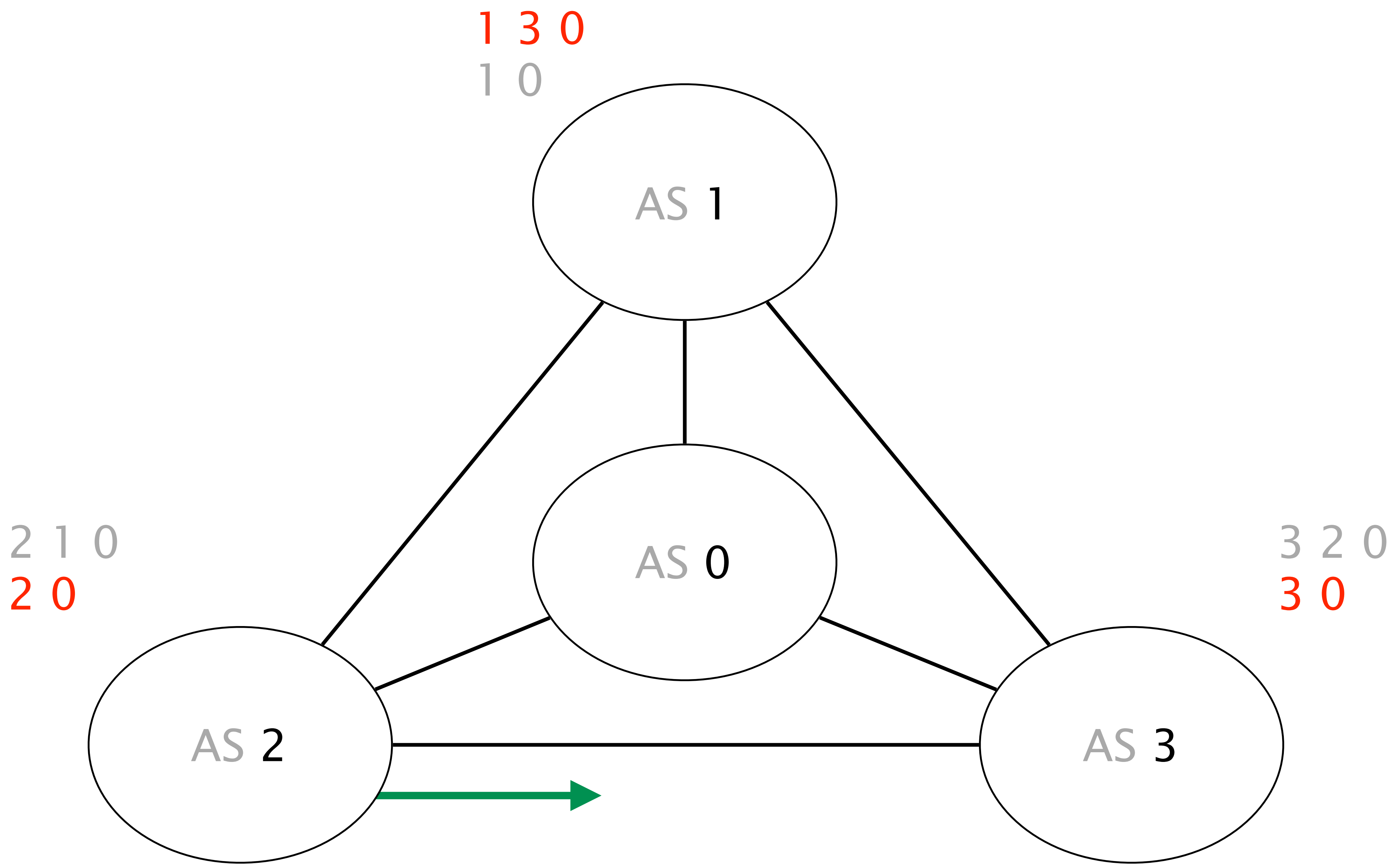


Upon reception,

AS 2 reverts back to its initial path 2 0

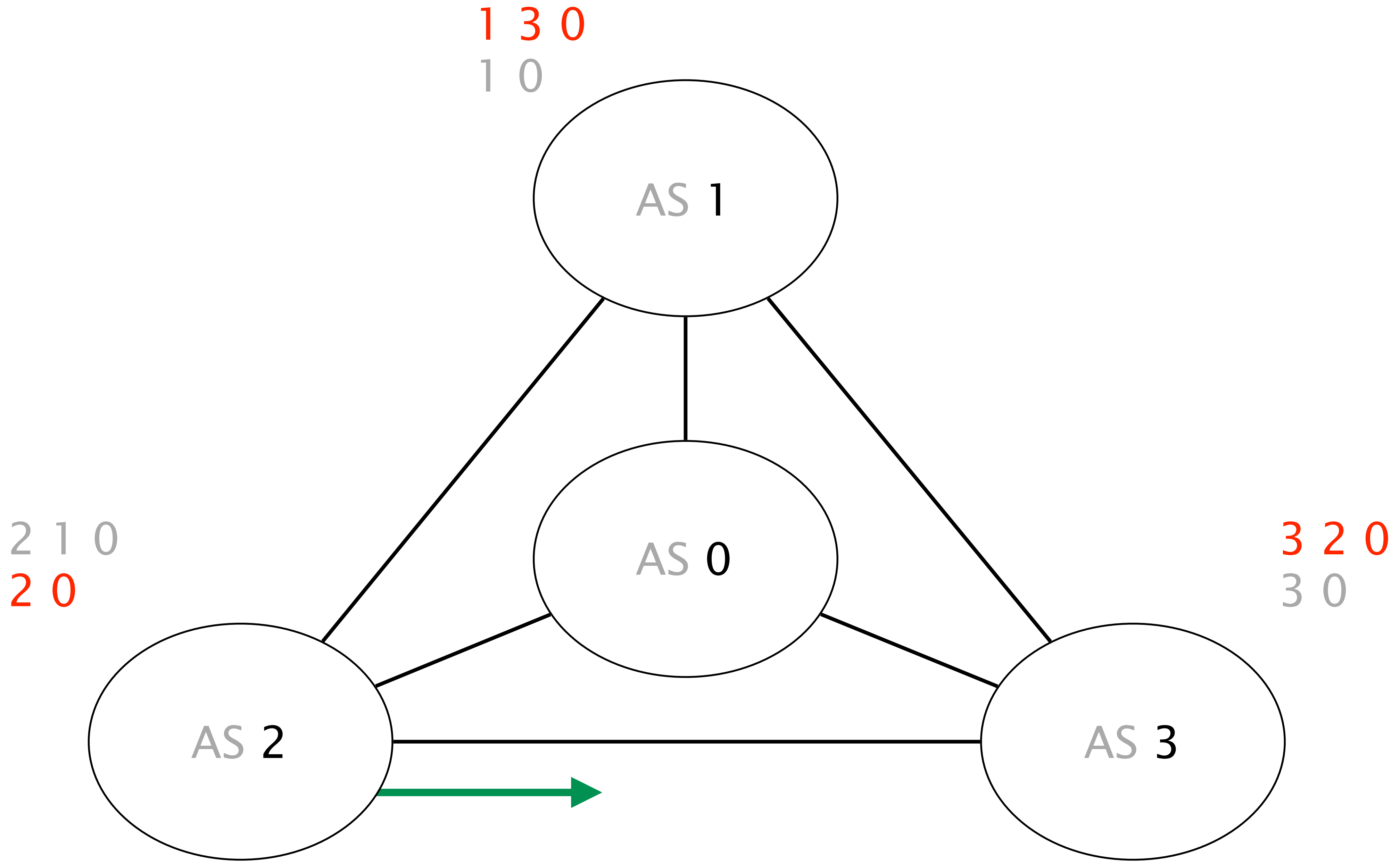


AS 2 advertises its path 2 0 to AS 3

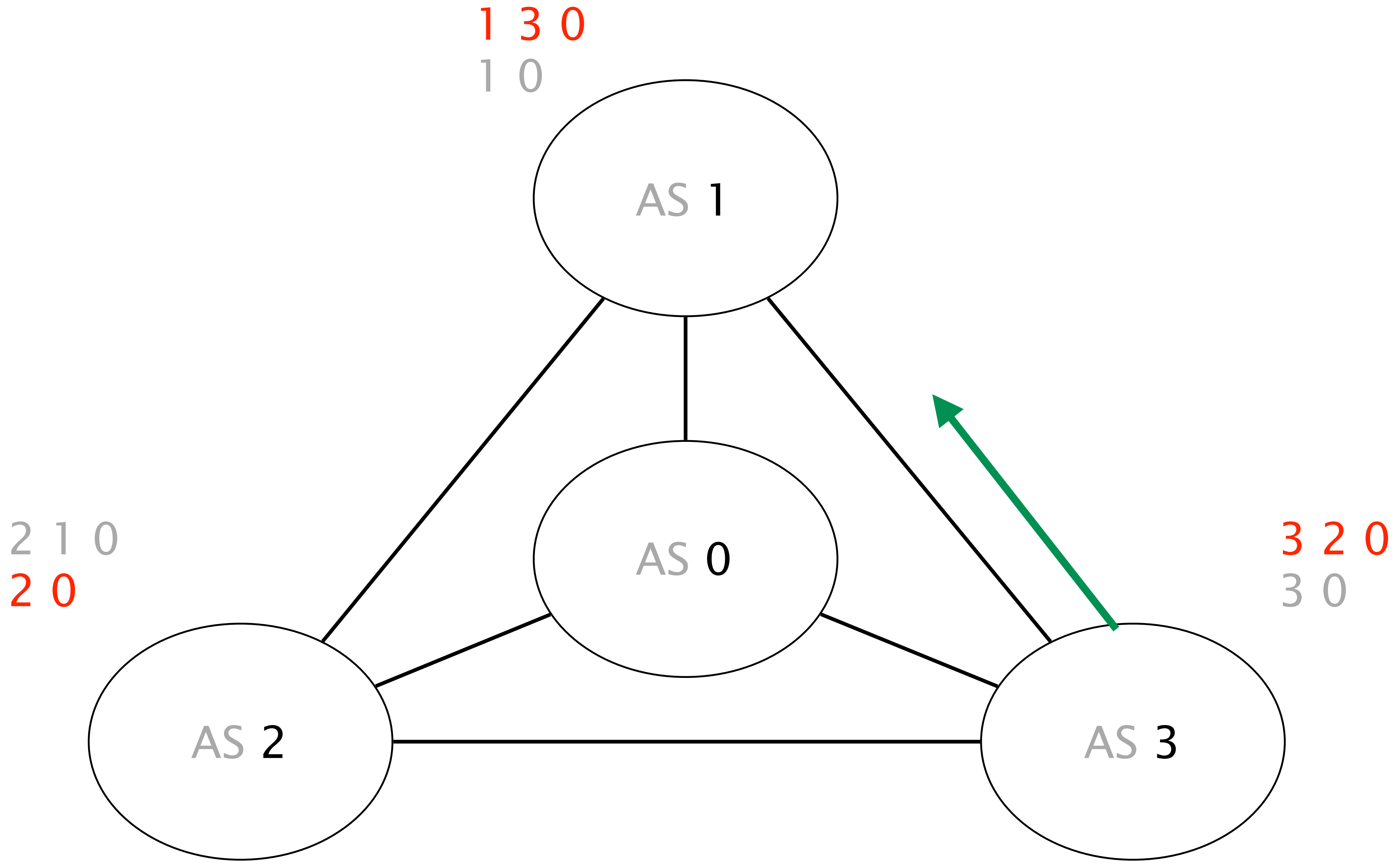


Upon reception,

AS 3 switches to 3 2 0 (preferred)

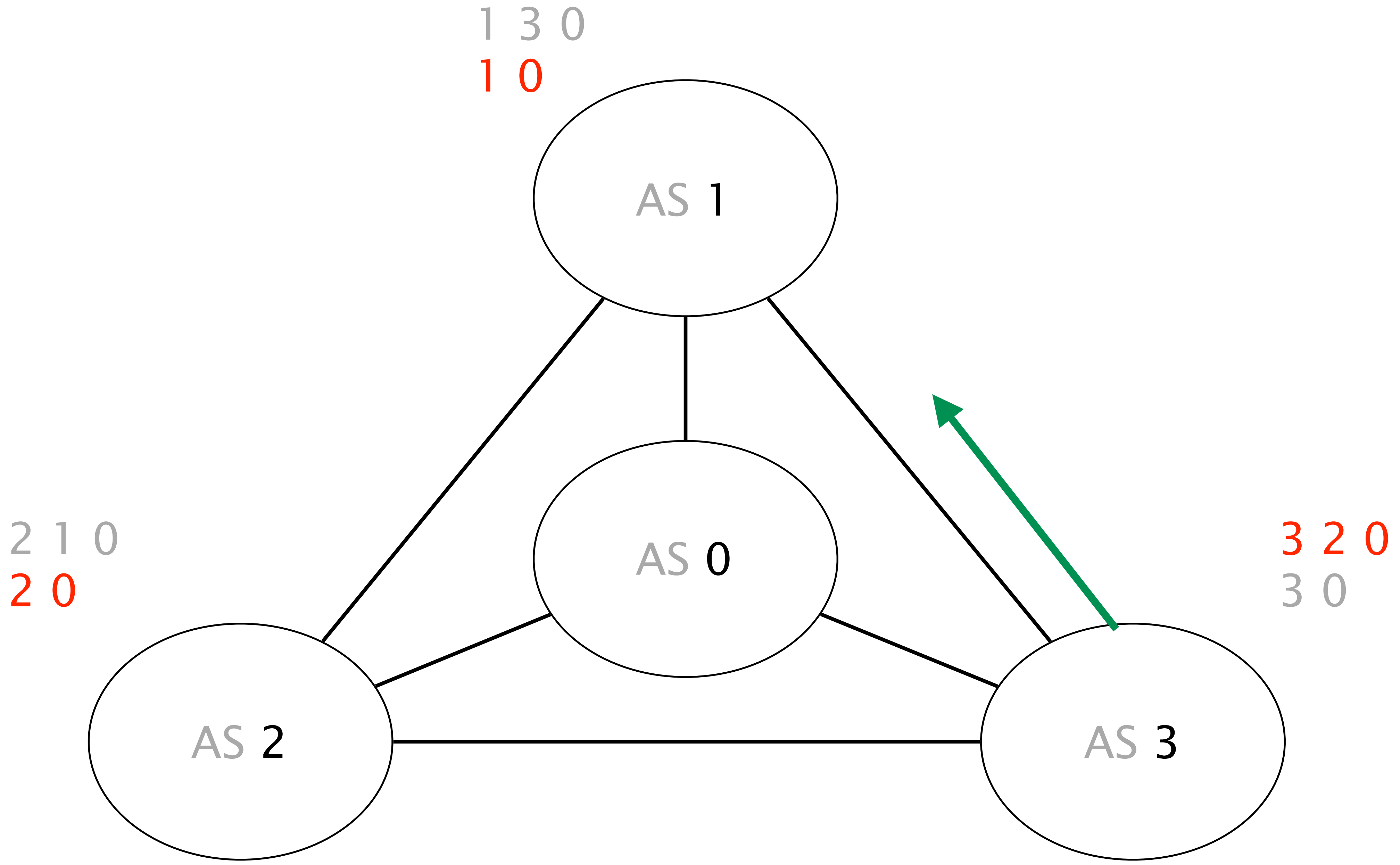


AS 3 advertises its new path 3 2 0 to AS 1

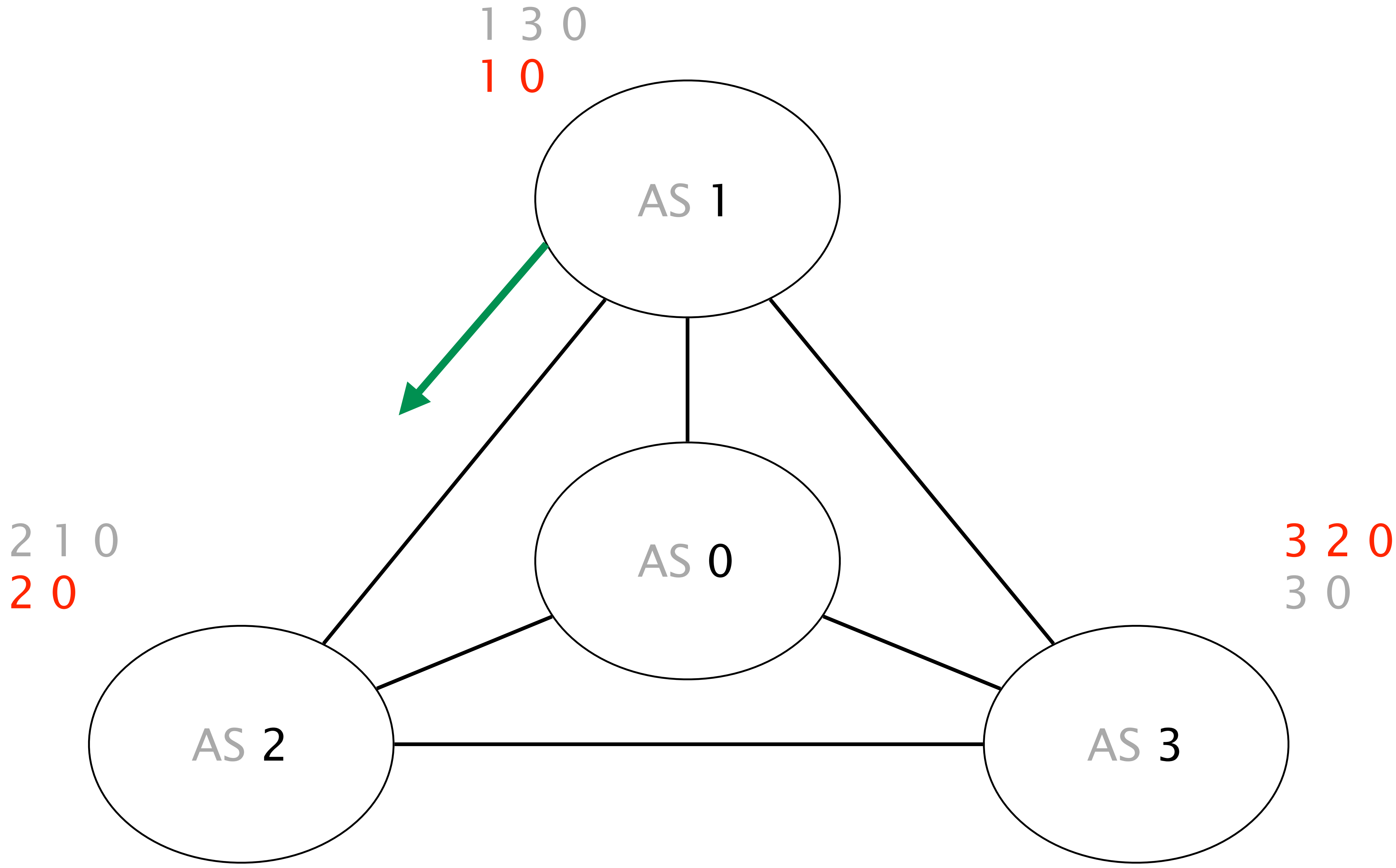


Upon reception,

AS 1 reverts back to 1 0 (initial path)

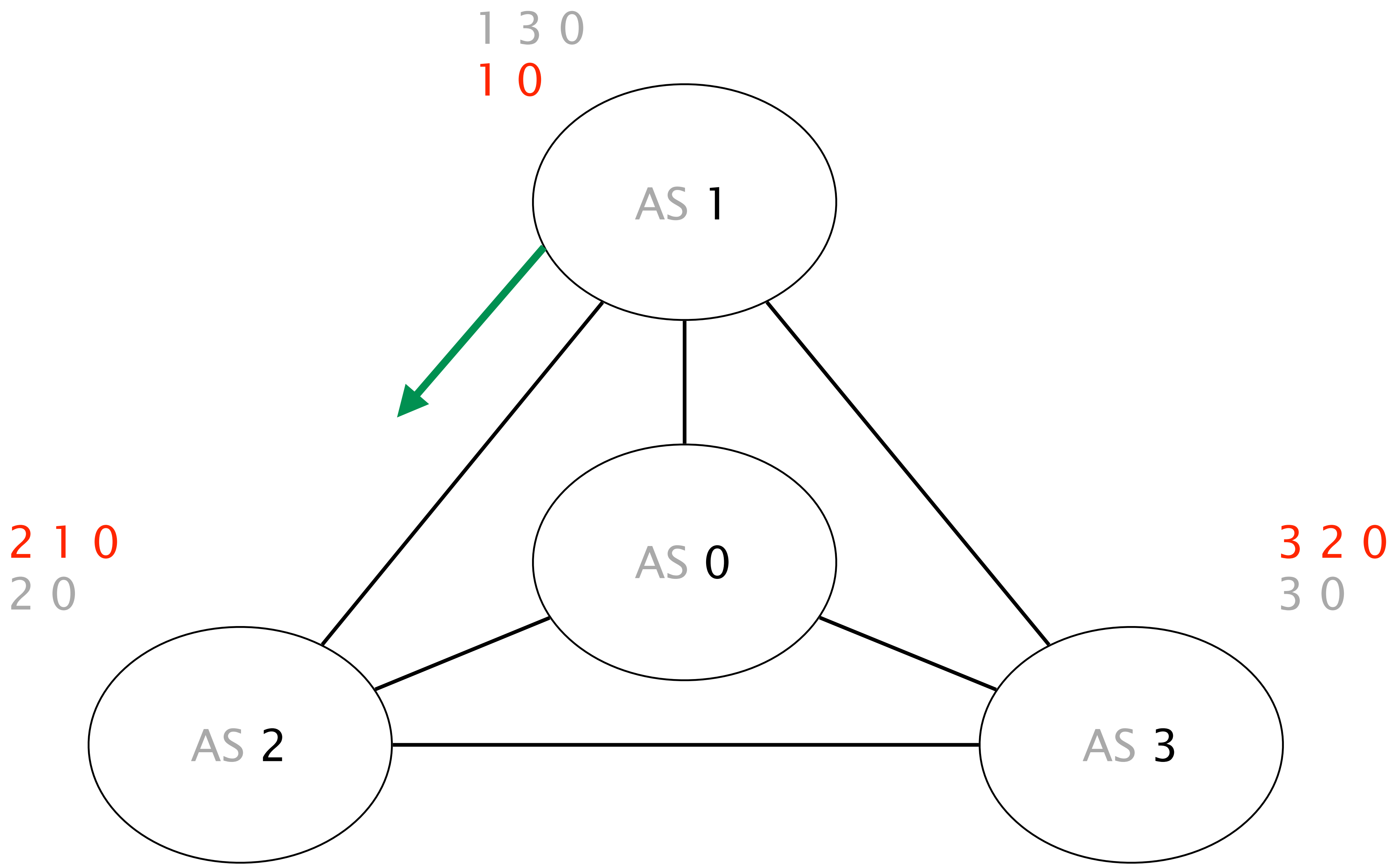


AS 1 advertises its new path 1 0 to AS 2

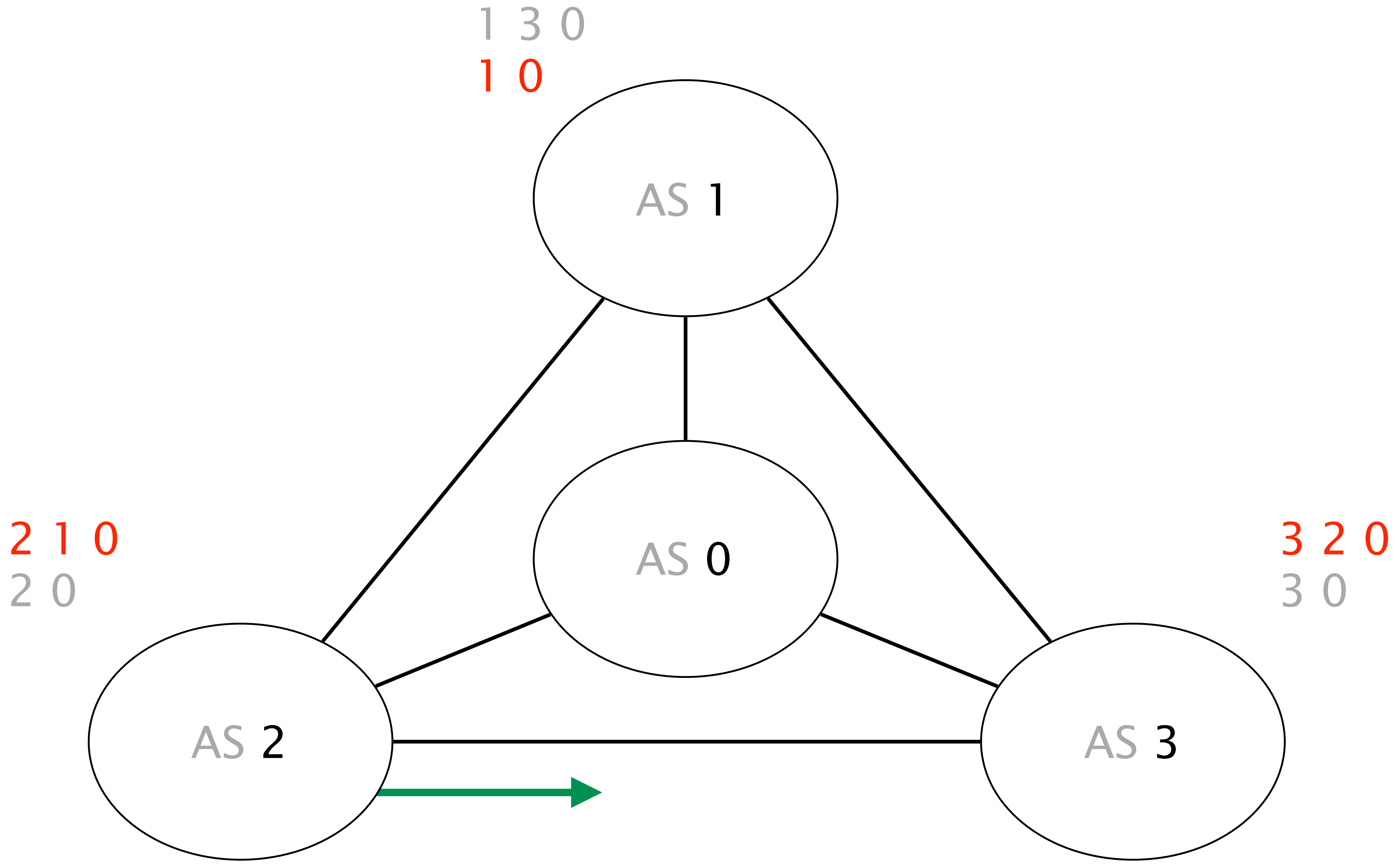


Upon reception,

AS 2 switches to 2 1 0 (preferred)

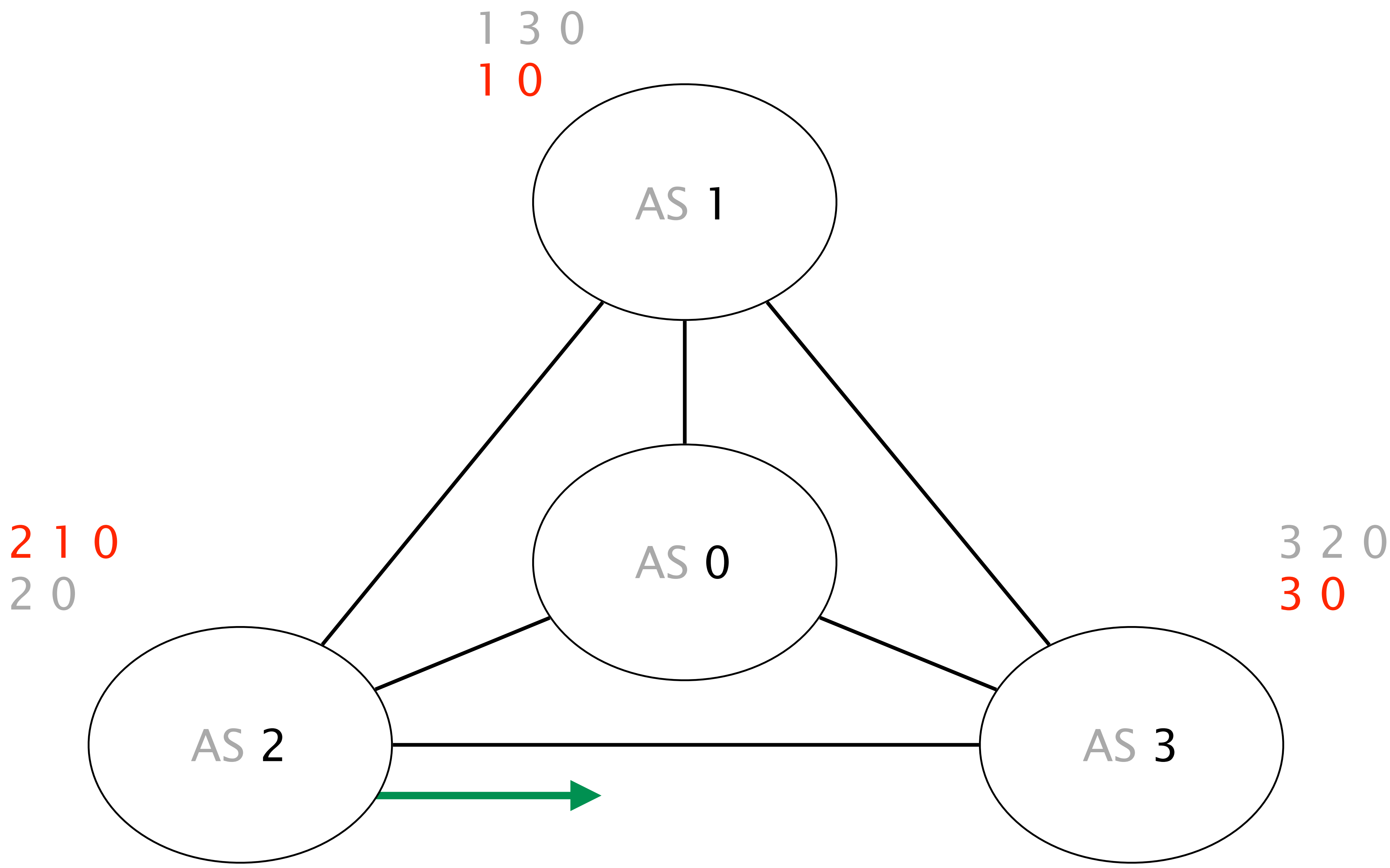


AS 2 advertises its new path 2 1 0 to AS 3

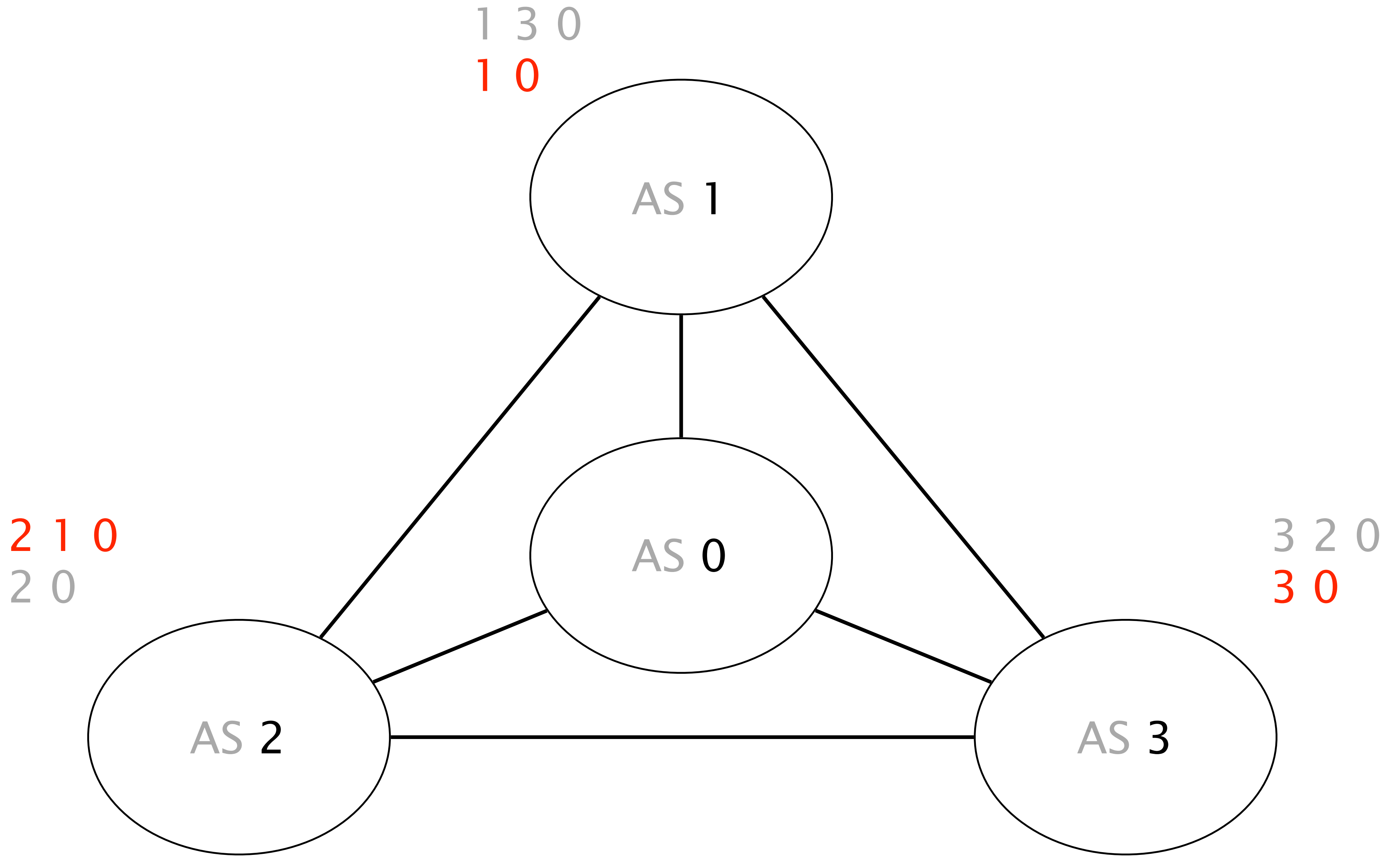


Upon reception,

AS 3 switches to its initial path 3 0



We are back where we started, from there on, the oscillation will continue forever



Policy oscillations are a direct consequence of policy autonomy

ASes are free to chose and advertise any paths they want

network stability argues against this

Guaranteeing the absence of oscillations is hard

even when you know all the policies!

Guaranteeing the absence of oscillations is hard

even when you know all the policies!

How come?

Theorem

Computationally, a BGP network is as “powerful” as

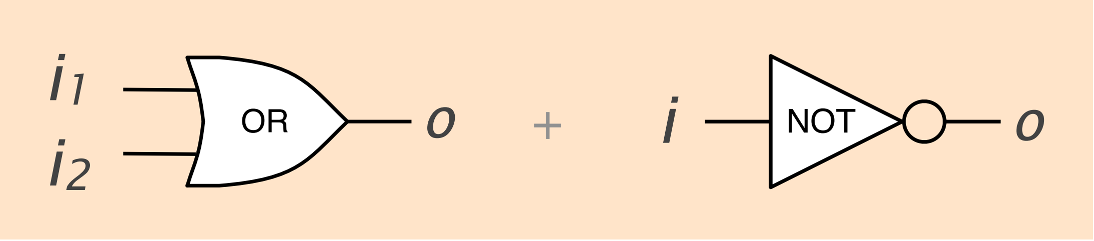
see “Using Routers to Build Logic Circuits: How Powerful is BGP?”

How do you prove such a thing?

How do you prove such a thing?

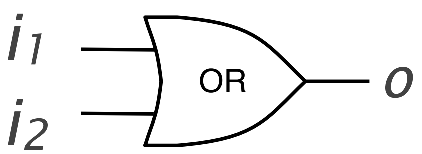
Easy, you build a computer using BGP…

Logic gates



Logic gates

Memory



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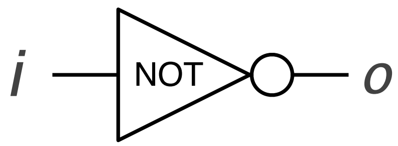

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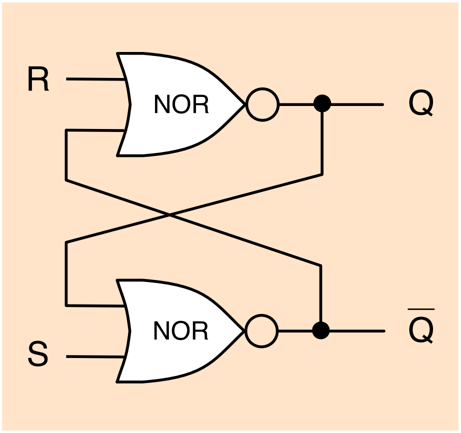
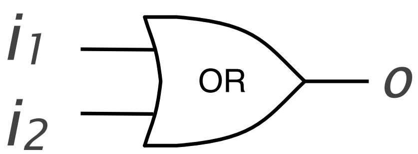


Logic gates



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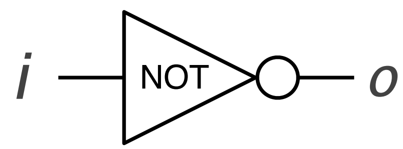

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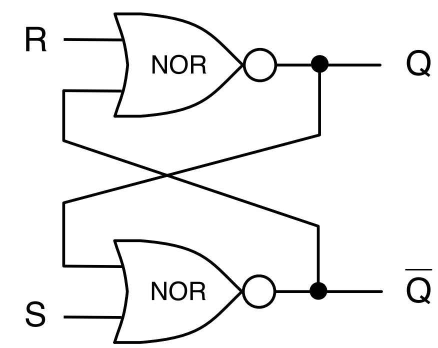
Memory



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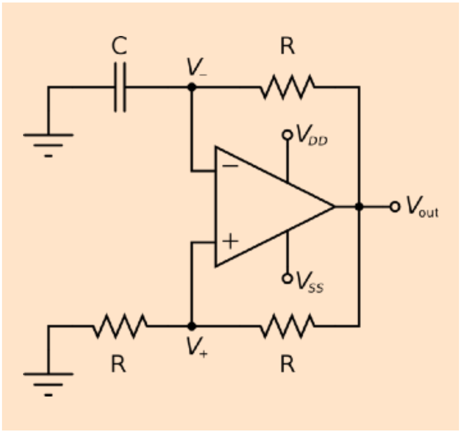
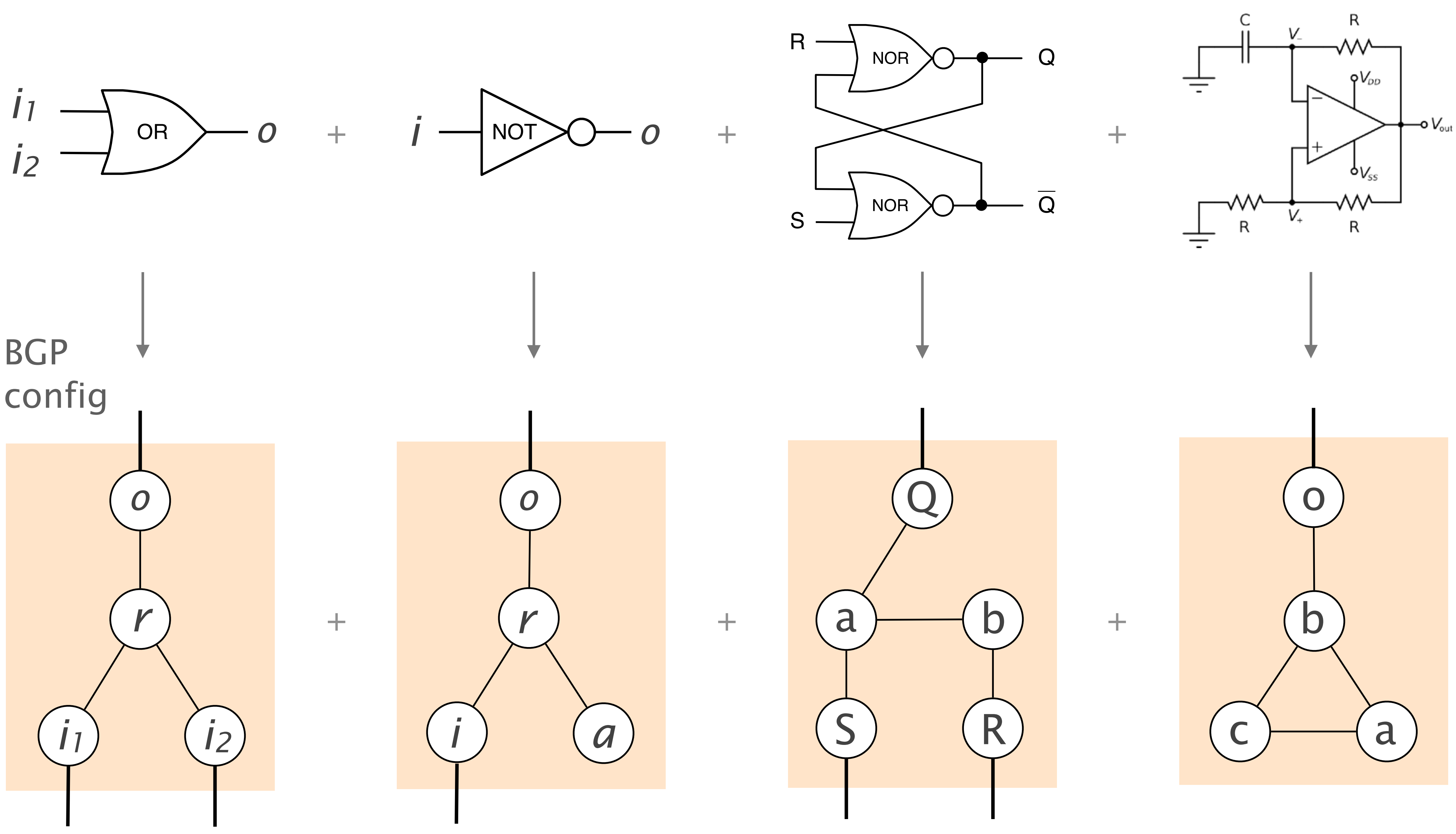
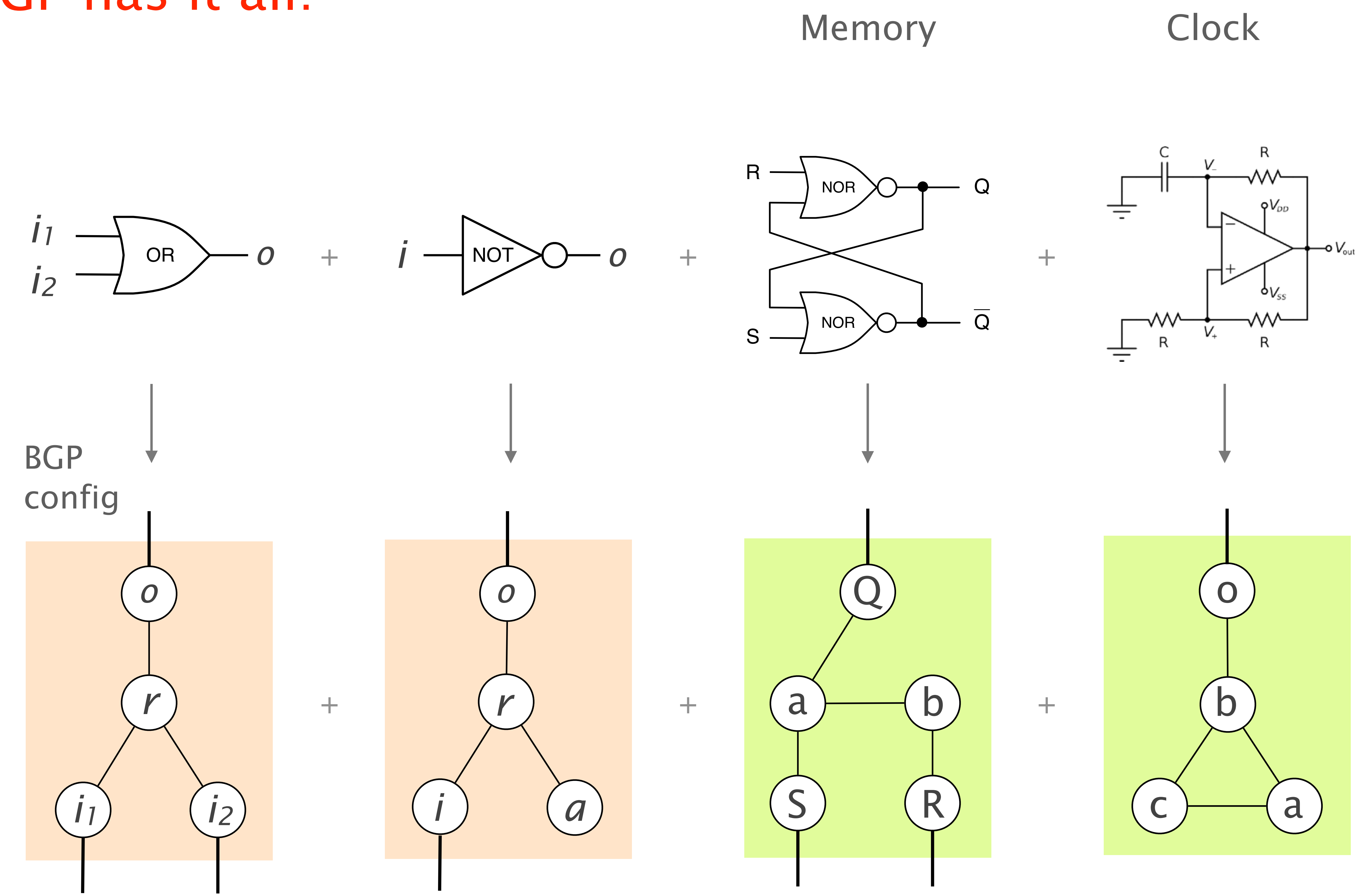
Clock



BGP has it all!



BGP has it all!

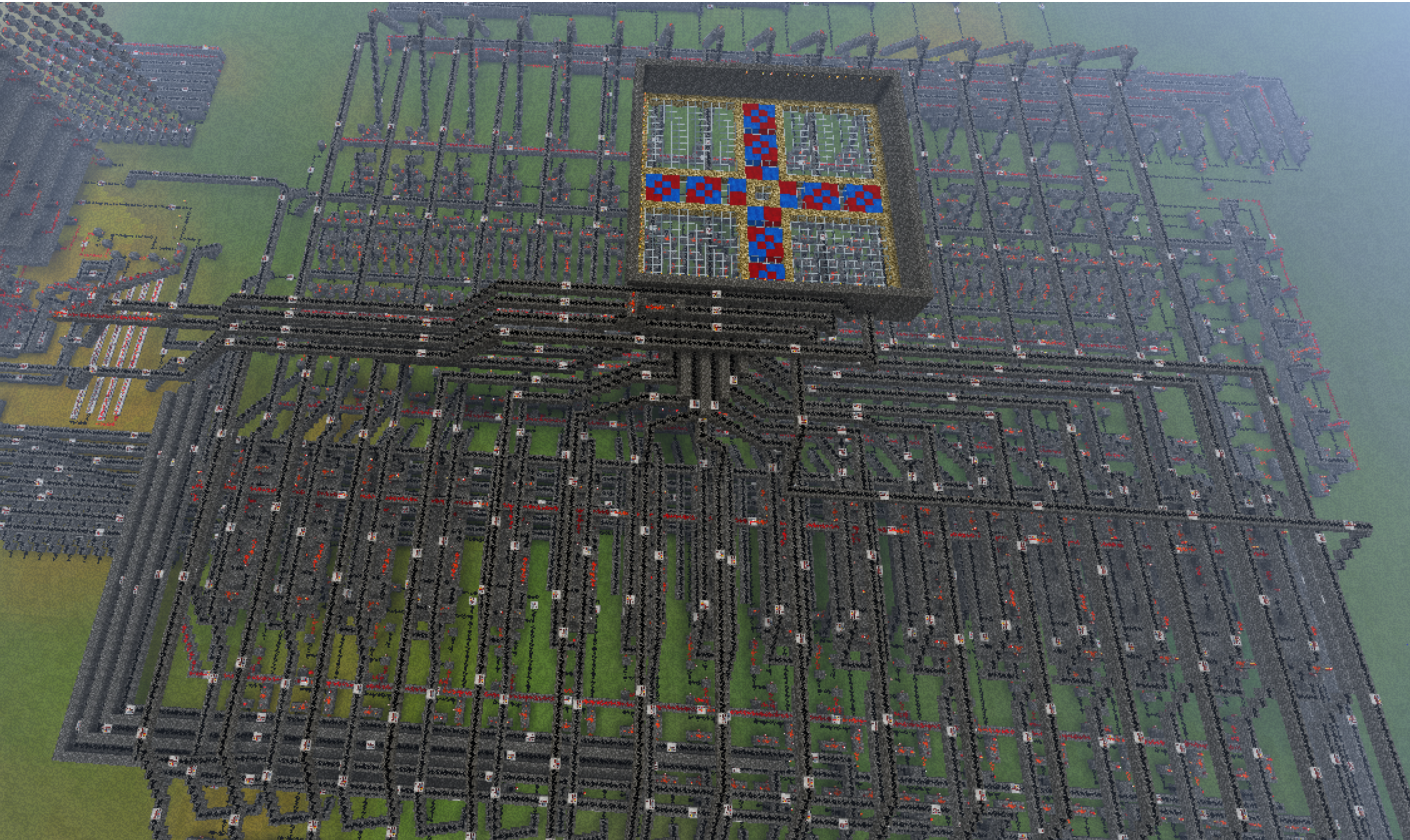


famous incorrect BGP configurations (Griffin et al.)

Instead of using Minecraft

for building a computer… use BGP!

Hack III, Minecraft’s largest computer to date



Together, BGP routers form

the largest computer in the world!

Router-level view of the Internet, OPTE project

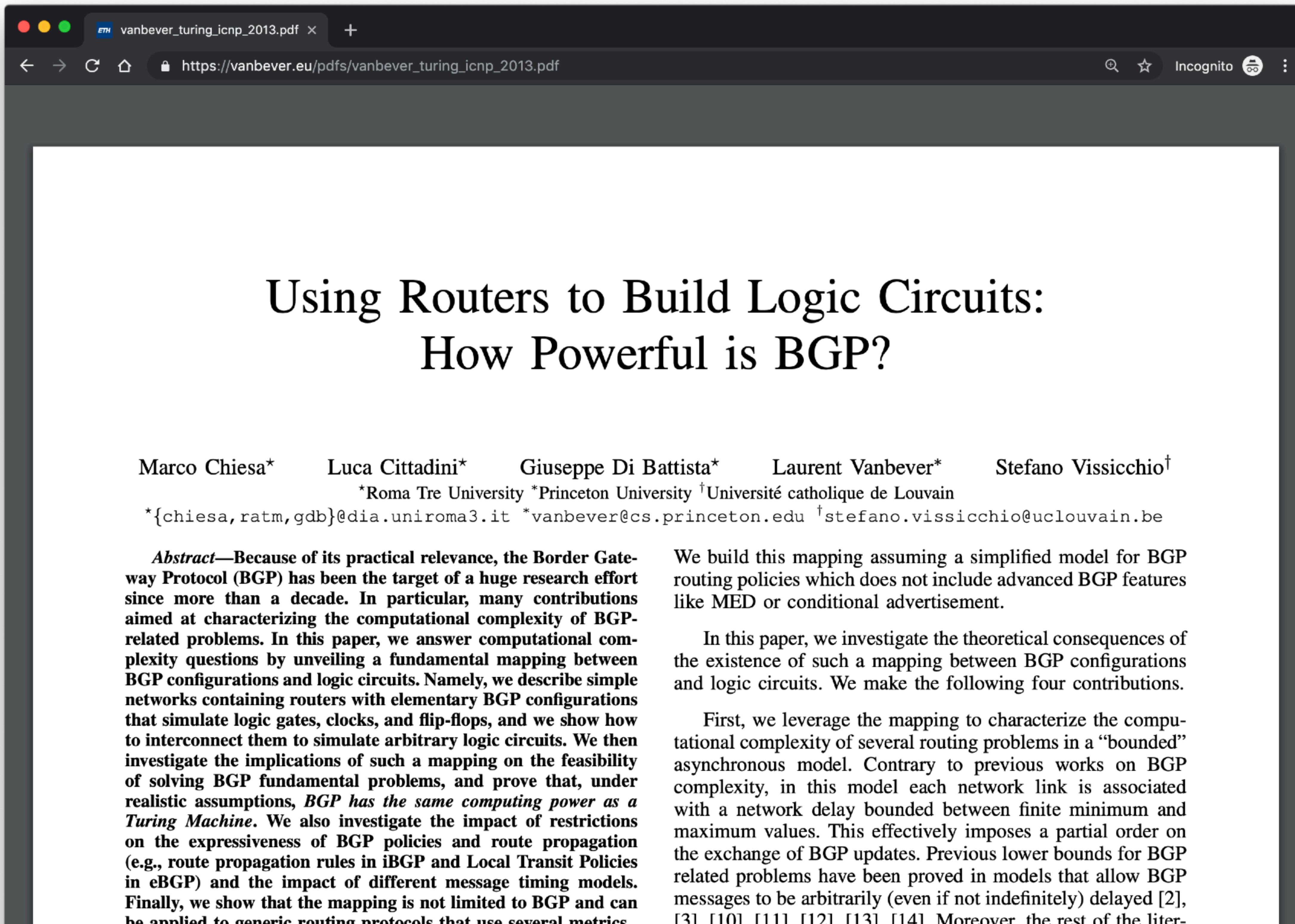
Checking BGP correctness is as hard as checking the termination of a general program

Theorem 1 Determining whether a finite BGP network converges is PSPACE-hard

Theorem 2 Determining whether an infinite BGP network converges is Turing-complete

Checking our paper for more details

https://vanbever.eu/pdfs/vanbever_turing_icnp_2013.pdf



Using Routers to Build Logic Circuits: How Powerful is BGP?

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***Abstract*—Because of its practical relevance, the Border Gateway Protocol (BGP) has been the target of a huge research effort since more than a decade. In particular, many contributions aimed at characterizing the computational complexity of BGP-related problems. In this paper, we answer computational complexity questions by unveiling a fundamental mapping between BGP configurations and logic circuits. Namely, we describe simple networks containing routers with elementary BGP configurations that simulate logic gates, clocks, and flip-flops, and we show how to interconnect them to simulate arbitrary logic circuits. We then investigate the implications of such a mapping on the feasibility of solving BGP fundamental problems, and prove that, under realistic assumptions, *BGP has the same computing power as a Turing Machine*. We also investigate the impact of restrictions on the expressiveness of BGP policies and route propagation (e.g., route propagation rules in iBGP and Local Transit Policies in eBGP) and the impact of different message timing models. Finally, we show that the mapping is not limited to BGP and can be applied to generic routing protocols that use several metrics.**

We build this mapping assuming a simplified model for BGP routing policies which does not include advanced BGP features like MED or conditional advertisement.

In this paper, we investigate the theoretical consequences of the existence of such a mapping between BGP configurations and logic circuits. We make the following four contributions.

First, we leverage the mapping to characterize the computational complexity of several routing problems in a "bounded" asynchronous model. Contrary to previous works on BGP complexity, in this model each network link is associated with a network delay bounded between finite minimum and maximum values. This effectively imposes a partial order on the exchange of BGP updates. Previous lower bounds for BGP related problems have been proved in models that allow BGP messages to be arbitrarily (even if not indefinitely) delayed [2], [3], [10], [11], [12], [13], [14]. Moreover, the rest of the liter-

In practice though,

BGP does not oscillate "that" often

known as "Gao-Rexford" rules

Theorem

If all AS policies follow the cust/peer/provider rules,
BGP is guaranteed to converge

Intuition

Oscillations require "preferences cycles"
which make no economical sense

Problems

Reachability

Security

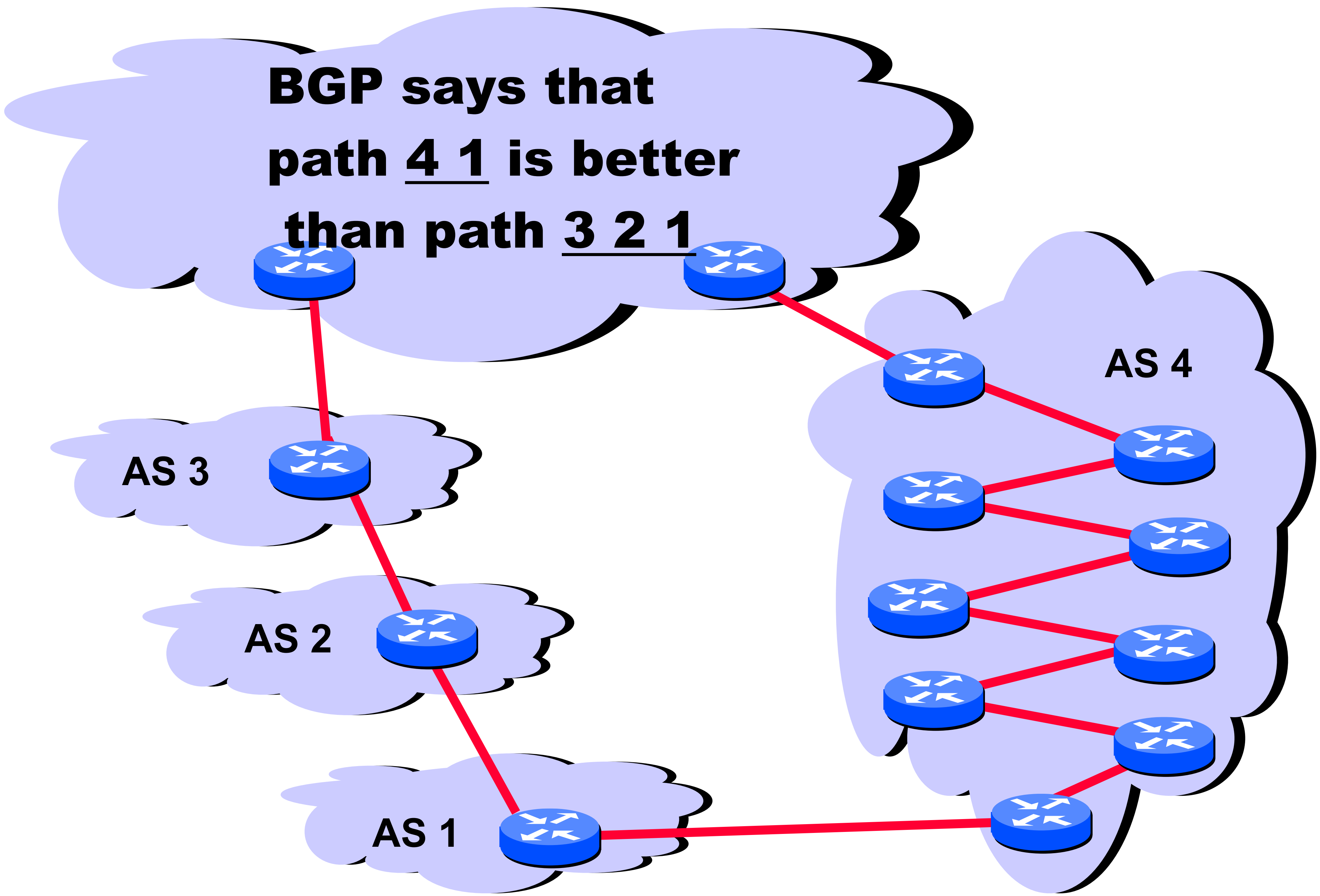
Convergence

Performance

Anomalies

Relevance

BGP path selection is mostly economical, not based on accurate performance criteria



Problems

Reachability

Security

Convergence

Performance

Anomalies

Relevance

BGP configuration is hard to get right,
you'll understand that very soon

BGP is both "bloated" and underspecified

lots of knobs and (sometimes, conflicting) interpretations

BGP is often manually configured

humans make mistakes, often

BGP abstraction is fundamentally flawed

disjoint, router-based configuration to effect AS-wide policy

Google routing blunder sent J... ×

Secure | https://www.theregister.co.uk/2017/08/27/google_routing_blunder_sent_japans_internet_dark/

Data Centre ▸ Networks

Google routing blunder sent Japan's Internet dark on Friday

Another big BGP blunder

By Richard Chirgwin 27 Aug 2017 at 22:35 40 SHARE ▼

Last Friday, someone in Google fat-thumbed a border gateway protocol (BGP) advertisement and sent Japanese Internet traffic into a black hole.

The trouble began when The Chocolate Factory "leaked" a big route table to Verizon, the result of which was traffic from Japanese giants like NTT and KDDI was sent to Google on the expectation it would be treated as transit.

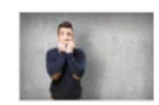
Since Google doesn't provide transit services, as BGP Mon explains, that traffic either filled a link beyond its capacity, or hit an access control list, and disappeared.

The outage in Japan only lasted a couple of hours, but was so severe that Japan Times reports the country's Internal Affairs and Communications ministries want carriers to report on what went wrong.

BGP Mon dissects what went wrong here, reporting that more than

Most read


Helicopter crashes after manoeuvres to 'avoid... DJI Phantom drone'


That terrifying 'unfixable' Microsoft Skype security flaw: THE TRUTH


Stephen Elop and the fall of Nokia revisited


BBC presenter loses appeal, must pay £420k in IR35 crackdown


Microsoft's Windows 10 Workstation adds killer feature: No Candy Crush

https://www.theregister.co.uk/2017/08/27/google_routing_blunder_sent_japans_internet_dark/

In August 2017

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Border Gateway Protocol (BGP) advertisement
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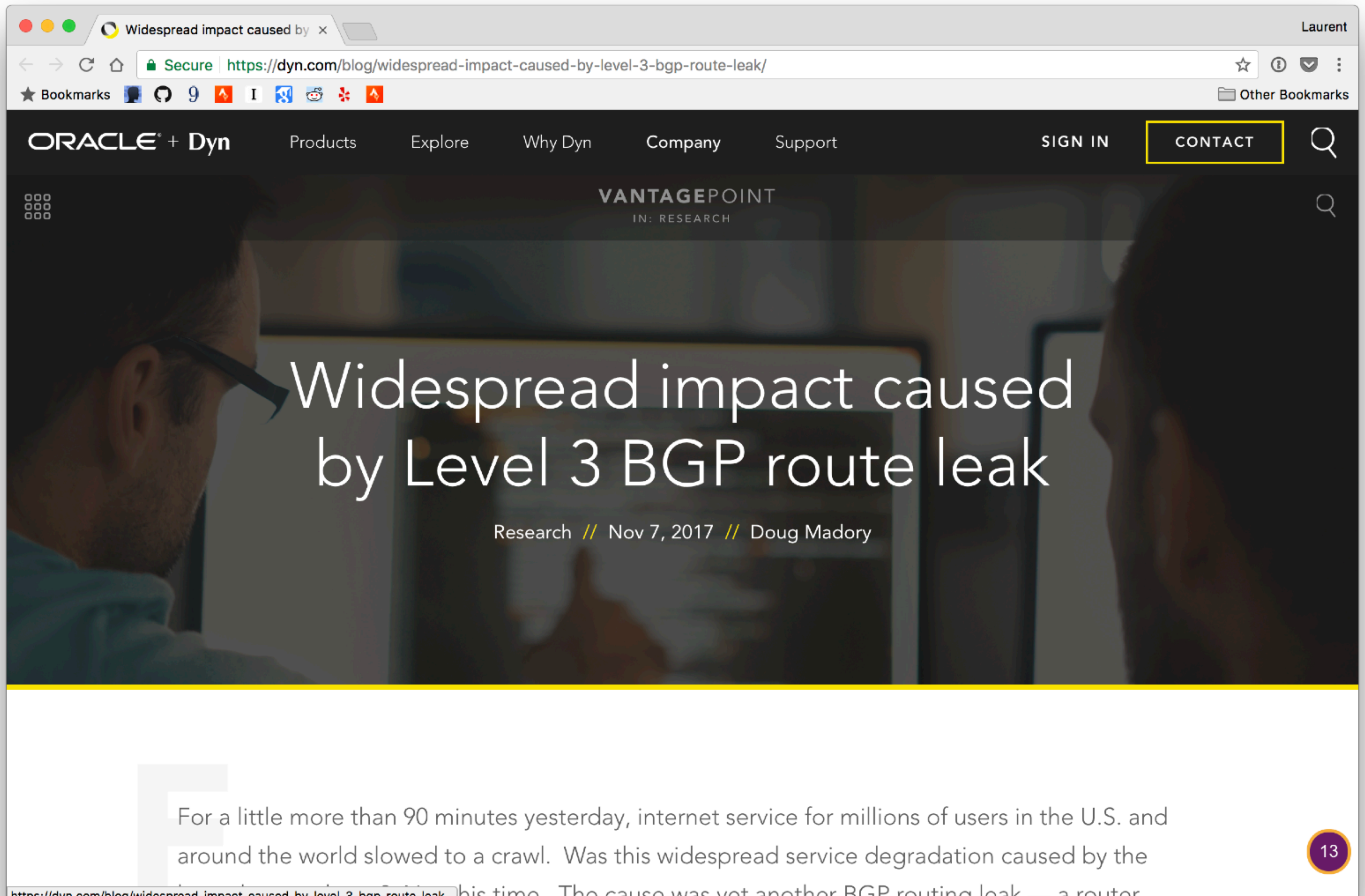
was sent to Google on the expectation
it would be treated as transit.

The outage in Japan only lasted a couple of hours
but was so severe that […] the country's
Internal Affairs and Communications ministries
want carriers to report on what went wrong.

Another example,

this time from November 2017



https://dyn.com/blog/widespread-impact-caused-by-level-3-bgp-route-leak/

For a little more than 90 minutes [...],

Internet service for millions of users in the U.S.
and around the world slowed to a crawl.

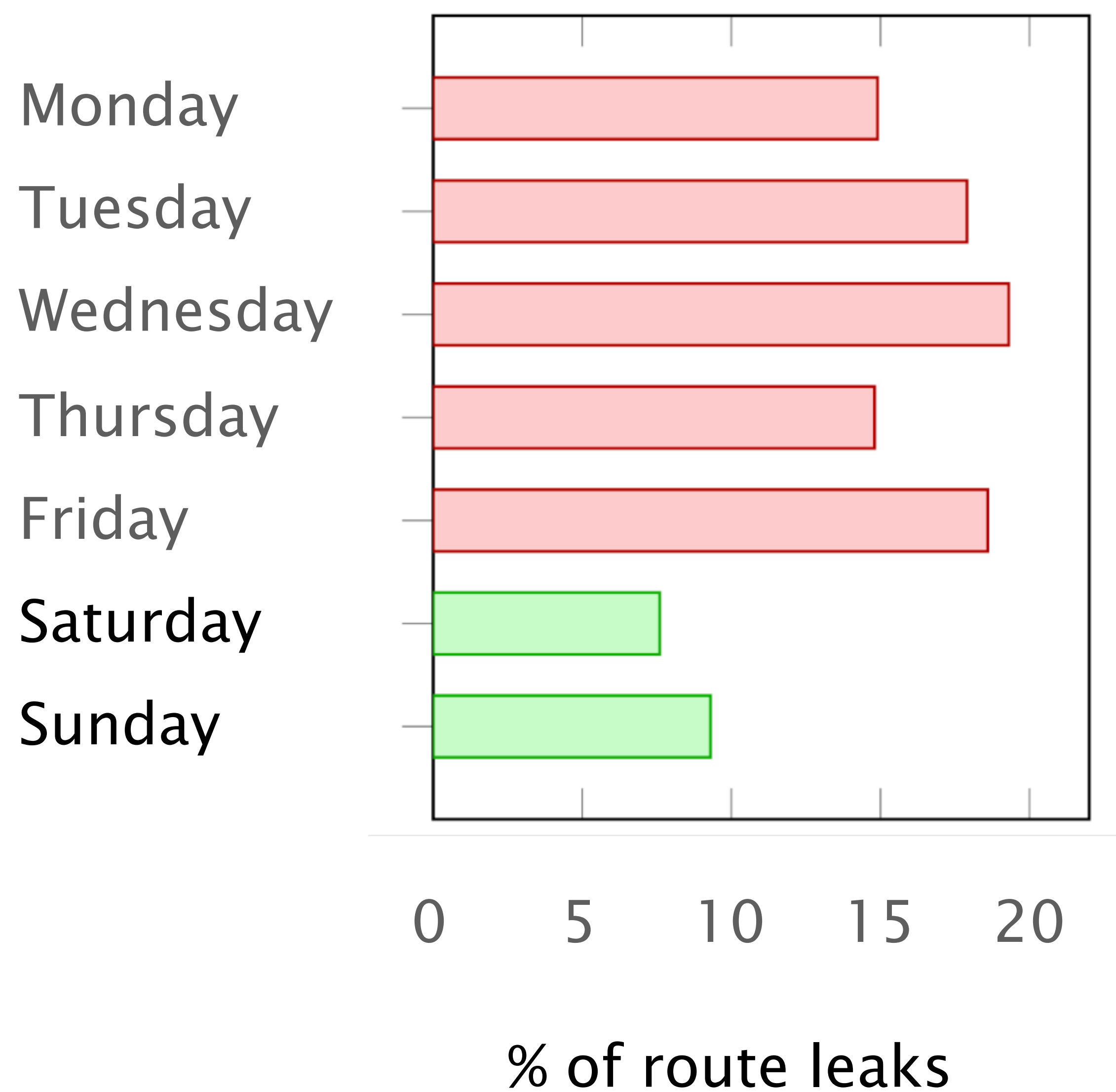
The cause was yet another BGP routing leak,
a router misconfiguration directing Internet traffic
from its intended path to somewhere else.

"Human factors are responsible

for 50% to 80% of network outages"

Juniper Networks, *What's Behind Network Downtime?*, 2008

Ironically, this means that the Internet works better during the week-ends…



source: Job Snijders (NTT)

Problems

Reachability

Security

Convergence

Performance

Anomalies

Relevance

The world of BGP policies is rapidly changing

ISPs are now eyeballs talking to content networks

e.g., Swisscom and Netflix/Spotify/YouTube

Transit becomes less important and less profitable

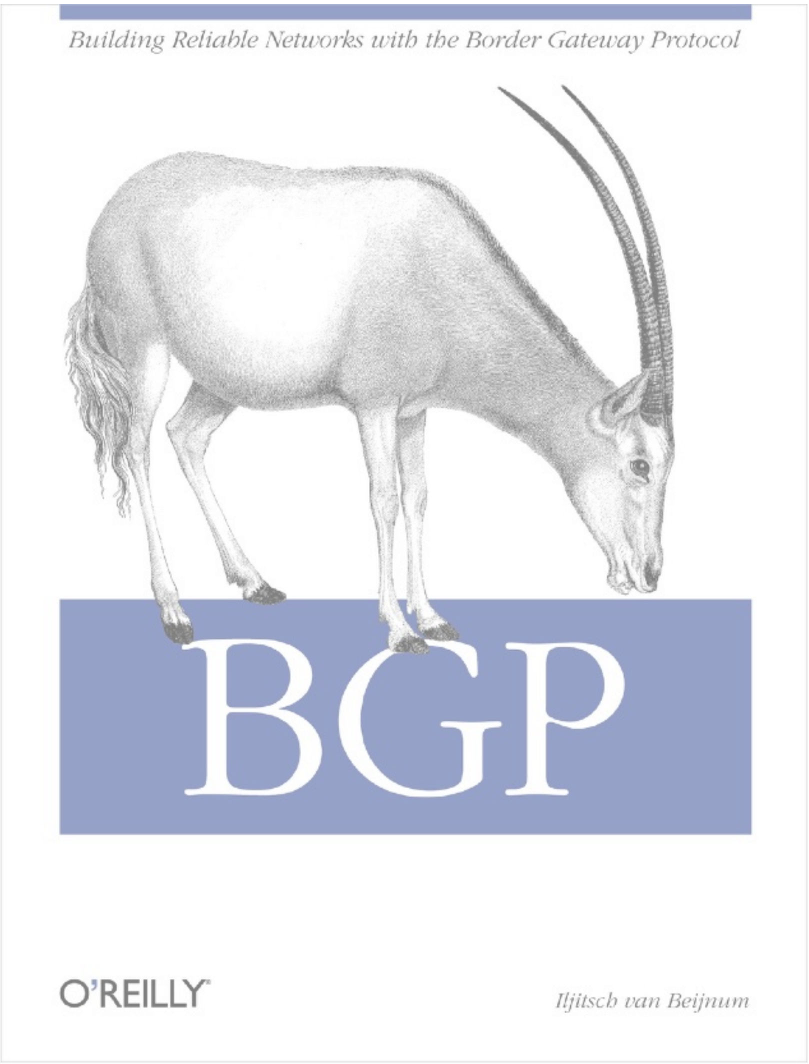
traffic move more and more to interconnection points

No systematic practices, yet

details of peering arrangements are private anyway

Border Gateway Protocol

policies and more



BGP Policies

Follow the Money

Protocol

How does it work?

Problems

security, performance, …

Communication Networks

Spring 2019

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nsg.ee.ethz.ch

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April 1 2019