BGP in 120 minutes

RIPE89

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About me

- →Wolfgang Tremmel
- →studied Informatik (Uni Karlsruhe)
  - →Degree: Diploma (1994)
- →Network Engineer at XLink
  - →Since 1996 Director NOC
  - →Since 2000 Senior Network Planner DSL at kpnQwest
- →2001 - 2005 Director Network Planning at VIA NET.WORKS
- →2006 - 2016 Manager Customer Support at DE CIX
- →since 2016: Head of DE-CIX Academy

DE CIX

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What is BGP about?

IPv4 Prefixes

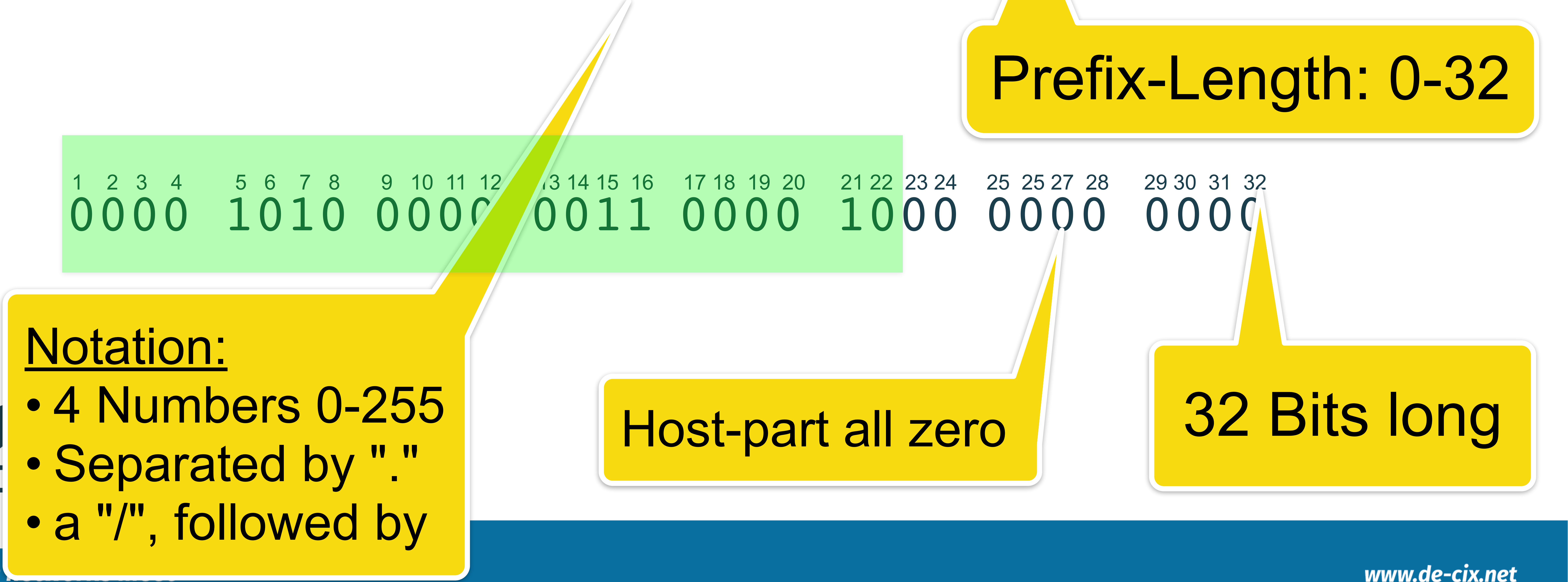
10.3.8.0/22

1 2 3 4	5 6 7 8	9 10 11 12	13 14 15 16	17 18 19 20	21 22 23 24	25 25 27 28	29 30 31 32
0000	1010	0000	0011	0000	1000	0000	0000

- → IPv4 and IPv6 addresses have a network and a host part
- → A **prefix** is just the network part
- → Important:
  - **The boundary between network and host can be anywhere!**

Characteristics of Prefixes: IPv4

10.3.8.0/22



Prefix-Length: 0-32

```
1 2 3 4   5 6 7 8   9 10 11 12   13 14 15 16   17 18 19 20   21 22 23 24   25 25 27 28   29 30 31 32
0000      1010      0000         0011          0000          1000          0000          0000
```

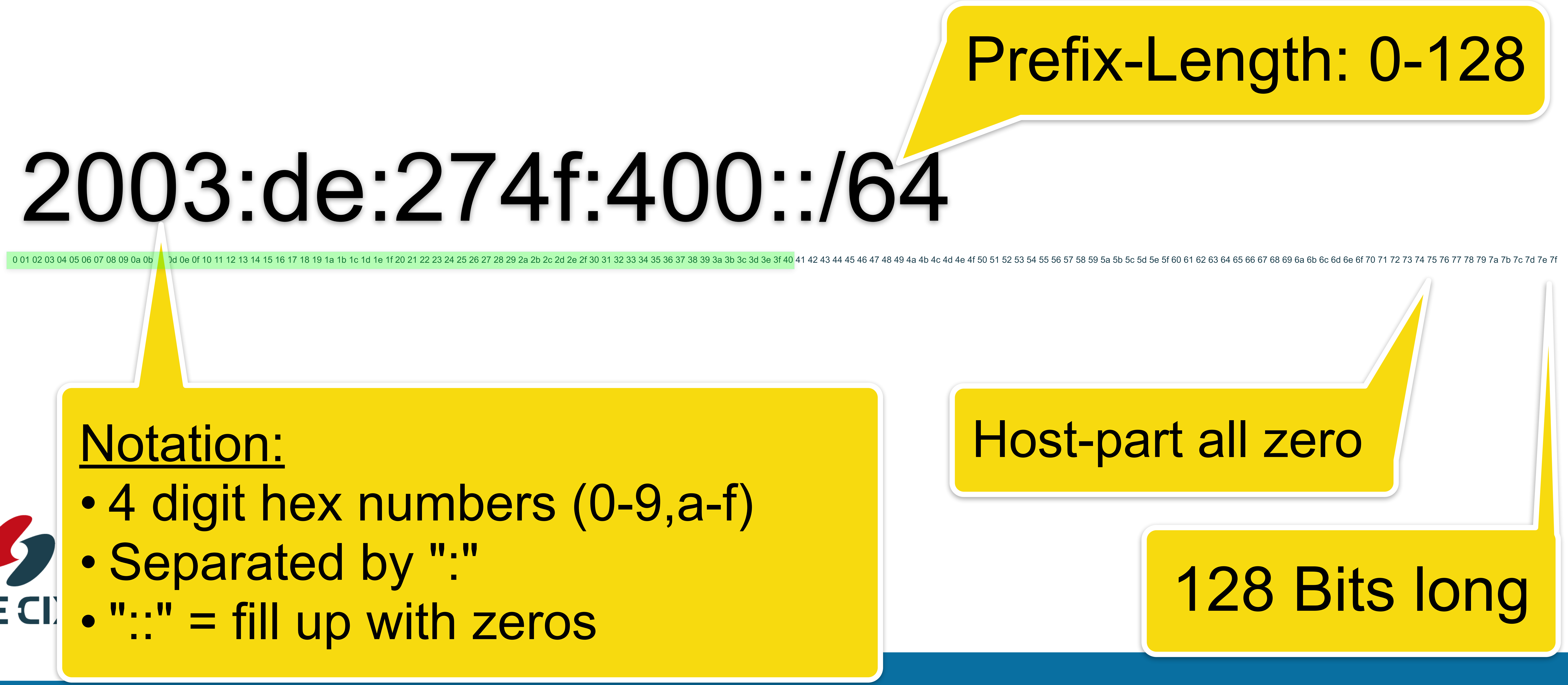
Notation:

- 4 Numbers 0-255
- Separated by "."
- a "/", followed by

Host-part all zero

32 Bits long

Characteristics of Prefixes: IPv6



Prefix-Length: 0-128

2003:de:274f:400::/64

0 01 02 03 04 05 06 07 08 09 0a 0b 0d 0e 0f 10 11 12 13 14 15 16 17 18 19 1a 1b 1c 1d 1e 1f 20 21 22 23 24 25 26 27 28 29 2a 2b 2c 2d 2e 2f 30 31 32 33 34 35 36 37 38 39 3a 3b 3c 3d 3e 3f 40 41 42 43 44 45 46 47 48 49 4a 4b 4c 4d 4e 4f 50 51 52 53 54 55 56 57 58 59 5a 5b 5c 5d 5e 5f 60 61 62 63 64 65 66 67 68 69 6a 6b 6c 6d 6e 6f 70 71 72 73 74 75 76 77 78 79 7a 7b 7c 7d 7e 7f

<u>Notation:</u>

- 4 digit hex numbers (0-9,a-f)
- Separated by ":"
- "::" = fill up with zeros

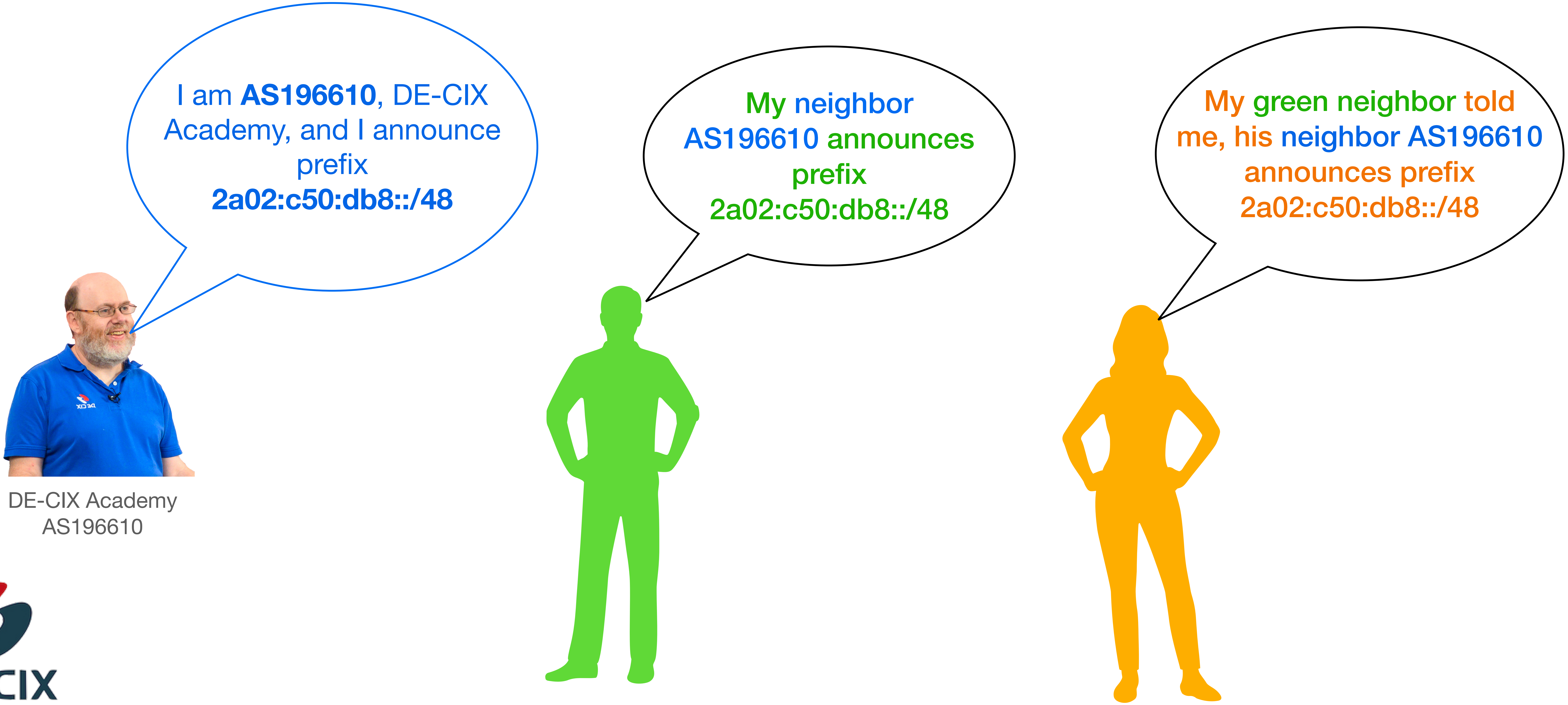
Host-part all zero

128 Bits long

How does BGP work?

BGP is a protocol to announce prefixes

Everybody has Neighbors



I am **AS196610**, DE-CIX Academy, and I announce prefix **2a02:c50:db8::/48**

My neighbor AS196610 announces prefix 2a02:c50:db8::/48

My green neighbor told me, his neighbor AS196610 announces prefix 2a02:c50:db8::/48

DE-CIX Academy
AS196610

2a02:c50:db8::/48
2a02:c50:db8::/48
2a02:c50:db8::/48
2a02:c50:db8::/48
192.0.2.0/24
198.51.100.0/24
2a02:c50:db8::/48

BGP announces prefixes

To neighbors

192.0.2.0/24
198.51.100.0/24
2a02:c50:db8::/48

- BGP **announces** IP prefixes to **neighbors**
  - These neighbors have to be **configured**
  - Each BGP speaking device is part of an **Autonomous System**
  - The path these announcements take is recorded - this is called the **Autonomous System Path**
  - The AS Path shows which Autonomous Systems have forwarded the prefix announcement
  - The rightmost AS in the AS Path is called the "**Originator**"

I am **AS196610**, DE-CIX
Academy, and I announc
prefix
2a02:c50:db8::/48

2a02:c50:db8::/48
🟧 🟩 🟦

What is an *Autonomous System*?

DE CIX

What is an Autonomous System?

Simple Definition

Formal Definition (RFC1930):

> "An AS is a connected group of one or more IP prefixes run by one or more network operators which has a SINGLE and CLEARLY DEFINED routing policy."

- A group of IP prefixes
  - But to route or announce them, you need hardware
  - A router (or multiple routers)
  - This router speaks BGP (to its neighbors)
  - And has an ***Autonomous System Number*** configured
- Another new term: **Autonomous System Number (ASN)**

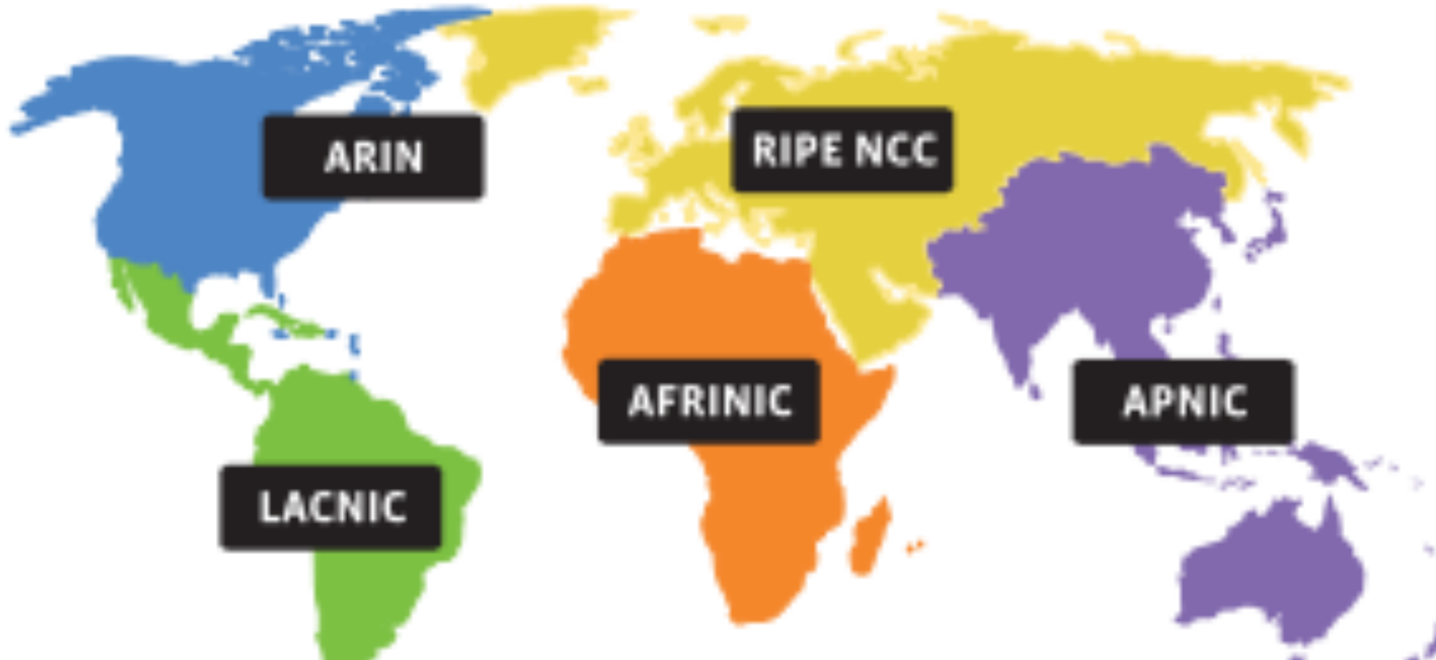
I am **AS196610**, DE-CIX Academy, and I announce prefix 2a02:c50:db8::/48

Autonomous System Number

or AS Number or ASN

> *"An AS has a **globally unique** number (sometimes referred to as an **ASN**, or Autonomous System Number) associated with it;*
> *this number is used in both the exchange of exterior routing information (between neighboring ASes), and as an **identifier of the AS** itself." (RFC1930)*

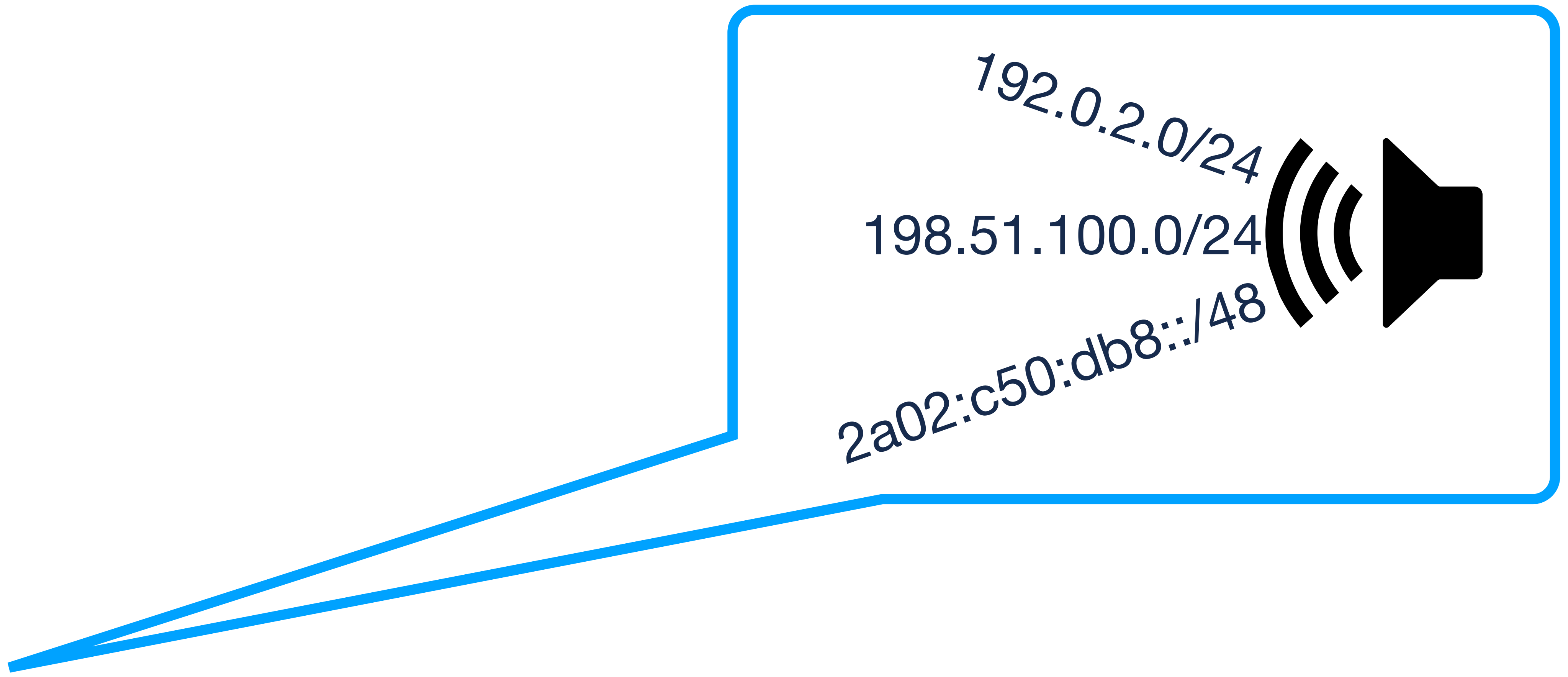
- Initially 16bit (0...65535) they are now 32bit long (0..."a lot")
- AS numbers are globally unique
- Unique means, somebody has to administrate them
- This is the IANA (Internet Assiged Numbers Authority)
  - But they have delegated that task to the 5 RIRs (Regional Internet Registries)
  - So in Europe: Become a member of the RIPE NCC and request one



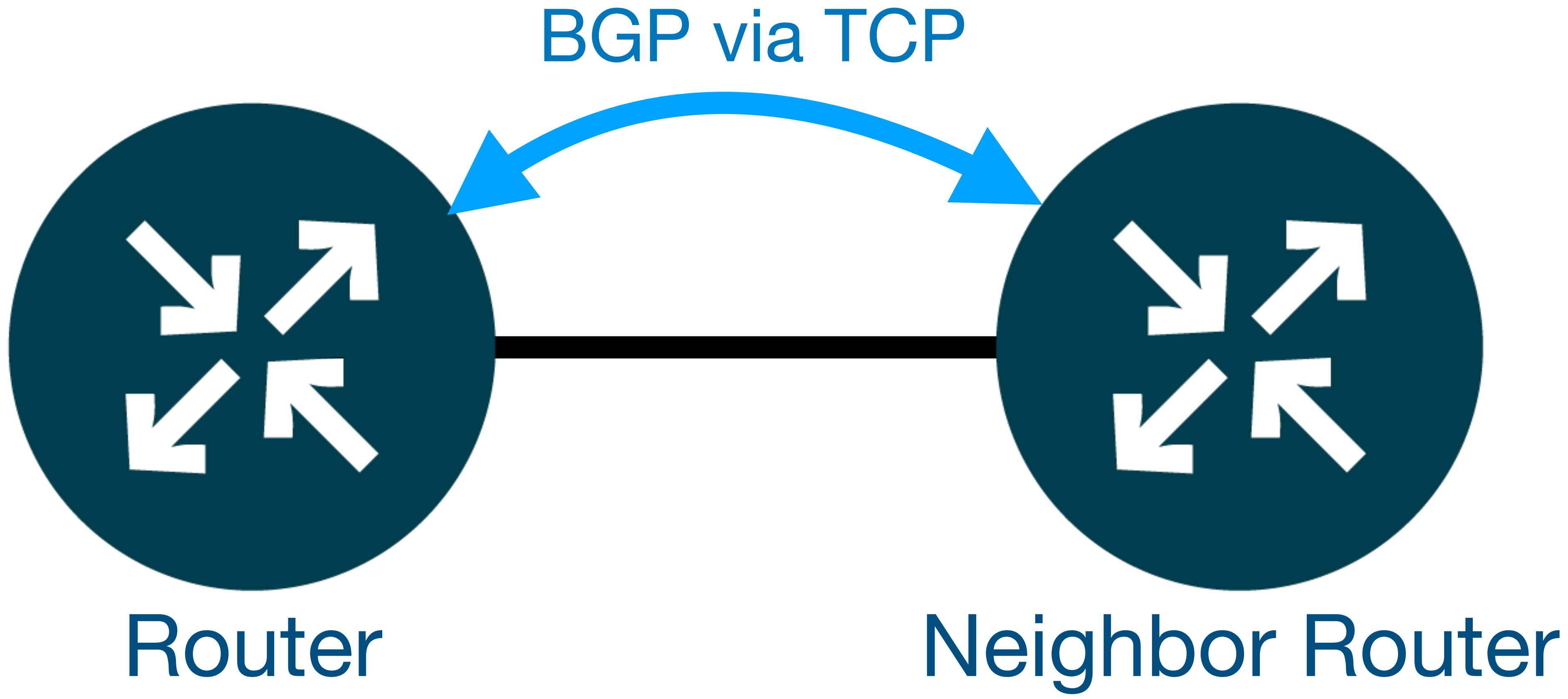
BGP Announcing Prefixes

BGP Neighbors

Directly connected neighbors

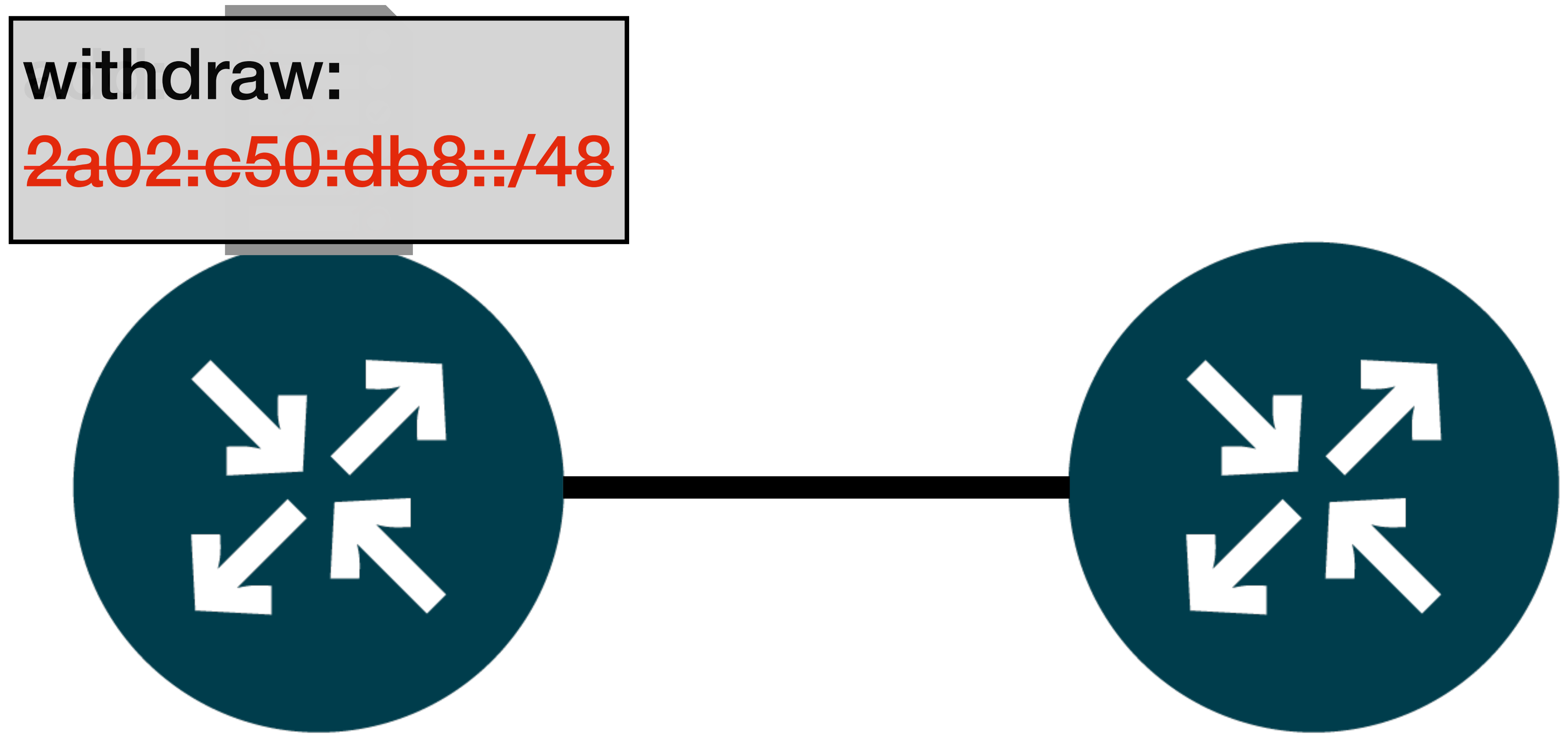


- BGP **announces** IP prefixes to **neighbors**
- These neighbors have to be **configured**
- BGP uses **TCP** to connect to a neighbor
- TCP brings already:
  - **Reliable transport** (sender knows that receiver got it)
  - **Flow control** (do not send faster than the receiver can receive)
  - **Framing** (putting BGP messages into packets)



BGP works incremental

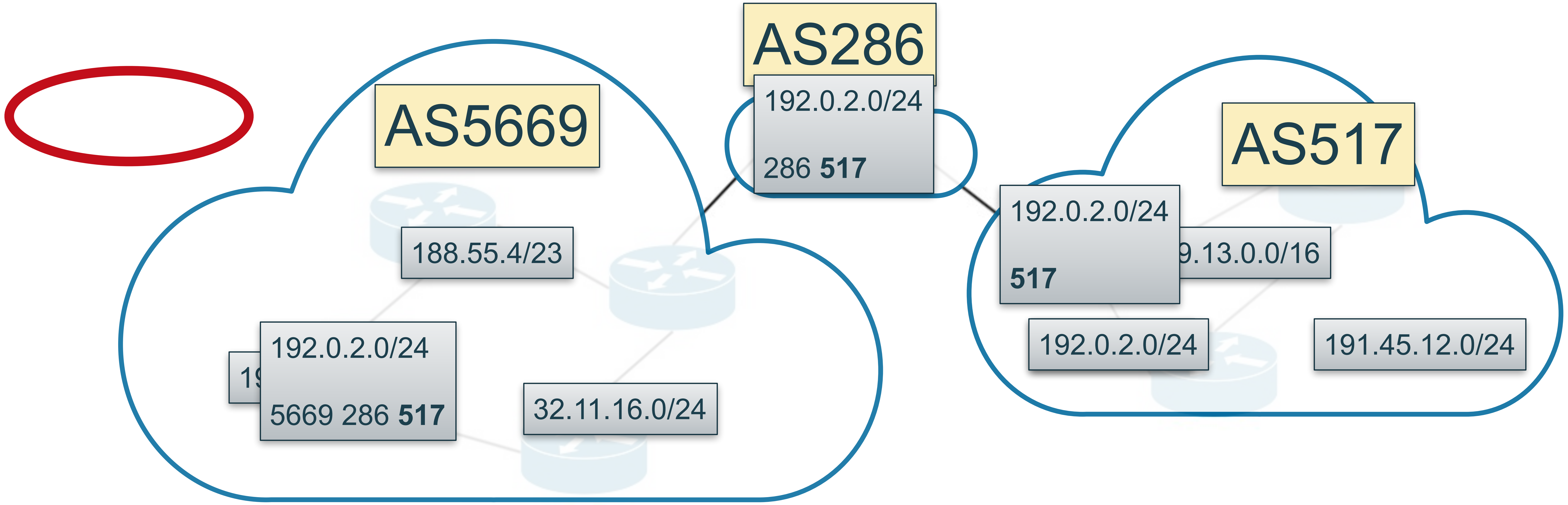
Using add- / withdraw- messages



- At session setup, BGP announces "everything" to its neighbor
- After that, updates are **incremental**:
  - If BGP learns about a new prefix, it sends an **add**-message to neighbors
  - If a prefix goes away, it sends a **withdraw** message to neighbors
- As long as the BGP session is "up", a router assumes its neighbors are "in sync" (= did not forget anything it sent)

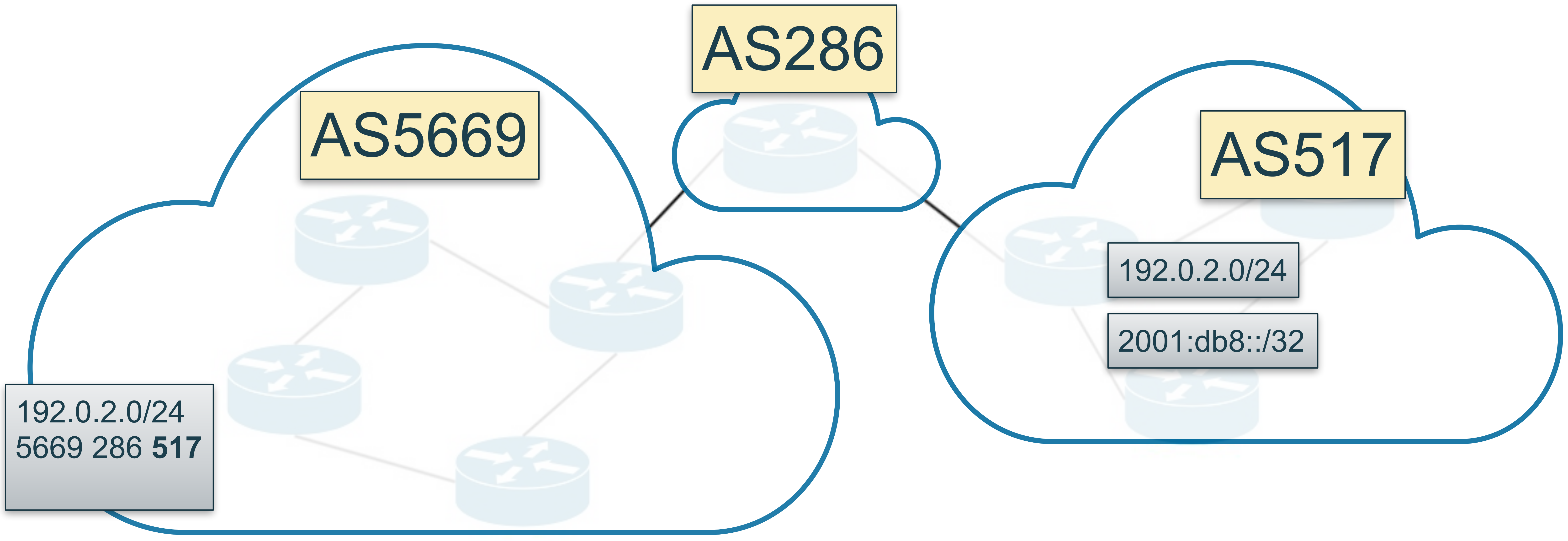
BGP Announcing Prefixes

Building the AS path



BGP Announcing Prefixes

- Prefixes
- AS Numbers
- AS Path



Attributes of BGP prefixes

Not only the AS path

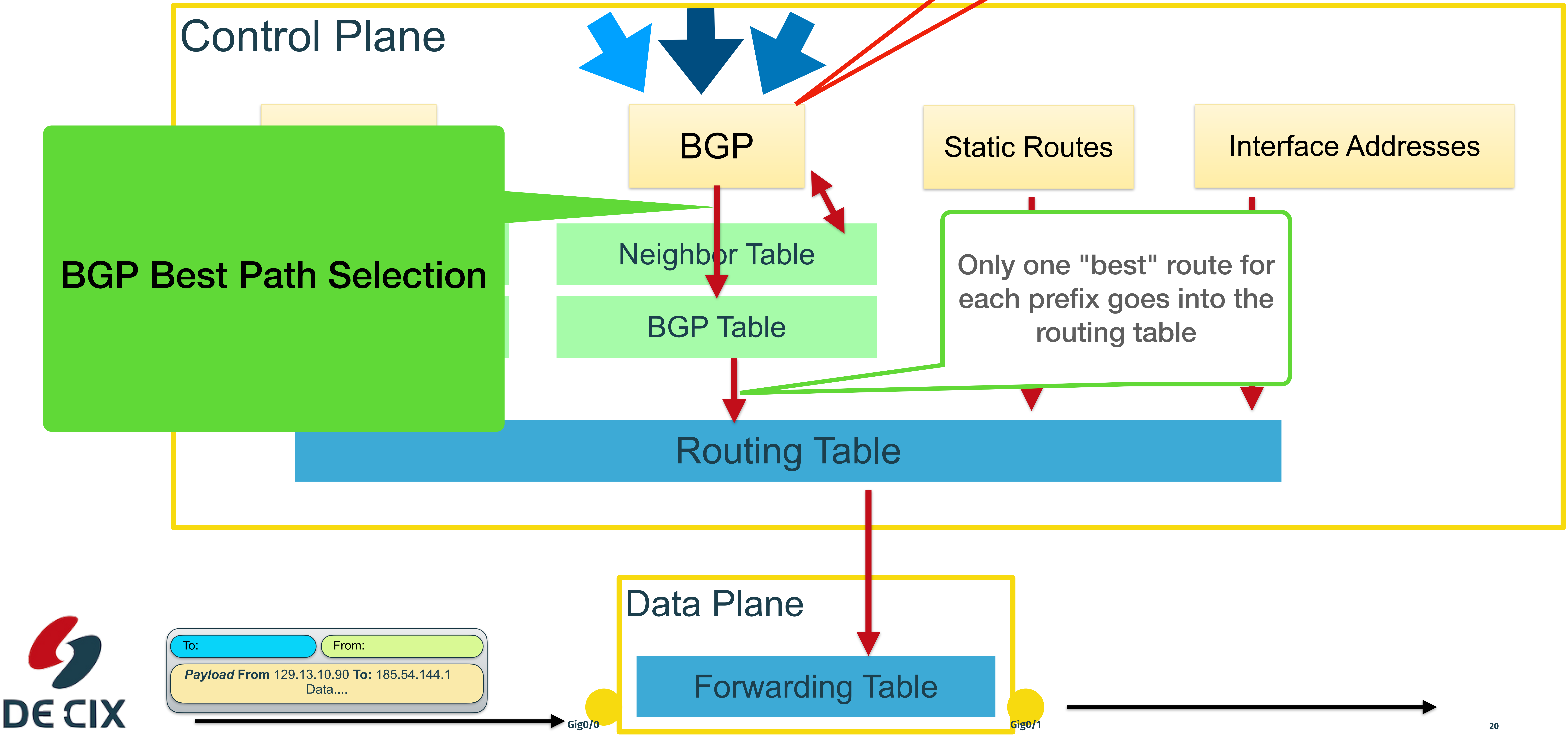
- **Mandatory** attributes: have to be there
  - Example: AS-Path
- **Optional** attribute: are, well, optional
  - Example: MED

- **Transitive** attributes
  - are kept on the prefix and forwarded via BGP
- **Non-transitive** attributes
  - are added to a prefix and not forwarded by the receiver

How a router works

Simplified

BGP receives information for the **same prefix** from multiple neighbors



BGP Best Path Selection

Only one "best" route for each prefix goes into the routing table

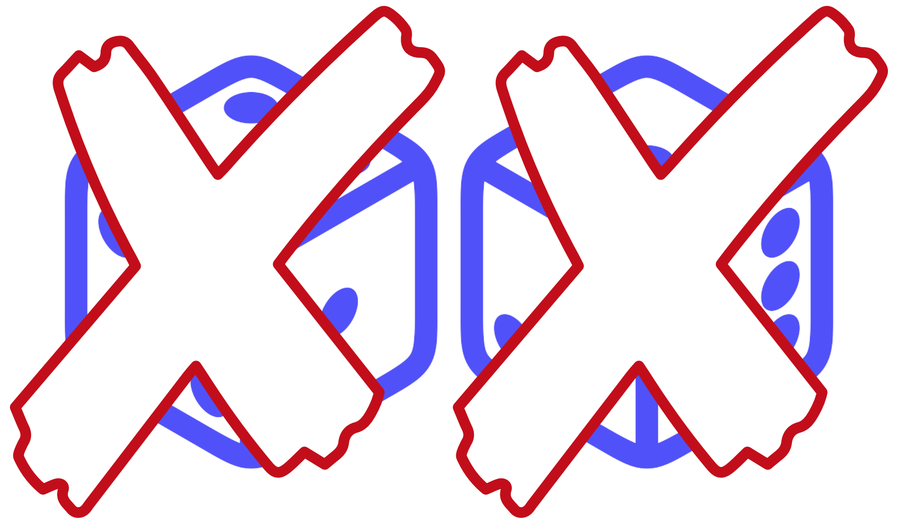
BGP Best Path Selection

BGP Best Path Selection Algorithm

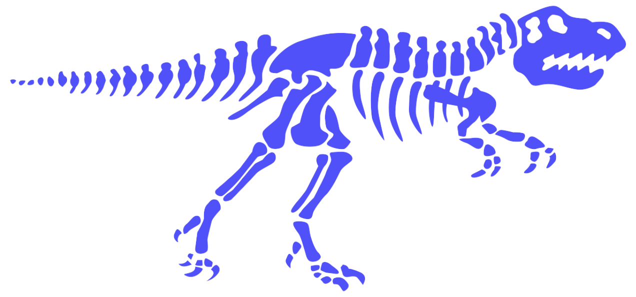
Motivation

1

- Only one single path for each destination is needed (and wanted)
- Decision must be based on attributes
- And must not be random, but deterministic

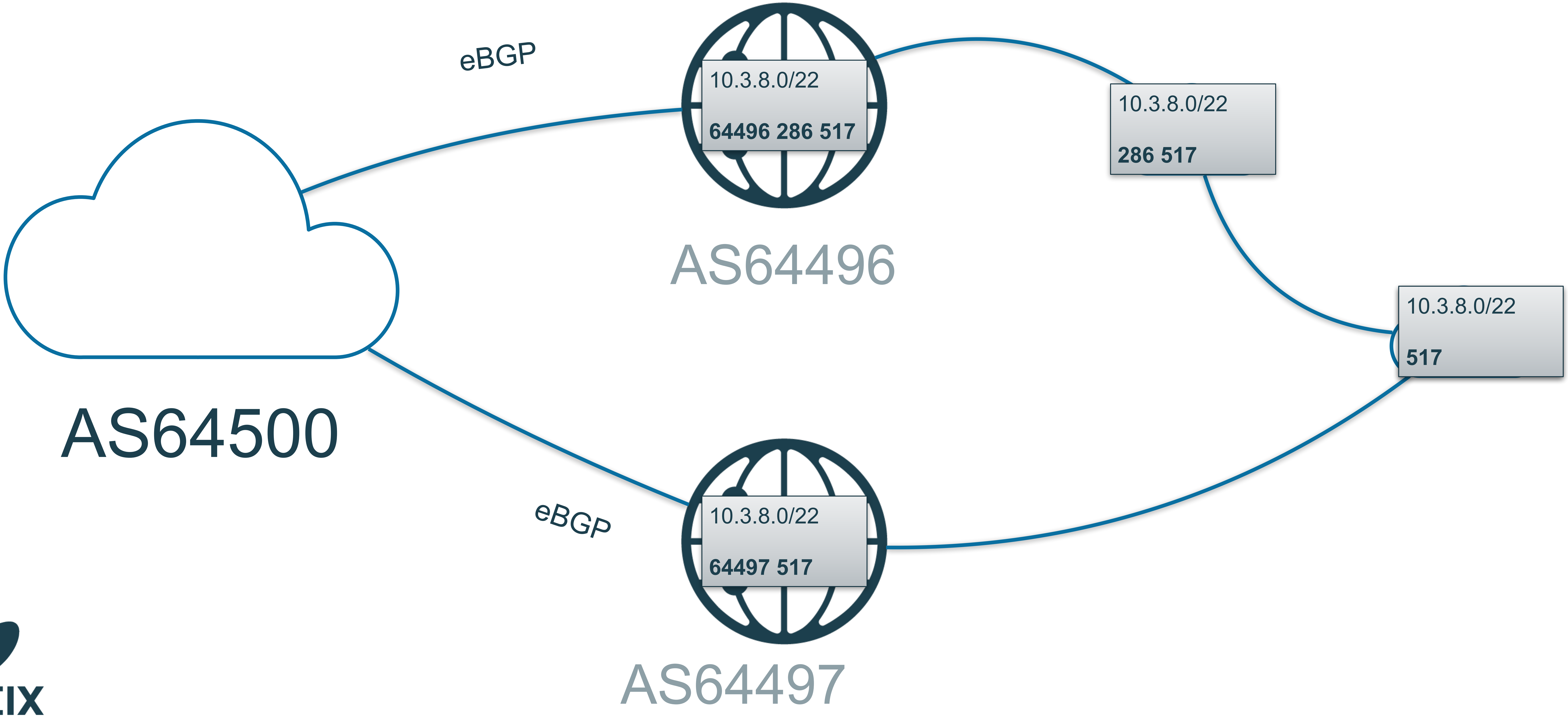


- Some of the criteria will sound strange
- Some are really outdated

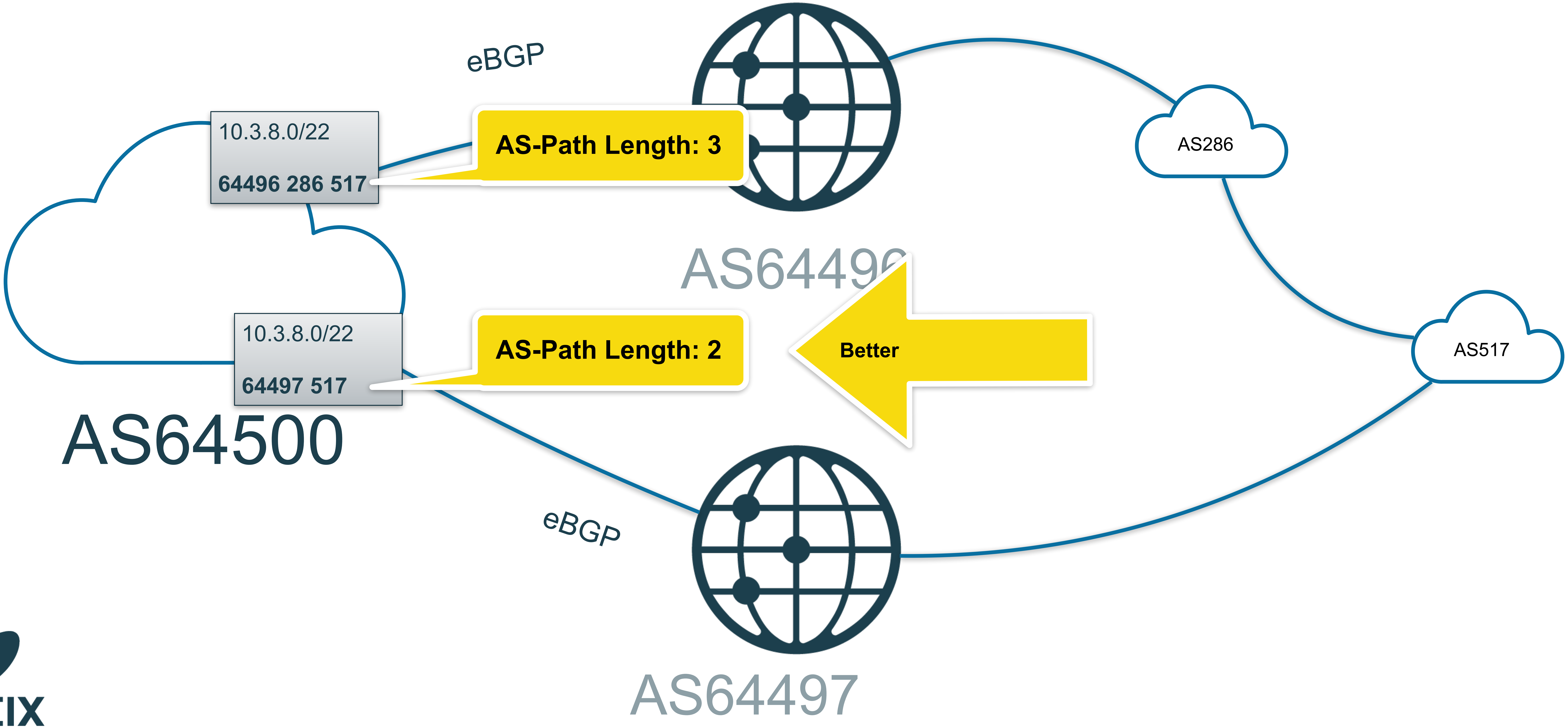


- So lets have a look how this works...

Let's get started.... with two upstreams



Let's get started.... with two upstreams



10.3.8.0/22

64496 286 517

AS-Path Length: 3

10.3.8.0/22

64497 517

AS-Path Length: 2

Better

BGP Best Path Selection

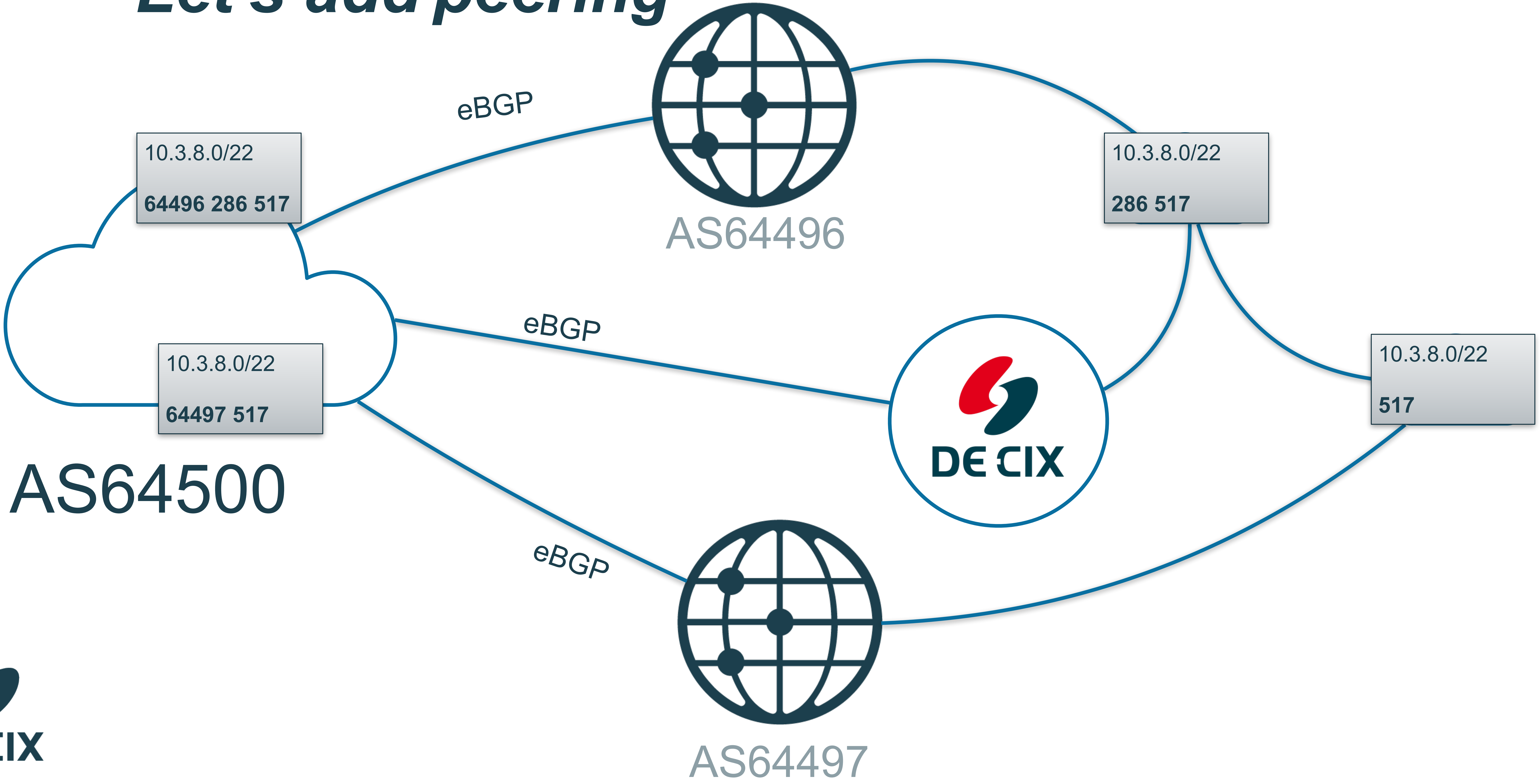
1	NextHop reachable?	Continue if "yes"
2		
3		
4		
5		
6		
7		
8		
9		
10		

AS-Path Length: 3

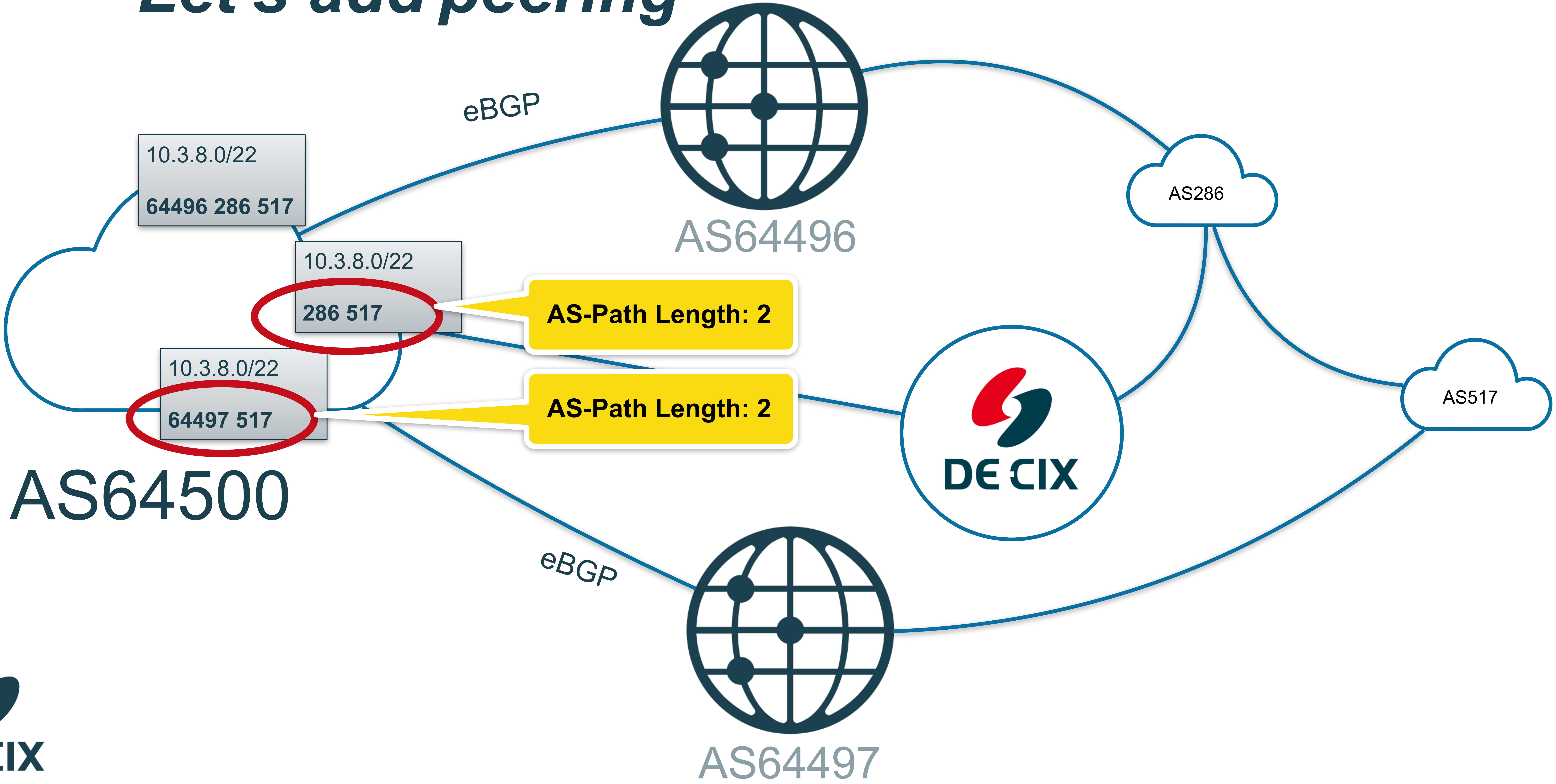
AS-Path Length: 2

Better

Let's add peering



Let's add peering



BGP Best Path Selection

1	NextHop reachable?	Continue if "yes"
2		
3	AS Path Length	shorter wins
4		
5		
6		
7		
8		
9		
10		

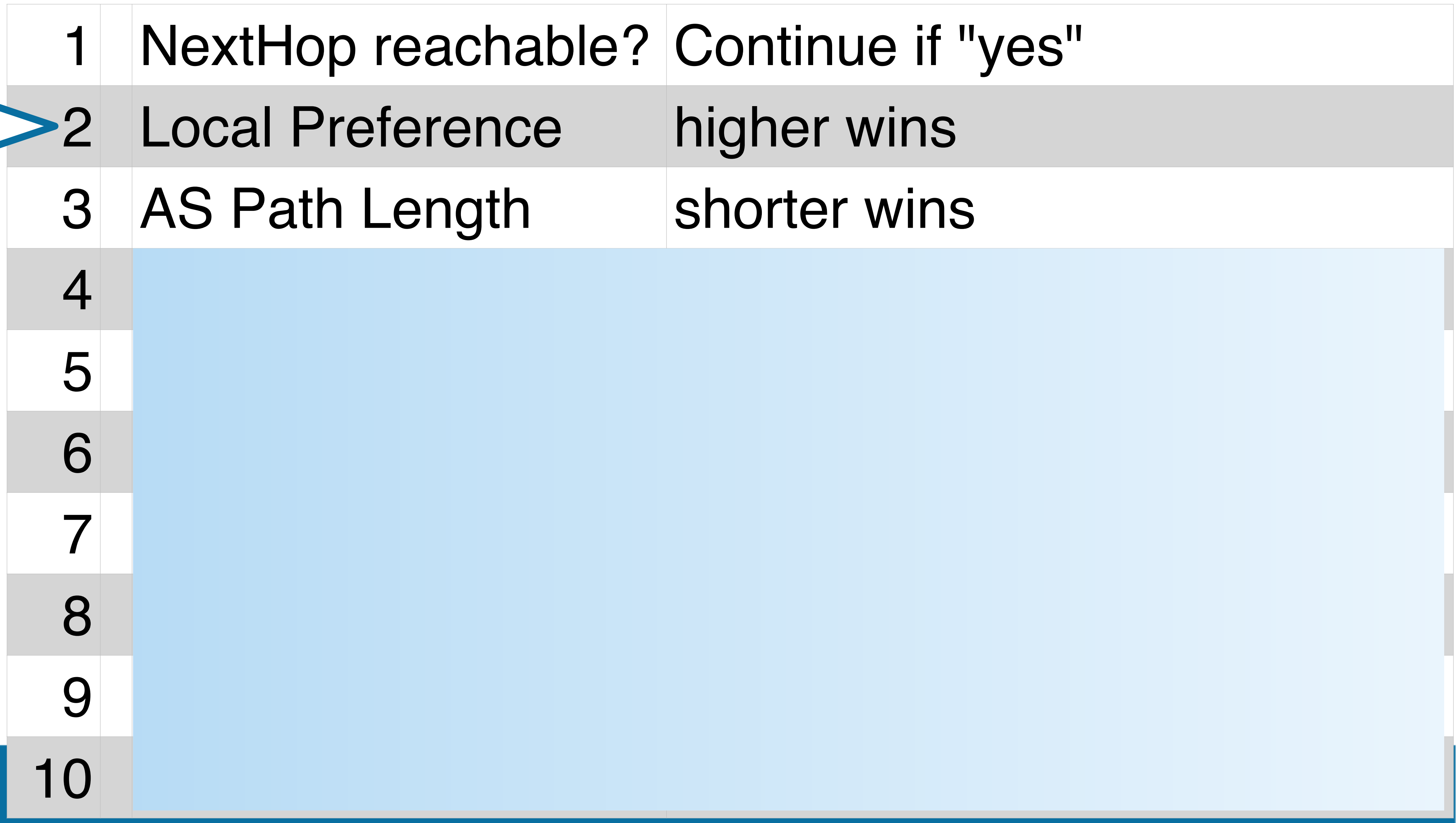
AS-Path Length: 2

AS-Path Length: 2

Local Preference

Why am I not using "100" here?

- Higher wins
- Integer value (32bit, 0-4294967295)
- Propagated via iBGP inside an Autonomous System
- Usually set using rules when receiving prefixes
- Typical values:
  - Customer prefixes: 10000
  - Peering prefixes: 1000
  - Upstream prefixes: 10



1	NextHop reachable?	Continue if "yes"
2	Local Preference	higher wins
3	AS Path Length	shorter wins
4		
5		
6		
7		
8		
9		
10		

BGP Route Selection: Origin Type

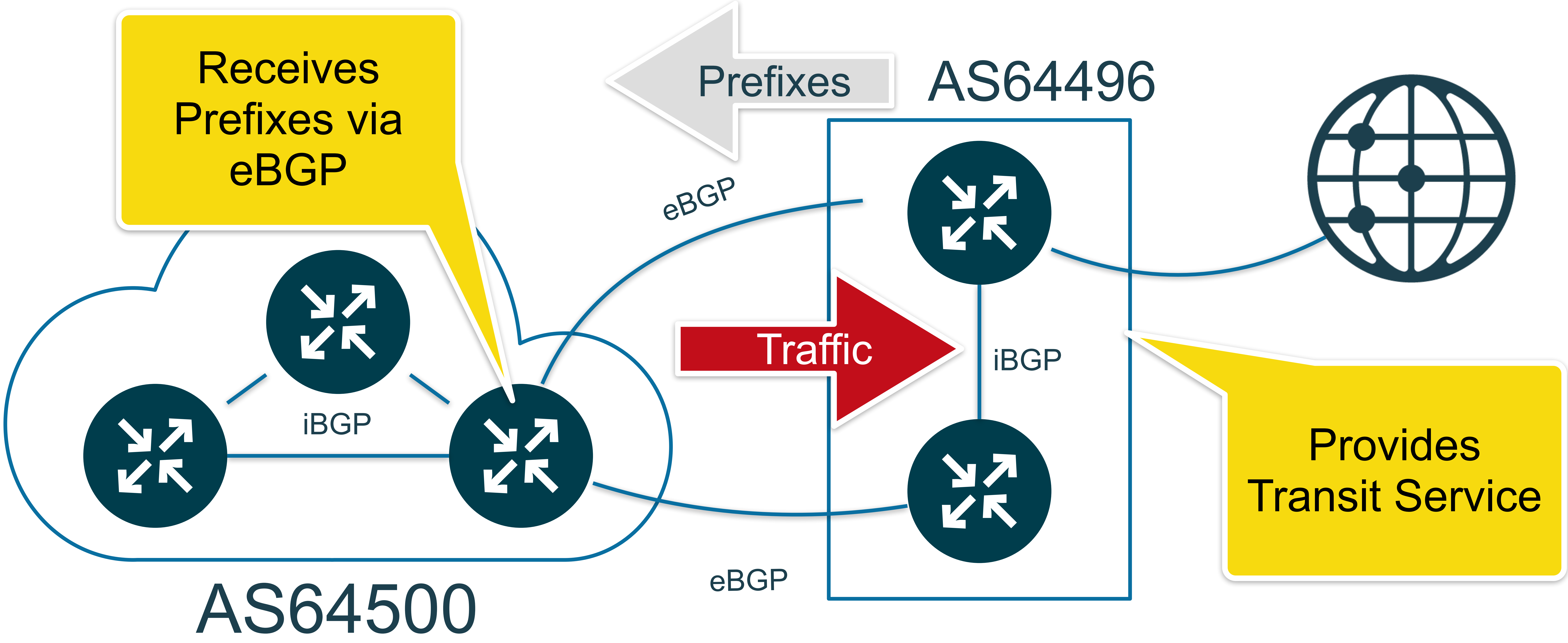
- Origin Type is a "historical" attribute
- Three possible values:
  - IGP - route is generated by BGP network statement - **"i"**
  - EGP - route is received from EGP - **"e"**
  - incomplete - redistributed from another protocol -
    "?" as the "real source" is unknown
- ***This rule is not really important***
- Fun fact: There are prefixed in the global routing table marked "e"

Exterior **G**ateway **P**rotocol

Predecessor of BGP which is no longer used

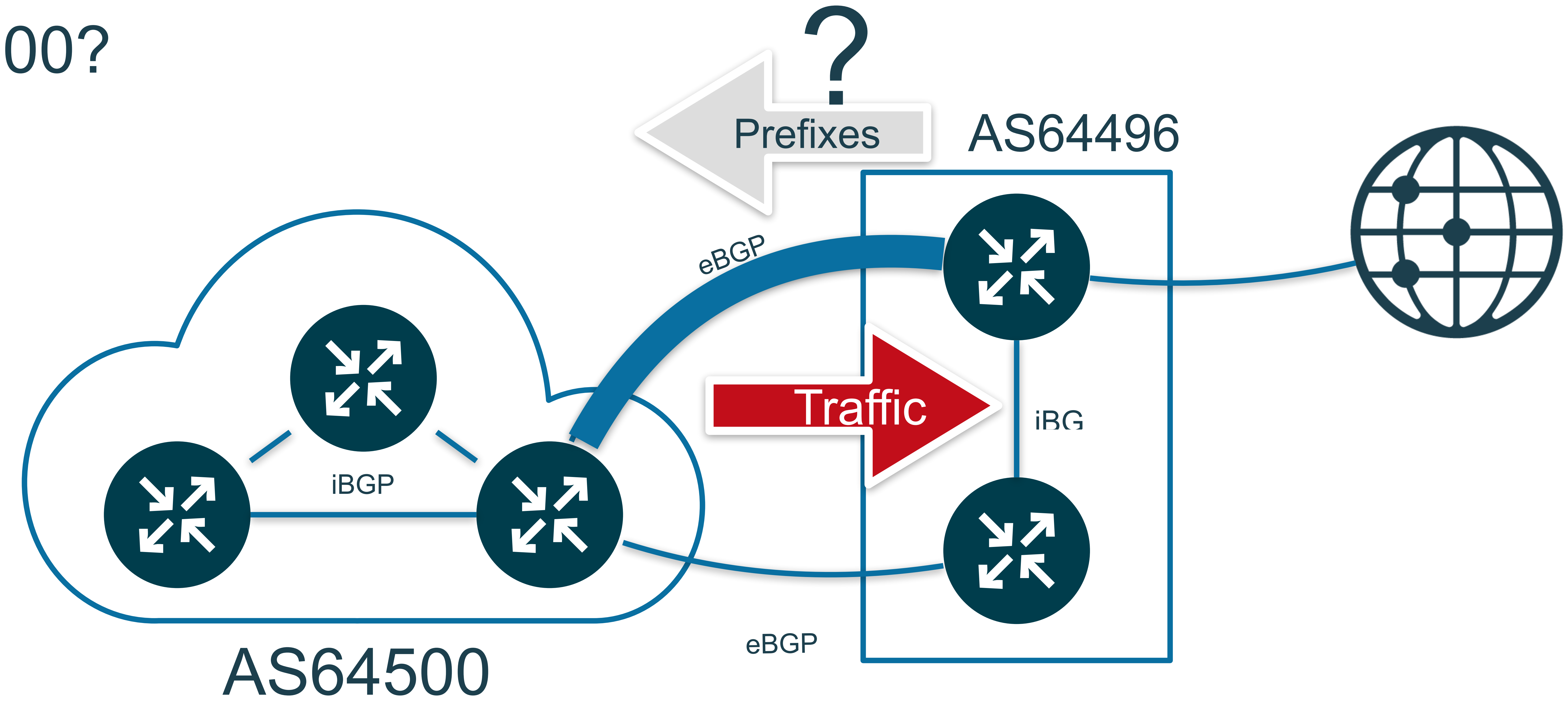
1	NextHop reachable?	Continue if "yes"
2	Local Preference	higher wins
3	AS Path Length	shorter wins
4		
5		
6		
7		
8		
9		
10		

Consider the following network



Consider the following network

- There are two circuits
- AS64496 wants one of them preferred
- How to tell AS64500?

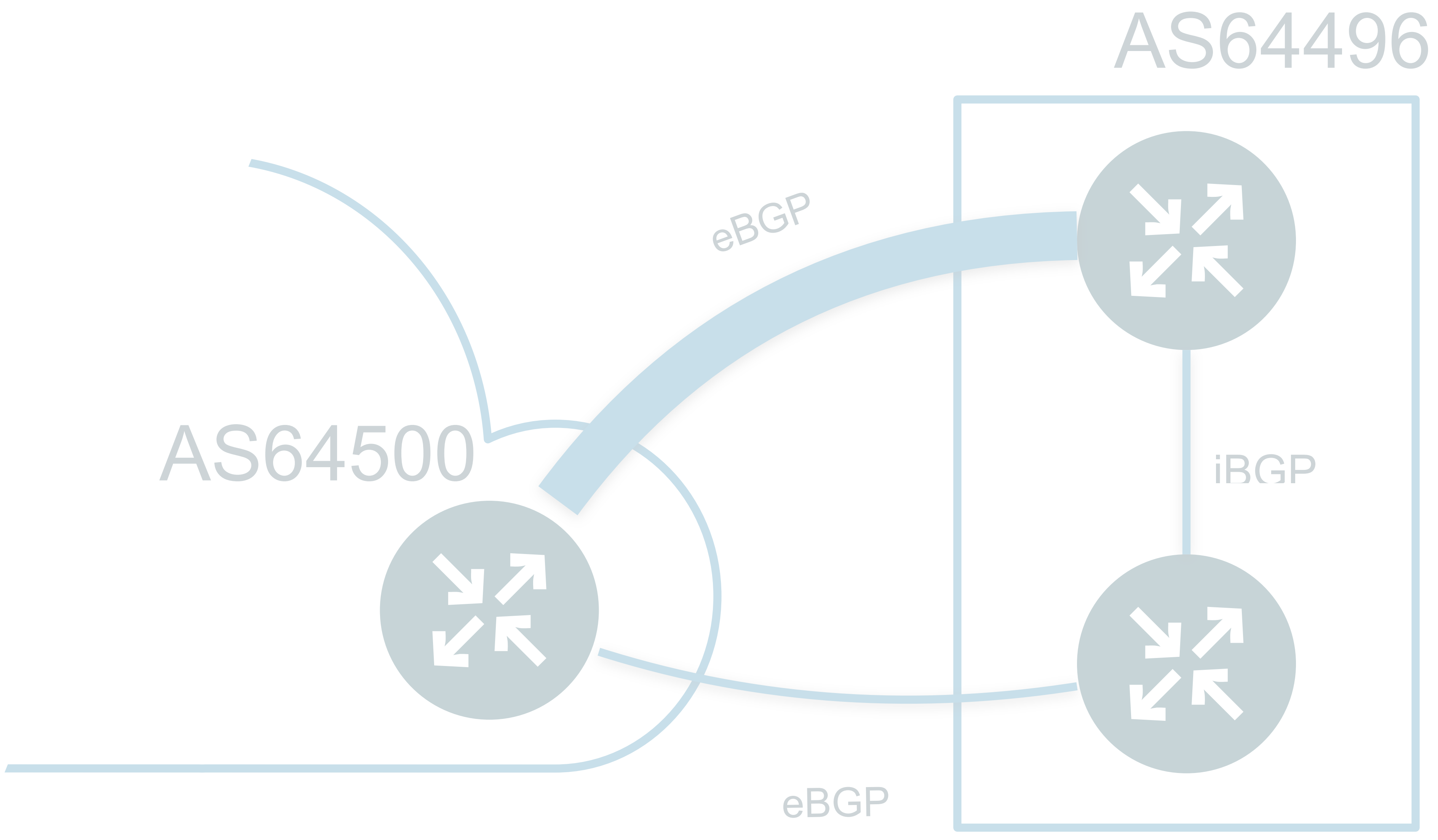


BGP Route Selection Algorithm:

How to tell your neighbor where you prefer traffic?

1	NextHop reachable?	Continue if "yes"
2	Local Preference	higher wins
3	AS Path Length	shorter wins
4	Origin Type	IGP over EGP over Incomplete
5		
6		
7		
8		
9		
10		

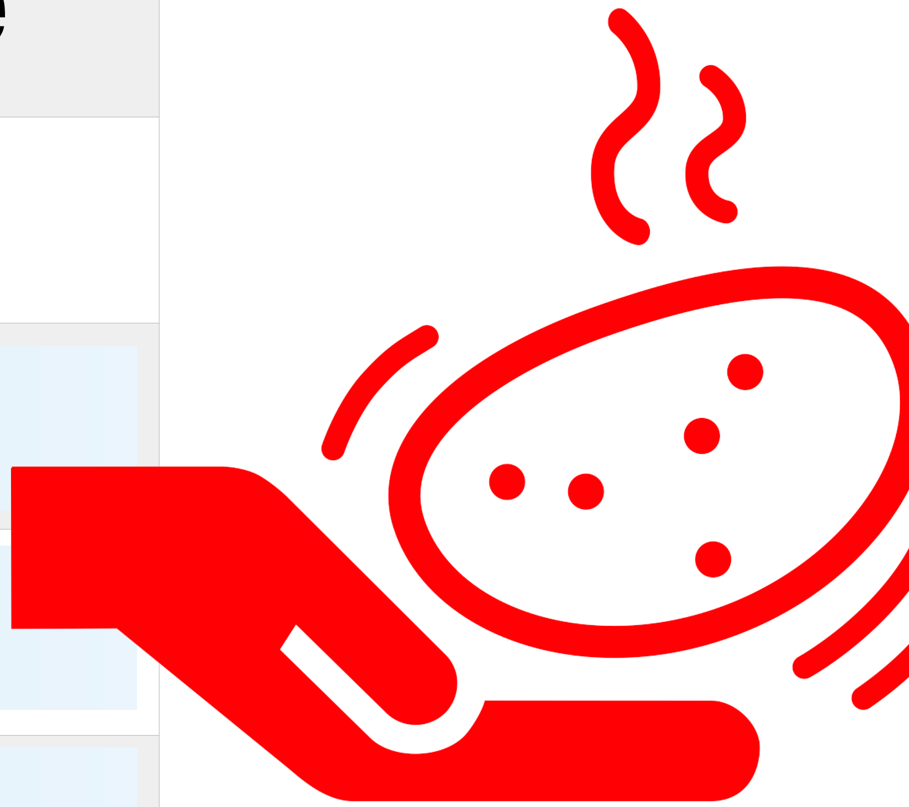
BGP Route Selection Algorithm: MED



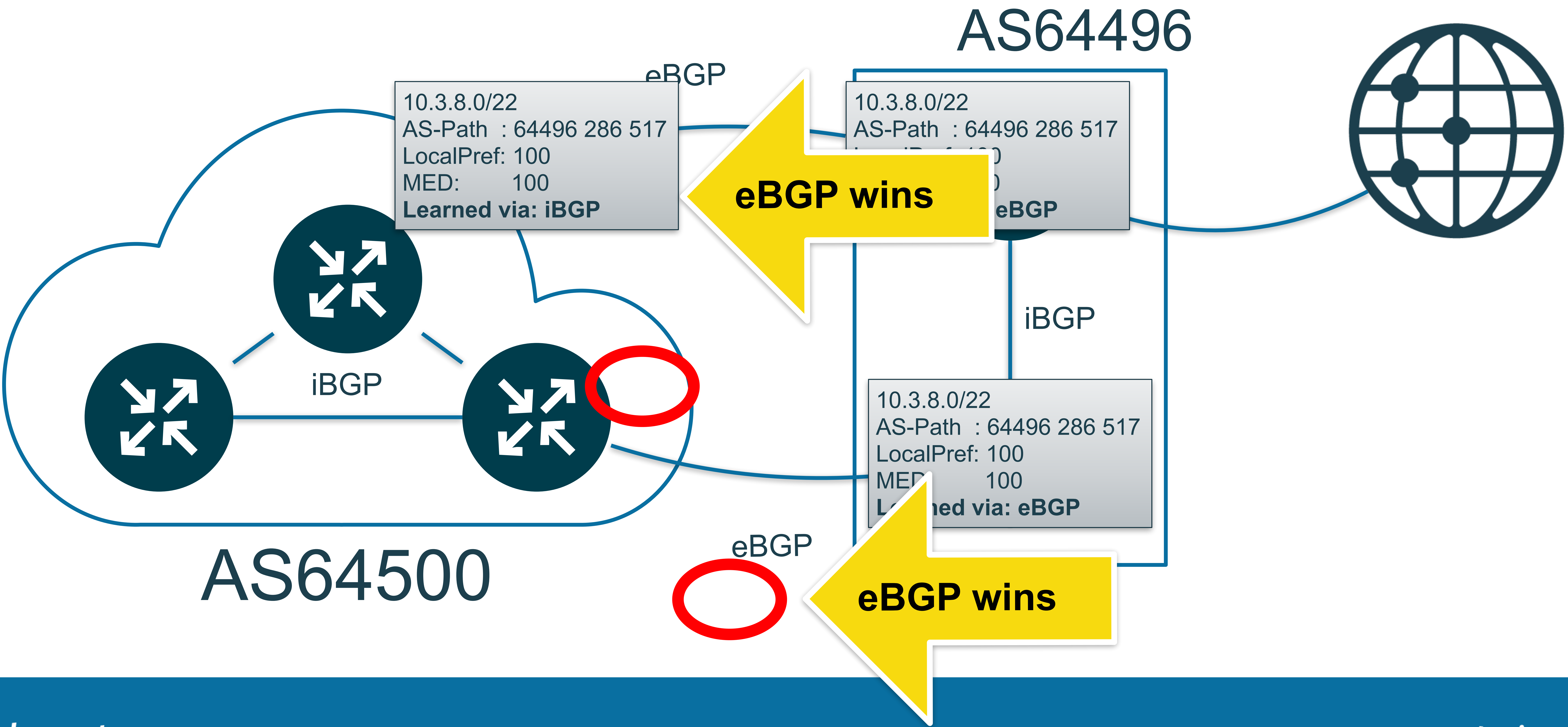
- → MED = **M**ulti-**E**xit **D**iscriminator
- → Only compared if next-hop AS is the same
- → 32bit value (0..4294967294)
- → Lower wins
- → Optional (does not have to be there), non-transitive (does not get forwarded)
- → A missing MED can be treated as "best" (=0, default) or "worst" (=4294967294)
- → And of course you can override whatever you receive

BGP Route Selection : Hot Potato Rules

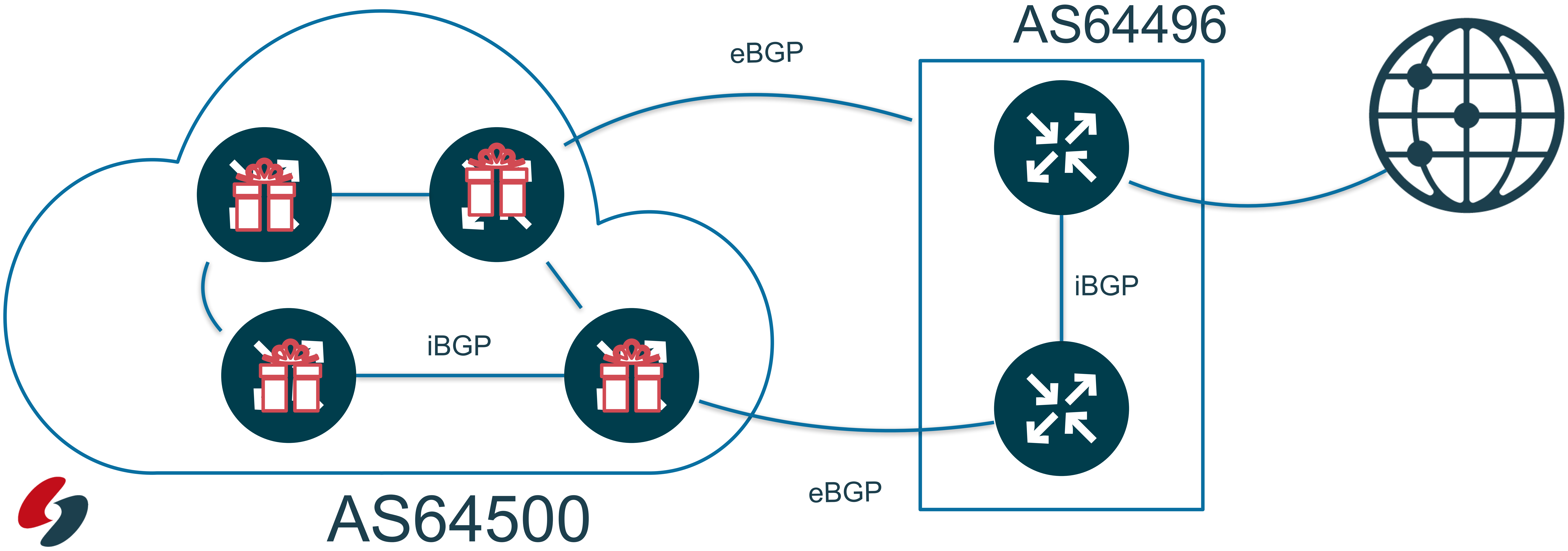
1	NextHop reachable?	Continue if "yes"
2	Local Preference	higher wins
3	AS Path Length	shorter wins
4	Origin Type	IGP over EGP over Incomplete
5	MED	lower wins
6		
7		
8		
9		
10		



BGP Route Selection : eBGP wins



BGP Route Selection : nearest exit wins

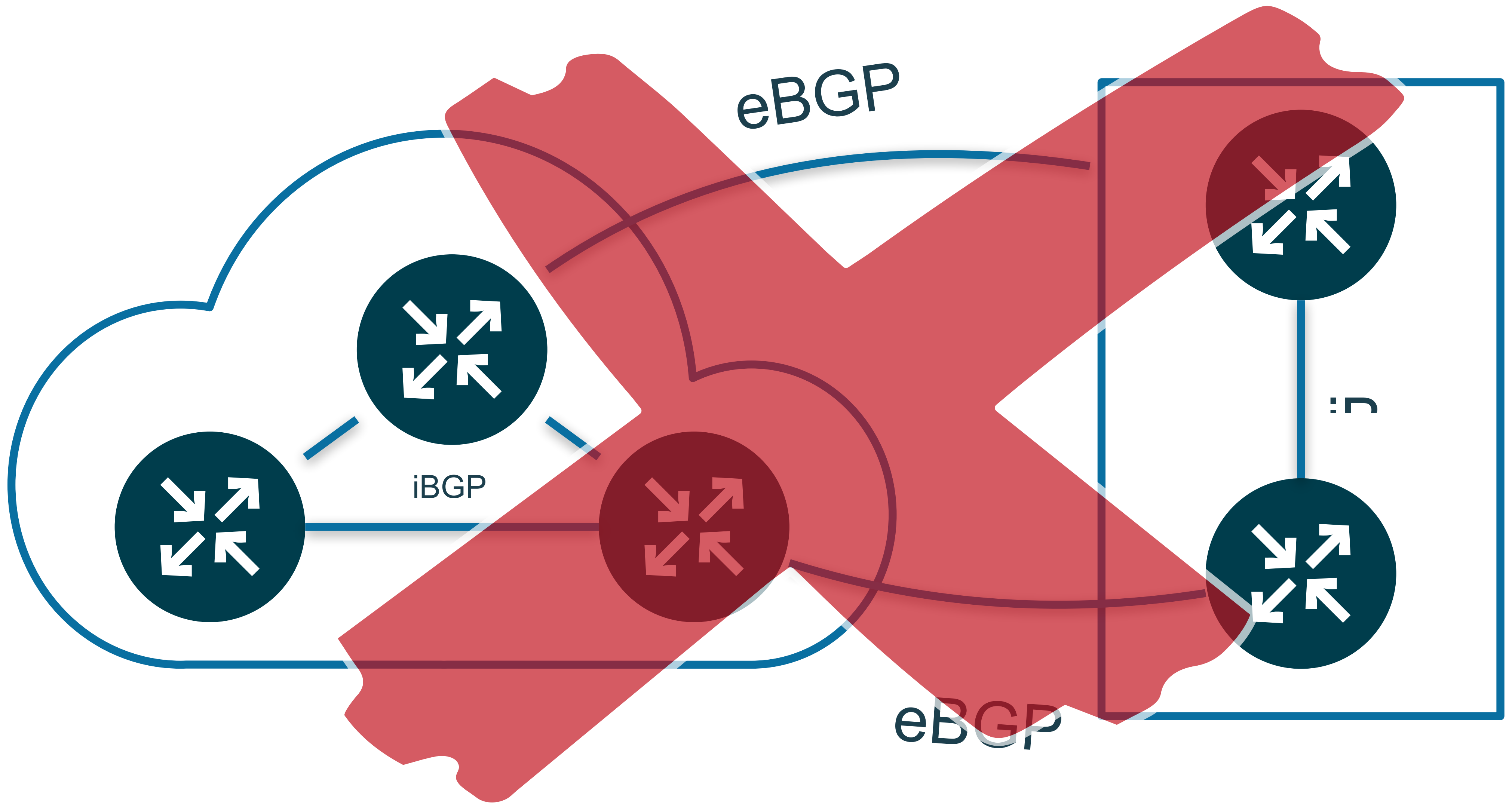


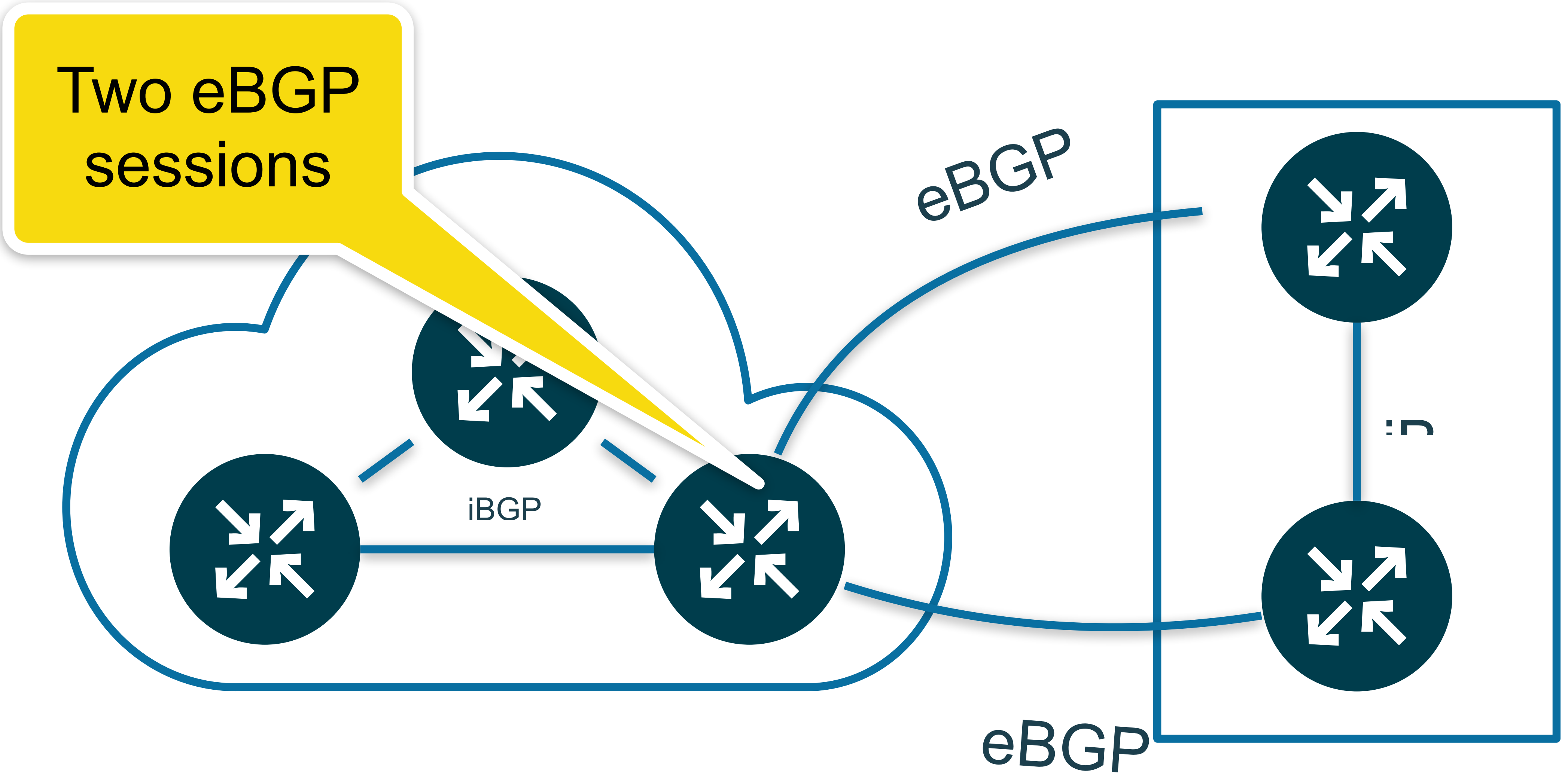
BGP Route Selection : Age / Stability

1	NextHop reachable?	Continue if "yes"
2	Local Preference	higher wins
3	AS Path Length	shorter wins
4	Origin Type	IGP over EGP over Incomplete
5	MED	lower wins
6	eBGP, iBGP	eBGP wins
7	Exit	nearest wins
8		
9		
10		

BGP Route Selection : Age / Stability

- → Exact phrasing is (Cisco):
  "When both paths are external, prefer the path that was received first"
- → So this applies only if a router has two (or more) eBGP sessions
- → Which happens quite often when connecting to Internet Exchanges




Two eBGP sessions

BGP Route Selection : Last Resort

1	NextHop reachable?	Continue if "yes"
2	Local Preference	higher wins
3	AS Path Length	shorter wins
4	Origin Type	IGP over EGP over Incomplete
5	MED	lower wins
6	eBGP, iBGP	eBGP wins
7	Exit	nearest wins
8	Age of route	older wins
9		
10		

BGP Route Selection : Last Resort

- → Router ID: lower wins
- → Neighbor IP: lower wins
- → Rules of last resort
- → ...because at the end one and only one best path has to be selected
- → Usually path selection stops before it gets to these two rules.

1	NextHop reachable?	Continue if "yes"
2	Local Preference	higher wins
3	AS Path Length	shorter wins
4	Origin Type	IGP over EGP over Incomplete
5	MED	lower wins
6	eBGP, iBGP	eBGP wins
7	Exit	nearest wins
8	Age of route	older wins
9	Router ID	lower wins
10	Neighbor IP	lower wins

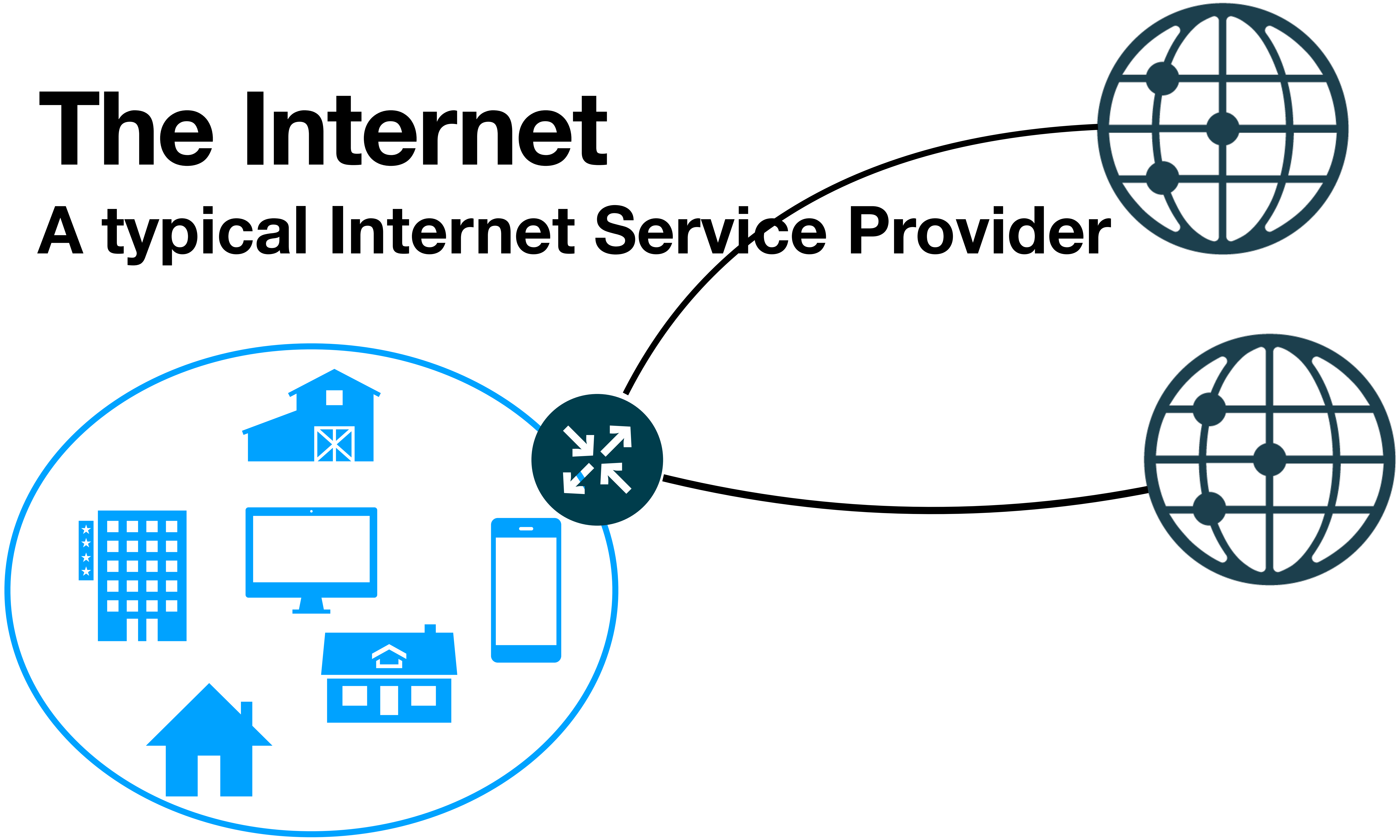
BGP Route Selection : Summary

1	NextHop reachable?	Continue if "yes"
2	Local Preference	higher wins
3	AS Path Length	shorter wins
4	Origin Type	IGP over EGP over Incomplete
5	MED	lower wins
6	eBGP, iBGP	eBGP wins
7	Exit	nearest wins
8	Age of route	older wins
9	Router ID	lower wins
10	Neighbor IP	lower wins

Network relationships

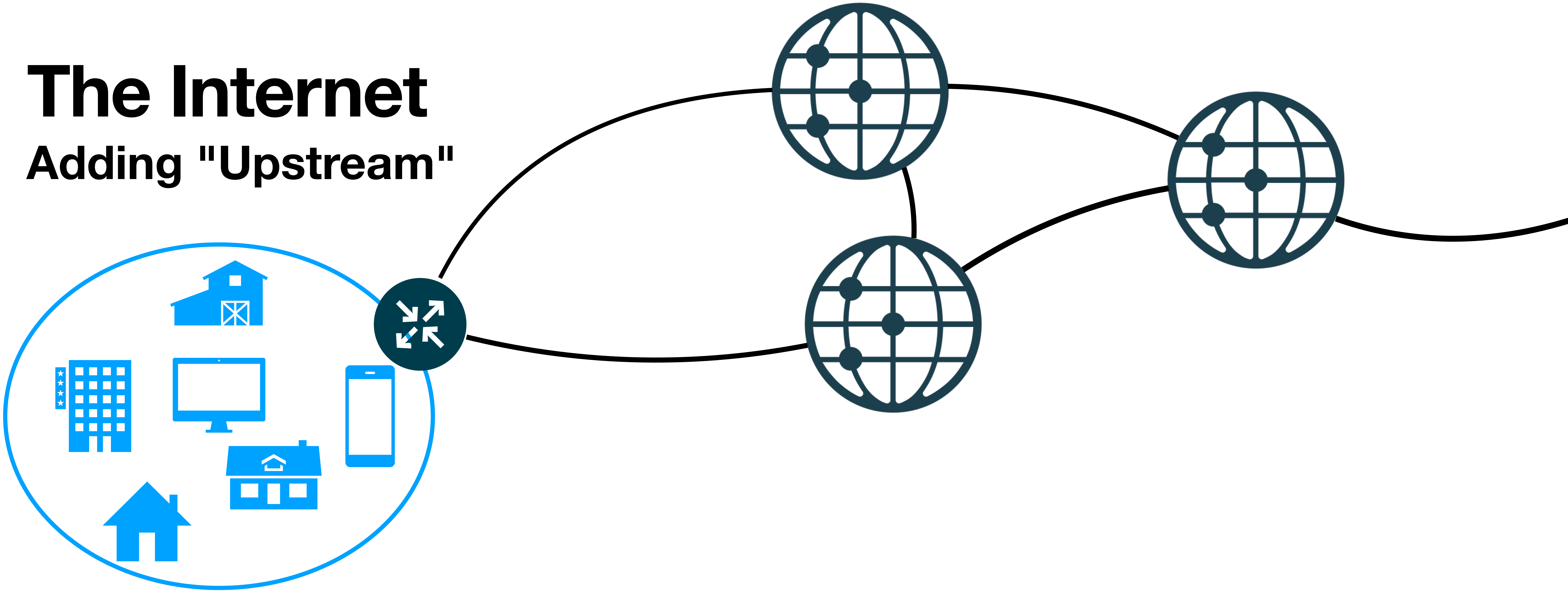
The Internet

A typical Internet Service Provider



The Internet

Adding "Upstream"



The Internet

Adding a 2nd ISP

DE-CIX

The Internet

Data transport via upstreams

The Internet

More direct via "peering"

The Internet

Peering on multiple levels

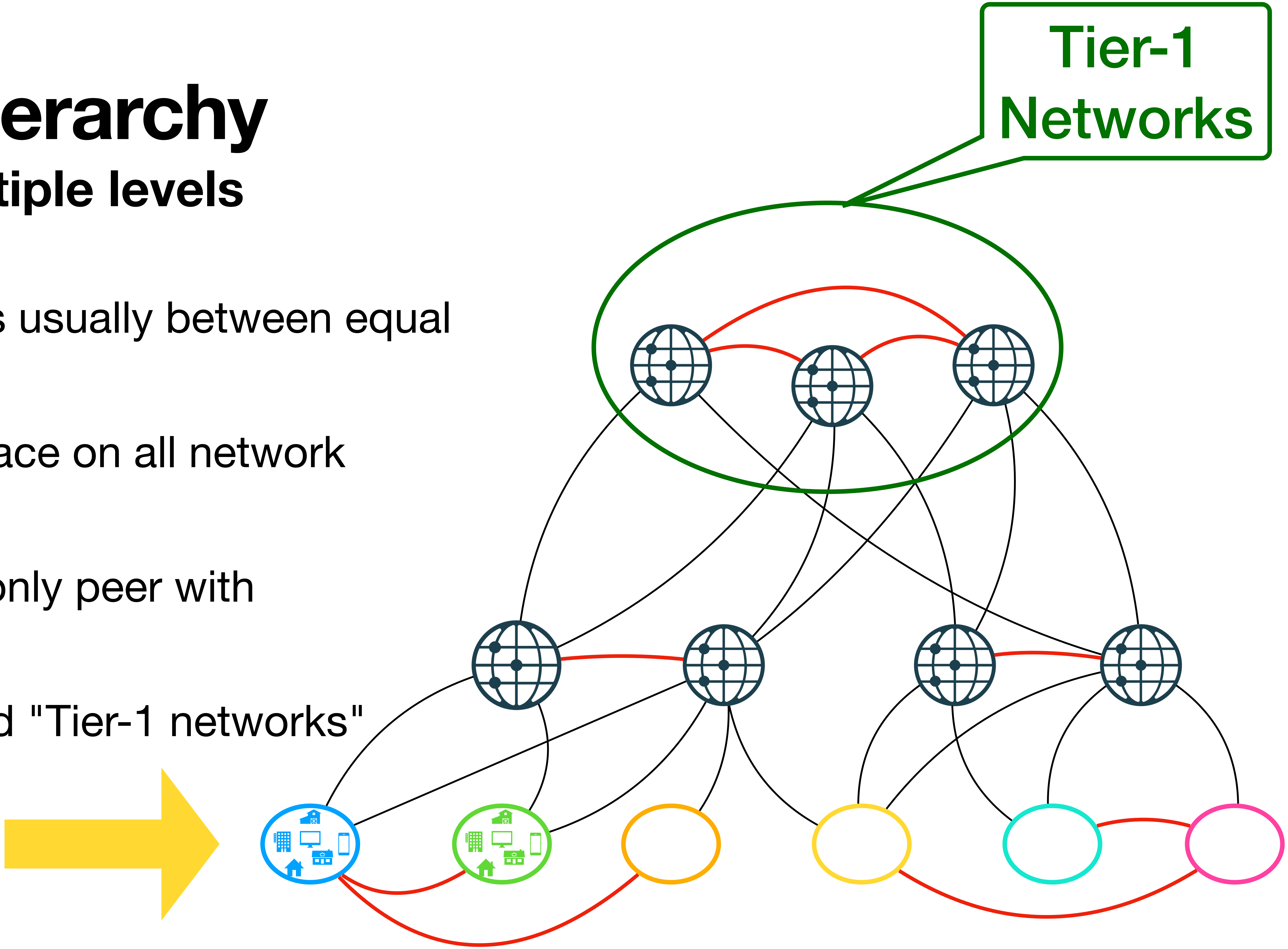
The Internet

Peering on multiple levels

Peering Hierarchy

Peering on multiple levels

- Peering happens usually between equal size networks
- Peering takes place on all network levels
- The "top ones" only peer with each other
    - They are called "Tier-1 networks"

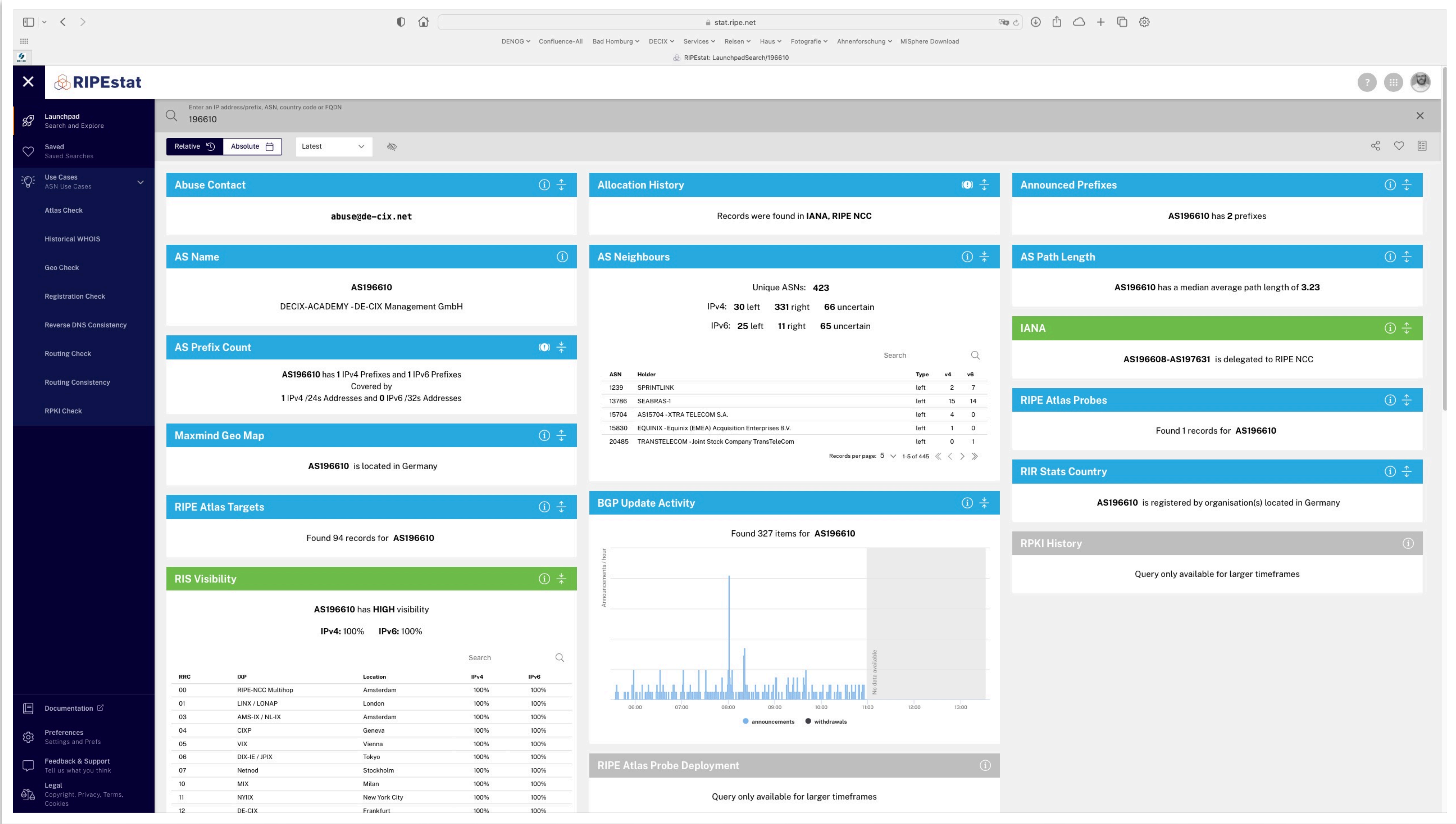


Public tools for BGP

Public tools for BGP

RIPE Stat

- Operated by the RIPE NCC (same entity handing out AS numbers in this region)
- Details about prefixes, ASes and more
- just check it out at https://stat.ripe.net



Enter an IP address/prefix, ASN, country code or FQDN: 196610

Abuse Contact

abuse@de-cix.net

AS Name

AS196610
DECIX-ACADEMY -DE-CIX Management GmbH

AS Prefix Count

AS196610 has 1 IPv4 Prefixes and 1 IPv6 Prefixes
Covered by
1 IPv4 /24s Addresses and 0 IPv6 /32s Addresses

Maxmind Geo Map

AS196610 is located in Germany

RIPE Atlas Targets

Found 94 records for AS196610

RIS Visibility

AS196610 has HIGH visibility

IPv4: 100% IPv6: 100%

RRC	IXP	Location	IPv4	IPv6
00	RIPE-NCC Multihop	Amsterdam	100%	100%
01	LINX / LONAP	London	100%	100%
03	AMS-IX / NL-IX	Amsterdam	100%	100%
04	CIXP	Geneva	100%	100%
05	VIX	Vienna	100%	100%
06	DIX-IE / JPIX	Tokyo	100%	100%
07	Netnod	Stockholm	100%	100%
10	MIX	Milan	100%	100%
11	NYIIX	New York City	100%	100%
12	DE-CIX	Frankfurt	100%	100%

Allocation History

Records were found in IANA, RIPE NCC

AS Neighbours

Unique ASNs: 423
IPv4: 30 left 331 right 66 uncertain
IPv6: 25 left 11 right 65 uncertain

ASN	Holder	Type	v4	v6
1239	SPRINTLINK	left	2	7
13786	SEABRAS-1	left	15	14
15704	AS15704 -XTRA TELECOM S.A.	left	4	0
15830	EQUINIX -Equinix (EMEA) Acquisition Enterprises B.V.	left	1	0
20485	TRANSTELECOM -Joint Stock Company TransTeleCom	left	0	1

Records per page: 5 1-5 of 445

BGP Update Activity

Found 327 items for AS196610

RIPE Atlas Probe Deployment

Query only available for larger timeframes

Announced Prefixes

AS196610 has 2 prefixes

AS Path Length

AS196610 has a median average path length of 3.23

IANA

AS196608-AS197631 is delegated to RIPE NCC

RIPE Atlas Probes

Found 1 records for AS196610

RIR Stats Country

AS196610 is registered by organisation(s) located in Germany

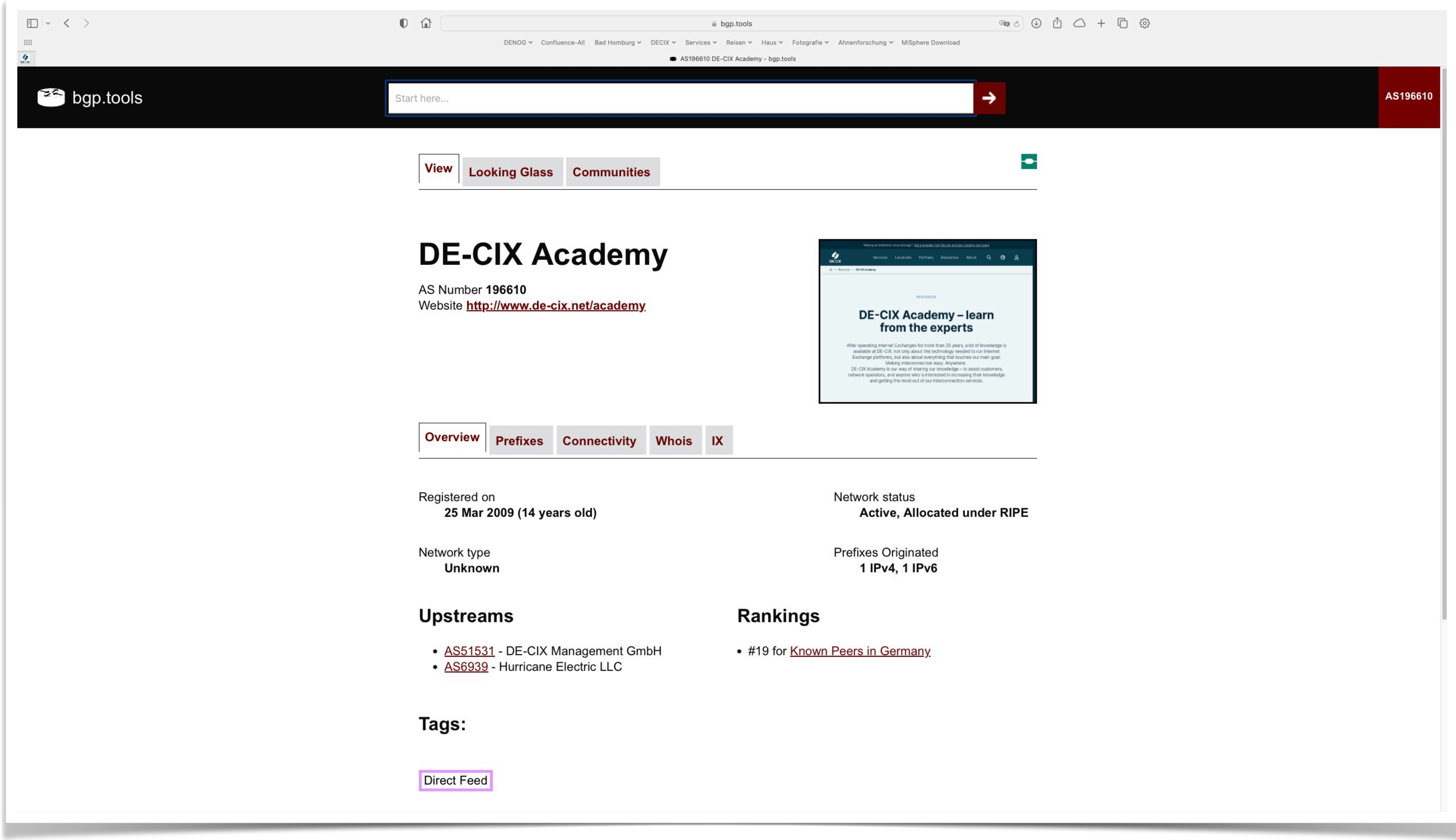
RPKI History

Query only available for larger timeframes

Public tools for BGP

bgp.tools

- Private initiative
- Free, offer premium monitoring service for a fee
- just check it out at https://bgp.tools



DE-CIX Academy

AS Number **196610**
Website http://www.de-cix.net/academy

DE-CIX Academy – learn from the experts

Registered on
25 Mar 2009 (14 years old)

Network status
Active, Allocated under RIPE

Network type
Unknown

Prefixes Originated
1 IPv4, 1 IPv6

Upstreams

- AS51531 - DE-CIX Management GmbH
- AS6939 - Hurricane Electric LLC

Rankings

- #19 for Known Peers in Germany

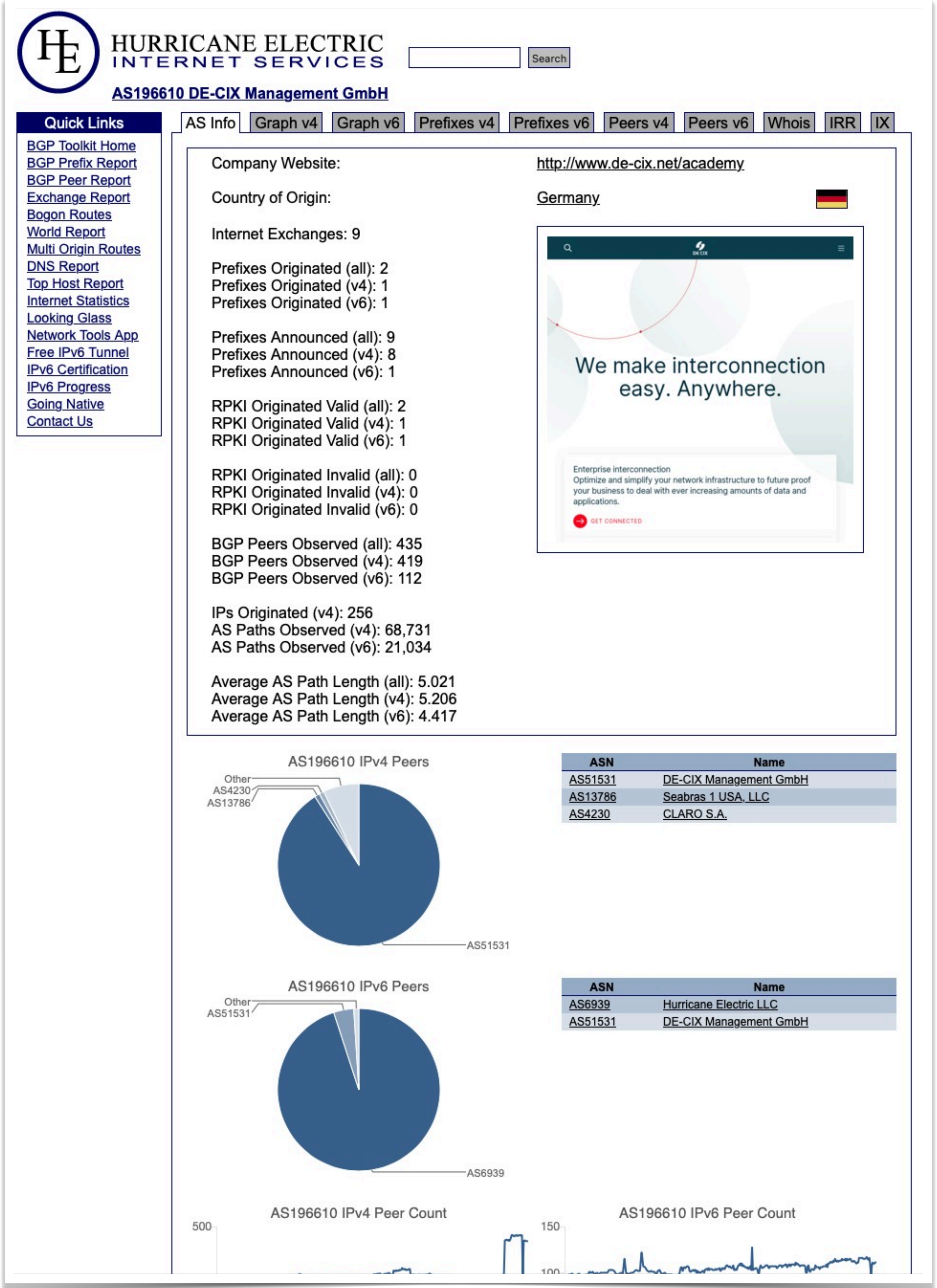
Tags:

Direct Feed

Public tools for BGP

bgp.he.net

- Operated by Hurricane Electric (he.net)
- Free, but shows only HEs point of view
- just check it out at https://bgp.he.net



Company Website: http://www.de-cix.net/academy

Country of Origin: Germany

Internet Exchanges: 9

Prefixes Originated (all): 2
Prefixes Originated (v4): 1
Prefixes Originated (v6): 1

Prefixes Announced (all): 9
Prefixes Announced (v4): 8
Prefixes Announced (v6): 1

RPKI Originated Valid (all): 2
RPKI Originated Valid (v4): 1
RPKI Originated Valid (v6): 1

RPKI Originated Invalid (all): 0
RPKI Originated Invalid (v4): 0
RPKI Originated Invalid (v6): 0

BGP Peers Observed (all): 435
BGP Peers Observed (v4): 419
BGP Peers Observed (v6): 112

IPs Originated (v4): 256
AS Paths Observed (v4): 68,731
AS Paths Observed (v6): 21,034

Average AS Path Length (all): 5.021
Average AS Path Length (v4): 5.206
Average AS Path Length (v6): 4.417

Enterprise interconnection
Optimize and simplify your network infrastructure to future proof your business to deal with ever increasing amounts of data and applications.

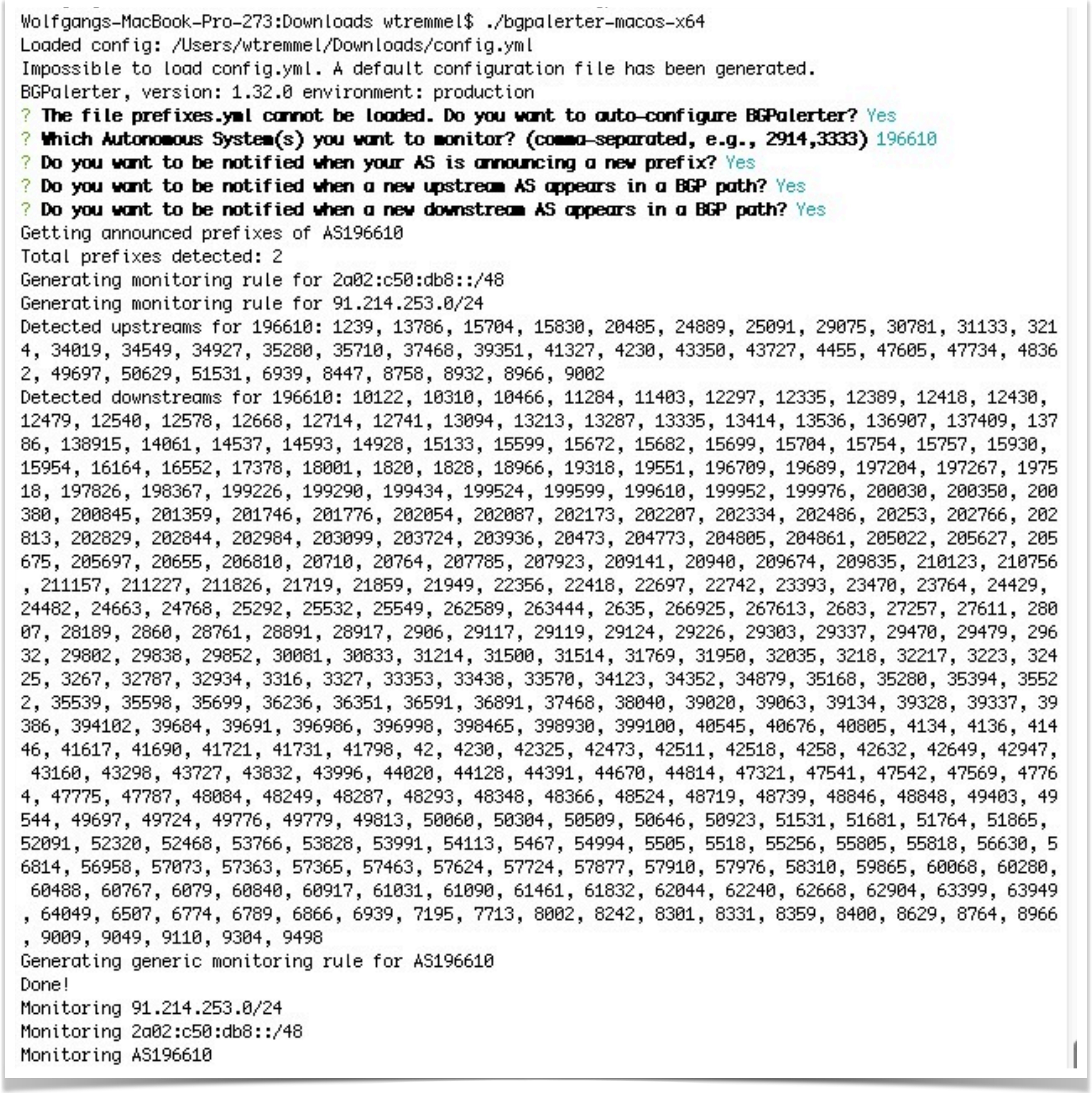
ASN	Name
AS51531	DE-CIX Management GmbH
AS13786	Seabras 1 USA, LLC
AS4230	CLARO S.A.

ASN	Name
AS6939	Hurricane Electric LLC
AS51531	DE-CIX Management GmbH

Public tools for BGP

BGP Alerter

- Open source tool running locally
- Using data from public datasets
  - like ris.ripe.net
- Get the source or a precompiled binary from https://github.com/nttgin/BGPalerter



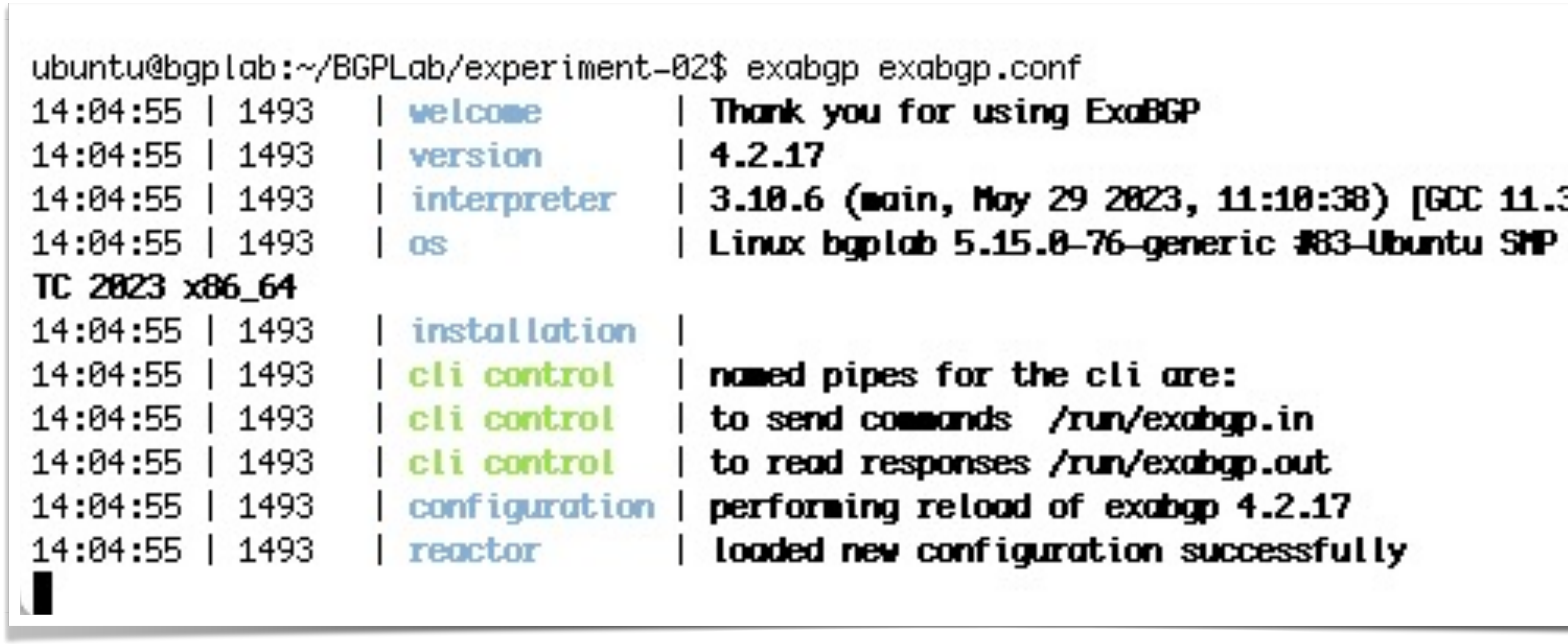
```
Wolfgangs-MacBook-Pro-273:Downloads wtremmel$ ./bgpalerter-macos-x64
Loaded config: /Users/wtremmel/Downloads/config.yml
Impossible to load config.yml. A default configuration file has been generated.
BGPalerter, version: 1.32.0 environment: production
? The file prefixes.yml cannot be loaded. Do you want to auto-configure BGPalerter? Yes
? Which Autonomous System(s) you want to monitor? (comma-separated, e.g., 2914,3333) 196610
? Do you want to be notified when your AS is announcing a new prefix? Yes
? Do you want to be notified when a new upstream AS appears in a BGP path? Yes
? Do you want to be notified when a new downstream AS appears in a BGP path? Yes
Getting announced prefixes of AS196610
Total prefixes detected: 2
Generating monitoring rule for 2a02:c50:db8::/48
Generating monitoring rule for 91.214.253.0/24
Detected upstreams for 196610: 1239, 13786, 15704, 15830, 20485, 24889, 25091, 29075, 30781, 31133, 321
4, 34019, 34549, 34927, 35280, 35710, 37468, 39351, 41327, 4230, 43350, 43727, 4455, 47605, 47734, 4836
2, 49697, 50629, 51531, 6939, 8447, 8758, 8932, 8966, 9002
Detected downstreams for 196610: 10122, 10310, 10466, 11284, 11403, 12297, 12335, 12389, 12418, 12430,
12479, 12540, 12578, 12668, 12714, 12741, 13094, 13213, 13287, 13335, 13414, 13536, 136907, 137409, 137
86, 138915, 14061, 14537, 14593, 14928, 15133, 15599, 15672, 15682, 15699, 15704, 15754, 15757, 15930,
15954, 16164, 16552, 17378, 18001, 1820, 1828, 18966, 19318, 19551, 196709, 19689, 197204, 197267, 1975
18, 197826, 198367, 199226, 199290, 199434, 199524, 199599, 199610, 199952, 199976, 200030, 200350, 200
380, 200845, 201359, 201746, 201776, 202054, 202087, 202173, 202207, 202334, 202486, 20253, 202766, 202
813, 202829, 202844, 202984, 203099, 203724, 203936, 20473, 204773, 204805, 204861, 205022, 205627, 205
675, 205697, 20655, 206810, 20710, 20764, 207785, 207923, 209141, 20940, 209674, 209835, 210123, 210756
, 211157, 211227, 211826, 21719, 21859, 21949, 22356, 22418, 22697, 22742, 23393, 23470, 23764, 24429,
24482, 24663, 24768, 25292, 25532, 25549, 262589, 263444, 2635, 266925, 267613, 2683, 27257, 27611, 280
07, 28189, 2860, 28761, 28891, 28917, 2906, 29117, 29119, 29124, 29226, 29303, 29337, 29470, 29479, 296
32, 29802, 29838, 29852, 30081, 30833, 31214, 31500, 31514, 31769, 31950, 32035, 3218, 32217, 3223, 324
25, 3267, 32787, 32934, 3316, 3327, 33353, 33438, 33570, 34123, 34352, 34879, 35168, 35280, 35394, 3552
2, 35539, 35598, 35699, 36236, 36351, 36591, 36891, 37468, 38040, 39020, 39063, 39134, 39328, 39337, 39
386, 394102, 39684, 39691, 396986, 396998, 398465, 398930, 399100, 40545, 40676, 40805, 4134, 4136, 414
46, 41617, 41690, 41721, 41731, 41798, 42, 4230, 42325, 42473, 42511, 42518, 4258, 42632, 42649, 42947,
 43160, 43298, 43727, 43832, 43996, 44020, 44128, 44391, 44670, 44814, 47321, 47541, 47542, 47569, 4776
4, 47775, 47787, 48084, 48249, 48287, 48293, 48348, 48366, 48524, 48719, 48739, 48846, 48848, 49403, 49
544, 49697, 49724, 49776, 49779, 49813, 50060, 50304, 50509, 50646, 50923, 51531, 51681, 51764, 51865,
52091, 52320, 52468, 53766, 53828, 53991, 54113, 5467, 54994, 5505, 5518, 55256, 55805, 55818, 56630, 5
6814, 56958, 57073, 57363, 57365, 57463, 57624, 57724, 57877, 57910, 57976, 58310, 59865, 60068, 60280,
 60488, 60767, 6079, 60840, 60917, 61031, 61090, 61461, 61832, 62044, 62240, 62668, 62904, 63399, 63949
, 64049, 6507, 6774, 6789, 6866, 6939, 7195, 7713, 8002, 8242, 8301, 8331, 8359, 8400, 8629, 8764, 8966
, 9009, 9049, 9110, 9304, 9498
Generating generic monitoring rule for AS196610
Done!
Monitoring 91.214.253.0/24
Monitoring 2a02:c50:db8::/48
Monitoring AS196610
```

DE CIX

Public tools for BGP

ExaBGP

- Open source tool to "talk" BGP
- Use cases:
    - for testing or even in production
    - announce prefixes
    - with any attributes you want
    - https://github.com/Exa-Networks/exabgp



```
ubuntu@bgplab:~/BGPLab/experiment-02$ exabgp exabgp.conf
14:04:55 | 1493    | welcome       | Thank you for using ExaBGP
14:04:55 | 1493    | version       | 4.2.17
14:04:55 | 1493    | interpreter   | 3.10.6 (main, May 29 2023, 11:10:38) [GCC 11.3
14:04:55 | 1493    | os            | Linux bgplab 5.15.0-76-generic #83-Ubuntu SMP
TC 2023 x86_64
14:04:55 | 1493    | installation  |
14:04:55 | 1493    | cli control   | named pipes for the cli are:
14:04:55 | 1493    | cli control   | to send commands  /run/exabgp.in
14:04:55 | 1493    | cli control   | to read responses /run/exabgp.out
14:04:55 | 1493    | configuration | performing reload of exabgp 4.2.17
14:04:55 | 1493    | reactor       | loaded new configuration successfully
```

Public tools for BGP

DE-CIX Academy BGP lab

- For teaching a BGP seminar
- Based on FRRouting
- Runs (multiple) routers in Docker containers
- Just needs a linux server as host
- Get it at https://gitlab.com/de-cix-public/team-academy/bgp/BGPLab

Managing BGP relationships

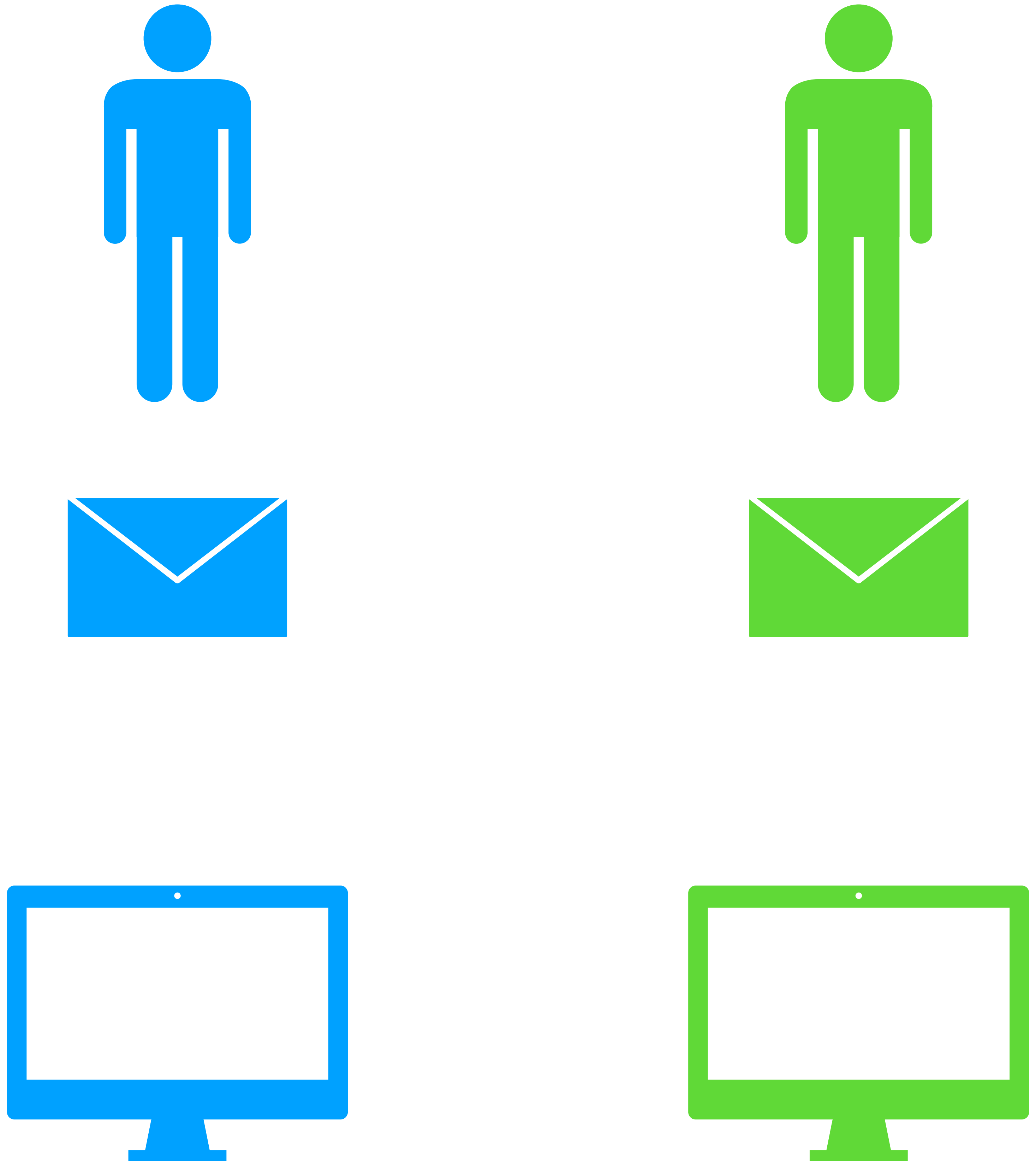
The lazy Network Manager

How to keep record of your peers

Setting up BGP sessions

Standard procedure

- Contact your neighbor
- Exchange a few emails
- Configure BGP



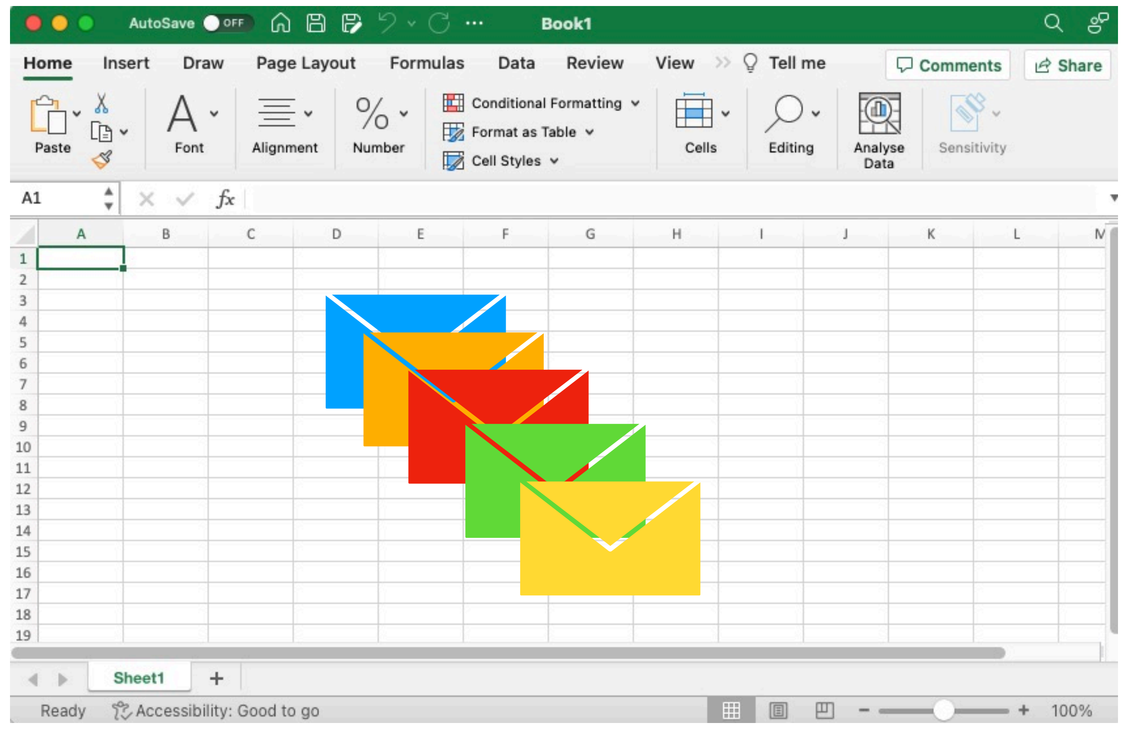
Years later...

You need to contact your neighbor

But where did I put the contact information

?

- I might have my original emails somewhere
- Or I put the contact information into an Excel sheet
- Or I configured it as a comment on my router
- Or....



But then you notice...

But then you notice...

Surprise, surprise...

- The contact you emailed with works no longer there
- The company name of your peer has changed
- The email address you have (peering@...) is no longer valid
- What now?

There is a solution

Why not have a common database?

For networks who peer...

- Put contact information into a central database
- Make it accessible for all networks who peer
- Everybody maintains their own information (hopefully)
- If you need some information, simply look it up

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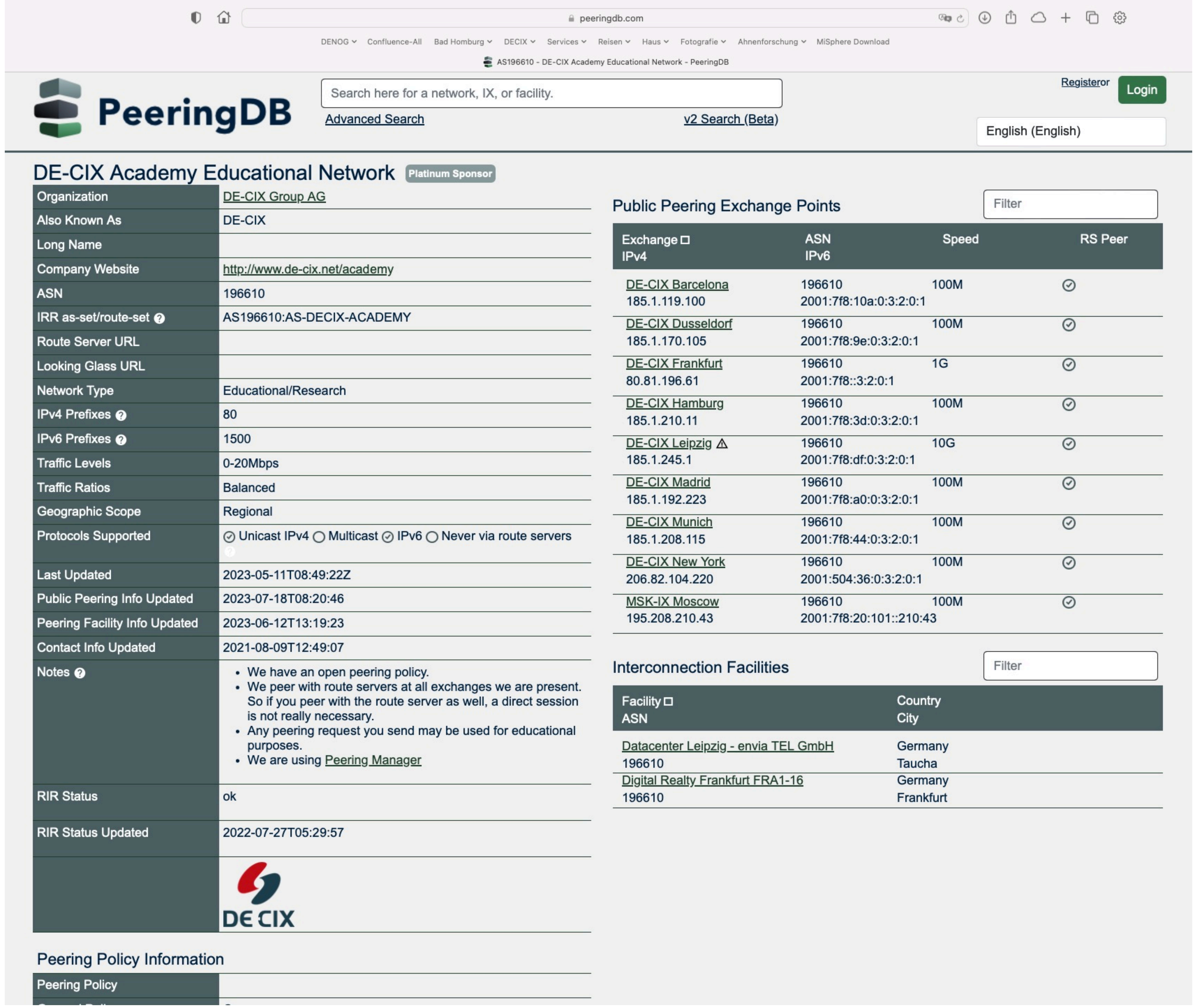
PeeringDB

A database for networks who peer

- Free for users
- Financed by sponsoring
- Some public information
- Contact data is private
- Check it out at https://peeringdb.com



DE-CIX Academy Educational Network Platinum Sponsor

Organization	DE-CIX Group AG
Also Known As	DE-CIX
Long Name	
Company Website	http://www.de-cix.net/academy
ASN	196610
IRR as-set/route-set ?	AS196610:AS-DECIX-ACADEMY
Route Server URL	
Looking Glass URL	
Network Type	Educational/Research
IPv4 Prefixes ?	80
IPv6 Prefixes ?	1500
Traffic Levels	0-20Mbps
Traffic Ratios	Balanced
Geographic Scope	Regional
Protocols Supported	✓ Unicast IPv4 ○ Multicast ✓ IPv6 ○ Never via route servers
Last Updated	2023-05-11T08:49:22Z
Public Peering Info Updated	2023-07-18T08:20:46
Peering Facility Info Updated	2023-06-12T13:19:23
Contact Info Updated	2021-08-09T12:49:07
Notes ?	• We have an open peering policy. • We peer with route servers at all exchanges we are present. So if you peer with the route server as well, a direct session is not really necessary. • Any peering request you send may be used for educational purposes. • We are using Peering Manager
RIR Status	ok
RIR Status Updated	2022-07-27T05:29:57
	DE CIX

Peering Policy Information

Peering Policy	

Public Peering Exchange Points

Filter

Exchange □ IPv4	ASN IPv6	Speed	RS Peer
DE-CIX Barcelona 185.1.119.100	196610 2001:7f8:10a:0:3:2:0:1	100M	✓
DE-CIX Dusseldorf 185.1.170.105	196610 2001:7f8:9e:0:3:2:0:1	100M	✓
DE-CIX Frankfurt 80.81.196.61	196610 2001:7f8::3:2:0:1	1G	✓
DE-CIX Hamburg 185.1.210.11	196610 2001:7f8:3d:0:3:2:0:1	100M	✓
DE-CIX Leipzig ⚠ 185.1.245.1	196610 2001:7f8:df:0:3:2:0:1	10G	✓
DE-CIX Madrid 185.1.192.223	196610 2001:7f8:a0:0:3:2:0:1	100M	✓
DE-CIX Munich 185.1.208.115	196610 2001:7f8:44:0:3:2:0:1	100M	✓
DE-CIX New York 206.82.104.220	196610 2001:504:36:0:3:2:0:1	100M	✓
MSK-IX Moscow 195.208.210.43	196610 2001:7f8:20:101::210:43	100M	✓

Interconnection Facilities

Filter

Facility □ ASN	Country City
Datacenter Leipzig - envia TEL GmbH 196610	Germany Taucha
Digital Realty Frankfurt FRA1-16 196610	Germany Frankfurt

Other versions of this presentation

BGP in 120 minutes

What we did today

- Length: 90-120 minutes
- Features:
  - me talking
  - you asking questions
- Covers:
  - The very basics of BGP
  - Up and including BGP best path selection / more depending on time

?

BGP 4-5 hour workshop

Not just the basics…

- Length: 4-5 hours, including at least one break
- Happened a number of times at workshop Sunday at DENOG
- Features:
  - Me talking
  - You asking questions
  - Limited number of **lab experiments** using FRRouting
- Covers:
  - The very basics of BGP
  - Up and including BGP best path selection
  - BGP Communities if time permits

3.5 Day BGP Seminar

All and everything

- Length: 3.5 days, starting Monday noon, finishing Thursday late afternoon,
- Classroom seminar, max. 14 attendees
- Features:
  - Me talking
  - You asking questions
  - Extensive number of lab experiments using FRRouting
- Covers:
  - All of BGP
  - Including BGP Security, Traffic Engineering, Peering Relationships
  - Tools useful for BGP and peering

BGP and Security

Protect your routing infrastructure

Reference Document on BGP Security

RFC 7454

RFC 7454

BGP Operations and Security

Abstract

The Border Gateway Protocol (BGP) is the protocol almost exclusively used in the Internet to exchange routing information between network domains. Due to this central nature, it is important to understand the security measures that can and should be deployed to prevent accidental or intentional routing disturbances.

This document describes measures to protect the BGP sessions itself such as Time to Live (TTL), the TCP Authentication Option (TCP-AO), and control-plane filtering. It also describes measures to better control the flow of routing information, using prefix filtering and automation of prefix filters, max-prefix filtering, Autonomous System (AS) path filtering, route flap dampening, and BGP community scrubbing.

Simple Measures

→Easy to implement

→Easy to maintain

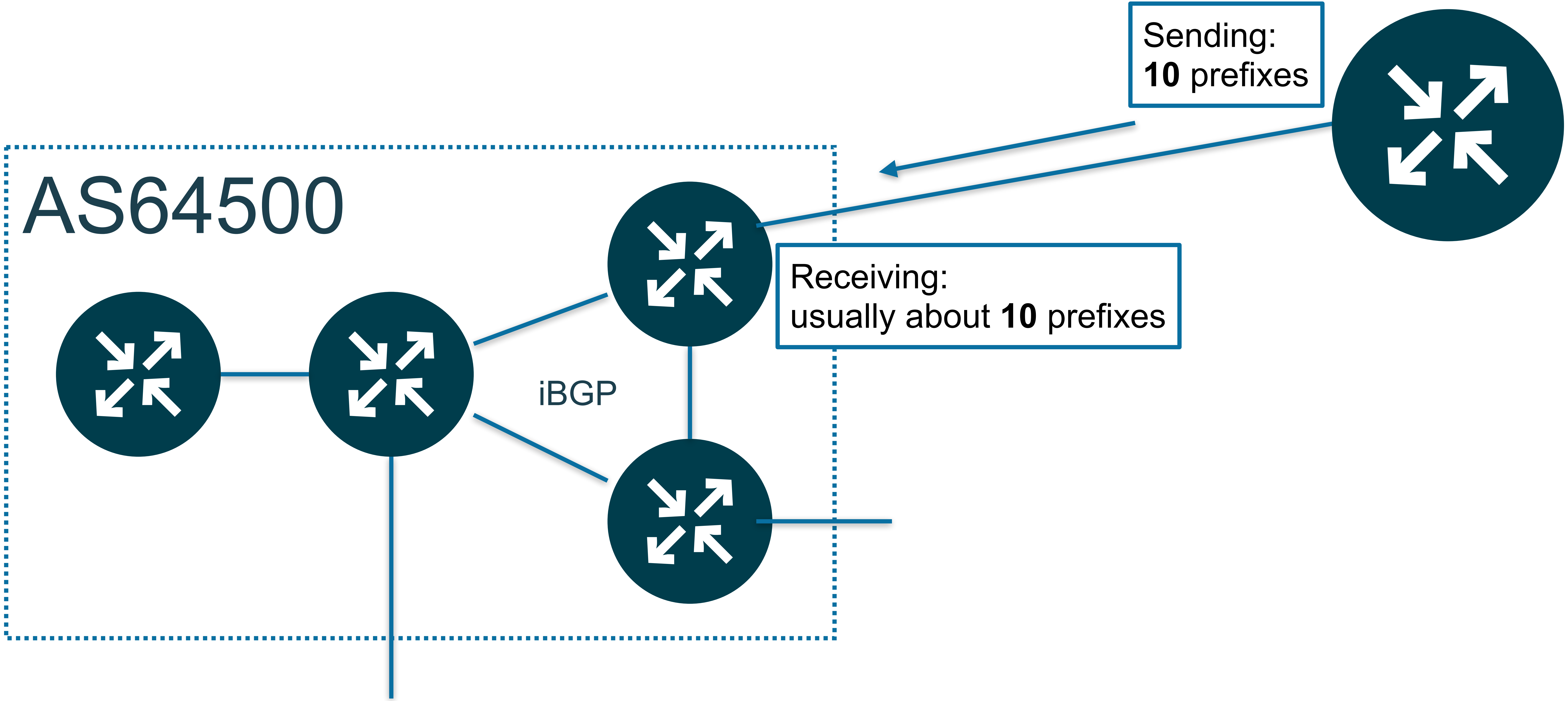
→...but only of limited use

→...still should be implemented

→List of measures:

1. **Maximum Prefix**

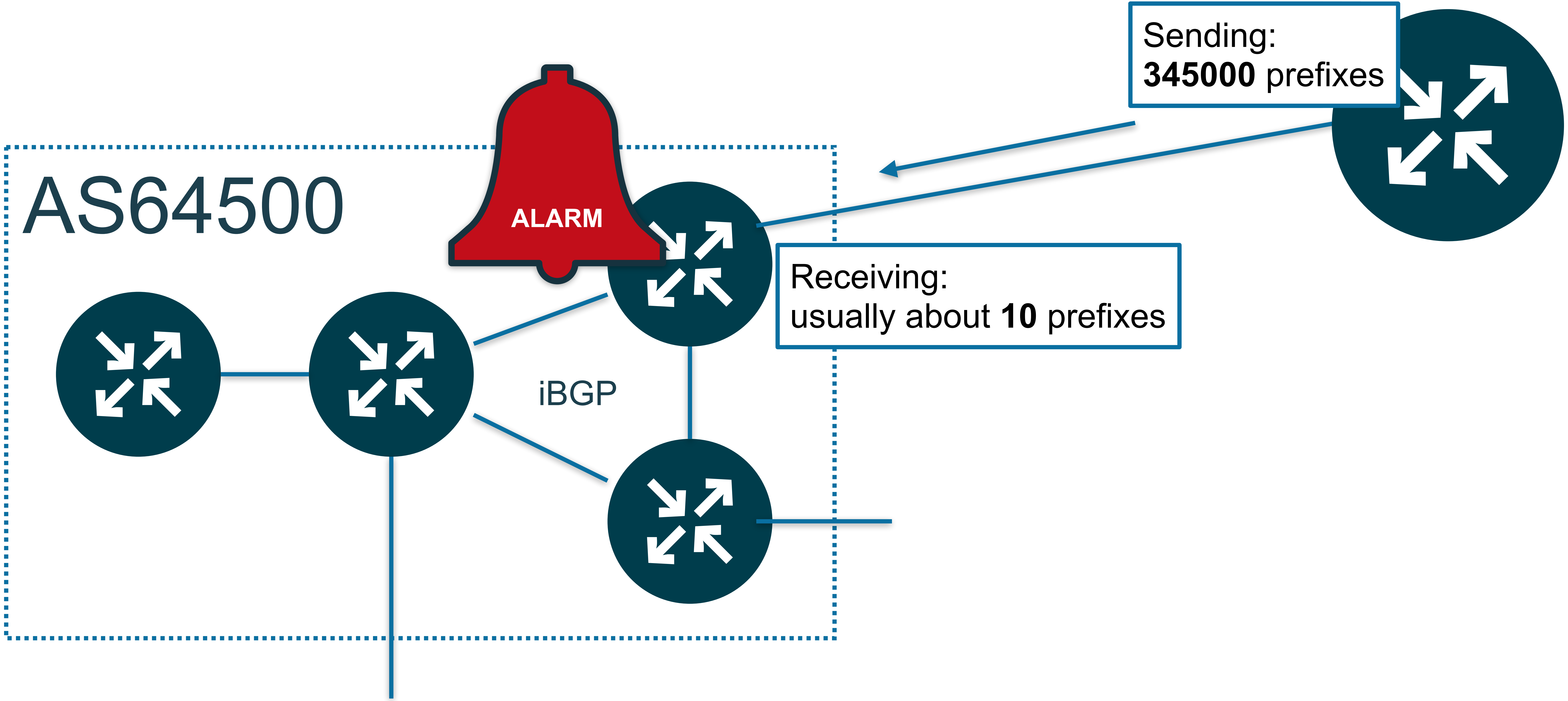
Maximum Prefix



Sending:
10 prefixes

Receiving:
usually about **10** prefixes

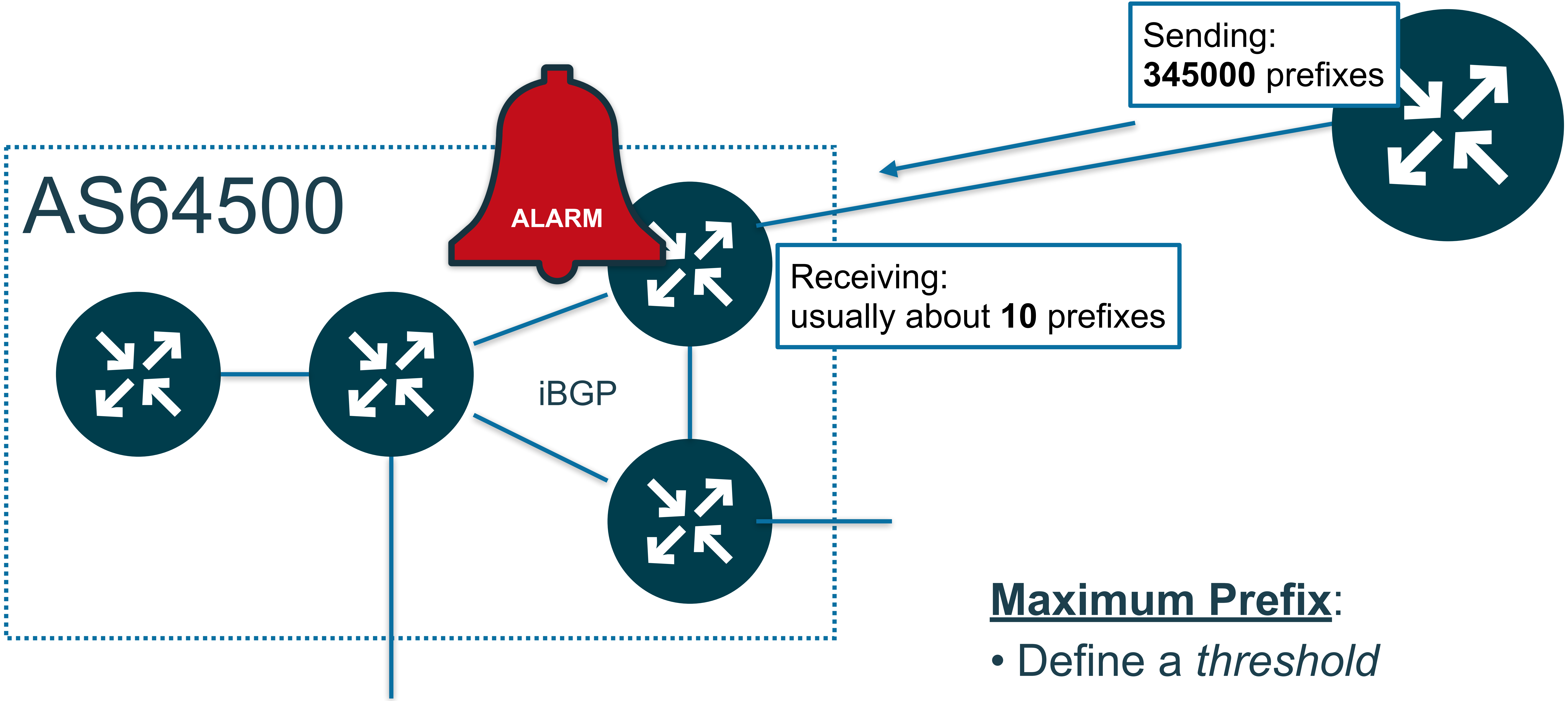
Maximum Prefix



Sending:
345000 prefixes

Receiving:
usually about **10** prefixes

Maximum Prefix



Maximum Prefix:

- Define a *threshold*
- Define an action if threshold is hit
  - Usually tear down the BGP session

Maximum Prefix

- →Good counter-measure against misconfigured peers
- →Possible actions:
  - →Tear down session (until manual intervention)
  - →Tear down and restart (after *n* minutes)
  - →Warning only
- →Best practices:
  - →Set threshold high enough (like 10* usual size)
  - →Configure a warning at 90% - so you **see** it!

Simple Measures

→Easy to implement

→Easy to maintain

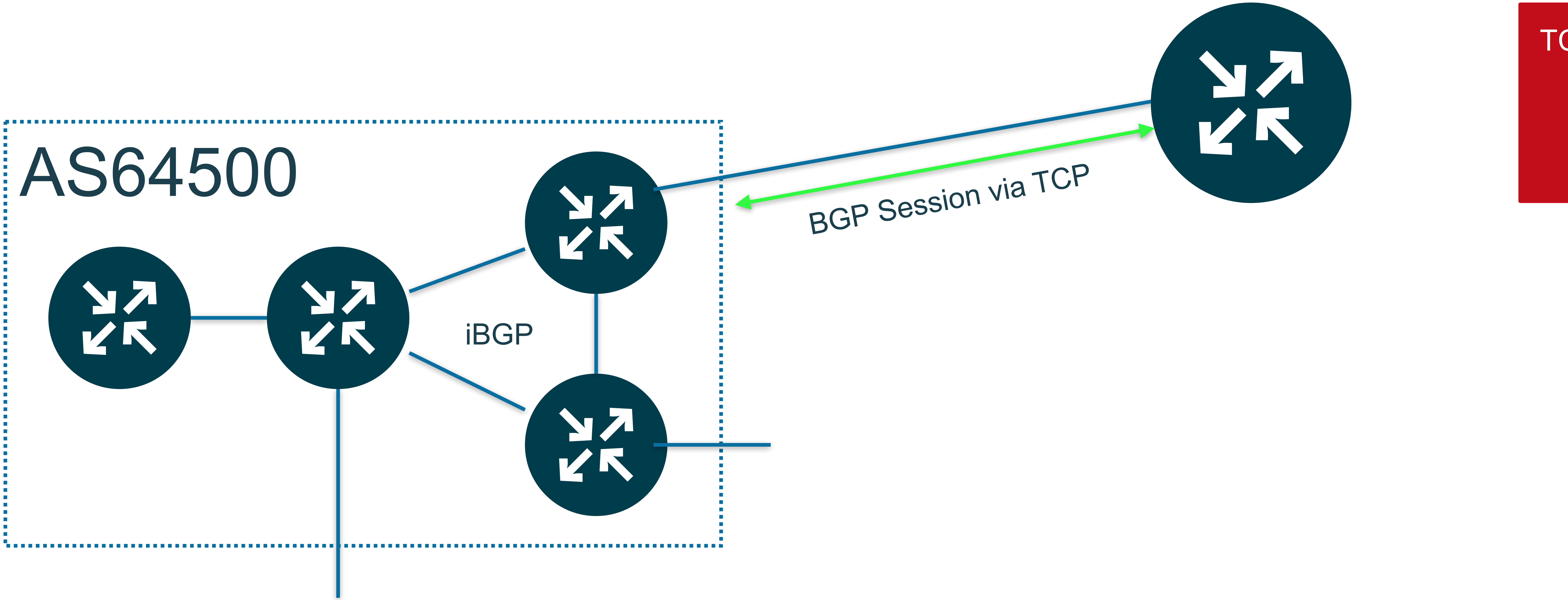
→...but only of limited use

→...still should be implemented

→List of measures:

1. Maximum Prefix
2. **MD5 Session Password / TCP AO**

MD5 Session Password / TCP AO



MD5 Session Password / TCP AO

TCP RST Packet

→Set the same password on each side

→Password is used to MD5 sign **each** TCP packet by the sender

→Receiver checks the signature

→If it does not match, packet is silently discarded

→Still used, even MD5 no longer state of the art

- →More modern approach: TCP-AO (authentication option) with stronger hashes

→Recommendation: Use this for iBGP, but not for eBGP

→Important: **You need some password management**!

Simple Measures

→Easy to implement

→Easy to maintain

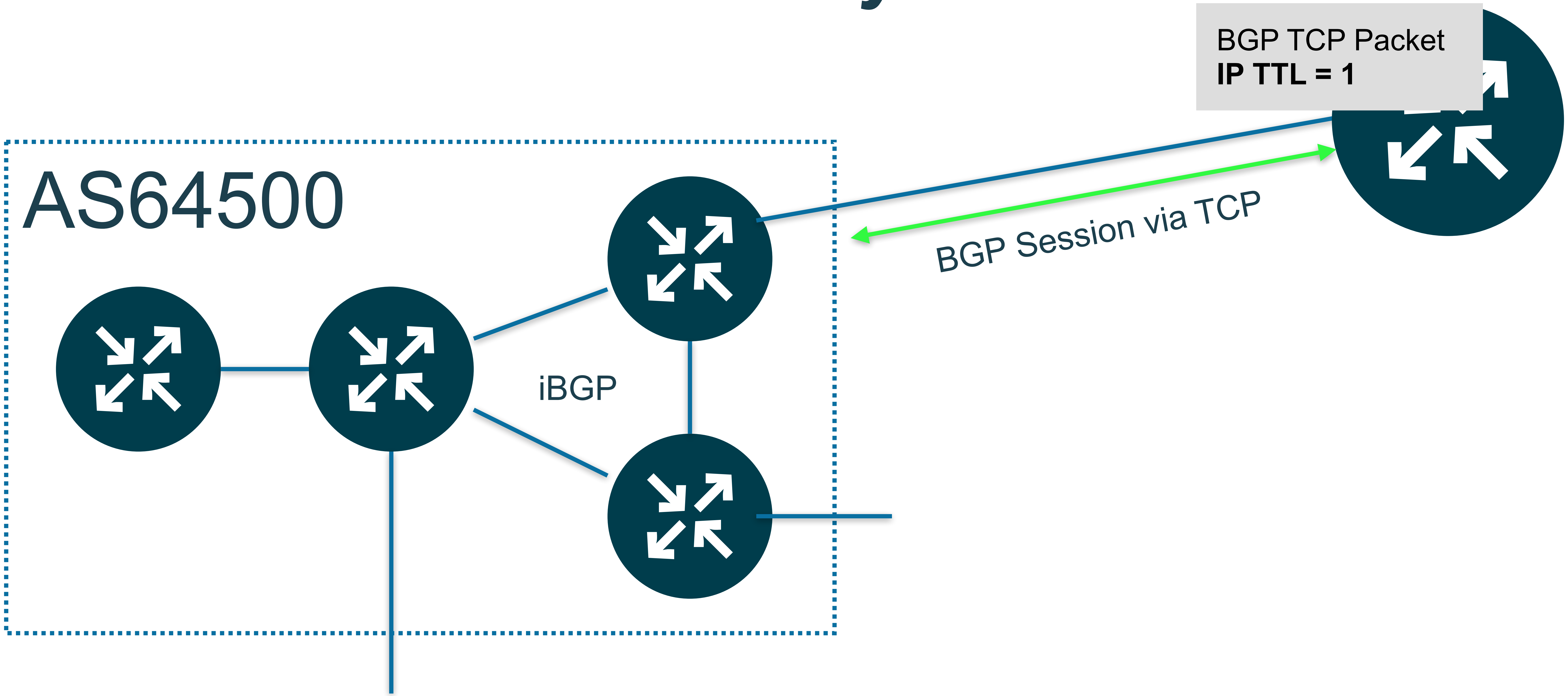
→...but only of limited use

→...still should be implemented

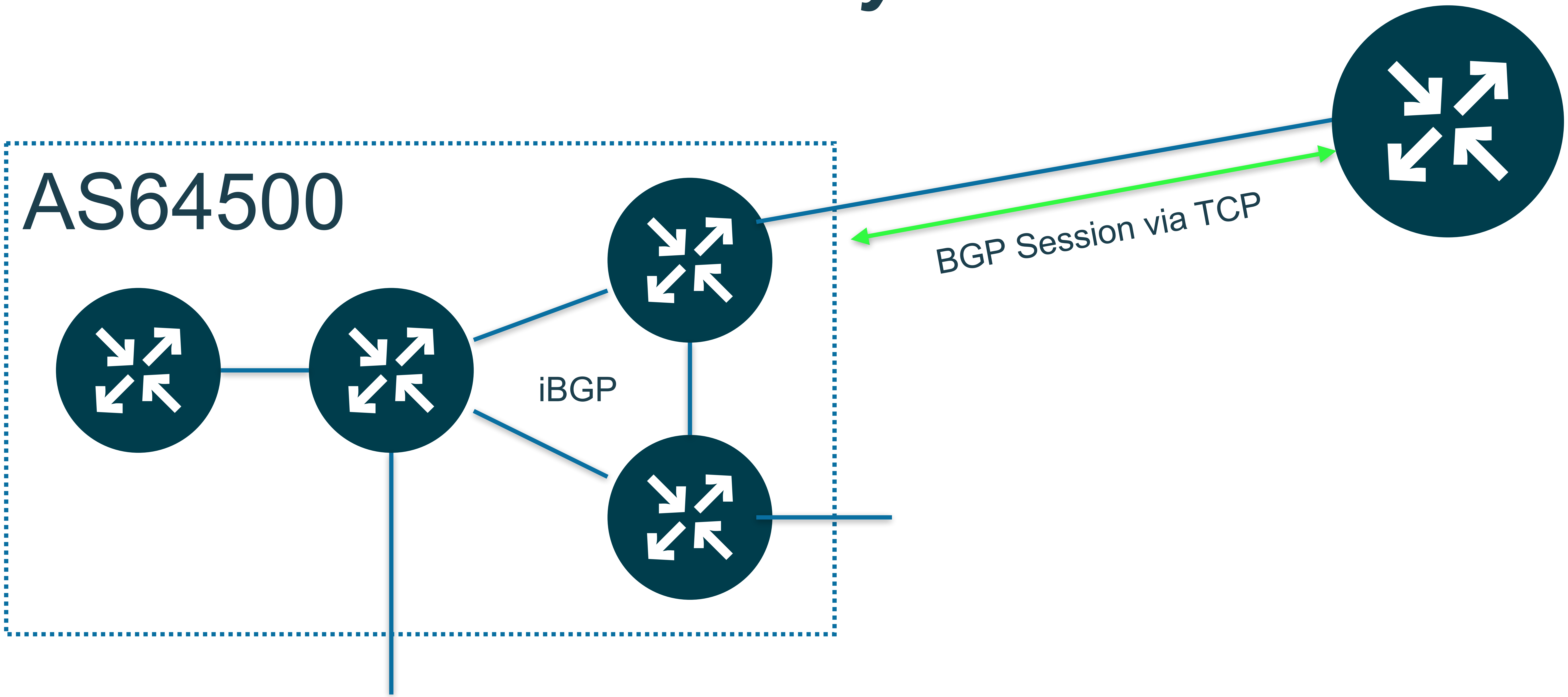
→List of measures:

1. Maximum Prefix
2. MD5 Password
3. **IP Time-to-live security**

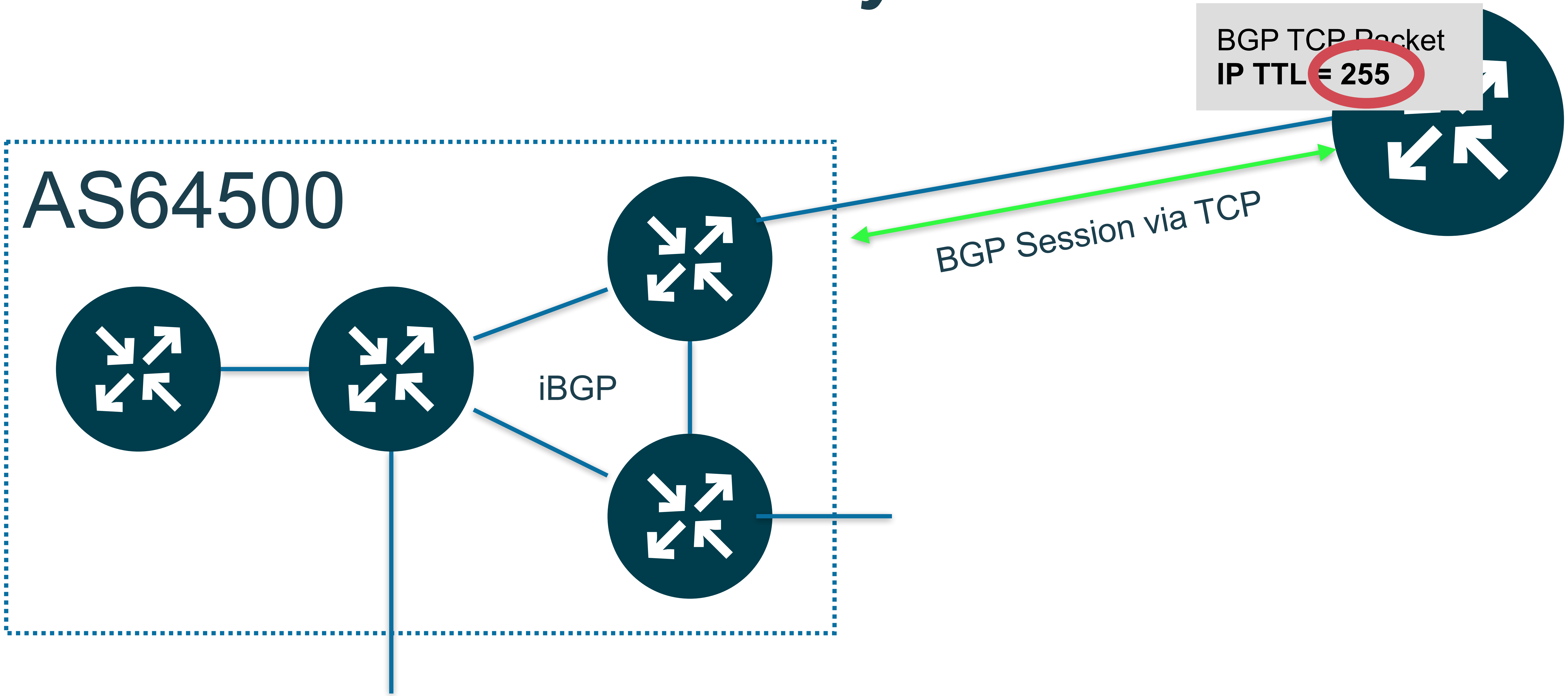
IP Time-to-live security



IP Time-to-live security



IP Time-to-live security



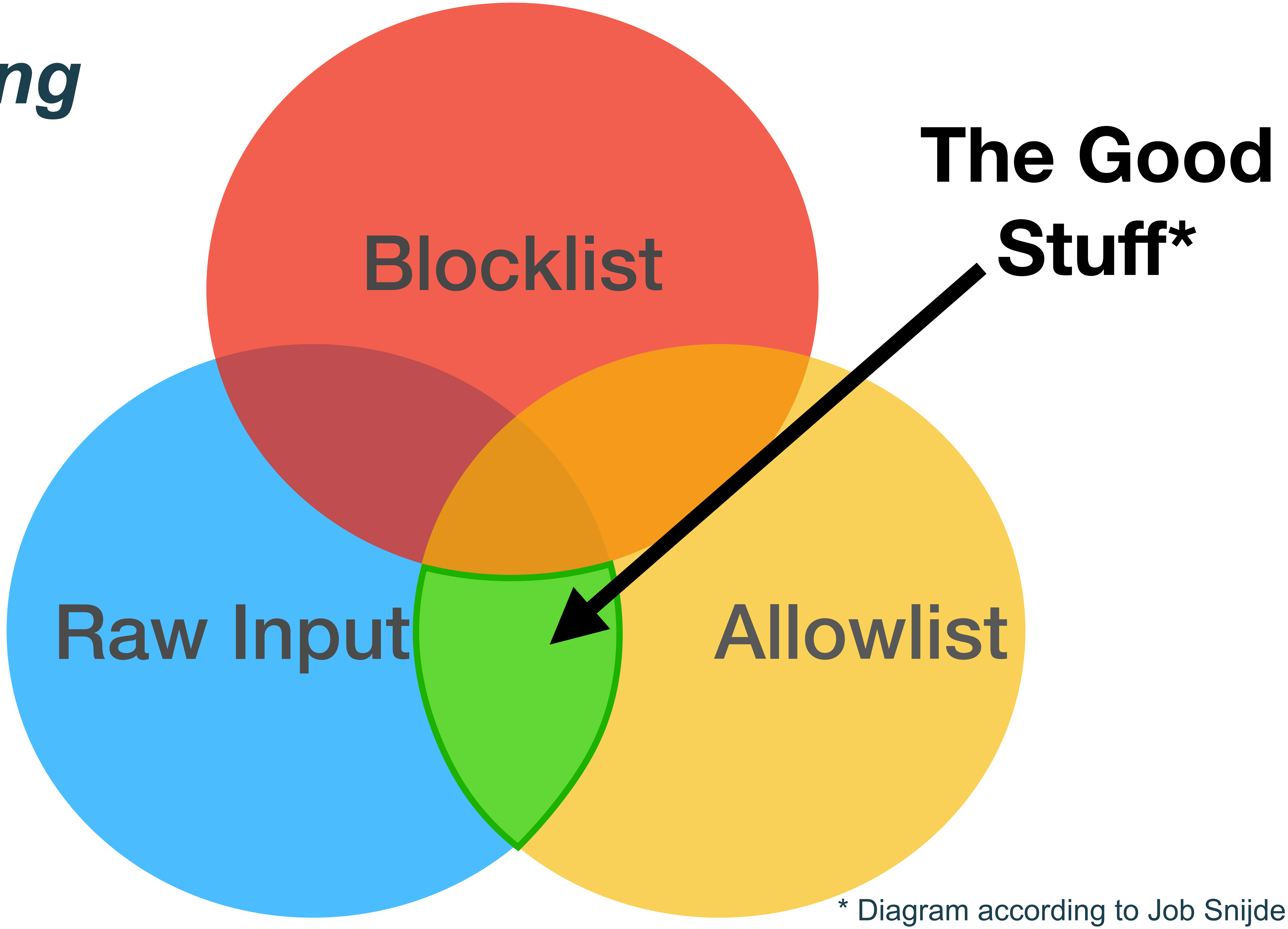
IP Time-to-live security

BGP TCP Packet
IP TTL = 255

- →Send IP packets with initial TTL of 255
- →Receiver checks if value is really 255
- →If not, packet is silently discarded
- →Very easy to implement (just enable it)
  - →But **must be configured on both sides**
- →Defined in RFC5082

BGP Filtering

BGP Filtering



* Diagram according to Job Snijders

BGP Filtering

Blocklist

→Filtering received prefixes

- → Prefix filtering
- →AS Path filtering
- →RPKI

* Diagram according to Job Snijders

Prefix filtering

→Block non-routable IPv4 prefixes like:

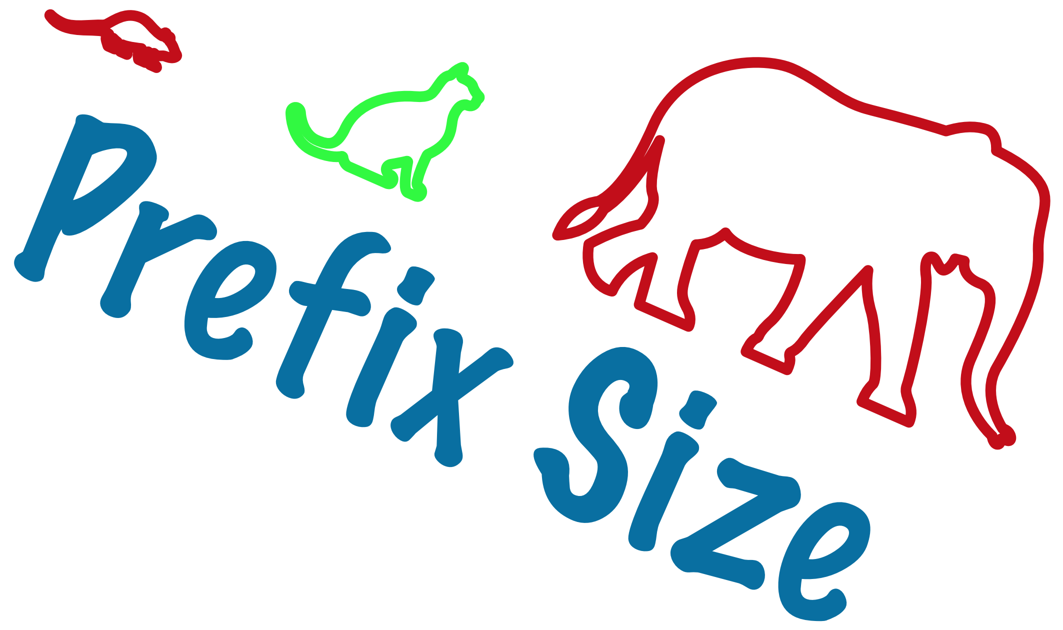
- →Private IPv4 space
  - →10.0.0.0/8, 172.16.0.0/12, 192.168.0.0/16
- →IPv4 networks reserved for documentation purposes
- →IPv4 multicast address space - 224.0.0.0/4
- →IPv4 reserved for "future use" - 240.0.0.0/4

→For IPv6

- →Allow only 2000::/3
- →Block everything else

```
ip prefix-list ipv4-unwanted permit 192.168.0.0/16 le 32
ip prefix-list ipv4-unwanted permit 172.16.0.0/12 le 32
ip prefix-list ipv4-unwanted permit 10.0.0.0/8 le 32
!
route-map upstream-in deny 100
  match ip address prefix-list ipv4-unwanted
```

Prefix filtering



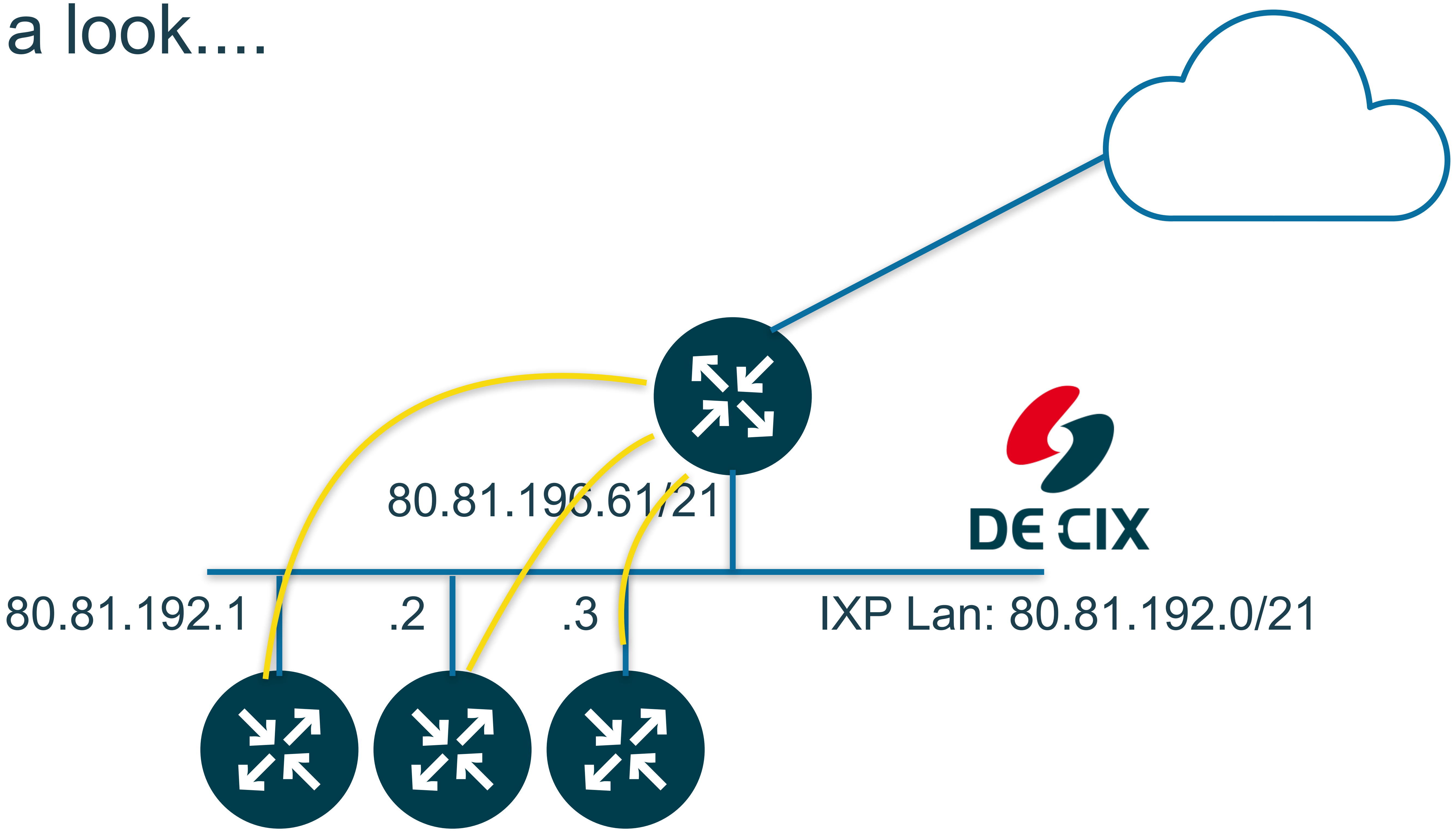
- →Filter against too small and too large prefixes
- →IPv4:
  - →Prefix sizes are /8 - /24
  - →Block everything smaller or larger (Exception: Blackholing)
- →IPv6:
  - →Prefix sizes are /19 - /48
- →You might allow a default route from your upstream providers

```
ip prefix-list ipv4-unwanted permit 0.0.0.0/0 ge 25
ip prefix-list ipv4-unwanted permit 0.0.0.0/0 ge 1 le 7
!
ipv6 prefix-list ipv6-unwanted permit ::/0 ge 49
ipv6 prefix-list ipv6-unwanted permit ::/0 le 18
!
route-map upstream-in deny 100
  match ip address prefix-list ipv4-unwanted
  match ipv6 address prefix-list ipv6-unwanted
```

More Prefix filtering

→IXP Lan Prefixes (and their more specifics)

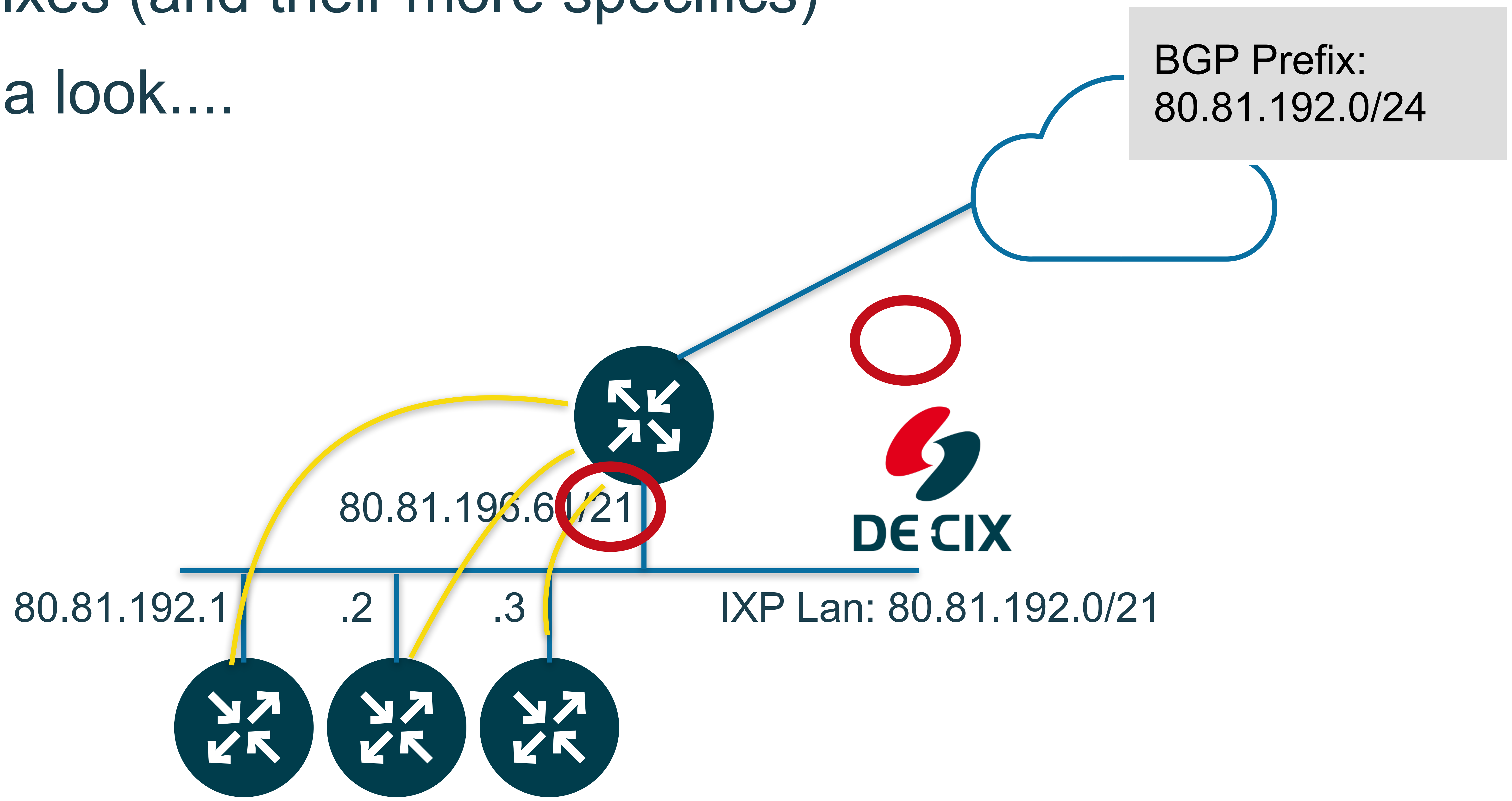
→Why? Have a look....



More Prefix filtering

→IXP Lan Prefixes (and their more specifics)

→Why? Have a look....



BGP Prefix:
80.81.192.0/24

More Prefix filtering

→IXP Lan Prefixes (and their more specifics)

→Your own prefixes

→Your customers prefixes (for the same reasons)

```
ip prefix-list ipv4-unwanted permit 80.81.192.0/21 le 32
!
ipv6 prefix-list ipv6-unwanted permit 2001:7f8::/64 le 128
!
route-map upstream-in deny 100
  match ip address prefix-list ipv4-unwanted
  match ipv6 address prefix-list ipv6-unwanted
```

AS path filtering

→even if the prefix is totally legit, the AS path might be bad

→if your own AS is in the path, prefixes are filtered automatically

→but you need to filter against...

  →private ASes (64512-65534 + 4200000000-4294967294)

  →reserved ASes - see IANA Special-Purpose AS Numbers

→**anywhere in the AS path!**

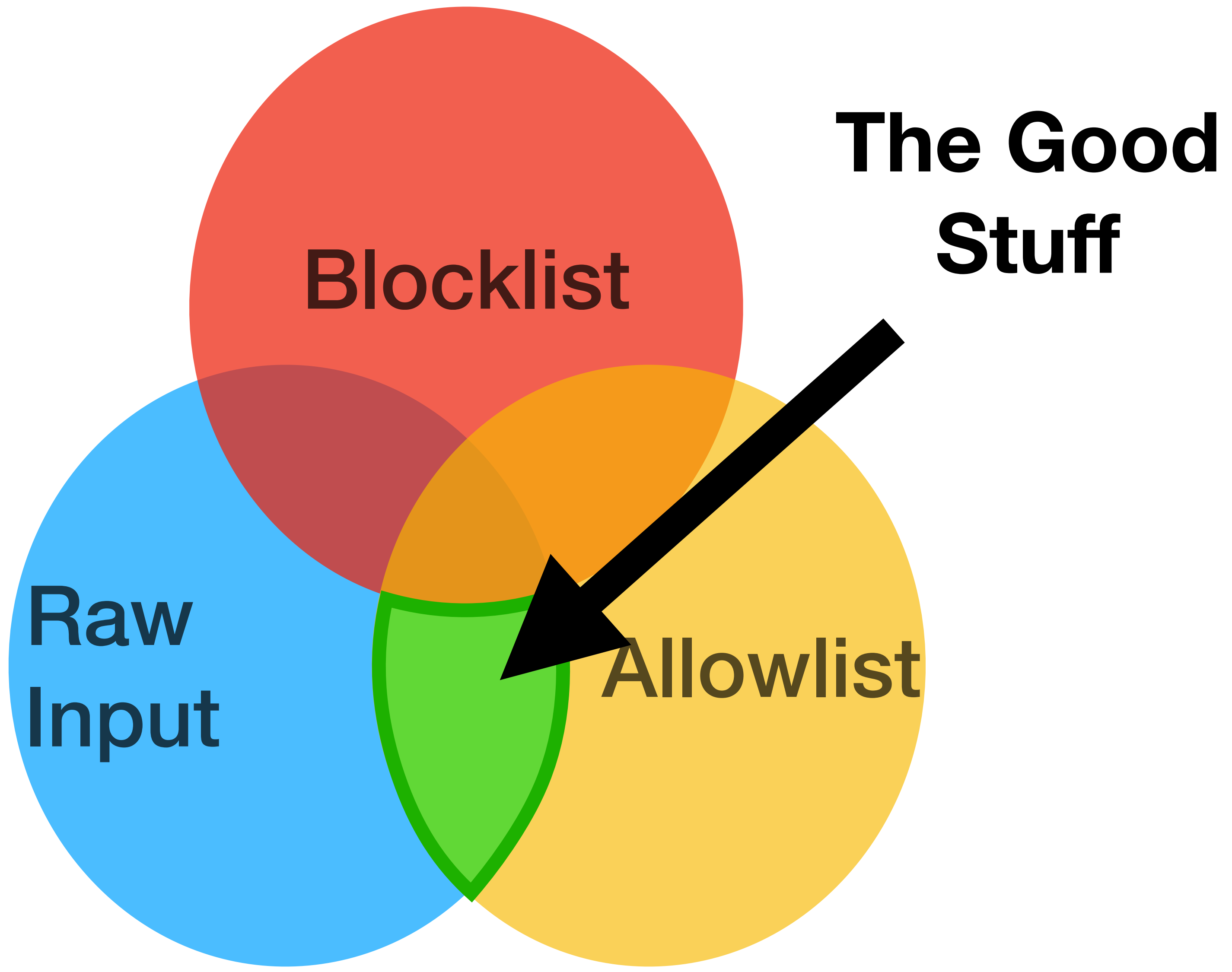
```
203.0.113.0/24    192.0.2.1   517  48854  65101  65102  203453  203453  203453  i
```

AS path filtering

- →private ASes (64512-65534 + 4200000000-4294967294)
- →reserved ASes - see IANA Special-Purpose AS Numbers
- →regular expressions can be used
- →but do not overdo it!
  - → _(6451[2-9]|645[2-9][0-9]|64[6-9][0-9]{2}|65[0-4][0-9]{2}|655[0-2][0-9]|6553[0-5])_
  - →completely valid, but unreadable
- →better split it up

Filtering from Customers

- →Here we need the "Allowlist"
  - →remember?
- →From customers allow only
  - →Customers prefixes
  - →Customers ASes (anywhere in the path)
  - →Use this to create an Allowlist **per customer**



Control your Announcements

have good

MANRS

MANRS

→Mutually

→Agreed

→Norms for

→Routing

→Security

MANRS

→Prevent propagation of incorrect routing information

→Filter incoming - what you do not let in, you cannot announce

→Do not announce anything outgoing you should not

→Prevent traffic with spoofed source IP addresses

→Facilitate global operational communication and coordination between network operators

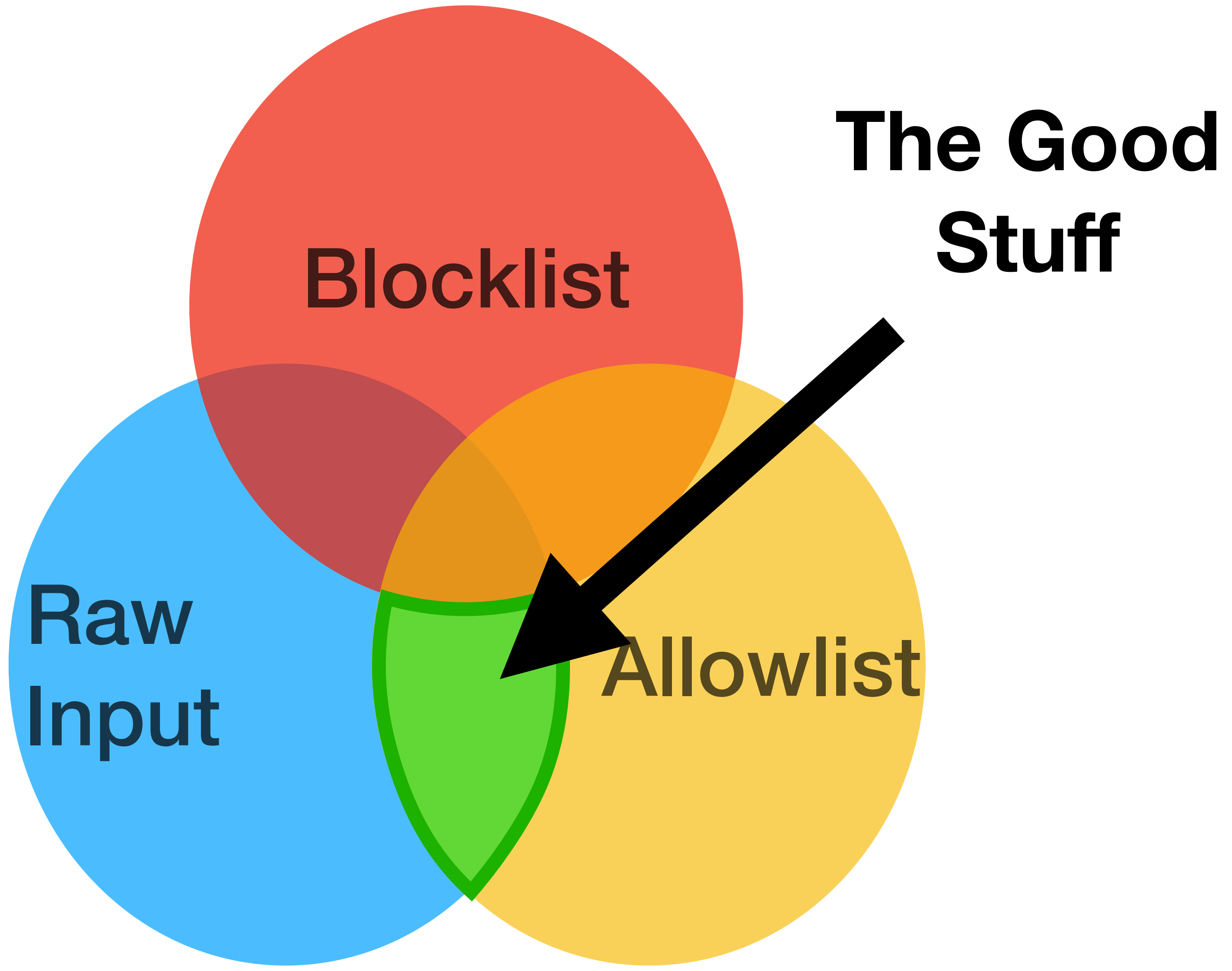
→= "talk to each other"

→Facilitate validation of routing information on a global scale

Conclusion

Conclusion

- →Protect your BGP routers and sessions
- →Filter incoming
  - →Unwanted IP Prefixes
  - →Bogus ASes in the path
  - →Allow from customers using an **Allowlist**
- →Filter outgoing
  - →Make sure you announce only valid prefixes



More security: RPKI

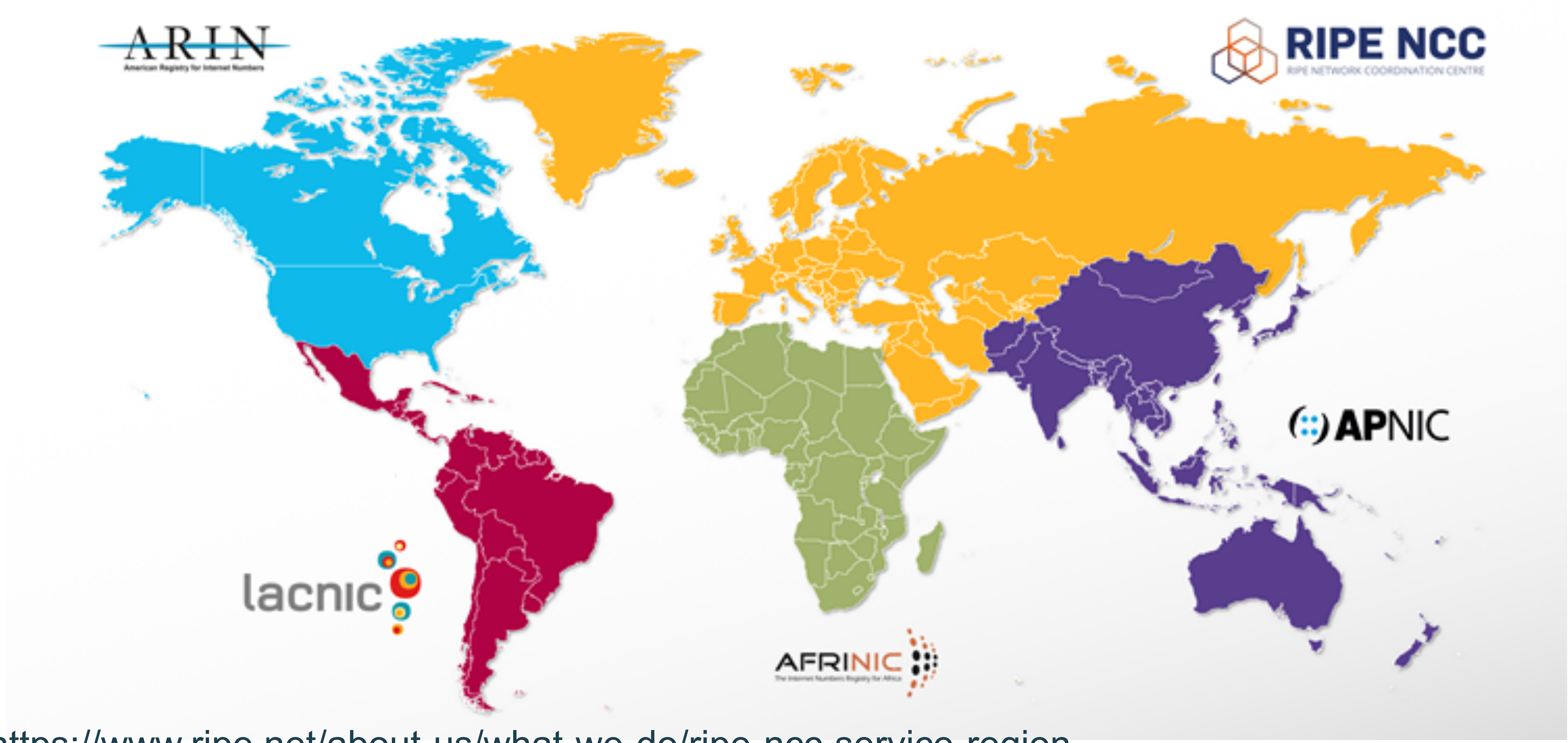
Part 1

RPKI - What is it?

Certificate - based proof of address assignment

→There are only five entities handing out IP resources

→These are the five RIRs


ARIN
American Registry for Internet Numbers
RIPE NCC
RIPE NETWORK COORDINATION CENTRE
APNIC
lacnic
AFRINIC
The Internet Numbers Registry for Africa

Source: https://www.ripe.net/about-us/what-we-do/ripe-ncc-service-region

Certificate - based proof of address assignment

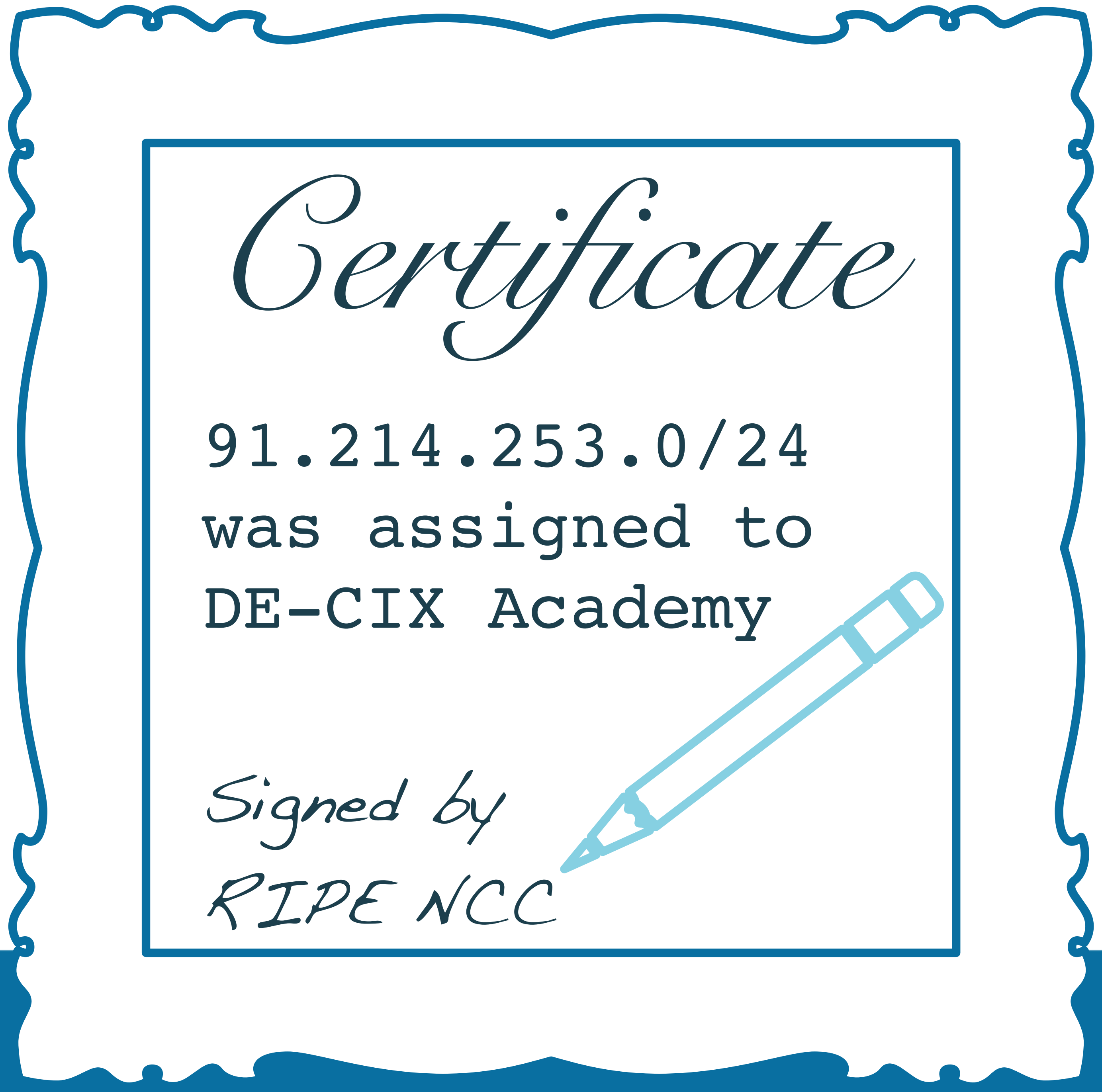
→There are only five entities handing out IP resources

→These are the five RIRs

→These are the trust-anchors in this model

→They have contractual proof who they gave which resource

→And sign you a certificate for it



Certificate

91.214.253.0/24
was assigned to
DE-CIX Academy

Signed by
RIPE NCC

What can you do with this certificate?

→You can create a ROA - Route Origin Authorization

→ROAs contains three values:

- →The IP prefix it is for
- →An Autonomous System Number you allow to originate that prefix
- →A range of allowed netmasks for this prefix

→And of course its digitally signed

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RPKI - Resource Public Key Infrastructure

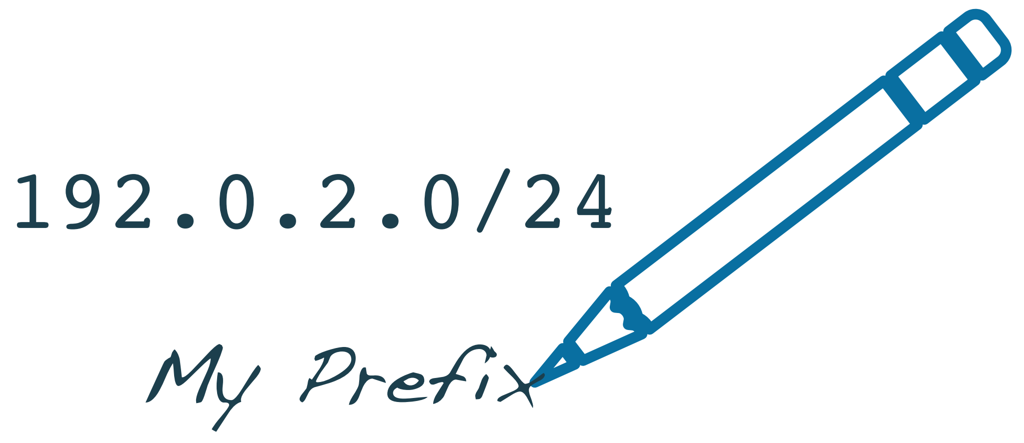
→Digitally signed route objects

→Resource holders can get their resources signed

→And can define how they are announced

- →Define an Origin-AS
- →Define a maximum length of a prefix
- →This is called a "ROA" (Route Origin Authorisation)

→Routers can use this to validate BGP announcements



RPKI - Resource Public Key Infrastructure

- →What problem does it want to solve?
  - →Certificate - based proof of resource assignment
    - →Resources are IP prefixes and AS numbers
  - →Verifiable originator AS for each prefix
  - →Only allow certain prefix lengths

Example of a ROA

- →So, if your prefix is 91.214.253.0/24
- →You might allow AS196610 to originate
- →The prefix and also a /25 more-specific
- →So the ROA looks like:
  - →91.214.253/24 AS196610 /24-/25
  - →Or in detail:

```
{
  "filename": "b2zDxaYsNBGNNz0Iu93sUJUQ27I.roa",
  "asn": "AS196610",
  "validity_period": "2019-01-01T01:20:09.000Z -
2020-07-01T00:00:00.000Z",
  "signing_time": "2019-01-01T01:20:09.000Z",
  "prefixes": [
    {
      "prefix": "91.214.253.0/24",
      "maxLength": 25
    }
  ],
  "validation_result": {
    "isValid": true,
    "error": [],
    "warning": []
  }
}
```

Part 2

RPKI - setting it up

Your certificates and ROAS

- →Hosted RPKI: Easiest deployment
  - →Your RIR hosts your certificates and ROAs for you
  - →takes care of signing and key roll over
  - →Most RIRs have a nice web interface for that
- →Non-Hosted RPKI: Run everything on your own
  - →If you heard about RPKI here the first time,
    this is probably not what you want to do

Part 3

Validating your ROAs

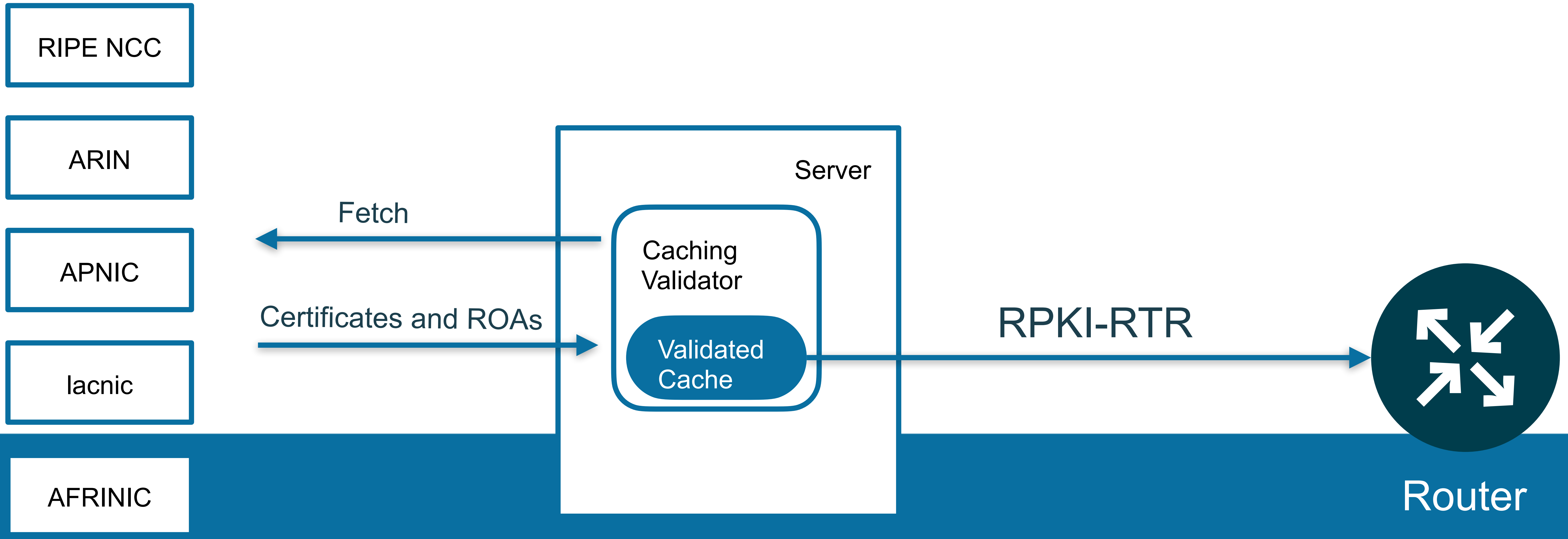
So what does a ***validator*** do?

→Fetch resource certificates and ROAs from RIRs (via rsync)

→Validates the "chain of trust"

- →Check signatures of certificates
- →Check signatures of ROAs

→Supplies a *validated cache* for your routers



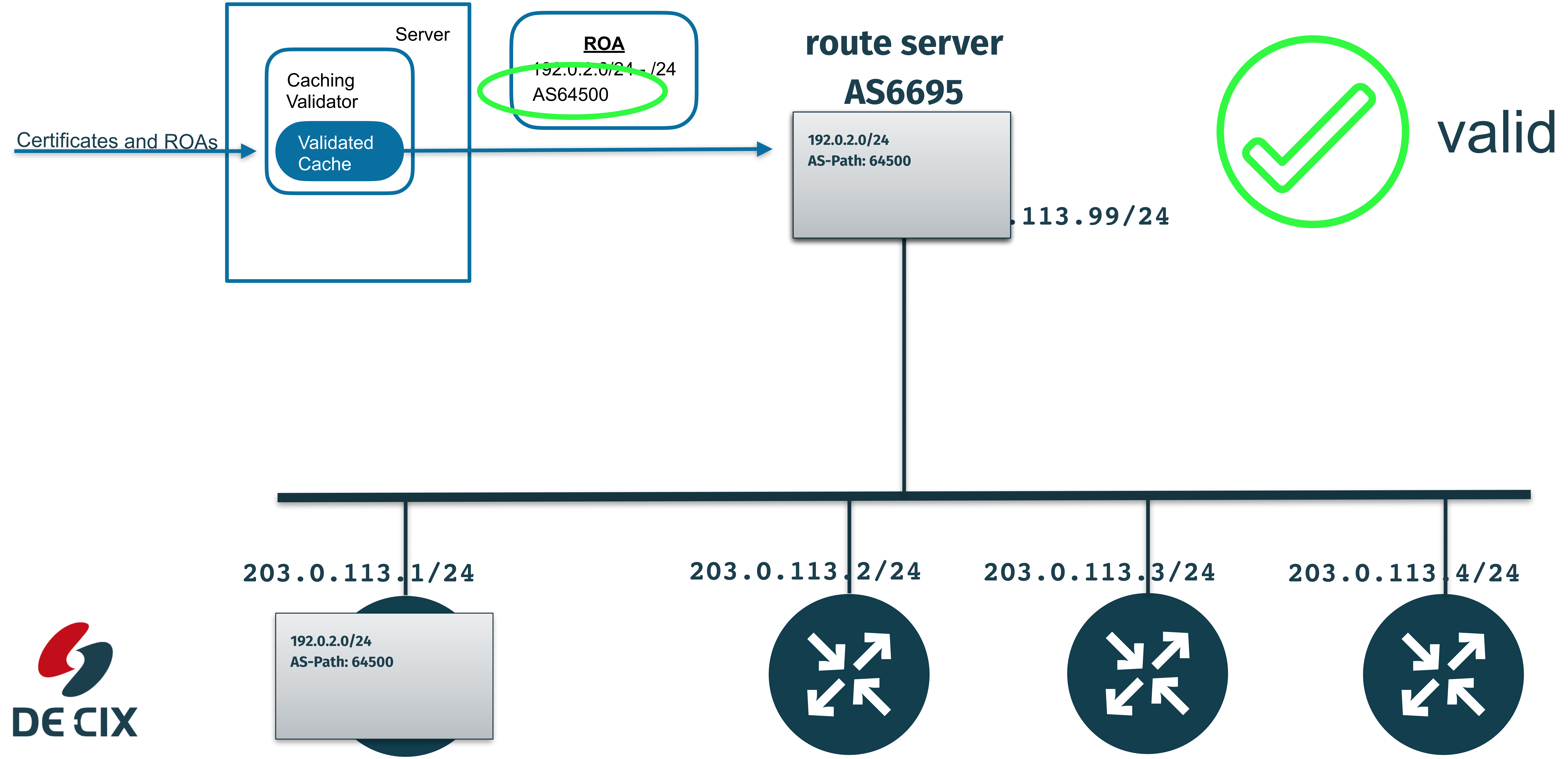
Example Validator: ROUTINATOR

- →by NLNetlabs
  - →https://nlnetlabs.nl/projects/rpki/routinator/
- →written in RUST
  - →runs either directly
  - →or inside a Docker container
- →Open Source
- →Small footprint
- →Very easy to install

Part 4

RPKI at DE-CIX

DE-CIX Route Servers are using RPKI



Certificates and ROAs

Server

Caching
Validator

Validated
Cache

ROA
192.0.2.0/24 - /24
AS64500

route server
AS6695

192.0.2.0/24
AS-Path: 64500

.113.99/24

valid

203.0.113.1/24

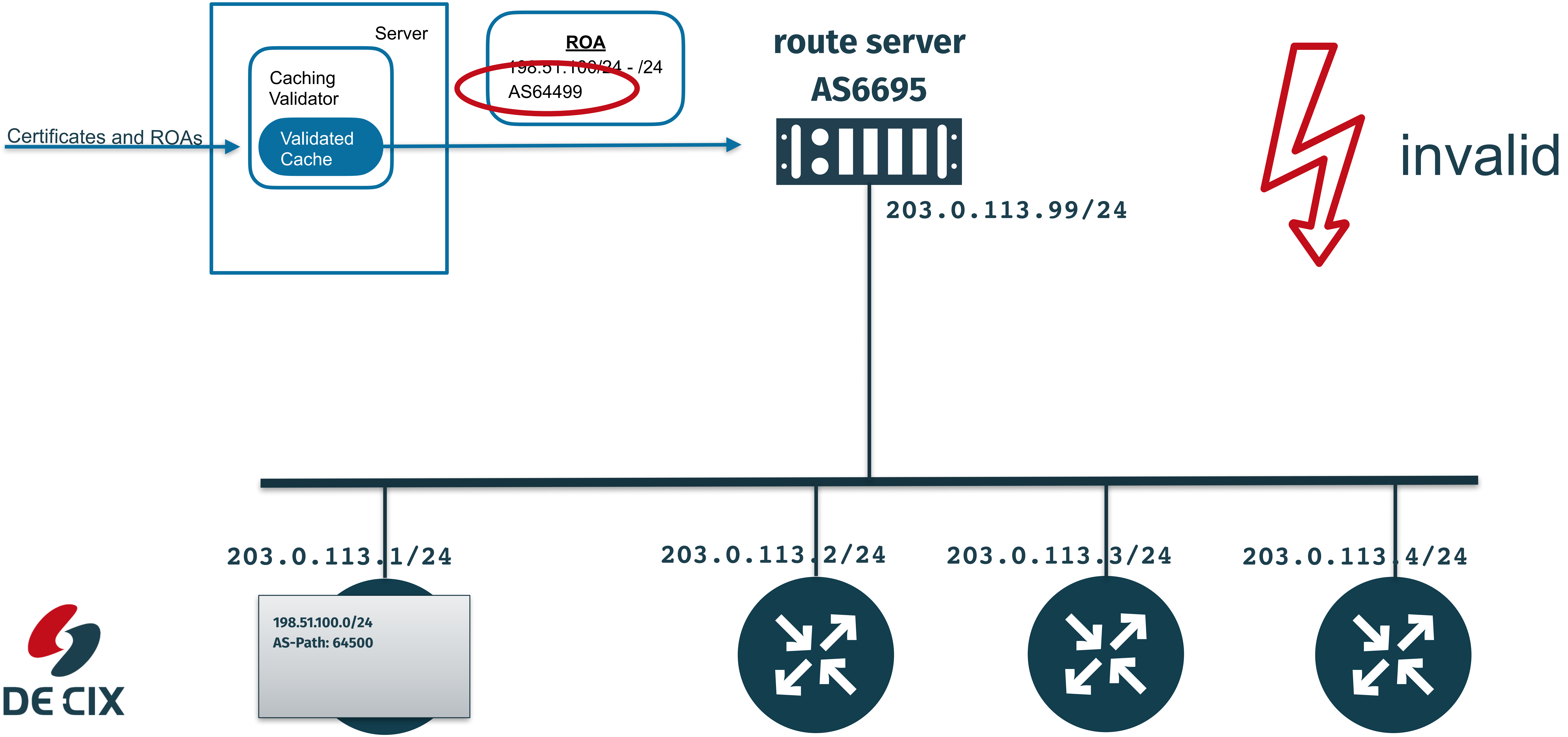
192.0.2.0/24
AS-Path: 64500

203.0.113.2/24

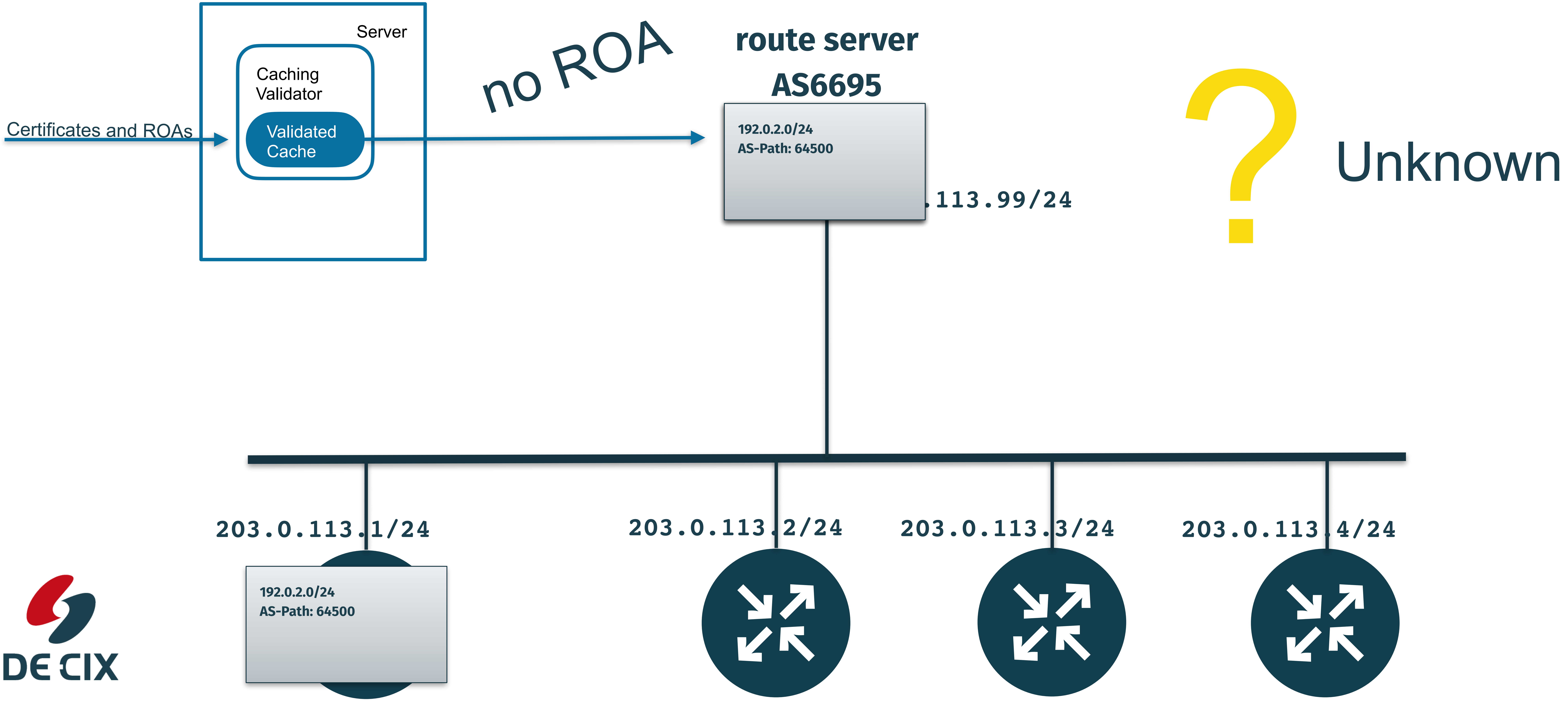
203.0.113.3/24

203.0.113.4/24

DE-CIX Route Servers are using RPKI

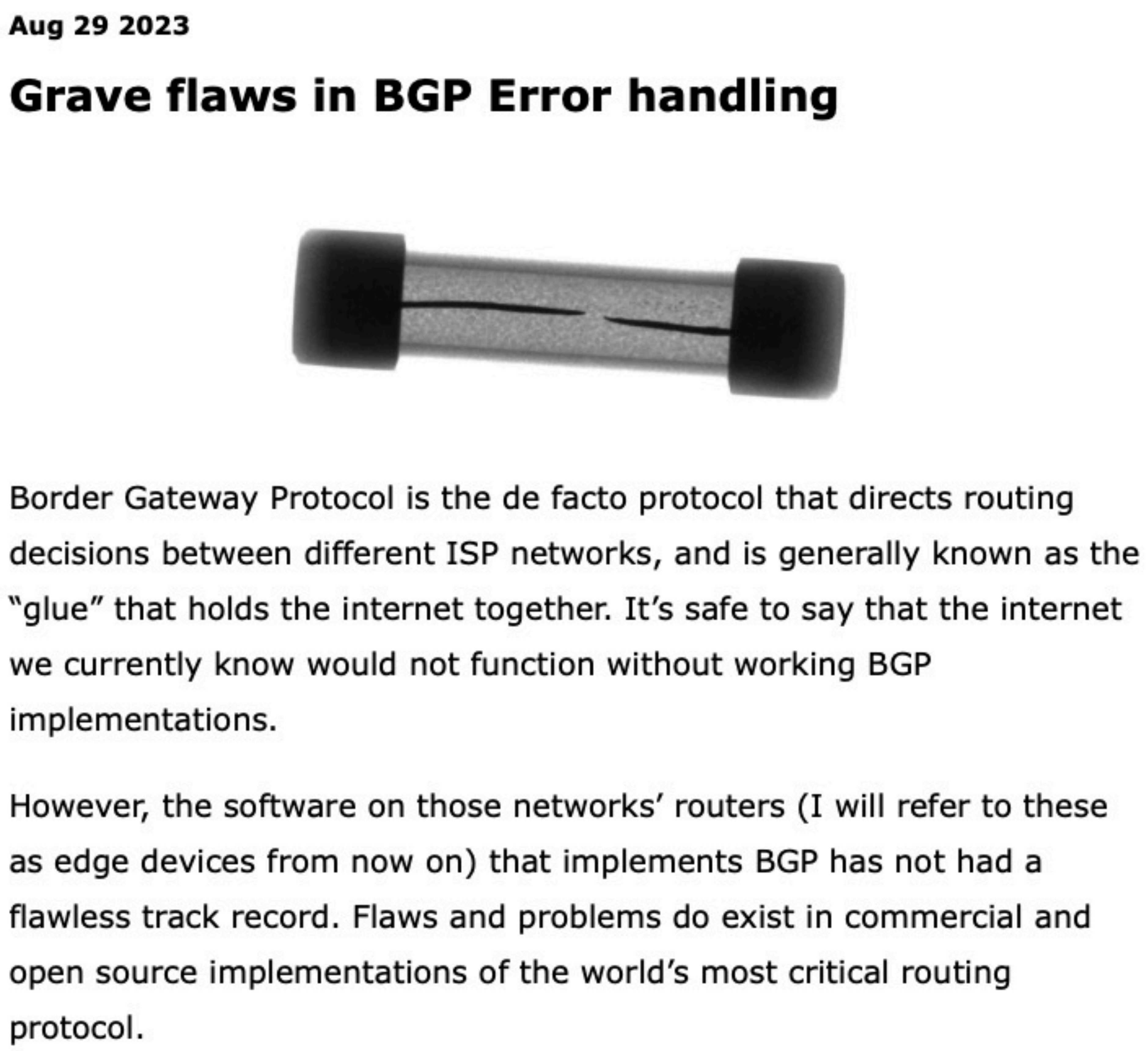


DE-CIX Route Servers are using RPKI



BGP Error Handling

Motivation: Blog entry



Aug 29 2023

Grave flaws in BGP Error handling

Border Gateway Protocol is the de facto protocol that directs routing decisions between different ISP networks, and is generally known as the “glue” that holds the internet together. It’s safe to say that the internet we currently know would not function without working BGP implementations.

However, the software on those networks’ routers (I will refer to these as edge devices from now on) that implements BGP has not had a flawless track record. Flaws and problems do exist in commercial and open source implementations of the world’s most critical routing protocol.

https://blog.benjojo.co.uk/post/bgp-path-attributes-grave-error-handling

What happened?

- 2023-06-02: a small network announced one of their prefixes with a "bad" attribute
- This attribute was not understood by their immediate neighbors, and so the announcement was re-announced with the "bad" attribute unchanged
- Further away, Juniper routers "kind of" understood the attribute, saw it was bad, and **dropped the session they received it from.**
- So many routers, seemingly unrelated to the originator of the prefix, suddenly dropped sessions.

Reminder: How BGP works

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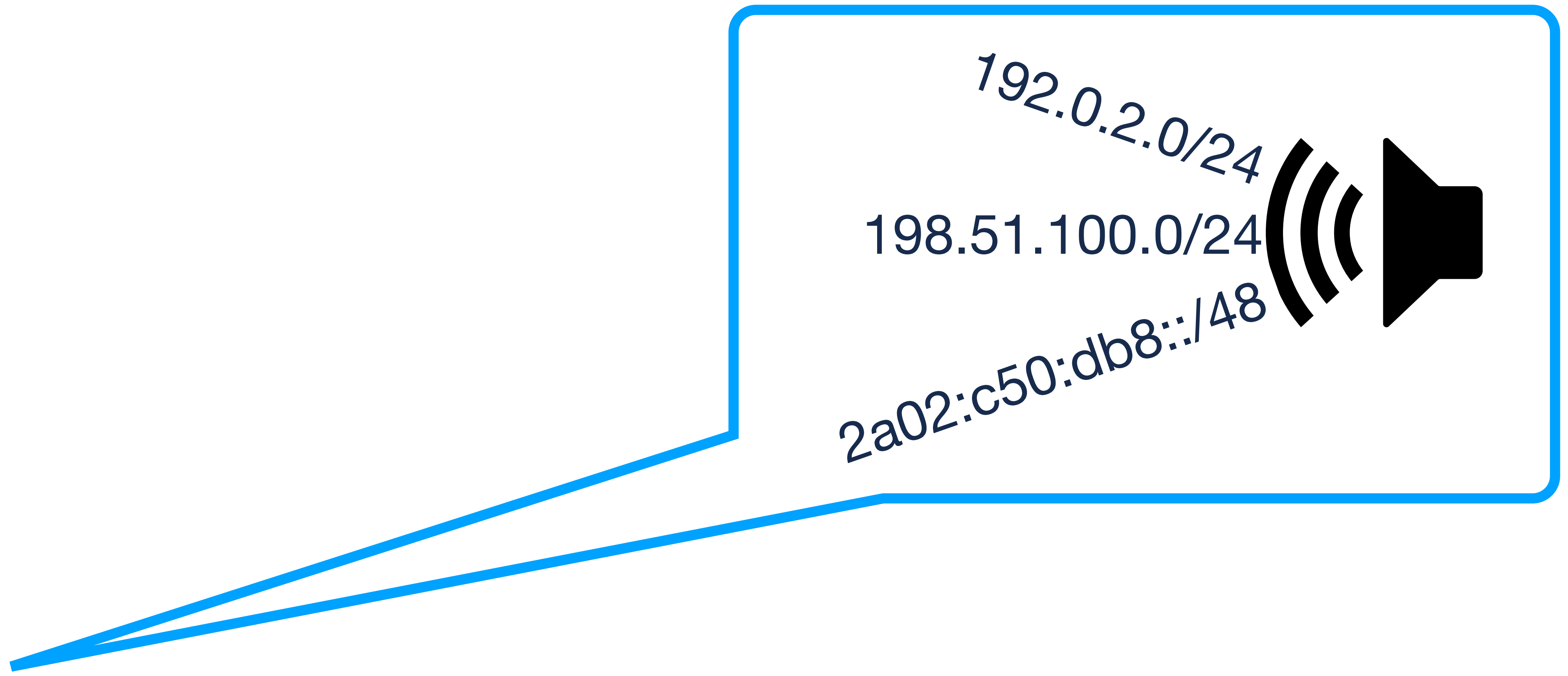
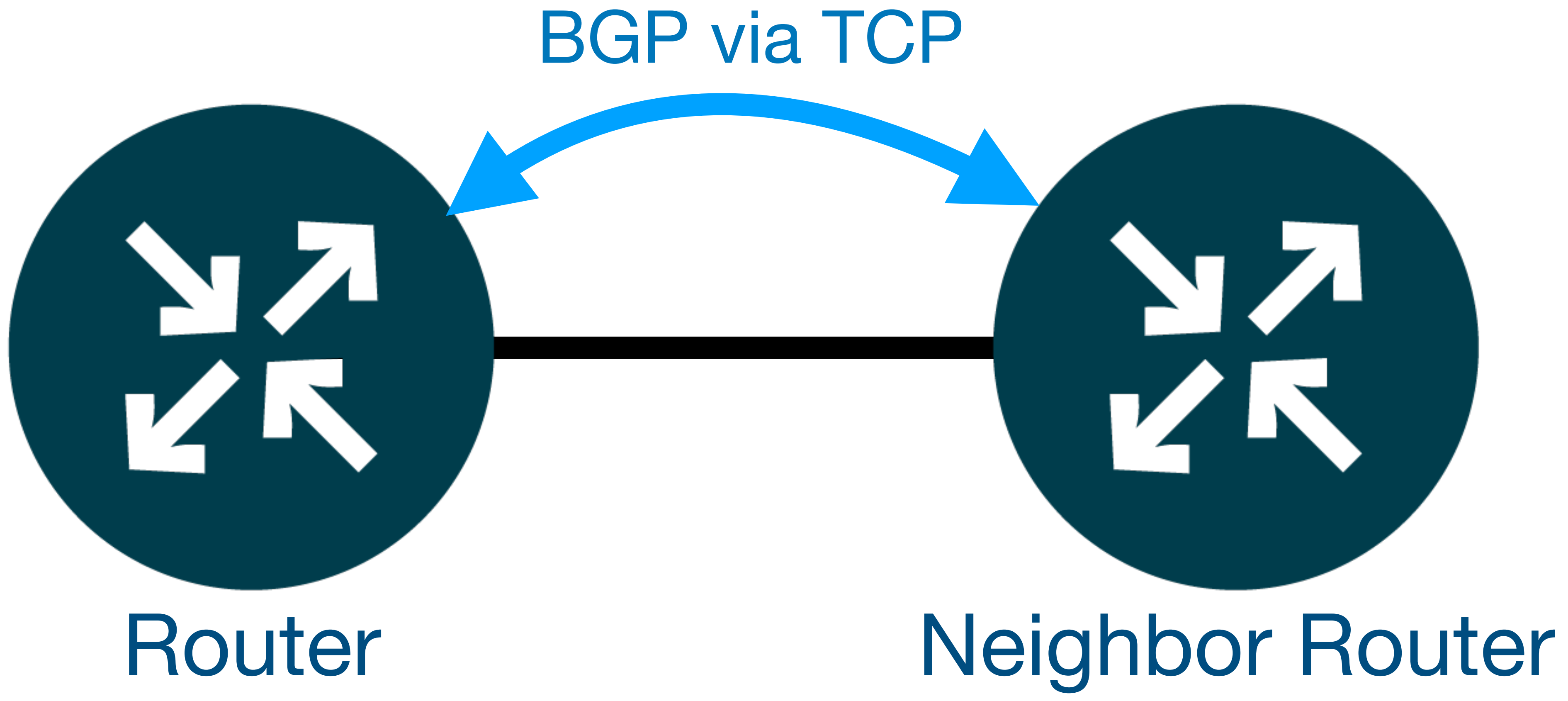
BGP Neighbors

Directly connected neighbors

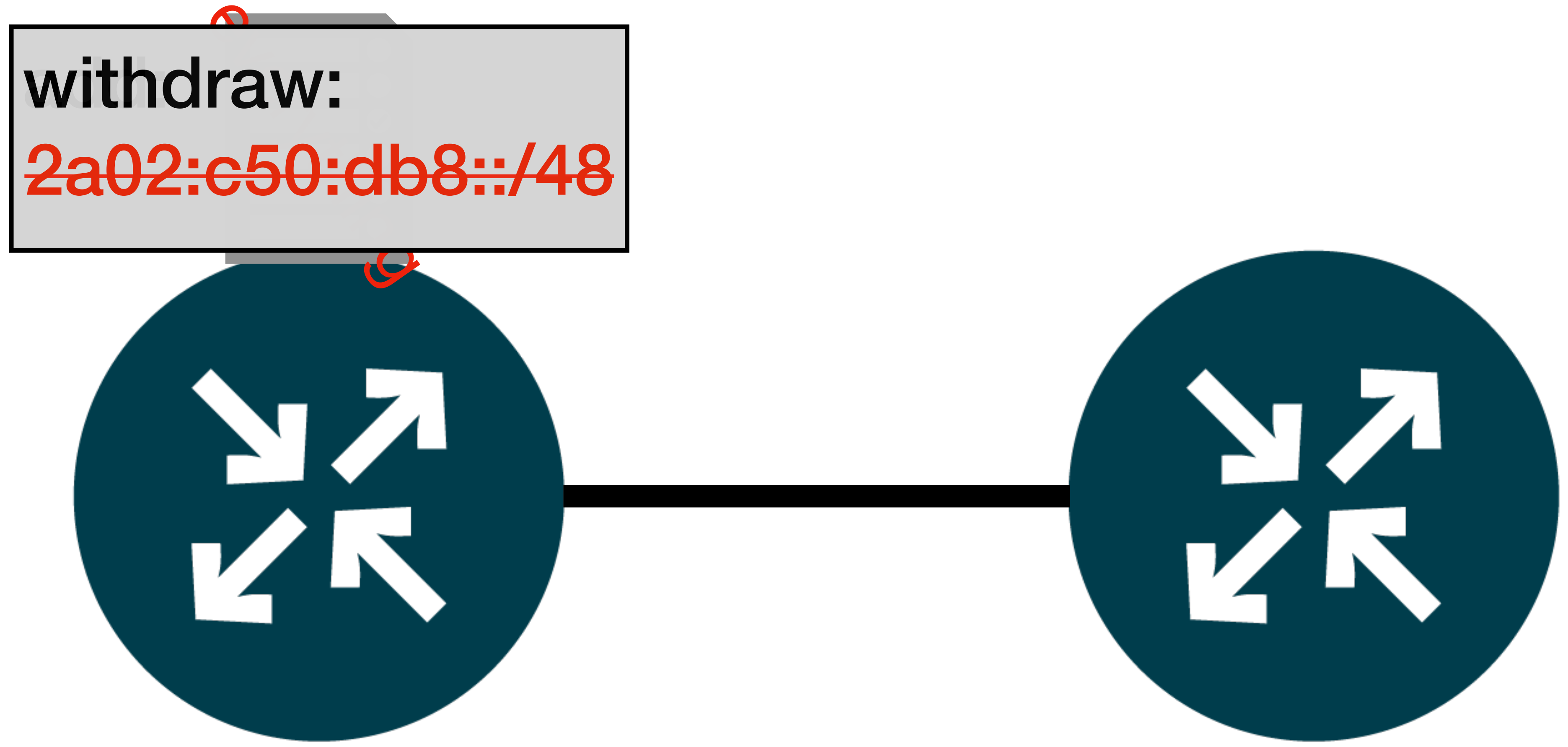


- BGP **announces** IP prefixes to **neighbors**
- These neighbors have to be **configured**
- BGP uses **TCP** to connect to a neighbor
- TCP brings already:
  - **Reliable transport** (sender knows that receiver got it)
  - **Flow control** (do not send faster than the receiver can receive)
  - **Framing** (putting BGP messages into packets)



BGP works incremental

Using add- / withdraw- messages



- At session setup, BGP announces "everything" to its neighbor
- After that, updates are **incremental**:
  - If BGP learns about a new prefix, it sends an **add**-message to neighbors
  - If a prefix goes away, it sends a **withdraw** message to neighbors
- As long as the BGP session is "up", a router assumes its neighbors are "in sync" (= did not forget anything it sent)

BGP Message Types

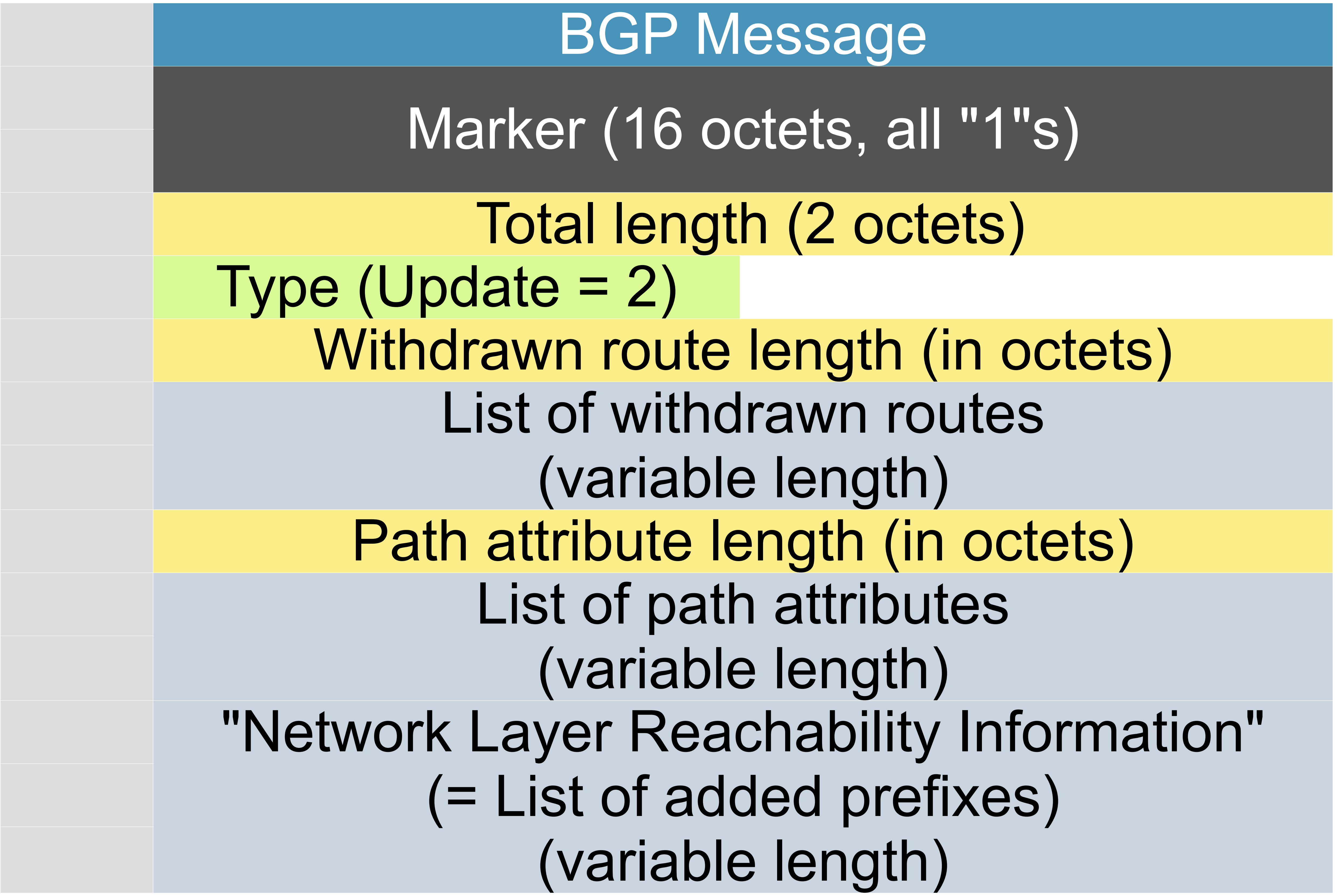
TCP containing BGP messages

- BGP has the following message types:
  - **OPEN** - initial message for setting up a session
  - **UPDATE** - incremental routing updates: adds and withdraws
  - **KEEPALIVE** - send this if you have nothing to send
  - **NOTIFICATION** - to tell the other side there was an error, and then close the BGP session.

Focus today: UPDATE message

Incremental routing updates

- Update messages can contain multiple things:
  - A list of "adds"
    - Named "Network Layer Reachability Information"
    - With common attributes
  - A list of "withdraws"
    - Withdraws do not have attributes



BGP Message

Marker (16 octets, all "1"s)

Total length (2 octets)

Type (Update = 2)

Withdrawn route length (in octets)

List of withdrawn routes (variable length)

Path attribute length (in octets)

List of path attributes (variable length)

"Network Layer Reachability Information" (= List of added prefixes) (variable length)

Attributes of BGP prefixes

Update message details

- **Mandatory** attributes: have to be there
  - Example: AS-Path
- **Optional** attribute: are, well, optional
  - Example: MED
- **Transitive** attributes
  - are kept on the prefix and forwarded via BGP
  - Even **(!)** when not understood by the forwarding device
- **Non-transitive** attributes
  - are added to a prefix and not forwarded by the receiver

How is this realized in the protocol?

More about BGP attributes

Flags

- First byte of any attribute is "Flags"
  - Optional (1) or Well-Known (0)
  - Transitive (1) or Non-Transitive (0) (well-known is always transitive)
  - Partial (1) or Complete (0) ("Partial" only for optional transitive)
  - Extended Length Bit (0 = one length octet, 1 = two length octets)
  - Rest of the flags are unused

Attribute Flags					Attribute Type Code	Length	
Opt	Transitive	Partial	Ext Len	Unused	1 Octet	1 or 2 Octets Depending on ExtLen Flag	

More about BGP attributes

Attribute Type Origin

- Well-known, Transitive, Mandatory, (and quite simple)
- Length is one octet
- Possible values:
  - 0 - IGP
  - 1 - EGP
  - 2 - Incomplete

Attribute Flags					Attribute Type Code	Length	Value
Opt **0**	Transitive **1**	Partial **0**	Ext Len **0**	Unused **0000**	1 Octets 0x1	1 Octet 0x1	0x0 = IGP 0x1 = EGP 0x2 = Incomplete

More about BGP attributes

Attribute Type AS Path

- Well-known, Mandatory
- Realized as "sequence of segments"
- Segment: (type, length, value)
  - Type = 1: Unordered set of ASes traversed
  - Type = 2: Ordered Set of ASes traversed
- Length: Number of ASes in value part

Segment		
Type	**Length**	**Value**
1= Unordered Set 2 = Ordered Set	1 Octet	List of AS numbers

But what happens if an attribute is malformed?

More about BGP attributes

Attribute Type Origin

- Well-known, Transitive, Mandatory, (and quite simple)
- Length is one octet
- Possible values:
  - 0 - IGP
  - 1 - EGP
  - 2 - Incomplete

0,1,2 are valid values

What happens if there is a "3" in the value field?

Attribute Flags					Attribute Type Code	Length	Value
Opt **0**	Transitive **1**	Partial **0**	Ext Len **0**	Unused **0000**	1 Octets 0x1	1 Octet 0x1	0x0 = IGP 0x1 = EGP 0x2 = Incomplete

Invalid values in attributes

RFC4271 - Section 6.3 "Update Message Error Handling"

```
All errors detected while processing the UPDATE message MUST be
   indicated by sending the NOTIFICATION message with the Error Code
   UPDATE Message Error.  The error subcode elaborates on the specific
   nature of the error.
```

```
If the ORIGIN attribute has an undefined value, then the Error Sub-
   code MUST be set to Invalid Origin Attribute.  The Data field MUST
   contain the unrecognized attribute (type, length, and value).
```

- What was a NOTIFICATION message again?
- **NOTIFICATION** - to tell the other side there was an error, and then close the BGP session.

Error in Update Messages

Shut down the BGP session

- So, if any of the well-known attributes contain an error
  - A notifcation is sent back
  - And the BGP session is closed
- This is a problem and a possible attack vector
- This was addressed in RFC7606:
  "Revised Error Handling for BGP UPDATE Messages"

Revised Error Handling for BGP UPDATE Messages

Treat the UPDATE like a WITHDRAW

- RFC7606 addresses the problem of dropping BGP sessions because of errors
    - A number of RFCs who address error handling are updated
    - In most cases now session is no longer dropped, but the malformed UPDATE is now treated like a WITHDRAW
    - Read the RFC for details.

Conclusion

Conclusion

- → BGP Error handling has been improved over the years
- → In case of malformed attributes, BGP today handles an announcement like a withdrawal
- → Implementation bugs may cause major disruptions
- → The quality of a BGP implementation is also affected by how quickly critical bugs are fixed
- → See the original blog entry about vendor reaction times

DE CIX

https://de-cix.net/academy

Links and further reading

DE-CIX Academy Resources

Lab and documentation

- DE-CIX Academy BGP Lab:
  https://gitlab.com/de-cix-public/team-academy/bgp/BGPLab
- Book: "BGP for networks who peer"
  https://github.com/wtremmel/BGP-for-networks-who-peer
- DE-CIX YouTube Channel: https://www.youtube.com/@DE-CIX

AS - Numbers

How to request an AS number

- Giving AS numbers to the RIRs: iana.org
- Requesting an AS number, links for:
  - ARIN
  - Lacnic
  - APNIC
  - RIPE NCC
  - Afrinic

BGP: Autonomous Systems

RFCs

- RFC1930: Guidelines for creation, selection, and registration of an Autonomous System (AS)
- RFC6793: BGP Support for Four-Octet Autonomous System (AS) Number Space

RFCs are Internet standards issued by the Internet Engineering Task Force (IETF)

Routing

Relevant RFCs

- RFC4632: Classless Inter-domain routing (CIDR)

RFCs are Internet standards issued by the Internet Engineering Task Force (IETF)

IPv6

Relevant RFCs

- RFC4291: IPv6 addressing architecture

RFCs are Internet standards issued by the Internet Engineering Task Force (IETF)

BGP - Best Path Selection

RFCs and Implementations

- RFC4271 - A Border Gateway Protocol 4 (BGP-4)
  - *Next Hop* is defined in Section 5.1.3
  - *AS Path* is defined in Section 5.1.2
  - *Local Preference*: Section 5.1.5
  - *Origin*: Section 5.1.1
  - *Multi Exit Discriminator (MED)*: Section 5.1.4
  - see 9.1 for the BGP best path selection algorithm
- BGP Best Path Selection by vendor
  - Cisco
  - Juniper
  - Mikrotik
  - Nokia
  - BIRD
  - FRRouting

1		NextHop reachable?	Continue if "yes"
2		Local Preference	higher wins
3		AS Path	shorter wins
4		**Origin Type**	**IGP over EGP over Incomplete**
5		**MED**	**lower wins**
6		**eBGP, iBGP**	**eBGP wins**
7		**Exit**	**nearest wins**
8		**Age of route**	**older wins**
9		**Router ID**	**lower wins**
10		**Neighbor IP**	**lower wins**

RFCs are Internet standards issued by the Internet Engineering Task Force (IETF)

BGP Attributes

Relevant RFCs

- BGP attribute types:
  - Registering new types: RFC2042
  - Published in BGP Parameters database at IANA

RFCs are Internet standards issued by the Internet Engineering Task Force (IETF)

BGP Security

Relevant RFCs

- RFC7454 - BGP Operations and Security
- Password protect BGP sessions
  - RFC2385 (obsolete) - Protection of BGP Sessions via the TCP MD5 Signature Option
  - RFC5925 - The TCP Authentication Option
- RFC5082 - The Generalized TTL Security Mechanism (GTSM)

RFCs are Internet standards issued by the Internet Engineering Task Force (IETF)

~~Relevant~~ RFCs

Historical (obsolete)

- RFC827: Exterior Gateway Architecture (EGP) (historical, obsolete)
-

RFCs are Internet standards issued by the Internet Engineering Task Force (IETF)