RIPE NCC
RIPE NETWORK COORDINATION CENTRE

BGP Routing Security

Training Course

RIPE NCC Learning & Development

RIPE NCC Training Material

Please find your training material at:

https://www.ripe.net/training-material

Schedule

09:00 - 09:30	**Coffee and Tea**
11:00 - 11:15	**Break**
13:00 - 14:00	**Lunch**
15:30 - 15:45	**Break**
17:30	**End**

Introductions

- Names
- Experiences with BGP and routing security
- Goals

Hello!

Overview

- The need for BGP Security
- Analyse BGP Threats and Attacks
- BGP Security Measures:
  - How to mitigate BGP threats
  - Protection of BGP sessions
  - **LAB 1** Securing BGP Sessions
  - Implementing Route Filtering
  - **LAB 2** Creating BGP Prefix Filters
  - **LAB 3** Filtering AS-Path/number of prefixes
  - Registering in the IRR System
  - **LAB 4** Creating route(6) objects
  - Implementing RPKI
  - **LAB 5.1** Creating ROAs
  - **LAB 5.2** BGP Origin Validation
- Next steps for BGP Security
- Best practices

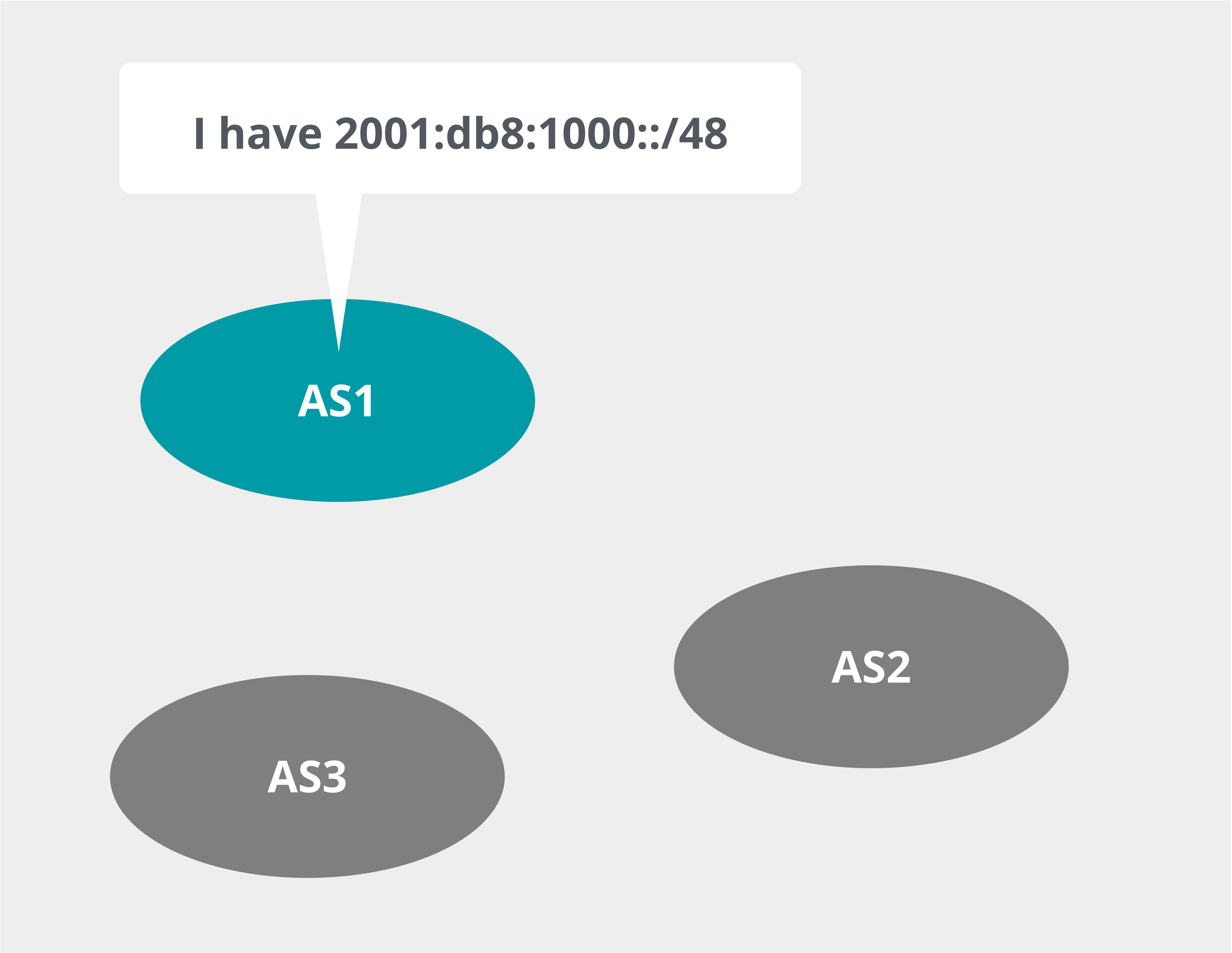
The Need for BGP Security

Section 1

Is BGP Secure?

In theory:

Only the legitimate resource holder should be announcing the prefix



Is BGP Secure?

In theory:

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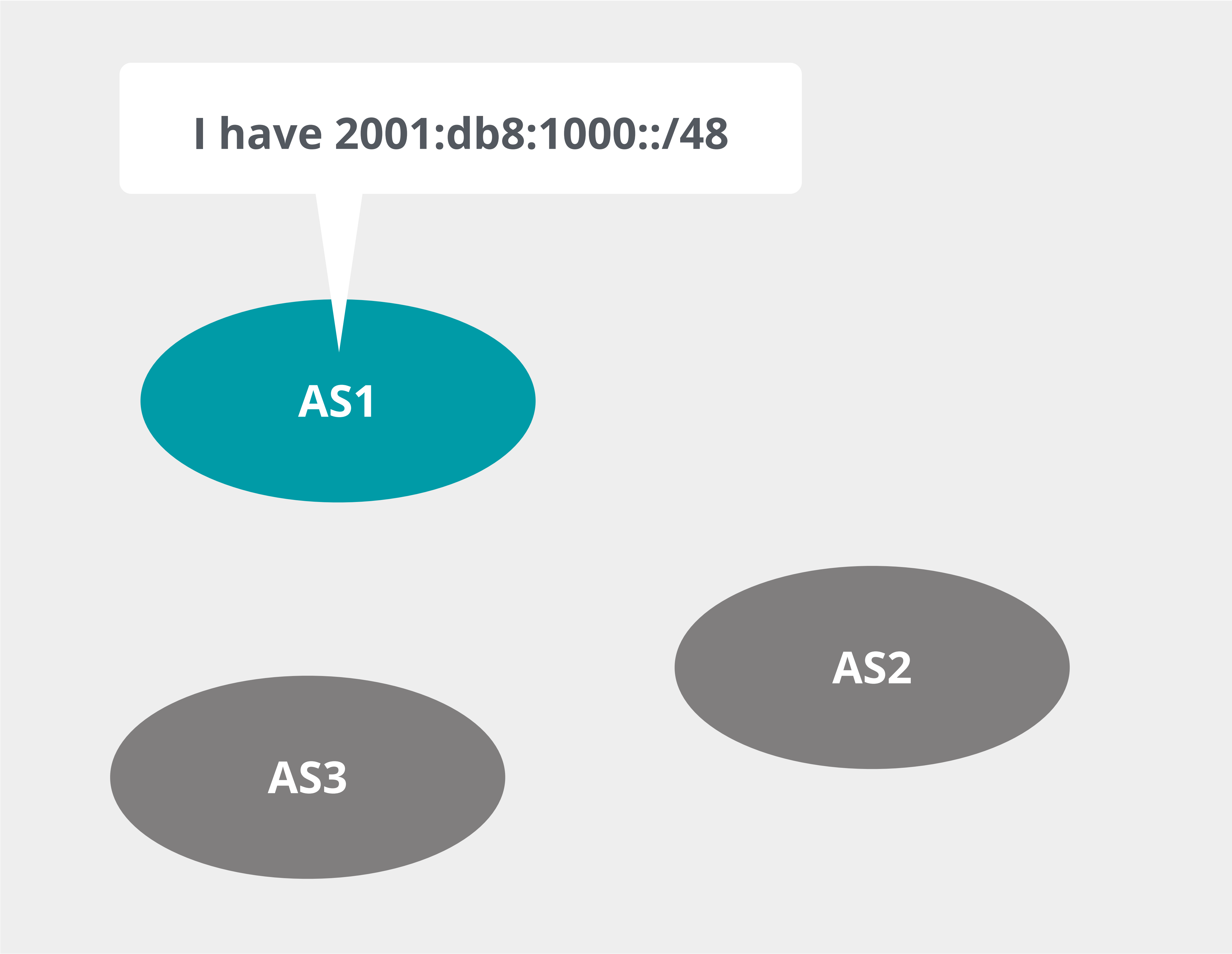
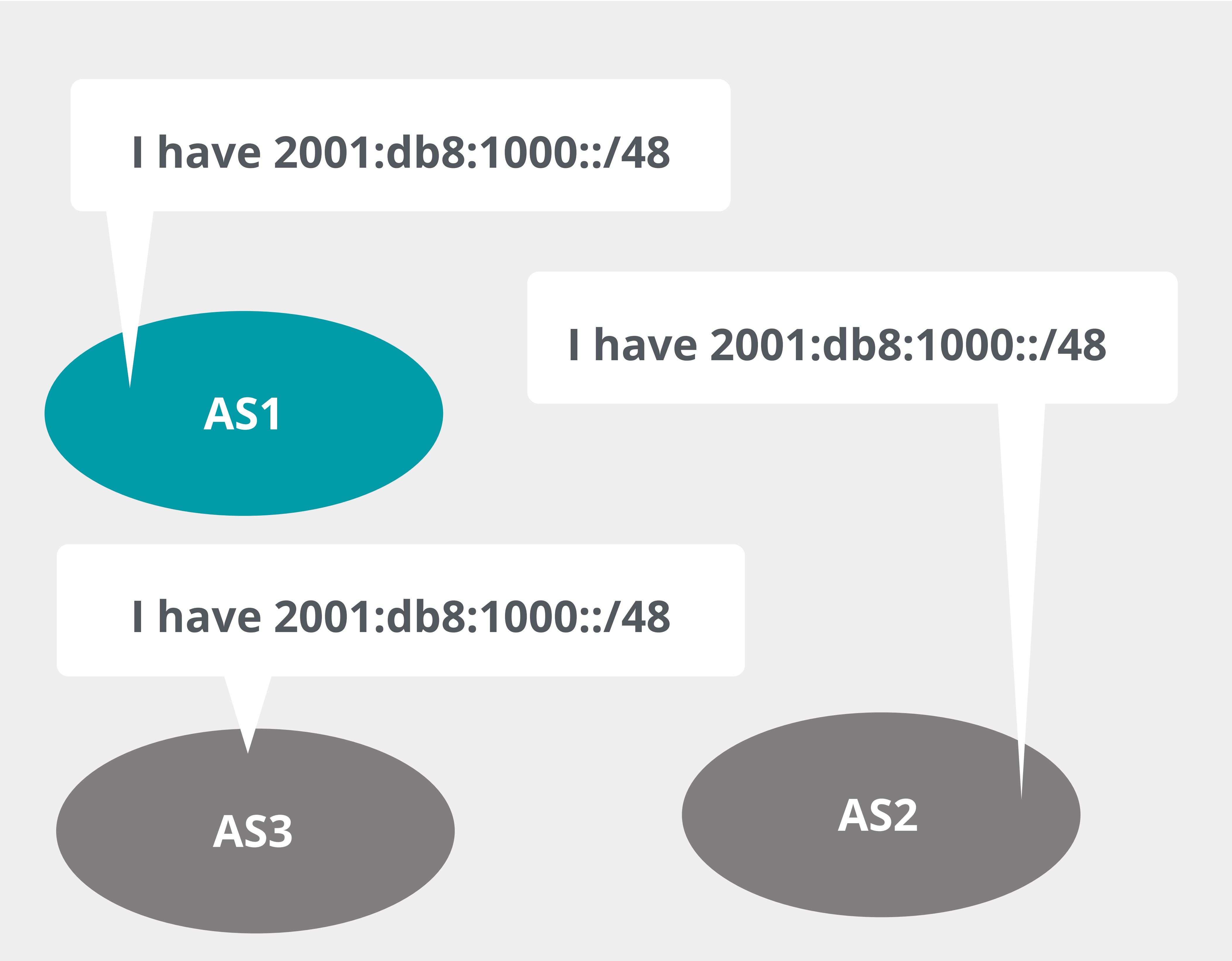


In practice:

Any AS can announce any prefix!

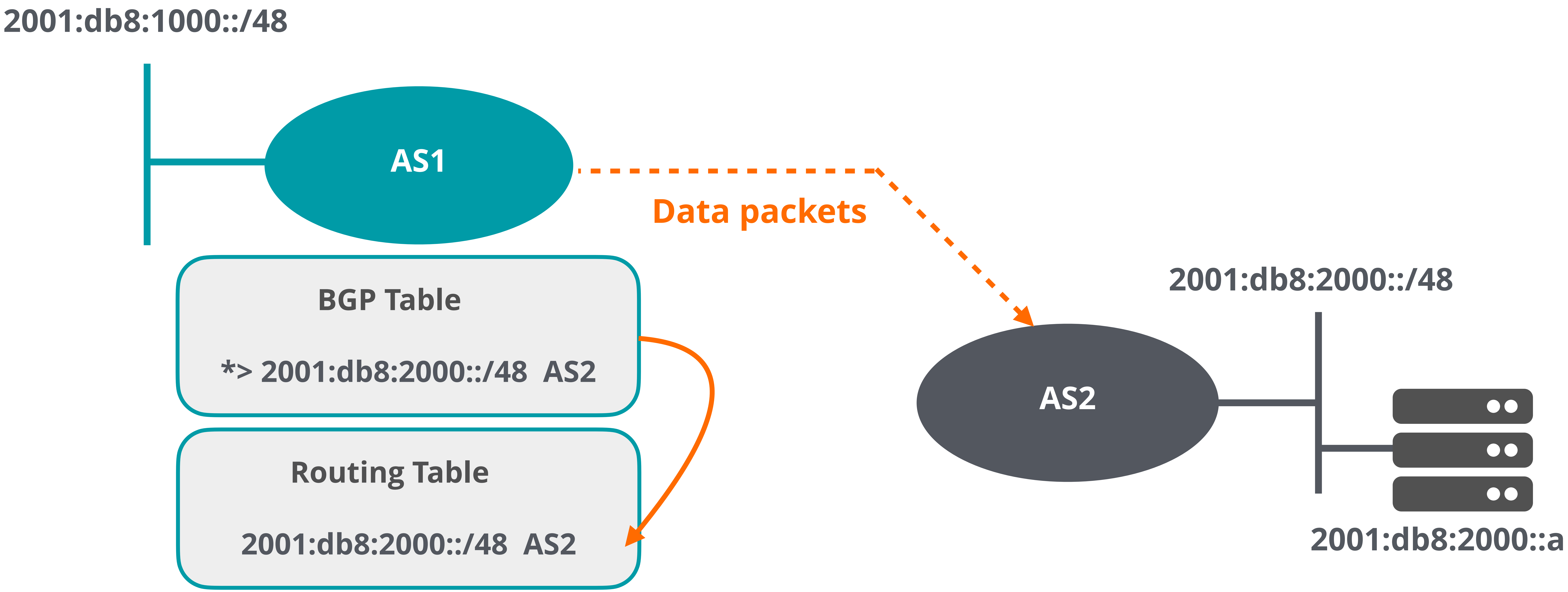


Is BGP Secure?

AS1 wants to access the server in AS2.

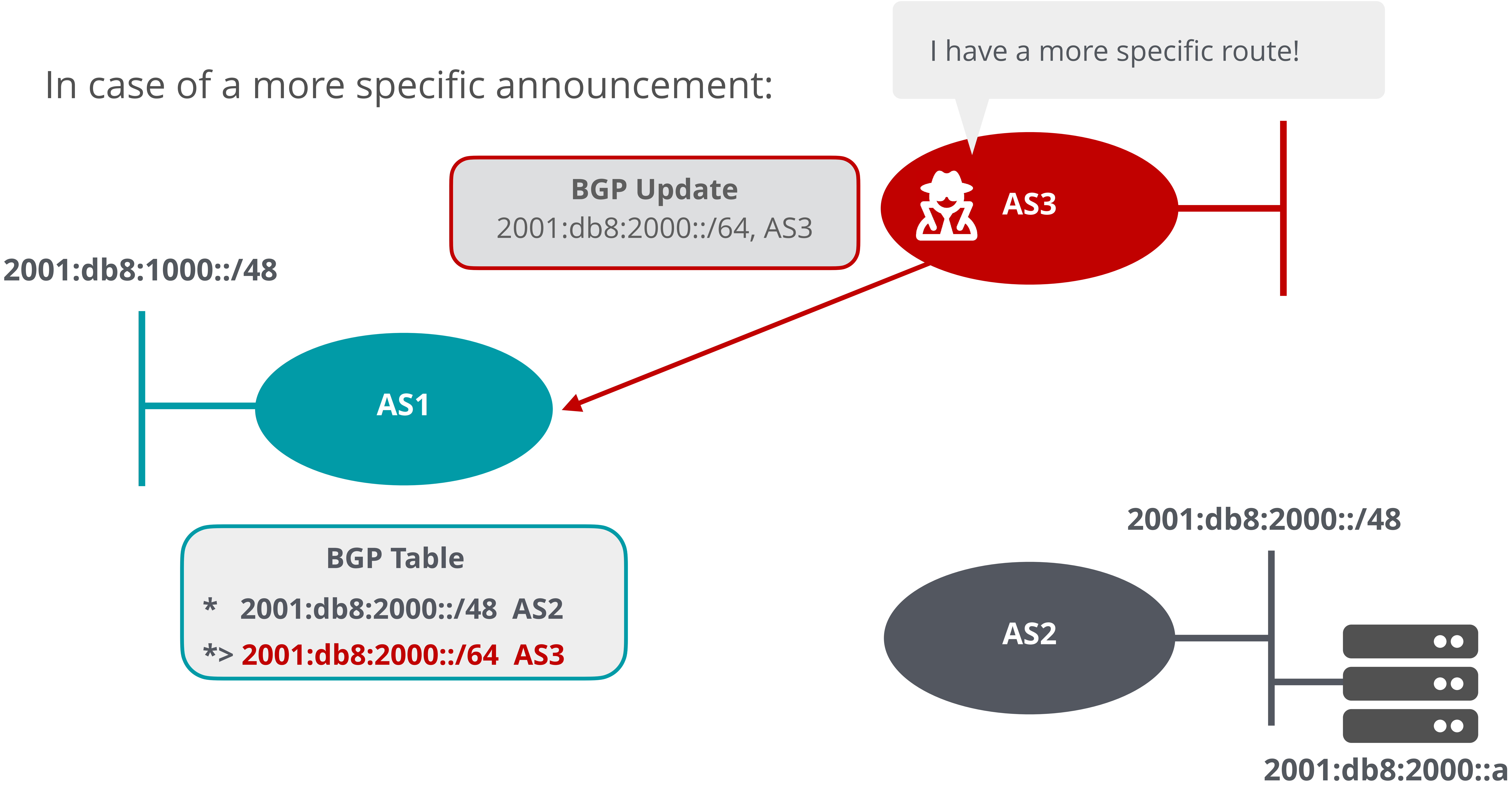
Is BGP Secure?

Data is forwarded based on routing table.



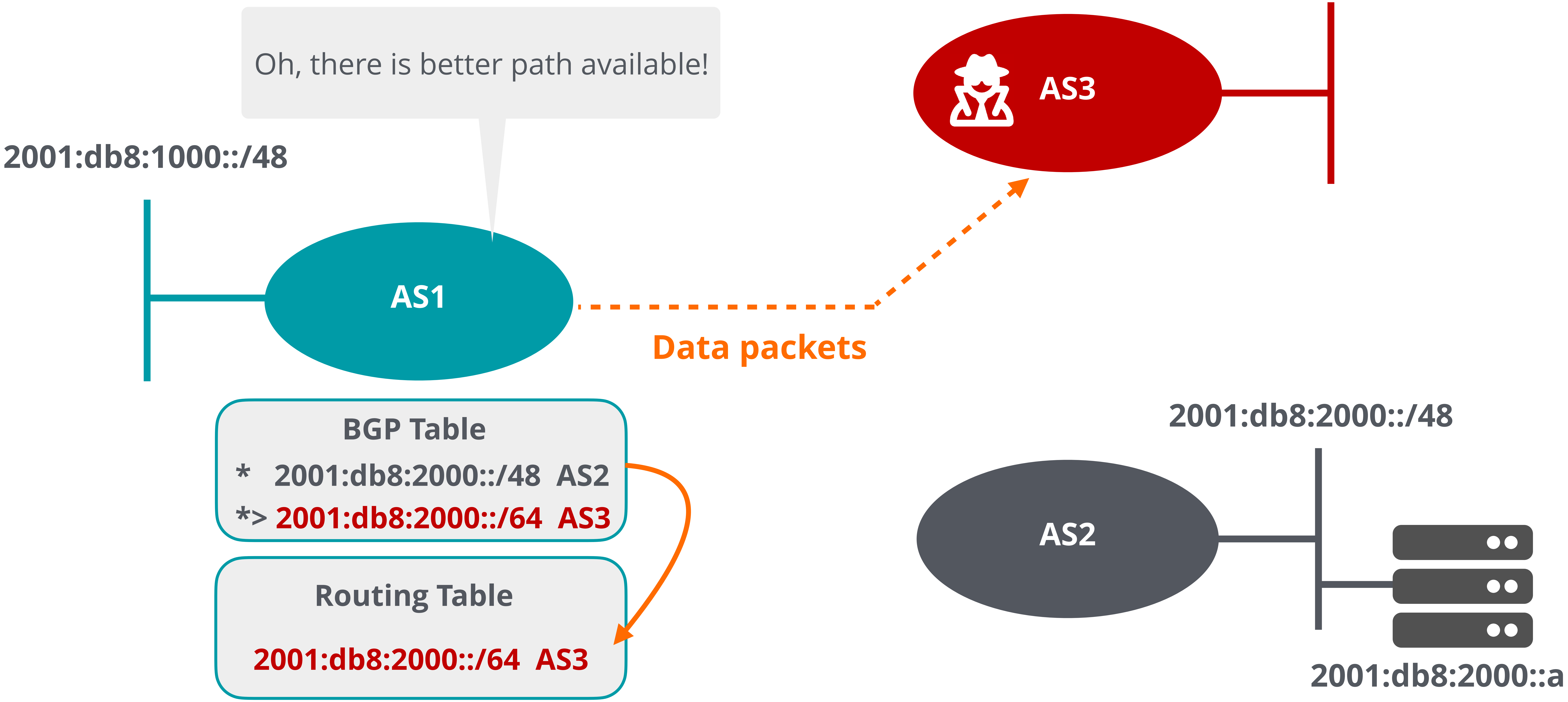
Is BGP Secure?

In case of a more specific announcement:



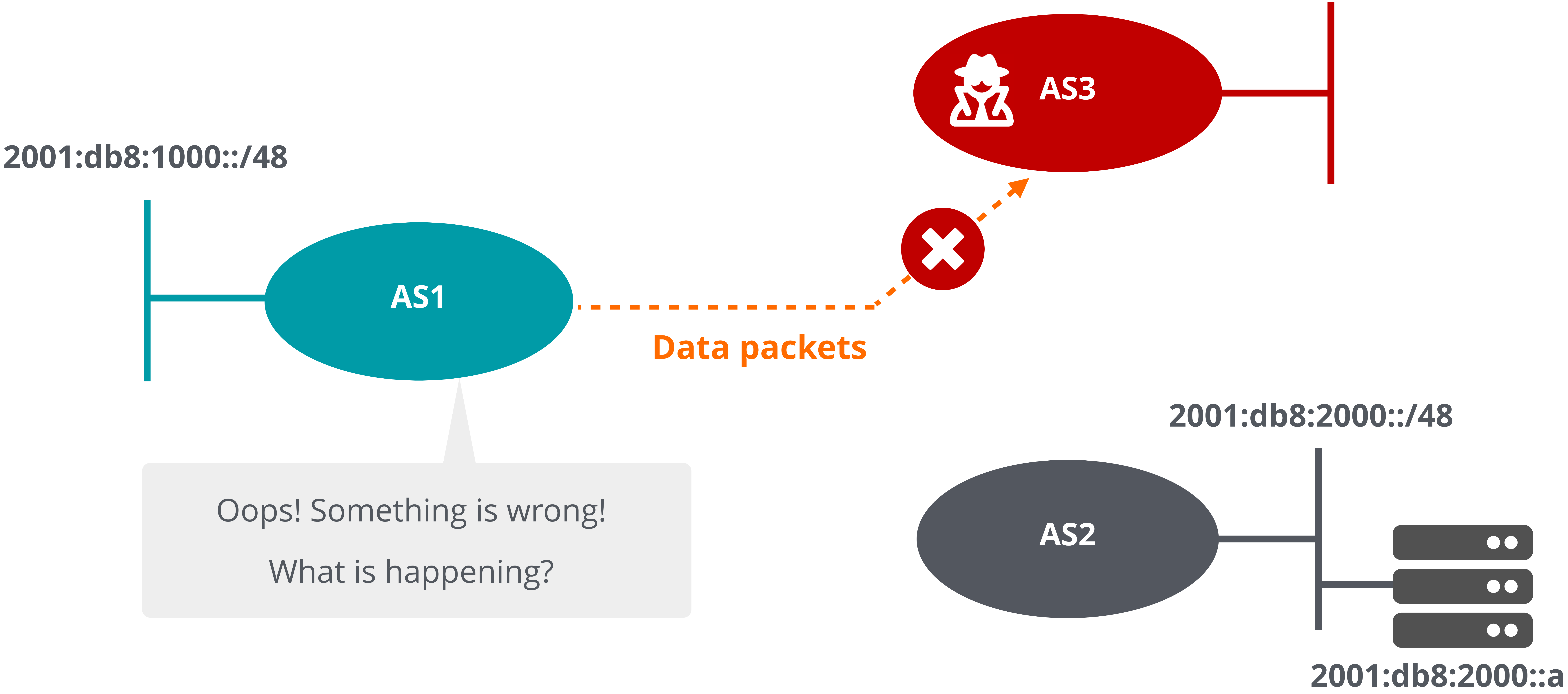
Is BGP Secure?

Traffic is diverted to the attacker:



Is BGP Secure?

And **blackholed**!



Questions

Analyse BGP Threats and Attacks

Section 2

Vulnerabilities of the BGP Protocol

Section 2.1

BGP Has Some Challenges

- It is only based on **trust**, no built-in security
- **No verification** of the correctness of prefixes or AS paths

RFC 4272 - “BGP Security Vulnerabilities Analysis”

BGP Has Three Main Vulnerabilities

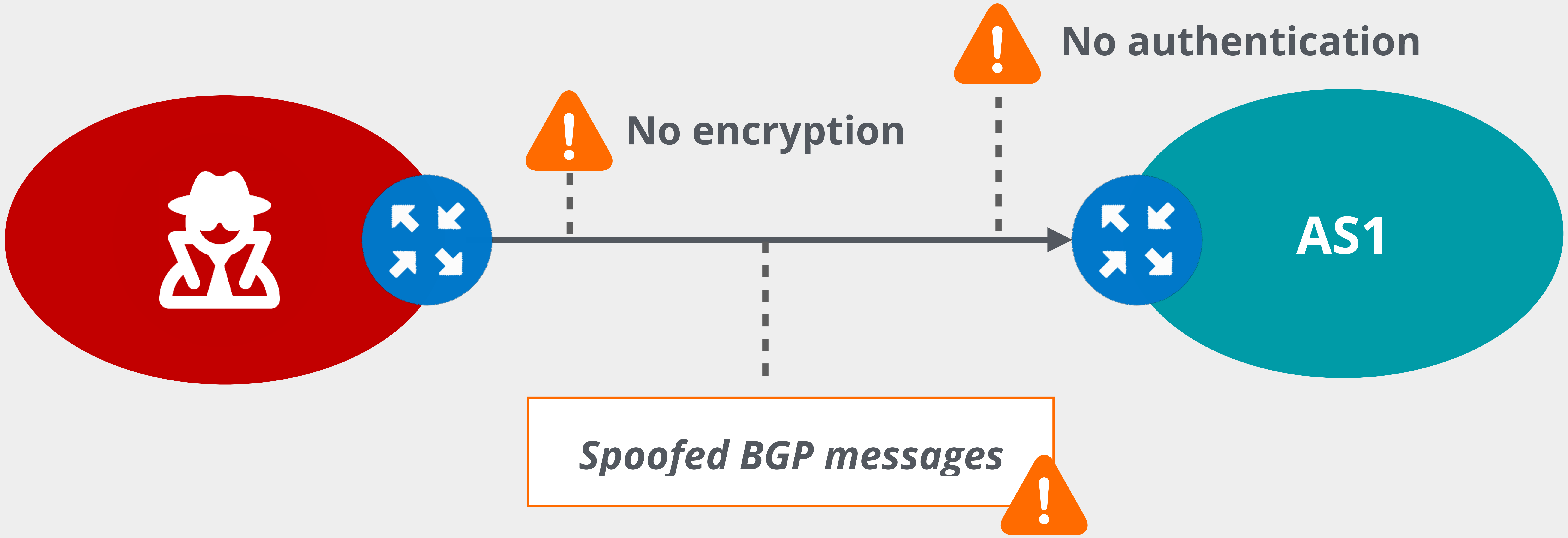
1. No internal mechanism to protect the integrity and source authenticity of BGP messages, and no confidentiality

2. No mechanism specified to validate the authority of an AS to announce a prefix

3. No mechanism to verify the authenticity of the attributes in a BGP update message

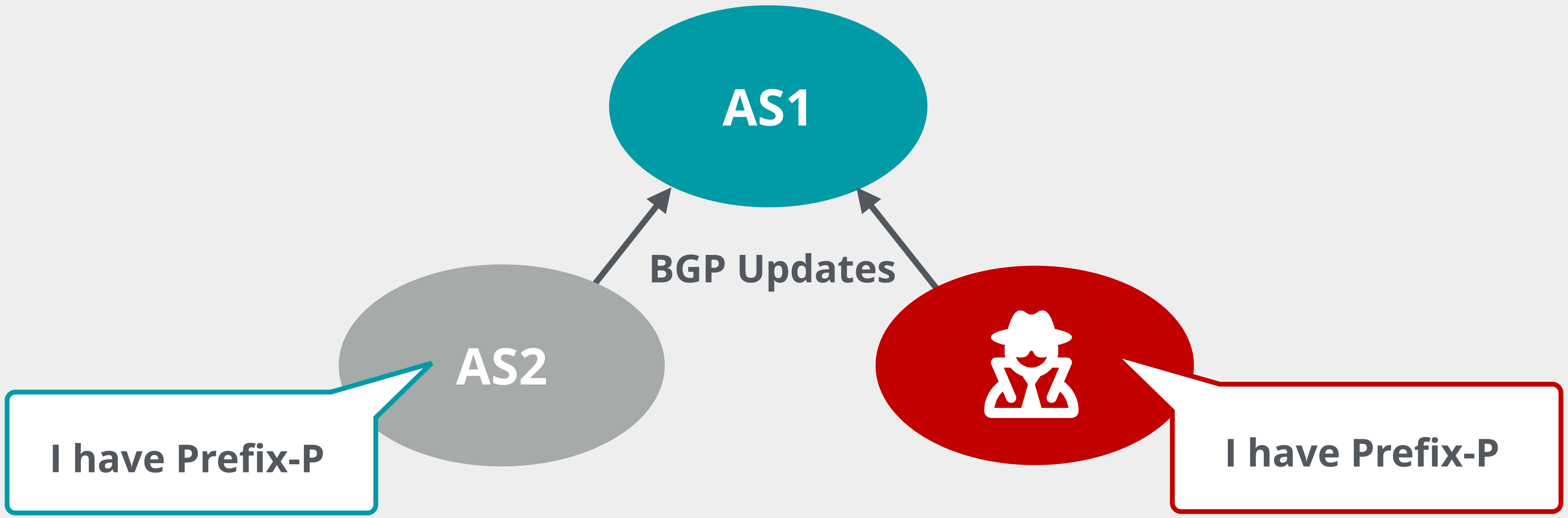
No Encryption or Authentication

- BGP **does not** have a built-in authentication mechanism
- BGP provides **no integrity** or **confidentiality**
- BGP messages do not use a freshness service and can be replayed



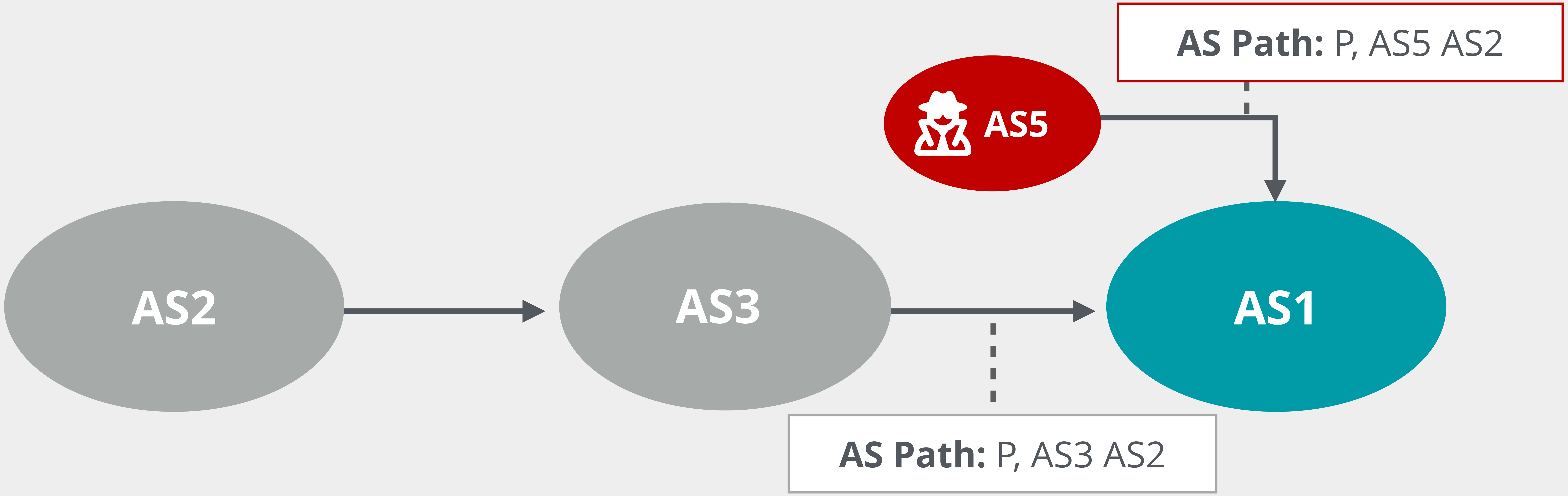
No Origin Validation

- BGP does not have a validity check for propagated routes
  - **Any AS can announce any prefix**



No Authentication of AS Path

- AS path attribute received in BGP update can not be validated
- Anyone can alter the path and prepend any ASN to the AS path



Due to these vulnerabilities

- Attacks can be conducted by exploiting TCP or BGP messages
- Any AS can announce any prefix
- Any AS can prepend any ASN to the AS path

Fake routing information may disrupt Internet routing

Causes of BGP Incidents

Section 2.2

Causes of BGP incidents can be divided into

Malicious

Accidental

Sometimes, it’s Just Human Error

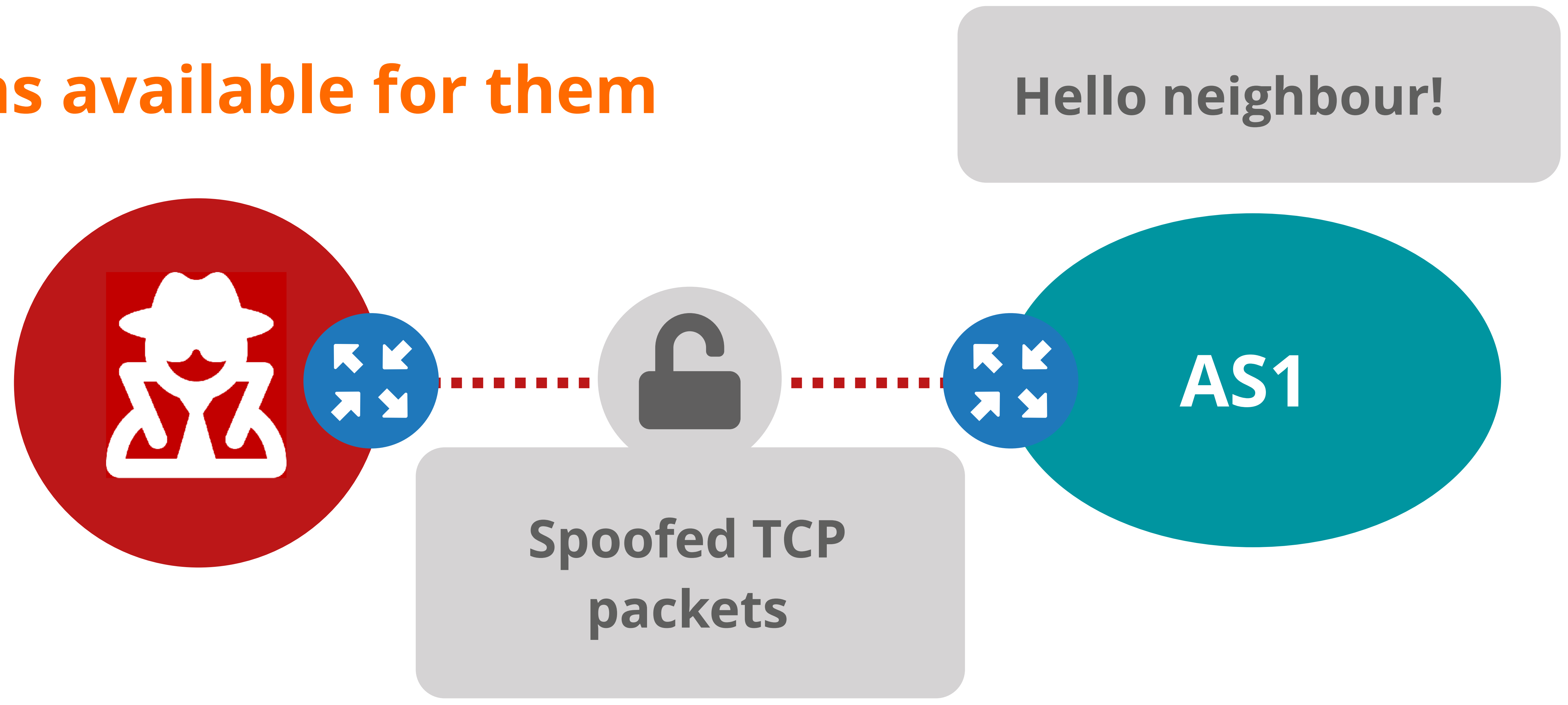
- Typo errors (fat finger)
  - May cause mis-origination
- Configuration errors
  - May cause mis-origination
  - AS path prepending mistake
- Simple mistakes may cause big problems!
  - BGP hijacks or **route leaks**

But Sometimes They're Malicious!

- ROUTE MANIPULATION ATTACKS
- TCP/IP PROTOCOL ATTACKS
- PROTOCOL MANIPULATION ATTACKS
- DENIAL-OF-SERVICE ATTACKS

TCP/IP Protocol Attacks

- BGP uses TCP: vulnerable to **TCP/IP based attacks**
  - **IP Spoofing**
  - **TCP Session Hijacking**
  - **SYN flooding attack**
- **No BGP-specific security solutions available for them**

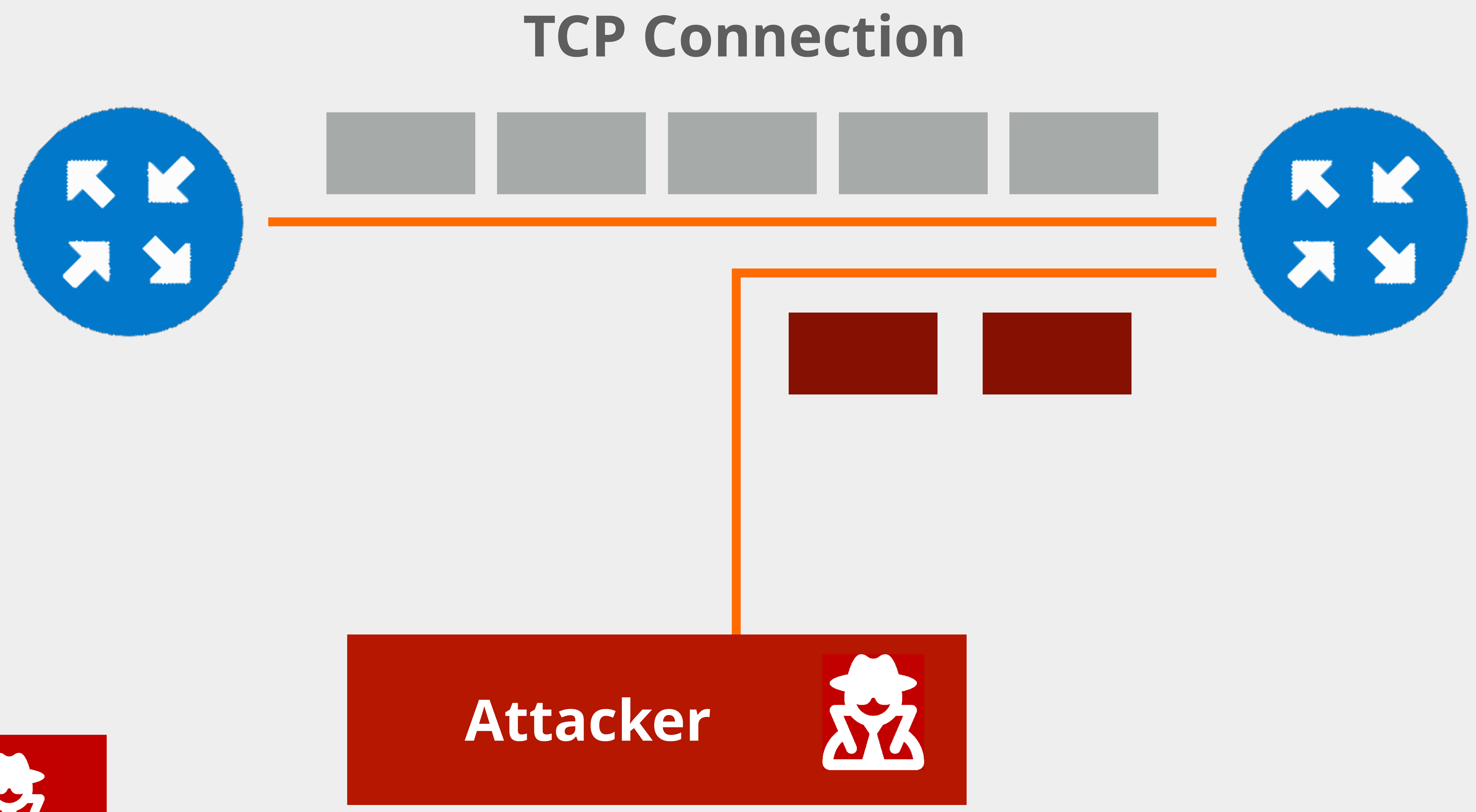


IP Spoofing

- An attacker could spoof an IP address of a BGP peer in order to:
  - Establish an unauthorised BGP session
  - Break an existing BGP session
  - Inject bogus routes or delete routes

TCP Session Hijacking

- Involves intrusion into an ongoing session



Same header fields

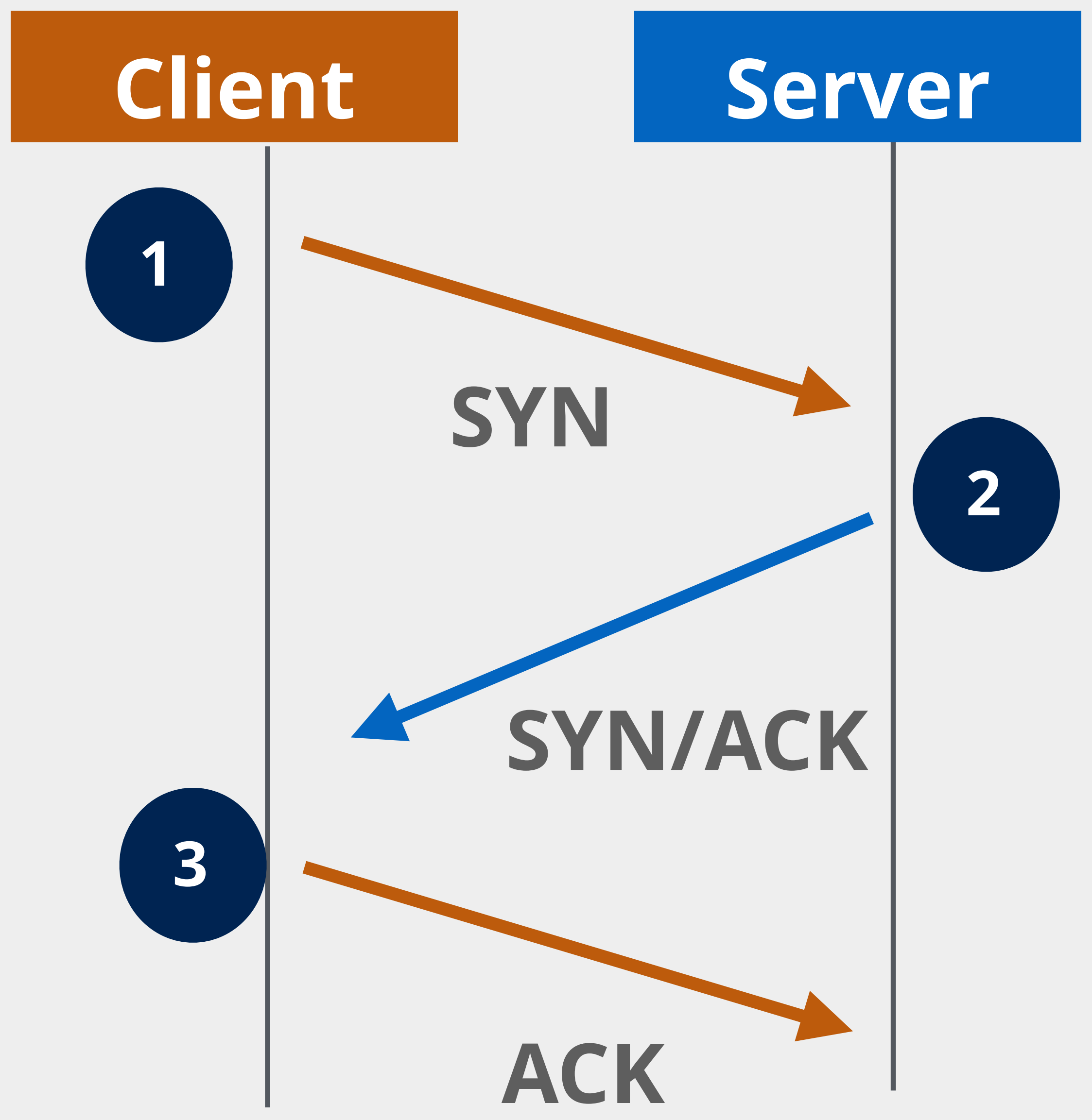
- Source IP
- Destination IP
- Source Port
- Destination Port

TCP Session Hijacking

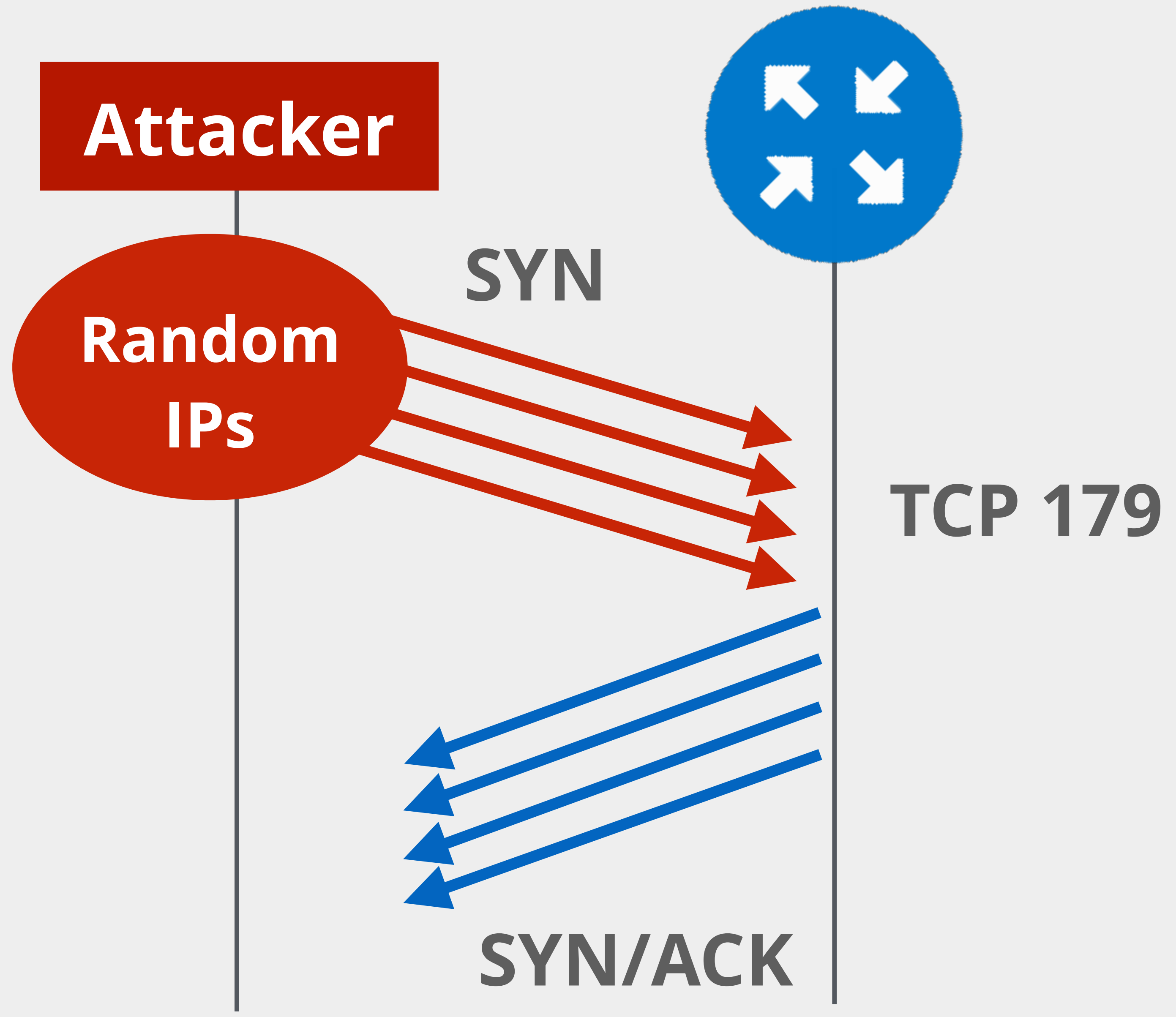
- **Requires an attacker to discover the following**:
  - src IP, dst IP, src port, dst port
  - sequence number of ongoing session
- **In BGP, it could be used to**
  - bring down the BGP session between peers (TCP RST)
  - inject false routes into BGP, delete or modify routes

SYN Flooding Attack

- A type of Denial-of-Service (DoS)
- Exploits the **three-way hand shake** process of a TCP connection
- **Goal:** Exhaust resources



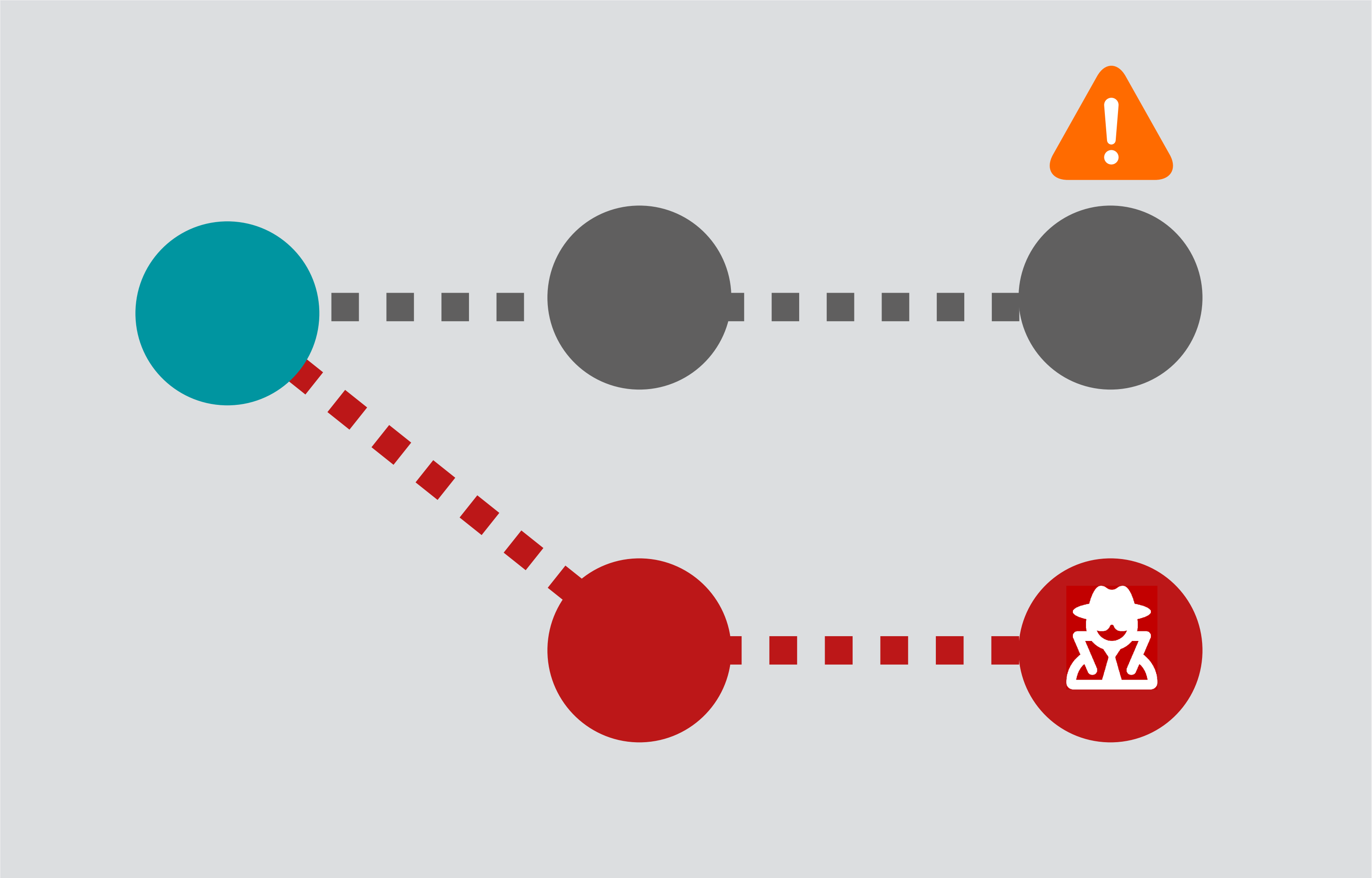
TCP 3-way Handshake



SYN Flooding Attack

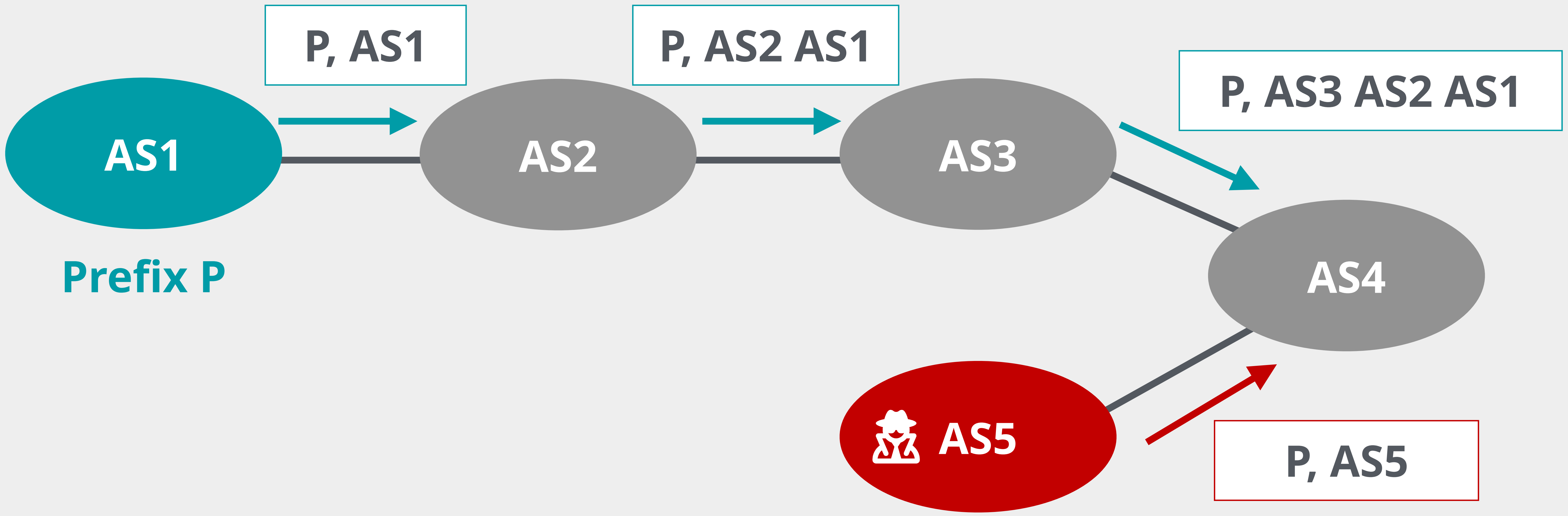
BGP Route Manipulation Attacks

- **Goal:** Blackholing, eavesdropping or traffic analysis
- Attacker can:
  - **Inject bogus routes** into BGP tables
  - **Reroute packets** based on their intentions
  - **Prevent traffic** from reaching the intended destination
- Can be classified as:
  - **BGP Origin Hijacks**
  - **BGP Path Hijacks**
  - **BGP Route Leaks**
- Very common! **Our focus on this course**



BGP Origin Hijack

- The hijacking AS:
  - Abuses mutual trust between ASes
  - Originates a prefix **that it is not authorised to originate!**
- Difficult to say whether it is an accident or an attack
- Traffic lost or received by attacker (eavesdrop)



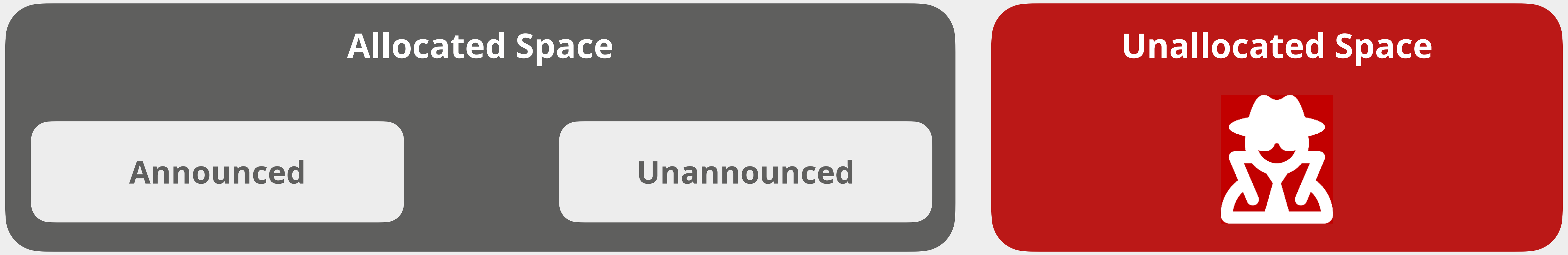
ROUTE MANIPULATION

Hijacks of Allocated Addresses

- Allocated address space could be:
  - Currently in use (**announced** prefixes)
  - Or unused IP space (**unannounced** prefixes)
- **Unannounced** prefixes are preferred by spammers
  - No operational impact
  - Potentially harms the reputation of the holder

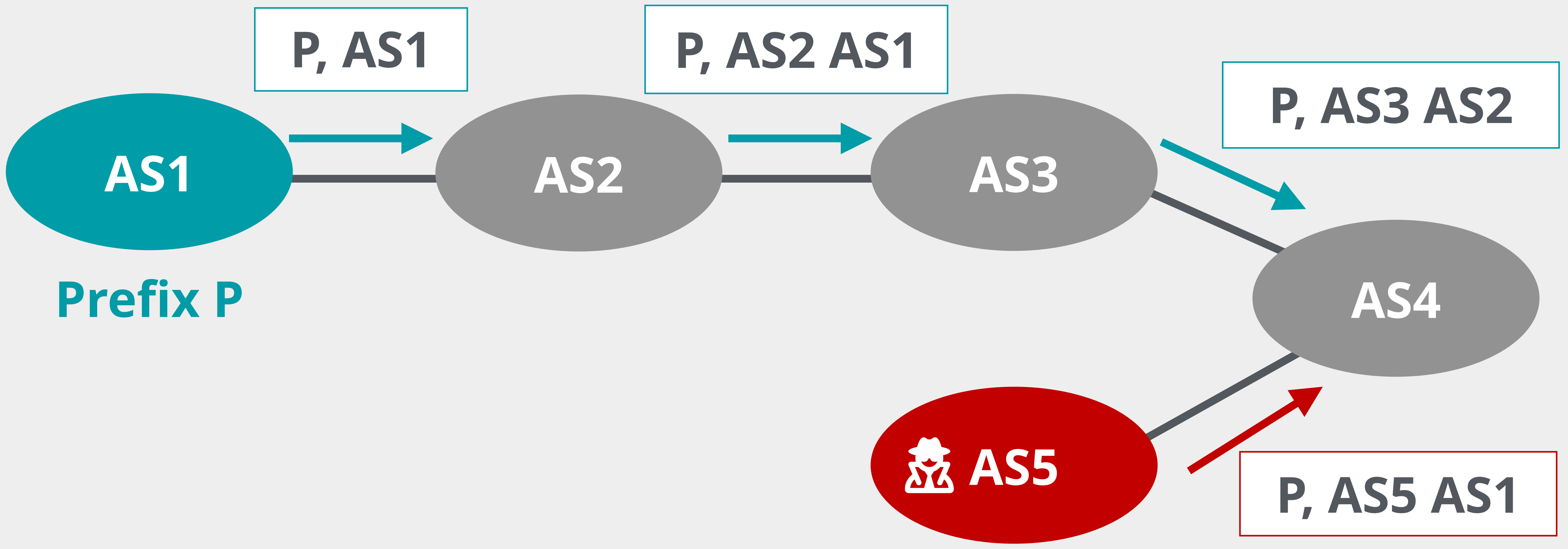
Hijacks of Unallocated Addresses

- IP blocks not assigned by IANA or RIRs
- Effective if full bogon filters not applied
- No whois entries, no complaints!
- Again, a good choice for spammers



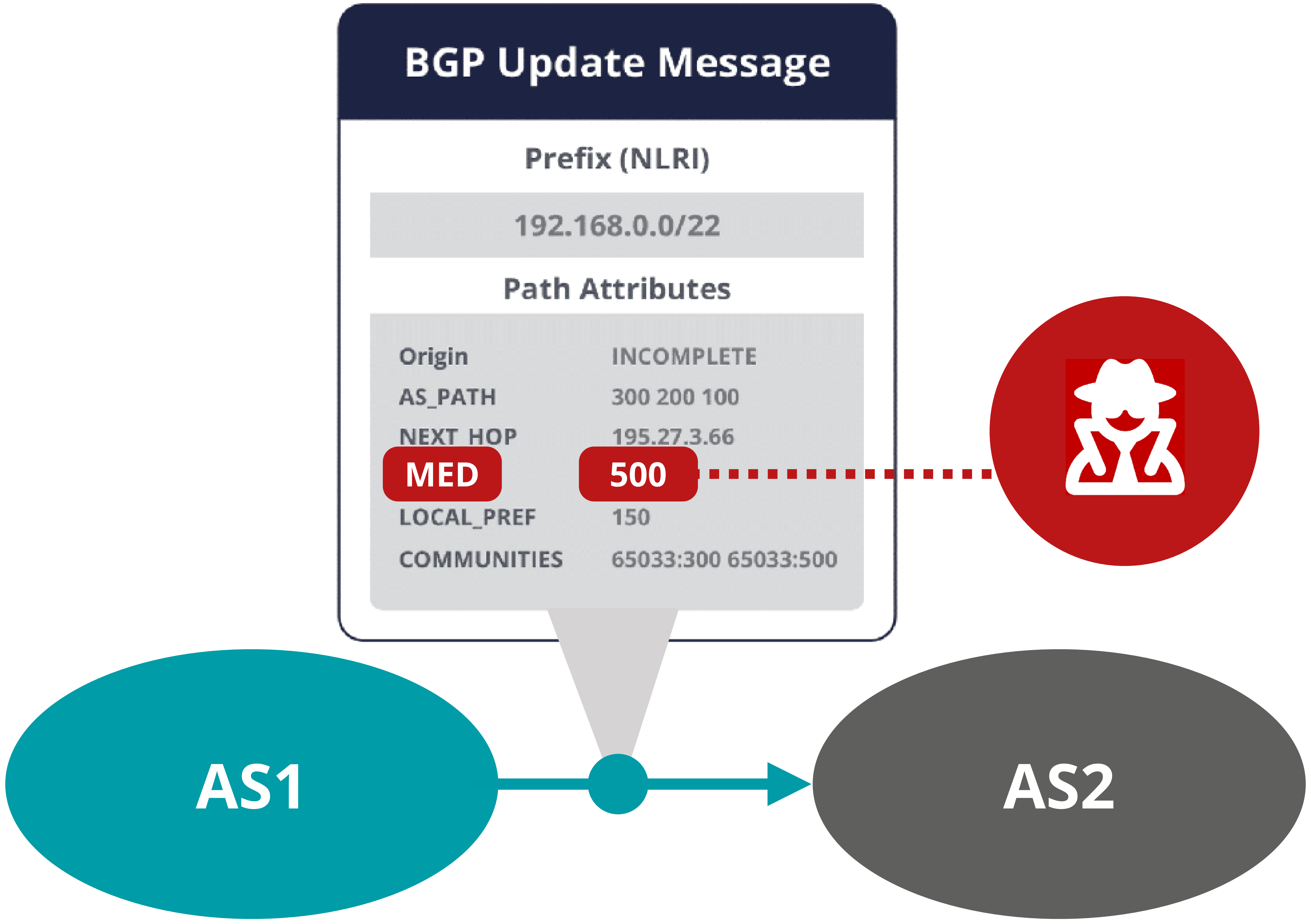
BGP Path Hijack

- No verification of path attributes in received BGP updates
- Hijacker can modify the AS Path and **redirect traffic**
- **Traffic lost** or **eavesdropped/modified** (adds latency)



Protocol Manipulation Attacks

- Relatively new type of attack, no reports yet
- A malicious AS aims to **manipulate properties of BGP protocol**
- An attacker may:
  - Modify MED attribute
  - Exploit RFD/MRAI timer



Protocol Manipulation Attacks

- **Multi-exit-discriminator (MED)**
  - A malicious AS may affect ASes' decisions by altering this attribute
- **Route Flap Damping (RFD) / Minimum Route Advertisement Interval (MRAI) timers**

HOW — A Malicious AS artificially withdraws and re-announces a route

EFFECT — ASes using RFD timer consider the route unstable and suppress it

EFFECT — ASes using MRAI timer delay the distribution of corresponding update message

Denial of Service (DoS) Attacks

- An **attacker** can execute DoS attacks in several ways:
  - BGP session failure due to congestion
  - Deliberate route flapping
  - Explosion of routing table size
  - Blackholing traffic
  - TCP attacks (SYN flooding or TCP Reset)
- DDoS solutions are already available
  - Not specifically for BGP speakers

To Summarise

- BGP is vulnerable to **mistakes** and **attacks**
- Attackers could:
  - Inject bogus routes into the BGP table
  - Hijack a BGP session and break peer-to-peer connections
  - Initiate a DoS attack and exhaust victim’s resources
  - Manipulate BGP and reroute packets
  - Intercept and eavesdrop
  - Blackhole the entire network, etc

BGP Incidents in Q3 2023

BGP route leaking ASes	Q3 2023	BGP hijacking ASes
1,865	July	9,262
1,861	August	11,848
1,887	September	9,368

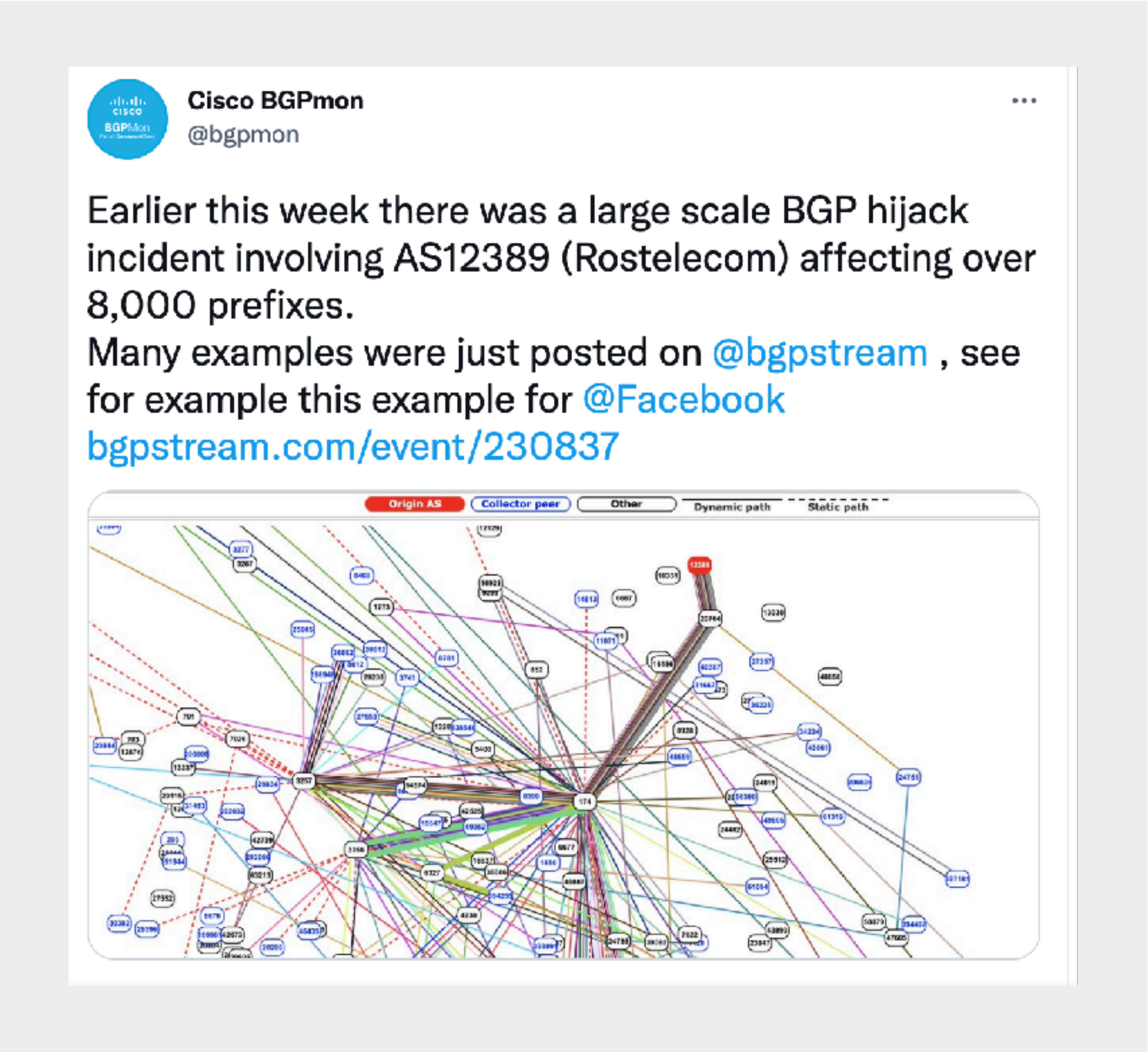
Unique route leakers
2,952

Unique hijackers
15,053

Source:
https://blog.qrator.net/en/q3-2023-ddos-attacks-statistics-and-observations_182/

April 2020: Akamai, Amazon

- **What happened?**
  - 8k+ routes hijacked by Rostelecom (AS12389)
  - 200+ CDNs and cloud providers impacted
  - Not known how much data leaked
- **Why?**
  - Malicious activity
  - Lack of good filtering by upstream providers/peers



Questions

BGP Security Measures

Section 3

How to Mitigate BGP Threats

Section 3.1

How to Mitigate BGP Threats?

- To deal with this, you need to:
  - **Secure message exchange** between BGP speakers
  - **Validate the routing** information you receive

Some authentication and verification mechanisms should be in place

Prevent propagation of incorrect routing information

How to Mitigate BGP Threats?

- It requires the following to be verified:

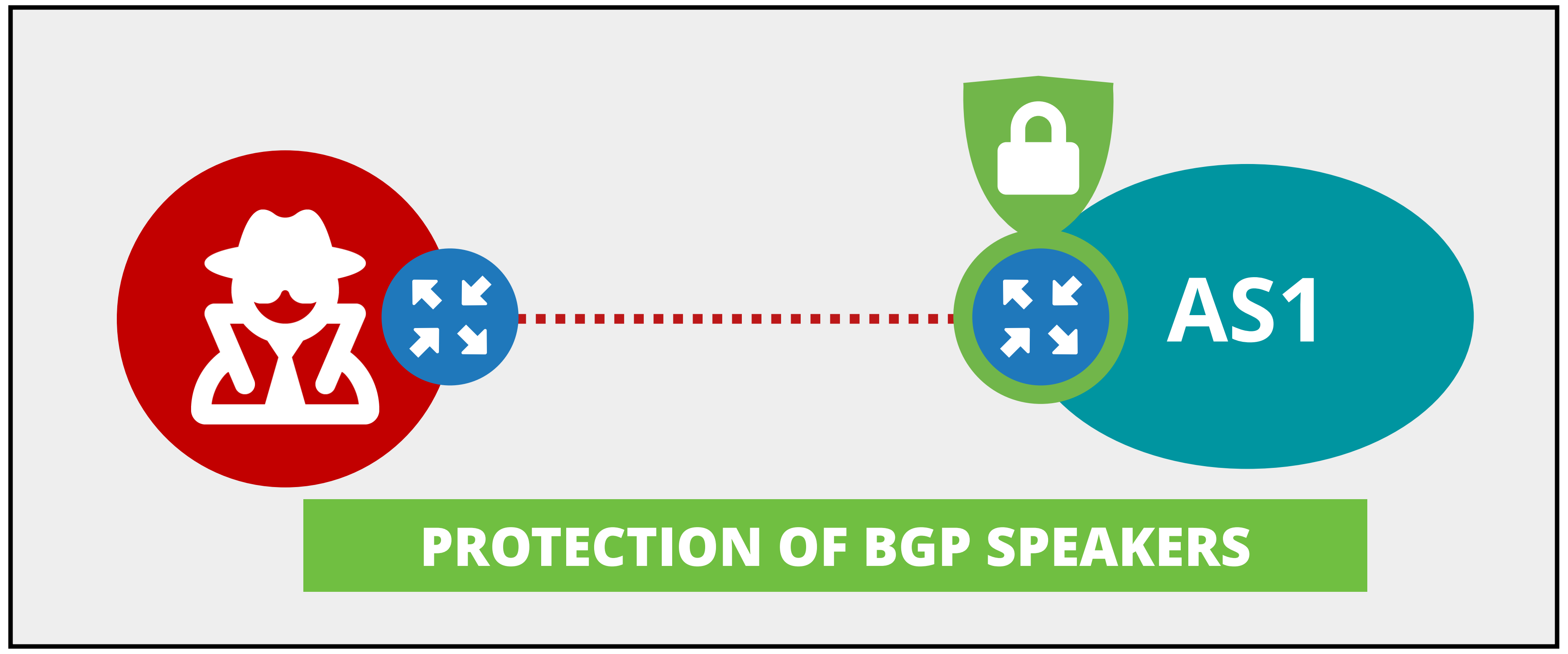
Does the BGP speaker belong to the AS that it claims?

Is the prefix originated by the legitimate holder or an AS that is authorised to originate it?

Does the AS path reflect the sequence of ASes that the BGP UPDATE packet has traversed?

Are the attributes in a BGP UPDATE message correct and have not been tampered with?

BGP Security Measures



Only BGP peers to send packets to TCP 179: Control Plane Policing (CoPP), or ACLs (if CoPP not supported)

Limit accepted BGP traffic

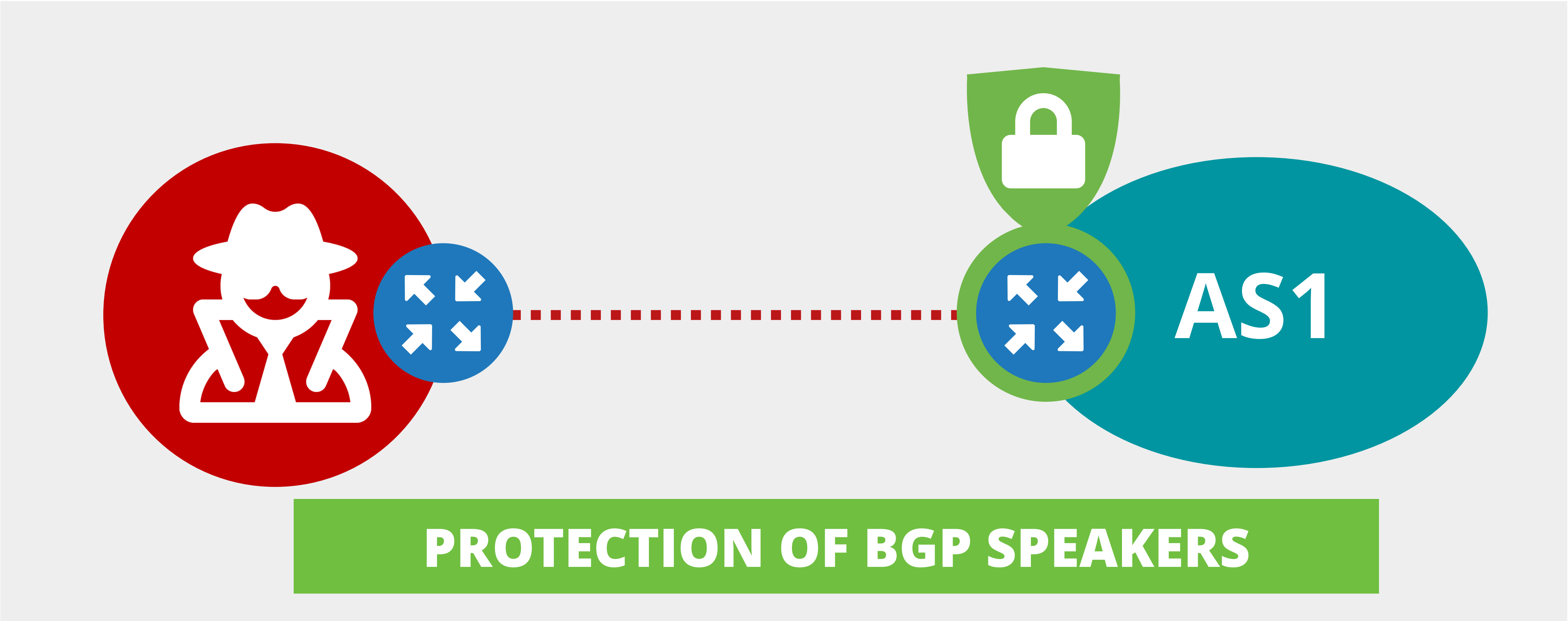
uRPF to mitigate DoS/DDoS attacks

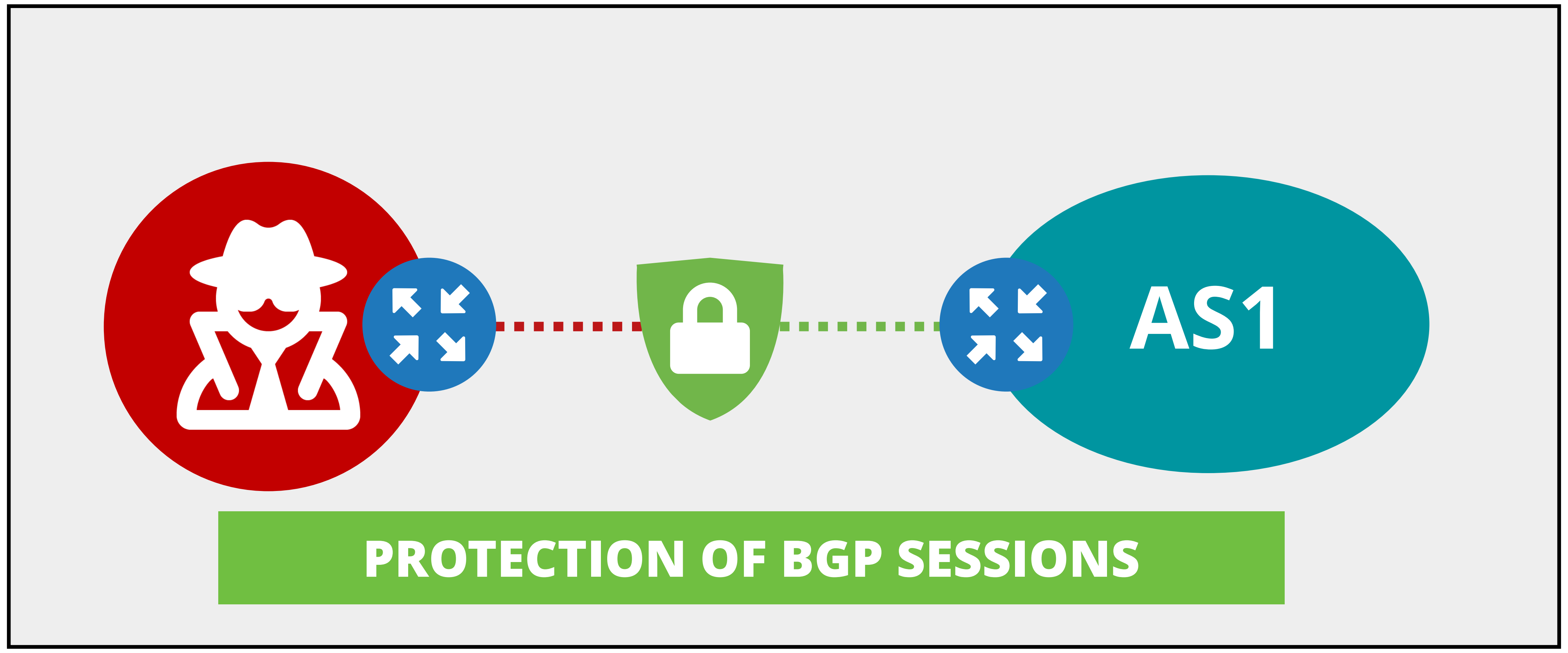
RIPE NCC Academy

BGP Security

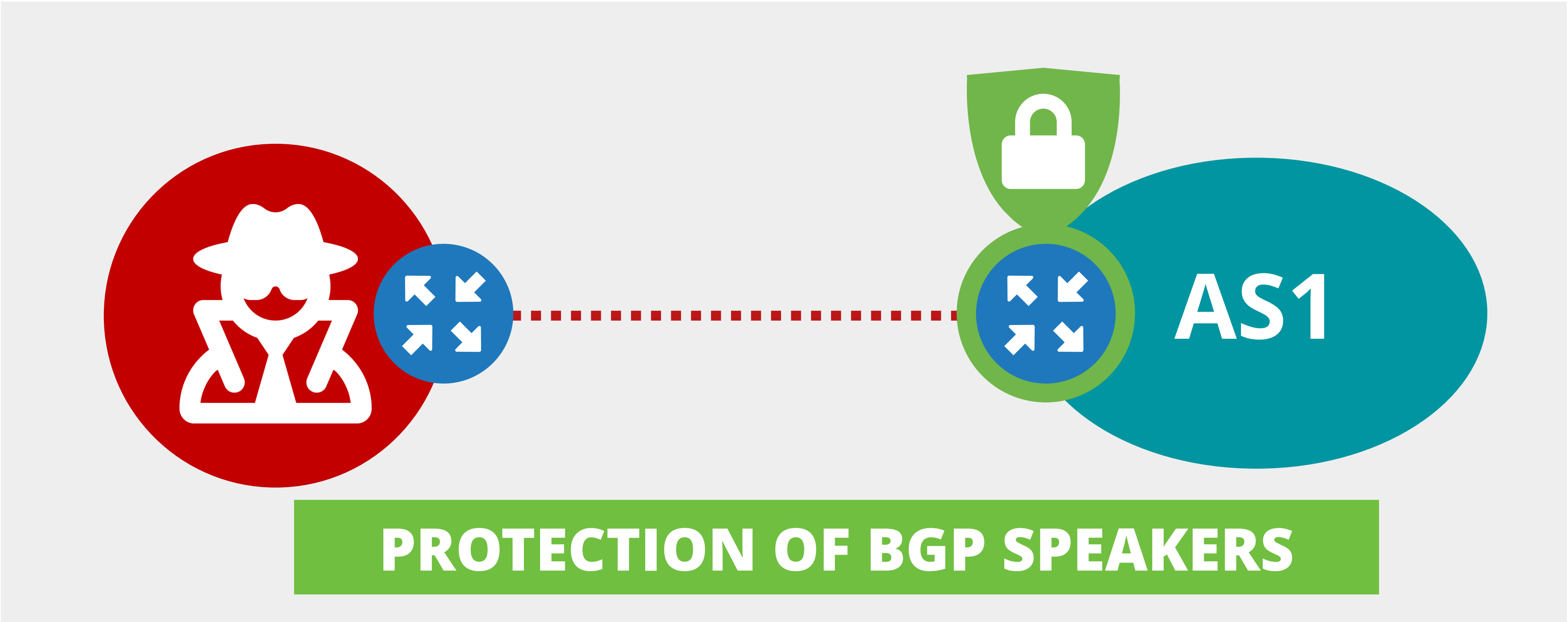
https://academy.ripe.net/bgp-security/

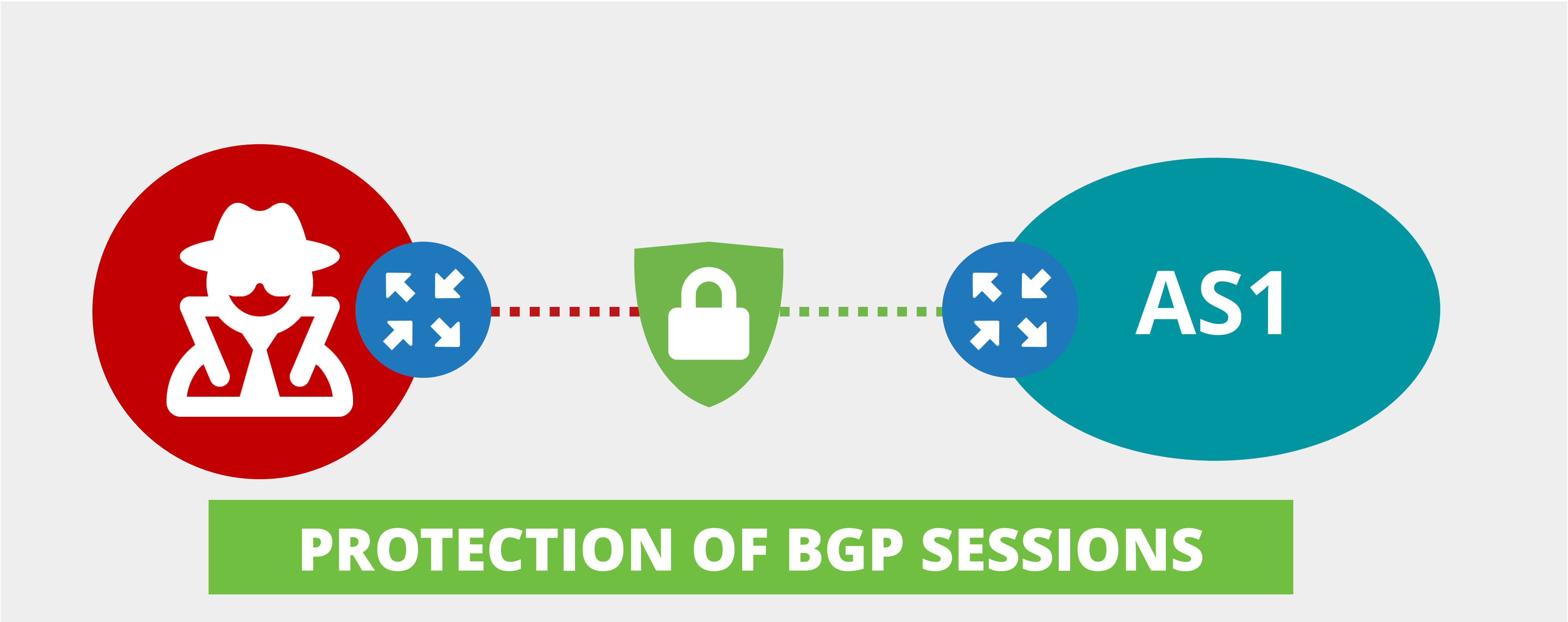
BGP Security Measures

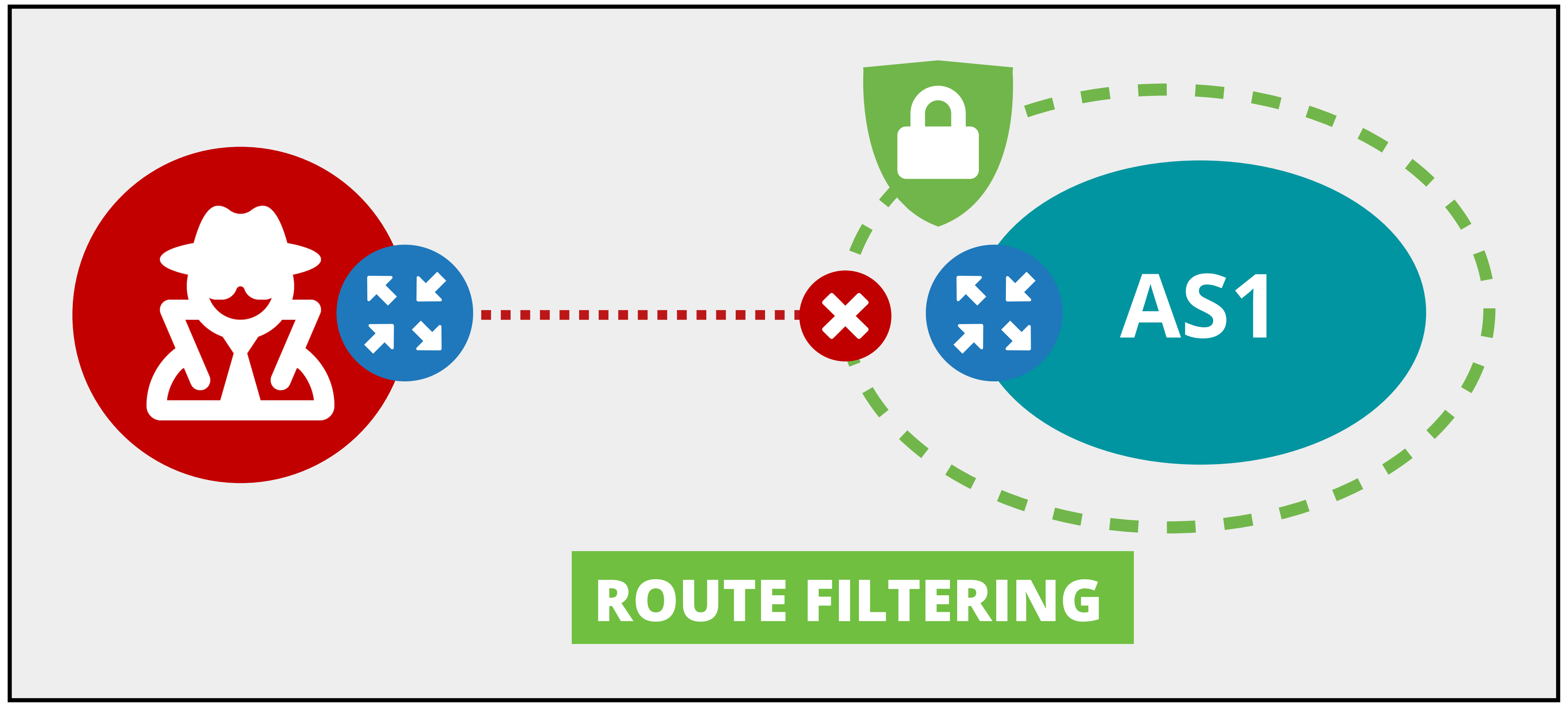




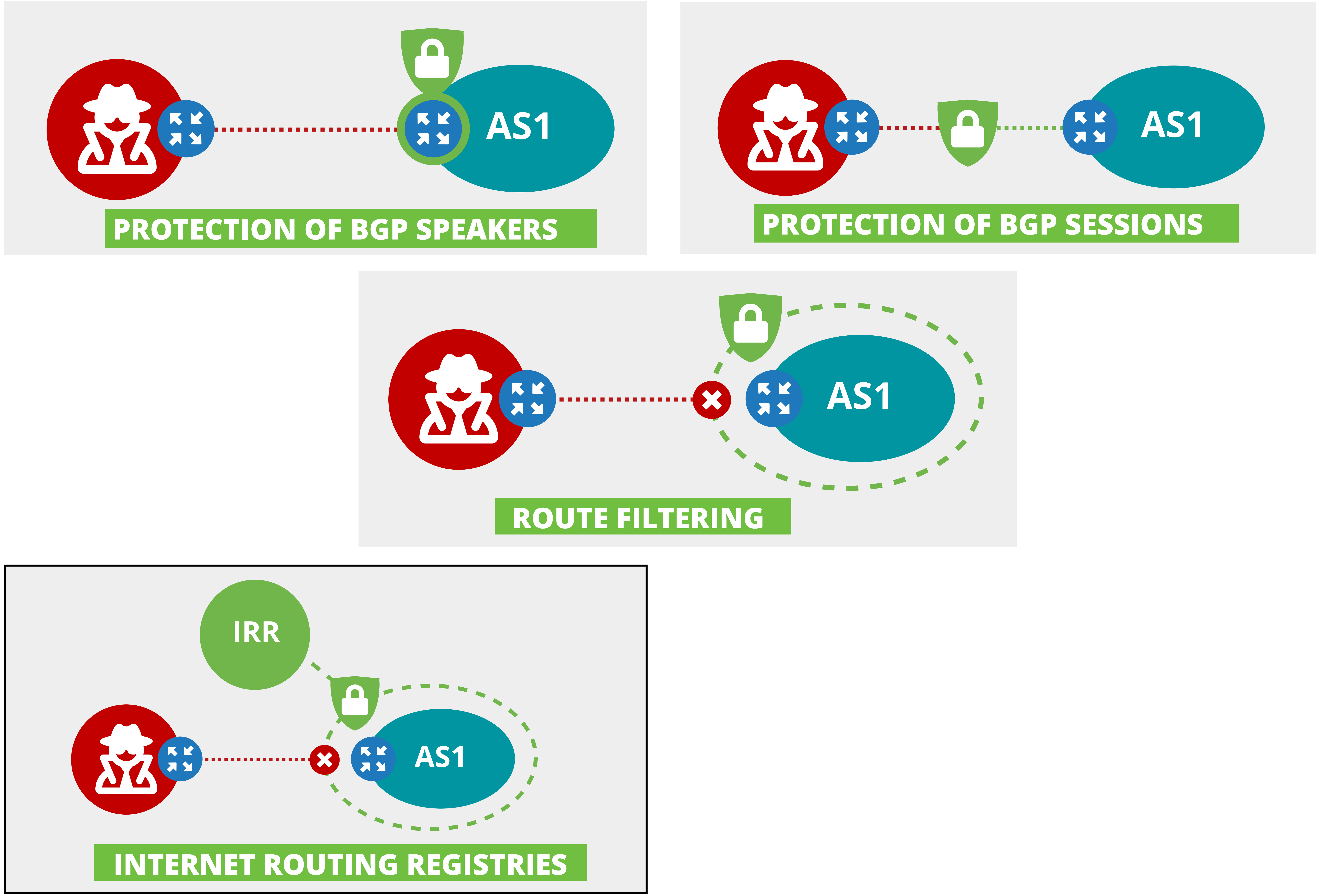
BGP Security Measures



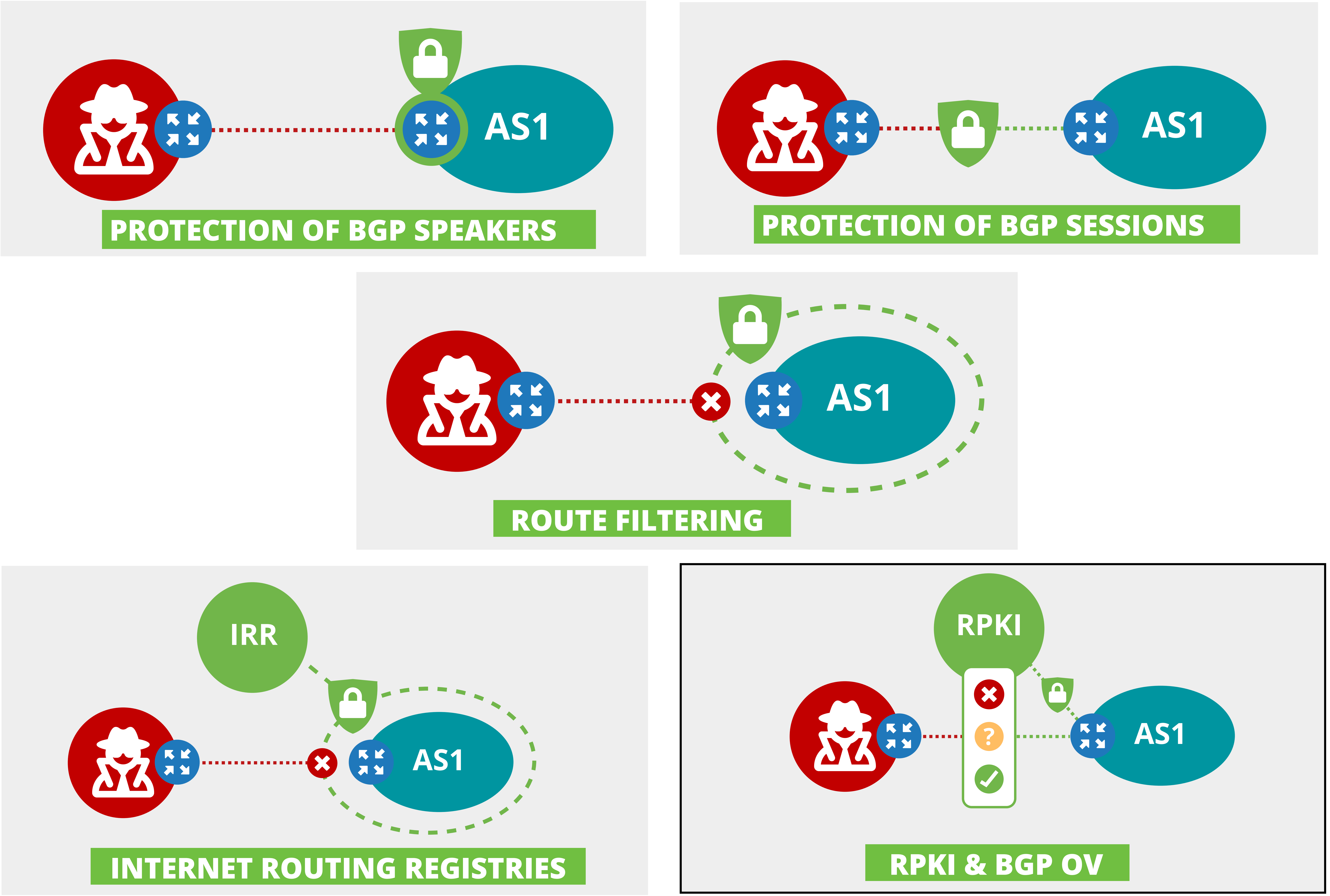




BGP Security Measures



BGP Security Measures



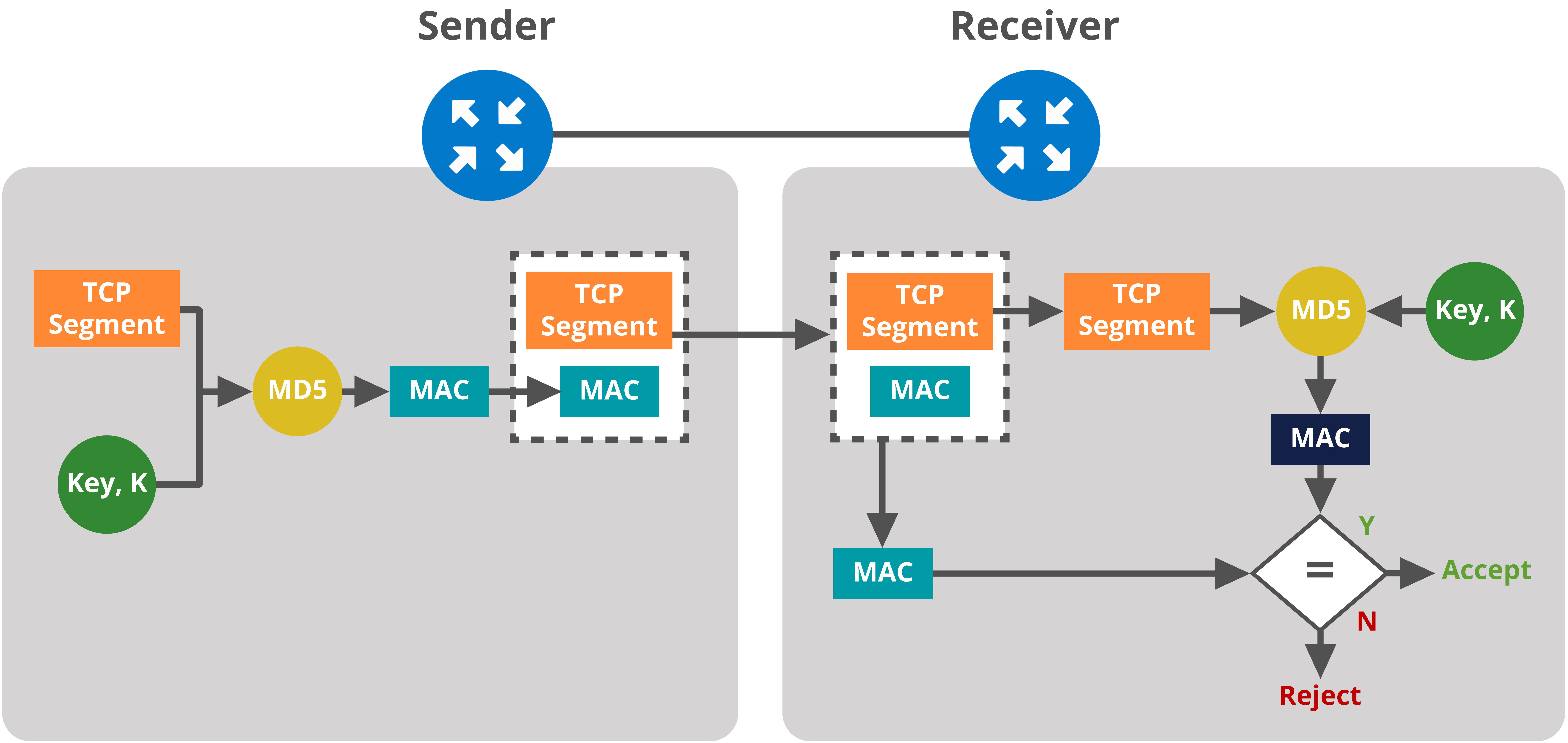
Protection of BGP Sessions

Section 3.2

BGP Session Protection

- BGP sessions are subject to TCP/IP vulnerabilities
  - IP Spoofing, TCP session hijacking, SYN flooding
- Attacks against message integrity and confidentiality are possible
  - Man-in-the-middle and replay attacks
- We will see three solutions:
  - **TCP MD5** and **TCP-AO**, to protect the BGP TCP session
  - BGP **TTL Security** (GTSM - Generalised TTL Security Mechanism)

TCP MD5



Sender
Receiver
TCP Segment
Key, K
MD5
MAC
TCP Segment
MAC
TCP Segment
MAC
TCP Segment
MD5
Key, K
MAC
MAC
=
Y
Accept
N
Reject

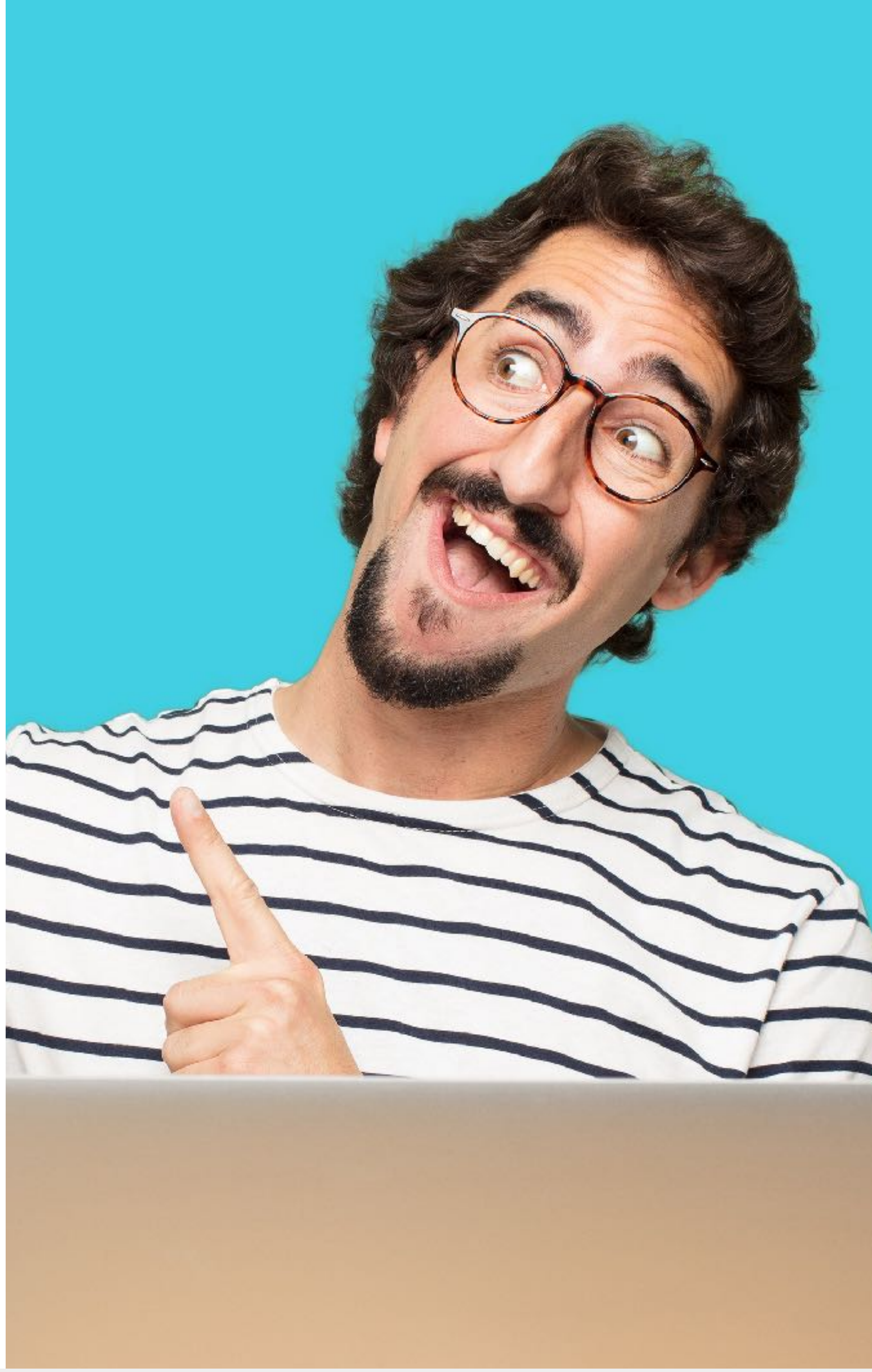
Limitations of TCP MD5

- Not a strong authentication mechanism
  - Supports only MD5 algorithm
- Doesn’t allow dynamic key rollover
  - Changing pre-shared keys requires TCP session reset
  - Problem for long-lived sessions

MD5 has been obsoleted by TCP-AO, not recommended.

TCP-AO

- **Enhances** security and authenticity of TCP segments in BGP and LDP sessions
- Supports multiple **stronger** authentication algorithms
  - HMAC-SHA-1-96 and AES-128-CMAC-96
- **Better** key management and agility
  - Change keys without resetting TCP session
- Protects long-lived TCP sessions against replay attacks

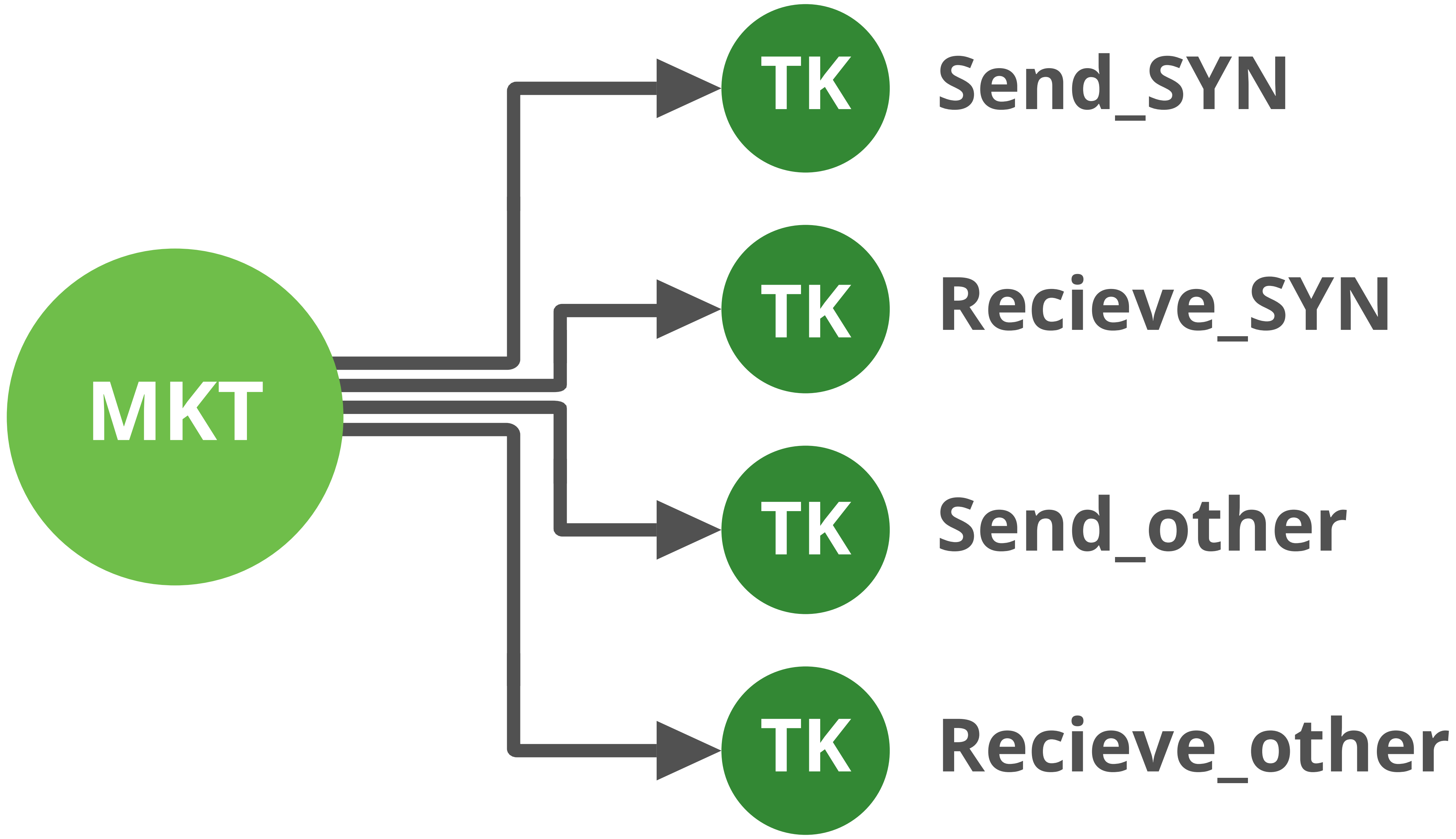


RFC 5925 - “The TCP Authentication Option”

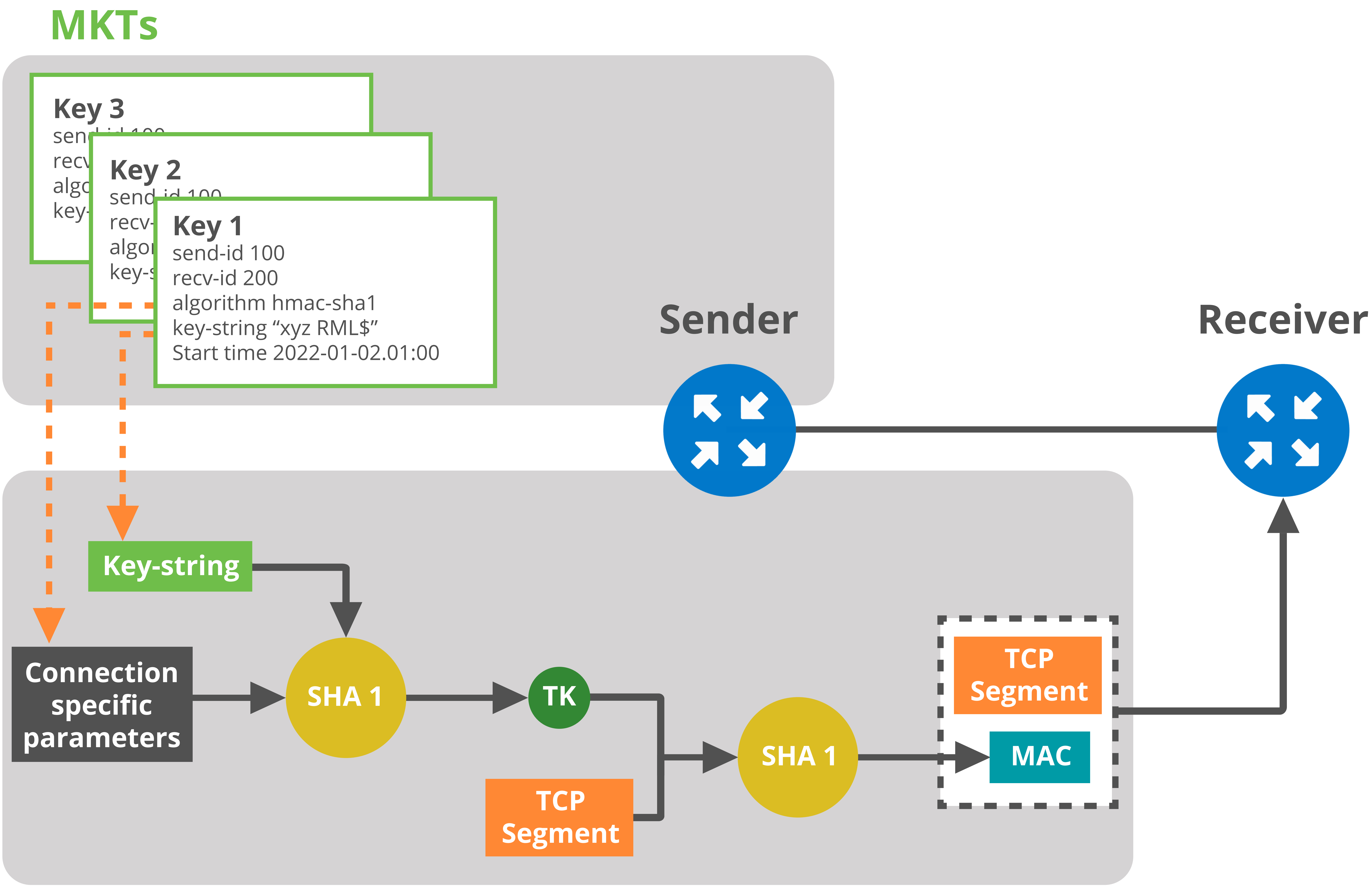
RFC 5926 - “Cryptographic Algorithms for the TCP-AO”

TCP-AO

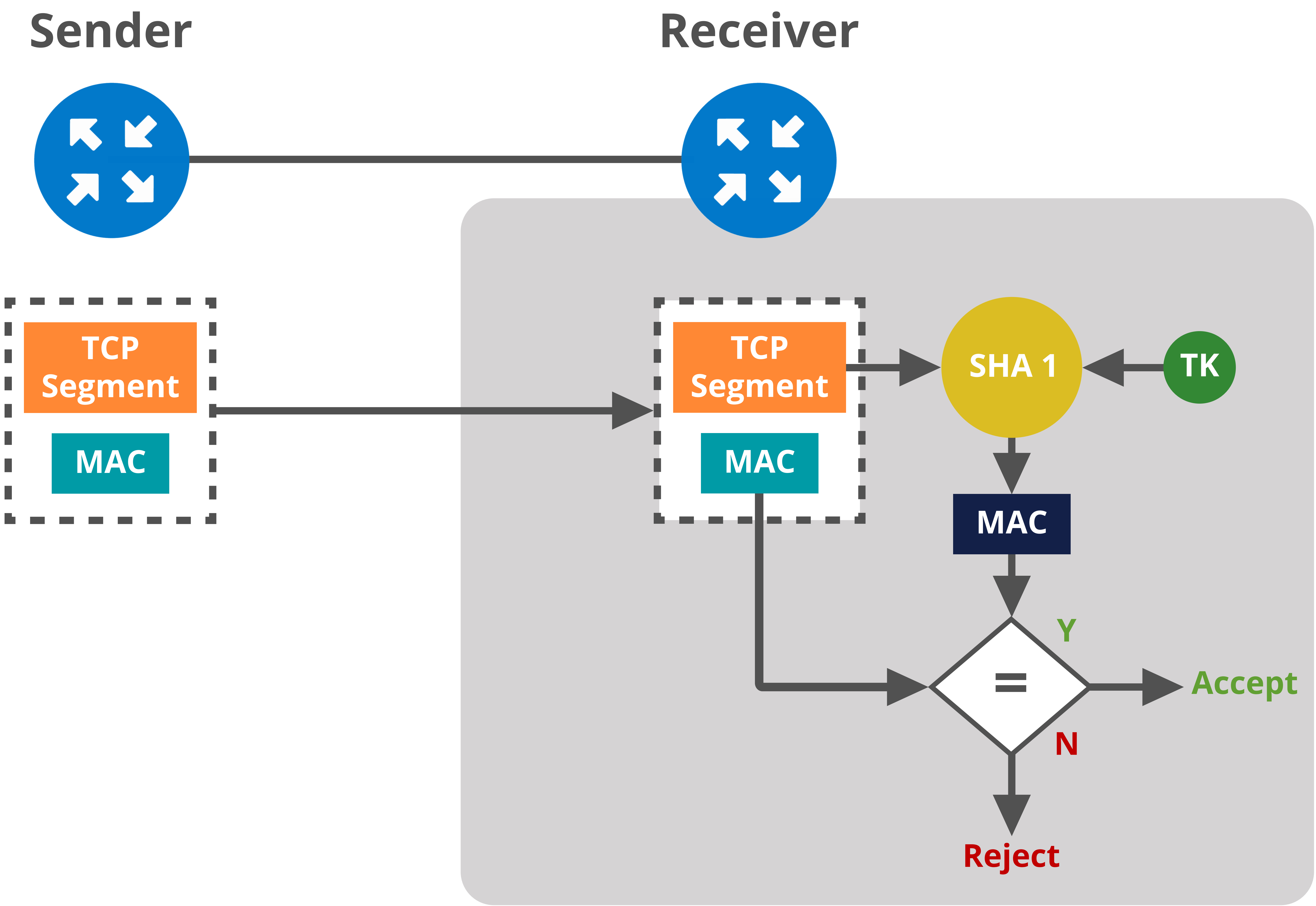
- Two sets of keys to authenticate incoming and outgoing segments:
  - **Master Key Tuples (MKTs)** (key-chain) and **Traffic keys**
- Four traffic keys are derived from each **MKT**



How Does it Work?



How Does it Work?



TCP AO Configuration

Sender

key chain **ao_hmac_chain** tcp
key 10
  send-id 115
  recv-id 300
  key string **test_key**
  cryptographic-algorithm **hmac-sha-1**

Receiver

key chain **ao_hmac_chain** tcp
key 18
  send-id 300
  recv-id 115
  key string **test_key**
  cryptographic-algorithm **hmac-sha-1**

- The **master-keys/key chains** must be **identical** on both BGP peers
- Send and receive **IDs must match**
- Make sure the **same MAC algorithm** is used on both sides

TCP AO Configuration

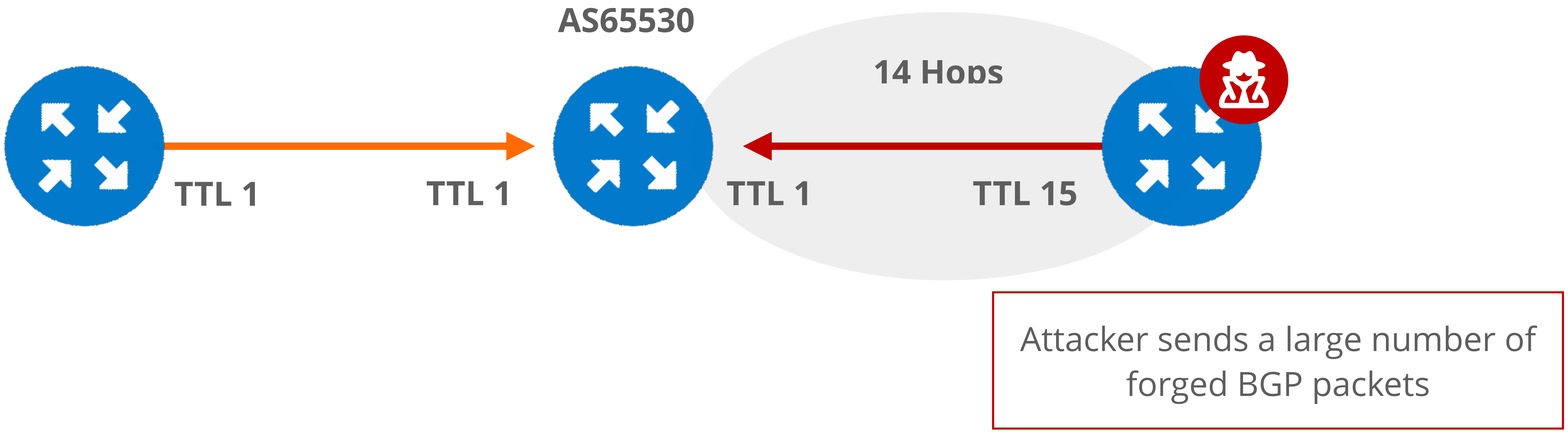
- Last step is to apply it to BGP neighbour

```
(config)# router bgp 65530
(config-keychain-tcp)# neighbour <peer-IPv4/IPv6-address> ao <keychain-name>
[include-tcp-options]
```

Configuration examples: https://github.com/TCP-AO/Configuration-examples

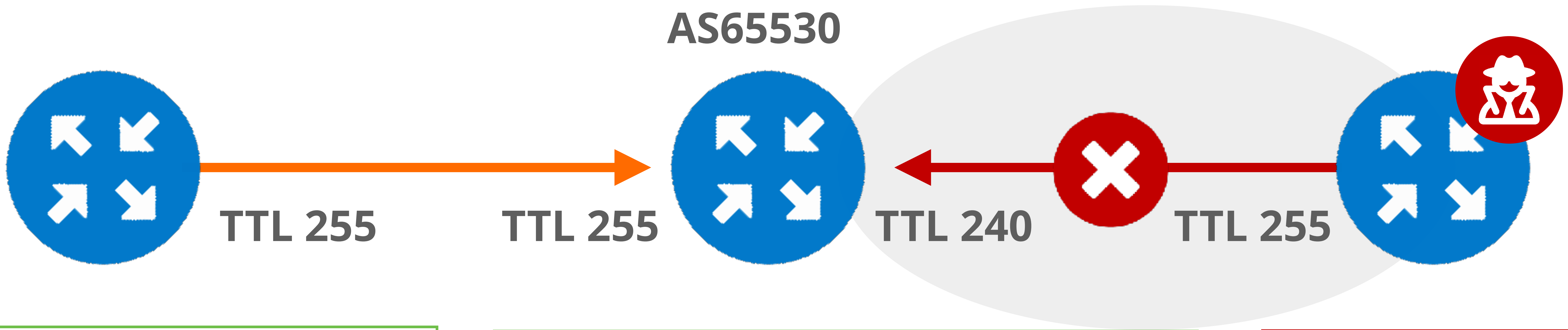
GTSM (TTL Security)

- **TTL/Hop limit =1** by default for eBGP sessions
- Remote attacker may adjust TTL and send spoofed packets
  - May execute **CPU utilisation-based attacks** (DoS attacks)



GTSM (TTL Security)

- Should be implemented on **directly connected eBGP peering**
  - **Send packets with TTL/Hop-limit 255. Discard packets if it is < 255**
  - Configured on both ends of a BGP session
- Could be applied to multi-hop BGP peering, but not so effective



GTSM **enabled**, TTL of all BGP packets are set to 255

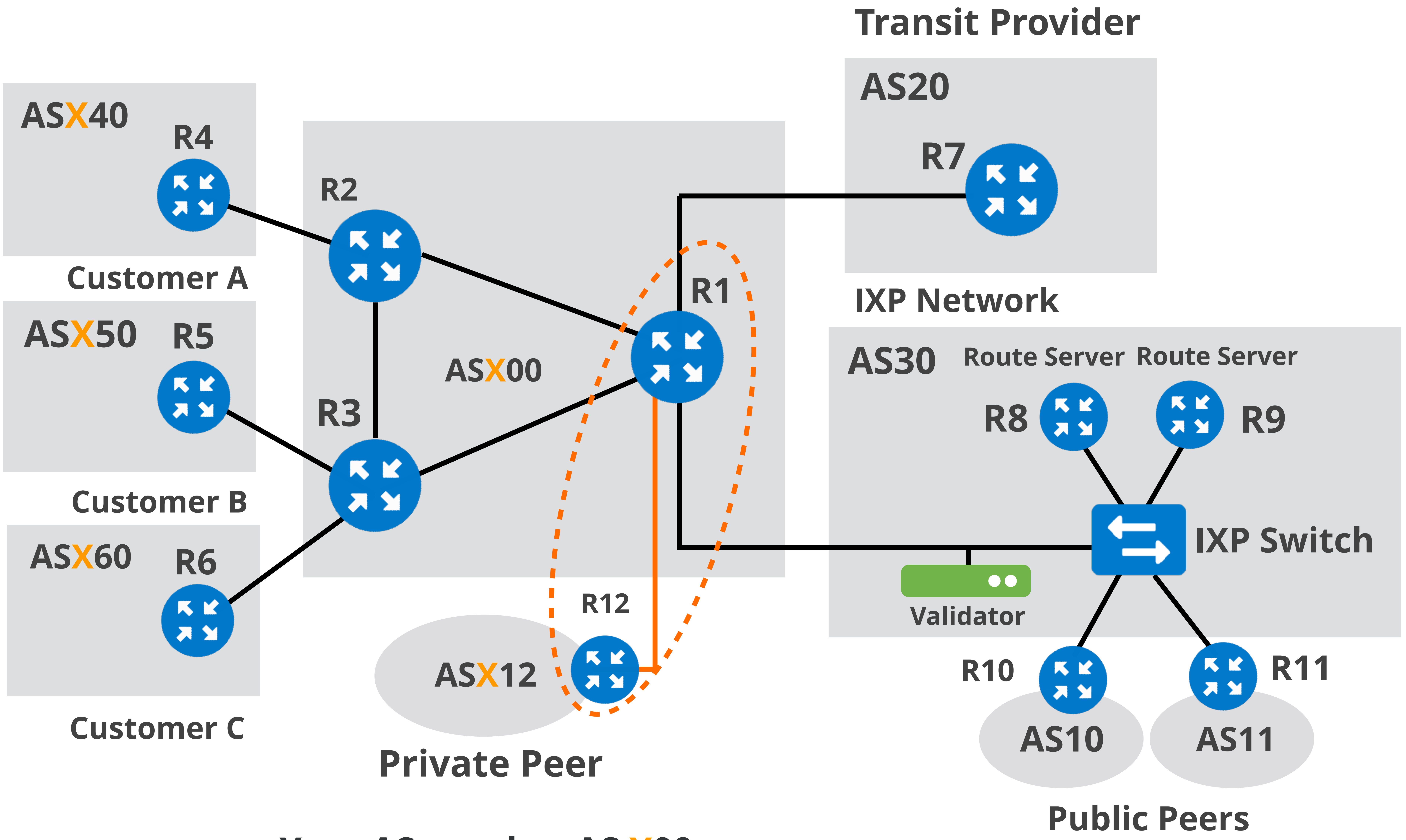
GTSM **enabled**, BGP packets with TTL less than 255 are dropped

Attacker sends a large number of forged BGP packets

Questions

Lab 1 - Securing BGP Sessions

15 min



Your AS number AS X00

Your IPv6 allocation 2001:db8:X00::/48

Lab 1 - Securing BGP Sessions

- **Description**: Implement two techniques to protect BGP sessions
- **Goal**:
    - Choose suitable and available security measures related to BGP sessions
- **Time:** 15 minutes
- **Tasks:**
    - 1.1 Configure MD5 authentication between two BGP routers
    - 1.2 Configure GTSM (TTL Security) in addition to MD5

Lab 1 - Securing BGP Sessions

- **What have you learned?**
  - You have to check which features are available
  - You can combine protection techniques

Implementing Route Filtering

Section 3.3

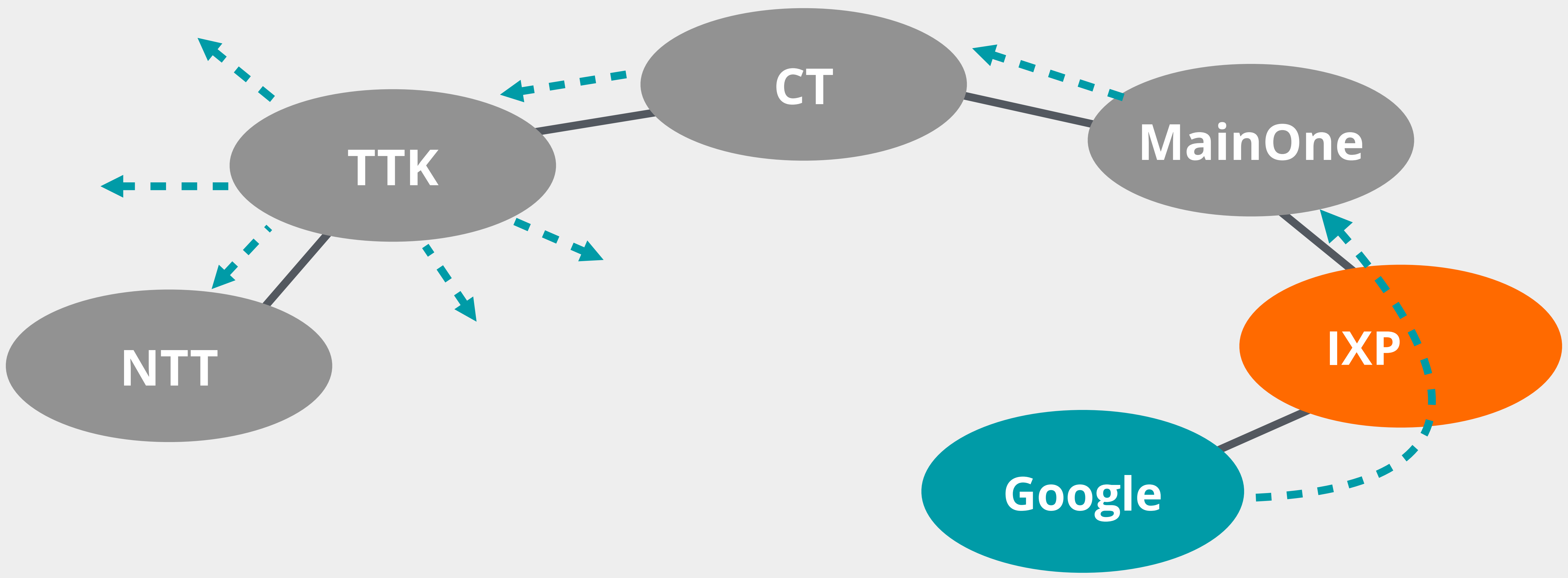
Route Leaks

"The propagation of BGP announcements beyond their intended scope" [RFC7908]

- Illegitimate propagation of legitimate prefixes (not bogus routes)
- Result from **human errors or misconfigurations**
  - And/or improper or missing BGP route filters between BGP peers
- Leads to incorrect or suboptimal routing

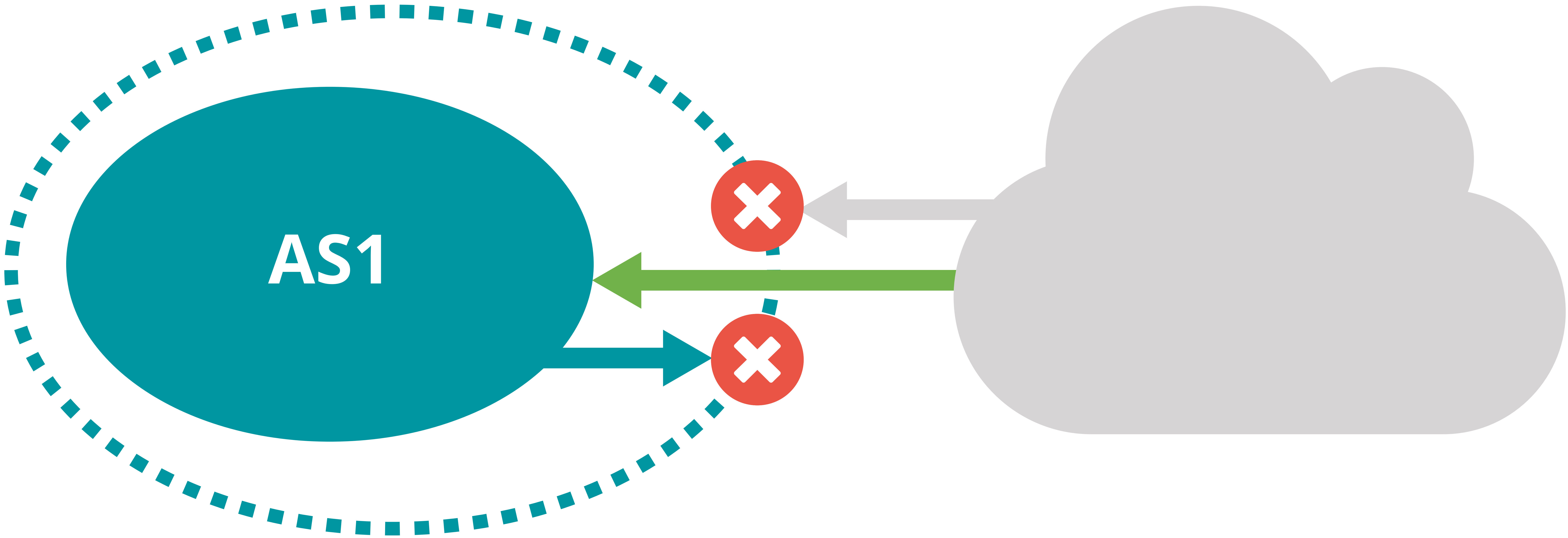
Google Prefix leak - November 2018

- What happened?
- MainOne leaked Google routes to CT and CT leaked them to other transits
  - Google services (G Suite and Google Search) affected by the leak
- Why?
  - Due to misconfigured filters



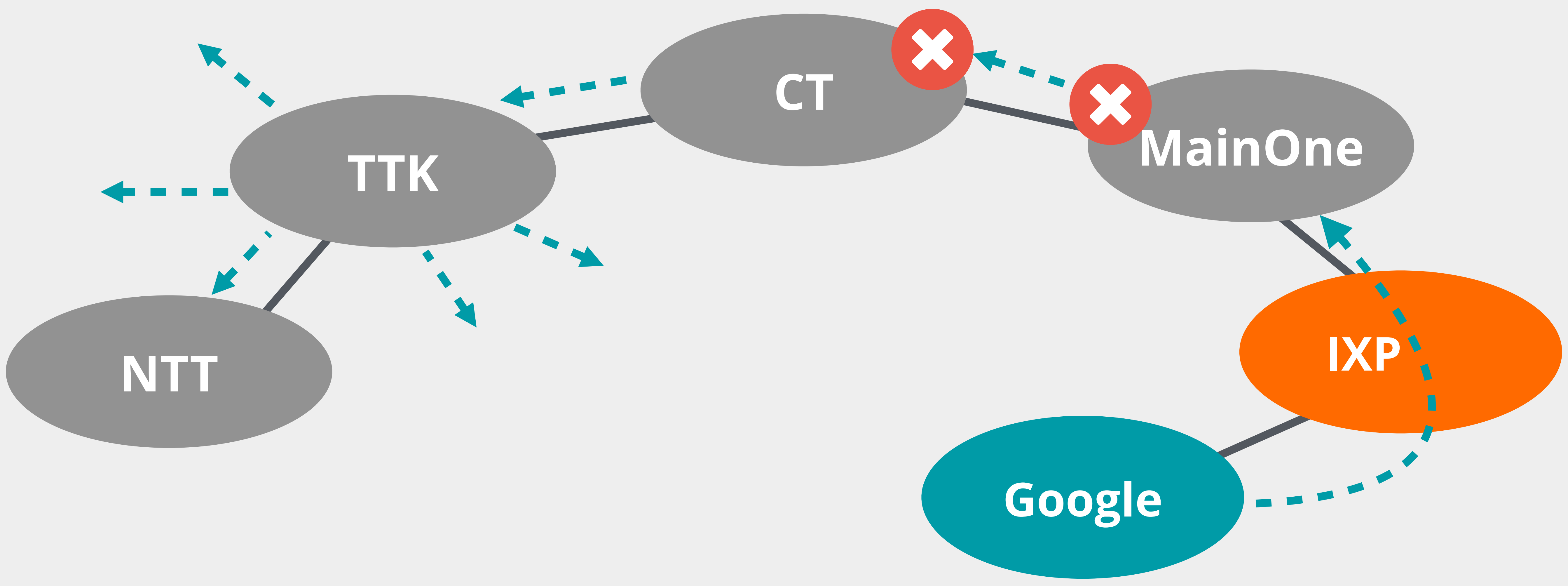
How to Prevent Route Leaks?

Route filtering is the most powerful mechanism!



Google Prefix leak - November 2018

- What's different with proper filters?
  - Google's prefix wouldn't reach CT
  - Proper outbound filters in MainOne, and/or
  - Proper inbound filters in CT



What is BGP route filtering?

- The most basic **protection** mechanism against malicious or accidental BGP incidents:
  - Prevents **route leaks**
  - Mitigates the impact of **BGP hijacks**
- Technique used to control prefixes on the BGP peering
  - Which prefixes will you **advertise** to your peers?
  - Which prefixes will you **accept** into your network?

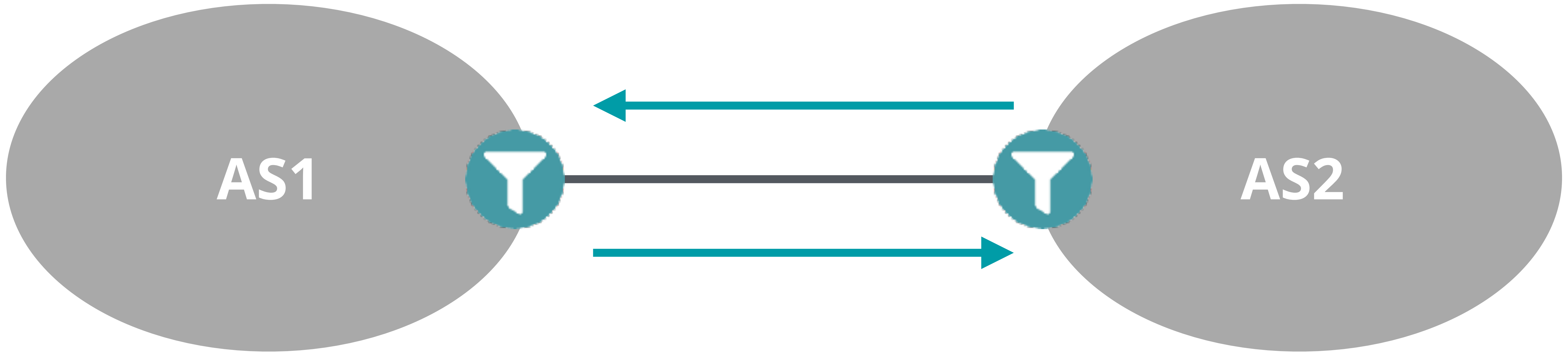
Essential for routing security!

Other Reasons for Filtering

- **Business relationships**
  - Customer-provider, peer-peer
- **Technical reasons**
  - Reduce memory utilisation, scalability
- **Traffic engineering**
  - Manipulate traffic flows and influence best path selection

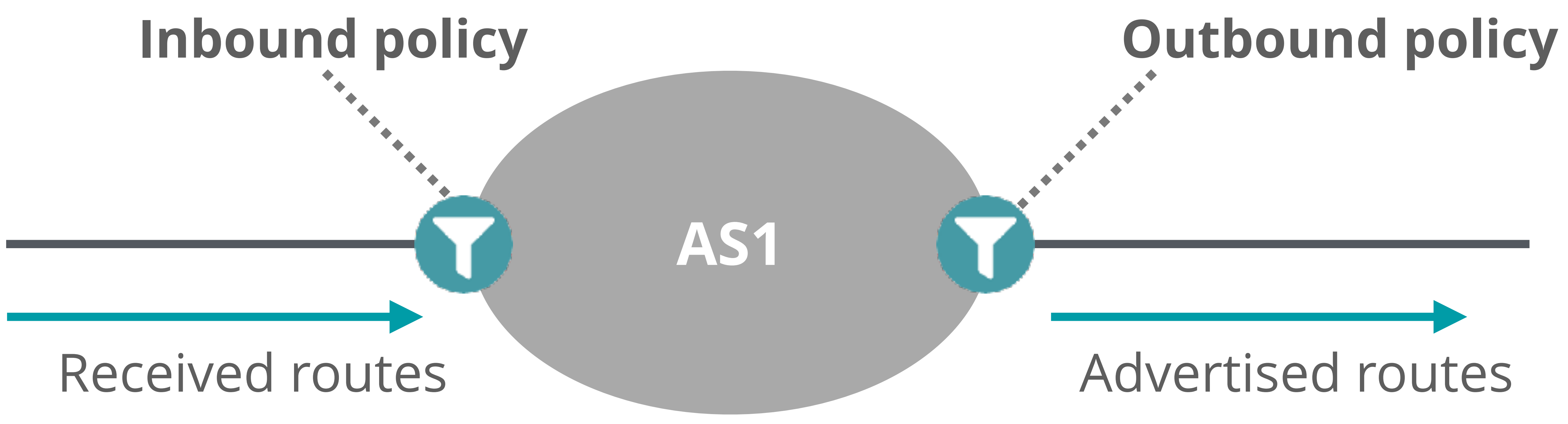
BGP Filters (BGP Policies)

- Used to filter prefixes exchanged between BGP peers
- Describe BGP peers and routing relationships with them
- Filters can match on
  - IP prefixes
  - AS paths
  - Or any other BGP attributes (e.g. MED, BGP communities, etc)



BGP Filters (BGP Policies)

- **Inbound policy:**
  - For **incoming** (received) routes
  - Detects configuration mistakes and attacks
- Should be applied on each eBGP peer
  - Both on ingress and egress
- **Outbound policy:**
  - For **outgoing** (advertised) routes
  - Limits propagation of routing information



Filtering Principles

- Filter **as close to the edge** as possible
- Filter **as precisely** as possible
- Two filtering approaches:
  - **Explicit Permit** (permit then deny any)
  - **Explicit Deny** (deny then permit any)

BGP filters

Prefix list

AS Path Filter

Prefix List

- Lists of routes you want to **accept** or **announce**
- You can create them **manually** or **automatically** with data from IRRs
- It can be done using scripts or tools:
  - Filtergen (Level3)
  - bgpq4
  - IRRToolSet
  - IRR Power Tools

Easy to use, but not highly scalable

Which Routes Should be Filtered?

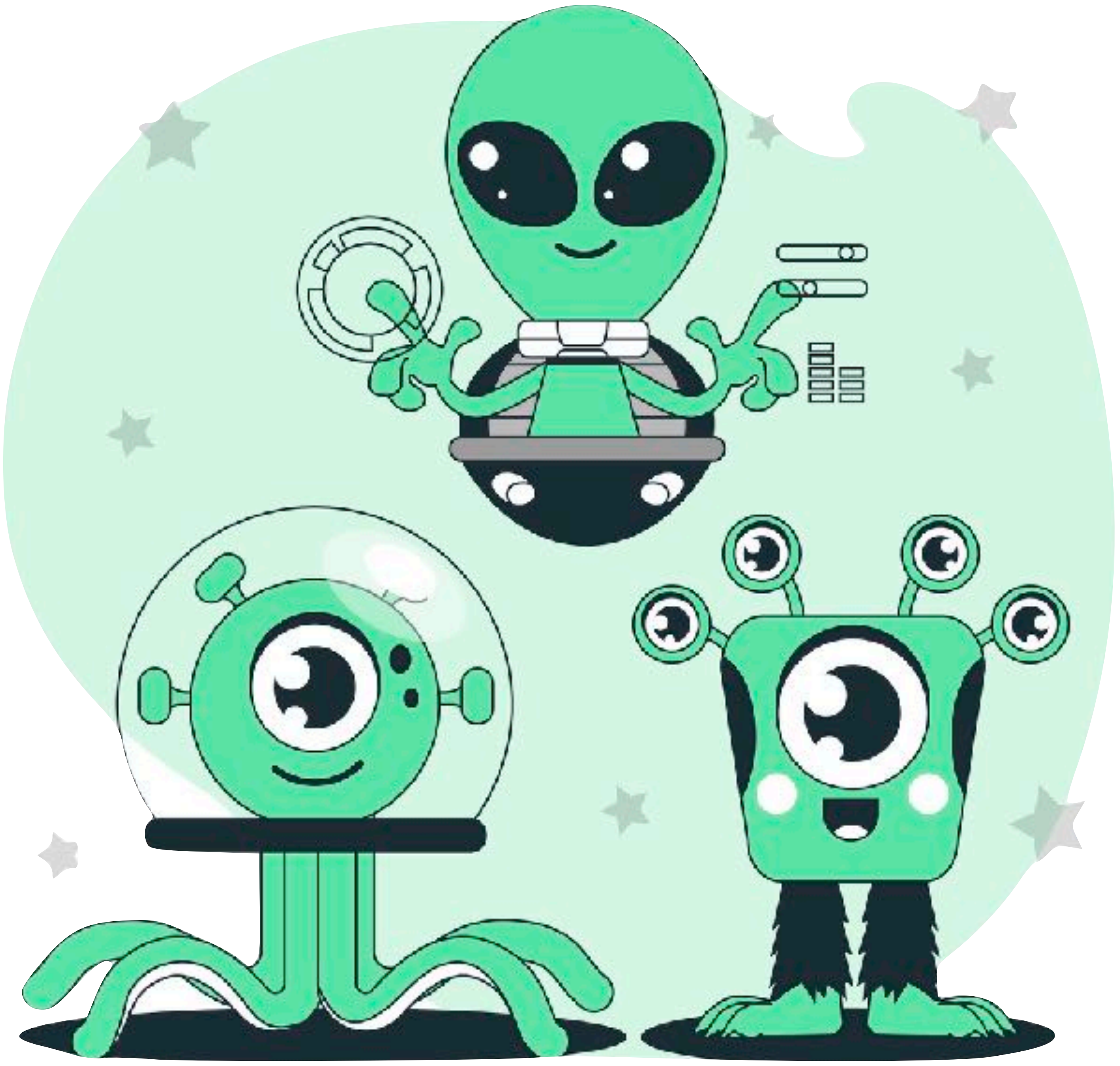
- Special-purpose prefixes (IPv4/IPv6) (Martians)
- Unallocated prefixes
- Routes that are too specific
- Prefixes belonging to the local AS
- IXP LAN prefixes
- The default route (0.0.0.0/0, ::/0)

RFC 7454 - "BGP Operations and Security"

- lists the prefixes to be filtered -

Special-purpose Prefixes

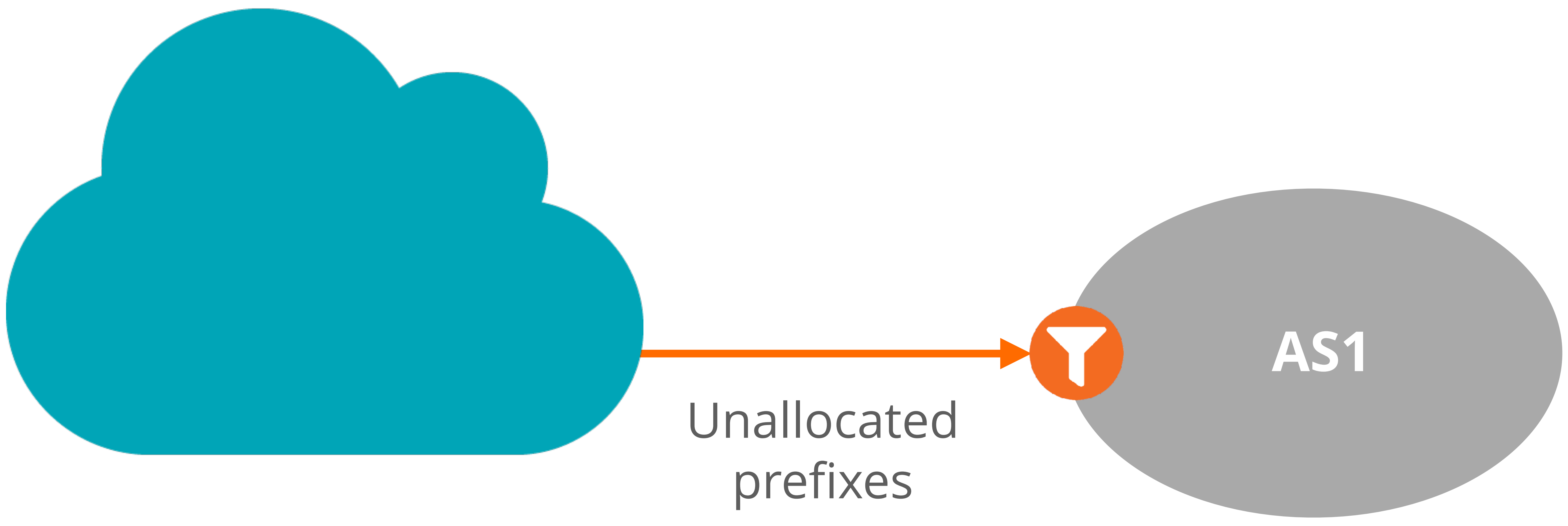
- Also known as **Martians**
  - RFC 1918 Private addresses
  - Reserved space (documentation, multicast, etc.)
- Not globally routable
  - Should be **discarded** on Internet BGP peering



http://www.iana.org/assignments/iana-ipv4-special-registry
http://www.iana.org/assignments/iana-ipv6-special-registry

Unallocated Prefixes

- **All unallocated prefixes should be filtered**
  - Prefixes not yet allocated by IANA to RIRs (only for IPv6)
  - Prefixes allocated to an RIR but have not yet been distributed by an RIR to LIRs/End-users
- Filtering unallocated prefixes requires regular update



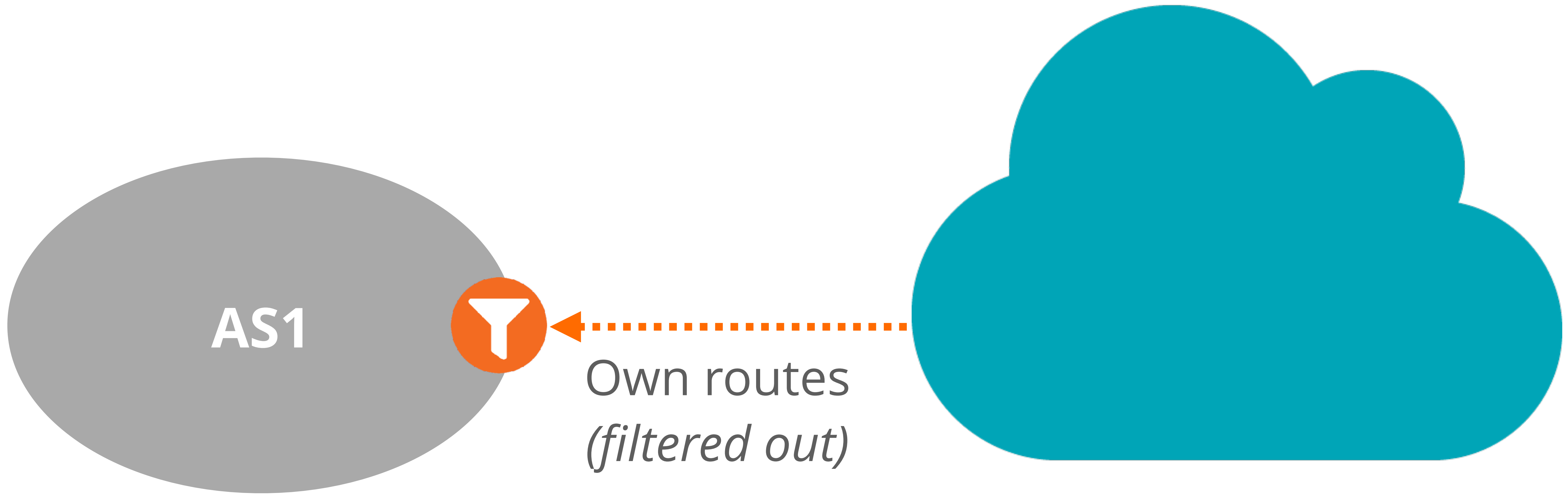
Longest Accepted Prefixes

- **Smaller prefixes should not be a part of global routing!**
  - /24 for IPv4 (*RIPE-399*)
  - /48 for IPv6 (*RIPE-532*)
- Those prefixes are generally neither announced nor accepted on the Internet

```
ip prefix-list SMALL-V4 permit 0.0.0.0/0 le 24
ipv6 prefix-list SMALL-V6 permit 2000::/3 le 48
```

Prefixes Belonging to the Local AS

- You should **filter your own prefixes** on all BGP peering
  - Prevents local traffic from leaking over an external peering
- Such filters can also be configured for downstream customers' prefixes
- In case of multi-homed customer, be careful not to break redundancy mechanism

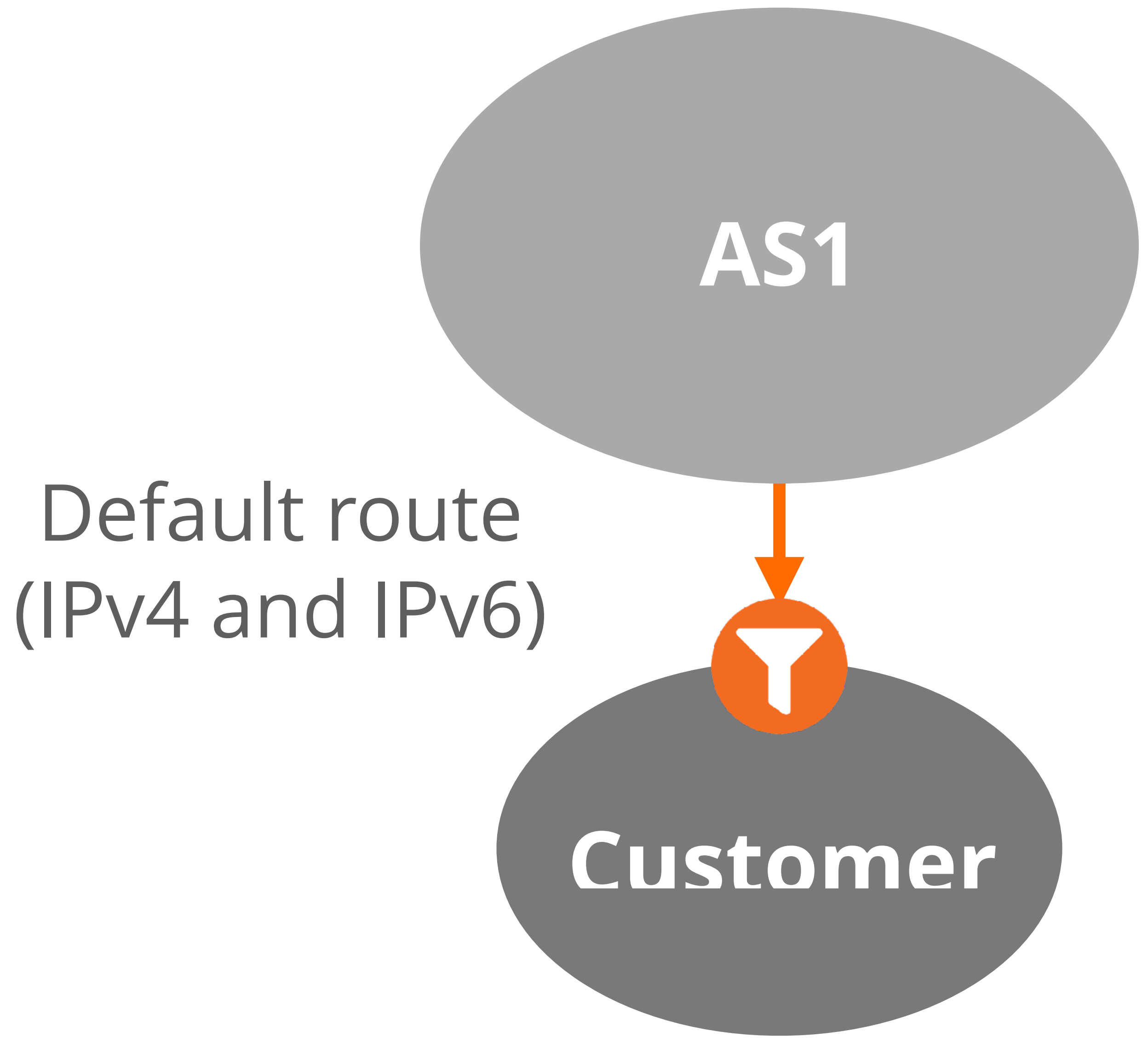


IXP LAN Prefixes

- IXP should originate its LAN prefix
  - Advertise it from its route server to all IXP members
- **Do not accept IXP LAN prefix from any of your eBGP peers!**
  - It may create a blackhole for connectivity to IXP LAN
- IXP prefix announcement should pass IRR-generated filters

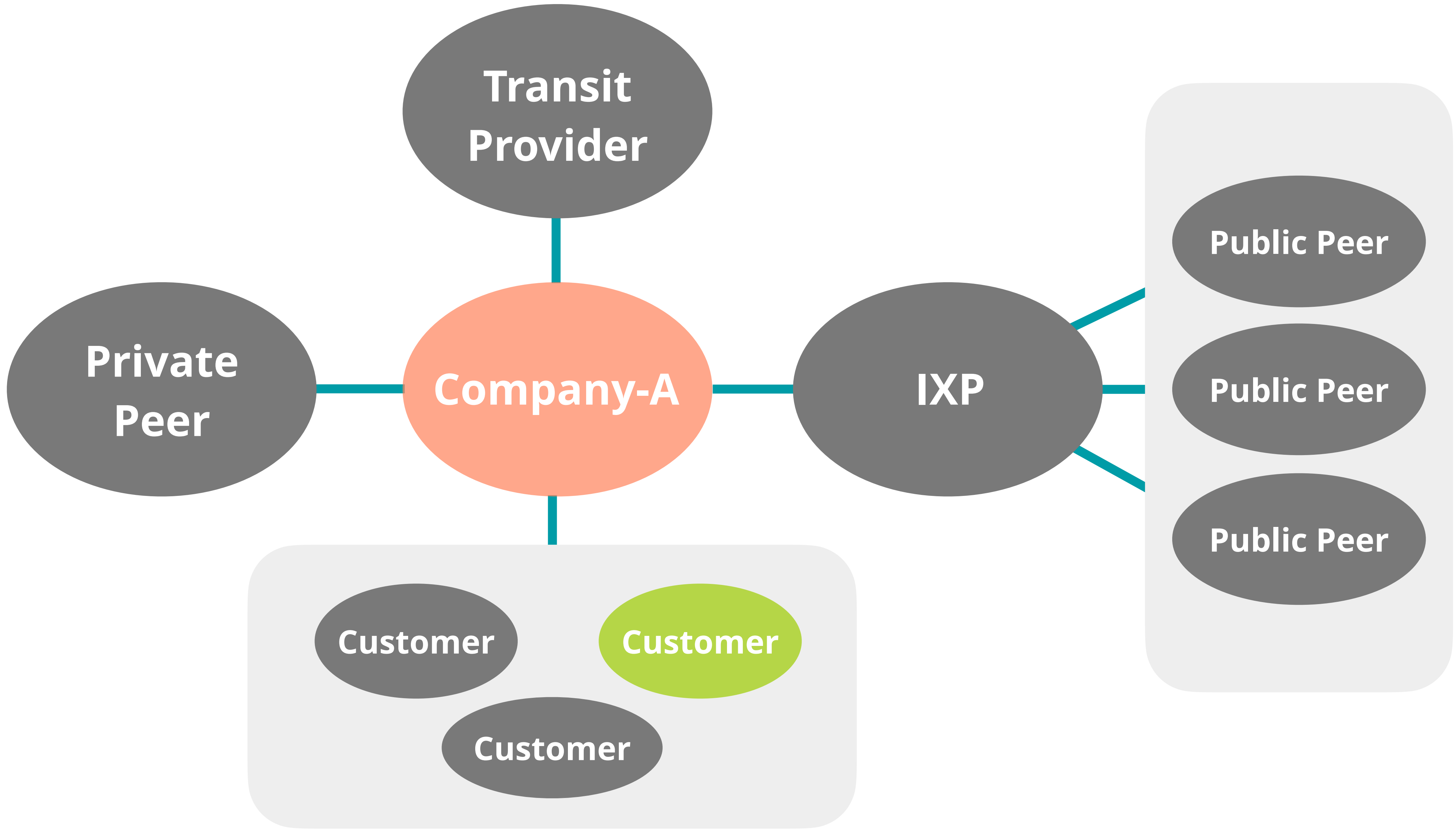
Default Route

- **0.0.0.0/0** (IPv4) and **::/0** (IPv6)
- Advertised or accepted only in specific customer-provider peering relationships
  - E.g.customer with stub network
- Should be **rejected** unless a special peering agreement is in place



Prefix Filtering Recommendations

- **In full routing networks**, some policies should be applied
  - On each BGP peer
  - For both **received** and **advertised** routes (inbound and outbound)
- Recommendations vary based on type of BGP peering relationships
  - Public and Private Peering
  - Transit Provider (Upstream)
  - Customer



Prefix Filtering Recommendations

	With Public/Private Peers		With Transit Provider		With Customers		Leaf Customer Network	
	Inbound	Outbound	Inbound	Outbound	Inbound	Outbound	Inbound	Outbound
	Strict: Allow only IRR declared **Loose:** see below	Allow only own & customer's prefixes. Additionally: see below	Allow default only, or for Full routing table (FRT): see below	Allow only own & customer's prefixes. Additionally: see below	If known, allow only customer's prefixes. If not: see below	Allow default only, or for Full routing table (FRT): see below	Depends on agreement with upstream. If **default** only allow that. If **FRT**: see below	Only announce your own prefixes. Also filter:
Special Purpose Prefixes	X	X	X	X	X	X	X	X
Prefixes Not Allocated by IANA	X		X		X			
Too Specific Routes	X	X	X	X	X	X	X	X
Prefixes Belonging to the Local AS	X		X		X		X	
IXP LAN Prefixes	X	X	X	X	X			X
Default Route	X	X	Depends on needs / agreement	X	X	Depends on needs / agreement	Depends on needs / agreement	X

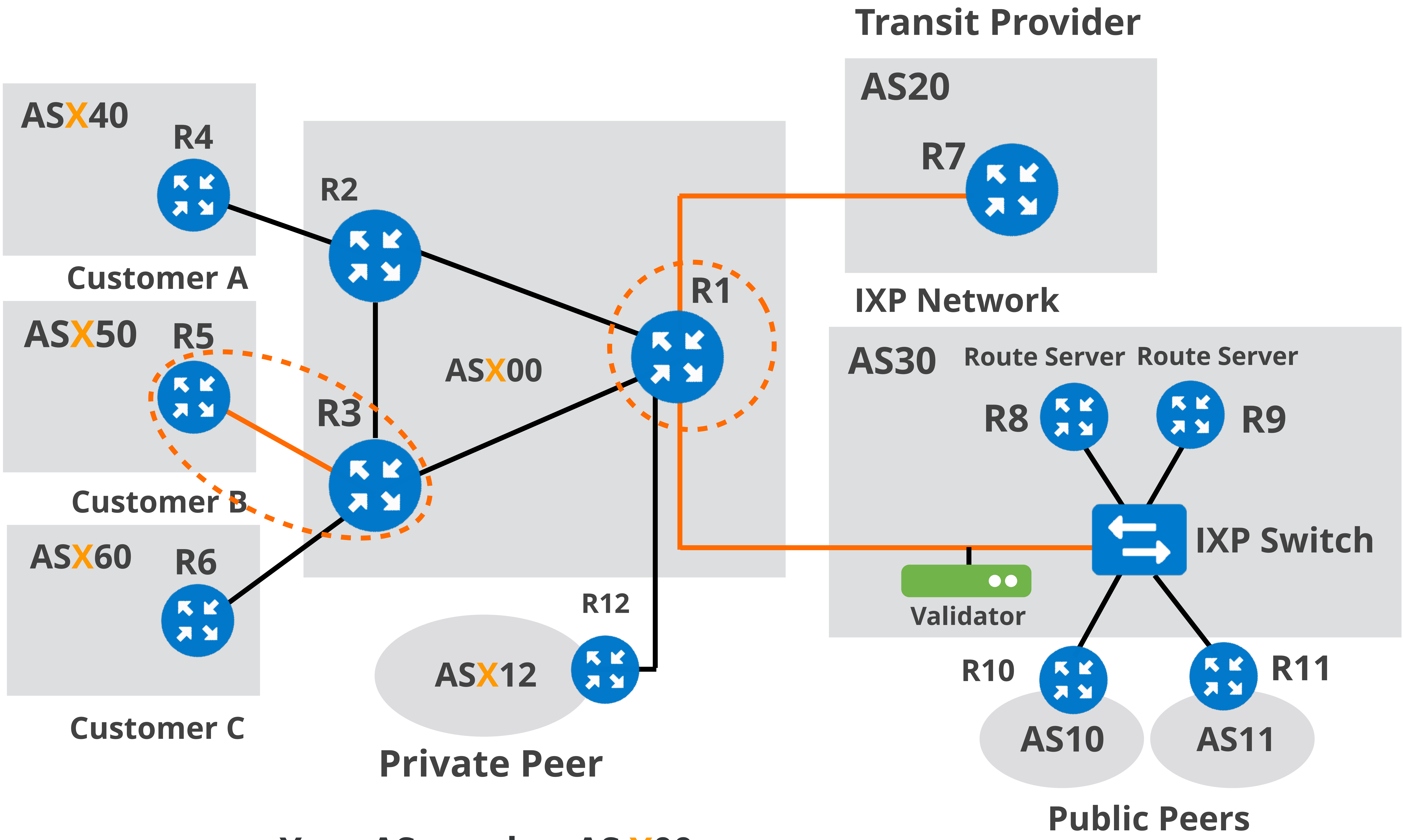
Questions

Lab 2 - Creating BGP Prefix Filters

40 min

Lab 2 - Creating BGP Prefix Filters

- **Description**: Configure BGP prefix filters with different types of peers.
- **Goals:**
  - Define BGP filter recommendations based on the routing relationships
  - Choose the appropriate methods for implementing BGP filters
- **Time**: 40 minutes
- **Tasks**:
  - 2.1 Configure prefix filters with Transit Providers and IXP Peers
  - 2.2 Configure prefix filters with Customers
  - (OPTIONAL) 2.3 Configure filters using communities with a private peer

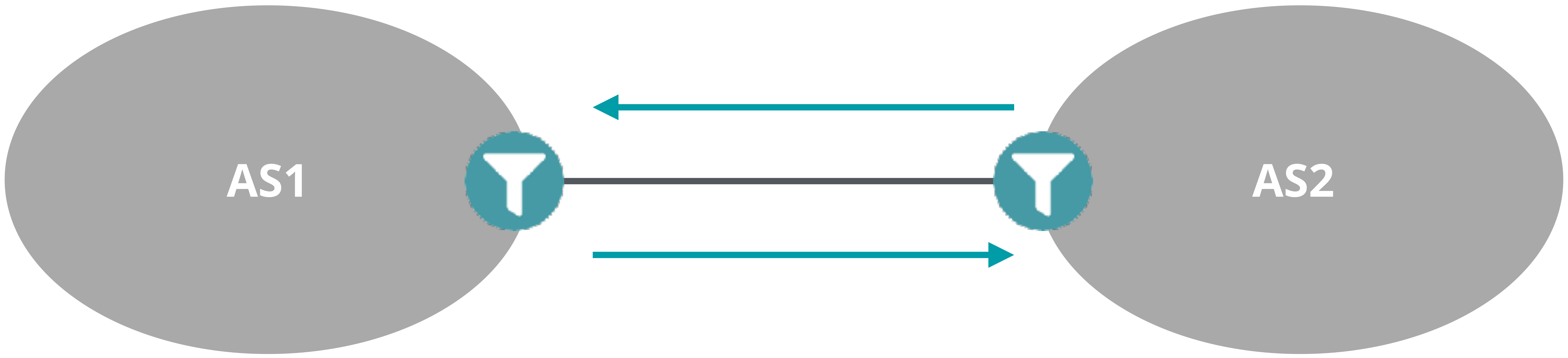


Your AS number AS X00

Your IPv6 allocation 2001:db8:X00::/48

Lab 2 - Creating BGP Prefix Filters

- What have you learned?
  - Filtering rules are different for different types of peering relationships (Customers, Transit Providers, Peers)
  - Inbound and outbound filtering rules are different



After the Prefix Filtering, we continue with more filtering…

AS Path Filtering

- Filters routes **based on AS path**
  - Permit or deny prefixes from **certain ASes**

```
router bgp 65564
  network 10.0.0.0 mask 255.255.255.0
  neighbor 172.16.1.1 remote-as 65563
  neighbor 172.16.1.1 filter-list 1 out
  neighbor 172.16.1.1 filter-list 2 in

ip as-path access-list 1 permit ^65564$
ip as-path access-list 2 permit ^65563$
```

Widely used and highly scalable

AS Path Filtering Recommendations

- From your customers **accept only:**
  - AS paths containing ASNs belonging to (or authorised to transit through) the customer
- **Do not accept:**
  - Prefixes with private AS numbers in the AS path (unless from customers)
  - Prefixes when the first AS number in the AS path is not the one of the peer's (unless towards a BGP route server)

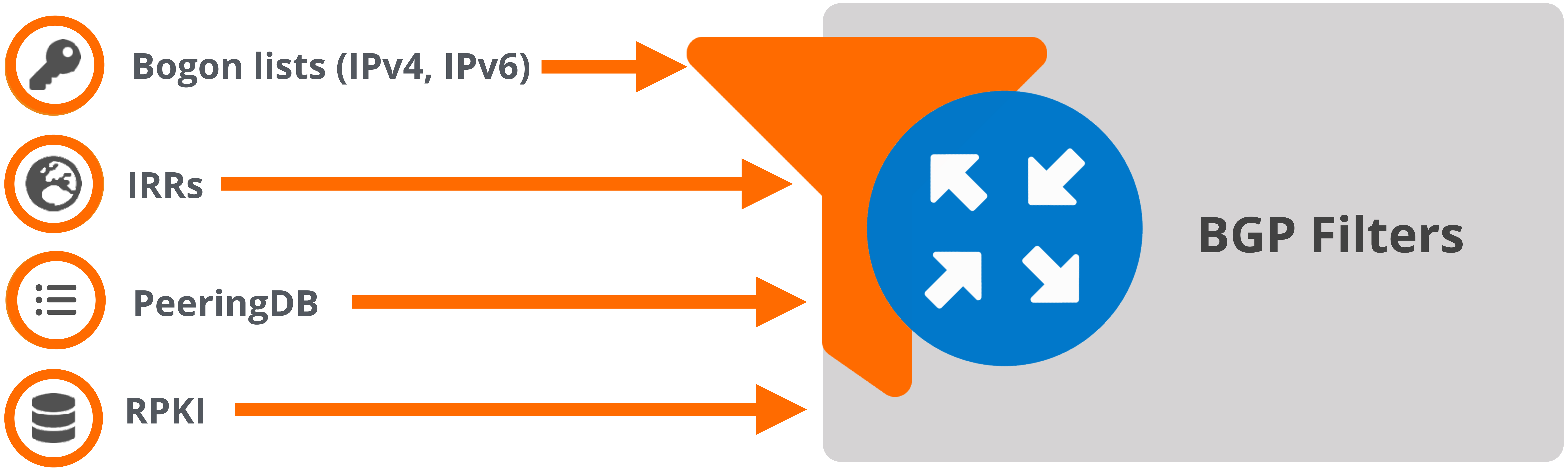
AS Path Filtering Recommendations

- Do not advertise:
  - Prefixes with a nonempty AS Path (unless you intend to provide transit for these prefixes)
  - Prefixes with upstream AS numbers in the AS Path to your peers (unless you intend to provide transit)
  - Private AS Paths (unless there is a special “private” arrangement with your peers)
- **Do not override BGP’s default behaviour**
  - Do not accept your own AS in the AS-path

BOGON ASN filtering

ASNs	Status	RFC
0	Reserved	RFC7607
23456	AS_TRANS	RFC6793
64496-64511	Reserved for use in docs and code	RFC5398
64512-65534	Reserved for Private Use	RFC6996
65535	Reserved	RFC 7300
65536-65551	Reserved for use in docs and code	RFC5398
65552-131071	Reserved	IANA
4200000000 - 4294967294	Reserved for Private Use	RFC6996
4294967295	Reserved	RFC 7300

Which Data Sources Can You Use for BGP Filters?



We will talk about IRRs and RPKI in other sections in this course

BOGON Lists

- **BOGONs** are prefixes that should never appear in the Internet routing table
  - Martians (RFC1918 Private addresses + Reserved space)
  - IANA unallocated space
- **Full BOGON** should be filtered as well
  - BOGONs + prefixes unallocated by RIRs
- The BOGON and full BOGON lists are **not static**

How to Get the List of (Full) BOGONs?

- Team Cymru provides lists of **BOGONs** and **full BOGONs**
- Offers variety of formats and methods
  - HTTP
  - BGP Peering (Bogon Route Server Project)
  - Routing Registries (RADB)
  - DNS

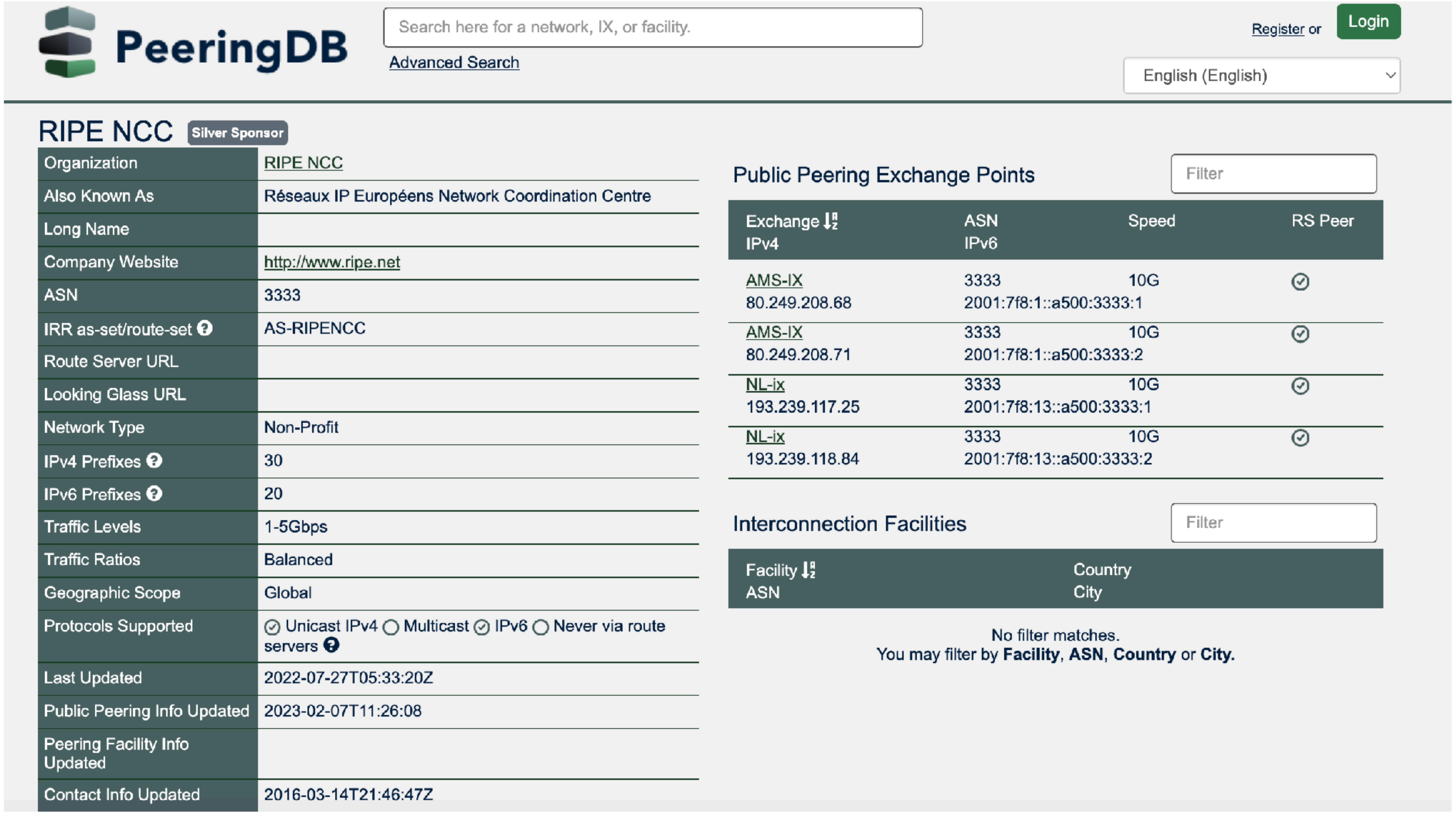
Team Cymru provides lists of BOGONs:
http://www.team-cymru.com/bogon-reference.html

PeeringDB

- **Web-based public database for BGP peering**
- Non-profit, community-driven initiative, run and promoted by volunteers
- First stop when making interconnection decisions
  - Default location for Internet peering data
  - Helps to decide where and whom to peer with
  - Provides contact info
  - Gives information about the peering policy

http://peeringdb.com

PeeringDB


PeeringDB
Search here for a network, IX, or facility.
Advanced Search
Register or
Login
English (English)
RIPE NCC
Silver Sponsor
Organization
RIPE NCC
Also Known As
Réseaux IP Européens Network Coordination Centre
Long Name
Company Website
http://www.ripe.net
ASN
3333
IRR as-set/route-set
AS-RIPENCC
Route Server URL
Looking Glass URL
Network Type
Non-Profit
IPv4 Prefixes
30
IPv6 Prefixes
20
Traffic Levels
1-5Gbps
Traffic Ratios
Balanced
Geographic Scope
Global
Protocols Supported
Unicast IPv4 Multicast IPv6 Never via route servers
Last Updated
2022-07-27T05:33:20Z
Public Peering Info Updated
2023-02-07T11:26:08
Peering Facility Info Updated
Contact Info Updated
2016-03-14T21:46:47Z
Public Peering Exchange Points
Filter
Exchange IPv4
ASN IPv6
Speed
RS Peer
AMS-IX
80.249.208.68
3333
2001:7f8:1::a500:3333:1
10G
AMS-IX
80.249.208.71
3333
2001:7f8:1::a500:3333:2
10G
NL-ix
193.239.117.25
3333
2001:7f8:13::a500:3333:1
10G
NL-ix
193.239.118.84
3333
2001:7f8:13::a500:3333:2
10G
Interconnection Facilities
Filter
Facility ASN
Country City
No filter matches.
You may filter by Facility, ASN, Country or City.

Other Recommended Filtering

- Other methods to control BGP routes:
  - Max-prefix filtering
  - BGP Route Flap Dampening
  - Next-hop Filtering
  - Optional BGP Community Scrubbing

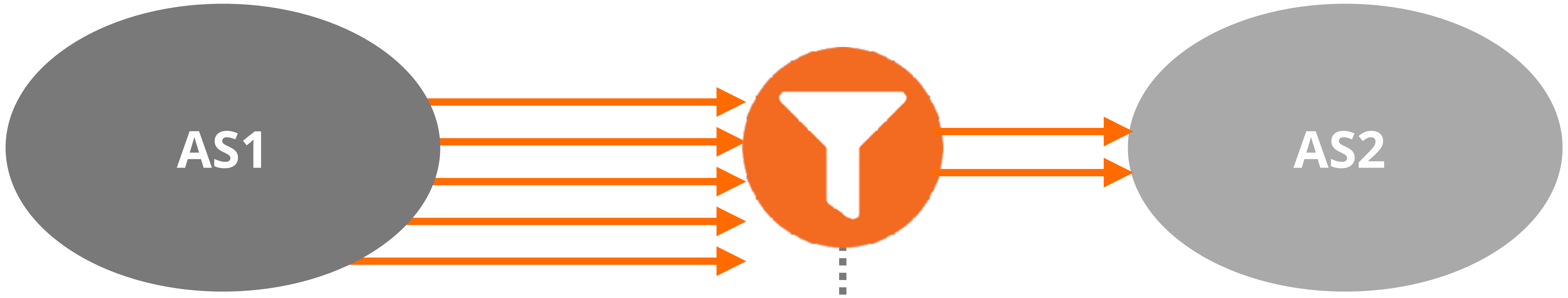
RIPE NCC Academy

BGP Security

https://academy.ripe.net/bgp-security/

Max-Prefix Filtering

- From peers:
    - **Set limit lower** than the number of Internet routes
    - Different per peer based on expected number of routes
- From upstreams that provide full route:
    - **Set limit higher** than the number of Internet routes
    - Limit should be decided based on router's capacity
- Regularly review the limits



Limit prefixes allowed

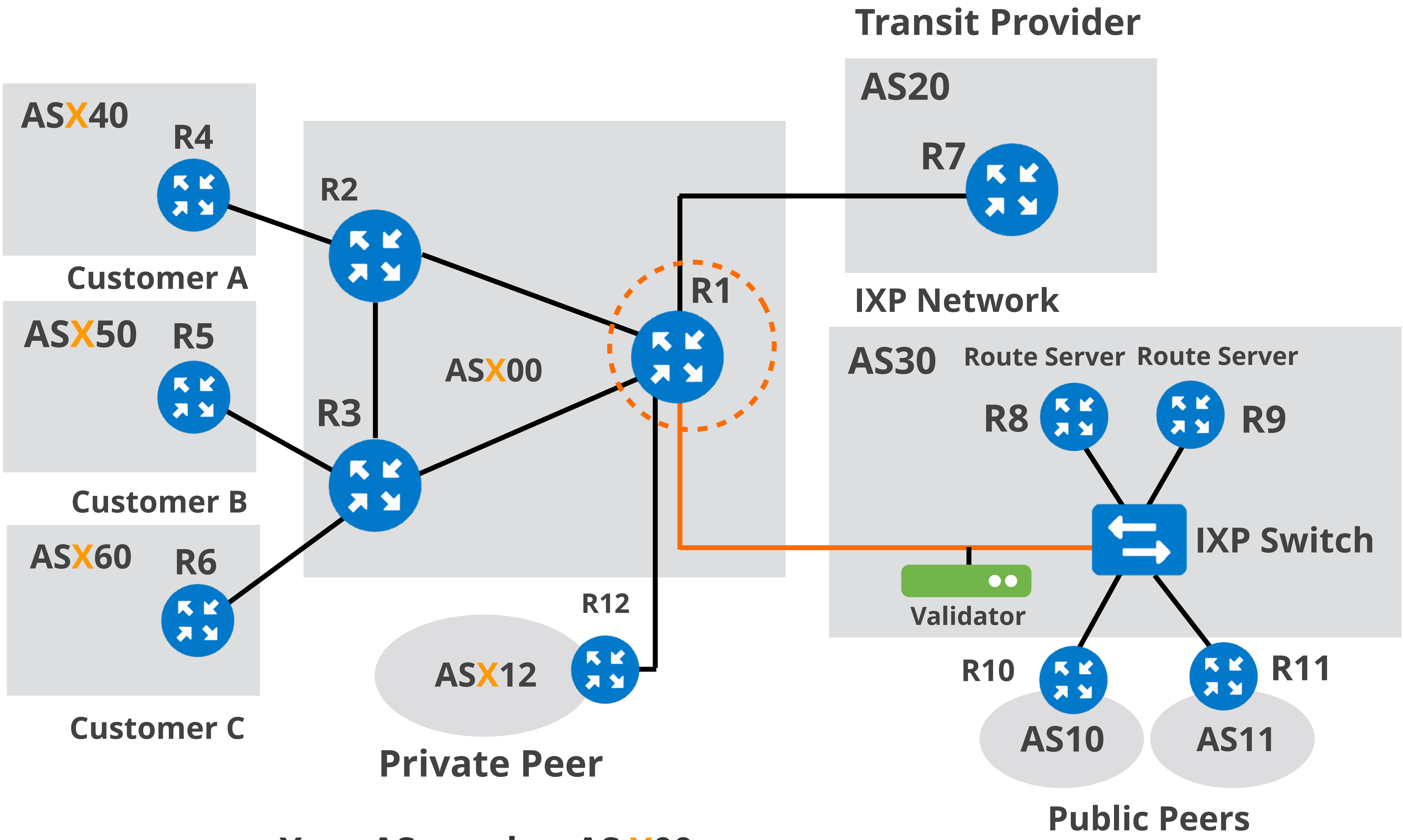
Questions

Lab 3 - Filtering AS-Path and Number of Prefixes

20 min

Lab 3 - Filtering AS-Path/Number of Prefixes

- **Description**: Configure AS-path filters and limit the number of accepted prefixes
- **Goals:**
  - Create consistent AS-path filter to secure a BGP network
  - Create BGP prefix-filter to discard more specifics
- **Time:** 20 minutes
- **Tasks:**
  - 3.1 Configure BGP filters based on AS-path information
  - 3.2 Configure a limit on the number of accepted BGP prefixes



Your AS number AS X00

Your IPv6 allocation 2001:db8:X00::/48

Lab 3 - Filtering AS-Path/Number of Prefixes

- **What have you learned?**
  - You can filter routes based on the ASNs included in the AS-PATH
  - Limiting the number of routes accepted in a BGP peering can avoid resource exhaustion
  - Reaching the limit of accepted routes takes down the peering

Registering in the IRR System

Section 3.4

IRR Support Routing Security

- The Internet Routing Registry (IRR) composed by many databases:
  - RIPE NCC, APNIC, RADB, JPIRR, Level3, NTTCom, etc.
- Their information can be used to:
  - Improve stability and consistency of routing
  - Provide global view of routing policies
  - Automation of creating BGP filters
  - Network Troubleshooting

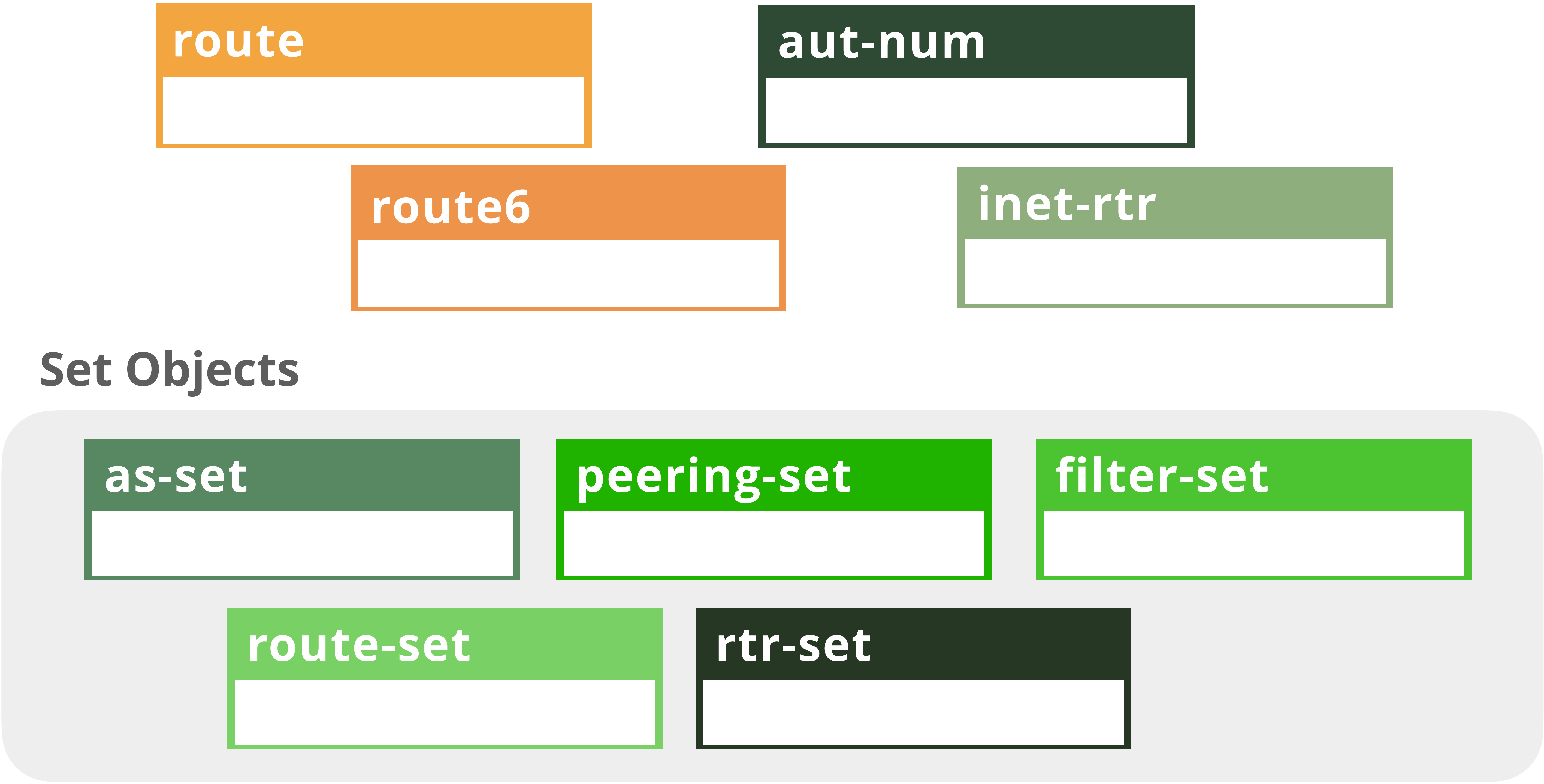
Source: http://www.irr.net

Why Register Routing Information?

- Document your routing policy
  - Associate network prefixes with an **origin AS**
- Helps to filter unauthorised announcements
  - **Mitigates** route hijacks and denial-of-service
- Many transit providers and IXPs **require** it
  - They build their filters based on the Routing Registry

The RIPE Routing Registry

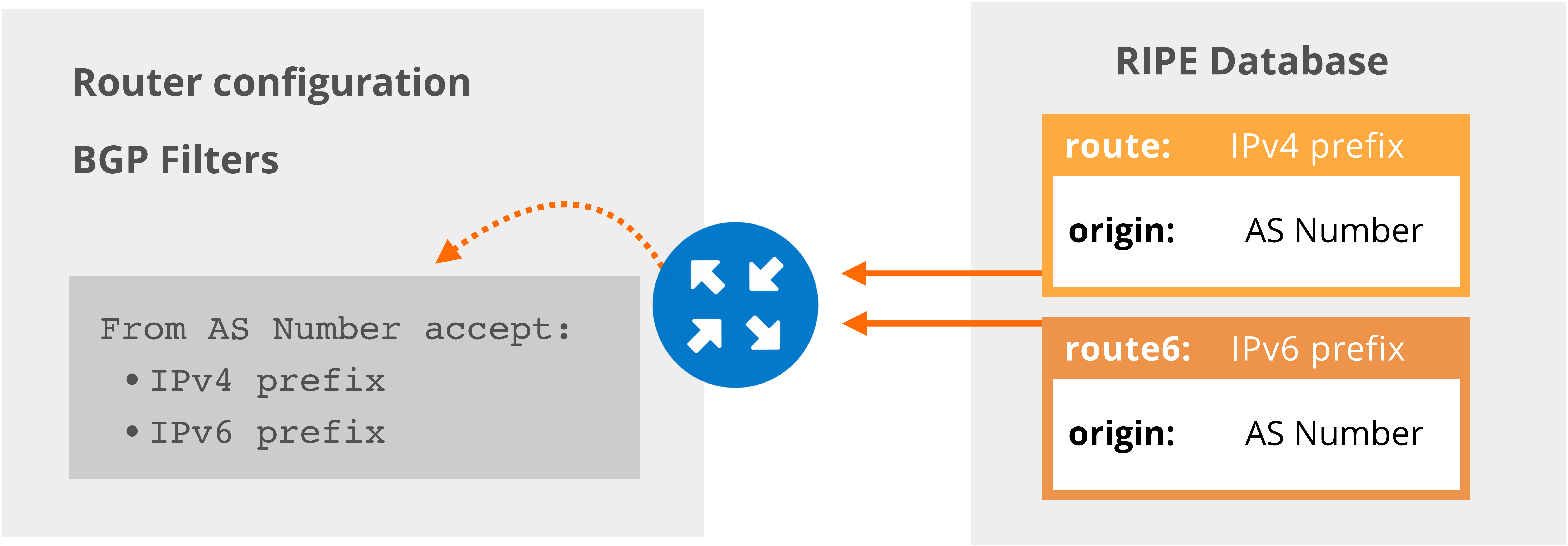
- A subset of the RIPE Database and part of the global IRR
- Used for registering **routing policy information**
- Includes several objects



Source: https://apps.db.ripe.net/docs/04.RPSL-Object-Types/

Route(6)

- Contains routing information for IPv4/IPv6 address space
- **Specifies from which AS a certain prefix may be originated**
- Used for creating BGP filters



Authorisation Rules for Route(6)

- You need permission from:
  1. **inetnum** or **inet6num**
  2. **route** or **route6**

1

Allocation

mnt-by: RIPE-NCC-HM-MNT
mnt-by: DEFAULT-LIR-MNT
mnt-routes: ANOTHER-MNT

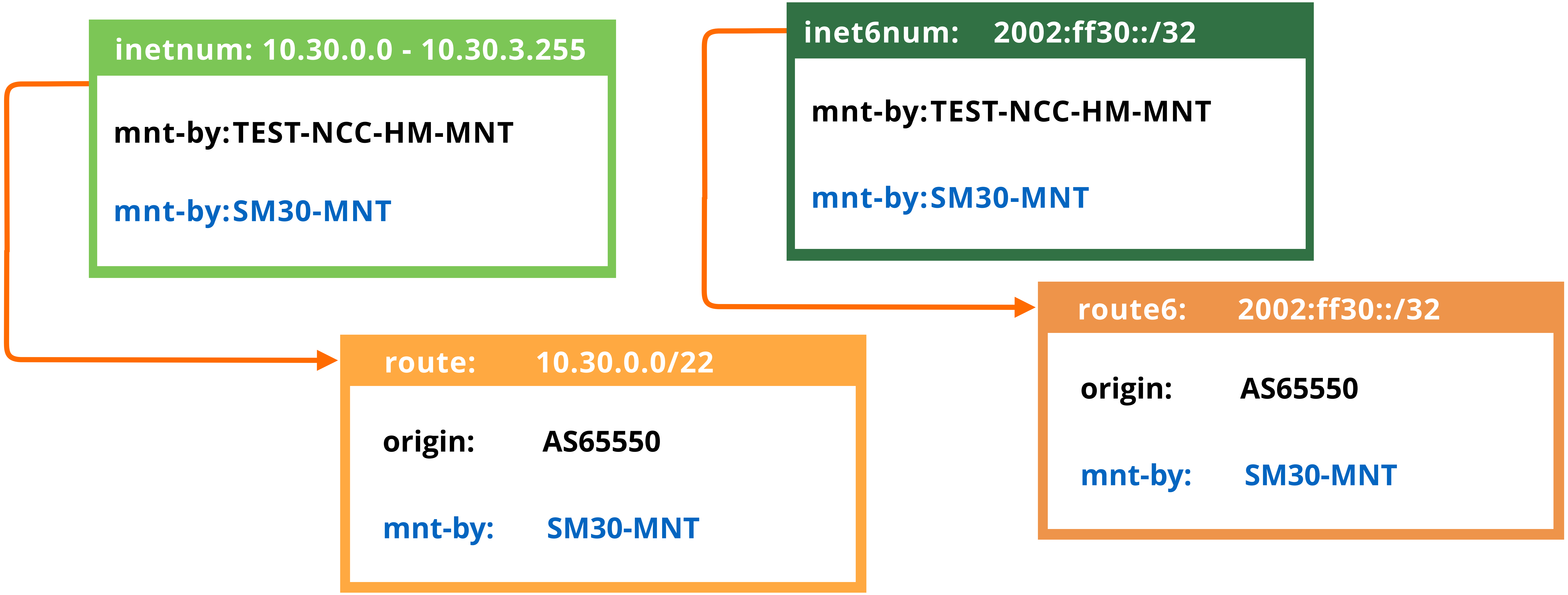
2

route(6)

origin: AS65550
mnt-by: ANOTHER-MNT

* **mnt-routes** delegates the creation of route(6) objects

Registering IP Routes



Aut-num

aut-num:	AS64500
as-name:	YOUR-AS-NAME
org:	ORG-EE2-RIPE
import:	**from AS65550 accept ANY**
export:	**to AS65550 announce AS64500**
import:	**from AS64496 accept ANY**
export:	**to AS64496 announce AS64500**
admin-c:	DV789-RIPE
tech-c:	JS123-RIPE
status:	ASSIGNED
mnt-by:	RIPE-NCC-END-MNT
mnt-by:	DEFAULT-LIR-MNT
source:	RIPE

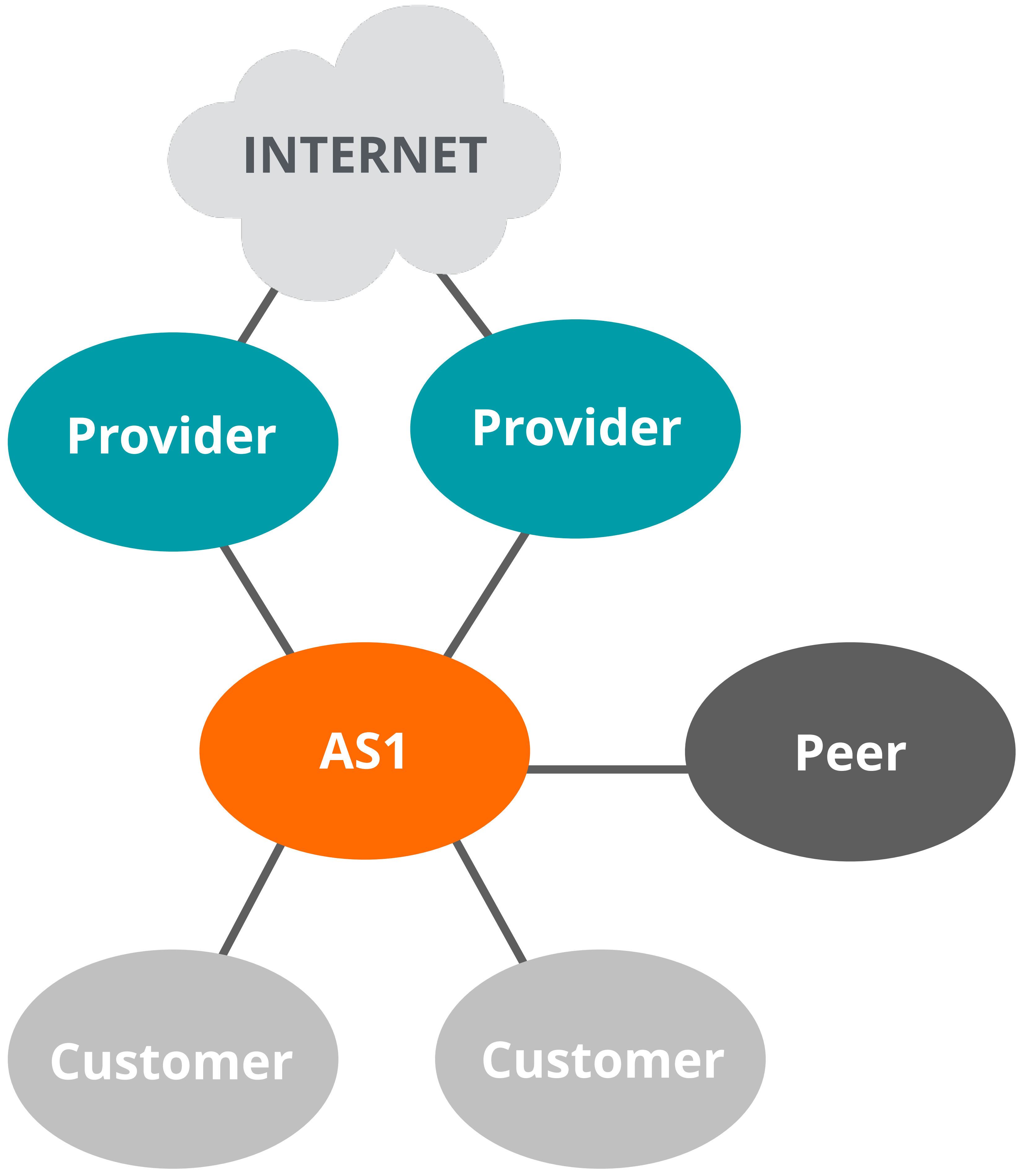
Registers **who** holds that AS Number

Defines the routing policy for an AS

- **Import** - specifies which routes you accept
- **Export** - specifies which routes you announce

BGP Routing Policy

- Who are your BGP peers? Which ASes
- What is your BGP relationship with them?
  - Customer, Provider, Peer
- What are your routing decisions?
  - Which prefixes to accept?
  - Which prefixes to announce?
  - Which prefixes will be preferred in case of multiple routes?



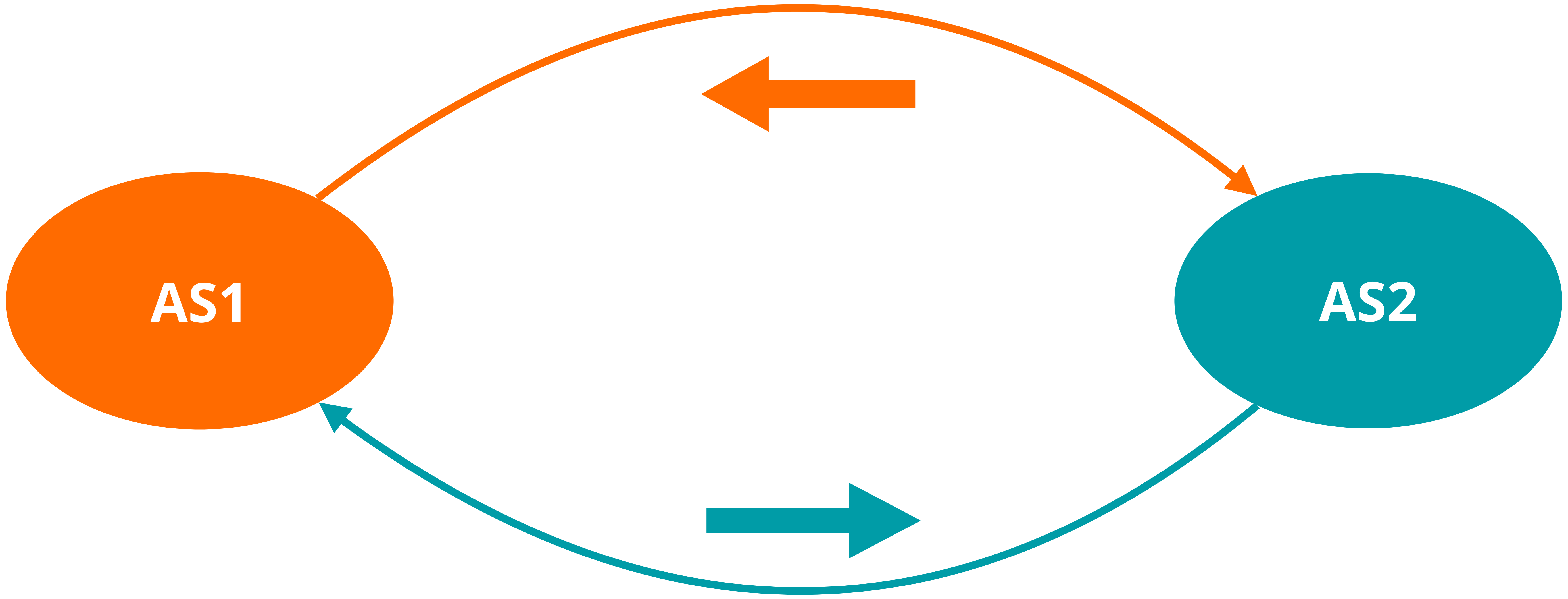
IRRs use RPSL Language

- **RPSL - Routing Policy Specification Language**
- Allows network operators to specify their routing policies
  - Generic way to describe BGP configuration in the IRR
  - Not vendor-specific
- Originated from a RIPE Document (RIPE-181)
- Can be translated into router configuration

RFC 2622 - Routing Policy Specification Language

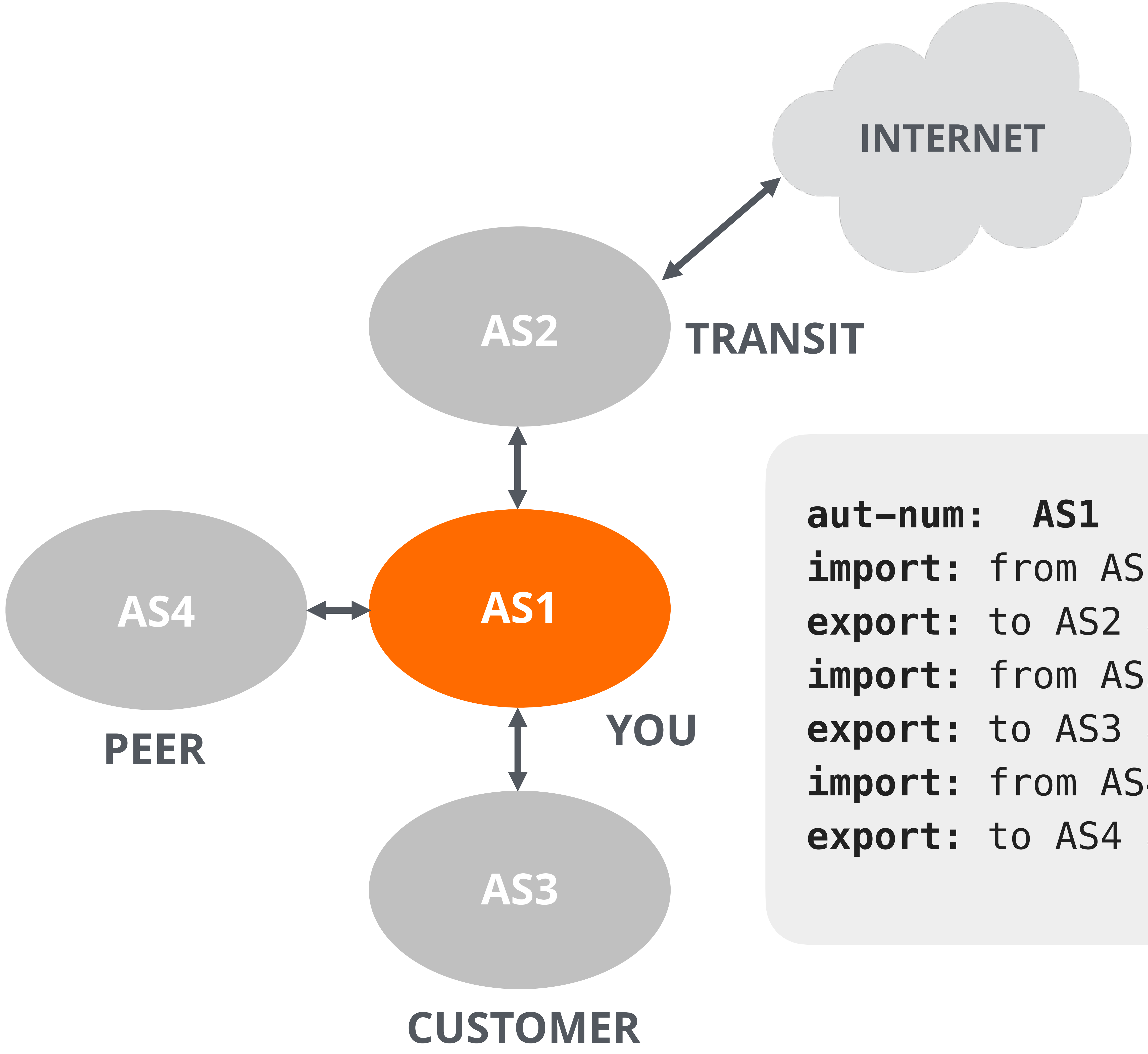
RFC 2650 - Using RPSL in Practice

Defining Routing Policy in RPSL




```
aut-num:  AS1
import: from AS2 accept AS2
export: to AS2 announce AS1
```

Routing Policy Example




```
aut-num:  AS1
import: from AS2 accept ANY
export: to AS2 announce AS1 AS3
import: from AS3 accept AS3
export: to AS3 announce ANY
import: from AS4 accept AS4
export: to AS4 announce AS1 AS3
```

RPSLng

- **RPSL is older** than IPv6, the defaults are IPv4
- IPv6 was added later using a different syntax
- You have to **specify** that it's IPv6

```
aut-num:   AS1
mp-import:  afi ipv6.unicast from AS201 accept AS201
mp-export:  afi ipv6.unicast to AS201 announce ANY
```

```
route-set:  rs-customers
members:    192.0.2.0/24
mp-members: 2001:db8:abcd::/48
```

RFC 4012 - "Routing Policy Specification Language next generation (RPSLng)"

Tools to check IRR status

RIPEstat

Routing Consistency

11 records found for **AS3333**

Filter results by

Prefix ↑	in BGP (RIS)	IRRs	RPKI ROV	VRPs
193.0.0.0/21	✓	RIPE	☺	✓ maxLength: 21
193.0.10.0/23	✓	RIPE	☺	✓ maxLength: 23
193.0.12.0/23	✓	RIPE	☺	✓ maxLength: 23
193.0.18.0/23	✓	RIPE	☺	✓ maxLength: 23
193.0.20.0/23	✓	RIPE	☺	✓ maxLength: 23
193.0.22.0/23	✓	RIPE	☺	✓ maxLength: 23
193.230.194.0/24				✓ maxLength: 24
2001:610:240::/42				✓ maxLength: 42
2001:67c:2e8::/48	✓	RIPE	☺	✓ maxLength: 48
2a13:27c0:10::/44				✓ maxLength: 44

Records per page: 10 1-10 of 11

https://stat.ripe.net

IRR EXPLORER

https://irrexplorer.nlnog.net/

Reality Check

- The IRR system has limitations
  - Conflicting data, no central authority, no holdership checks, not updated
- It is still widely used
- Improving IRR accuracy
  - Keep your IRR information up to date
  - Route filtering using IRRdv4 (validates against RPKI)
  - IRR databases should remove inconsistent records regularly

Questions

Lab 4 - Creating Route(6) Objects

15 min

Lab 4 - Creating route(6) Objects

- **Description**: Create a route6 object in the RIPE Test Database
- **Goals:**
  - Register routing information in the RIPE Database
- **Time:** 15 minutes
- **Tasks:**
  - Create a RIPE NCC Access account (if you don’t have one)
  - Search for your IPv6 allocation and AS number
  - Create a route6 object for your allocated IPv6 prefix

Lab 4 - Creating route(6) Objects

- **What have you learned?**
  - Which RIPE DB objects contain IPv6 routing information
  - How RIPE DB protects its objects and the accuracy of data

route(6)

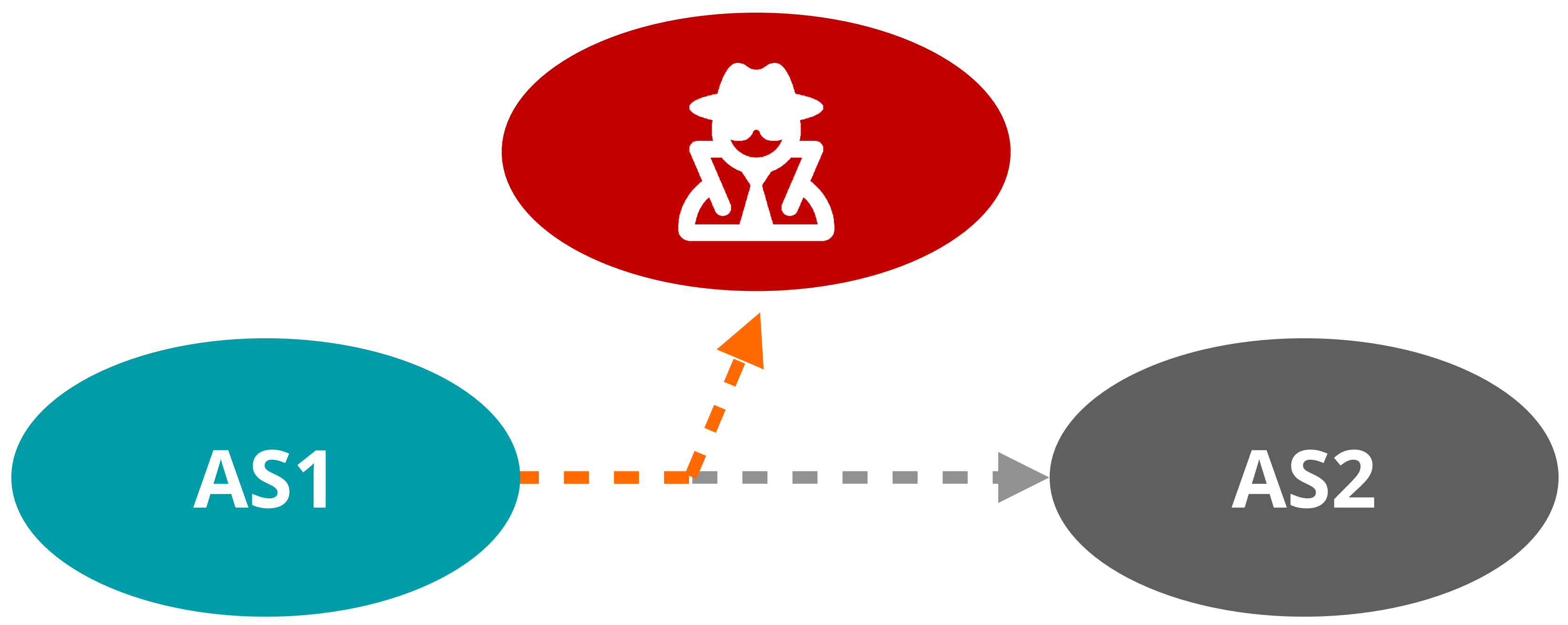
origin: AS65550
mnt-by: ANOTHER-MNT

Implementing RPKI

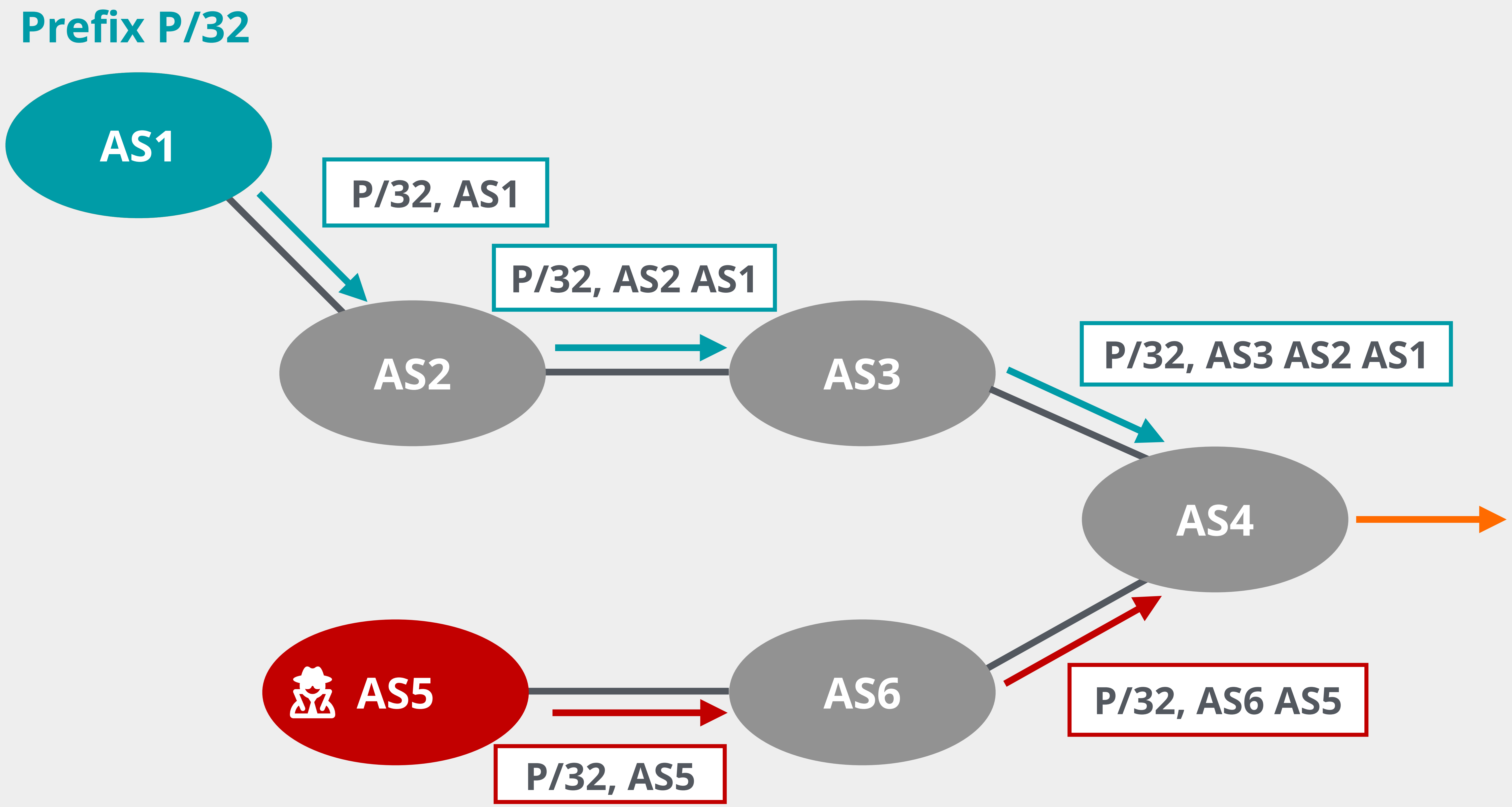
Section 3.5

BGP Origin Hijacks

- An AS originates a prefix that is not authorised to originate
- Hijacker impersonates the legitimate holder
    - May hijack an **allocated** or **unallocated** address space
- It may announce the exact same prefix or more specifics
    - Prefix Hijack
    - **Sub-prefix Hijack** (De-aggregation hijack or subnet attack)



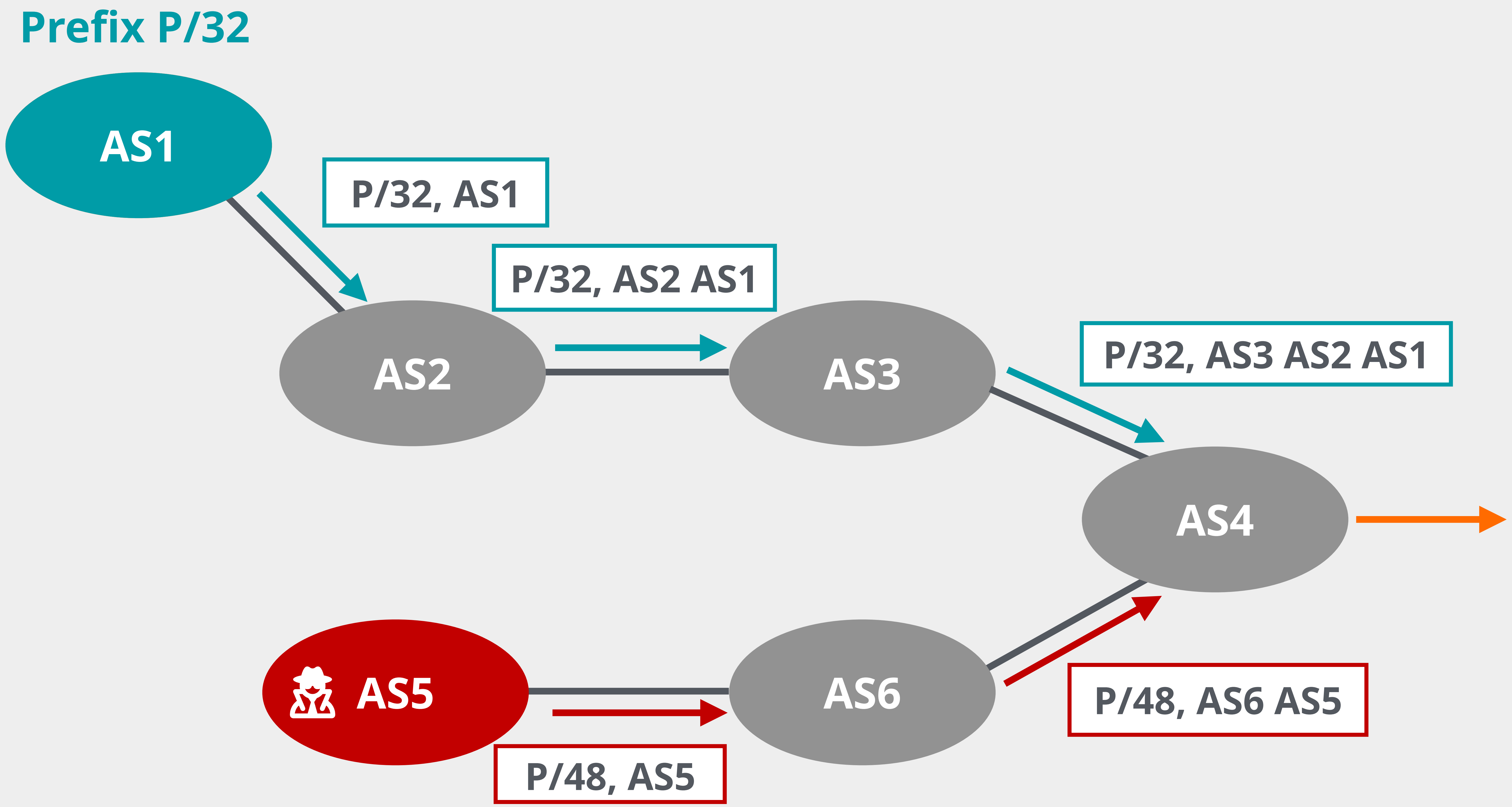
Prefix Hijack



This is a **local hijack!**

Only some networks are affected based on BGP path selection process

Sub-prefix Hijack (Subnet Attack)

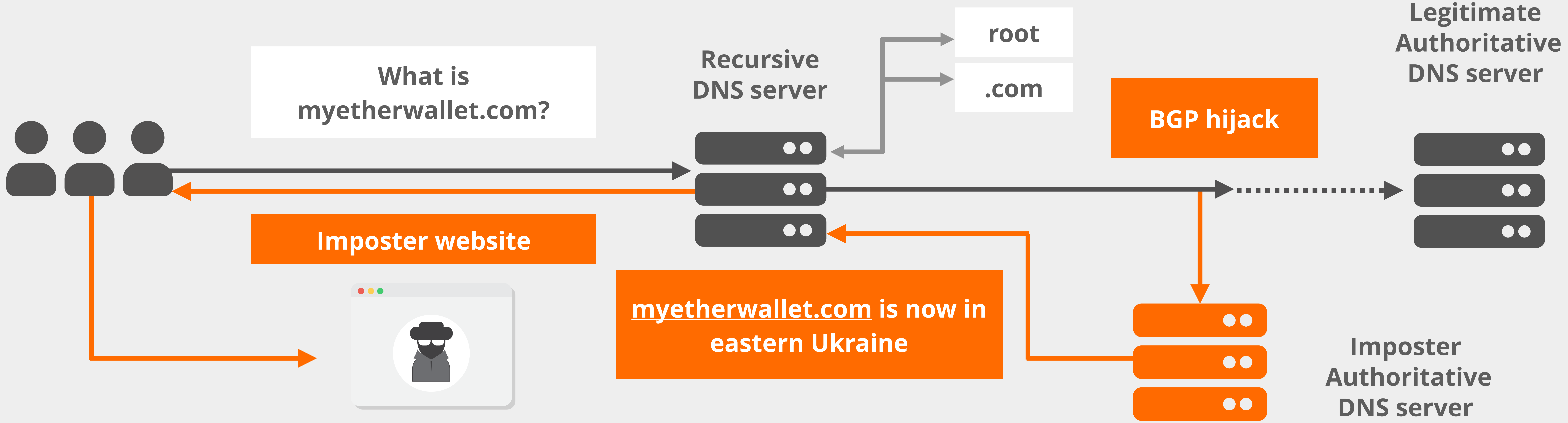


This is a **global hijack!**

All traffic for more specific prefix will be forwarded to the hijacker's network

April 2018: Amazon MyEtherWallet

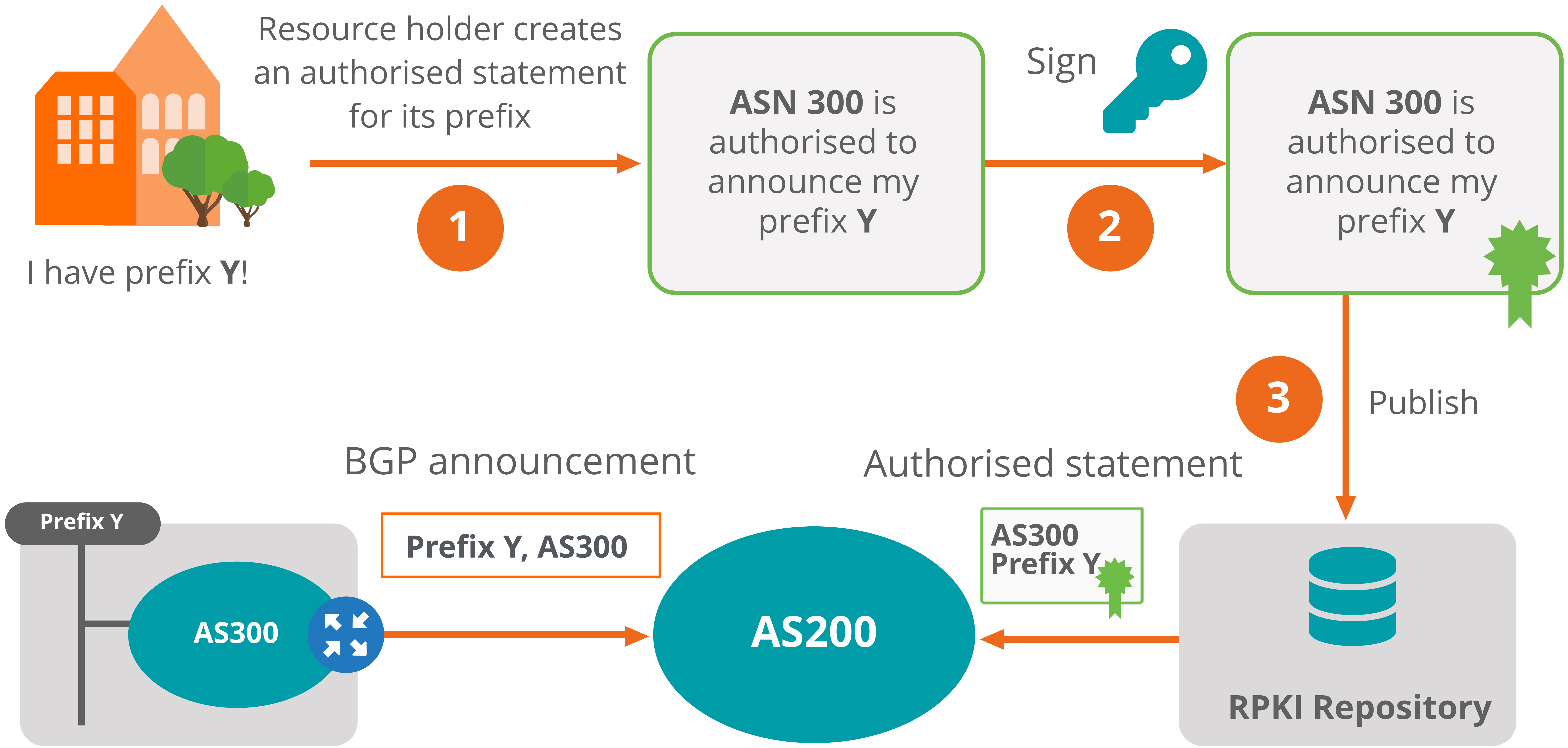
- BGP hijack of Amazon DNS
- What happened?
- Why?
    - Attack to steal cryptocurrency



What is RPKI?

- A security framework for the Internet
- **Verifies the association between resource holders and their resources**
  - Attaches digital certificate to IP addresses and AS numbers
- Used to **validate the origin** of BGP announcements (BGP OV)
  - Is the originating ASN authorised to originate a particular prefix?
  - Helps to mitigate **BGP Origin Hijacks** and **Route leaks**

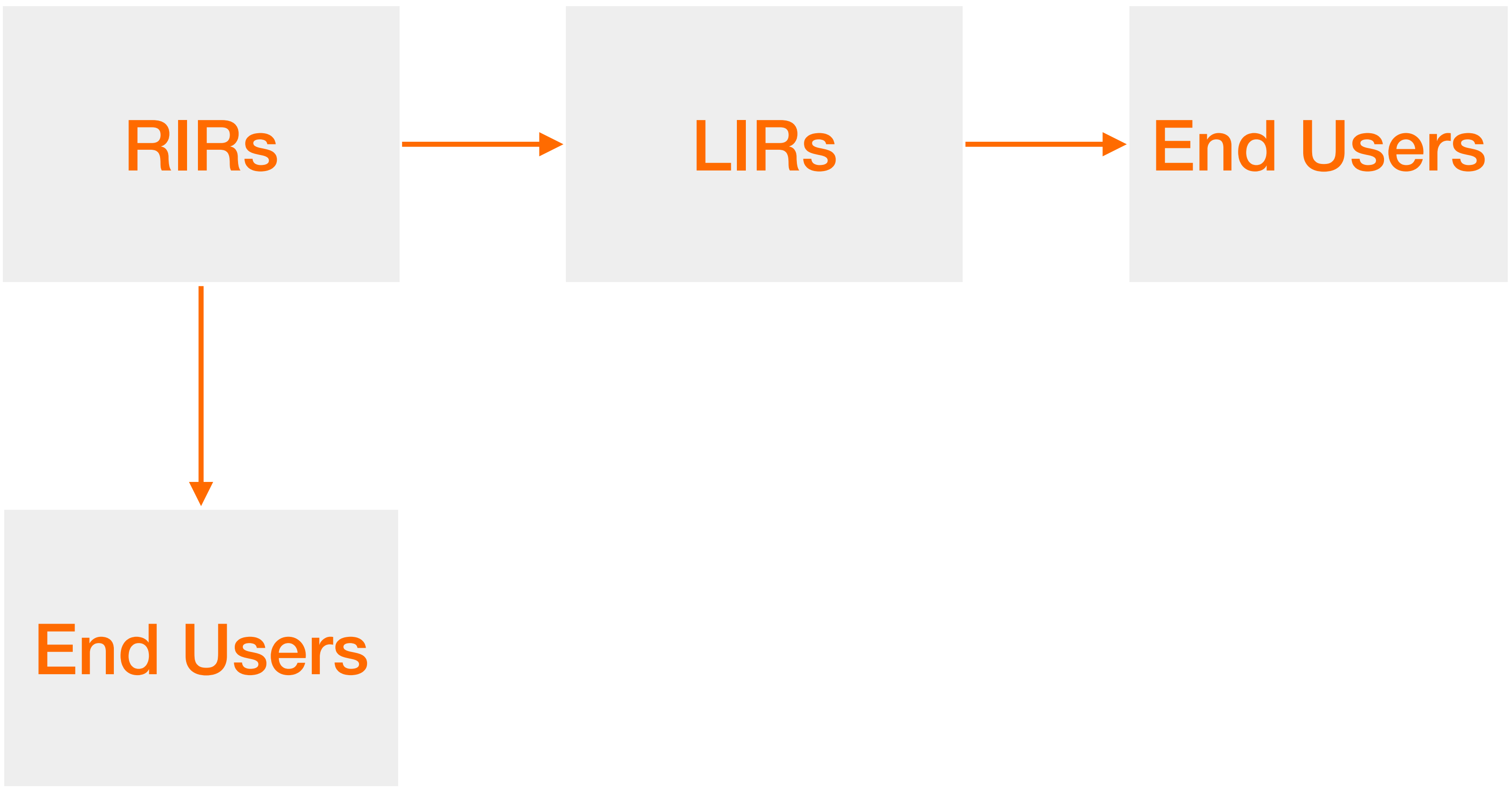
How Does RPKI Work?

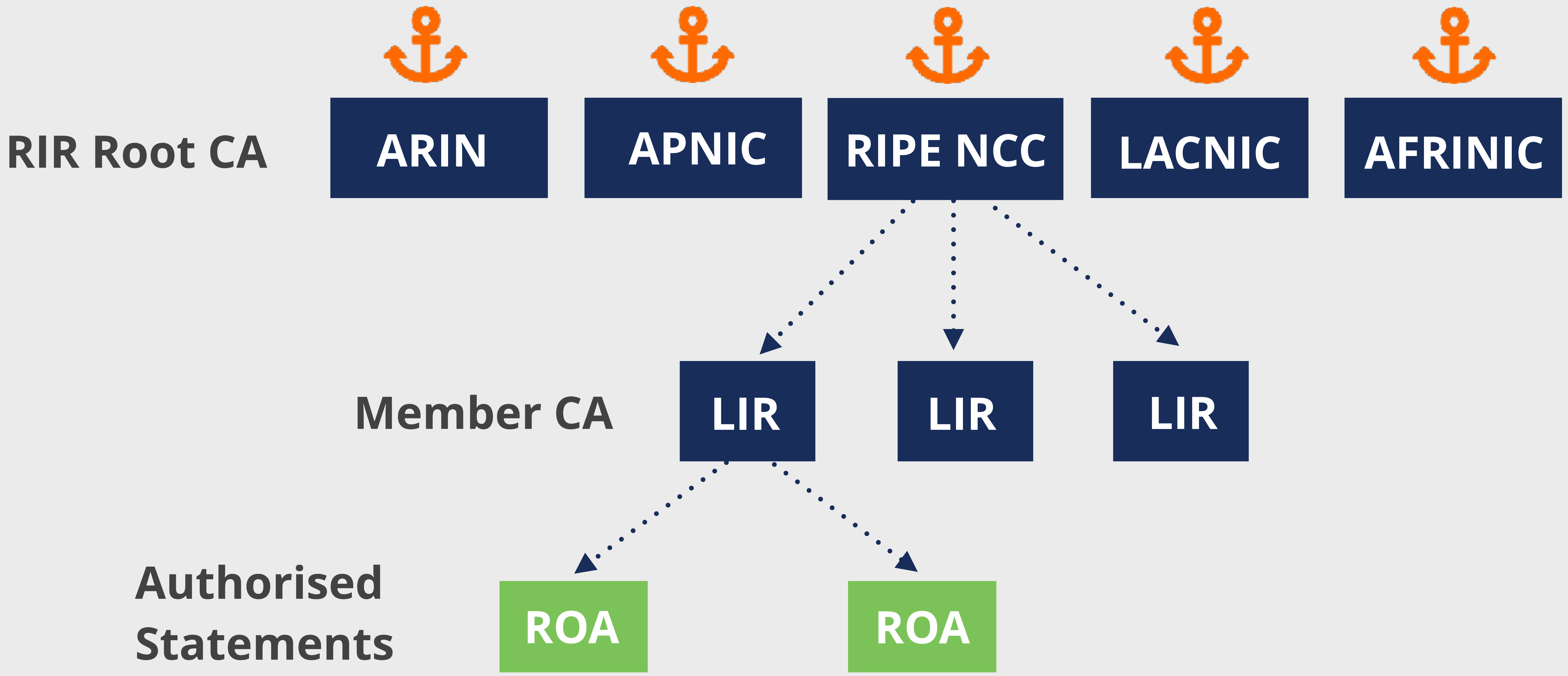


Others use those statements to make better routing decisions

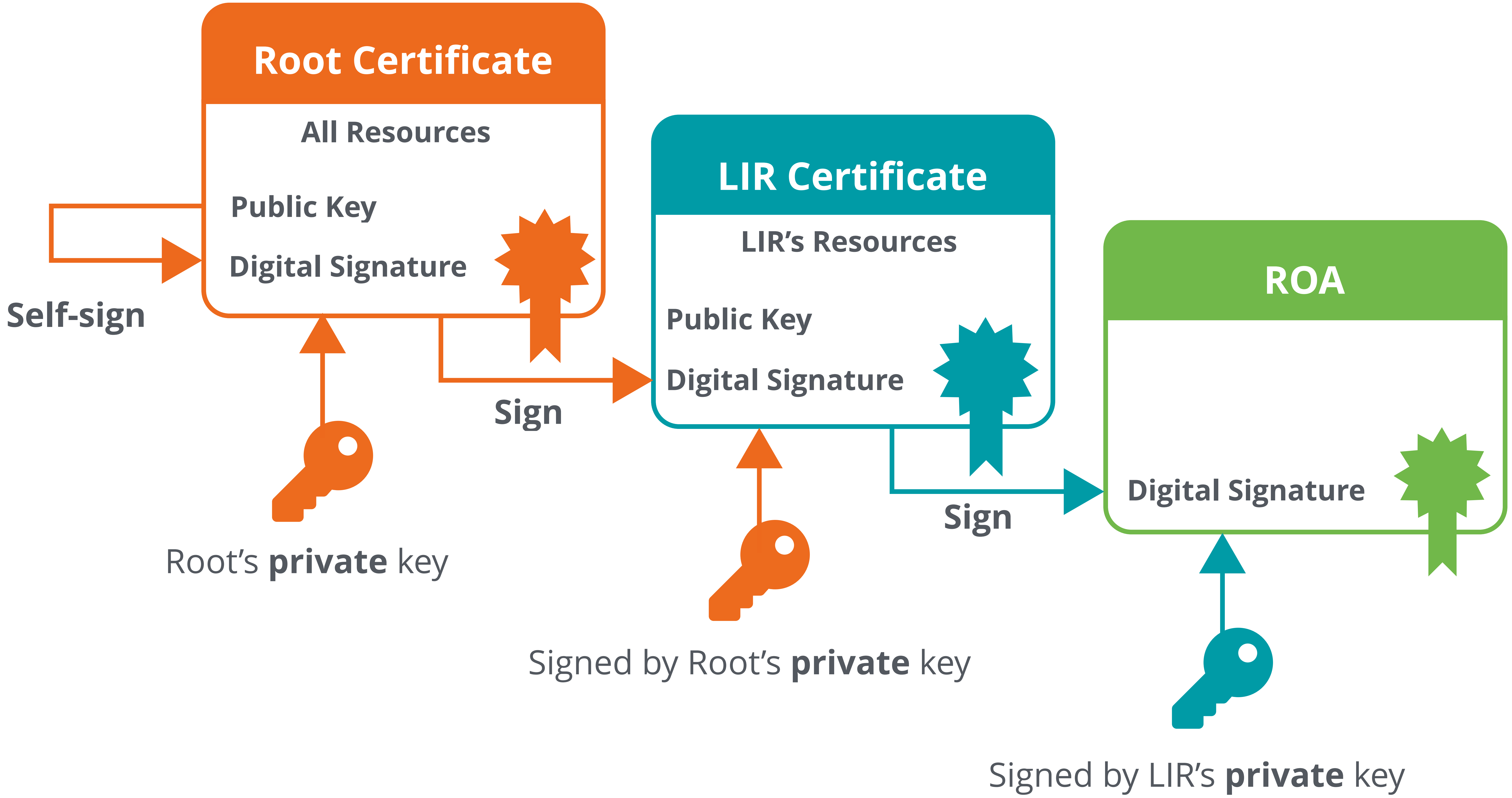
Trust in RPKI

- RPKI relies on five RIRs as Trust Anchors
- Certificate structure follows the RIR hierarchy
- RIRs issue certificates to resource holders





RPKI Chain of Trust



Elements of RPKI

- The RPKI system consists of two parts:

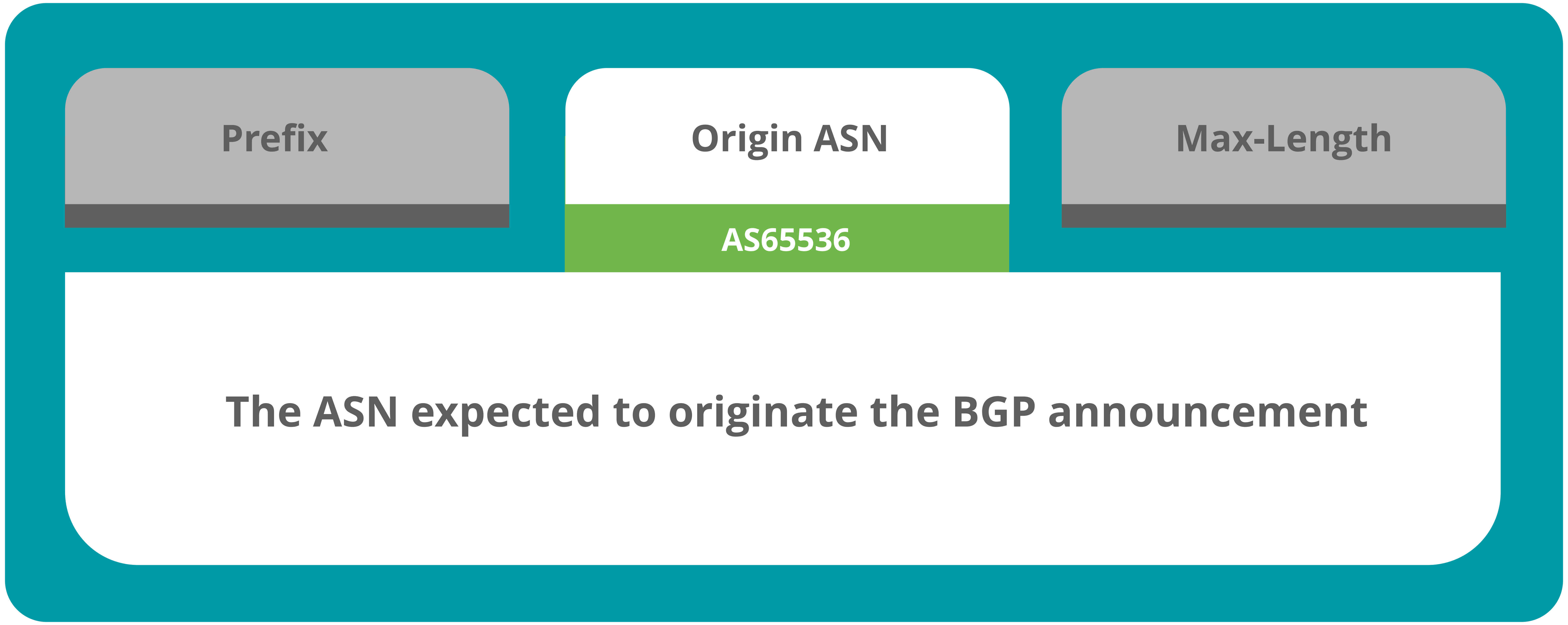
SIGNING		VALIDATION
Create ROAs for your prefixes in the RPKI system	+	Verify the information provided by others

What is in a ROA?

Prefix	Origin ASN	Max-Length
2001:db8::/48		

The network for which you are creating the ROA

What is in a ROA?



What is in a ROA?

Prefix

Origin ASN

Max-Length

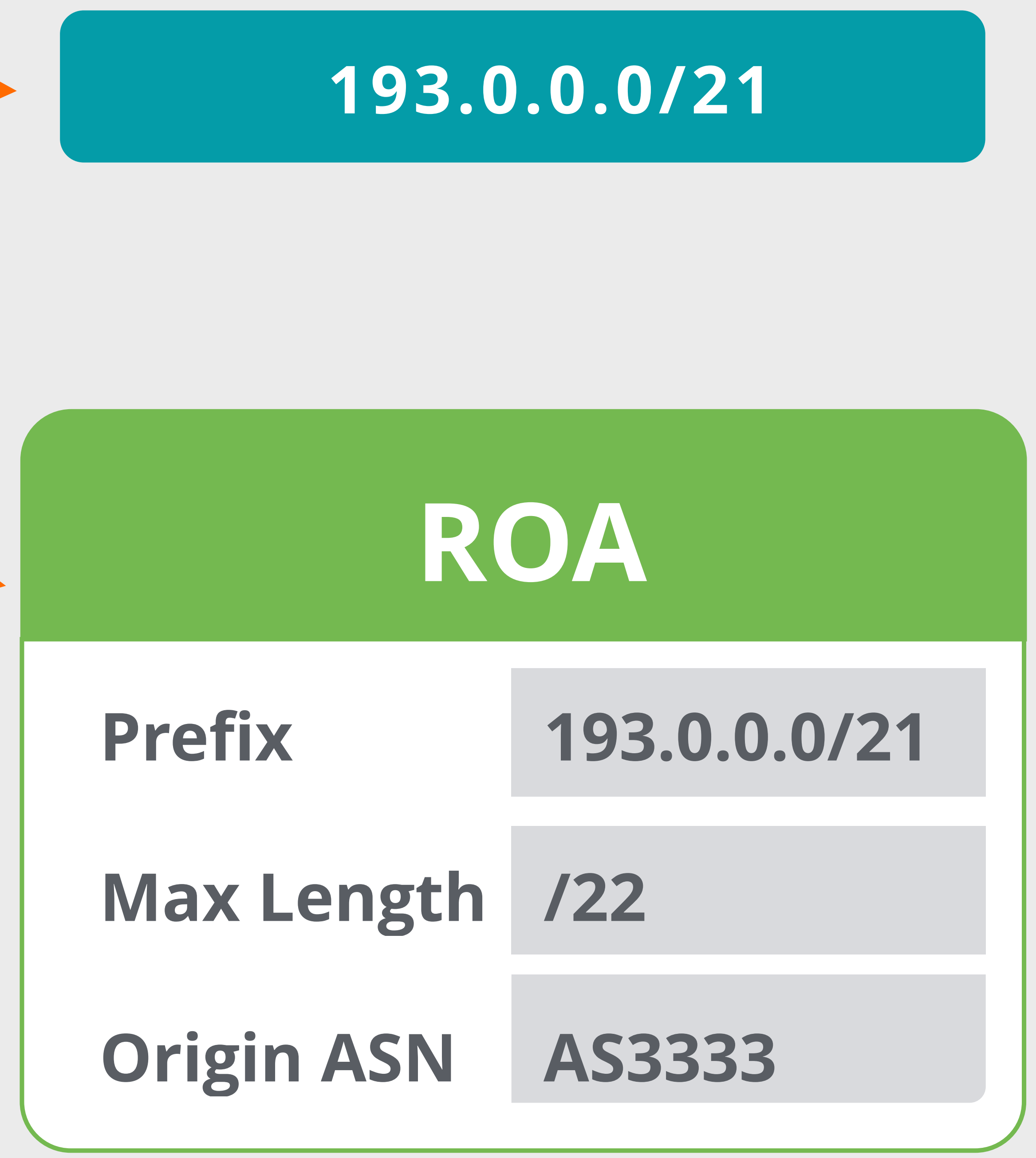
/48

The max prefix length the ROA is authorising to advertise

Max-Length

RIPE NCC (AS3333) has an IP address allocation

RIPE NCC creates this ROA

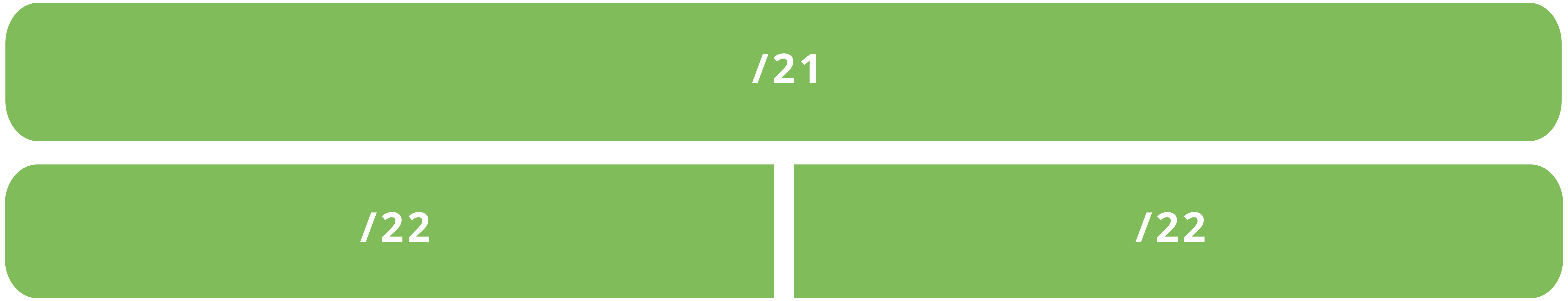


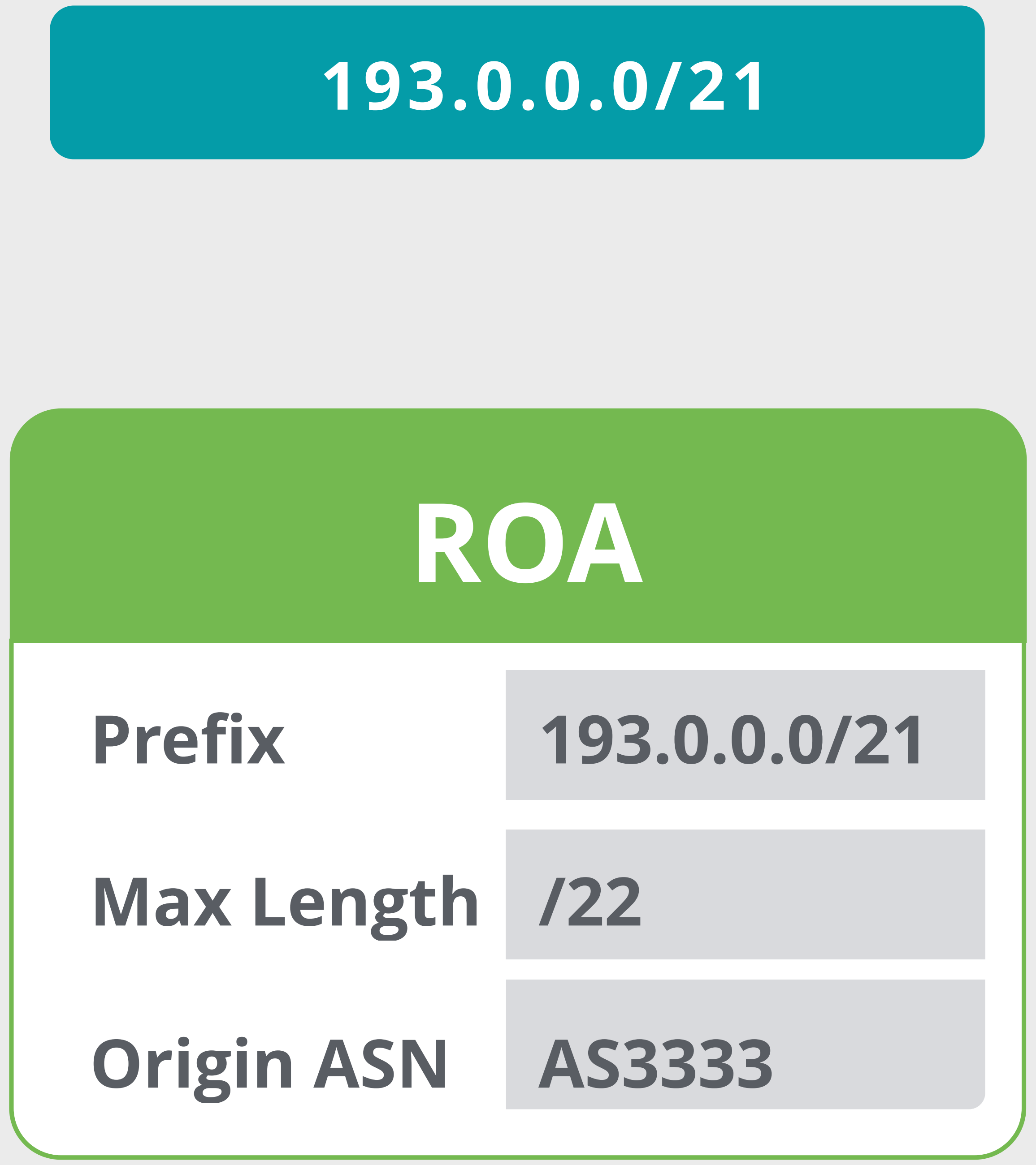
Max-Length

RIPE NCC (AS3333) has an IP address allocation

RIPE NCC creates this ROA

According to the ROA:



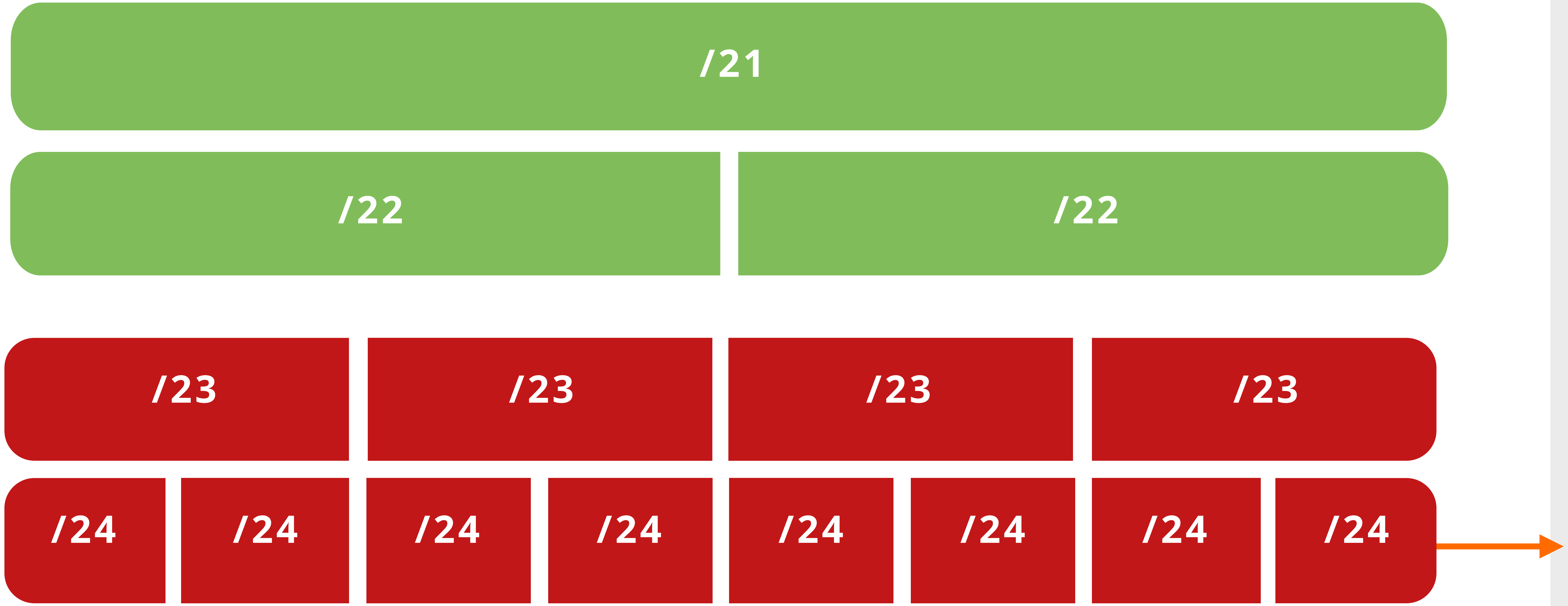


Max-Length

RIPE NCC (AS3333) has an IP address allocation

RIPE NCC creates this ROA

According to the ROA:



193.0.0.0/21

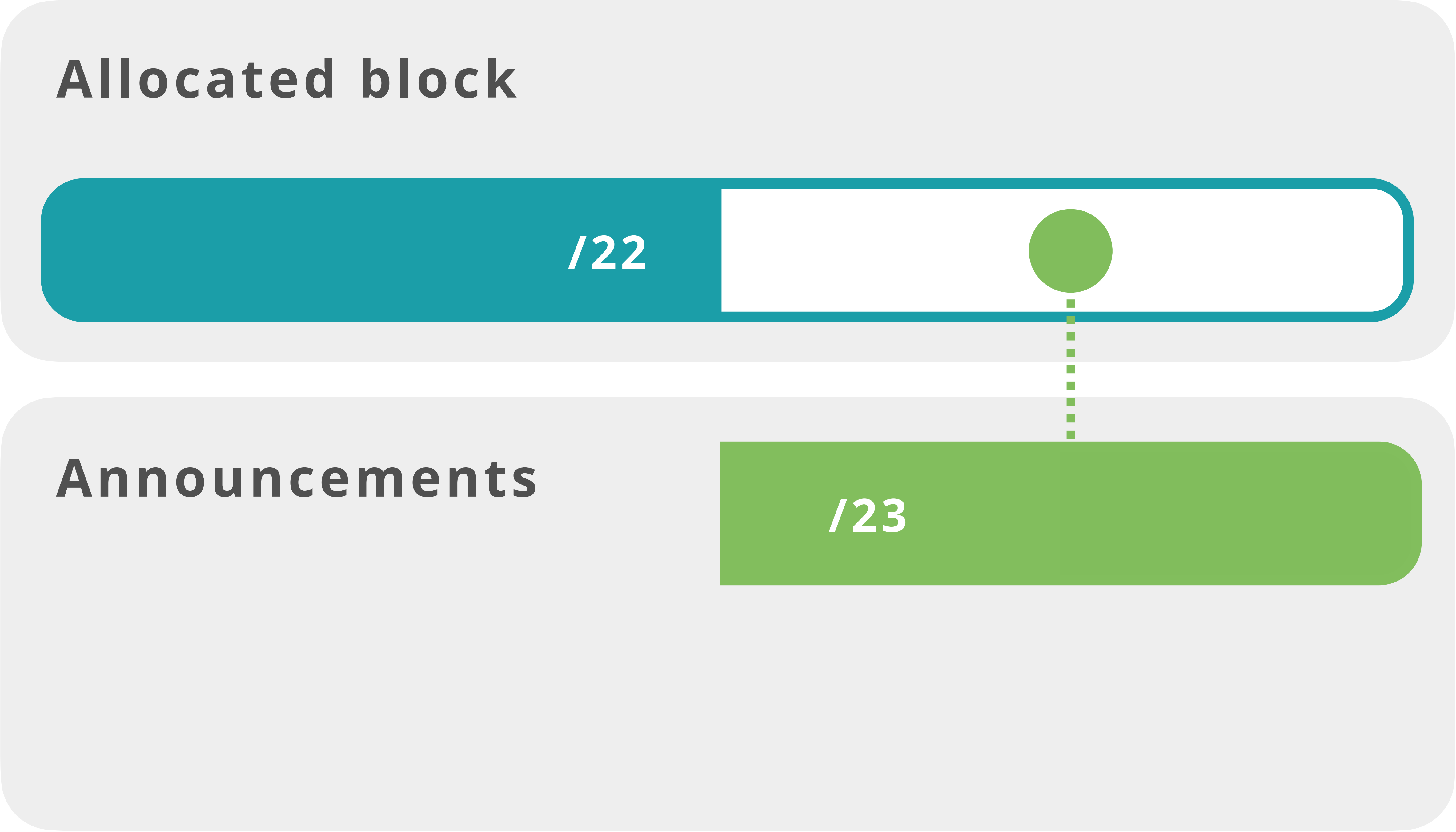
ROA

Prefix	193.0.0.0/21
Max Length	/22
Origin ASN	AS3333

Any other more specific announcements are unauthorised by the ROA

How Should We Use Max-Length?

Case 1: You create a single ROA authorising the entire /22

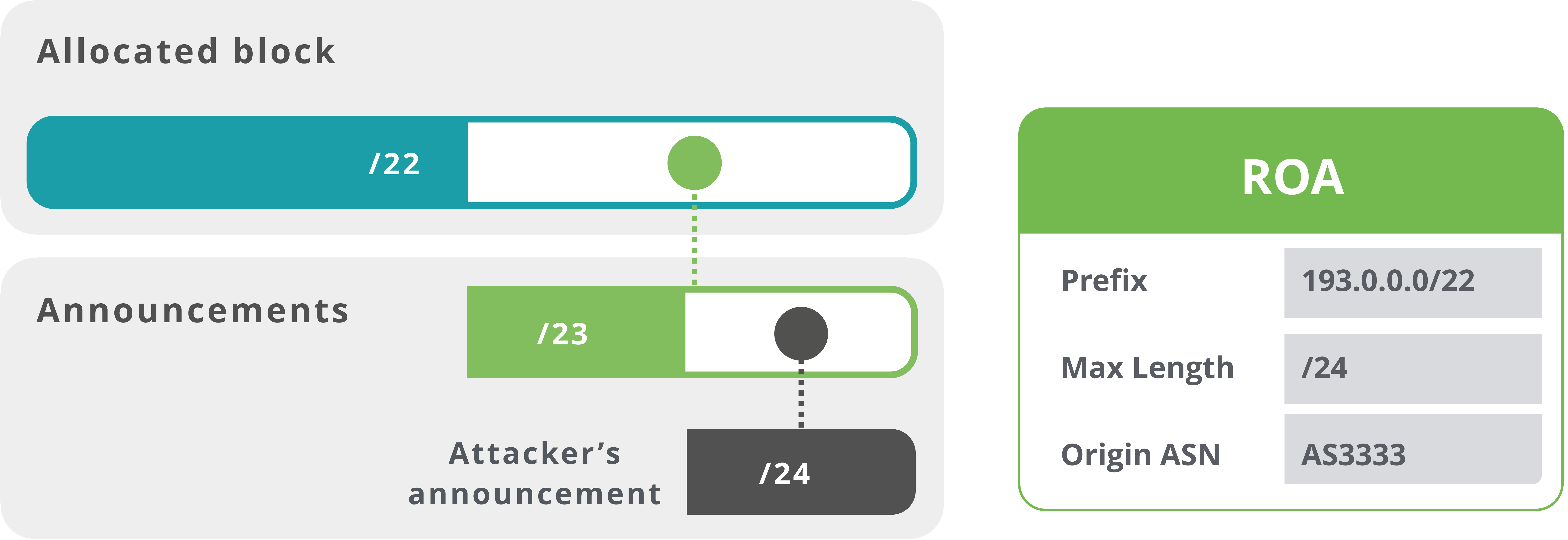


ROA

Prefix	193.0.0.0/22
Max Length	/24
Origin ASN	AS3333

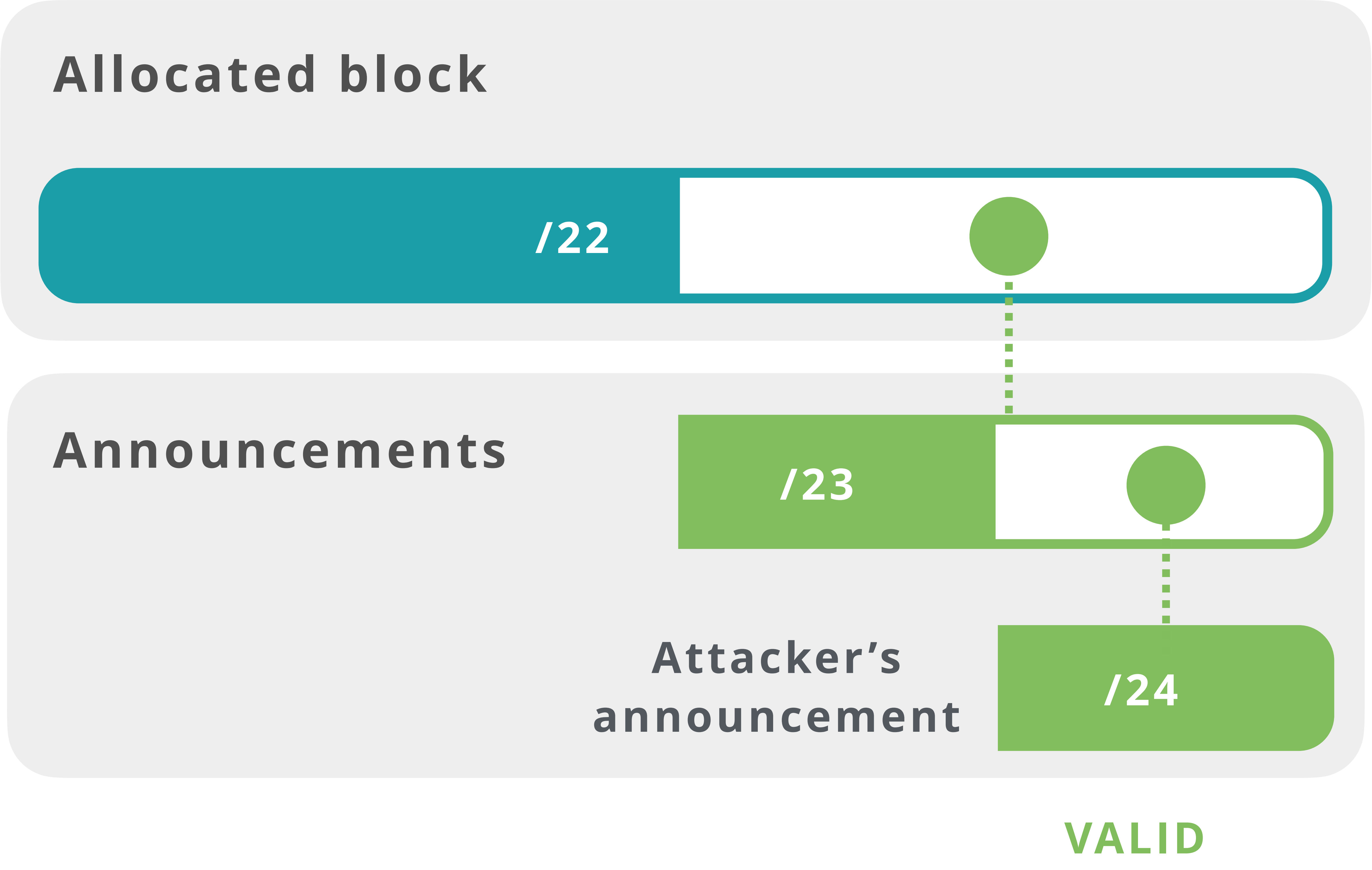
How Should We Use Max-Length?

Case 1: You create a single ROA authorising the entire /22



How Should We Use Max-Length?

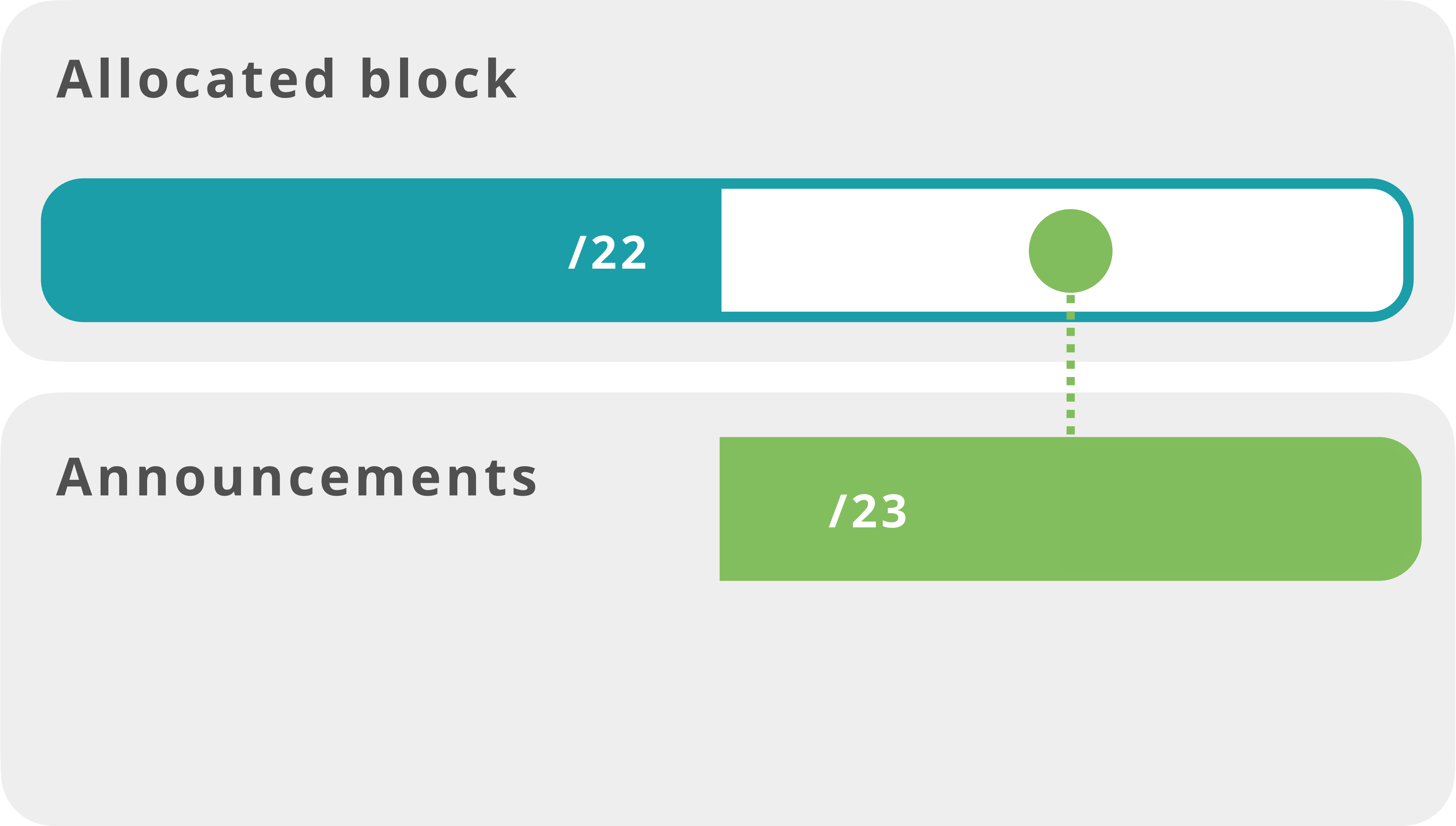
Case 1: You create a single ROA authorising the entire /22



ROA	
Prefix	193.0.0.0/22
Max Length	/24
Origin ASN	AS3333

How Should We Use Max-Length?

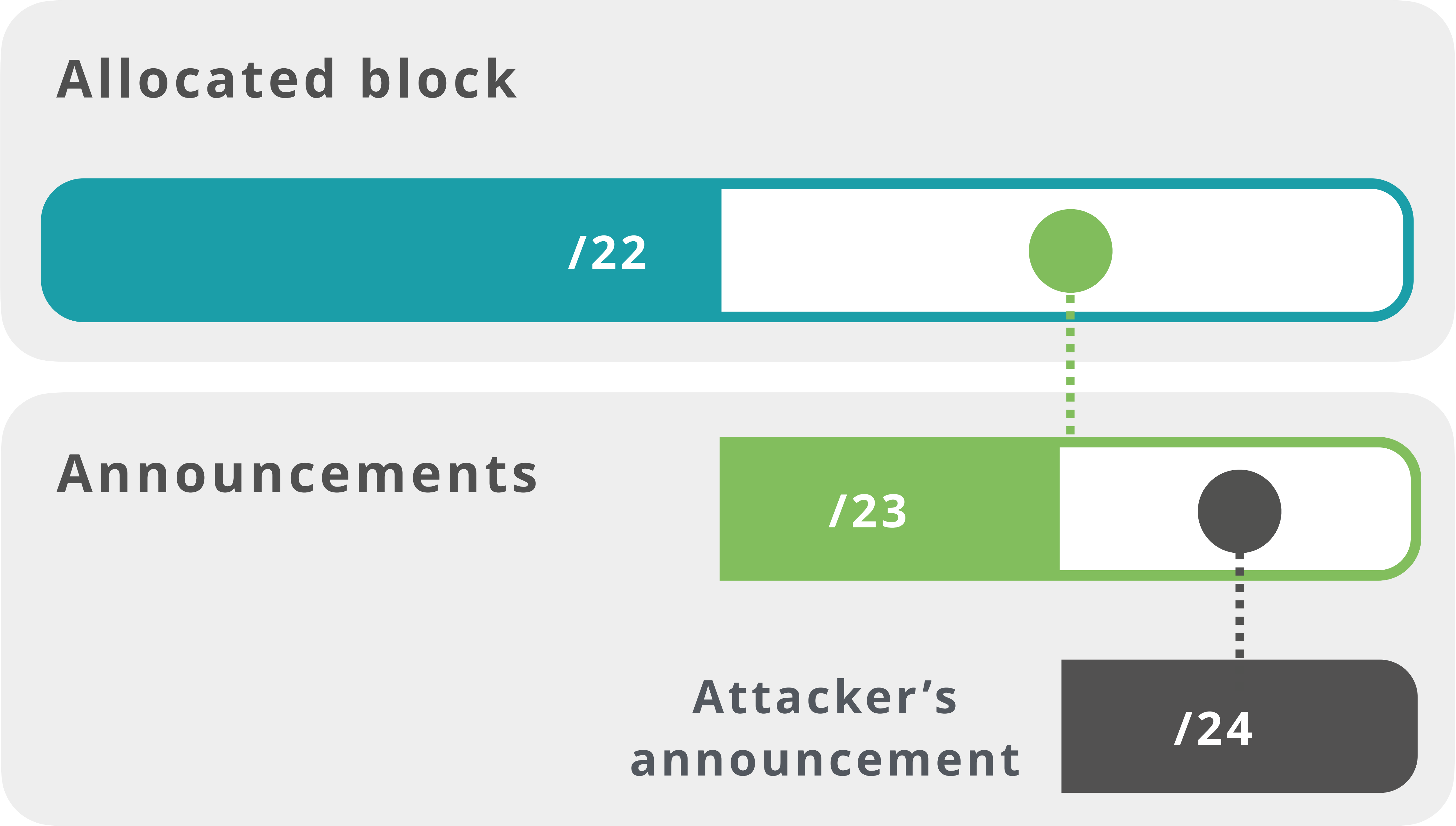
Case 2: You create ROAs only for your BGP announcement



ROA	
Prefix	193.0.0.0/22
Max Length	/23
Origin ASN	AS3333

How Should We Use Max-Length?

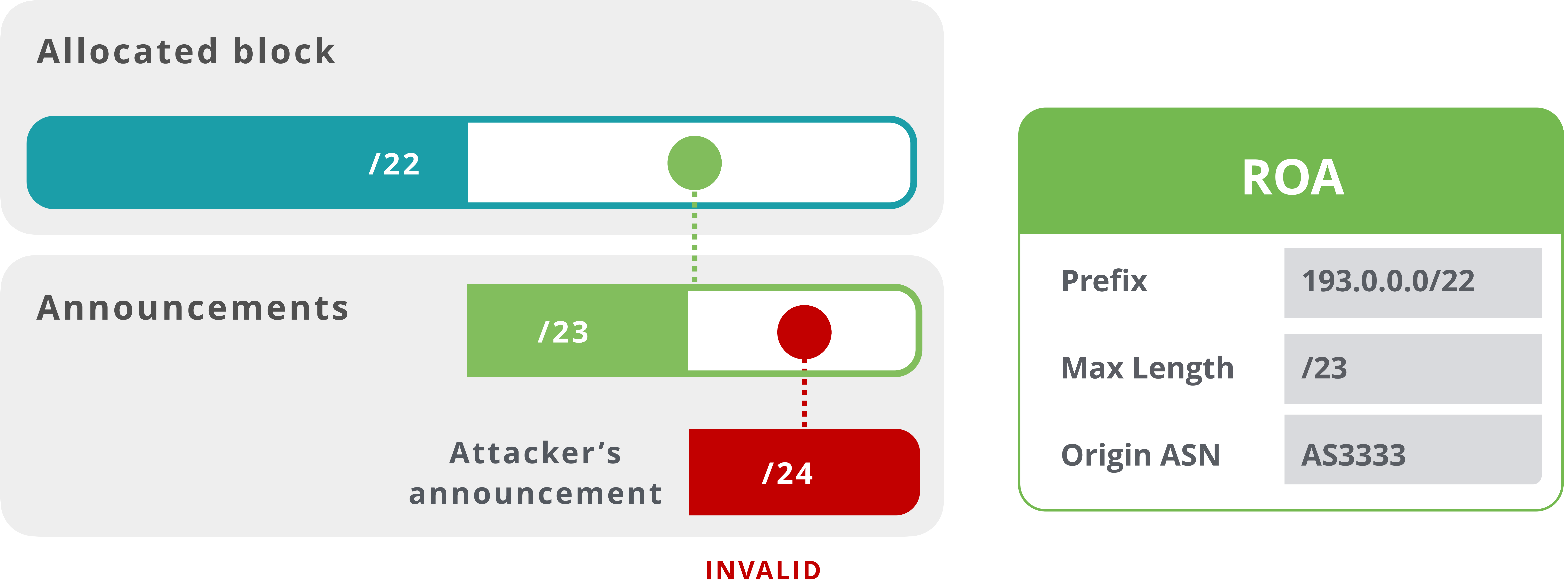
Case 2: You create ROAs only for your BGP announcement



ROA	
Prefix	193.0.0.0/22
Max Length	/23
Origin ASN	AS3333

How Should We Use Max-Length?

Case 2: You create ROAs only for your BGP announcement



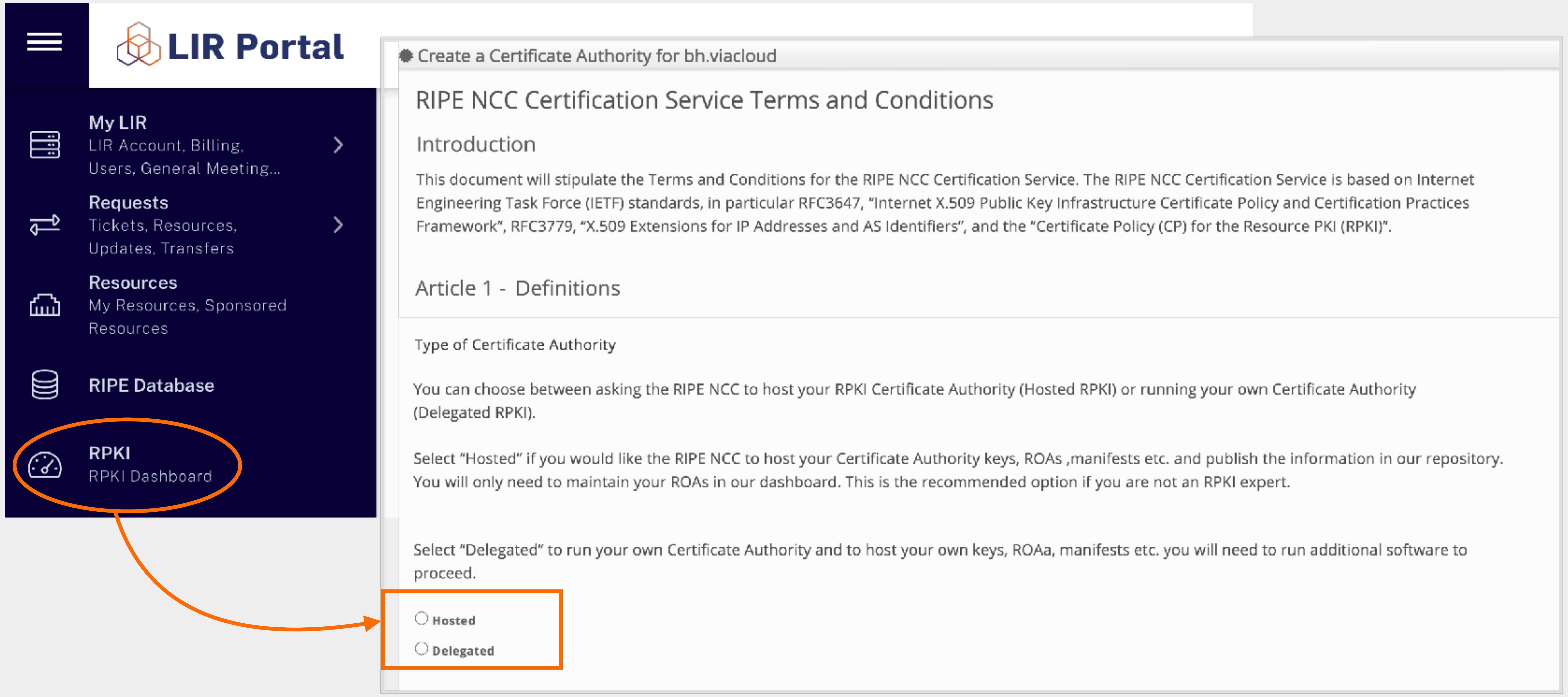
Create ROAs only for your BGP announcements!

How to create a ROA? Easy!

- Login to LIR Portal (my.ripe.net)
- Go to the RPKI Dashboard
- Choose which RPKI model to use

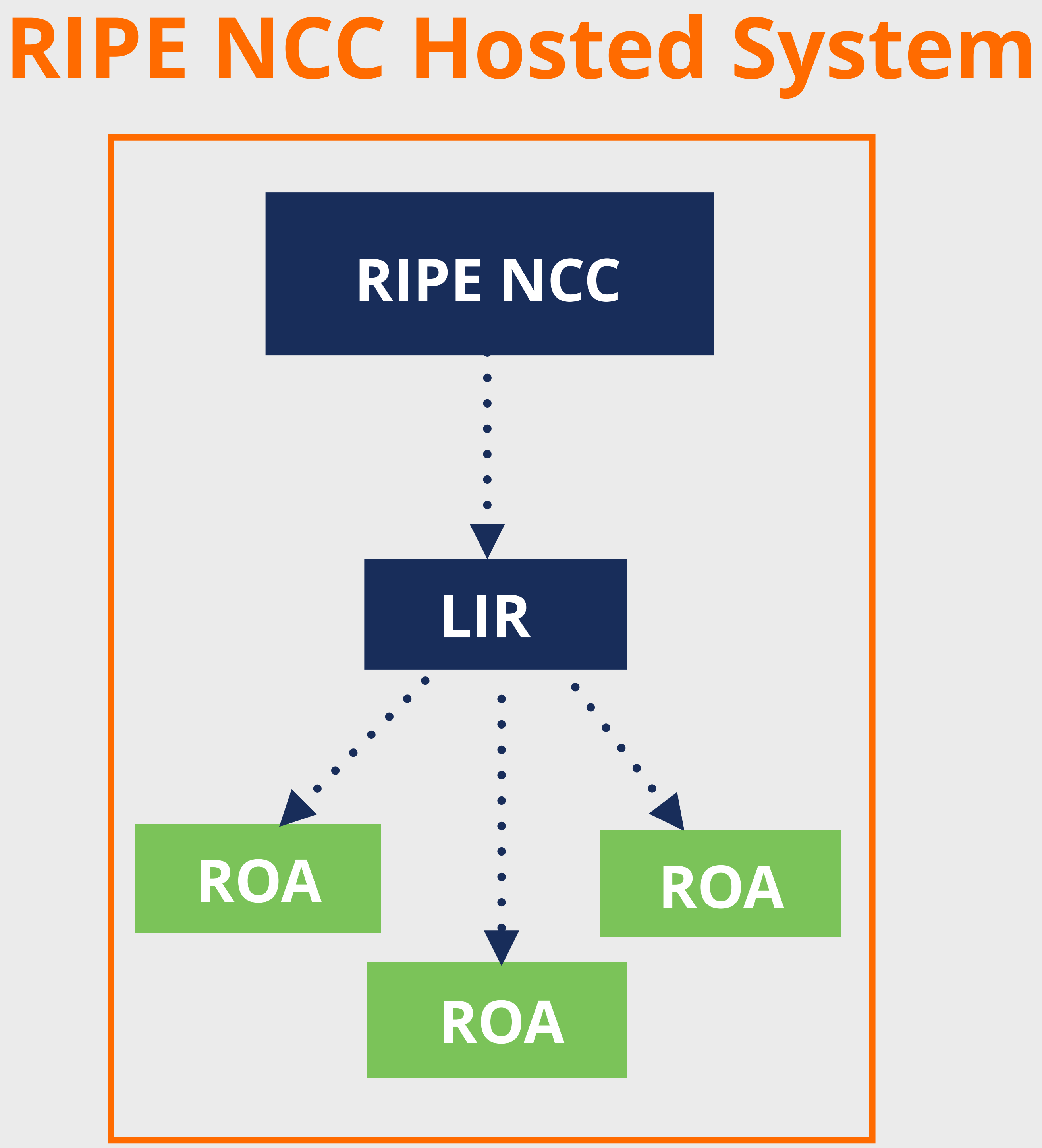
Hosted

Delegated



Hosted RPKI

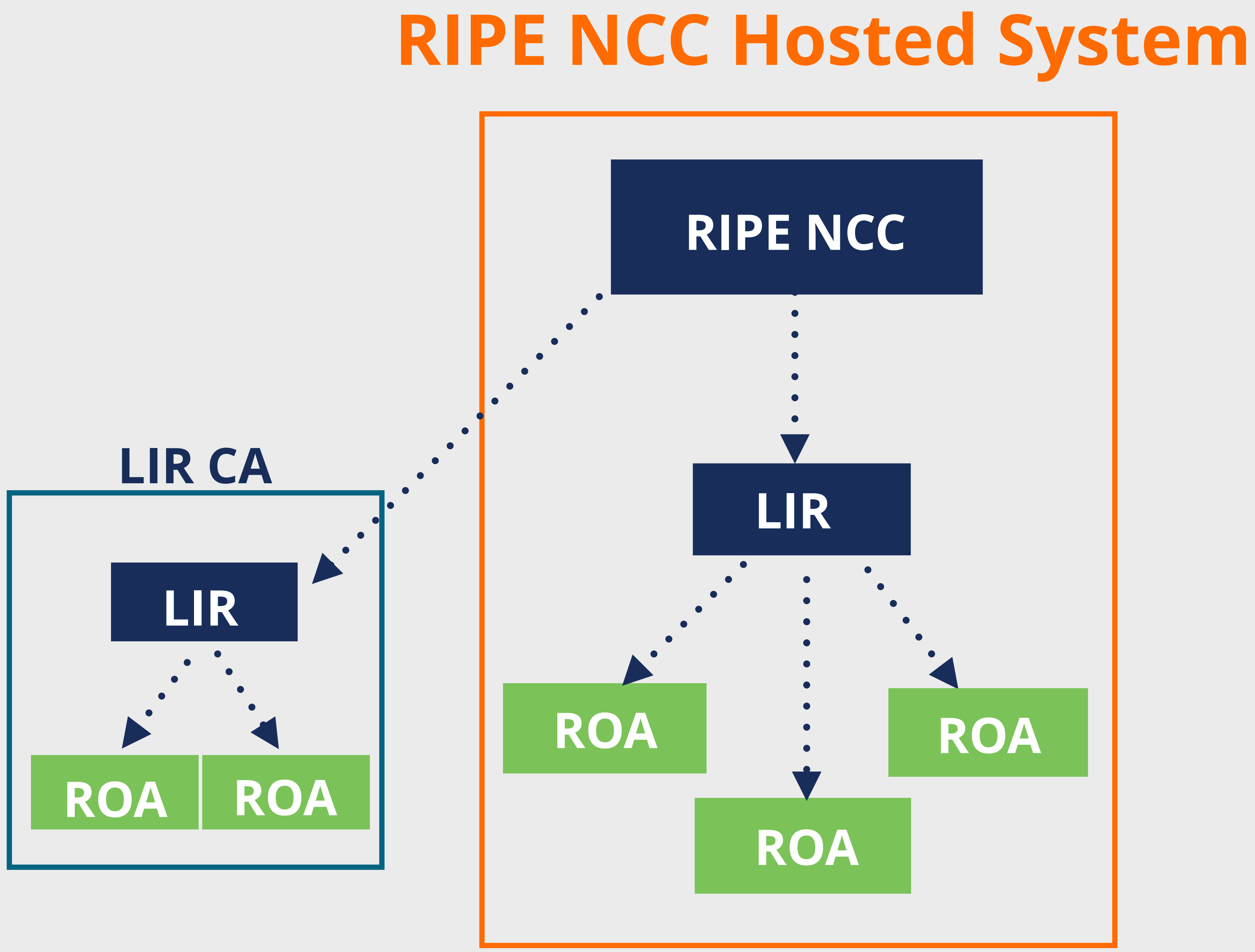
- ROAs are created and published using the **RIR's member portal**
- RIR hosts a CA for LIRs and signs all ROAs
- Automated signing and key rollovers
- Allows LIRs to focus on creating and publishing ROAs



Delegated RPKI

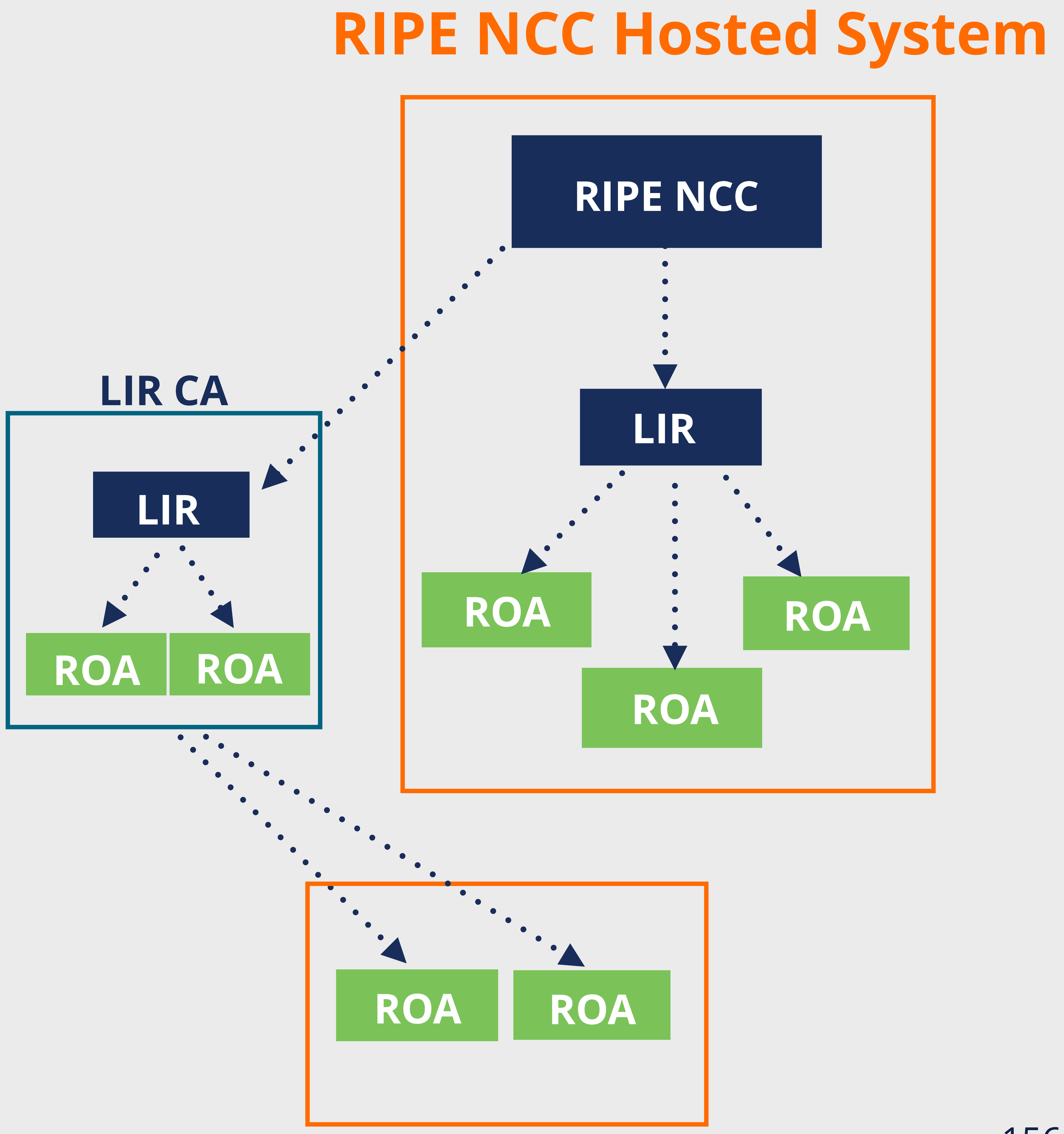
- Each LIR manages its part of the RPKI system:
  - Runs its own CA as a child of the RIR
  - Manages keys/key rollovers
  - Creates, signs and publishes ROAs

- Certificate Authority (CA) Software
  - **Krill** (NLnet Labs)
  - **rpkid** (Dragon Research Labs)

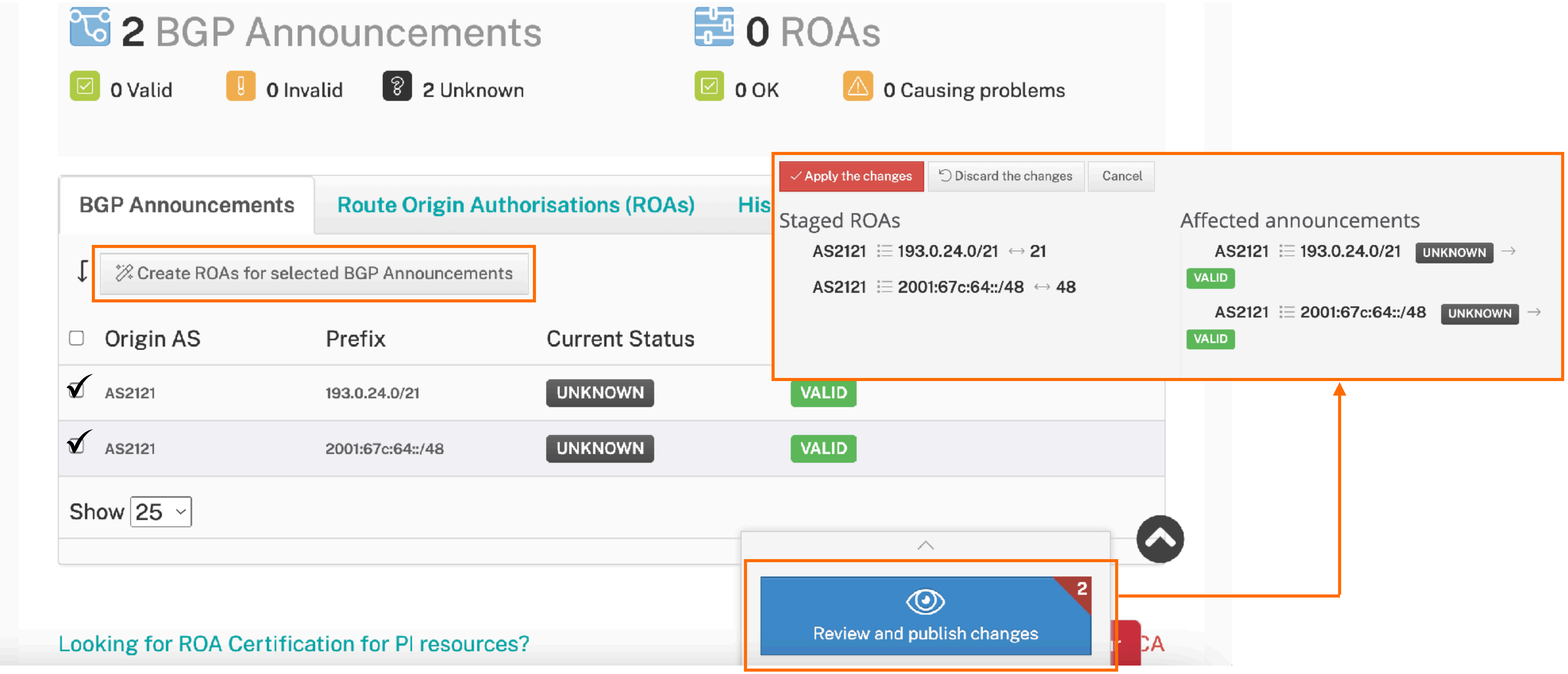


Hybrid RPKI

- In-between hosted and delegated RPKI
- The LIR:
  - Runs its own CA as a child of the RIR
  - Manages keys/key rollovers and ROAs
  - Maintains key-pairs and objects and send them to RIR
  - RIR publishes ROAs in its repository
- Supported by APNIC, ARIN, RIPE NCC and NIRs
- AKA “Publication in parent” or “Publication as a service”



RIPE NCC Hosted Solution



Certifying PI Resources

Requested and managed by PI End User or by Sponsoring LIR

1. Complete the wizard successfully

Start the wizard to set up Resource Certification for PI and Legacy End User resources

2. Login to https://my.ripe.net and request a certificate
   - Sign in with your RIPE NCC Access account
3. Manage your ROAs

Questions

Lab 5 - RPKI
5.1 - Creating ROAs

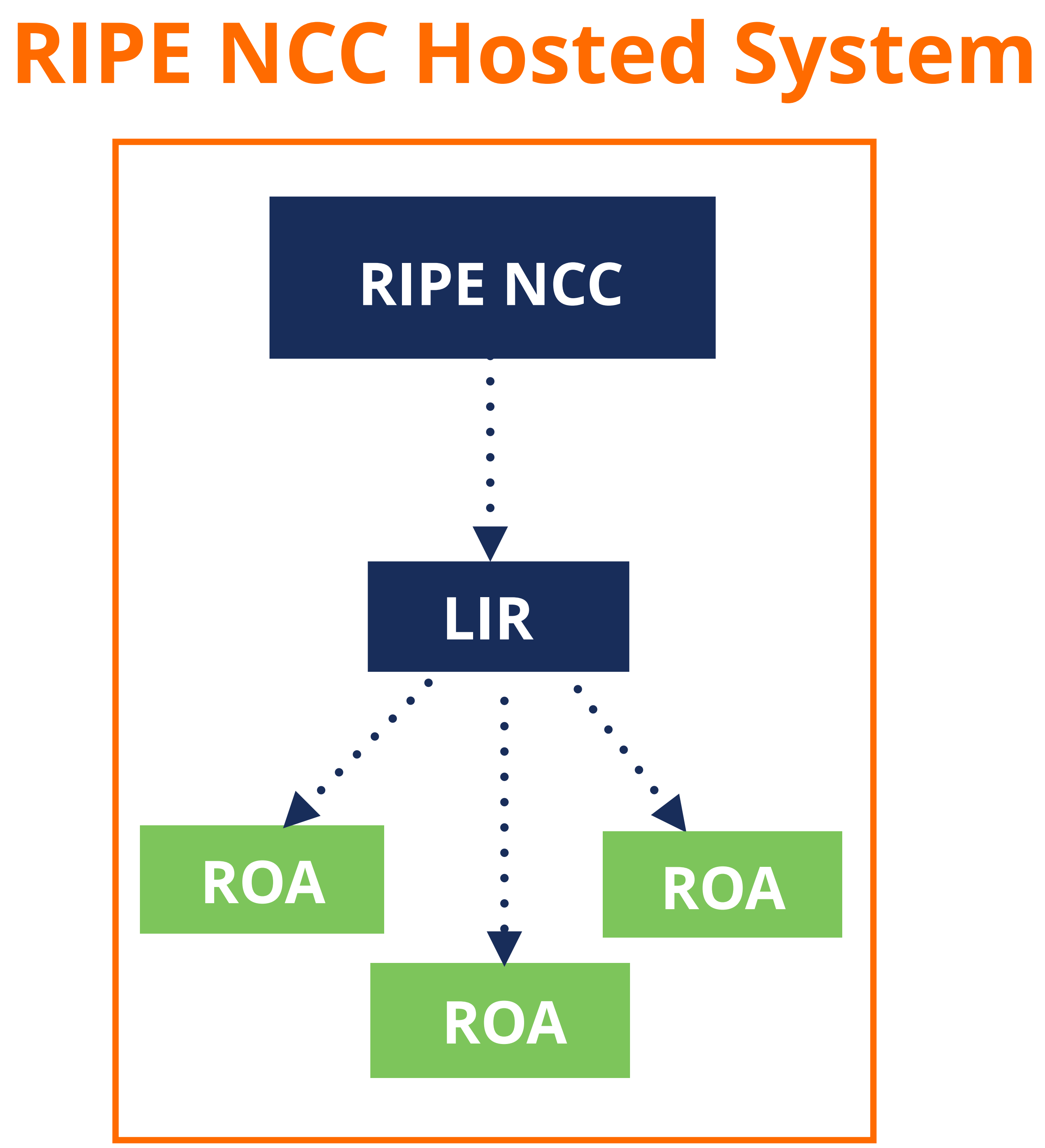
15 min

Lab 5.1 RPKI - Creating ROAs

- **Description**: Create (see demo) ROAs in the test RPKI Dashboard
- **Goals:**
  - Identify elements of the RPKI infrastructure
  - Register routing information in the RPKI dashboard by creating a ROA
- **Time:** 15 minutes
- **Tasks:**
  - 5.1 Check your BGP announcements
  - 5.1 Create (or see a demo) ROAs in the test RPKI Dashboard
  - 5.1 Create (or see a demo) a more specific ROA for one of your prefixes

Lab 5.1 RPKI - Creating ROAs

- **What have you learned?**
  - How to create ROAs using the RIPE NCC Hosted RPKI service web interface



Elements of RPKI

- The RPKI system consists of two parts:

SIGNING

Create ROAs for your prefixes in the RPKI system

+

VALIDATION

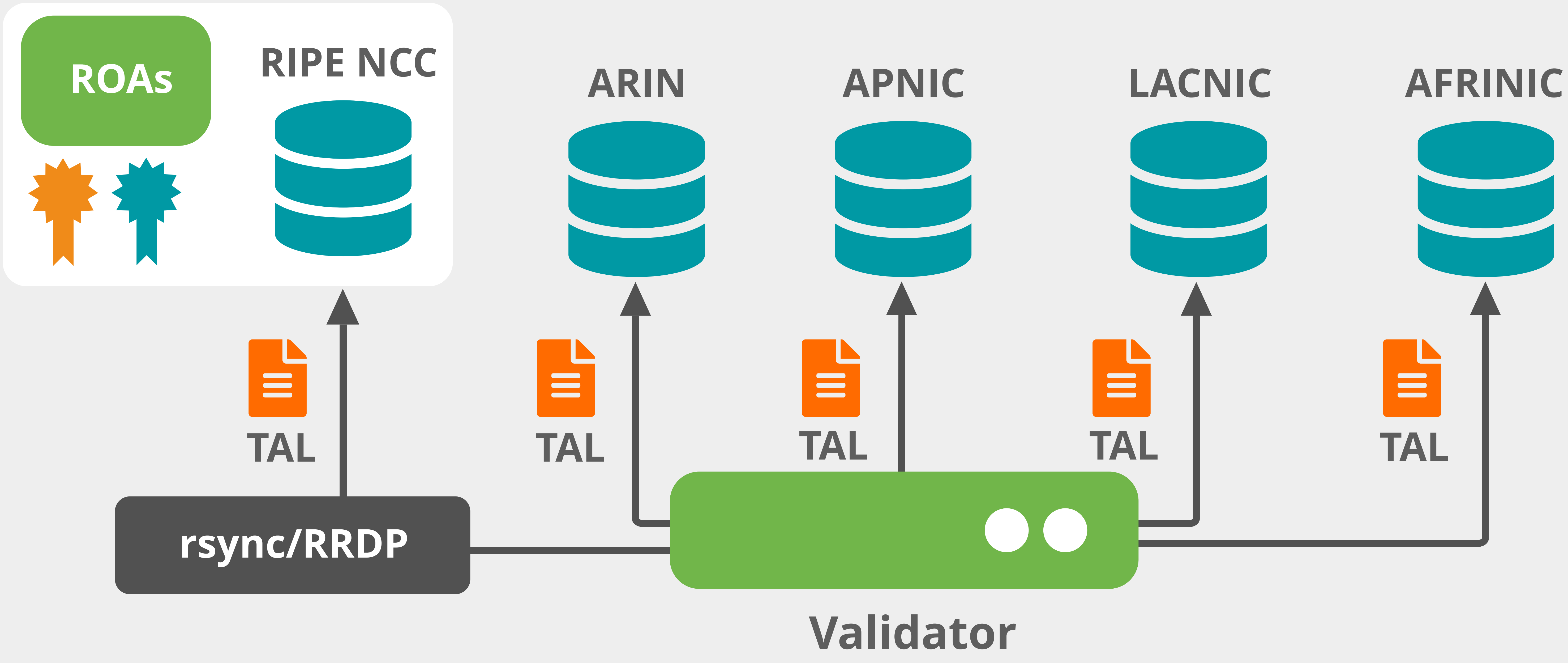
Verify the information provided by others

RPKI Validation

- Verifying the information provided by others
- First, **validate the RPKI data**
  - Install a validator software locally in your network
  - Verify holdership through a public key and certificate infrastructure
- Second, **validate the origin** of BGP announcements
  - Known as BGP Origin Validation (**BGP OV**) or Route Origin Validation (**ROV**)
  - This is done in a BGP router in your network

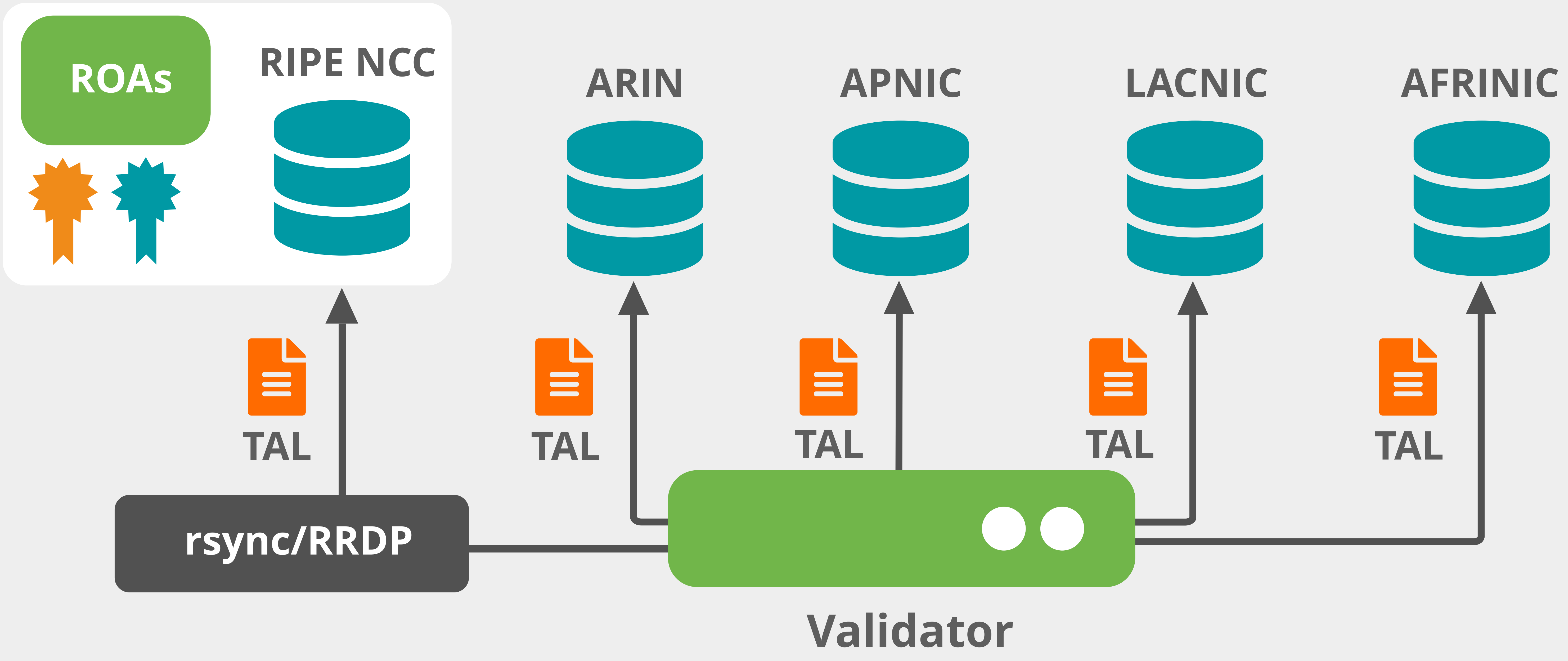
RPKI Validator

- Also known as **Relying Party (RP)** software
- Connects to RPKI repositories via **rsync** or **RRDP** protocol
- Uses information in TALs to connect to the repositories

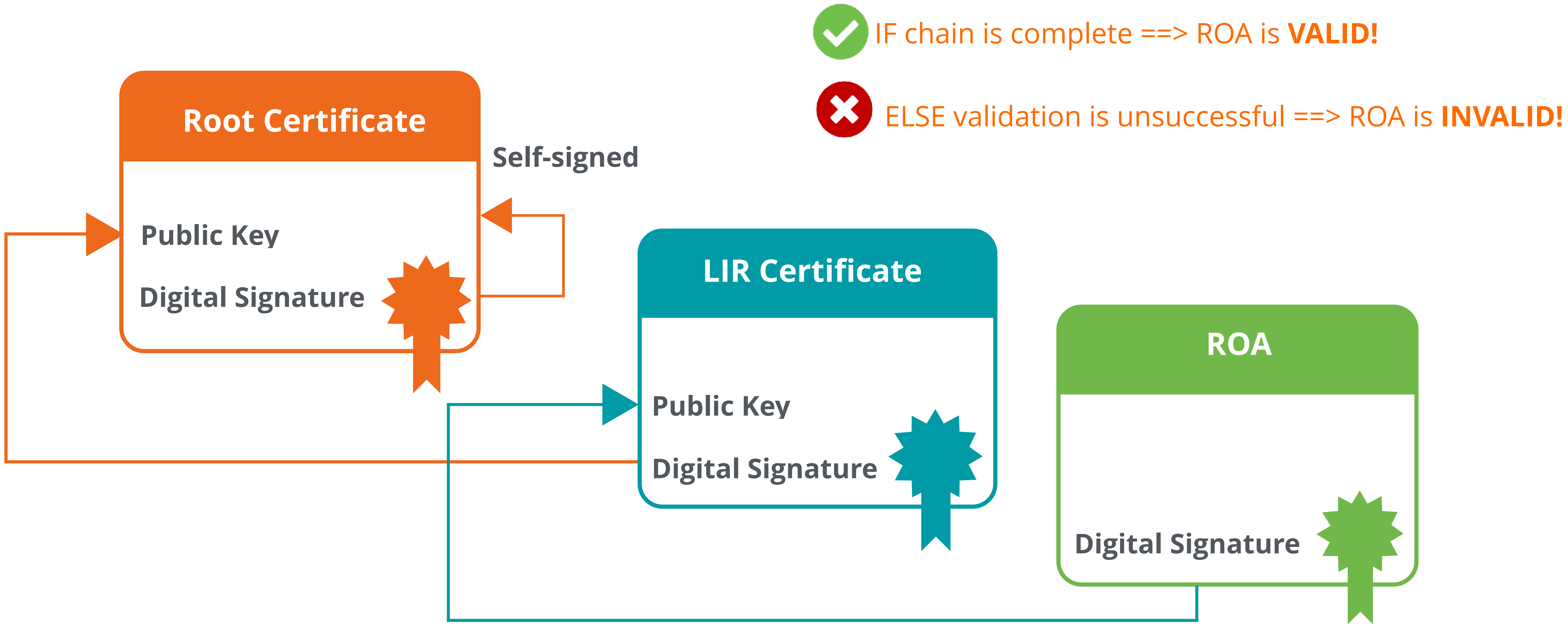


RPKI Validator

- Downloads ROAs from RPKI repositories
  - From RIRs and external repos
- Validates the chain of trust for all ROAs and associated CAs
  - Creates a local "validated cache" with all the valid ROAs



ROA Validation Process



RPKI Validator Options

- **Routinator**
  - Built by NLNet Labs
- **FORT**
  - Open source RPKI validator
- **rpki-client**
  - Integrated in OpenBsd

Links for RPKI Validators:

https://github.com/NLnetLabs/routinator.git

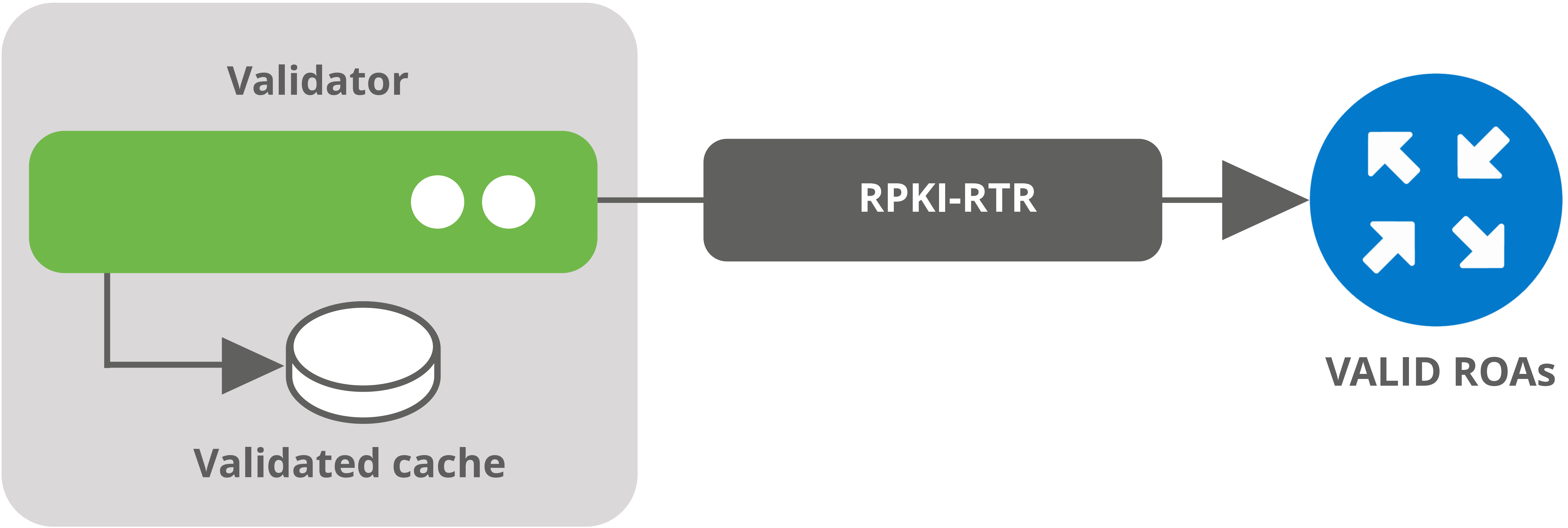
https://github.com/NICMx/FORT-validator/

https://www.rpki-client.org/

More Information:

https://rpki.readthedocs.io

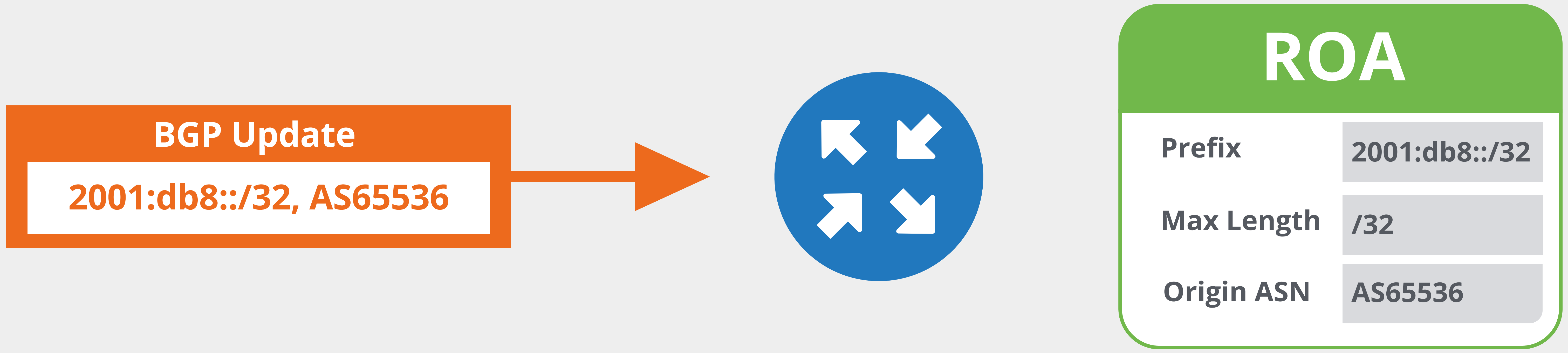
Valid ROAs are sent to the router



Router uses this information to make better routing decisions!

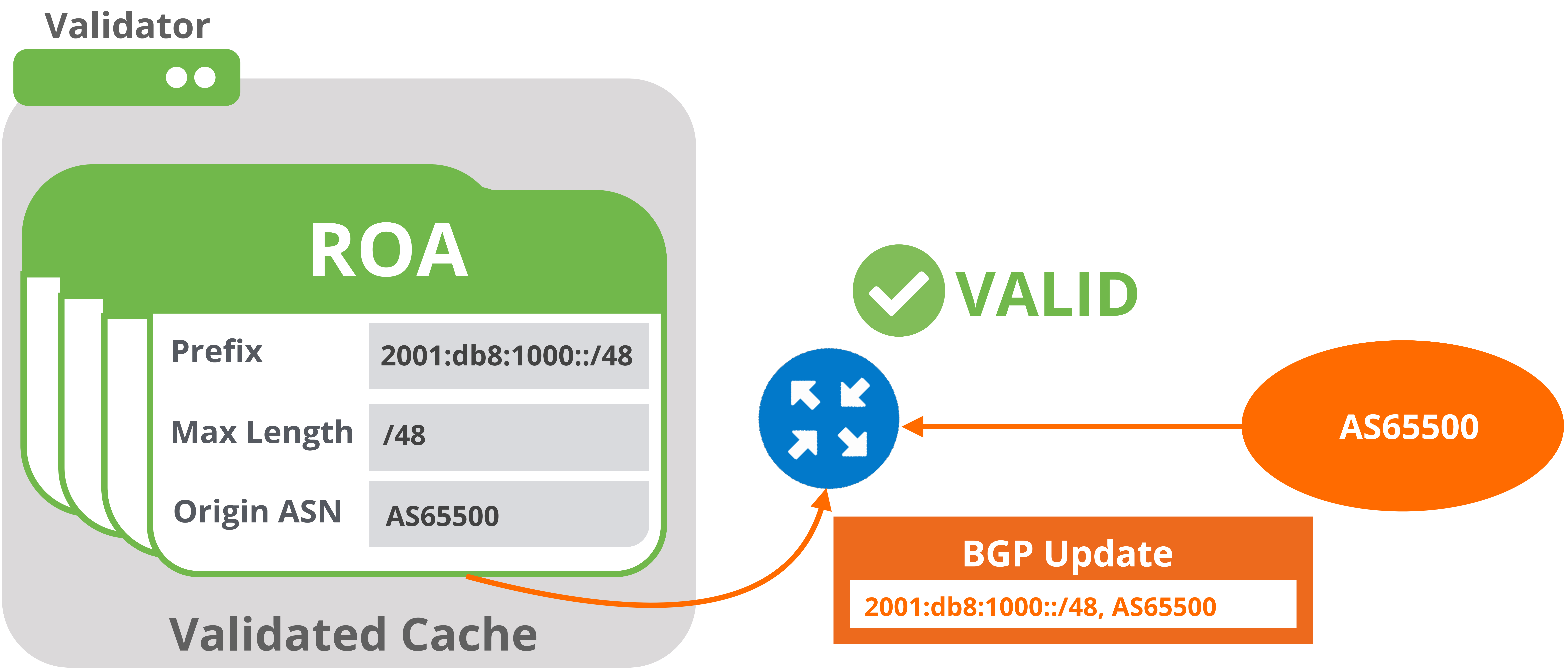
BGP Origin Validation (BGP OV)

- RPKI based route filtering
- BGP announcements are compared against the **valid** ROAs
  - **Origin ASN** and **max-length** must match!
- Router decides the validation states of **routes**:
  - **Valid**, **Invalid** or **Not-Found**

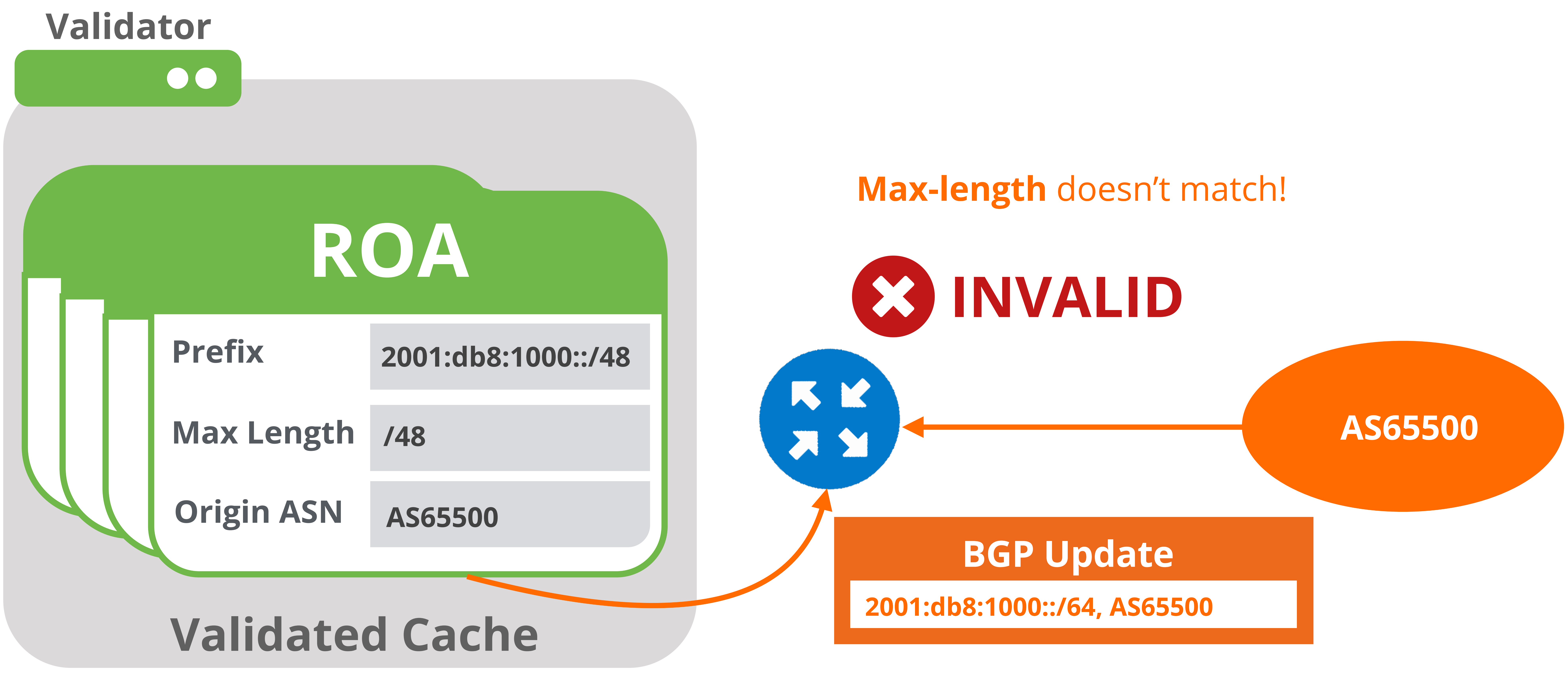


RFC 6811 - BGP Prefix Origin Validation https://datatracker.ietf.org/doc/html/rfc6811

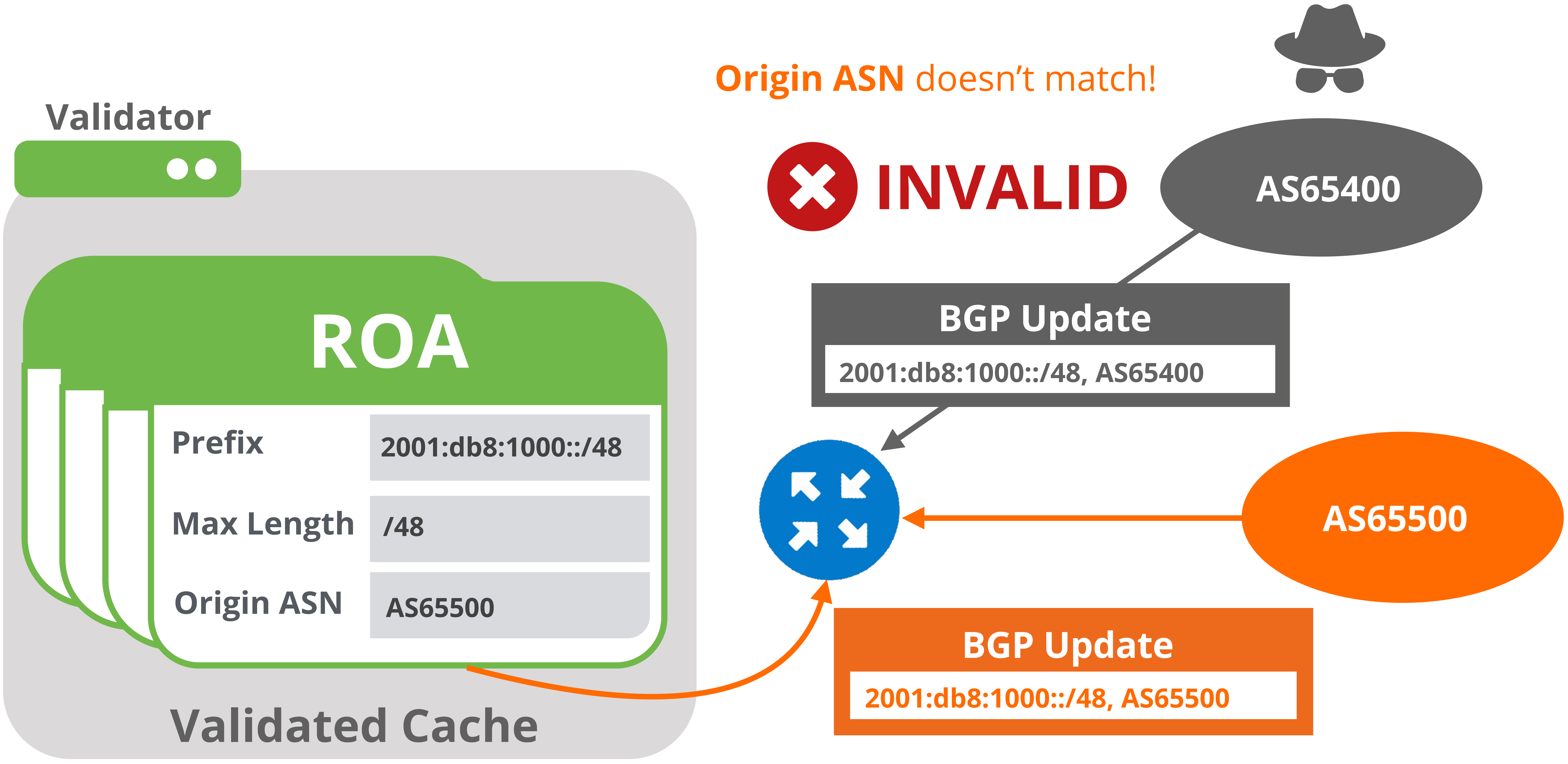
How Does RPKI Validate the Origin?



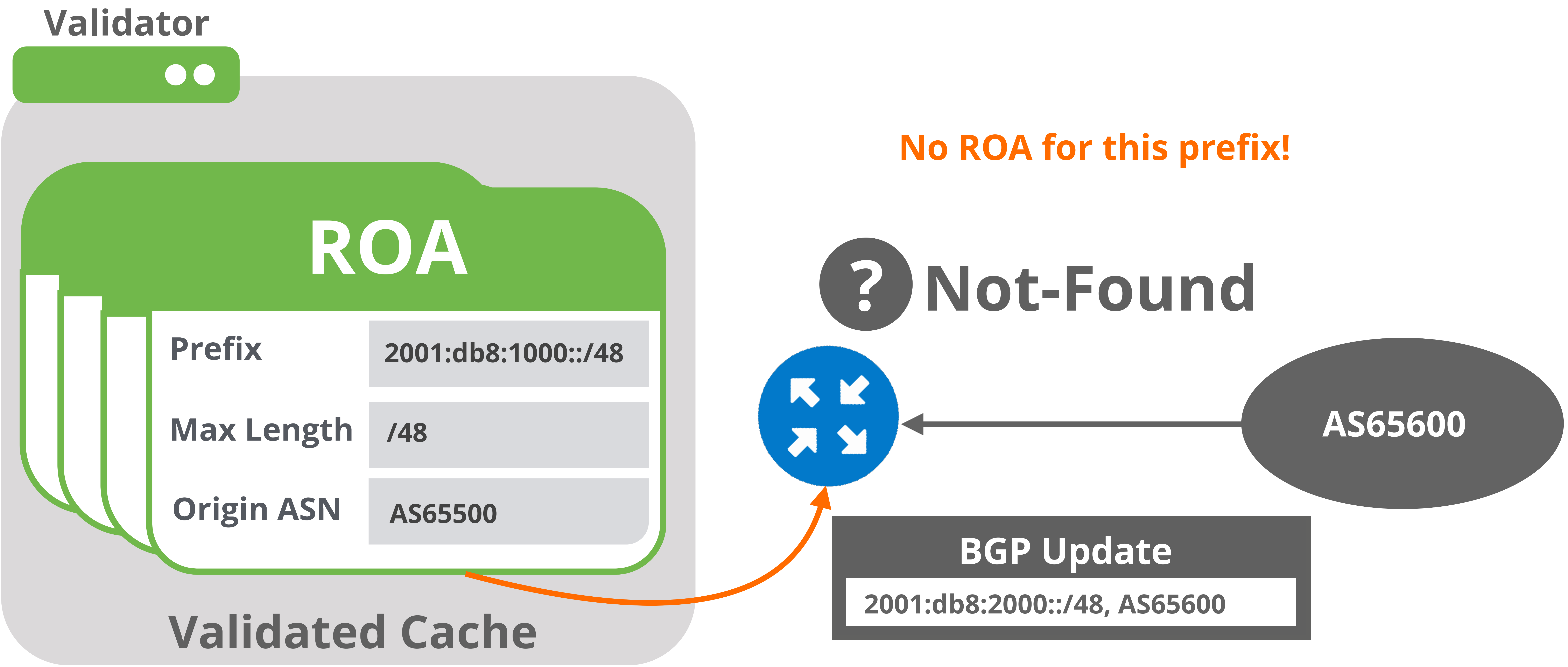
How Does RPKI Validate the Origin?



How Does RPKI Validate the Origin?



How Does RPKI Validate the Origin?



The General Rule

IF ROA exists that validates the prefix

↓

The prefix is **Valid**

ELSE IF any ROA invalidates the prefix

↓

The prefix is **Invalid**

ELSE

↓

The prefix is **Not found**

After Validating

- You have to make a decision: Accept or Discard

Valid →	Accept the prefix
Invalid →	Discard the prefix
Not Found →	Accept the prefix

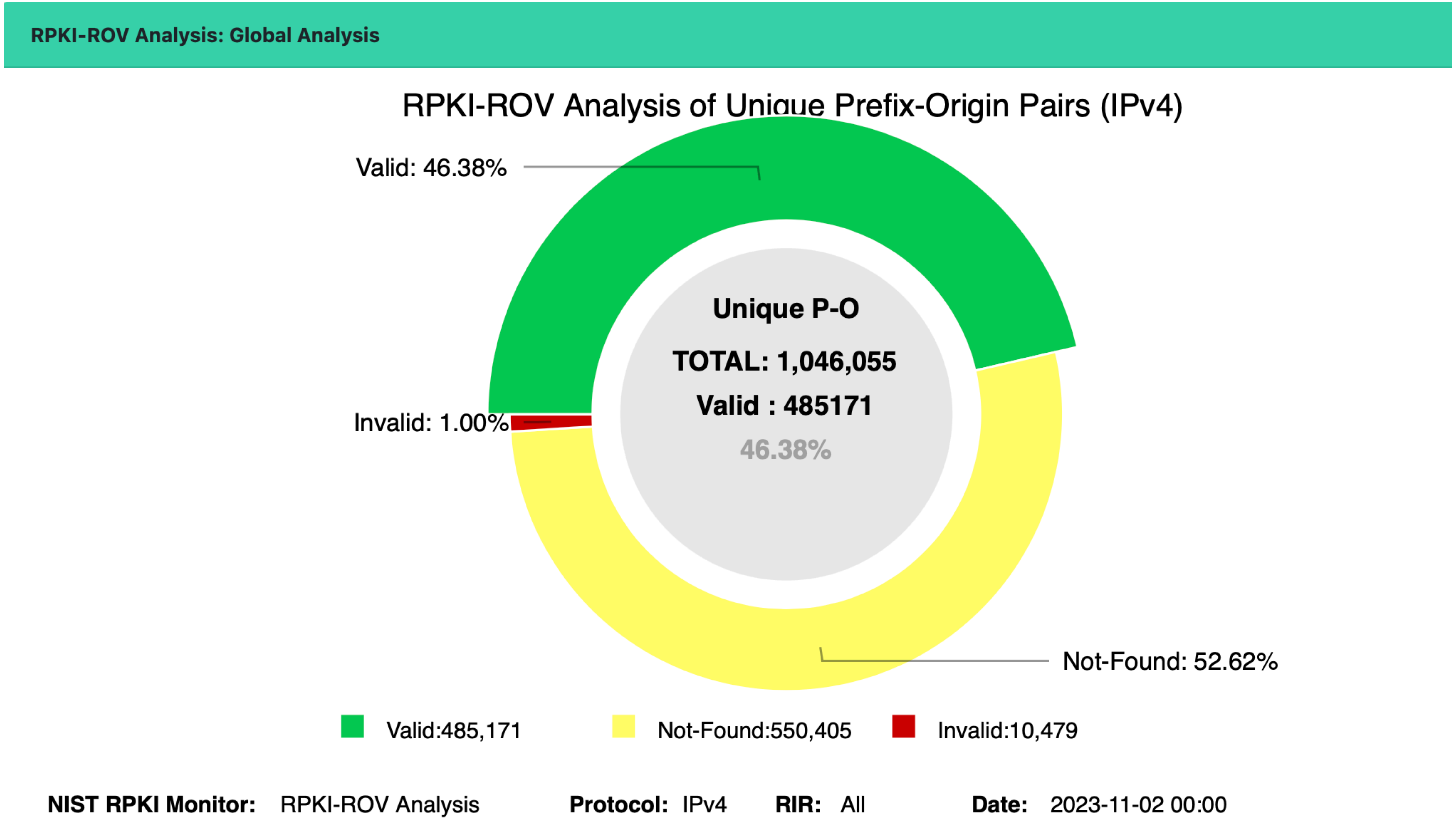
Do not consider dropping prefixes with “Not-Found” RPKI validation state!

Major Networks and RPKI Invalids

- Major networks are dropping invalids
  - Telia, AT&T, Cloudflare, Netflix, Swisscom, Cogent etc
- They follow a phased approach: First peers, then customers
  - Tag invalids on all peers, then on all customers
  - Drop invalids for all peers, then for all customers

More information: https://isbgpsafeyet.com/

RPKI-ROV Analysis Globally (IPv4)



https://rpki-monitor.antd.nist.gov

Questions

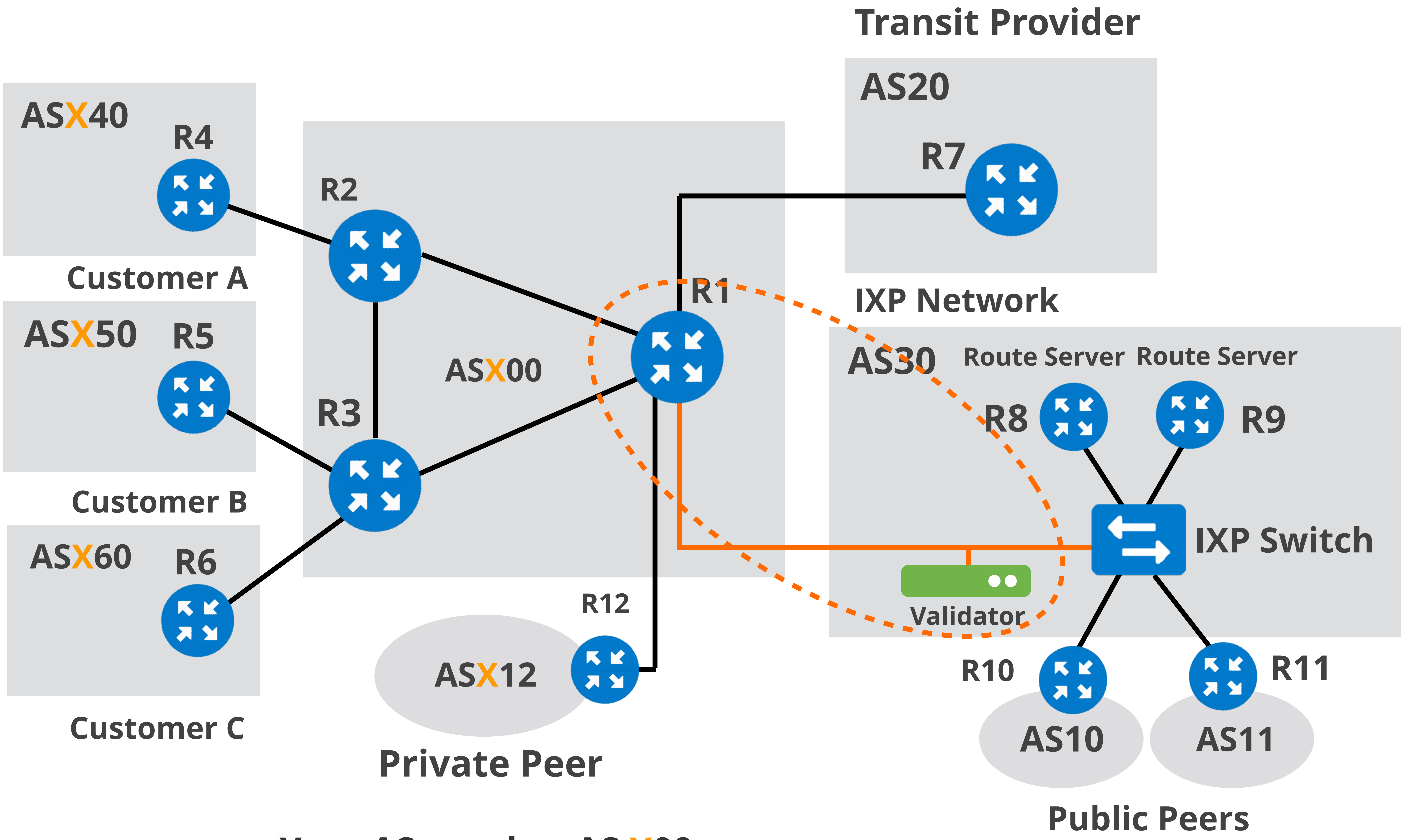
Lab 5 - RPKI

5.2 - BGP Origin Validation with RPKI

20 min

Lab 5.2 RPKI - BGP Origin Validation

- **Description**: Implement BGP Origin Validation and discard BGP announcements with "Invalid" RPKI status
- **Goals:**
  - Validate BGP announcements by using RPKI information (BGP OV)
  - Use RPKI data to discard BGP Invalids
- **Time:** 20 minutes
- **Tasks:**
  - 5.2 Check valid ROAs on Routinator's GUI
  - 5.2 Connect the Validator and the BGP router
  - 5.2 Create a BGP Hijack

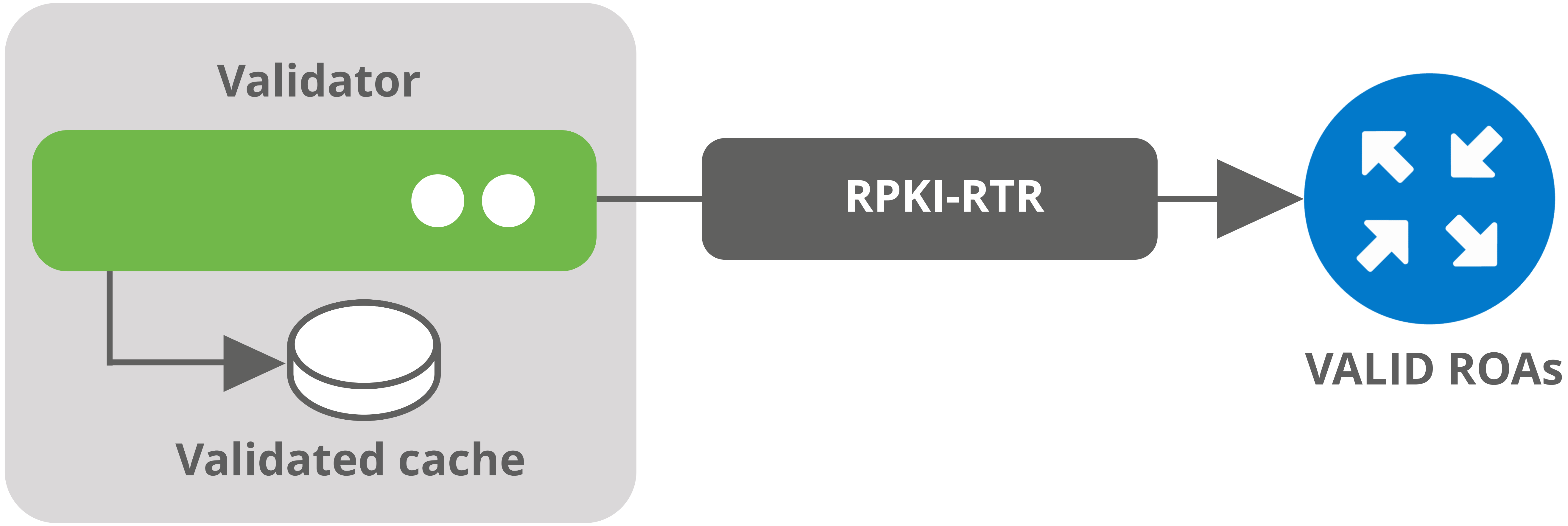


Your AS number AS X00

Your IPv6 allocation 2001:db8:X00::/48

Lab 5.2 RPKI - BGP Origin Validation

- **What have you learned?**
  - How to use the GUI of Routinator validator software
  - The steps to follow to implement BGP OV in your network
  - How does RPKI OV works in a simple BGP Hijack scenario



Next Steps for BGP Routing Security

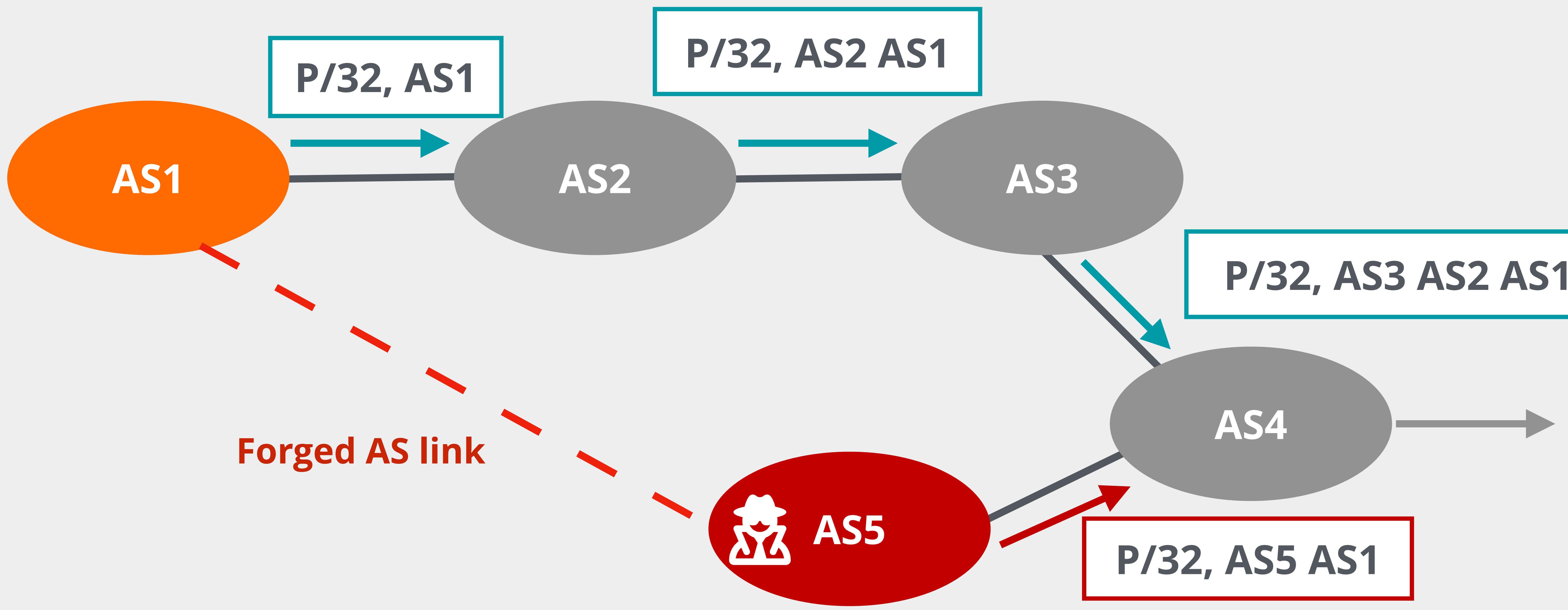
Section 4

What's Next for Routing Security?

Dealing with Path Hijacks...

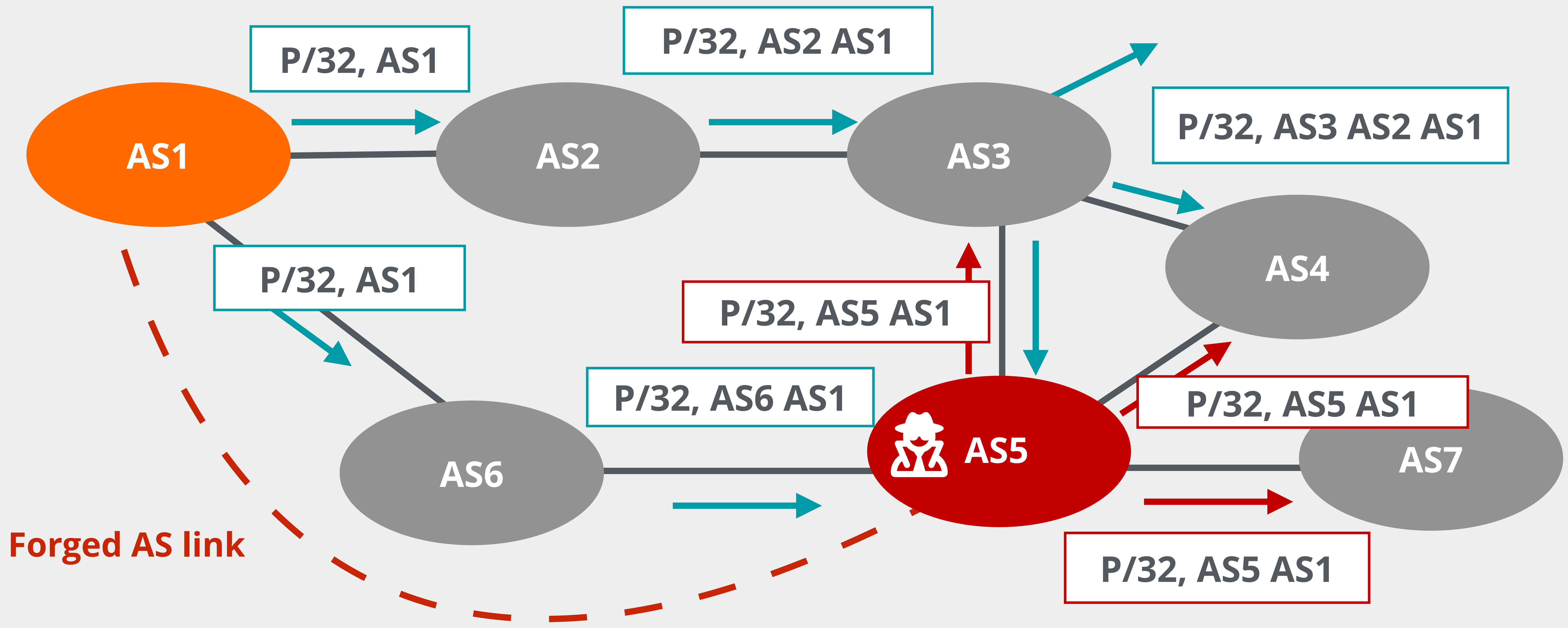
Fake Path with Correct Origin

- The origin of the path does not change!
- The attacker:
  - Creates a forged AS link between two ASes
  - Reroutes the traffic to itself



Modifying an Existing Path

- Neighbours of the attacker receive a false path
- The attacker can do either of these two things:
  - Analyse the traffic and then route to AS1
  - Drop the traffic to AS1



What's Next for Routing Security?

- RPKI today focuses on **Origin Validation!**
- But RPKI OV can not detect path manipulations!
  - Origin AS remains intact in the altered AS Path
- Them, what to do?
- The solution is to **validate the full BGP path**
- **Tentative solutions: BGPsec [RFC 8205] and ASPA**

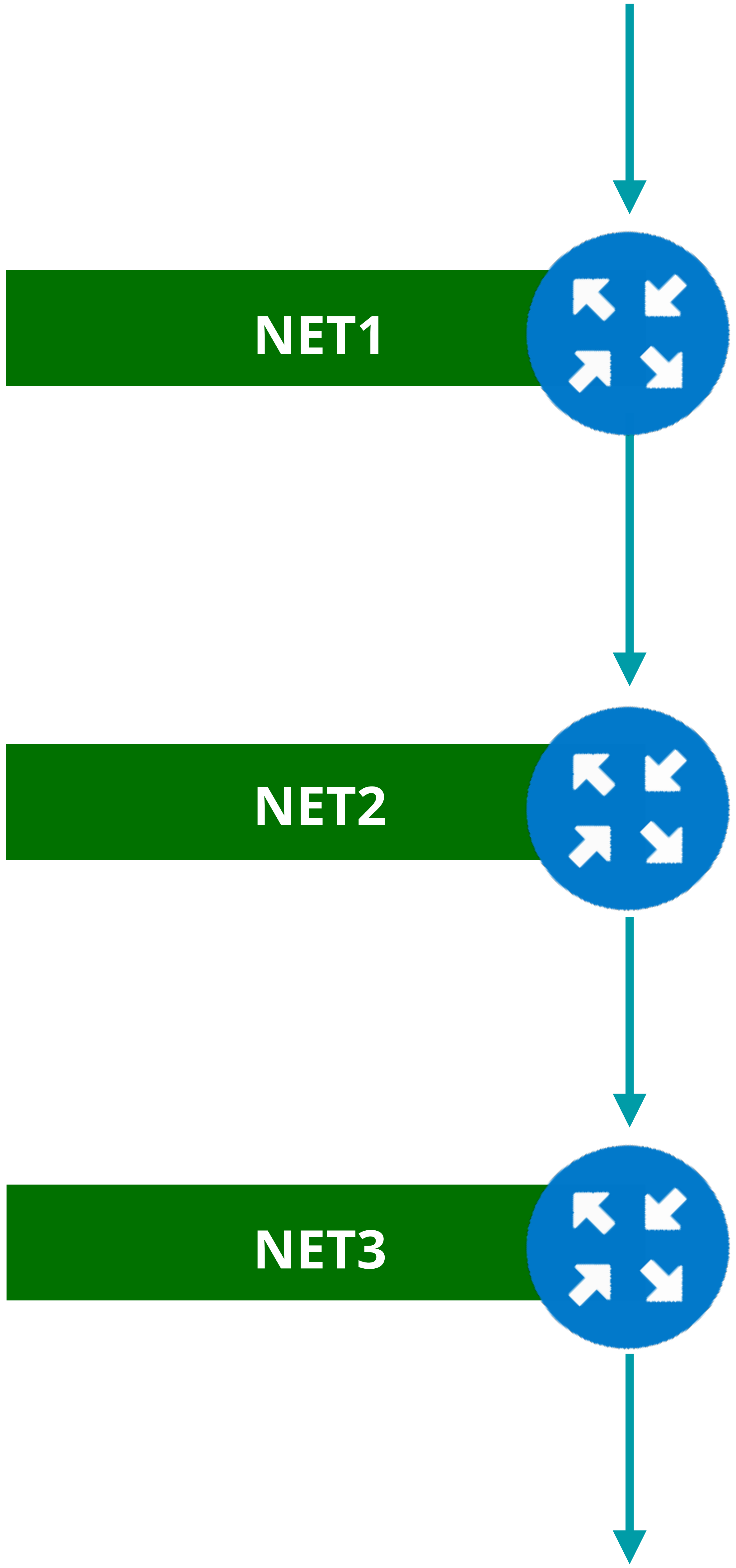
RPKI is a stepping stone to **Path validation**!

BGPSec

- Designed to supplement BGP Origin Validation
- Relies on the RPKI certificates
  - Router certificates are issued to routers within an AS
- Introduces a new BGP path attribute, **BGPsec_PATH**
  - Optional, non-transitive attribute
  - Carries digitally signed AS path information
  - Support is negotiated between BGP speakers

BGP Operations

- Routers sign the AS path in a BGP UPDATE message
- Each BGP UPDATE containing BGPsec_PATH attribute:
  - Can **advertise** a single prefix only
  - Can only be **sent** to one AS at a time
- Routers verify the chain of trust of **all of the signatures** of the AS Path



Network: 192.168.0.0/16
AS Path: NET1, ...
BGPSEC: (key1, signature1)

Network: 192.168.0.0/16
AS Path: NET2, NET1, ...
BGPSEC: (key1, signature1)
(key2, signature2)

Network: 192.168.0.0/16
AS Path: NET3, NET2, NET1, ...
BGPSEC: (key1, signature1)
(key2, signature2)
(key3, signature3)

BGPSec Has Some Limitations…

- Does not offer origin validation
- Does not prevent route leaks
- Expensive to run, requires more powerful routers
  - UPDATE messages are larger because of digital signatures
  - One UPDATE message is required for each prefix
  - BGP speakers need to perform cryptographic functions
- Does not support incremental deployment

That’s why progress is very slow and no deployment yet!

ASPA

- **A**utonomous **S**ystem **P**rovider **A**uthorisation
- Introduces a new digitally signed object, an **ASPA**
  - ASPA object defines upstreams for a defined AS
- ASPA proposes a lightweight solution for path validation
  - Leverages existing RPKI infrastructure
  - Does not require a new BGP attribute
  - Requires a database where ASPA objects could be queried
  - Verifies the sequence of ASes along the path

How Does ASPA Work?

- Customer AS creates an ASPA object and signs it
  - Authorises a set of **Provider ASes** to propagate its route announcements
- In the Validation process, receiving AS

1. Verifies that if there is a cryptographically valid ASPA for that customer
   - Is provider AS authorised to propagate a given customer’s route?
2. Verifies the AS path
   - Have routes been received from a customer, a provider, or from a route server?

If validation fails, then the route should be rejected!

More About ASPA

- ASPA helps to detect route leaks and hijacks
- Incremental deployment is possible
- Still in draft state (about to become an RFC)
- Already supported in a couple of validators
- Support in OpenBGPD and NIST BGP-SRx

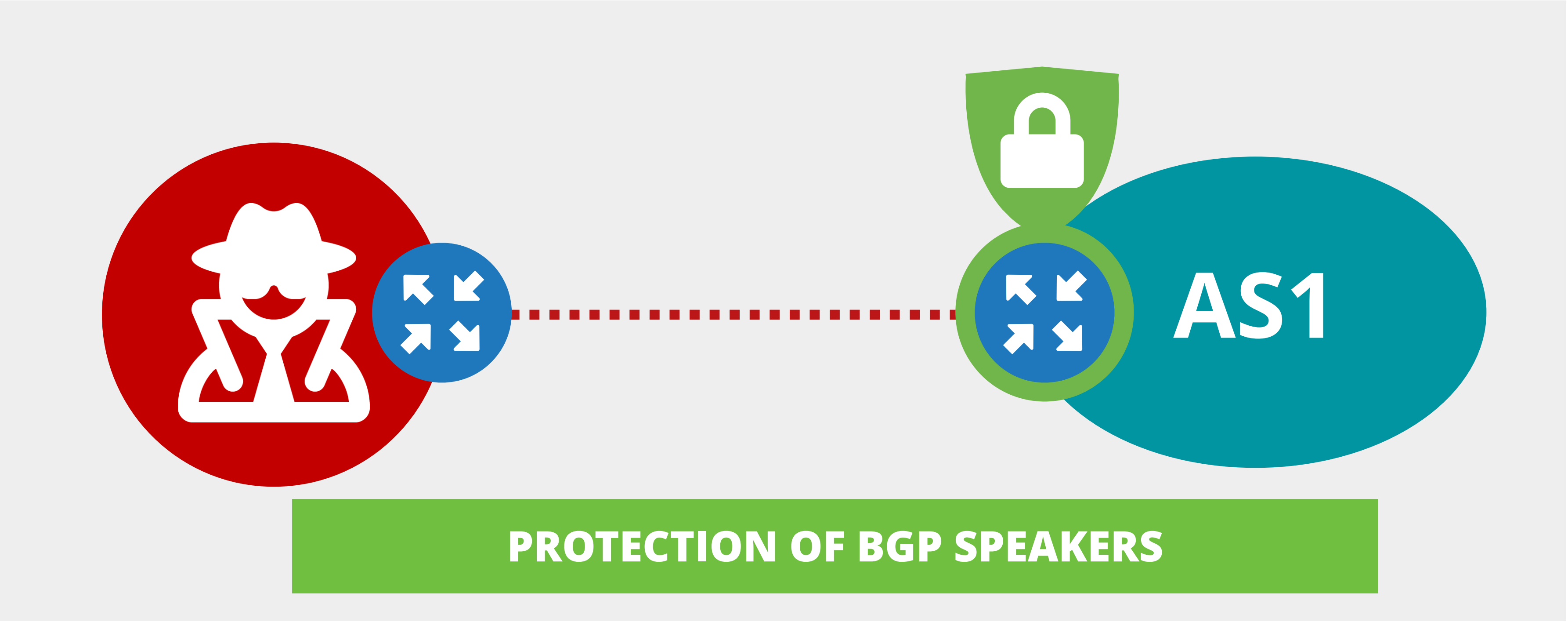
Best Practices

Section 5

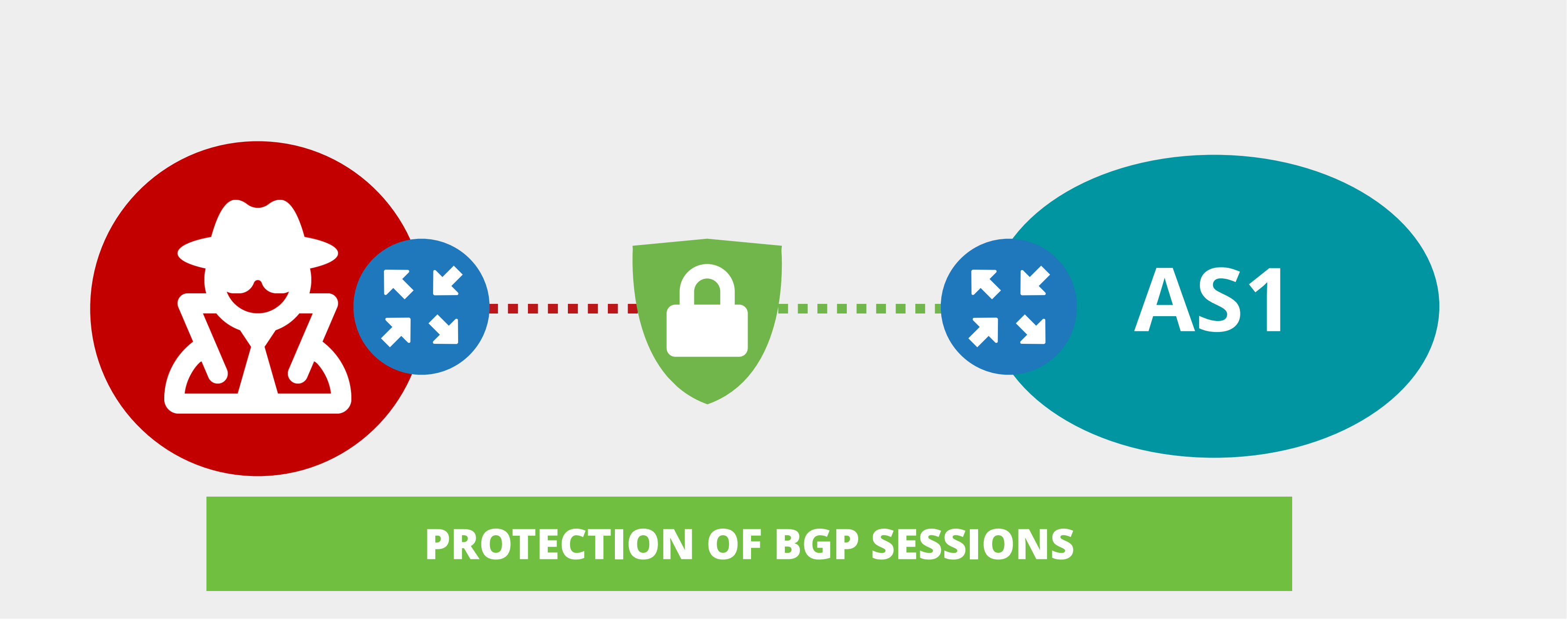
For Secure Internet Routing

- Do not be the cause!
  - Announce the right **prefixes** to the right **peers**
- Do not distribute others’ mistakes or attacks!
  - **Validate** the routing information you receive
- Do not be the victim!
  - Take all the measures you can to **protect** your network

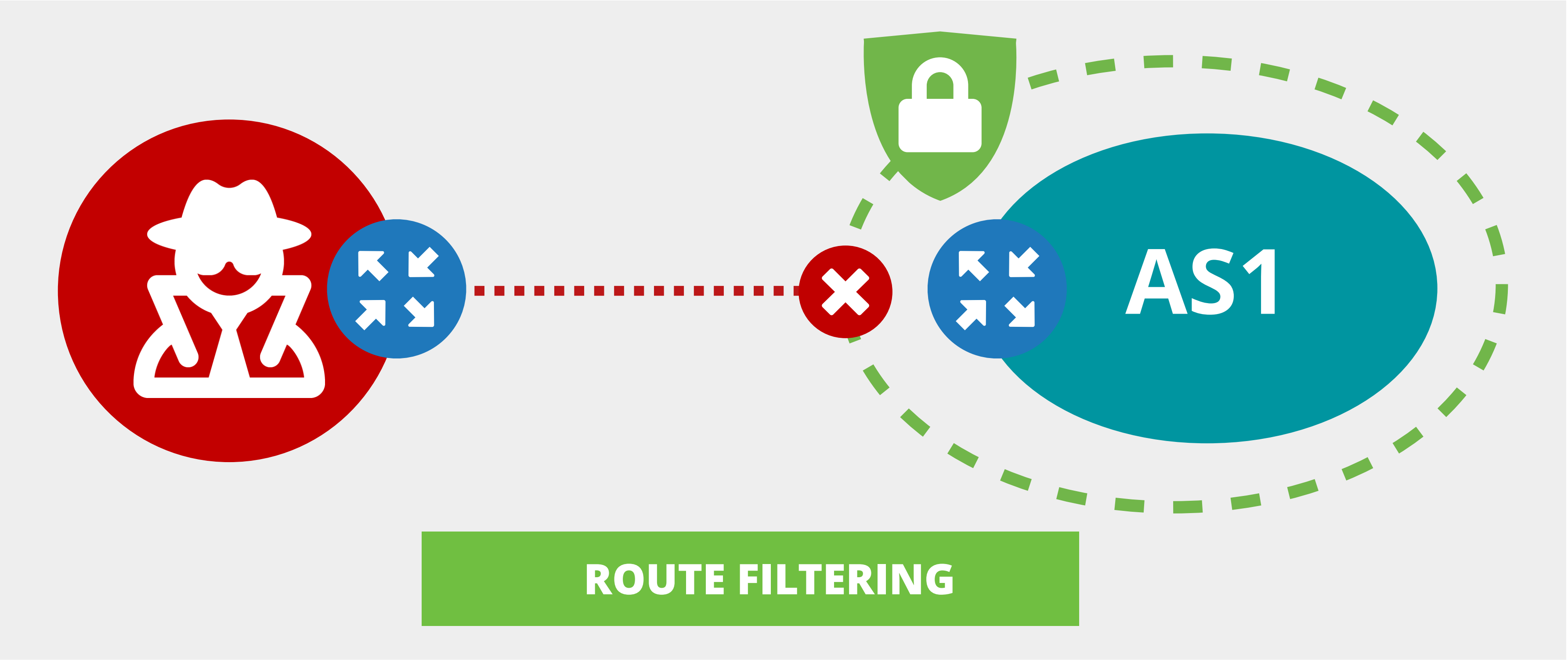
BGP Security Measures



- Only BGP peers to send packets to TCP 179: Control Plane Policing (CoPP) or ACLs (if CoPP not supported)
- Limit accepted BGP traffic
- uRPF to mitigate DoS/DDoS attacks

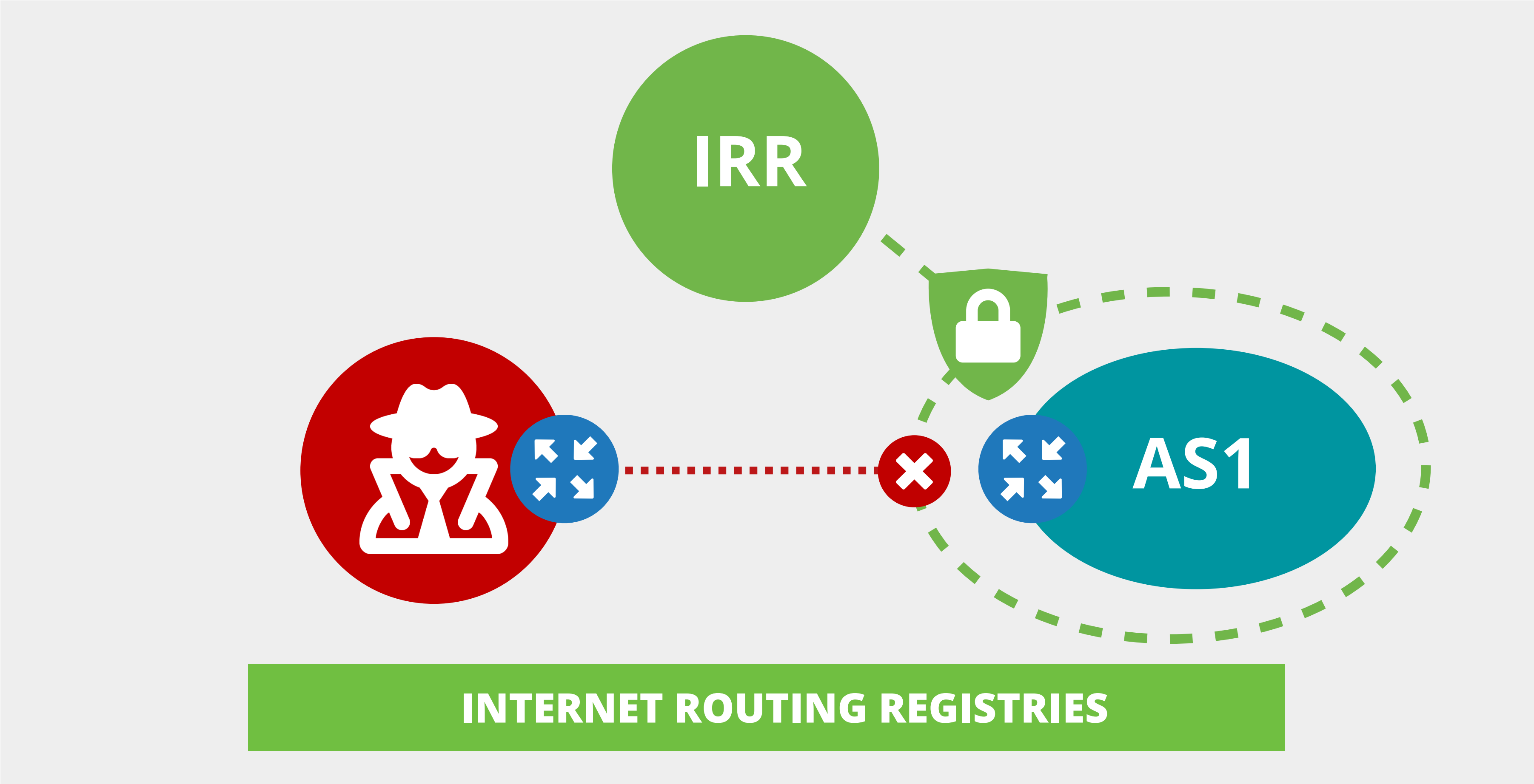


- MD5 — LAB
- TCP-AO
- BGP TTL Security (GTSM) — LAB

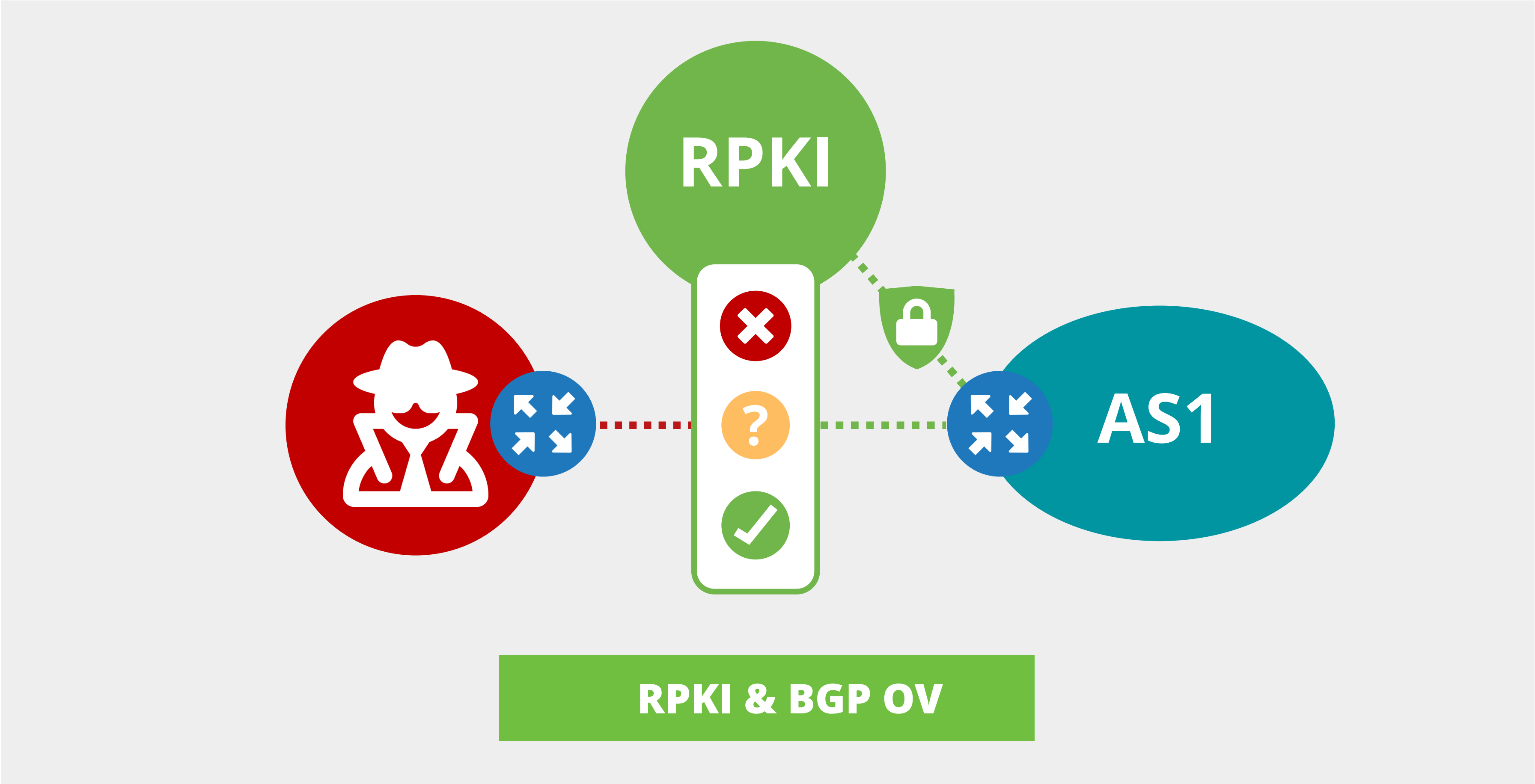


- Inbound/outbound filters by type of peer — LAB
- Filtering based on prefixes and/or AS Path — LAB
- Manual or Automatic (IRRs) configuration

BGP Security Measures



- Create your route(6) objects in IRR (LAB)
- Update your IRR info regularly
- Automate filters creation (IRR) (double check)
- Document your Routing Policy



- Create ROAs for your address space (LAB)
- max-length considerations (your most specific)
- or, one ROA per prefix and more-specific
- Implement BGP Origin Validation (OV) (LAB)
- Discard INVALID routes
- Never discard NOT-FOUND routes

Check Your Routing

- RIPEstat
  - https://stat.ripe.net
- IXP Country Jedi
  - https://jedi.ripe.net/latest/
- Bgpmon
  - https://routeviews.org
  - http://traceroute.org
- IRR Explorer
  - https://irrexplorer.nlnog.net
- RIPE Atlas
  - https://atlas.ripe.net
- NLNOG Ring
  - https://ring.nlnog.net
- HE BGP Toolkit
  - https://bgp.he.net
- BGP.tools
  - https://bgp.tools/

Questions

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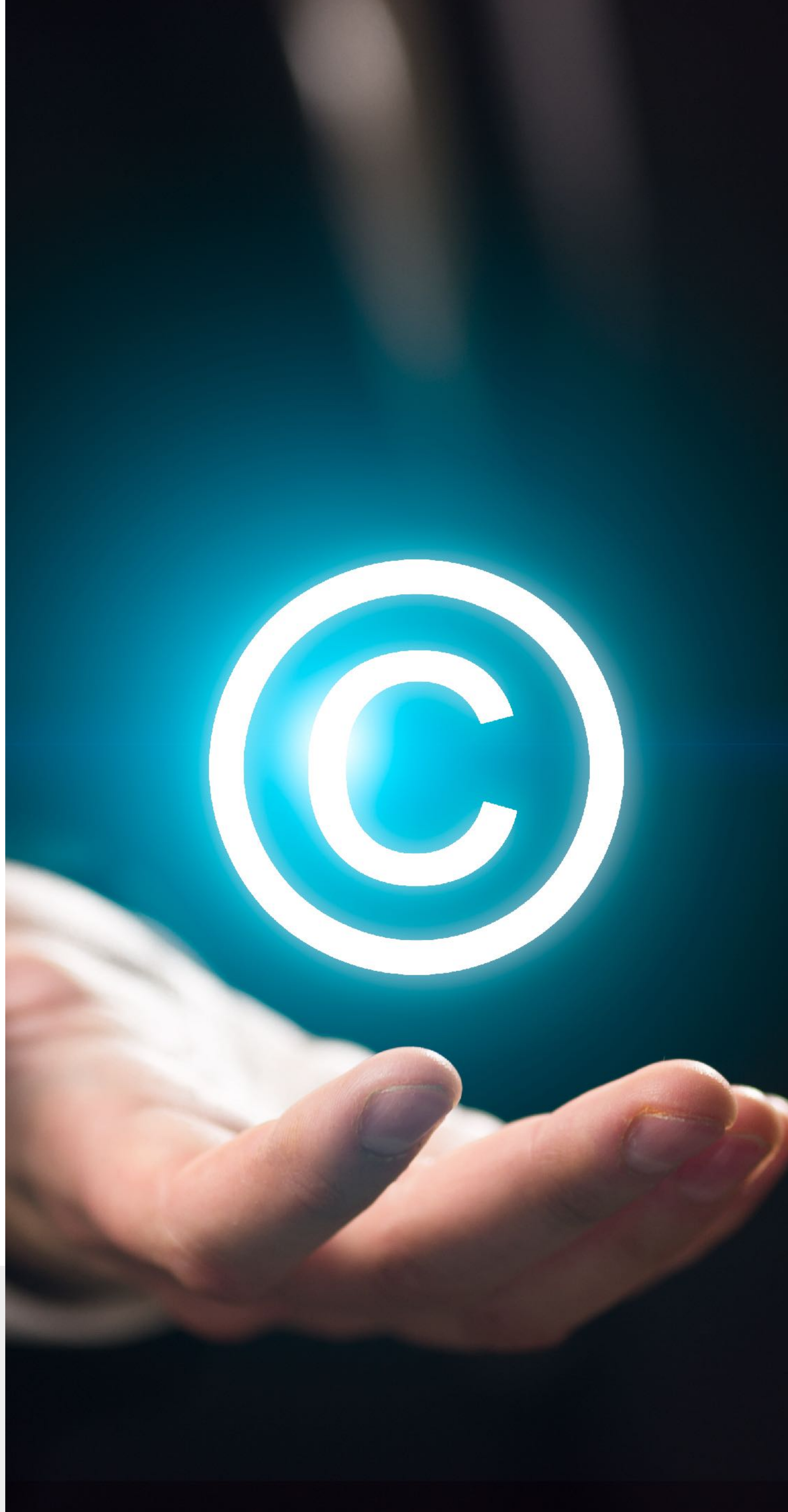

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