Communication Networks

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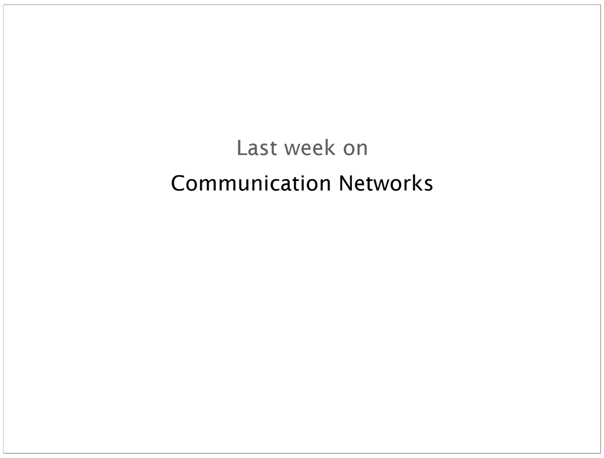
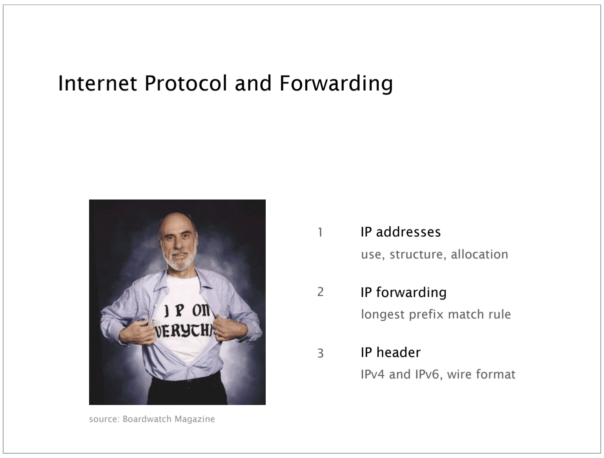
Materials inspired from Scott Shenker & Jennifer Rexford



Last week on

Communication Networks



Internet Protocol and Forwarding

1 IP addresses

use, structure, allocation

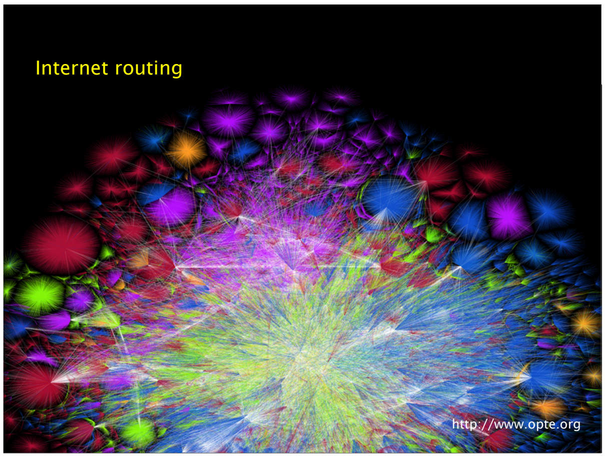
2 IP forwarding

longest prefix match rule

3 IP header

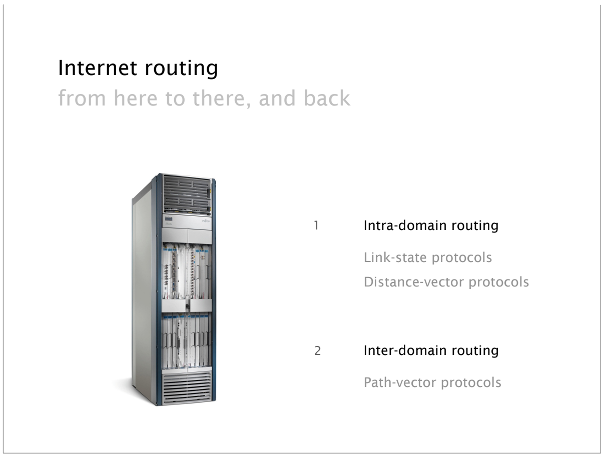
IPv4 and IPv6, wire format

source: Boardwatch Magazine



Internet routing

http://www.opte.org



Internet routing

from here to there, and back

1 Intra-domain routing

Link-state protocols

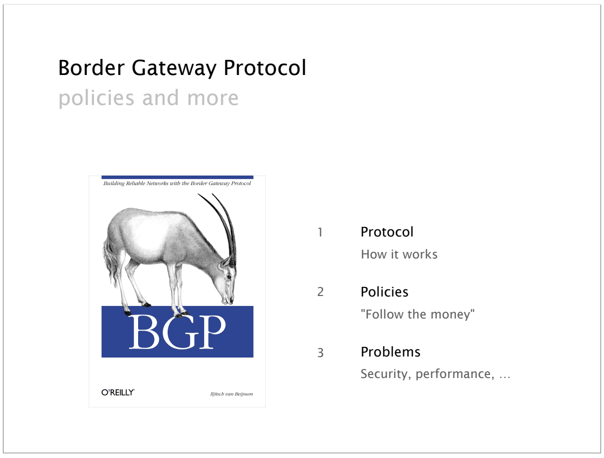
Distance-vector protocols

2 Inter-domain routing

Path-vector protocols

This week on

Communication Networks



Border Gateway Protocol

policies and more

1 Protocol

How it works

2 Policies

"Follow the money"

3 Problems

Security, performance, …

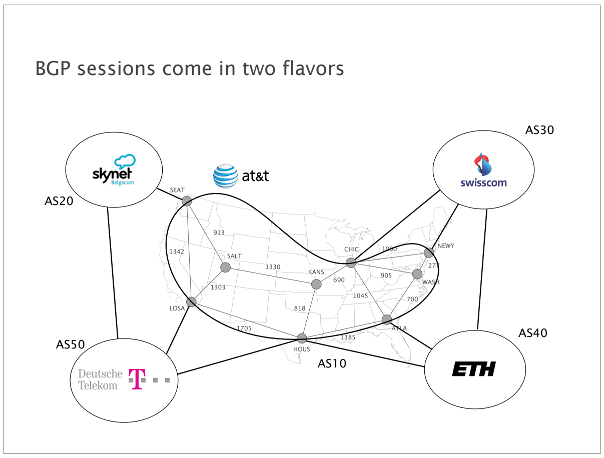
Border Gateway Protocol

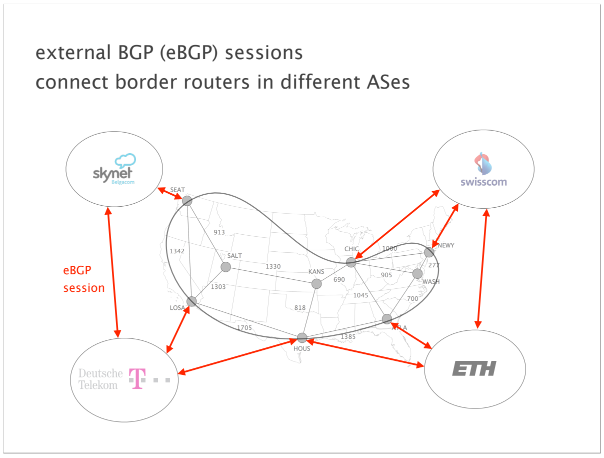
policies and more

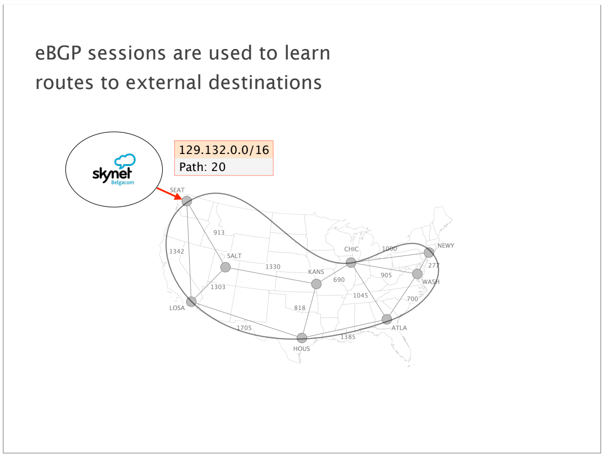
1 Protocol
How it works

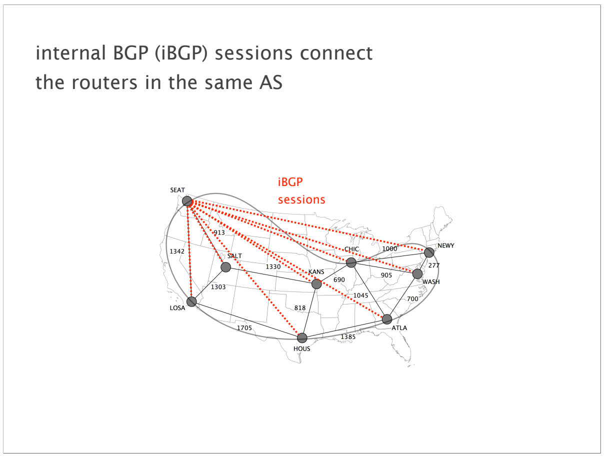
Policies
"Follow the money"

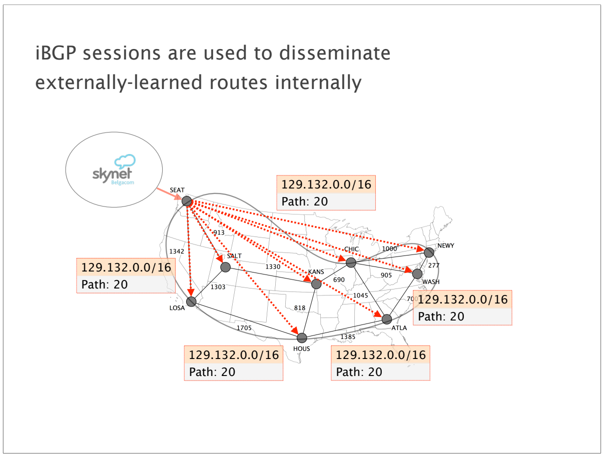
Problems
Security, performance, …

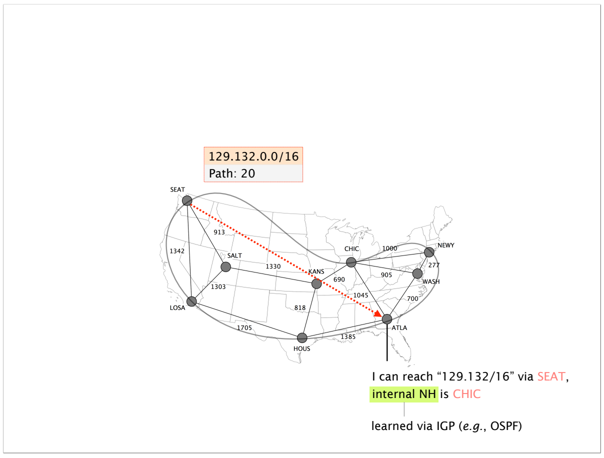

BGP sessions come in two flavors


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


eBGP sessions are used to learn
routes to external destinations

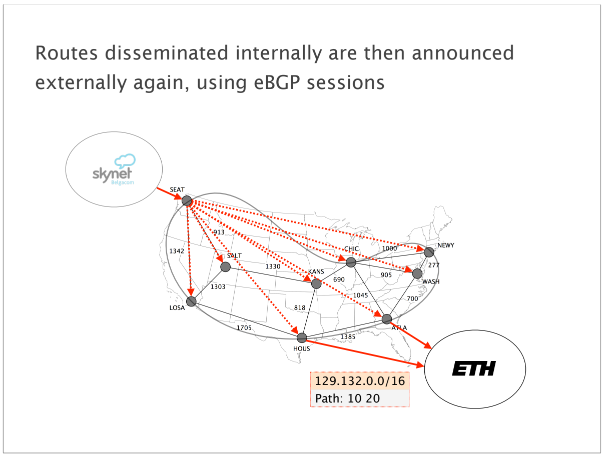

internal BGP (iBGP) sessions connect
the routers in the same AS


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

IP prefix

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

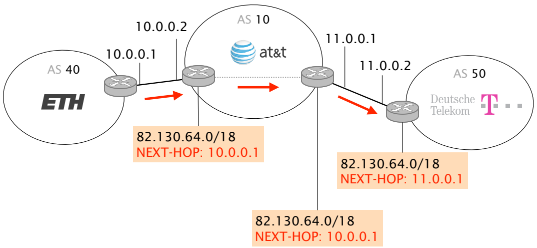
are either local (*only* seen on iBGP)

or global (seen on iBGP *and* eBGP)

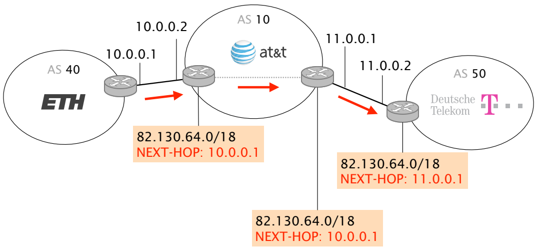
Attributes	Usage
NEXT-HOP	egress point identification
AS-PATH	loop avoidance outbound traffic control inbound traffic control
LOCAL-PREF	outbound traffic control
MED	inbound traffic control

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

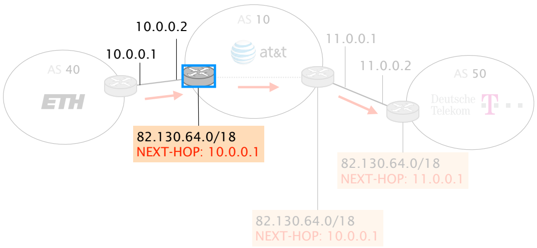
The NEXT-HOP is set when the route enters an AS,
by default, it does not change *within* the AS



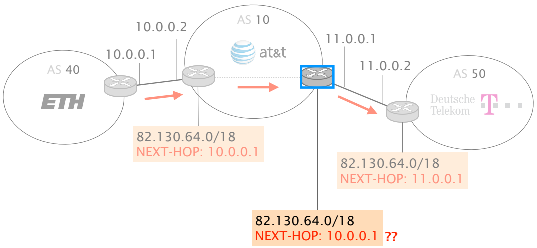
For externally-learned routes, this means that the NEXT-HOP is
the IP address of the neighbor's eBGP router, here 10.0.0.1 for at&t



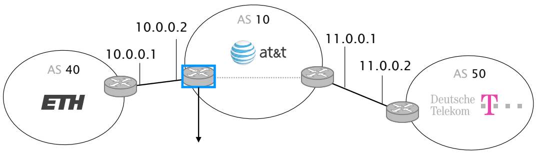
For this router, reaching 10.0.0.1 is not a problem as it is directly connected to the corresponding subnet (10.0.0.0/30)



That router is *not* directly to the NEXT-HOP's subnet (10.0.0.0/30) and does not know how to reach it, it will therefore drop the BGP route…

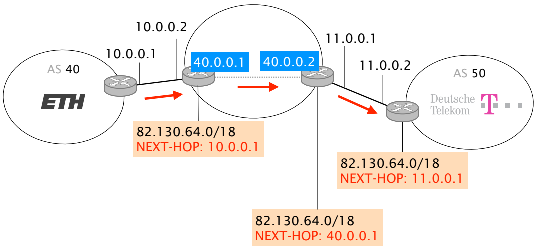


One solution is for the external router to redistribute the prefixes attached to the external interfaces into the IGP

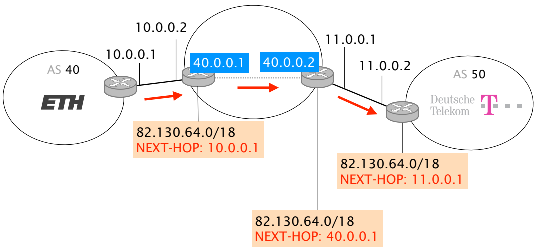


announce 10.0.0.0/30
in OSPF

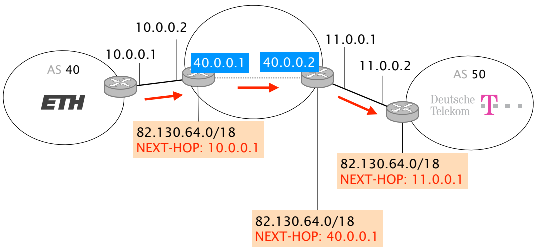
Another solution is for the border router to rewrite the NEXT-HOP before sending it over iBGP, usually to its loopback address



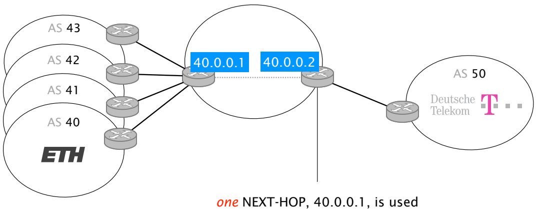
Of course, loopback addresses need to be reachable network-wide. Typically, each router advertise its loopback (as a /32) in the IGP



Rewriting the next-hop to the eBGP router's loopback is known as **"next-hop-self"**

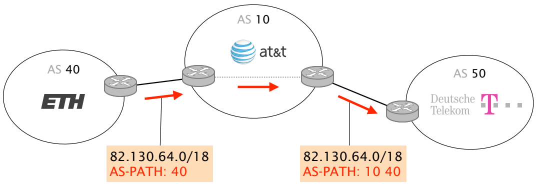


The advantage of next-hop-self is to spare the need to advertise *each* prefix attached to an external link in the IGP

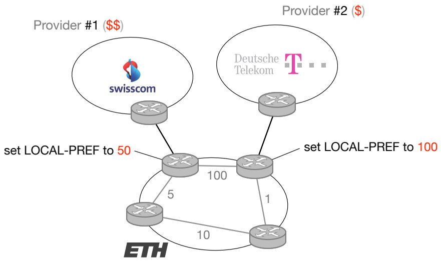


one NEXT-HOP, 40.0.0.1, is used
to reach routes announced by AS 40, 41, 42, 43…

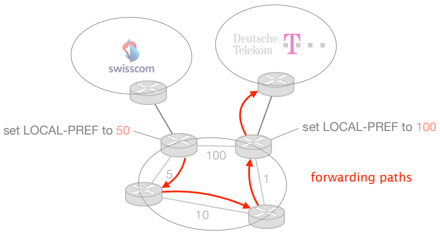
The AS-PATH is a global attribute that lists all the ASes a route has traversed (in reverse order)



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

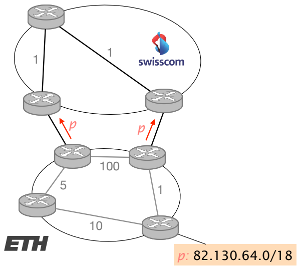


By setting a higher LOCAL-PREF,
all routers end up using DT to reach any external prefixes,
even if they are closer (IGP-wise) to the Swisscom egress

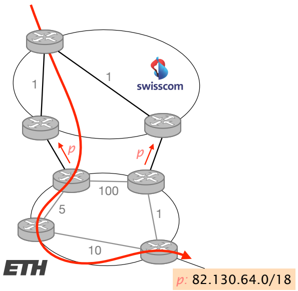


The MED is a *global* attribute which encodes the relative “proximity” of a prefix wrt to the announcer

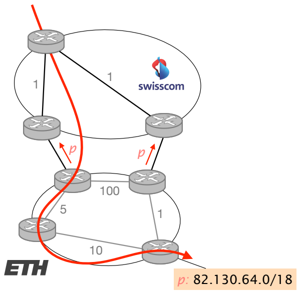
Swisscom receives two routes to reach p



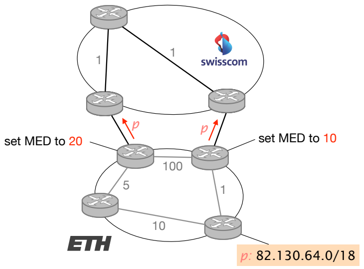
Swisscom receives two routes to reach p
and chooses (arbitrarily) its left router as egress



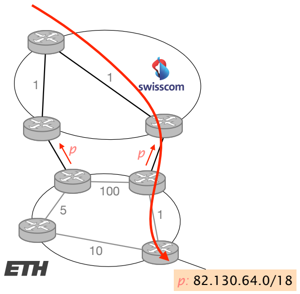
Yet, ETH would prefer to receive traffic for p
on its right border router which is closer to the actual destination



ETH can communicate that preferences to Swisscom
by setting a higher MED on *p* when announced from the left



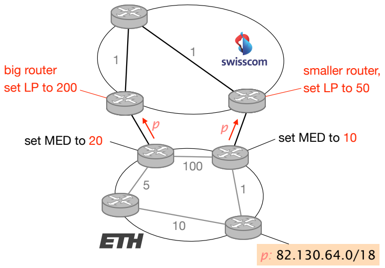
Swisscom receives two routes to reach *p*
and, *given it does not cost it anything more*,
chooses its right router as egress



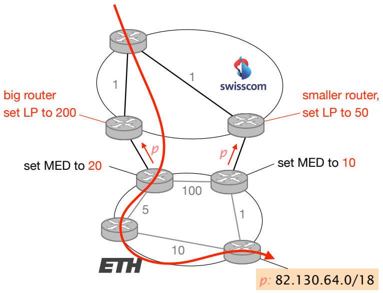
Swisscom receives two routes to reach *p*
and, *given it does not cost it anything more*,
chooses its right router as egress

But what if it does?

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



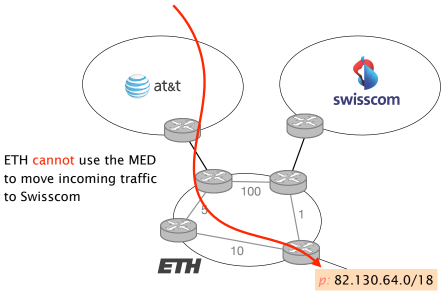
In this case, Swisscom will not care about the MED value
and still push the traffic via its left router



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

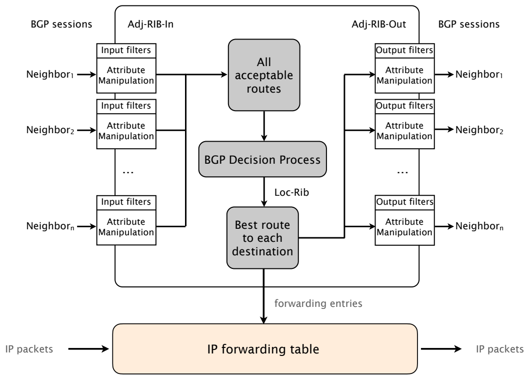
IP prefix

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

Neighbor$_1$

Neighbor$_2$

Neighbor$_n$

Input filters

Attribute Manipulation

...

All acceptable routes

BGP Decision Process

Loc-Rib

Best route to each destination

Output filters

Attribute Manipulation

Neighbor$_1$

Neighbor$_2$

Neighbor$_n$

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

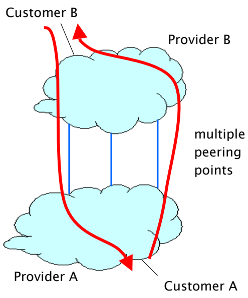
These two steps aim at directing traffic as quickly as possible out of the AS (early exit routing)

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



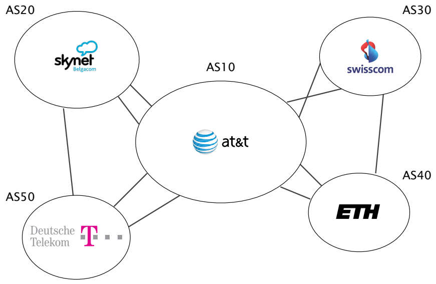
Border Gateway Protocol
policies and more

Protocol
How it works

2 Policies
"Follow the money"

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:

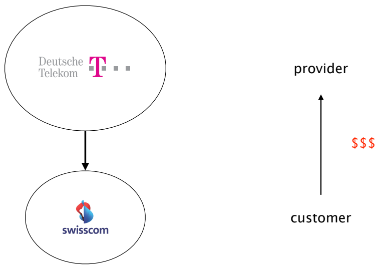
- customer/provider
- peer/peer

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

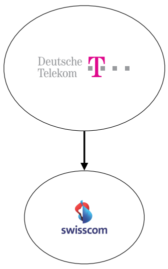
There are 2 main business relationships today:

- 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

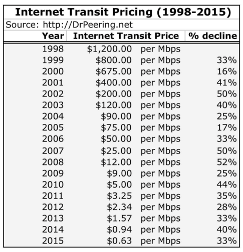
- sorts all values in decreasing order
- removes the top 5% values
- bills wrt highest remaining value

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

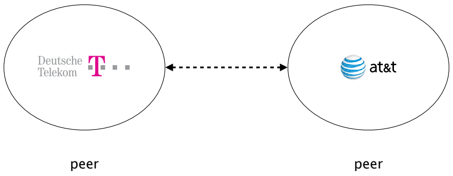
Year	Internet Transit Price		% decline
1998	$1,200.00	per Mbps	
1999	$800.00	per Mbps	33%
2000	$675.00	per Mbps	16%
2001	$400.00	per Mbps	41%
2002	$200.00	per Mbps	50%
2003	$120.00	per Mbps	40%
2004	$90.00	per Mbps	25%
2005	$75.00	per Mbps	17%
2006	$50.00	per Mbps	33%
2007	$25.00	per Mbps	50%
2008	$12.00	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:

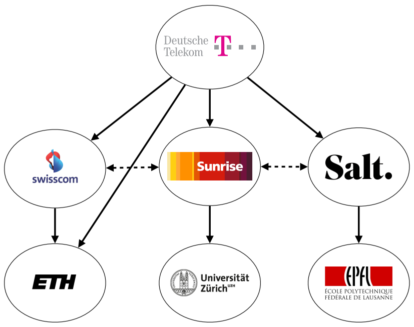
- customer/provider
- peer/peer

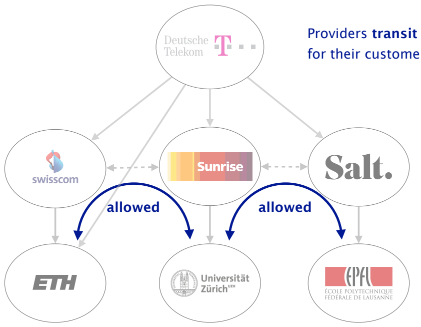
Peers don't pay each other for connectivity, they do it *out of common interest*



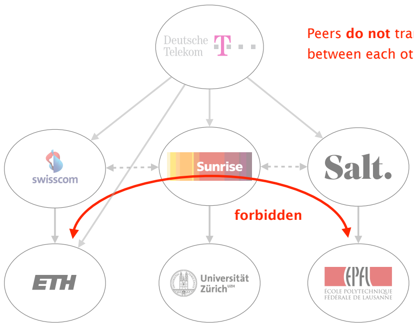
DT and ATT exchange *tons* of traffic.
they save money by directly connecting to each other

To understand Internet routing,
follow the money

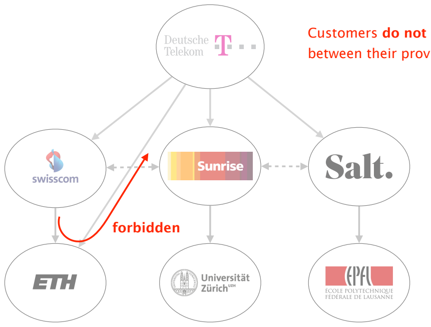




Providers **transit** traffic for their customers



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

which path to use?

Export

which path to advertise?

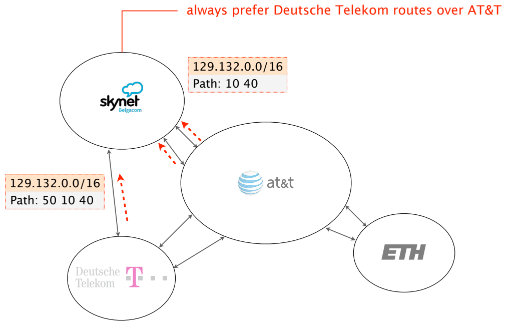
Selection

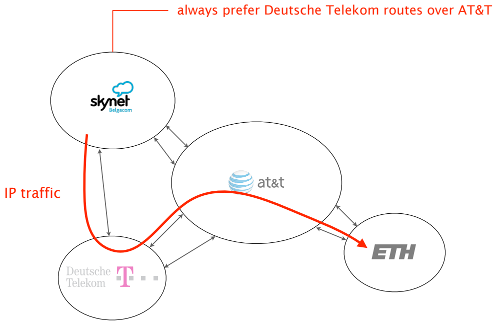
Export

which path to use?

control outbound traffic

which path to advertise?





Business relationships conditions *route selection*

For a destination *p*, prefer routes coming from

- customers over
- peers over
- providers

route type

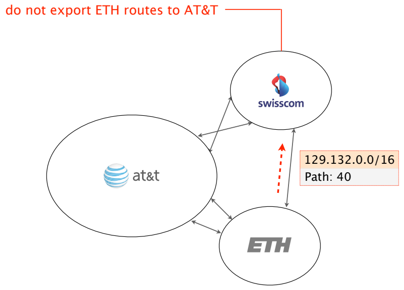
Selection

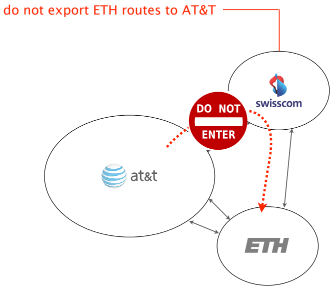
Export

which path to use?

which path to advertise?

control inbound traffic





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

Selection

Export

which path to use?

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Selection

which path to use?

control outbound traffic

Export

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Business relationships conditions
route selection

For a destination *p*, prefer routes coming from

- customers over
- peers over
- providers

route type

Selection

which path to use?

Export

which path to advertise?

control inbound traffic

Business relationships conditions
route exportation

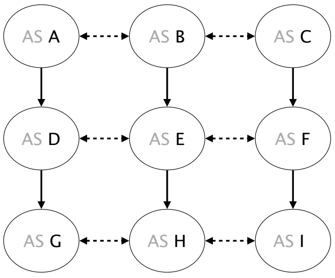
		send to		
		customer	peer	provider
	customer			
from	peer			
	provider			

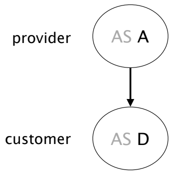
Routes coming from customers are propagated to everyone else

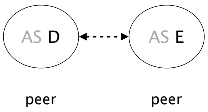
		send to		
		customer	peer	provider
	customer	✓	✓	✓
from	peer			
	provider			

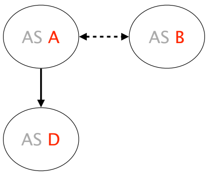
Routes coming from peers and providers are only propagated to customers

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

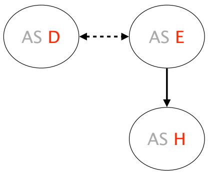




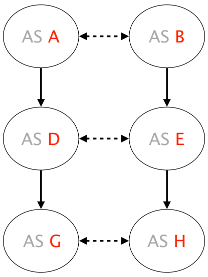




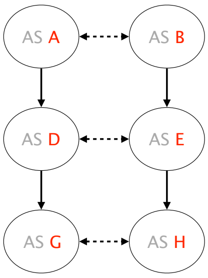
Is (B, A, D) a valid path? Yes/No



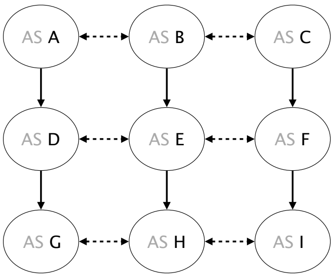
Is (H, E, D) a valid path? Yes/No



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?

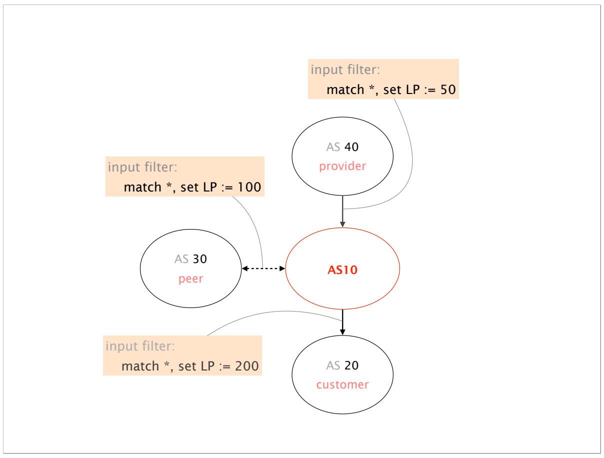
Let's look at how operators implement customer/provider and peer policies in practice

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

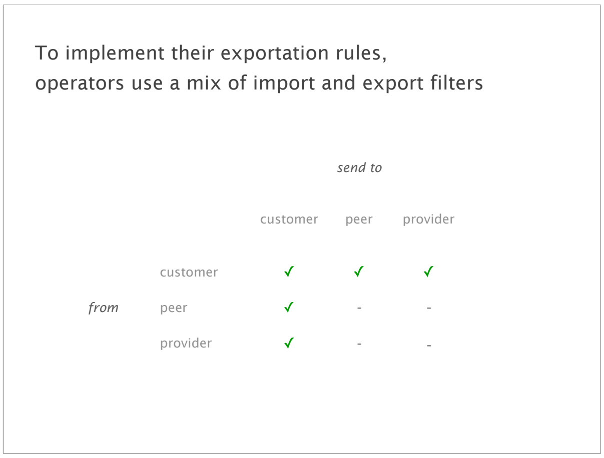
input filter:
match *, set LP := 100

AS 30
peer

AS10

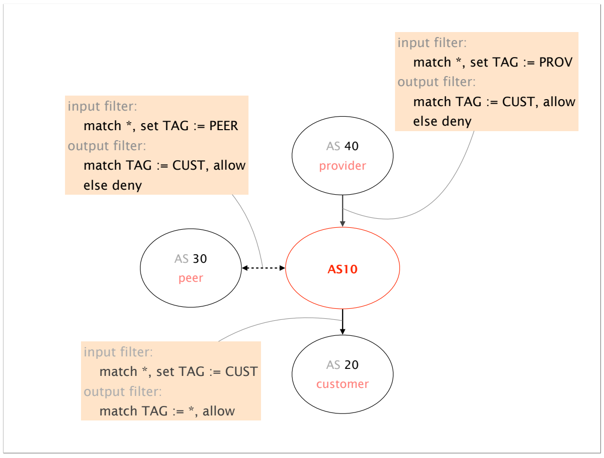
input filter:
match *, set LP := 200

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

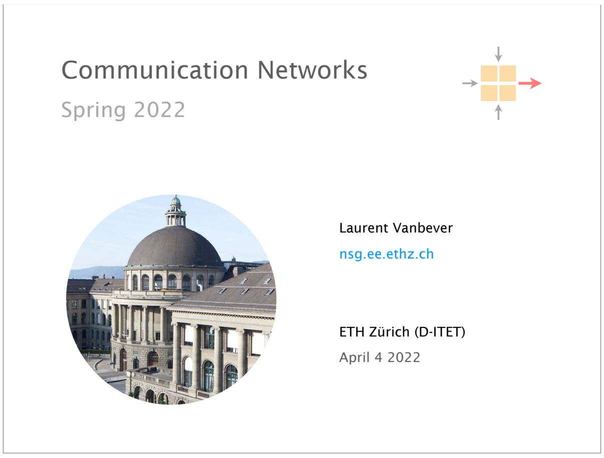
AS 40
provider

AS 30
peer

AS10

input filter:
match *, set TAG := CUST
output filter:
match TAG := *, allow

AS 20
customer



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