



RIPE NCC

RIPE NETWORK COORDINATION CENTRE

RGP 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

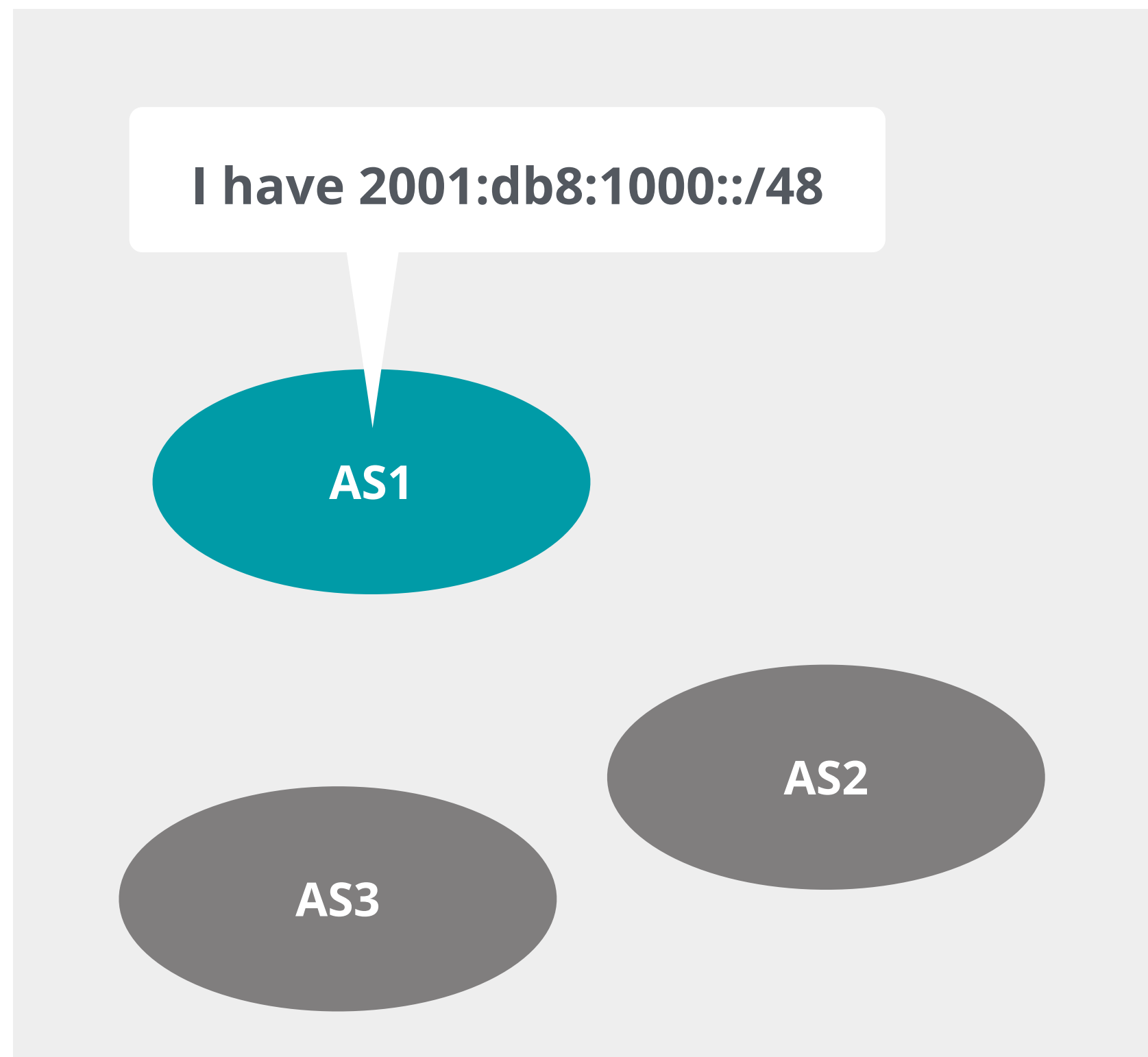
Section 1

Is BGP Secure?



In theory:

Only the legitimate resource holder
should be announcing the prefix

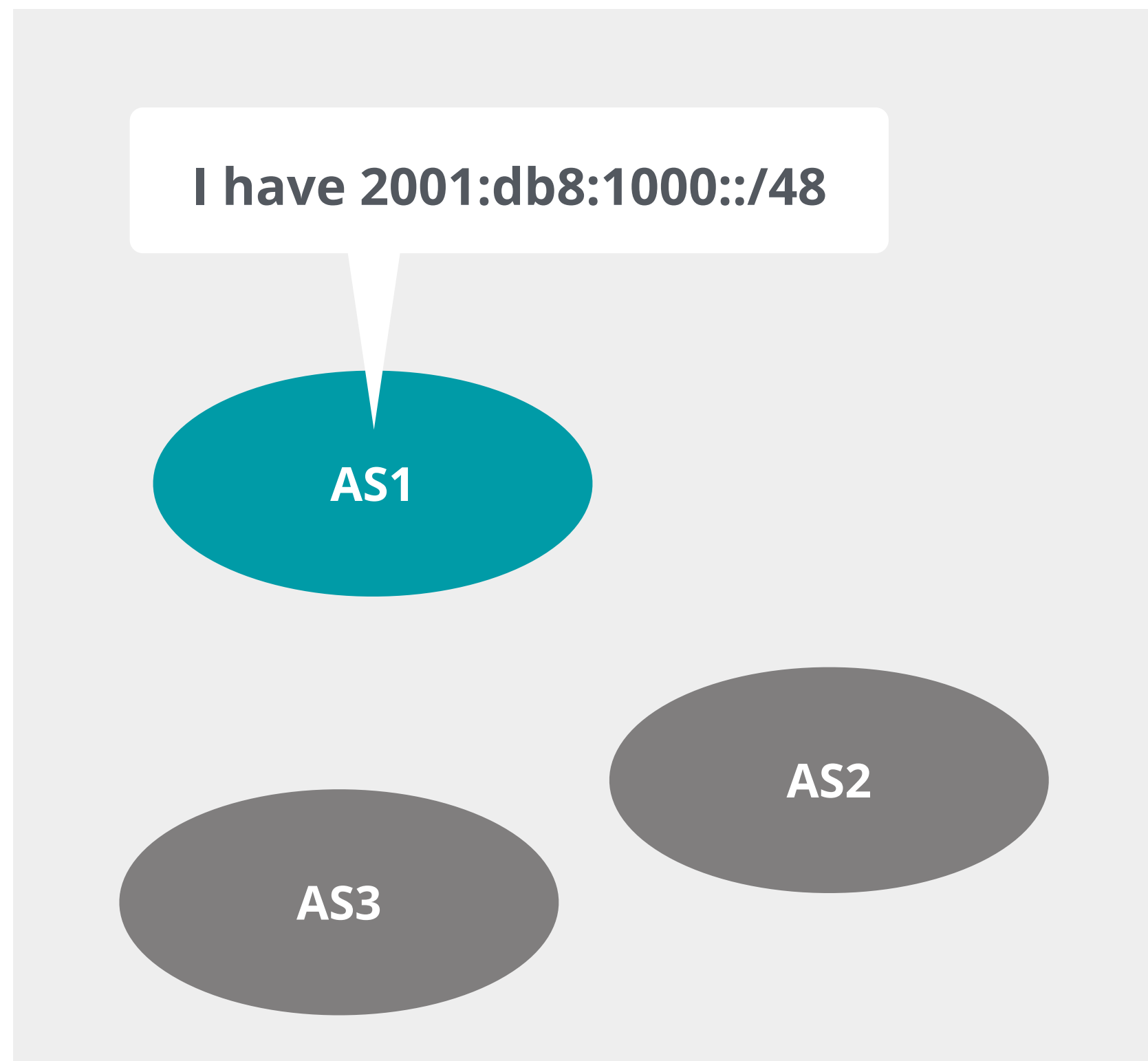


Is BGP Secure?



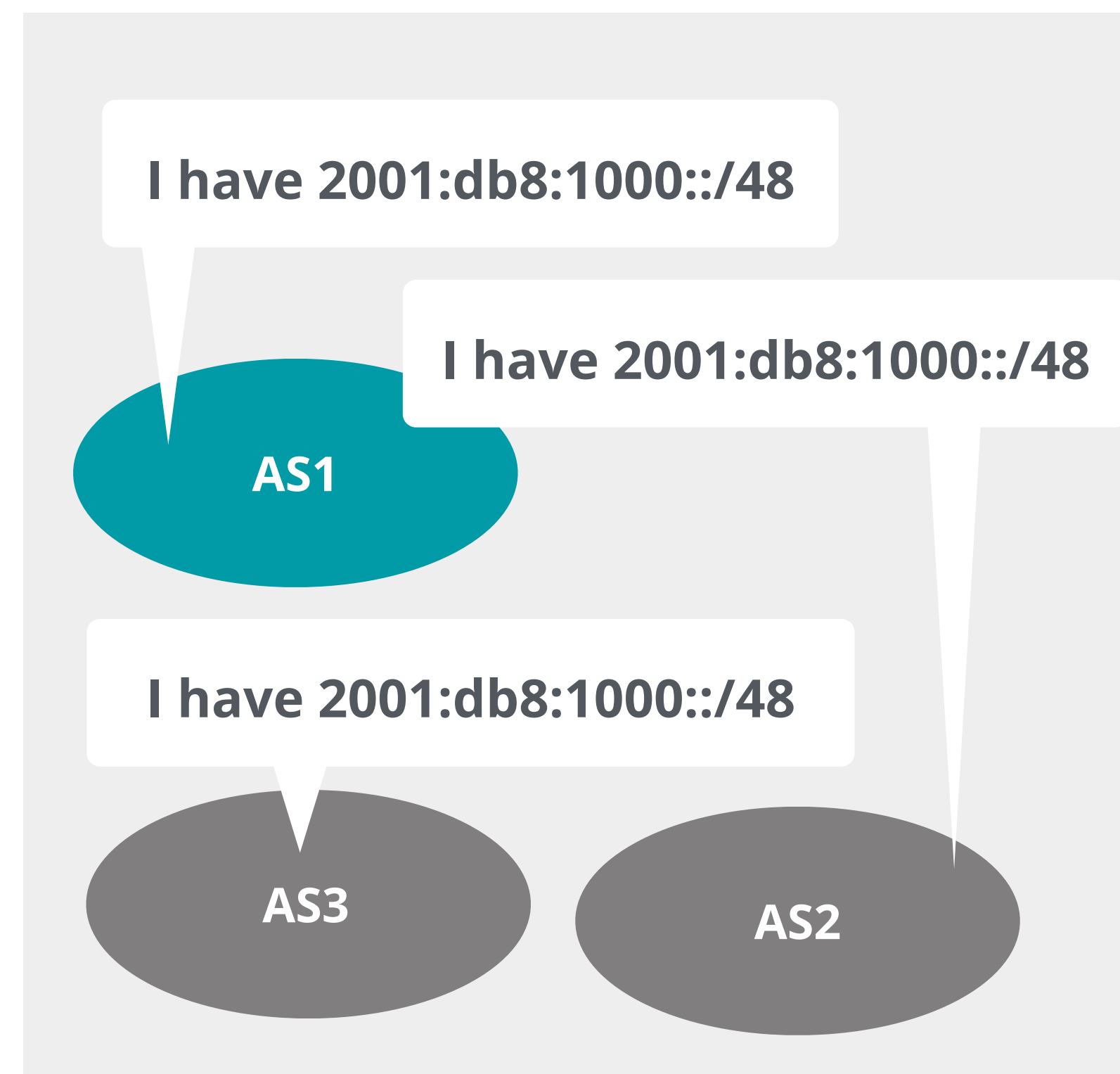
In theory:

Only the legitimate resource holder should be announcing the prefix



In practice:

Any AS can announce any prefix!



Is BGP Secure?

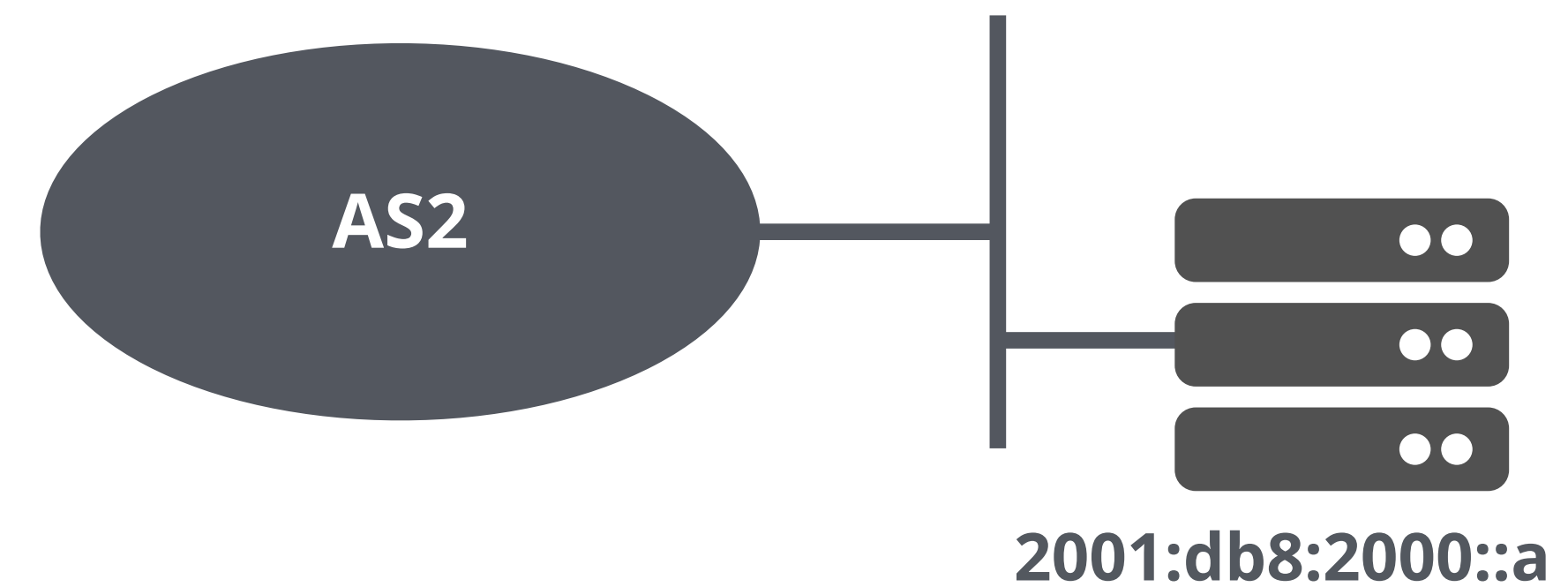


AS1 wants to access the server in AS2.

2001:db8:1000::/48



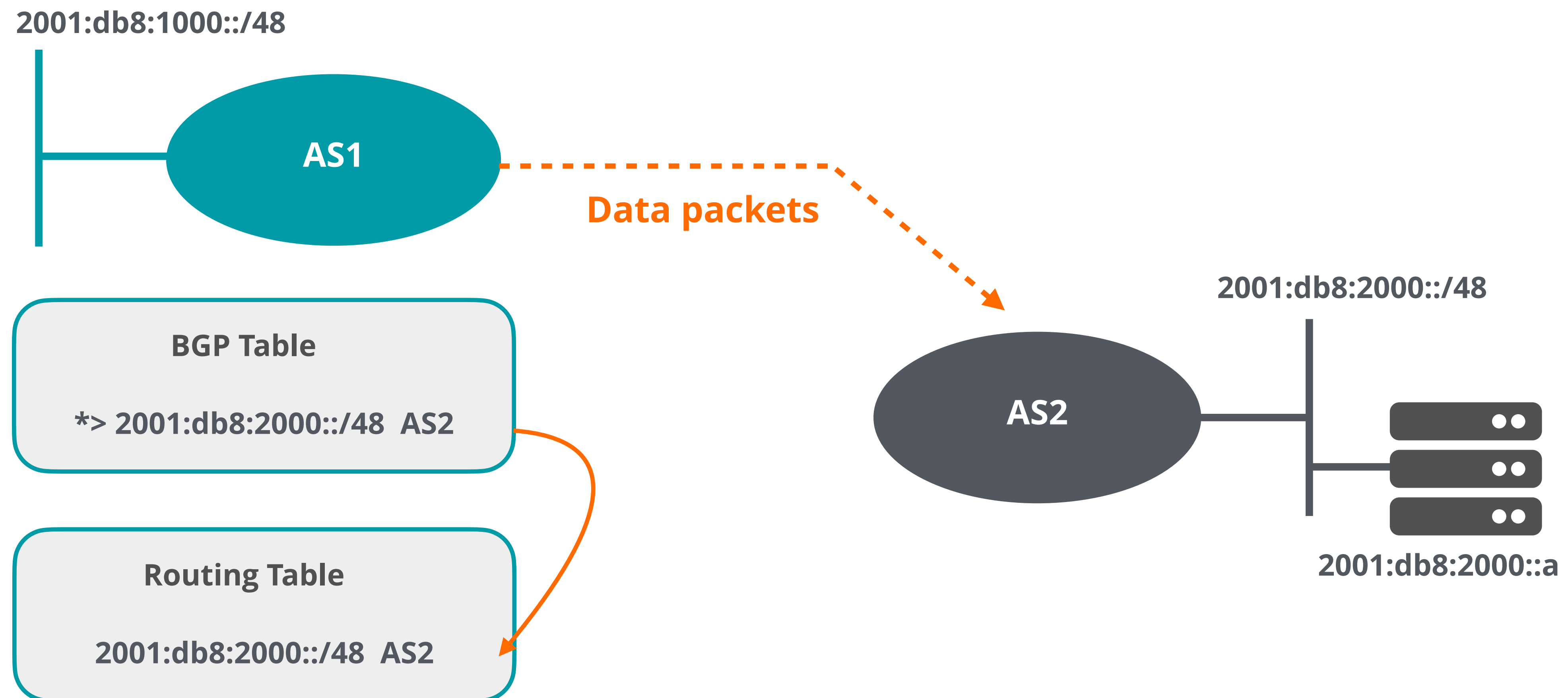
2001:db8:2000::/48





Is BGP Secure?

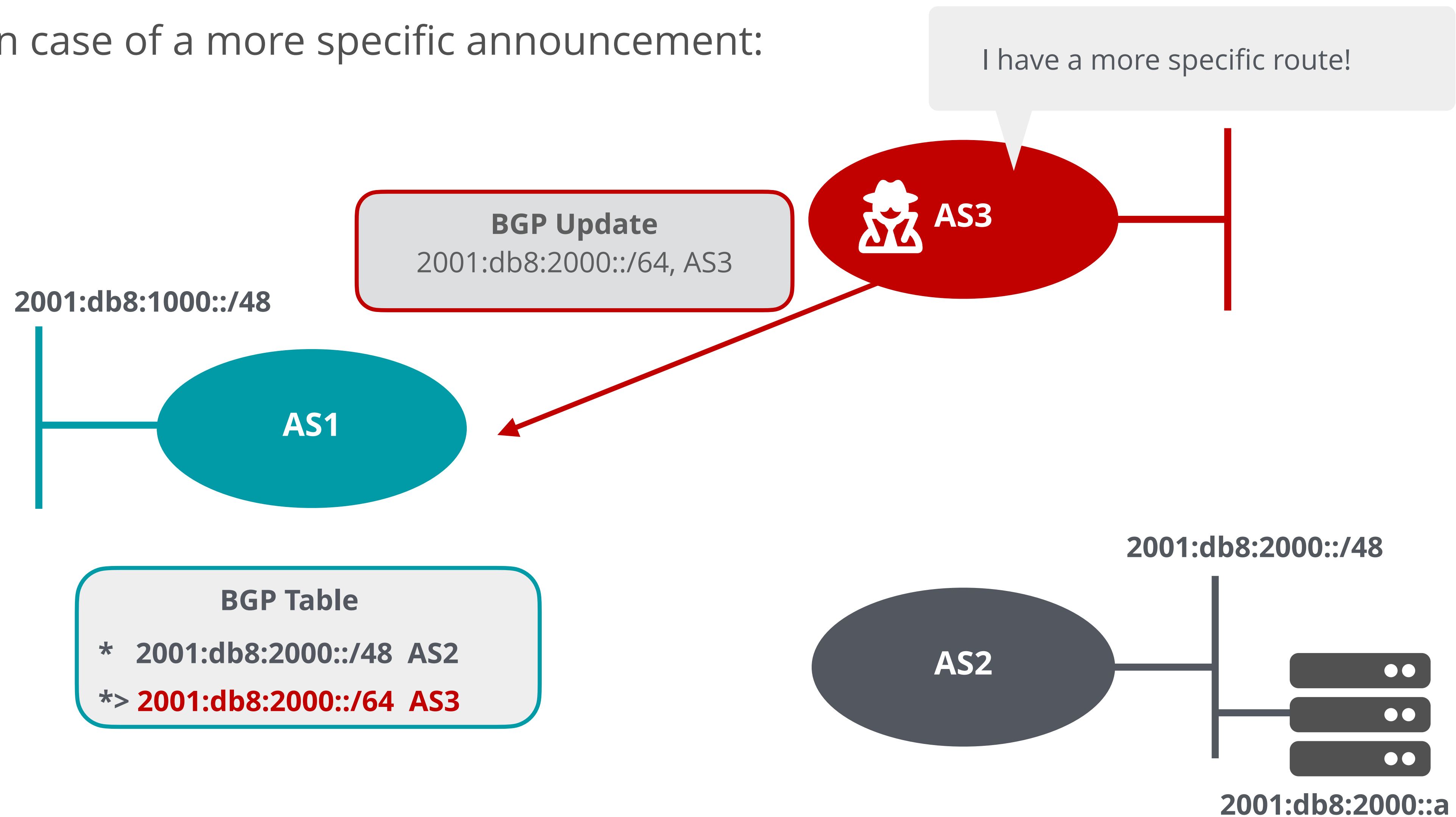
Data is forwarded based on routing table.





Is BGP Secure?

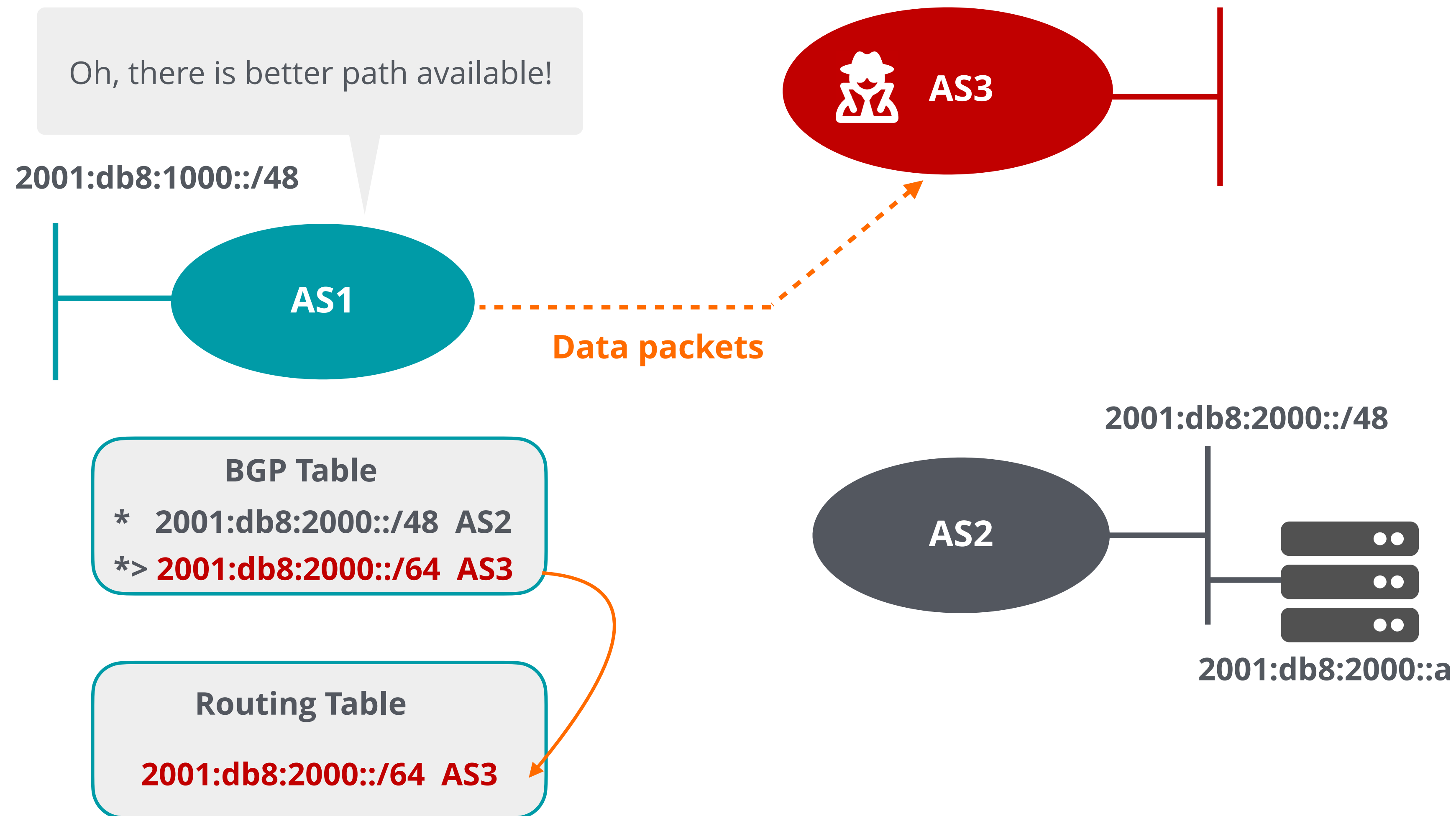
In case of a more specific announcement:





Is BGP Secure?

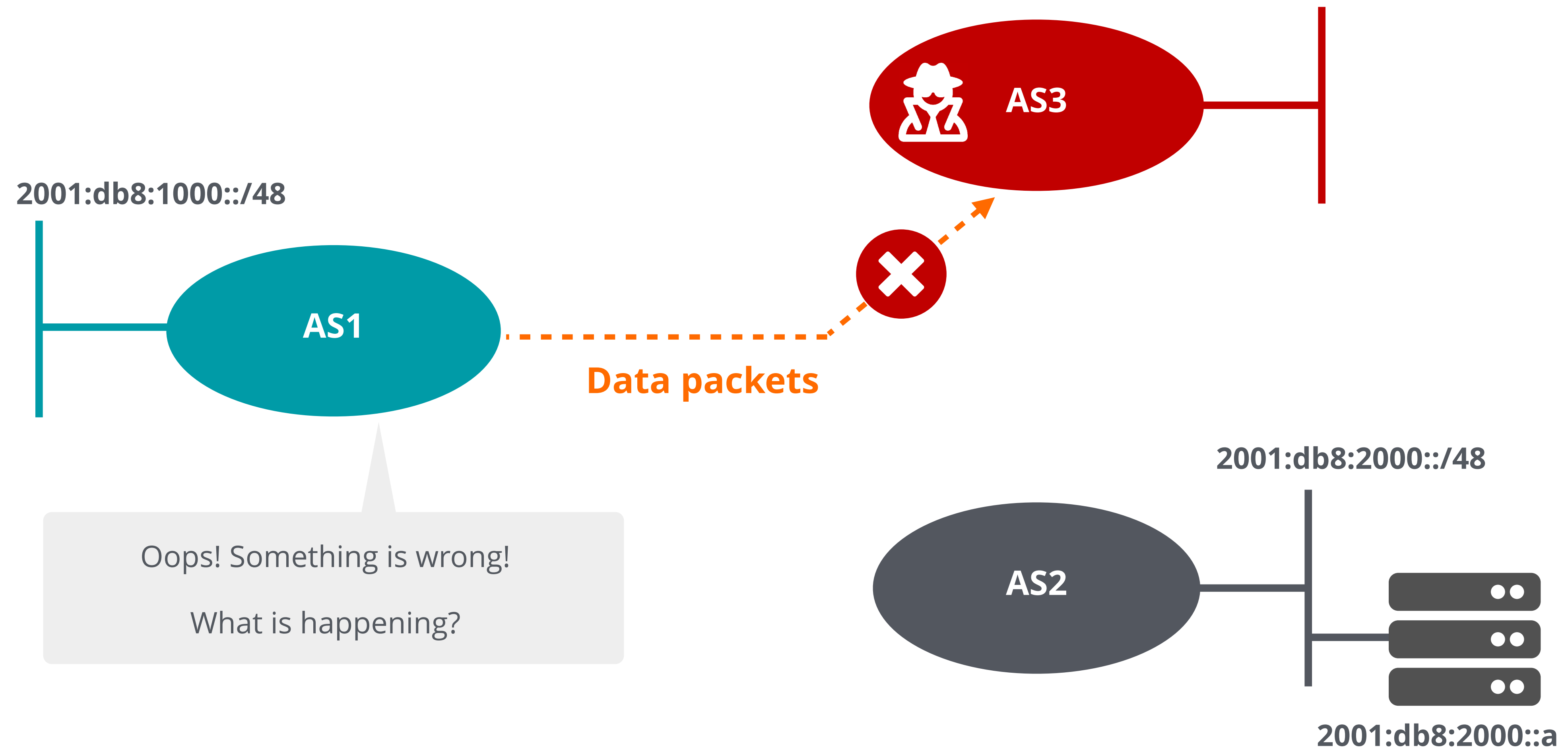
Traffic is diverted to the attacker:



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





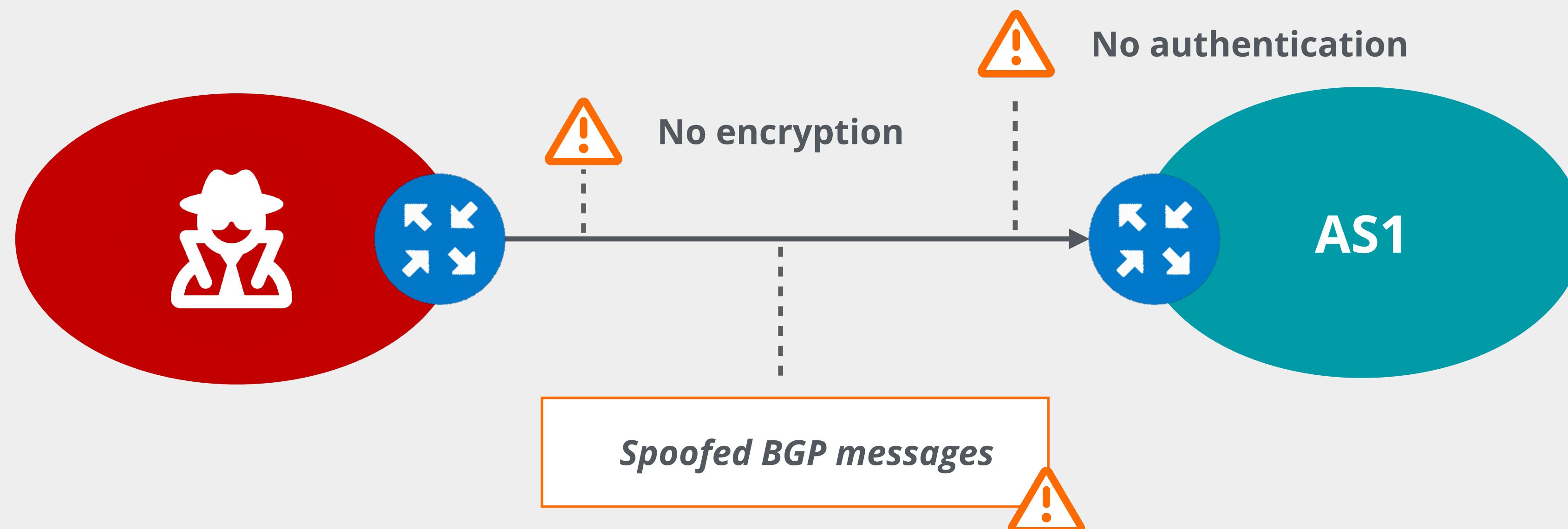
BGP Has Three Main Vulnerabilities

- 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

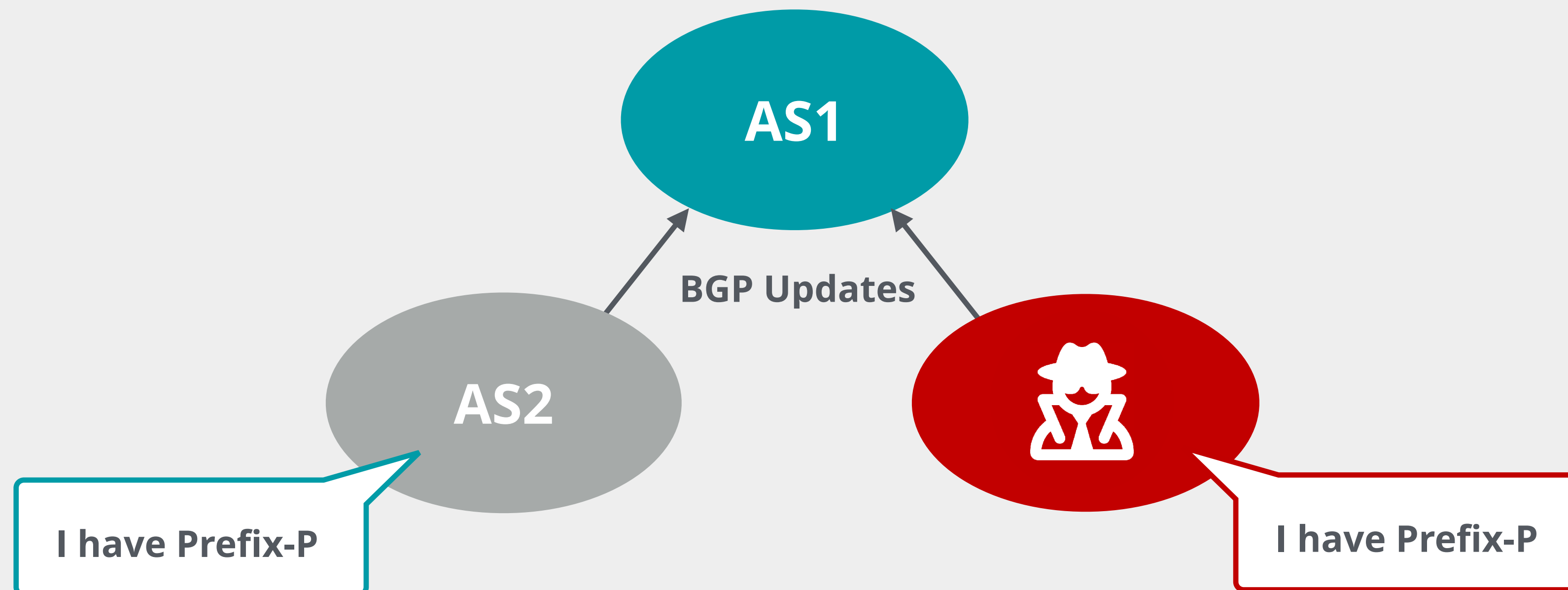
- BGP **does not** have a built-in authentication mechanism
- BGP provides **no integrity** or **confidentiality**
- BGP messages do not use a freshness service and can be replayed





No Origin Validation

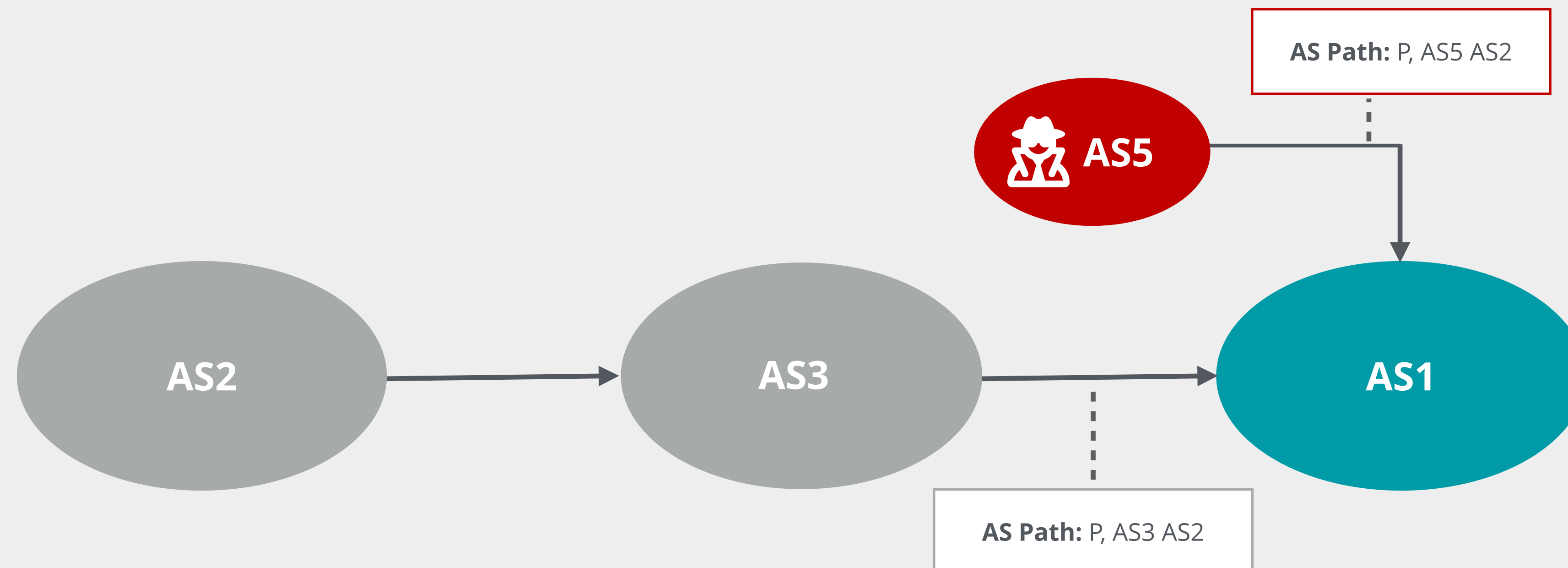
- BGP does not have a validity check for propagated routes
- **Any AS can announce any prefix**





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

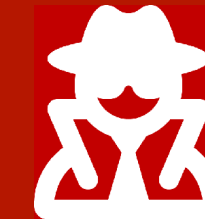
- Typo errors (fat finger)
 - May cause mis-origination
- Configuration errors
 - May cause mis-origination
 - AS path prepending mistake
- Simple mistakes may cause big problems!
 - BGP hijacks or **route leaks**



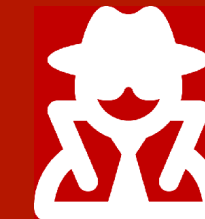
But Sometimes They're Malicious!



ROUTE MANIPULATION ATTACKS



TCP/IP PROTOCOL ATTACKS



PROTOCOL MANIPULATION ATTACKS



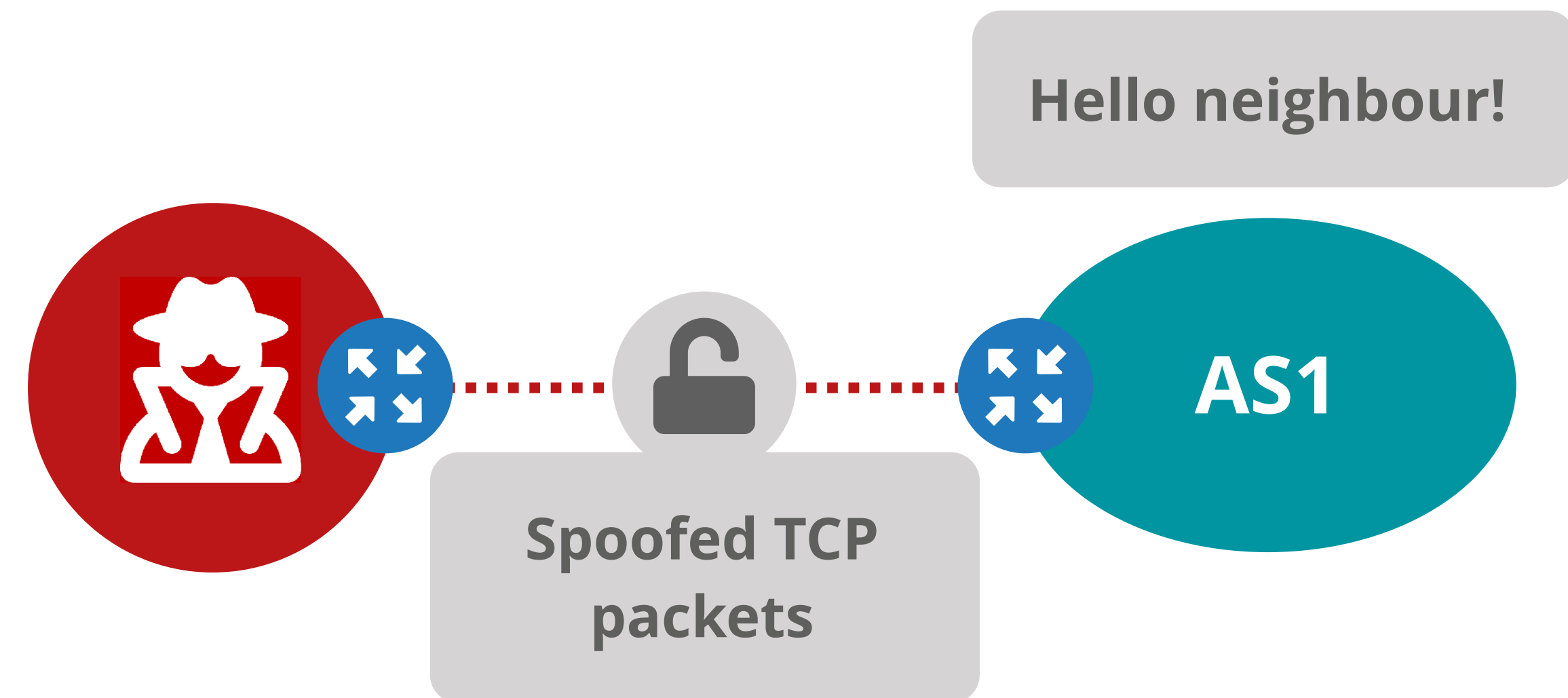
DENIAL-OF-SERVICE ATTACKS





TCP/IP Protocol Attacks

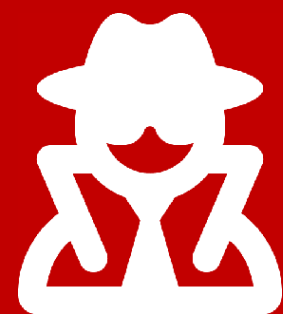
- BGP uses TCP: vulnerable to **TCP/IP based attacks**
 - IP Spoofing
 - TCP Session Hijacking
 - SYN flooding attack
- **No BGP-specific security solutions available for them**





IP Spoofing

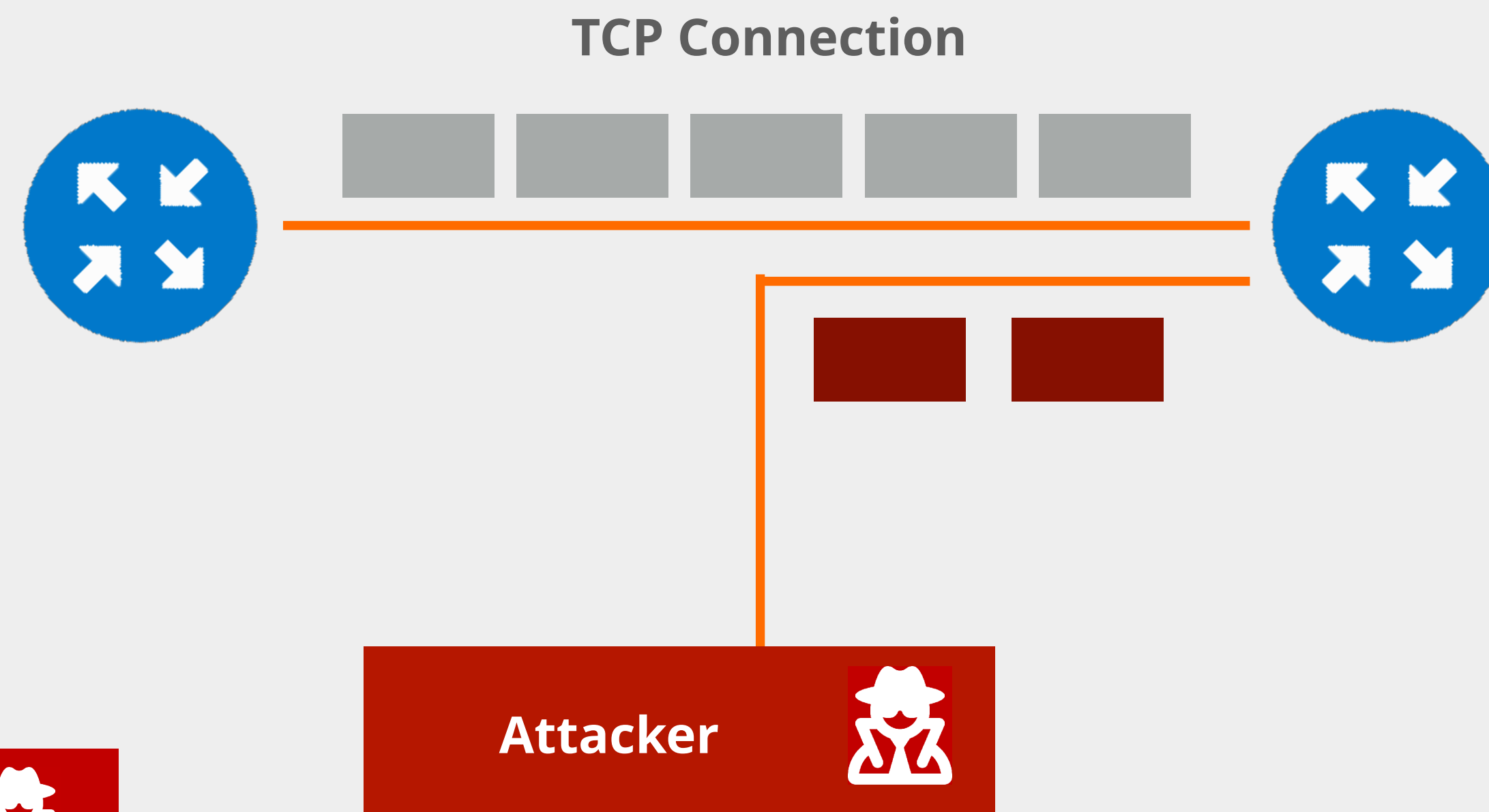
- An attacker could spoof an IP address of a BGP peer in order to:
 - Establish an unauthorised BGP session
 - Break an existing BGP session
 - Inject bogus routes or delete routes





TCP Session Hijacking

- Involves intrusion into an ongoing session



Same header fields

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





TCP Session Hijacking

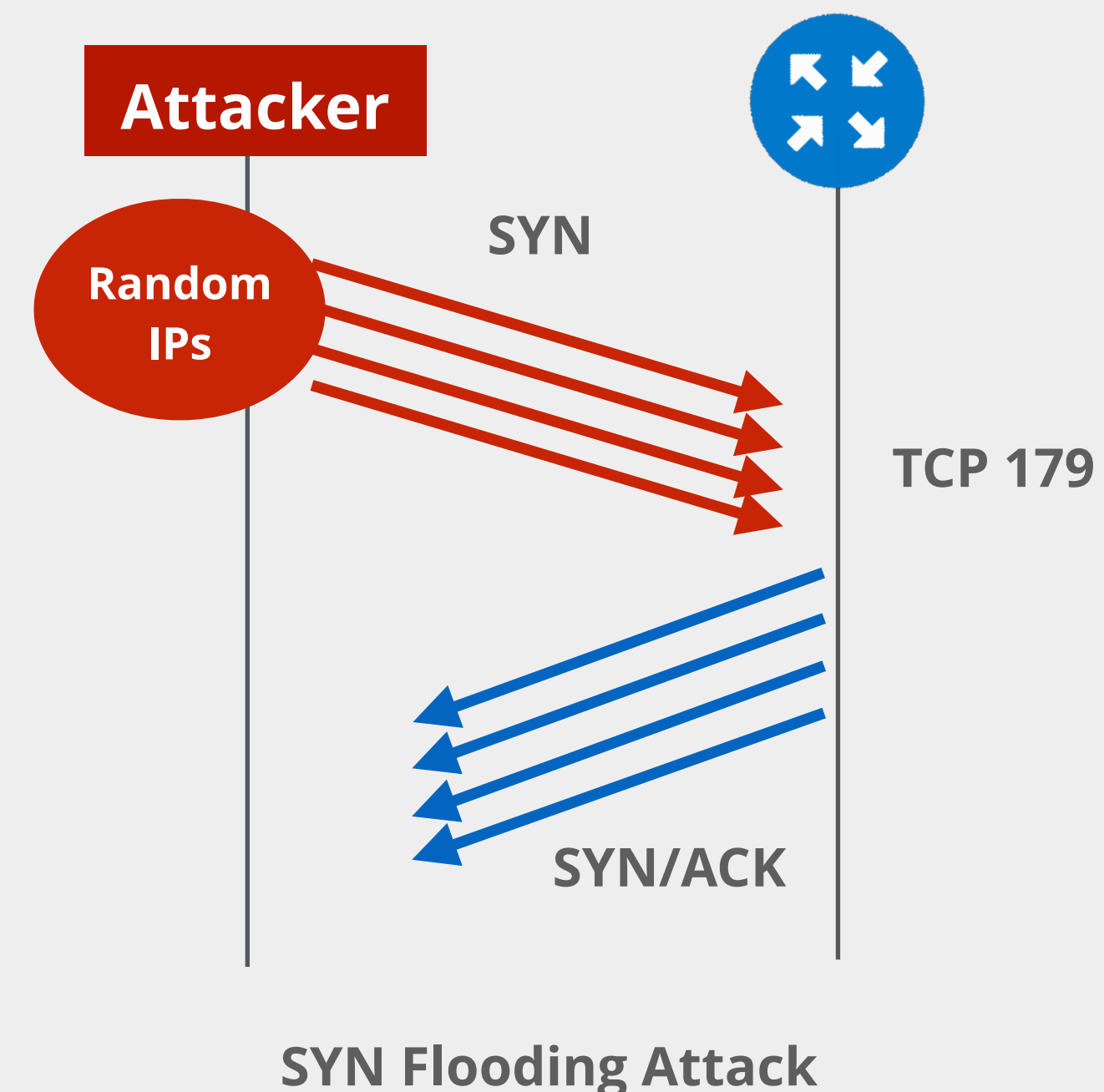
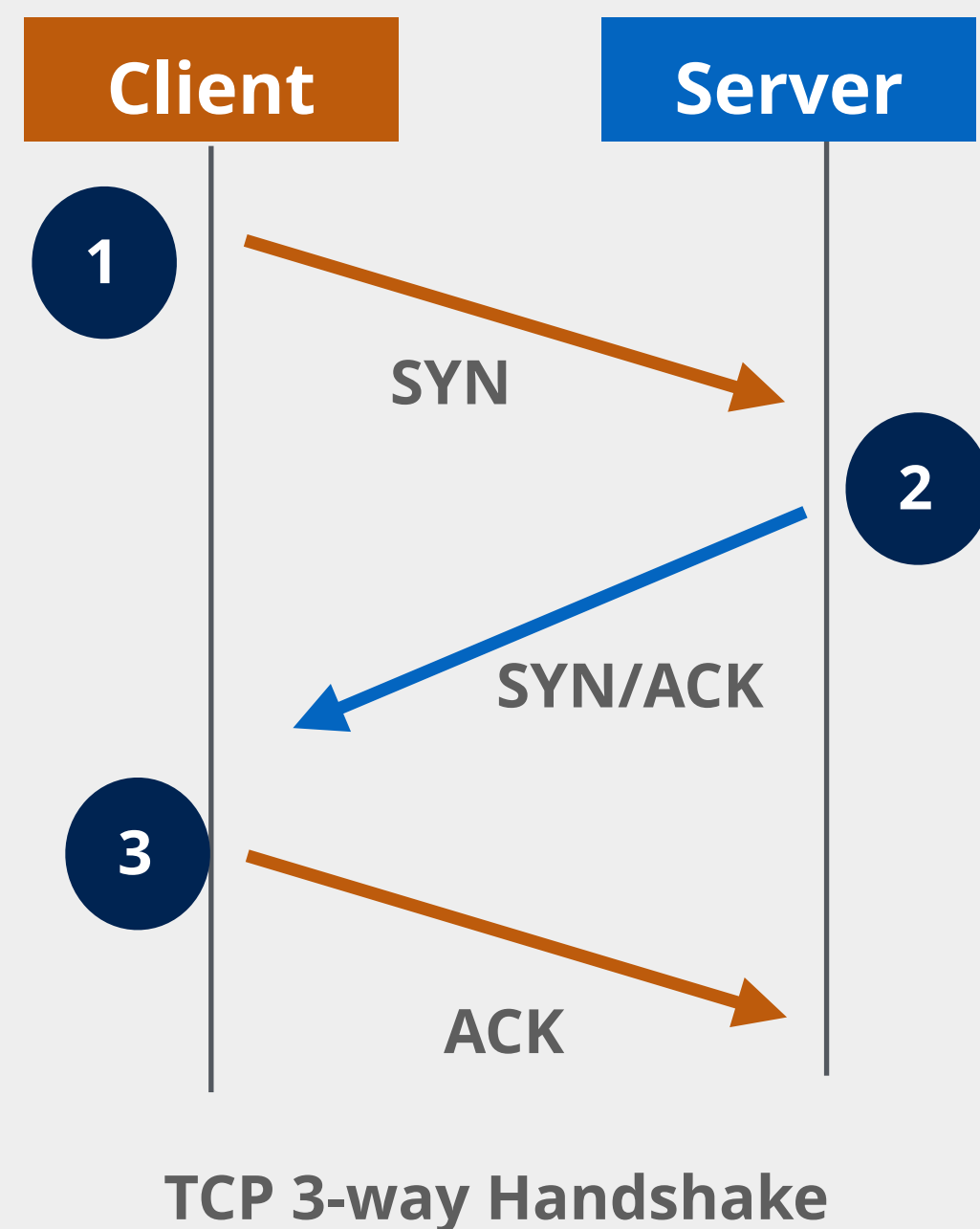
- **Requires an attacker to discover the following:**
 - src IP, dst IP, src port, dst port
 - sequence number of ongoing session
- **In BGP, it could be used to**
 - bring down the BGP session between peers (TCP RST)
 - inject false routes into BGP , delete or modify routes





SYN Flooding Attack

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

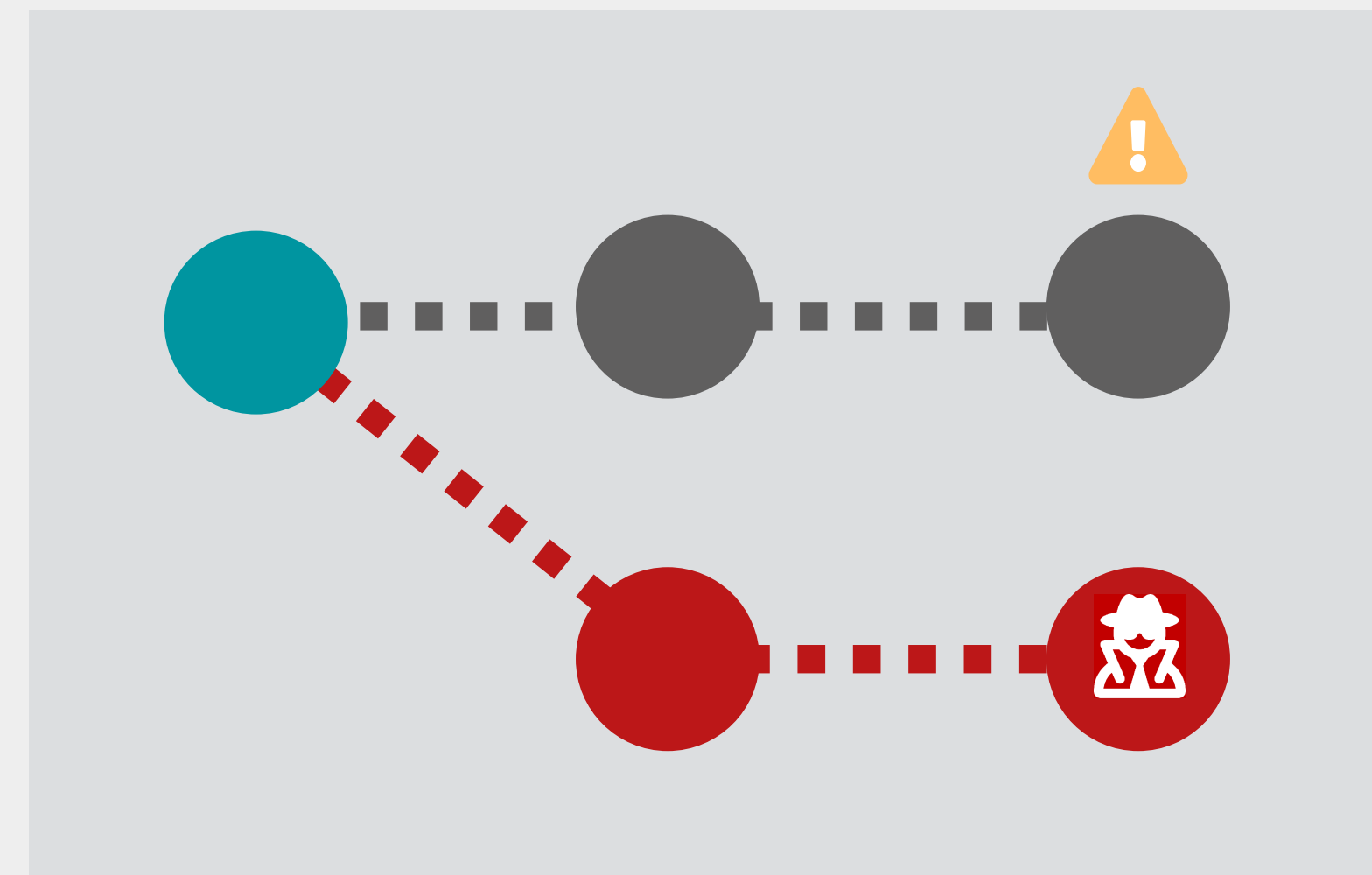




BGP Route Manipulation Attacks

- **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

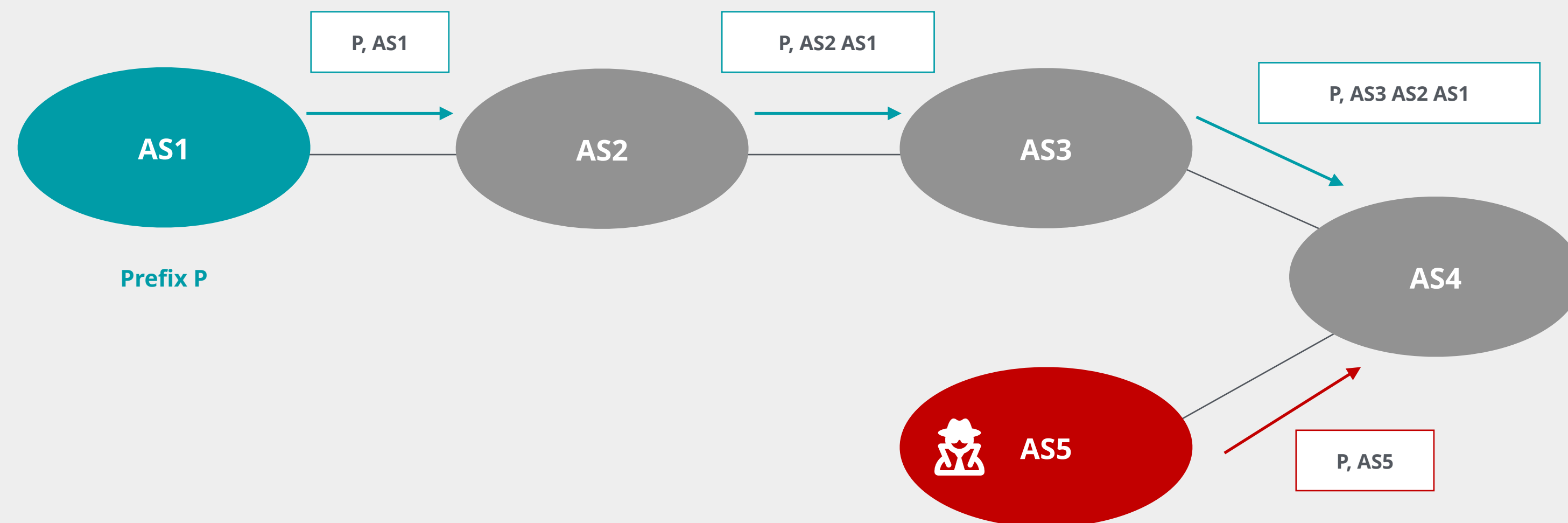
- Can be classified as:
 - **BGP Origin Hijacks**
 - **BGP Path Hijacks**
 - **BGP Route Leaks**
- Very common! **Our focus on this course**





BGP Origin Hijack

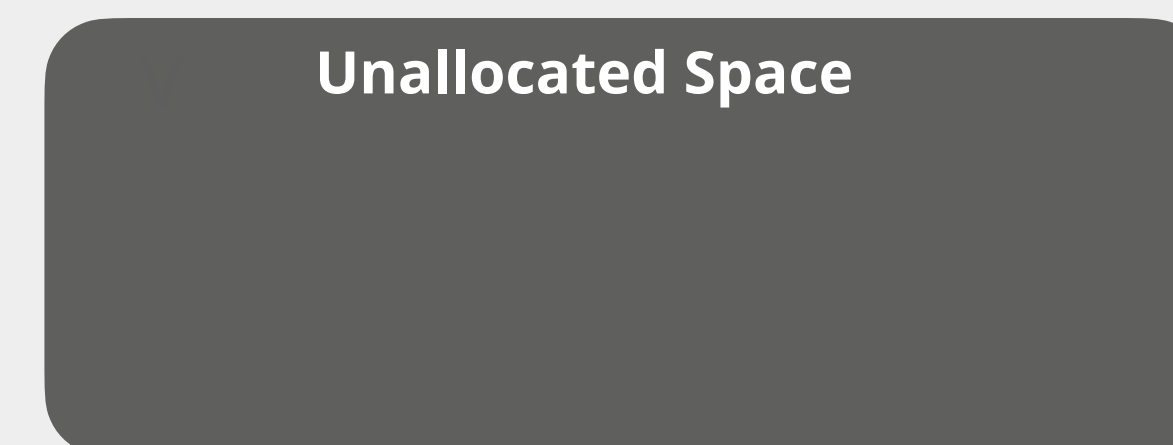
- The hijacking AS:
 - Abuses mutual trust between ASes
 - Originates a prefix **that it is not authorised to originate!**
- Difficult to say whether it is an accident or an attack
- Traffic lost or received by attacker (eavesdrop)





Hijacks of Allocated Addresses

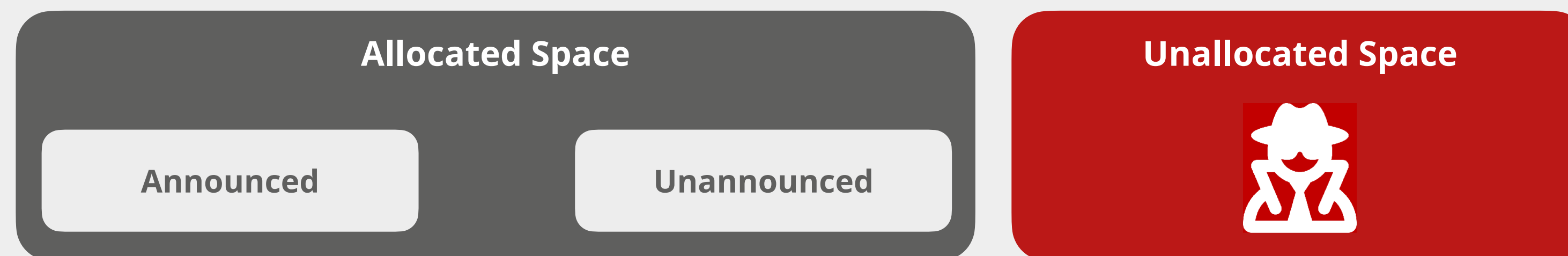
- Allocated address space could be:
 - Currently in use (**announced** prefixes)
 - Or unused IP space (**unannounced** prefixes)
- **Unannounced** prefixes are preferred by spammers
 - No operational impact
 - Potentially harms the reputation of the holder





Hijacks of Unallocated Addresses

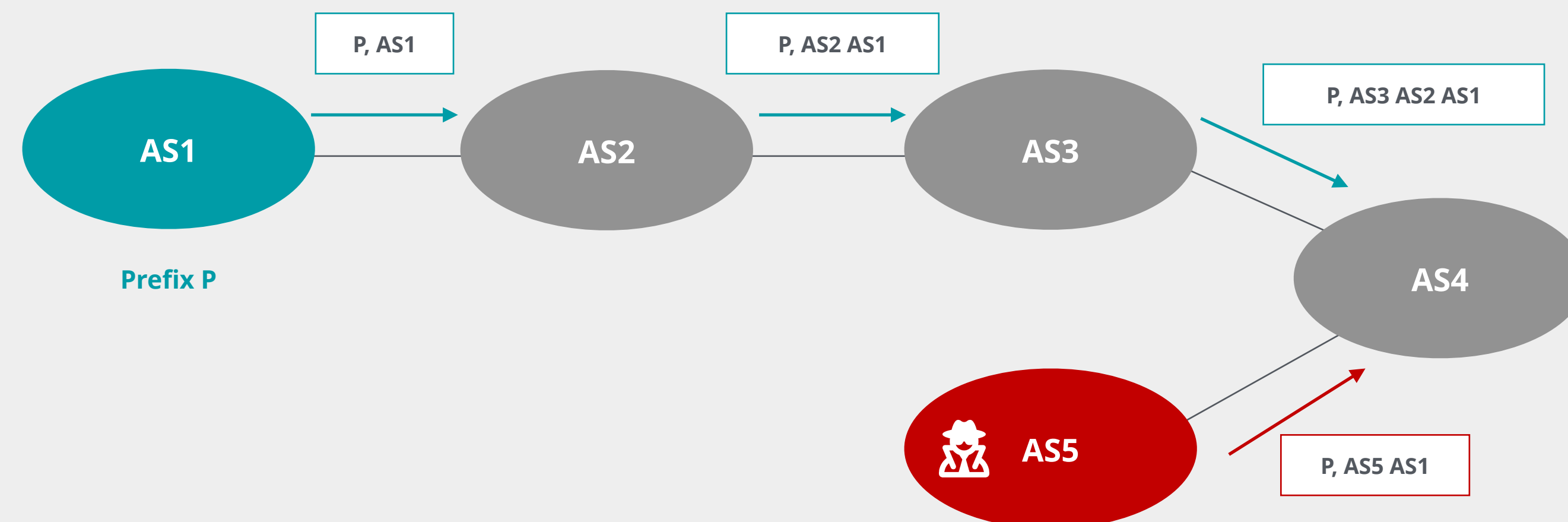
- IP blocks not assigned by IANA or RIRs
- Effective if full bogon filters not applied
- No whois entries, no complaints!
- Again, a good choice for spammers





BGP Path Hijack

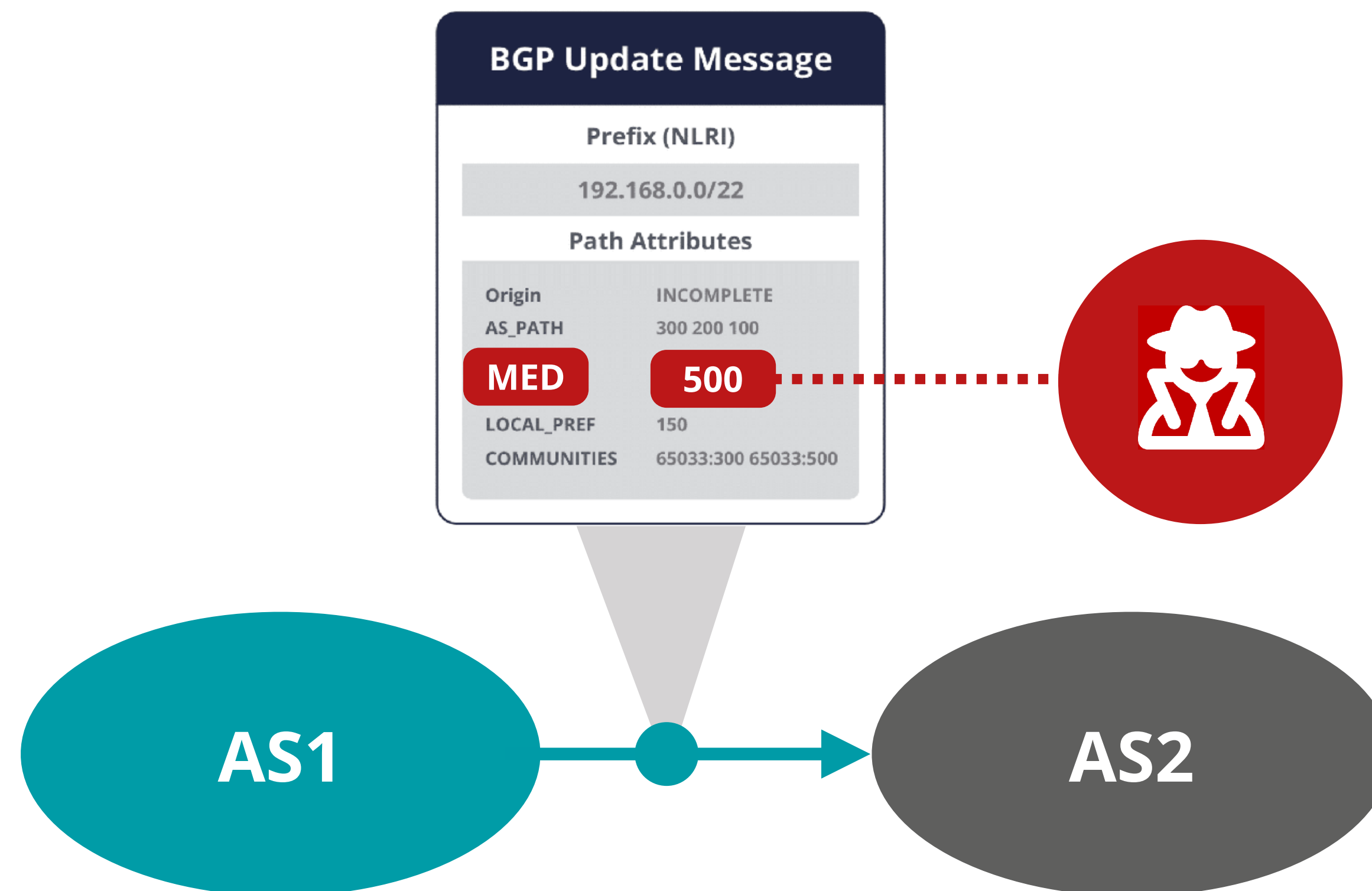
- No verification of path attributes in received BGP updates
- Hijacker can modify the AS Path and **redirect traffic**
- **Traffic lost** or **eavesdropped/modified** (adds latency)





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

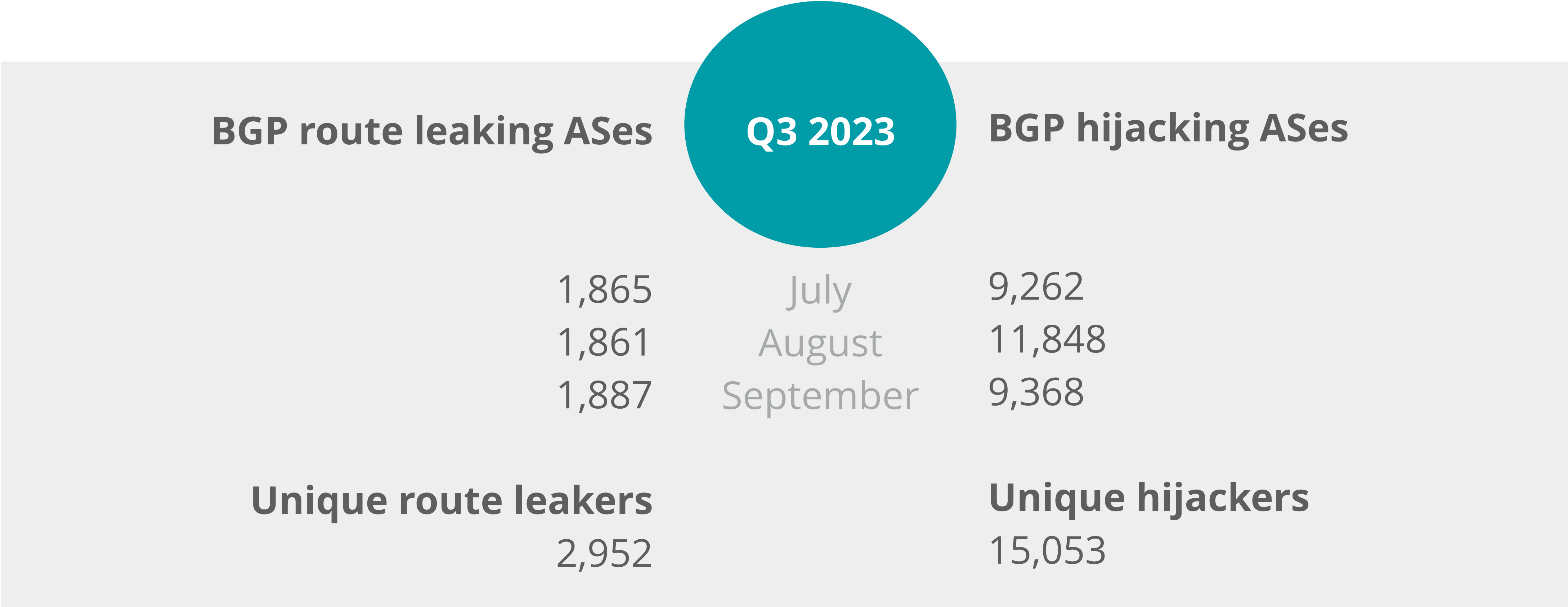




To Summarise

- 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



Source:

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

April 2020: Akamai, Amazon

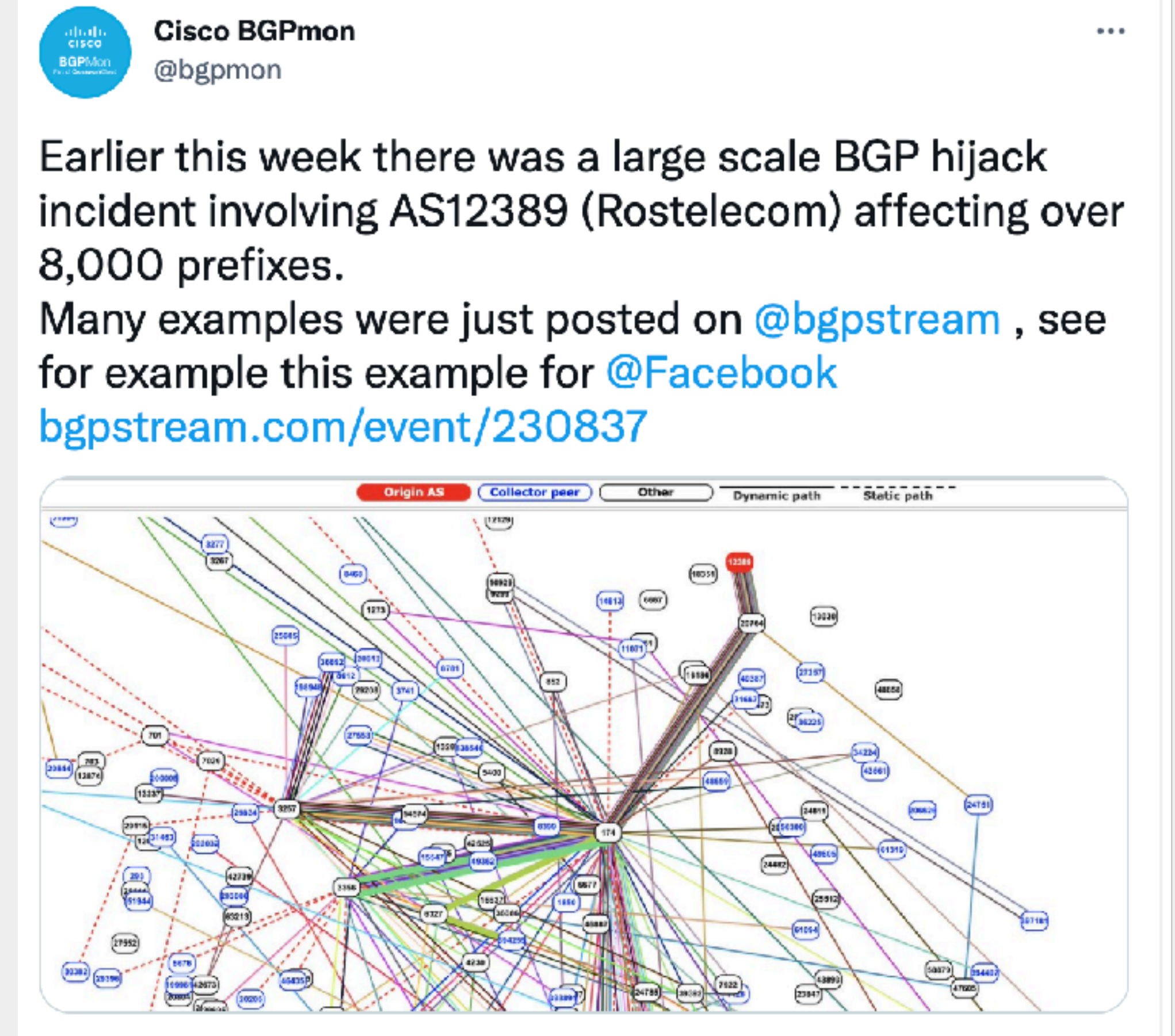


- What happened?

- 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?

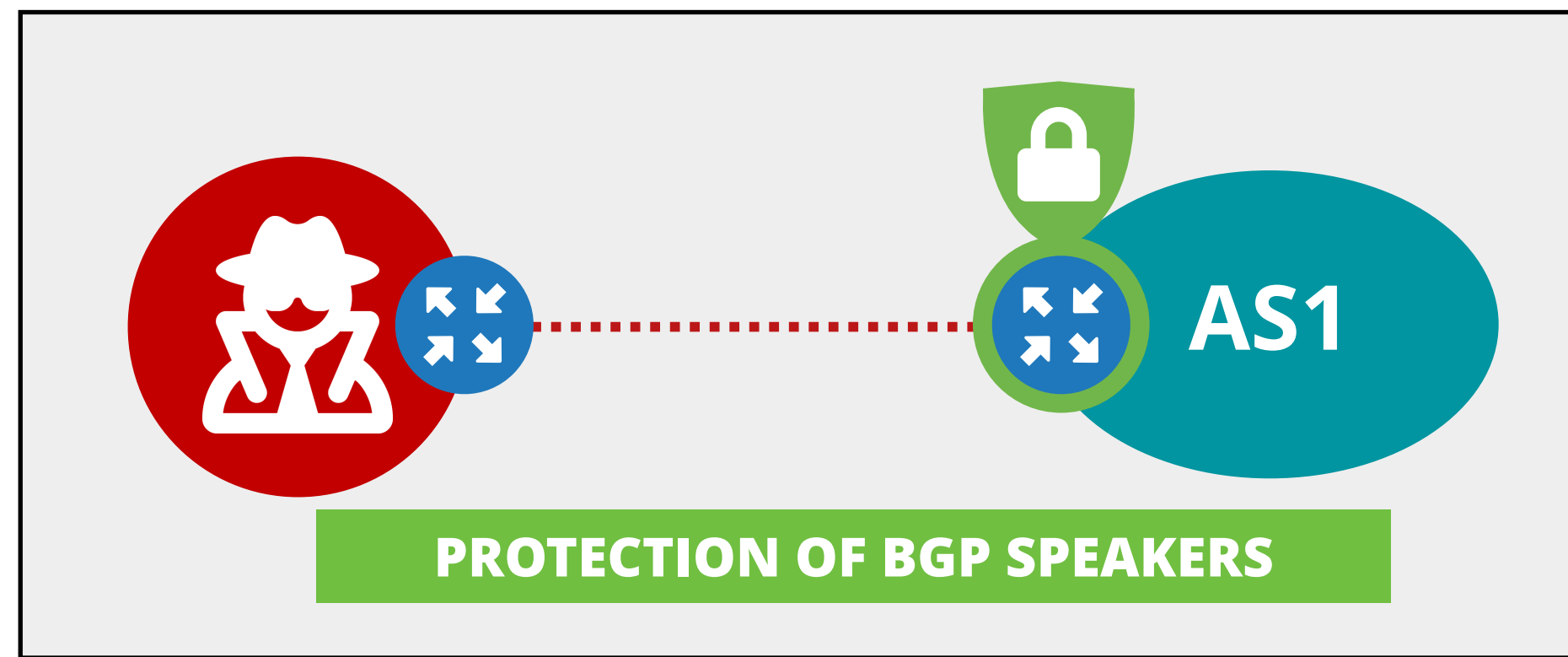


Does the AS path reflect the sequence of ASes that the BGP UPDATE packet has traversed?



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

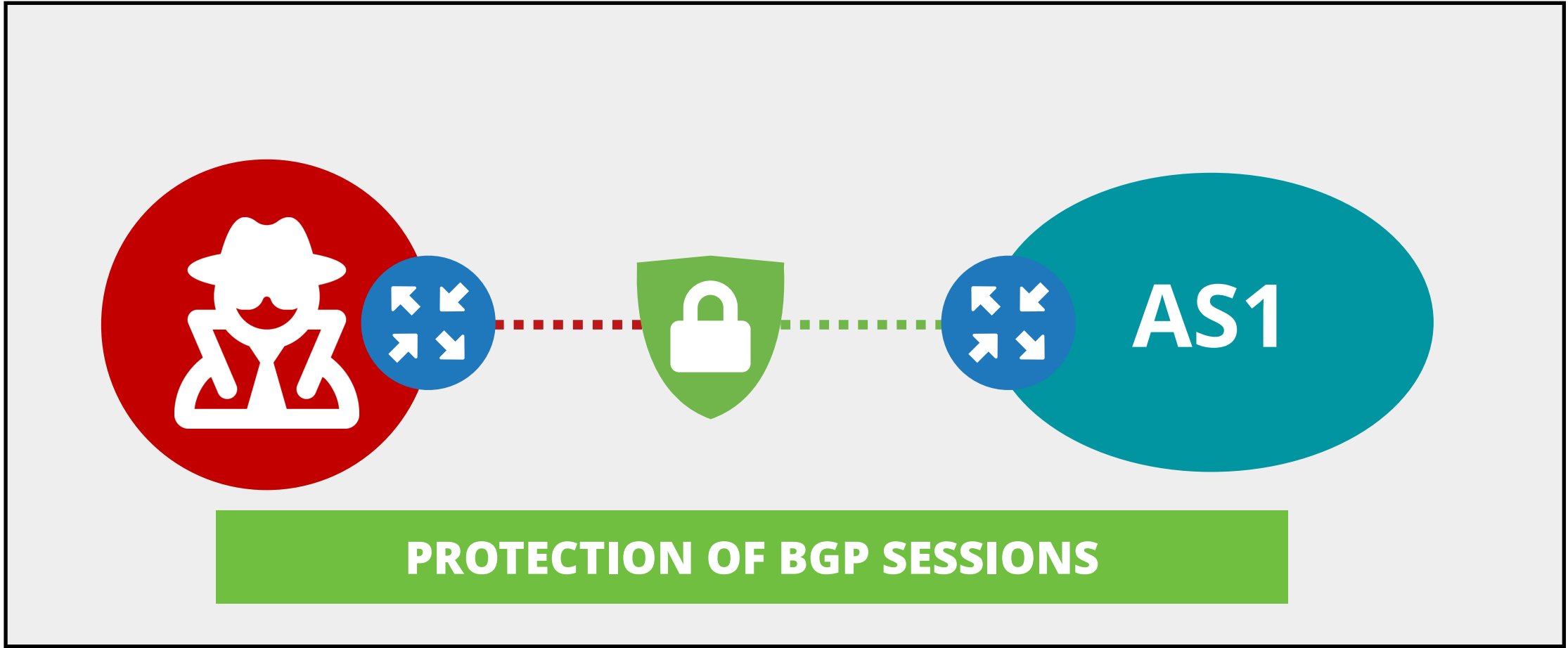
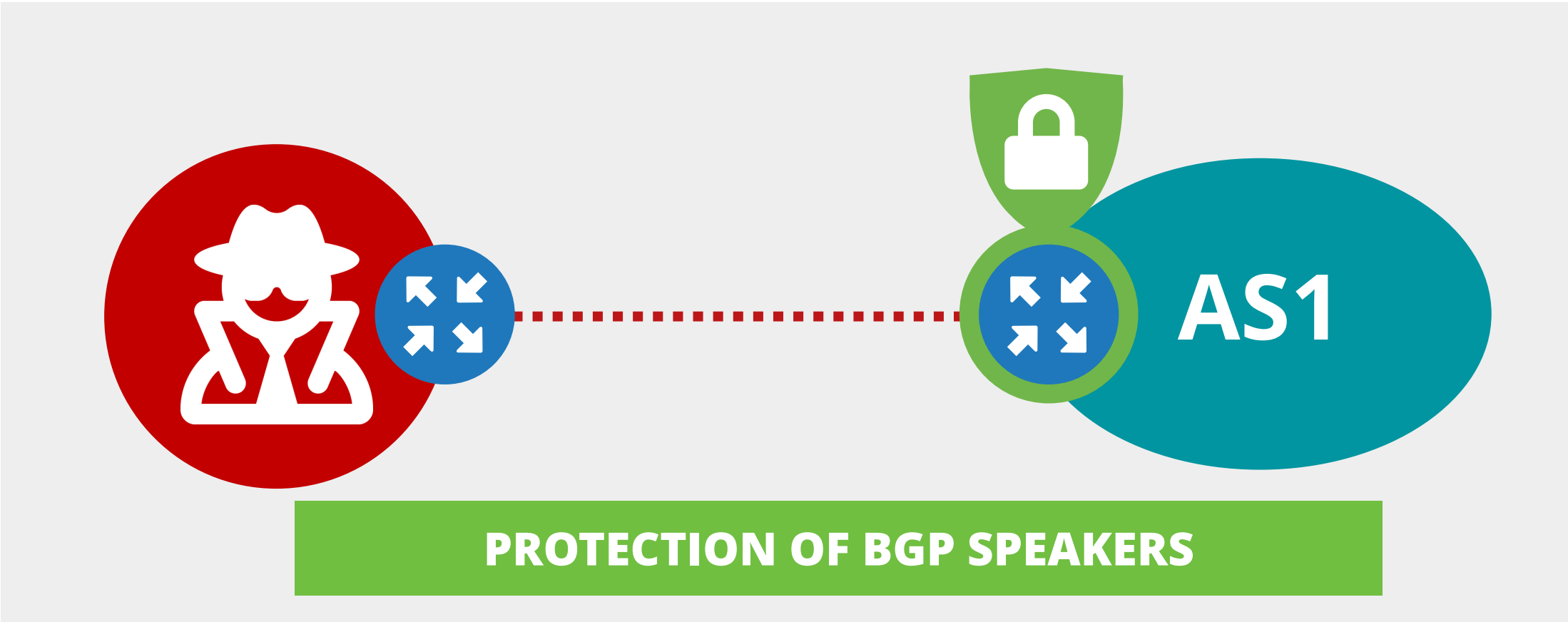
 **RIPE NCC Academy**



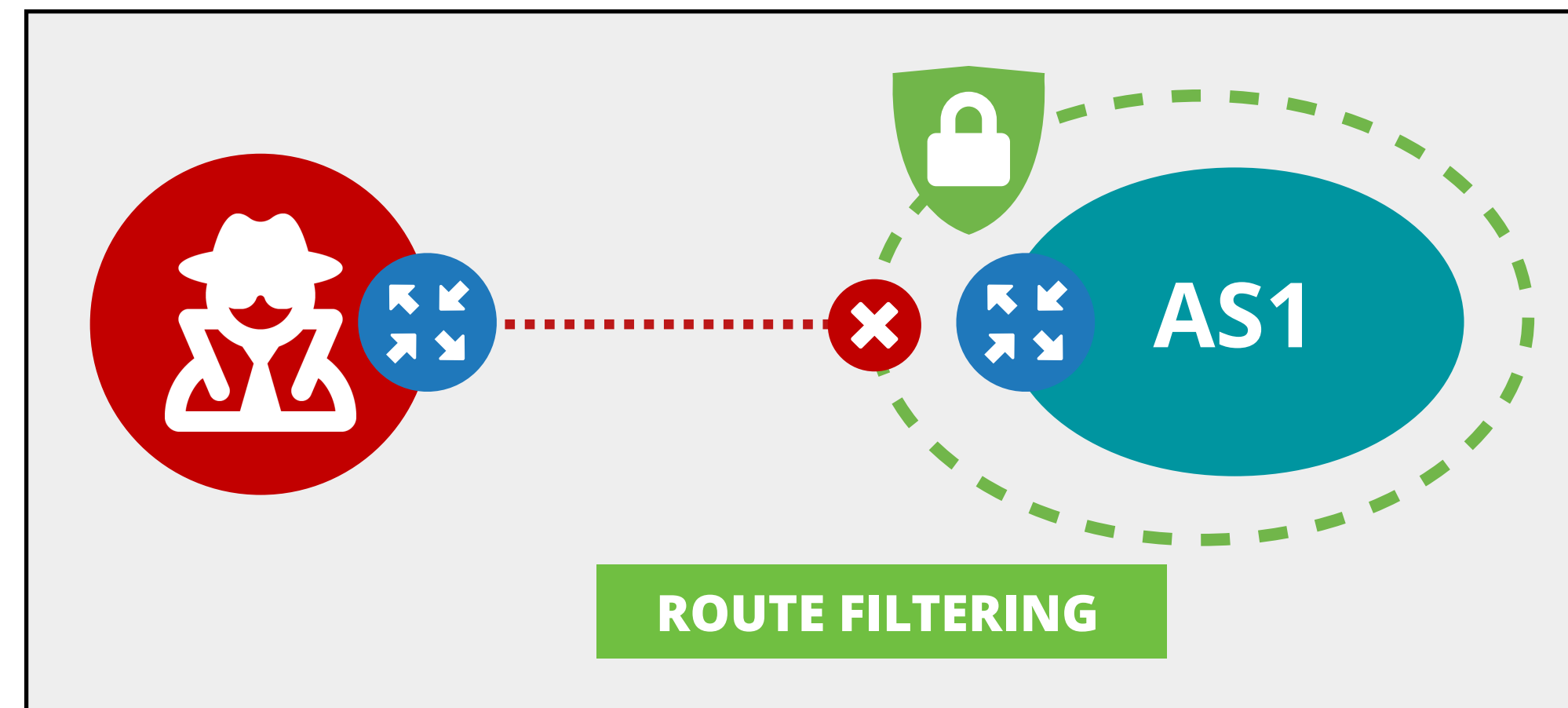
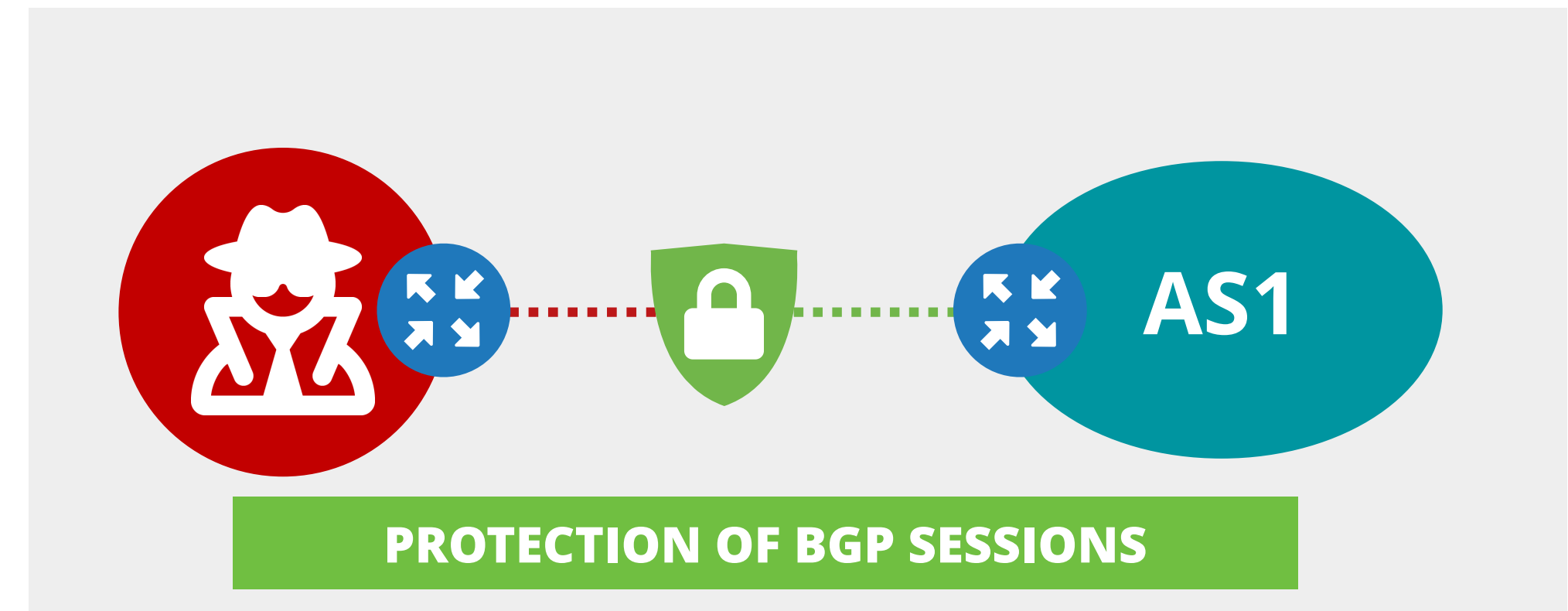
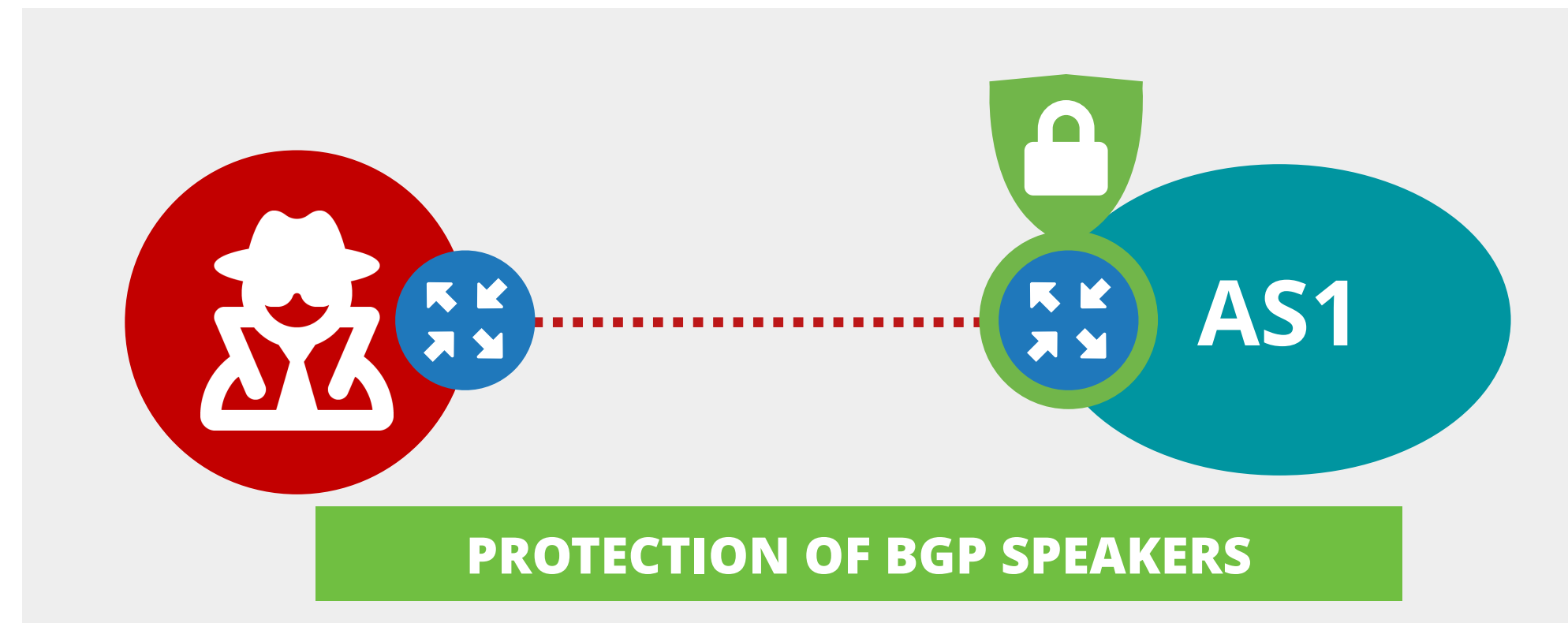
BGP Security

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

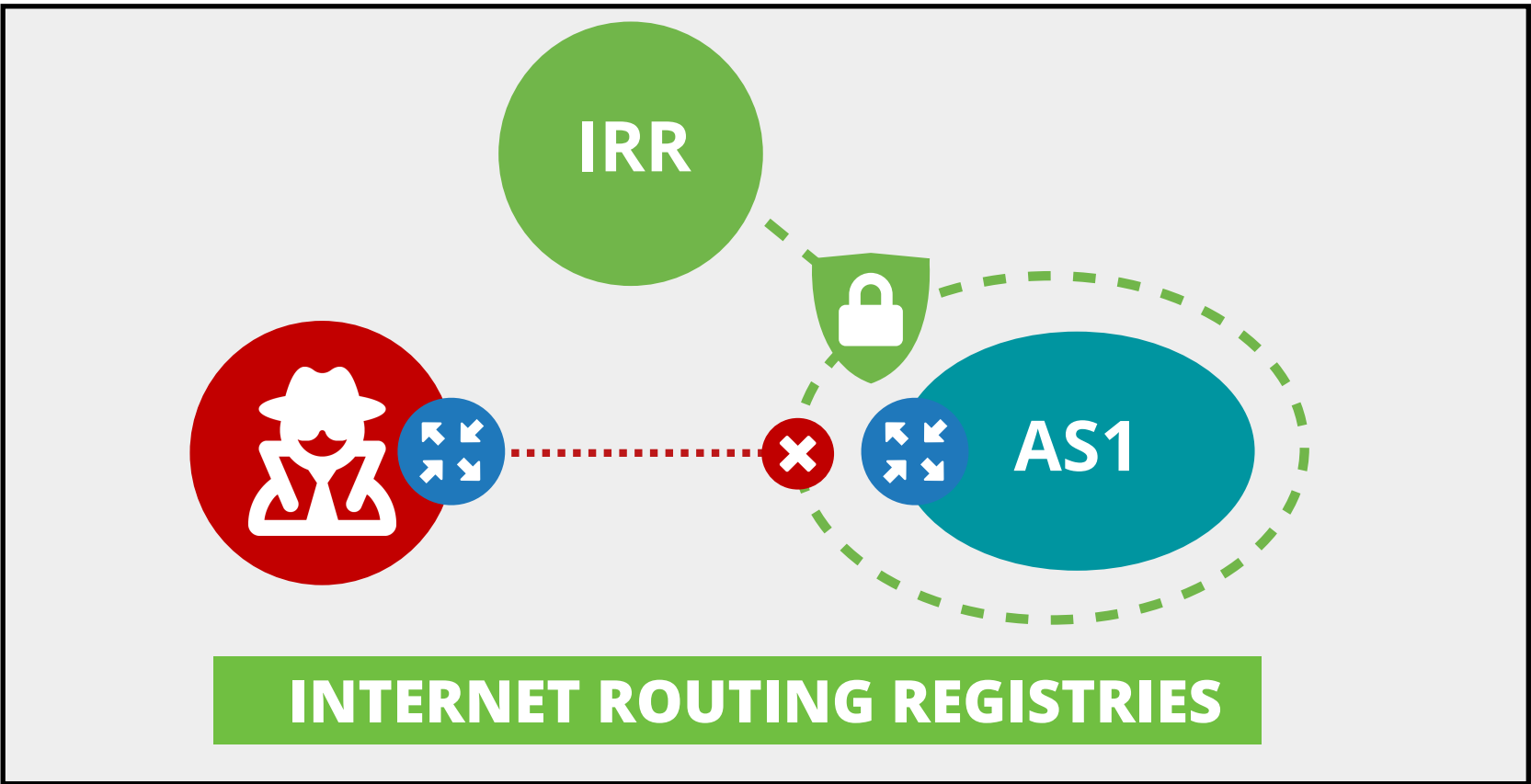
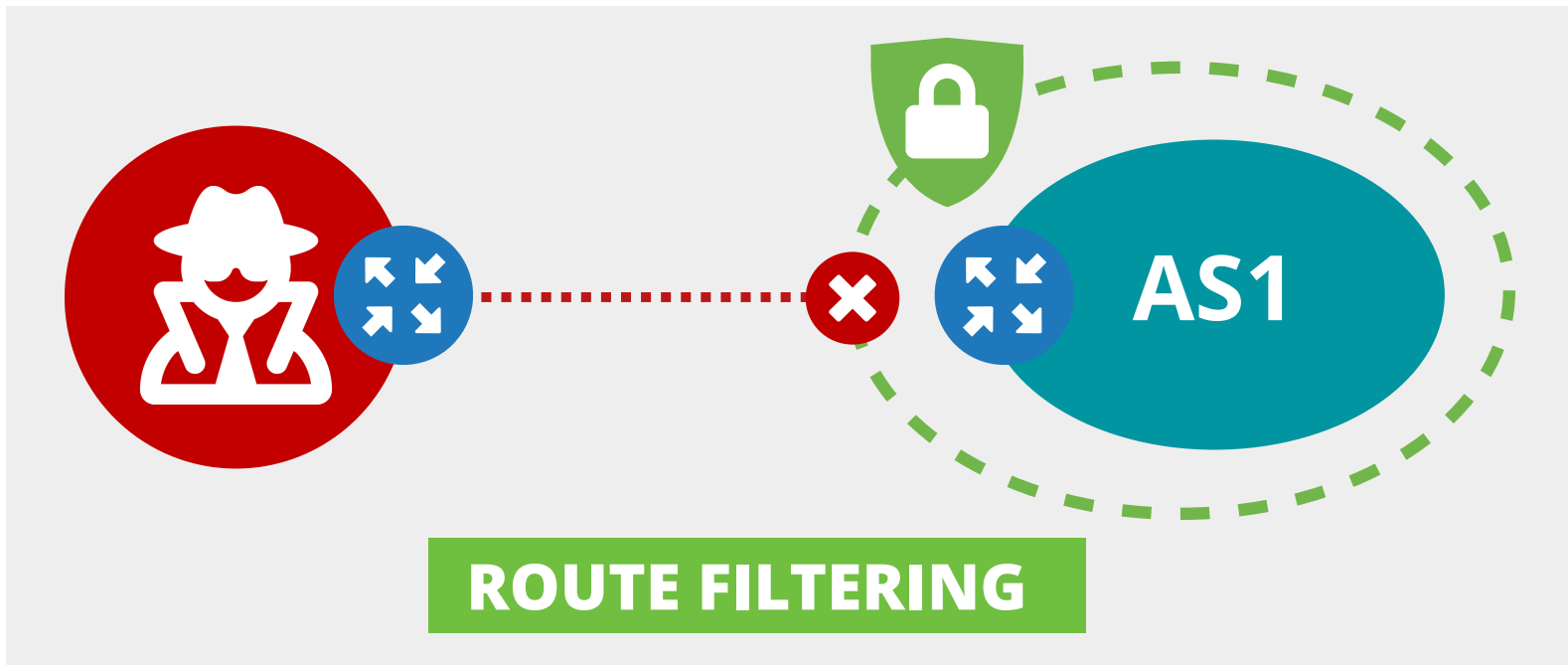
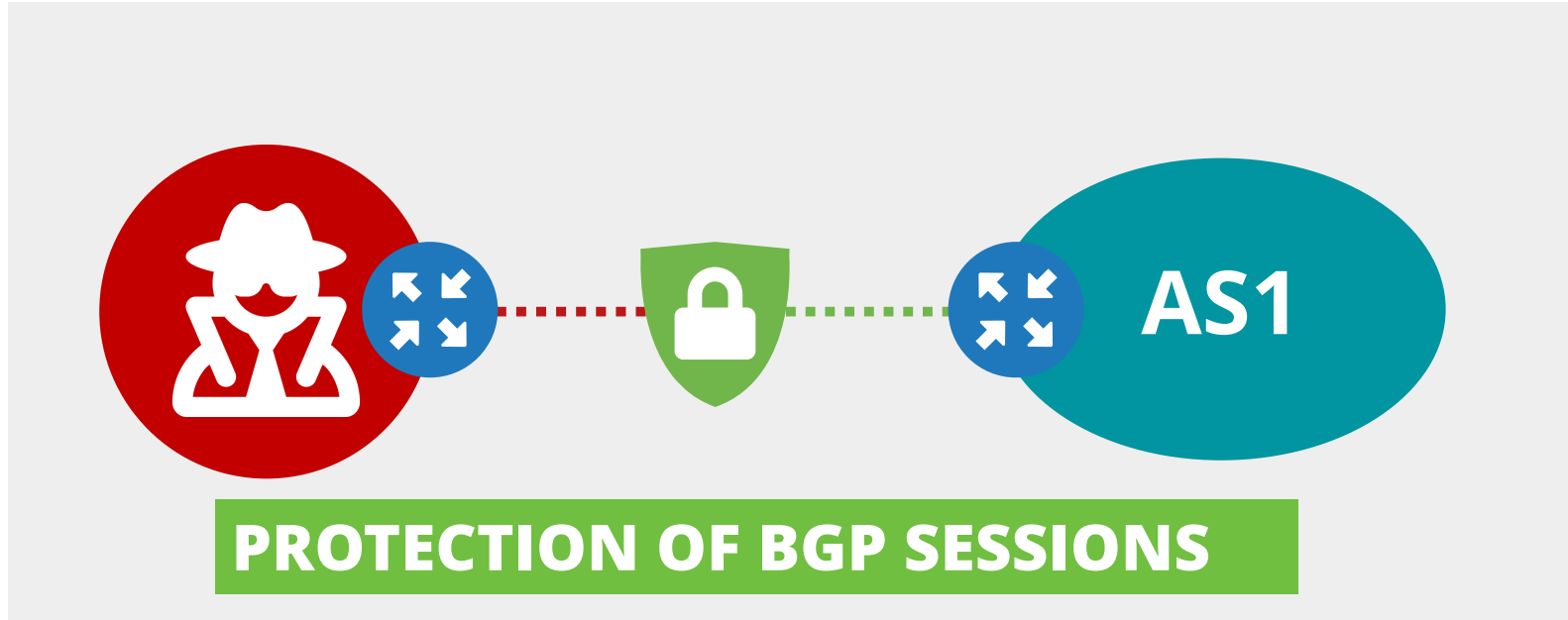
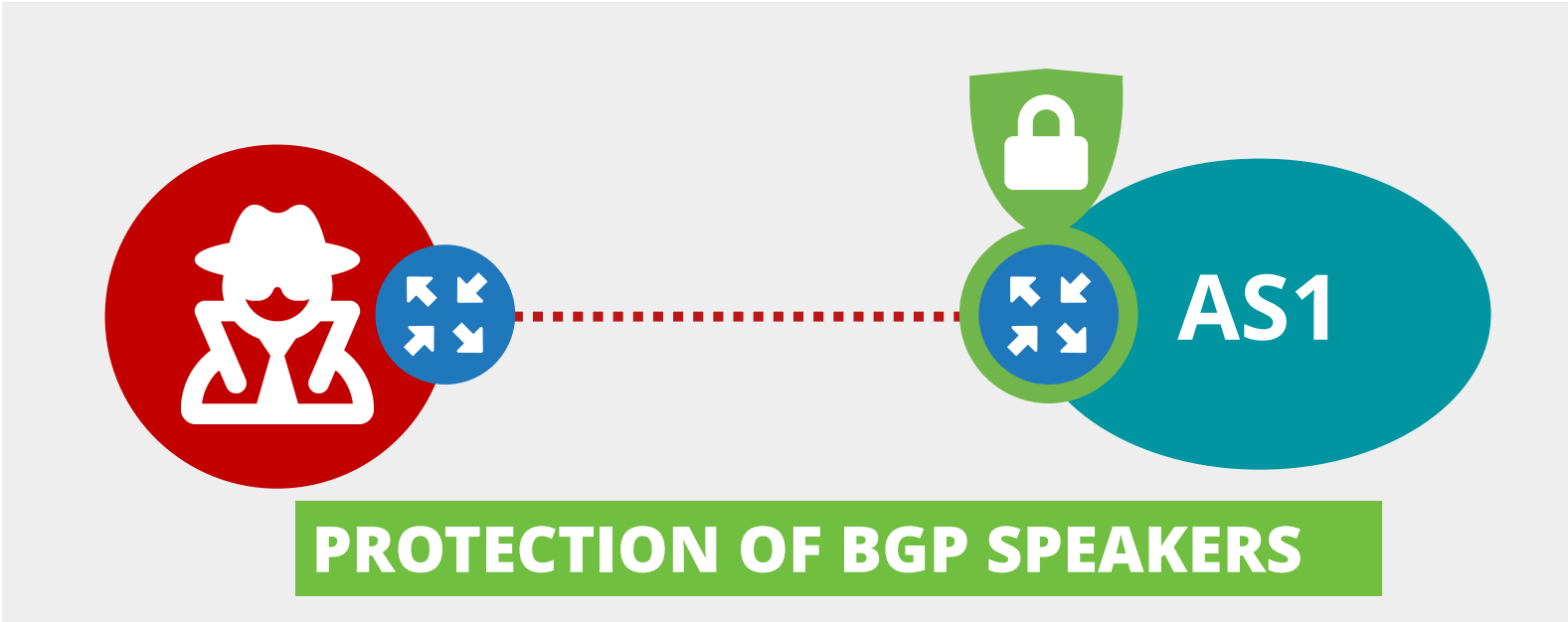
BGP Security Measures



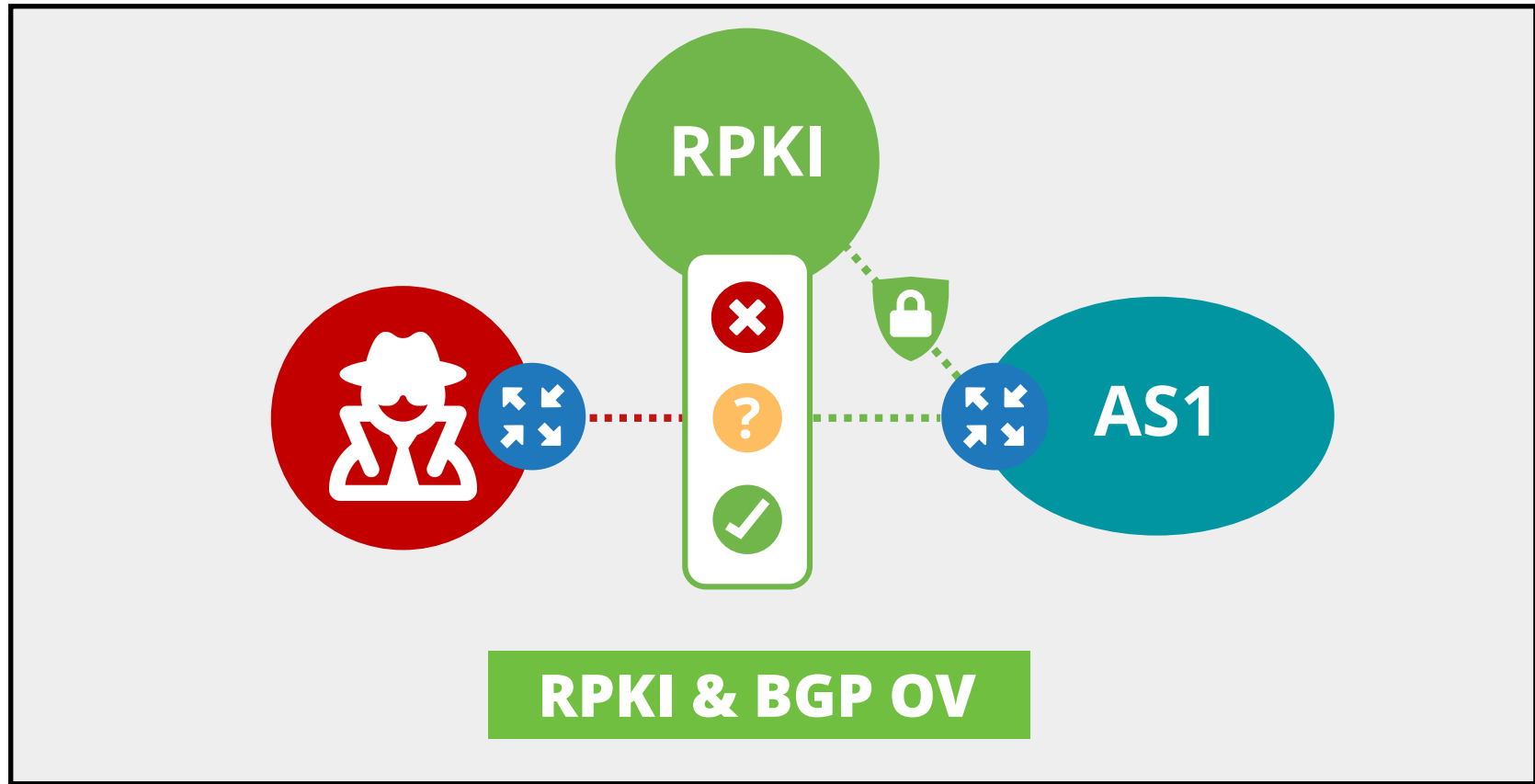
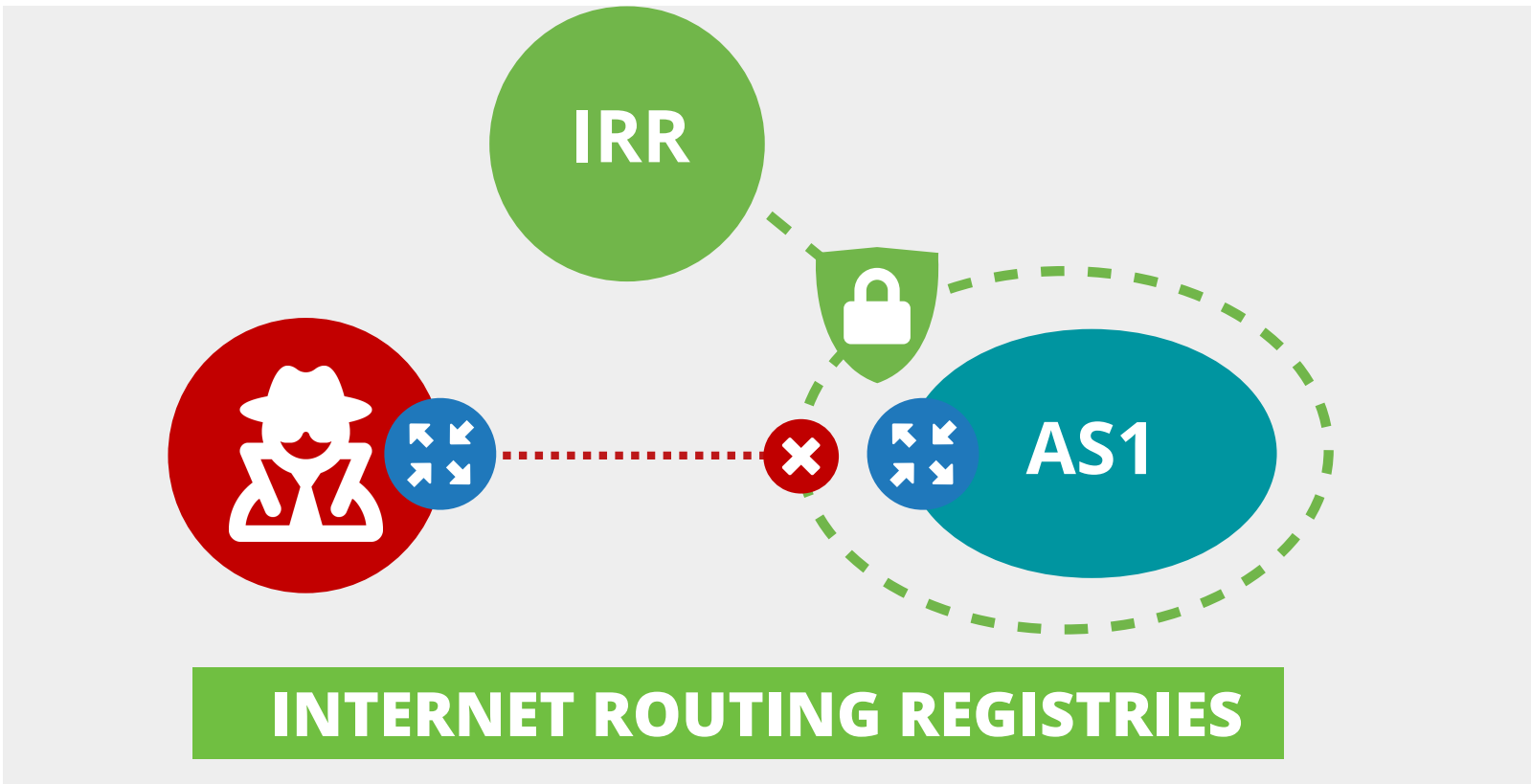
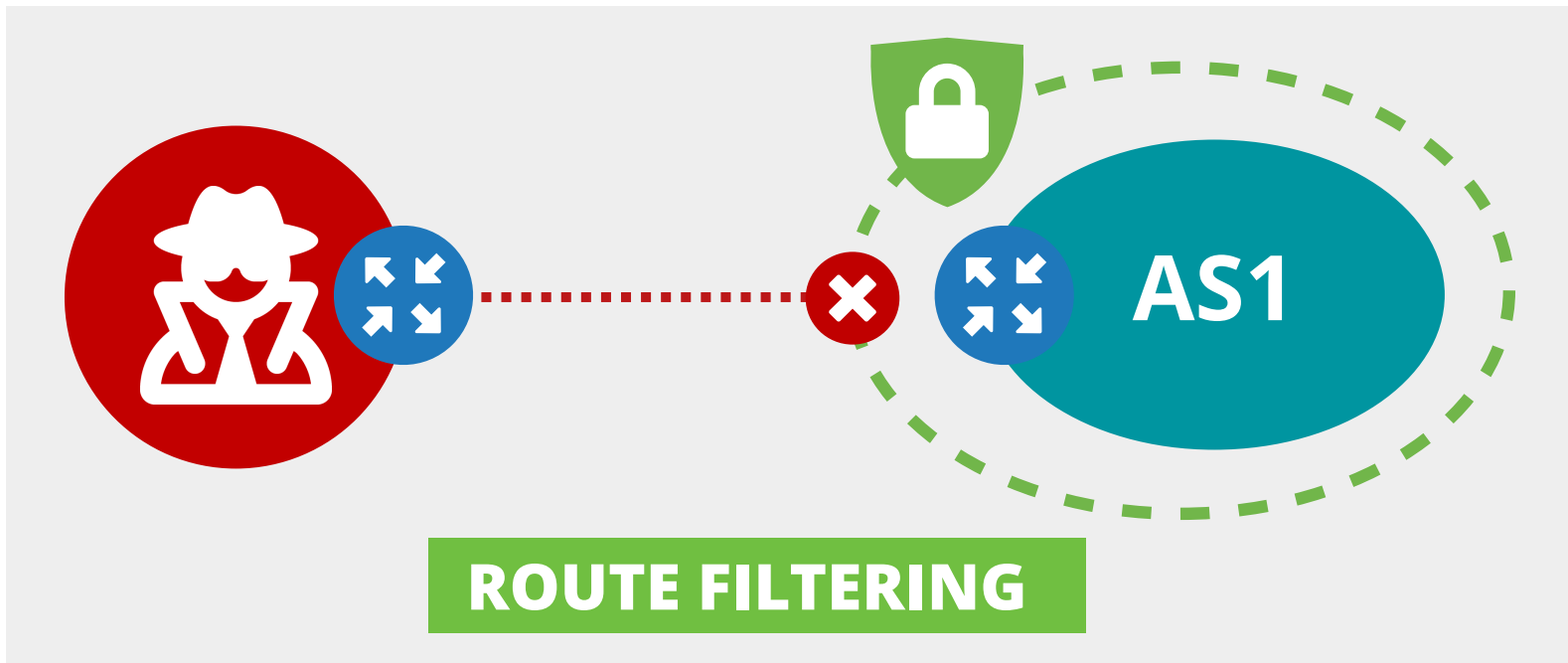
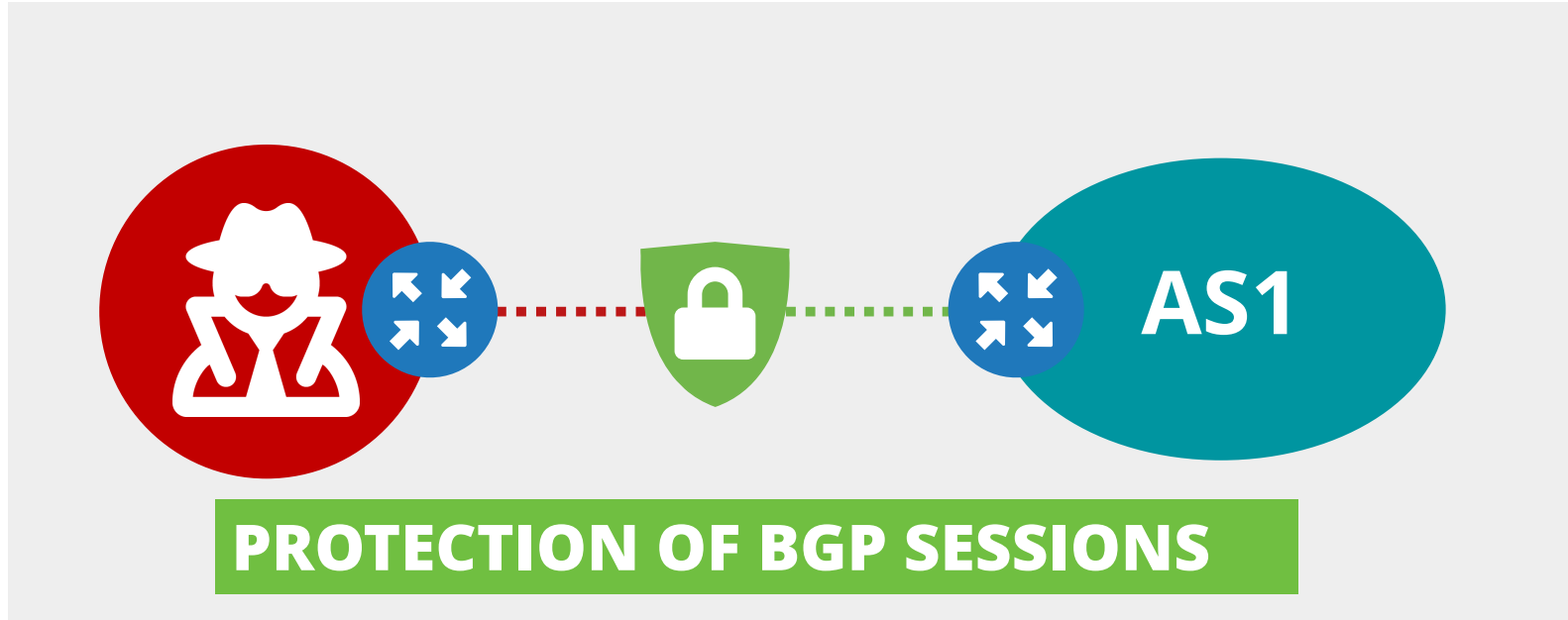
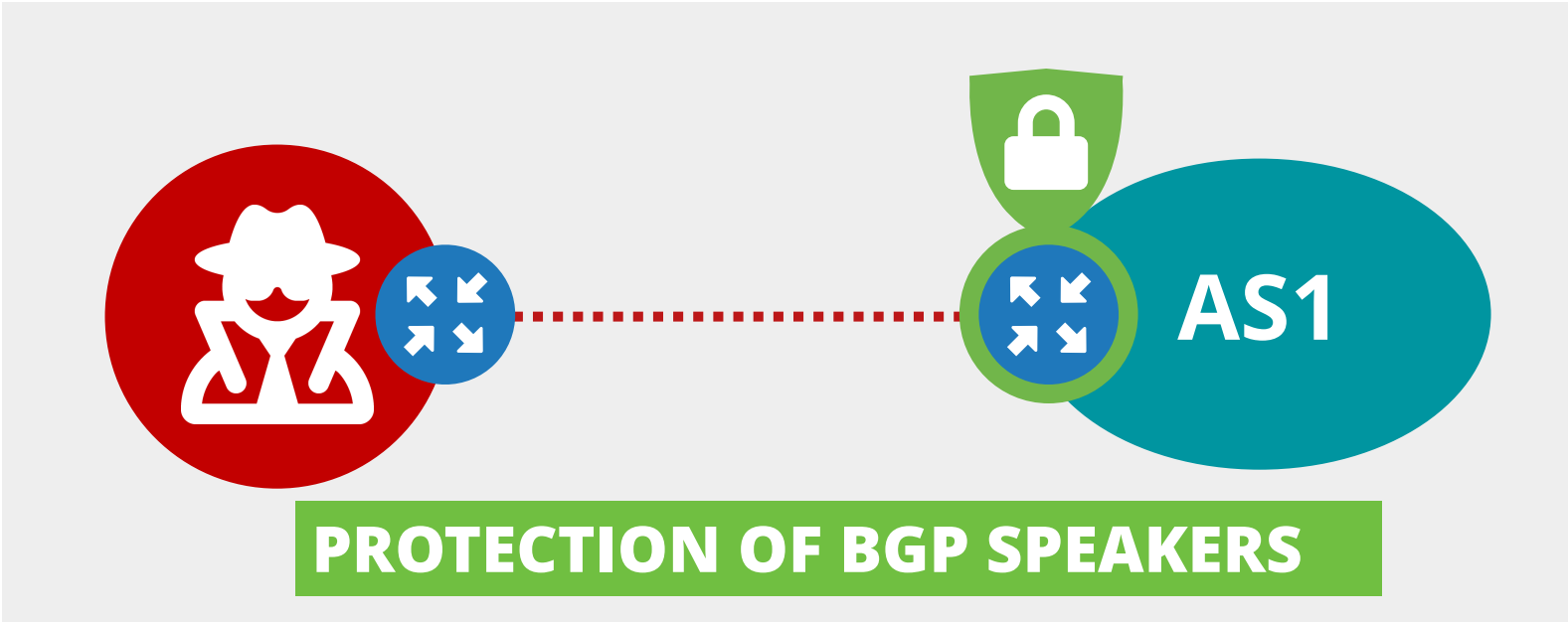
BGP Security Measures



BGP Security Measures



BGP Security Measures





Protection of BGP Sessions

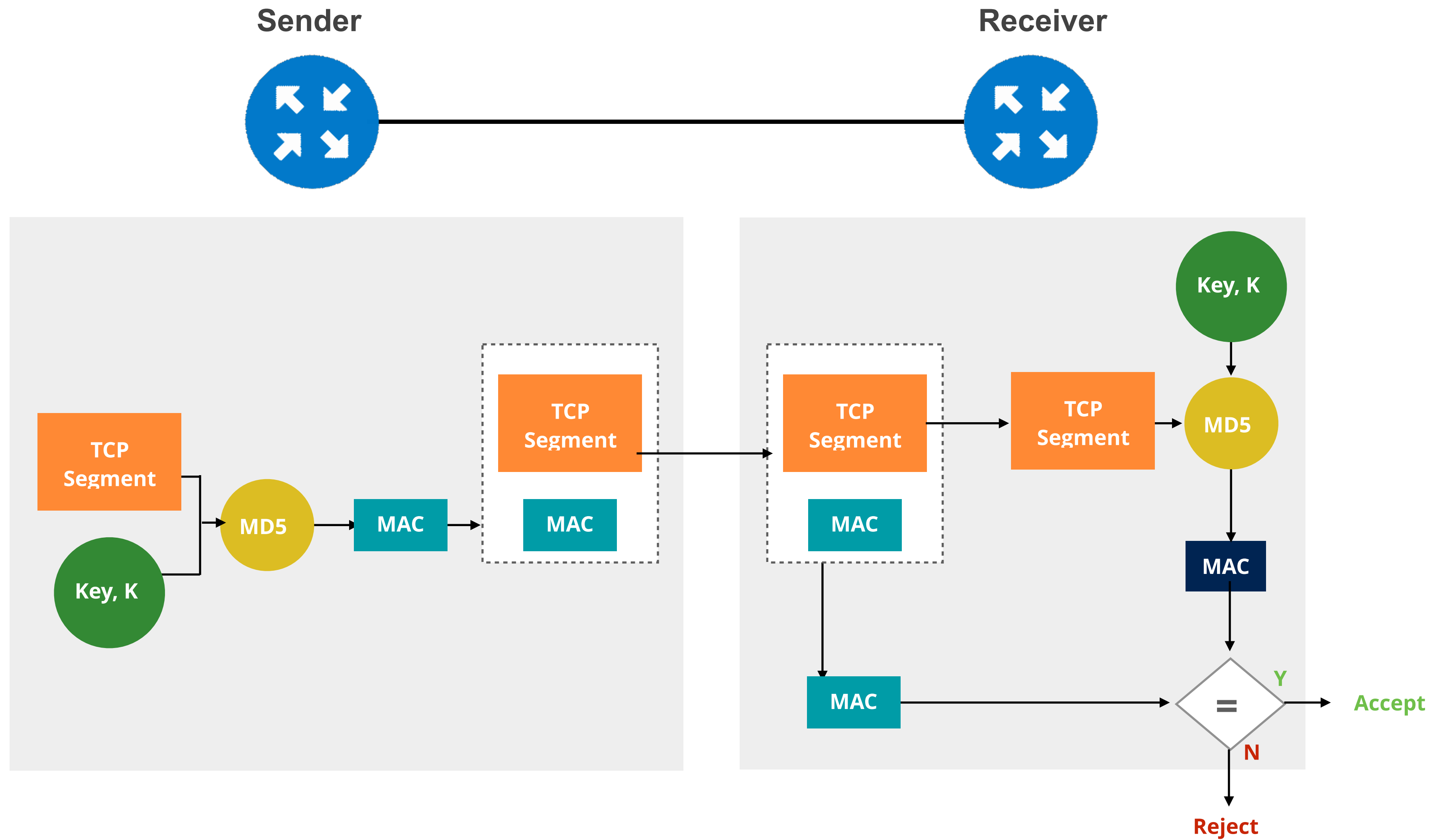
Section 3.2



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)

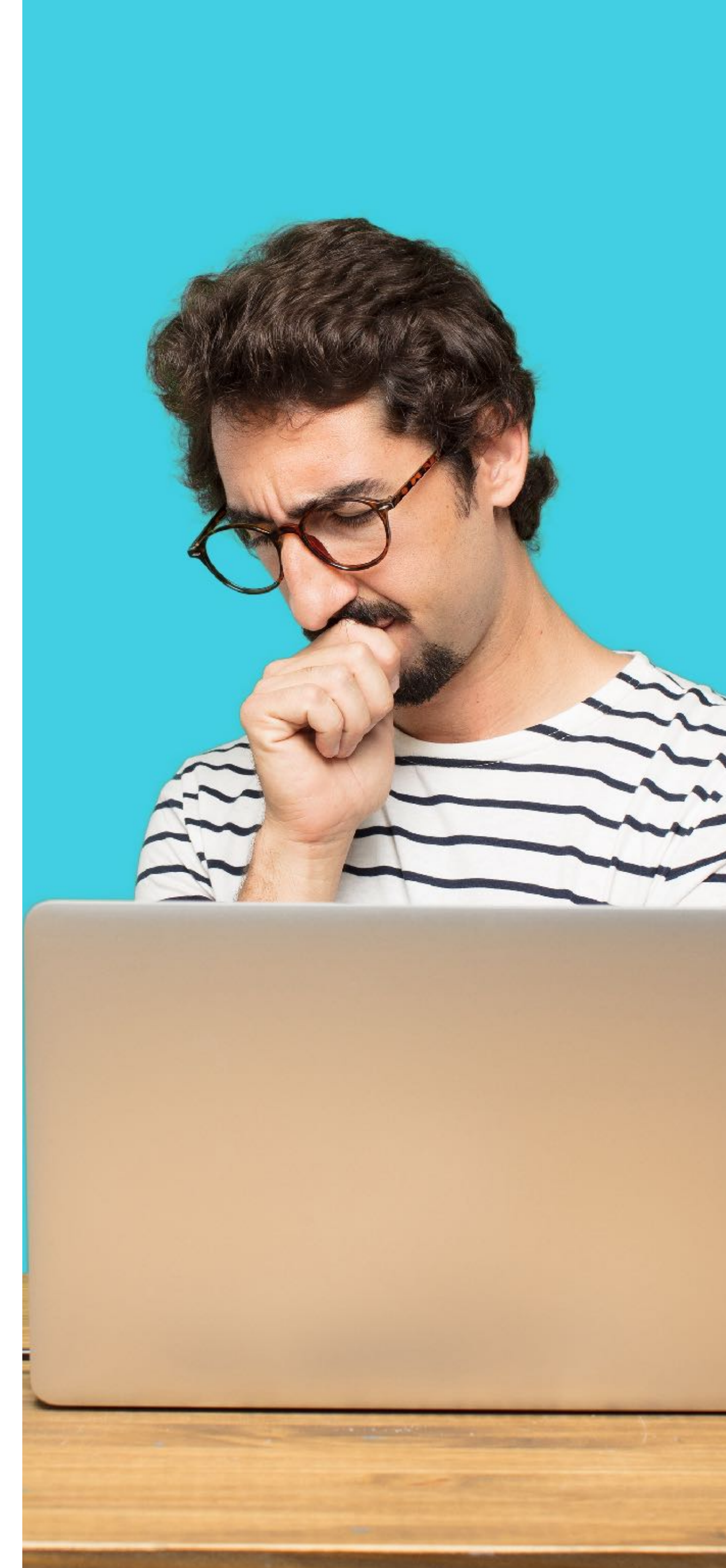
TCP MD5



Limitations of TCP MD5

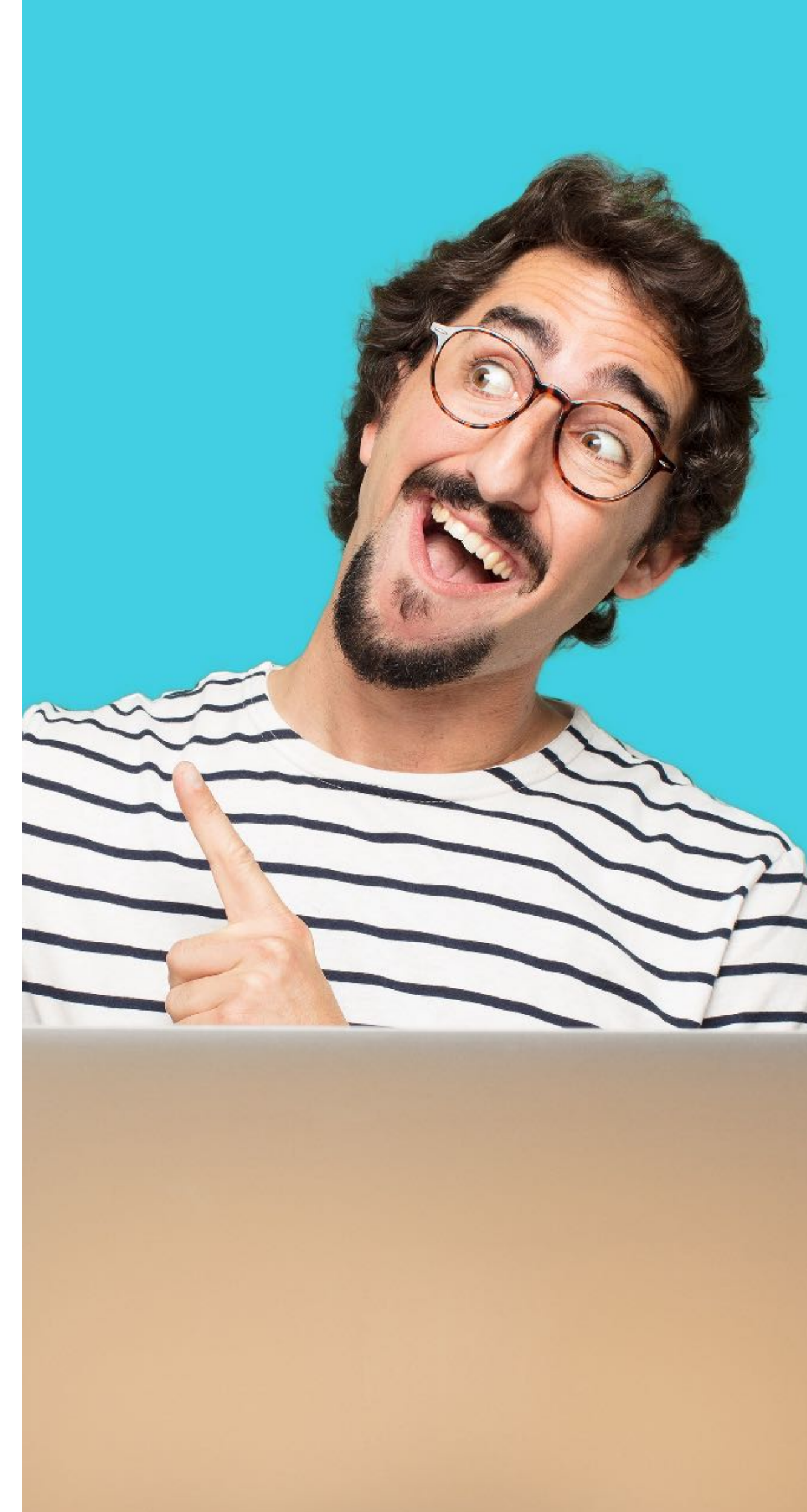
- Not a strong authentication mechanism
 - Supports only MD5 algorithm
- Doesn't allow dynamic key rollover
 - Changing pre-shared keys requires TCP session reset
- Problem for long-lived sessions

It has been obsoleted by TCP-AO and not recommended anymore!



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



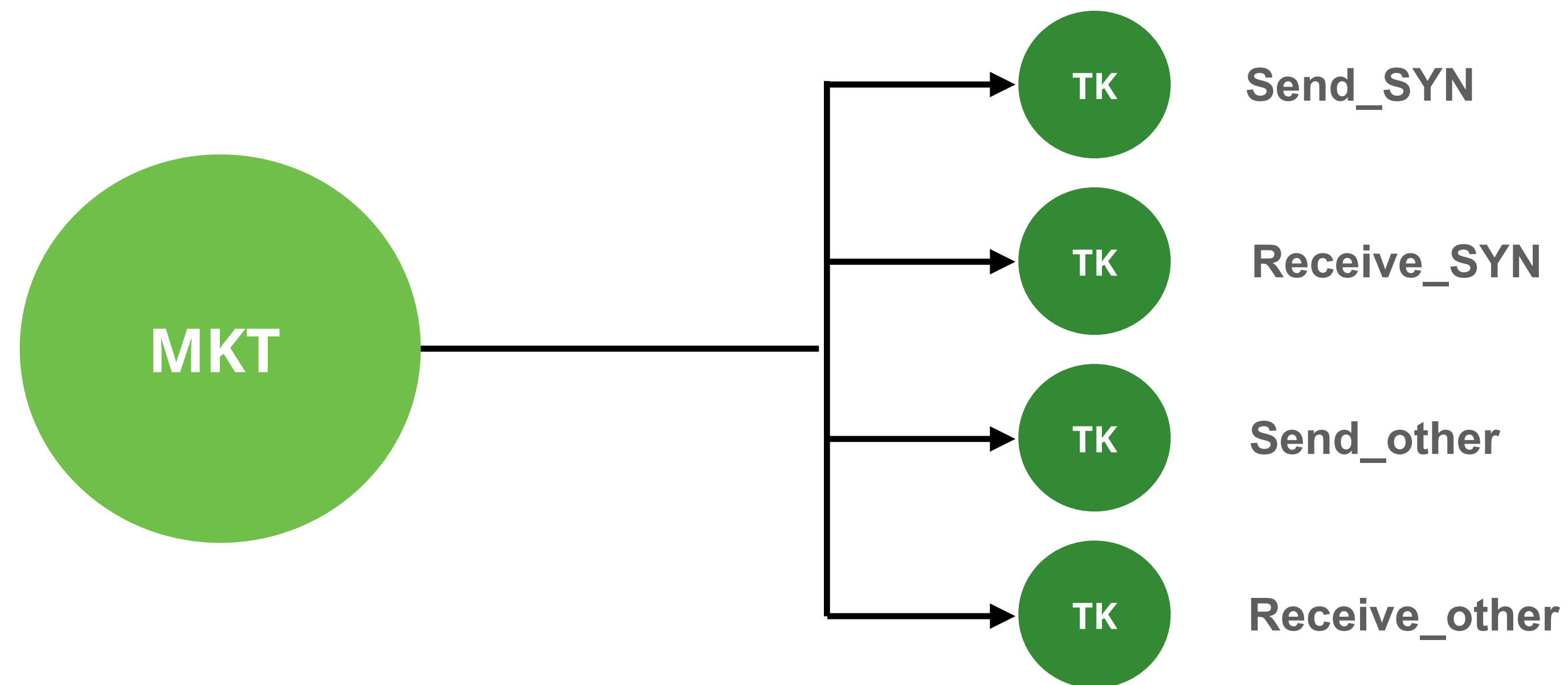
RFC 5925 - "The TCP Authentication Option"

RFC 5926 - "Cryptographic Algorithms for the TCP-AO"

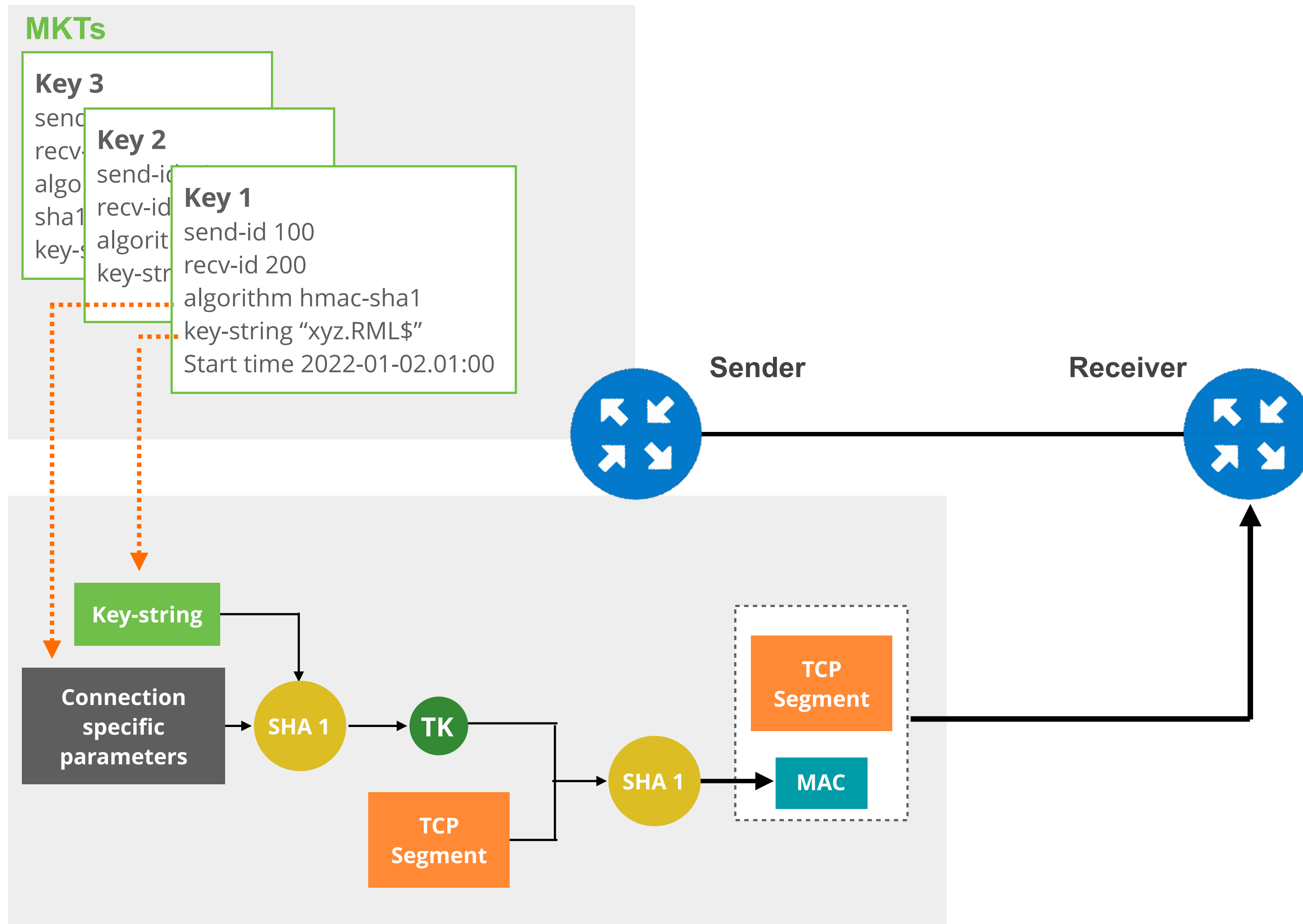


TCP-AO

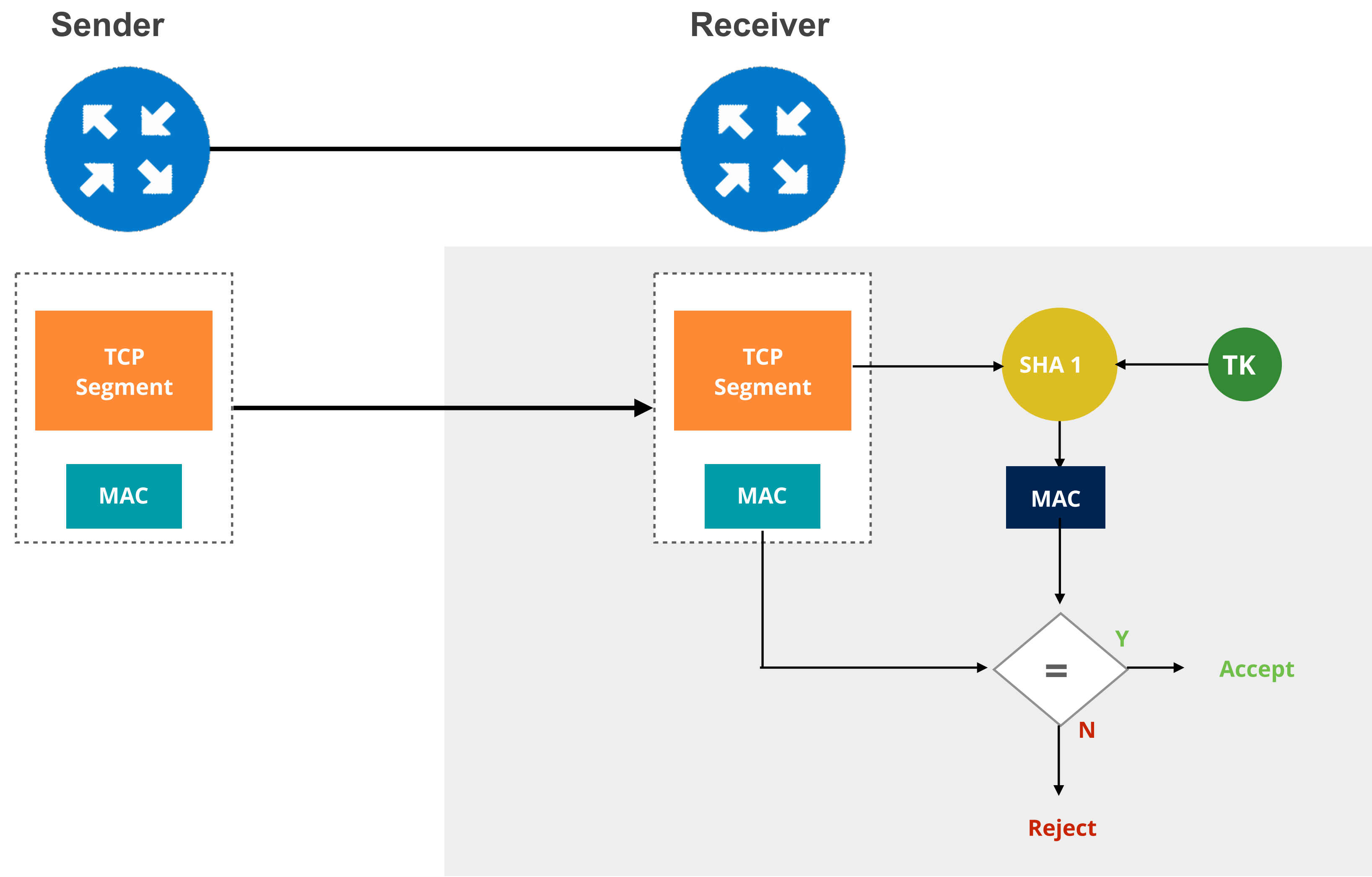
- Two sets of keys to authenticate incoming and outgoing segments:
 - **Master Key Tuples (MKTs)** (key-chain) and **Traffic keys**
- Four traffic keys are derived from each **MKT**



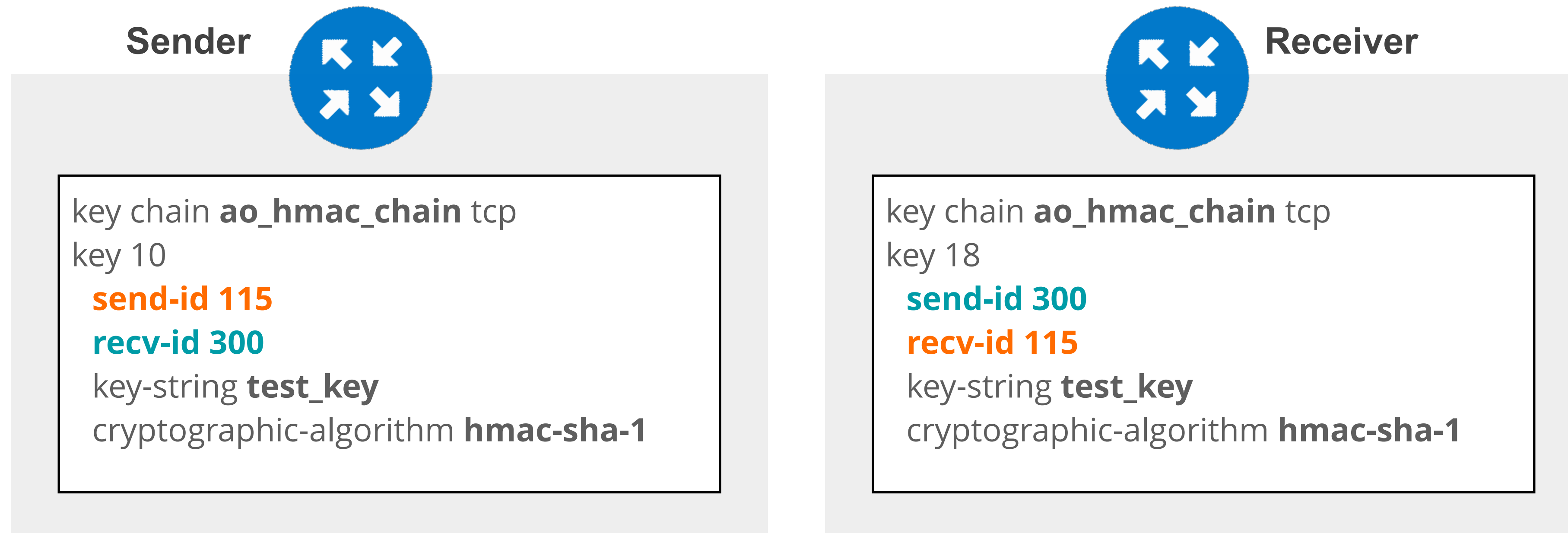
How Does it Work?



How Does it Work?



TCP AO Configuration



- 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

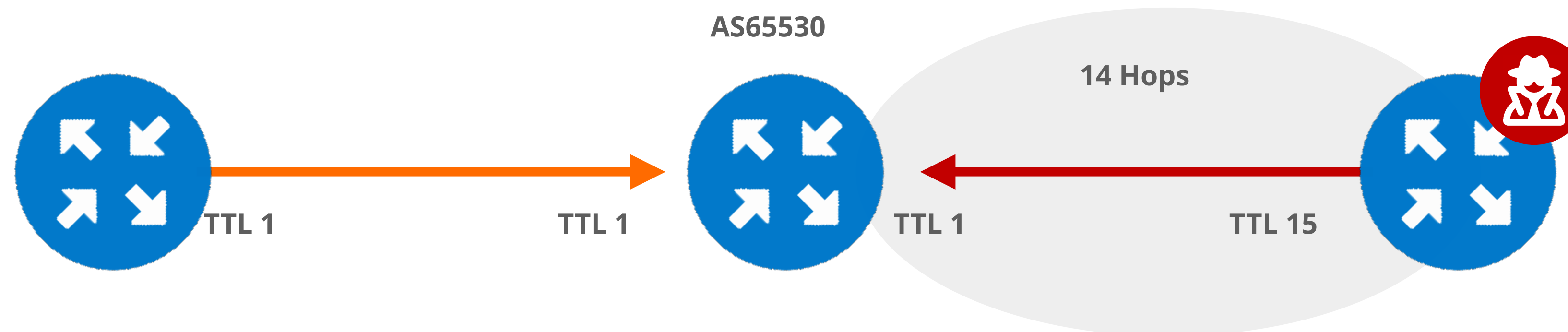
```
(config)# router bgp 65530
(config-keychain-tcp)# neighbour <peer-IPv4/IPv6-address> ao <keychain-name>
[include-tcp-options]
```

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)

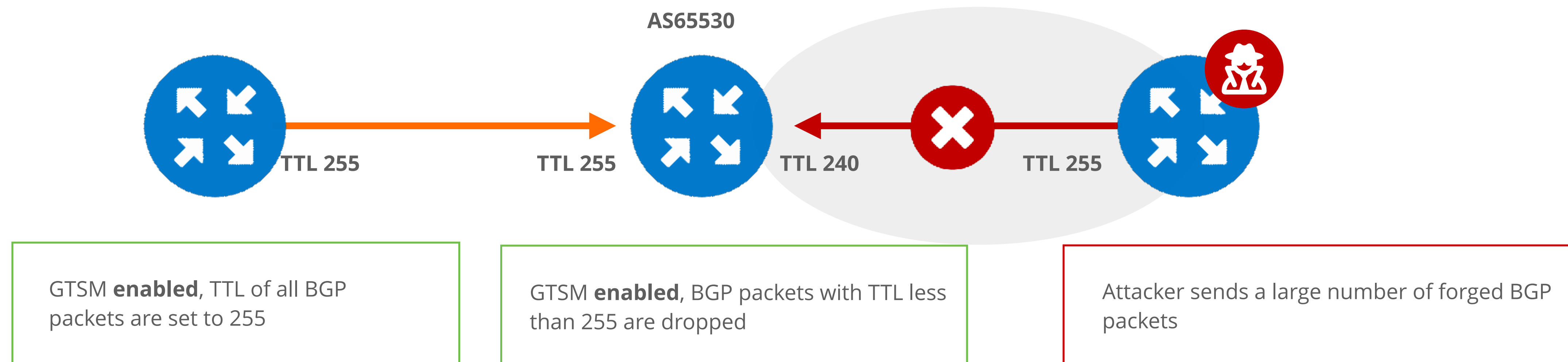


Attacker sends a large number of forged BGP packets



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





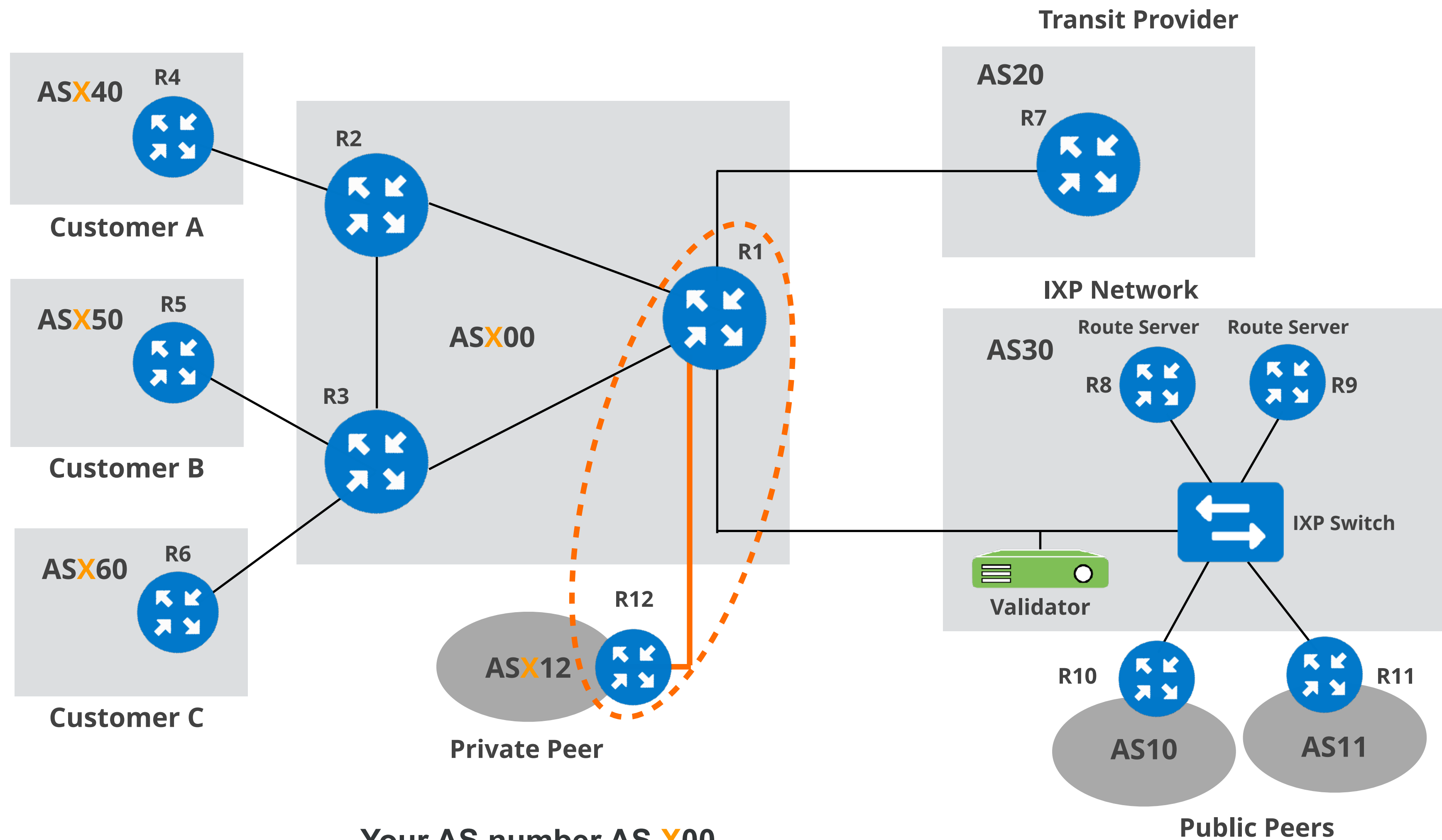
Questions



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



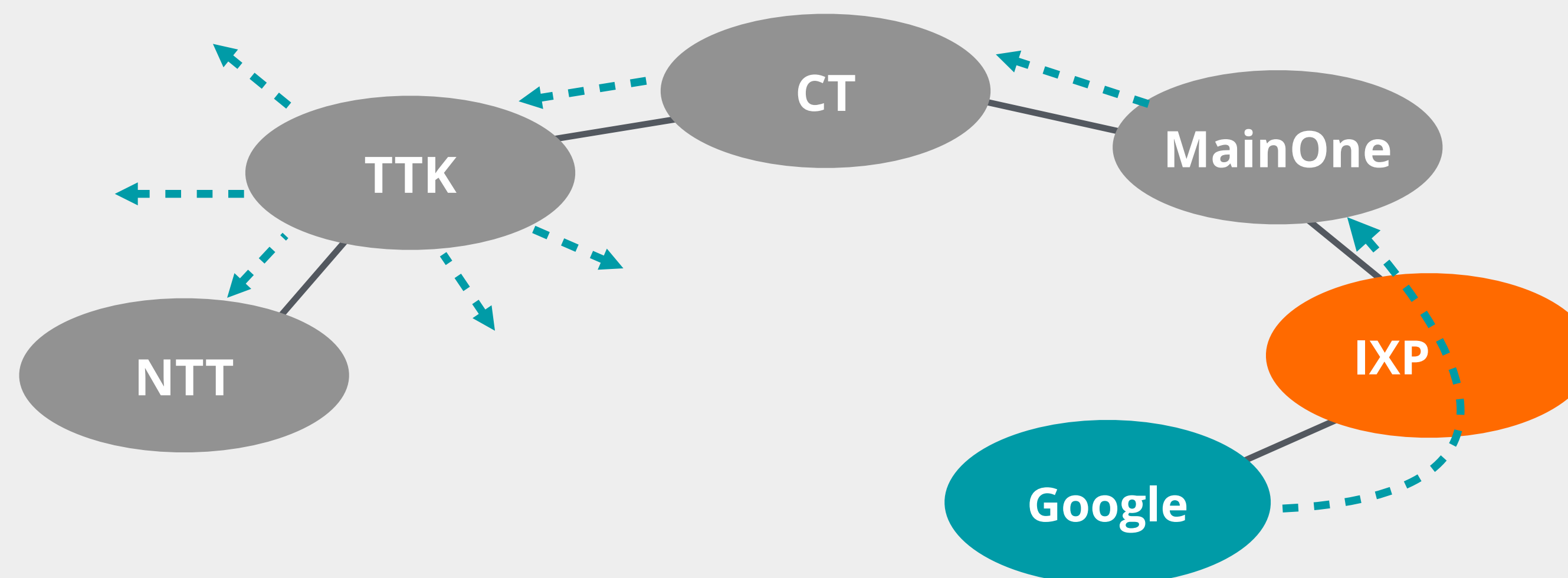
“The propagation of BGP announcements beyond their intended scope” [RFC7908]

- 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

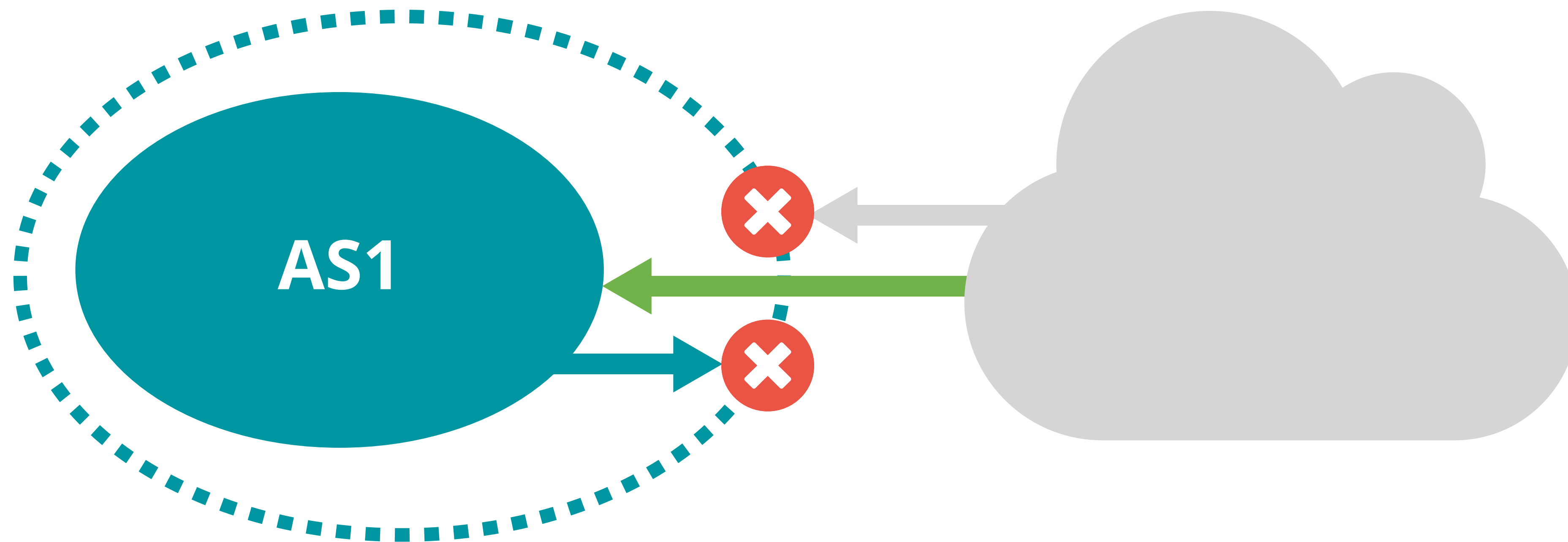
- What happened?
- MainOne leaked Google routes to CT and CT leaked them to other transits
 - Google services (G Suite and Google Search) affected by the leak
- Why?
 - Due to misconfigured filters



How to Prevent Route Leaks?



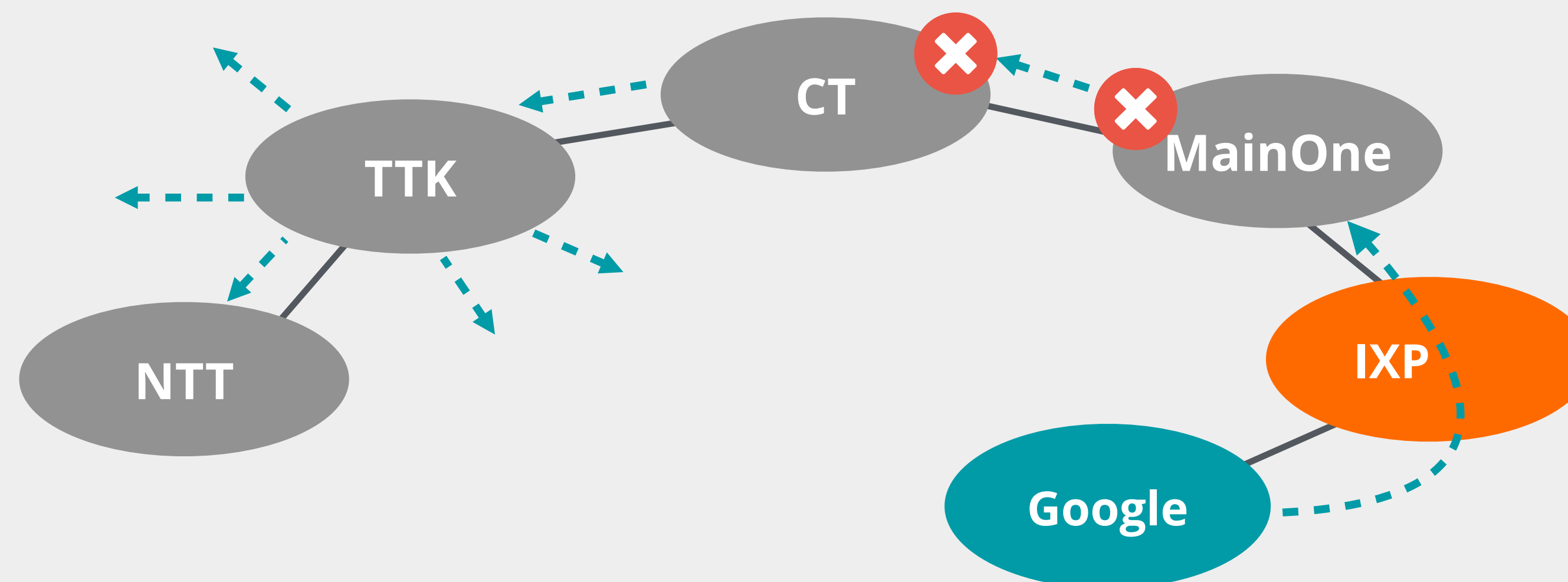
Route filtering is the most powerful mechanism!





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!





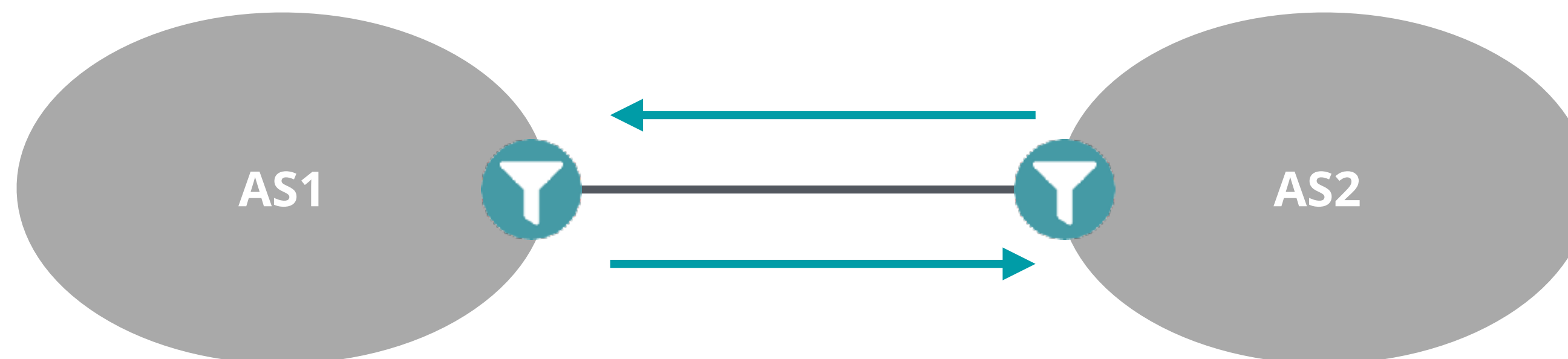
Other Reasons for Filtering

- **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)

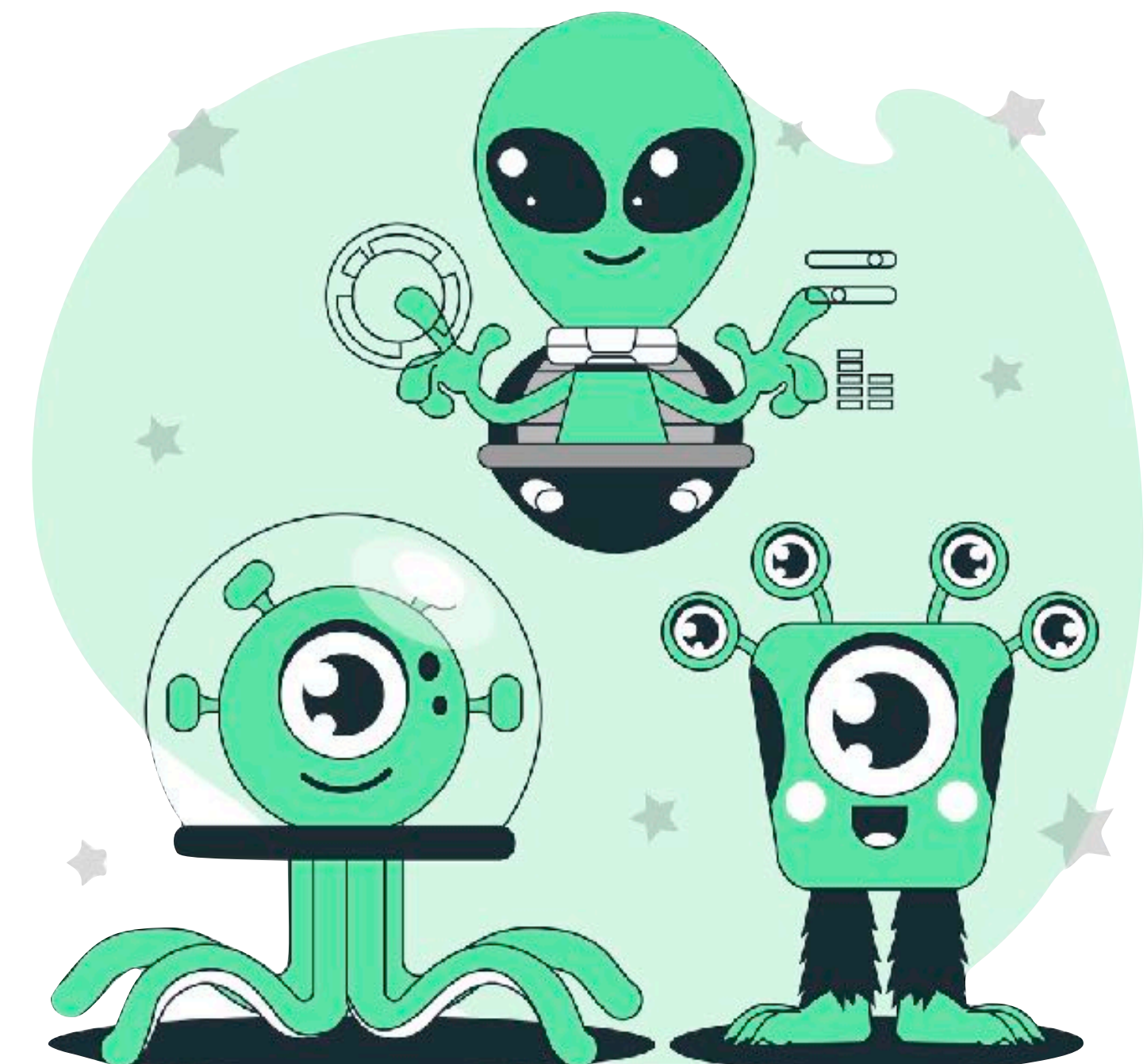
RFC 7454 - "BGP Operations and Security"

- 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



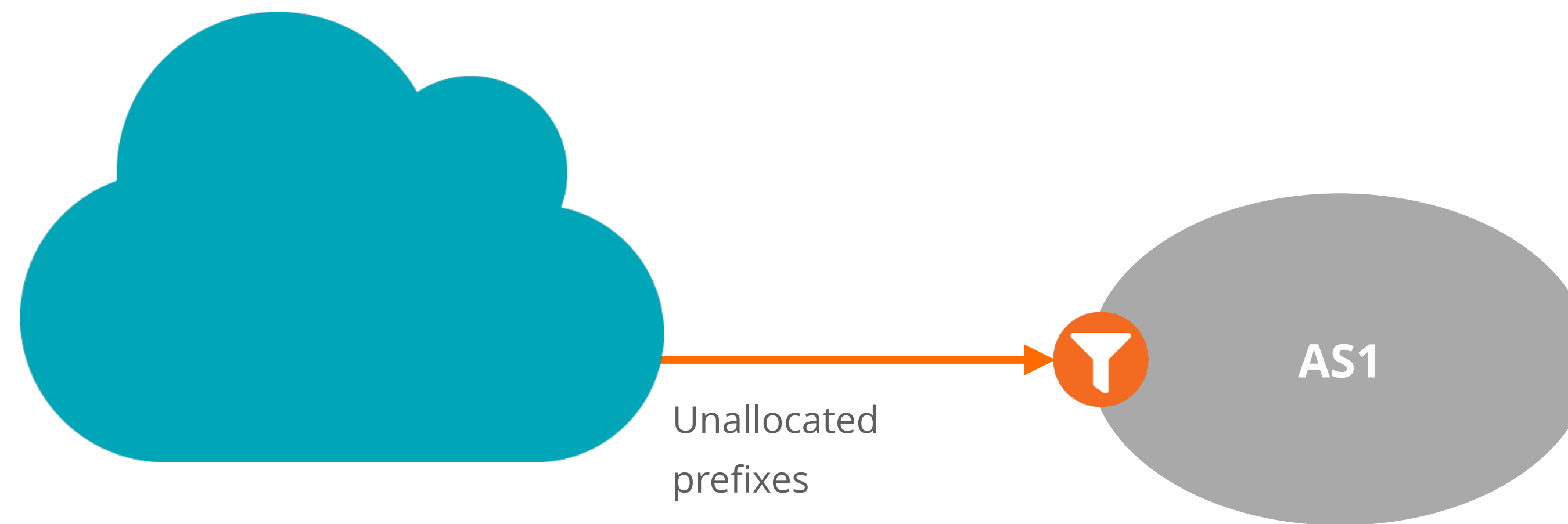
<http://www.iana.org/assignments/iana-ipv4-special-registry>

<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 assigned by an RIR to end-users
- Filtering unallocated prefixes requires regular update





Longest Accepted Prefixes

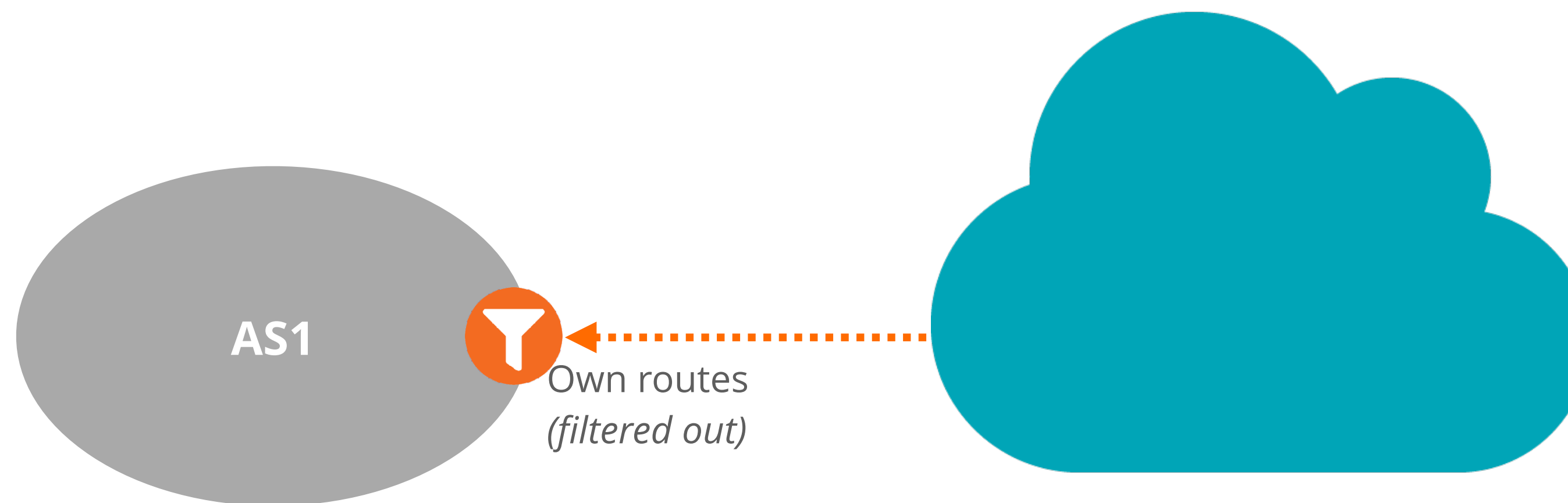
- **Smaller prefixes should not be a part of global routing!**
 - /24 for IPv4 (*RIPE-399*)
 - /48 for IPv6 (*RIPE-532*)
- Those prefixes are generally neither announced nor accepted on the Internet

```
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





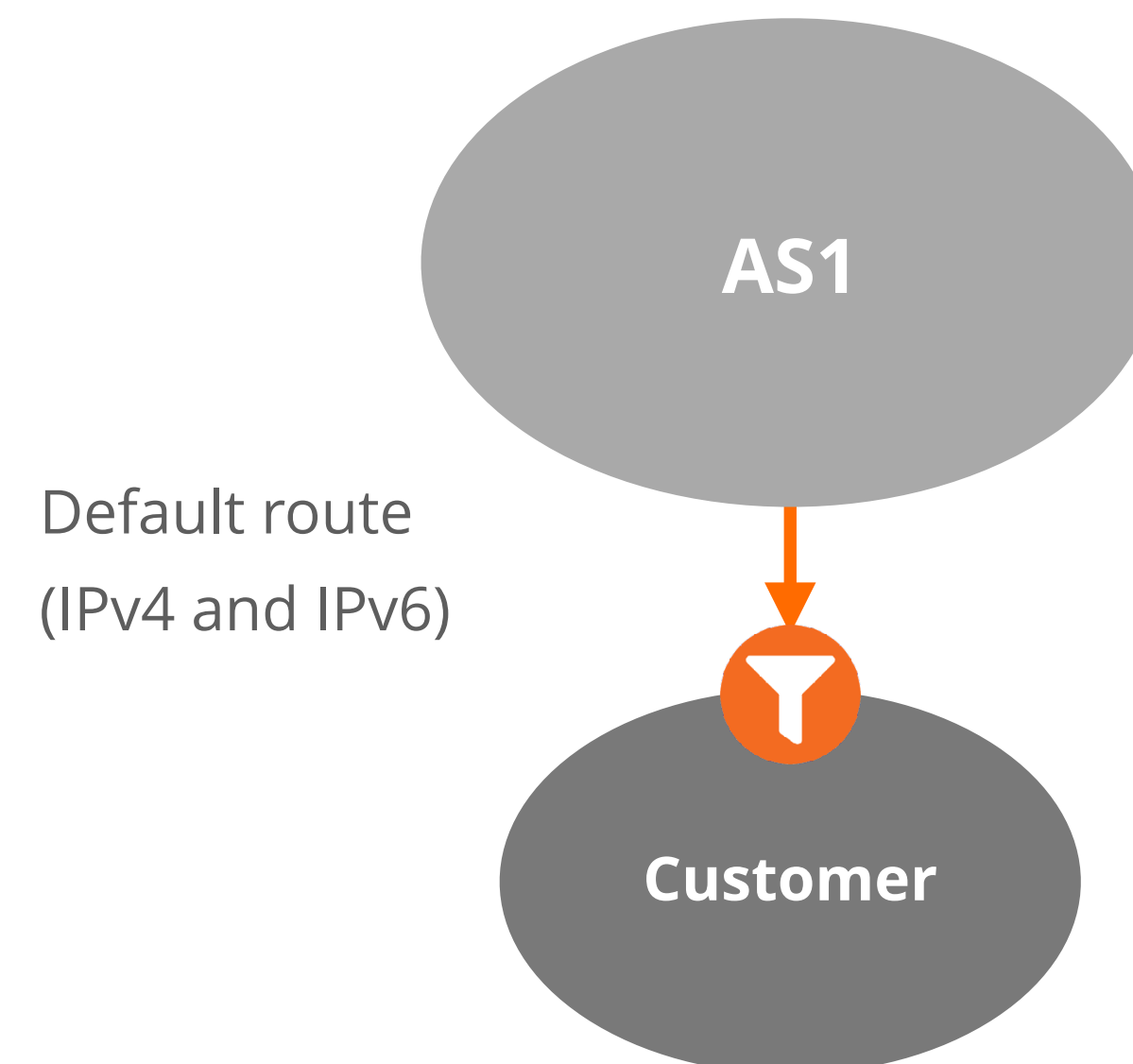
IXP LAN Prefixes

- 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

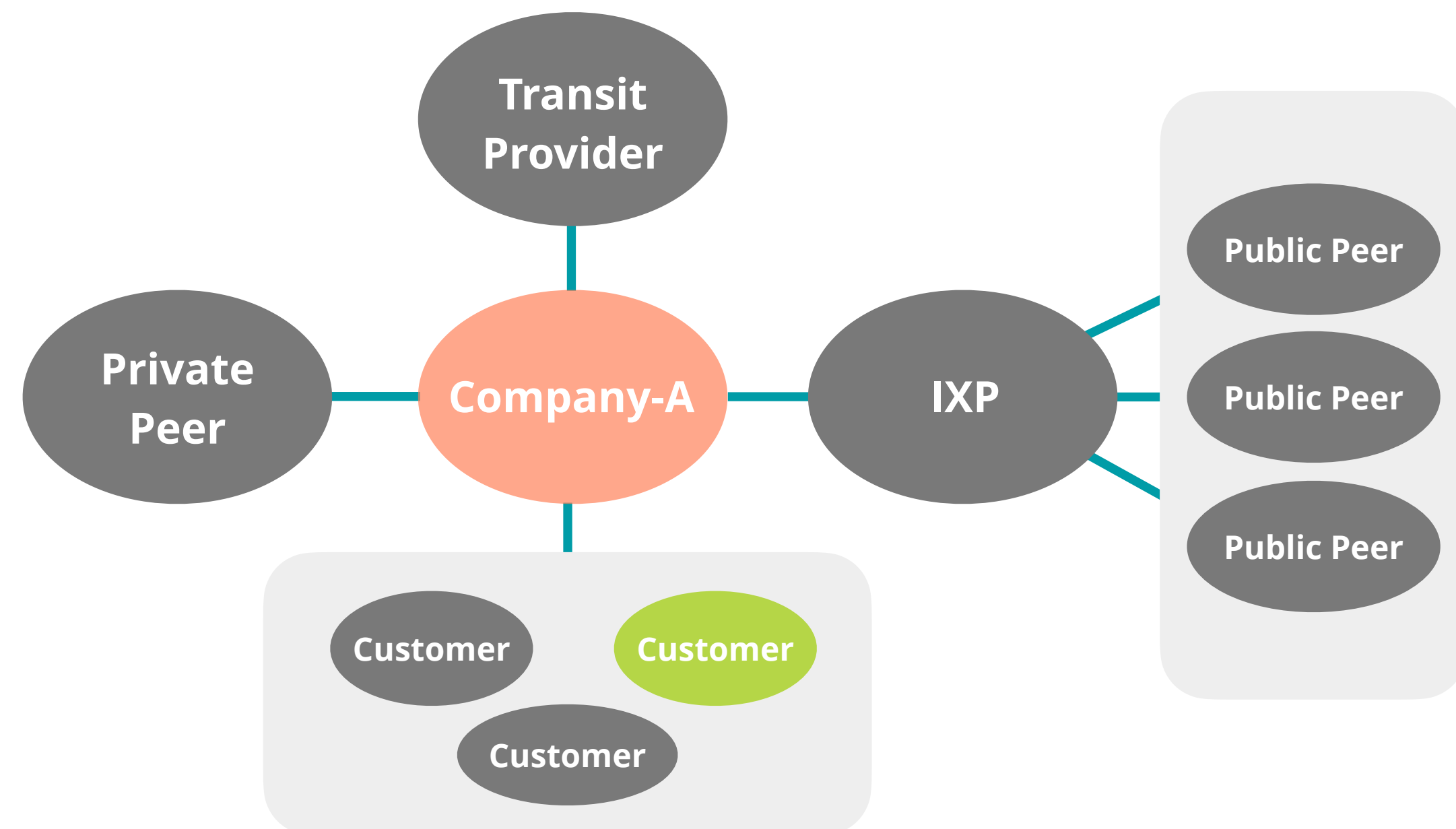
- **0.0.0.0/0** (IPv4) and **::/0** (IPv6)
- Advertised or accepted only in specific customer-provider peering relationships
 - E.g. customer with stub network
- Should be **rejected** unless a special peering agreement is in place





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

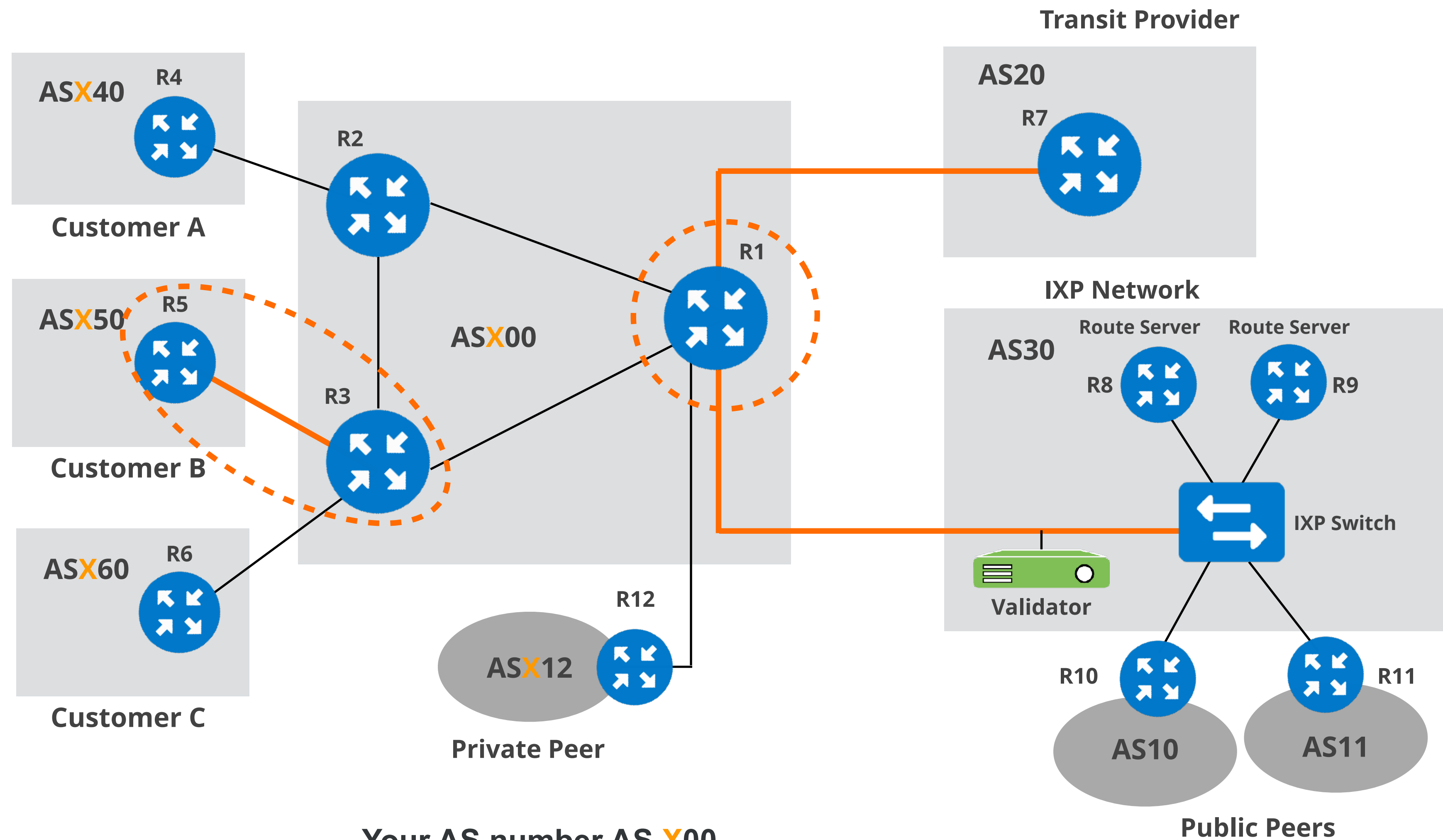


40 min



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

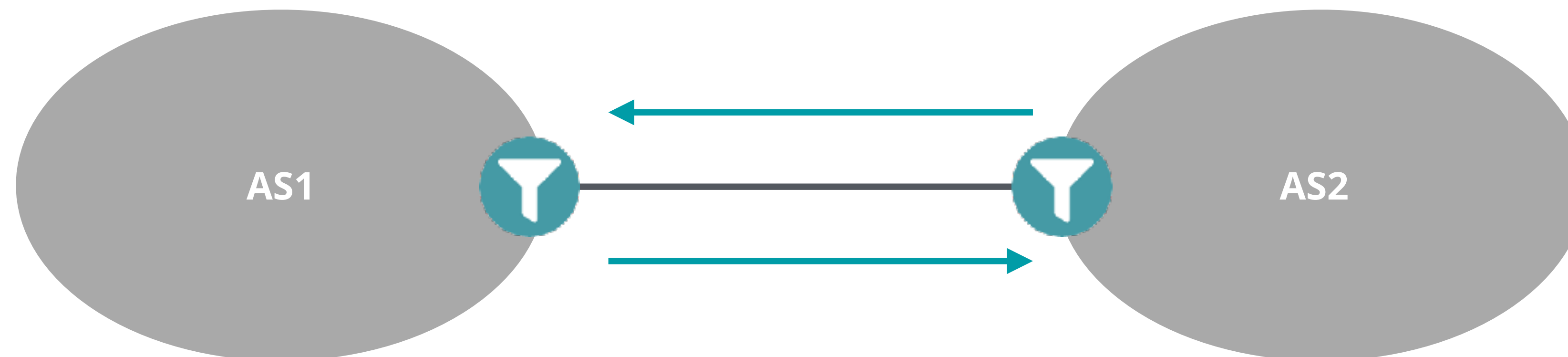


Your AS number AS X00
Your IPv6 allocation 2001:db8:X00::/48



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

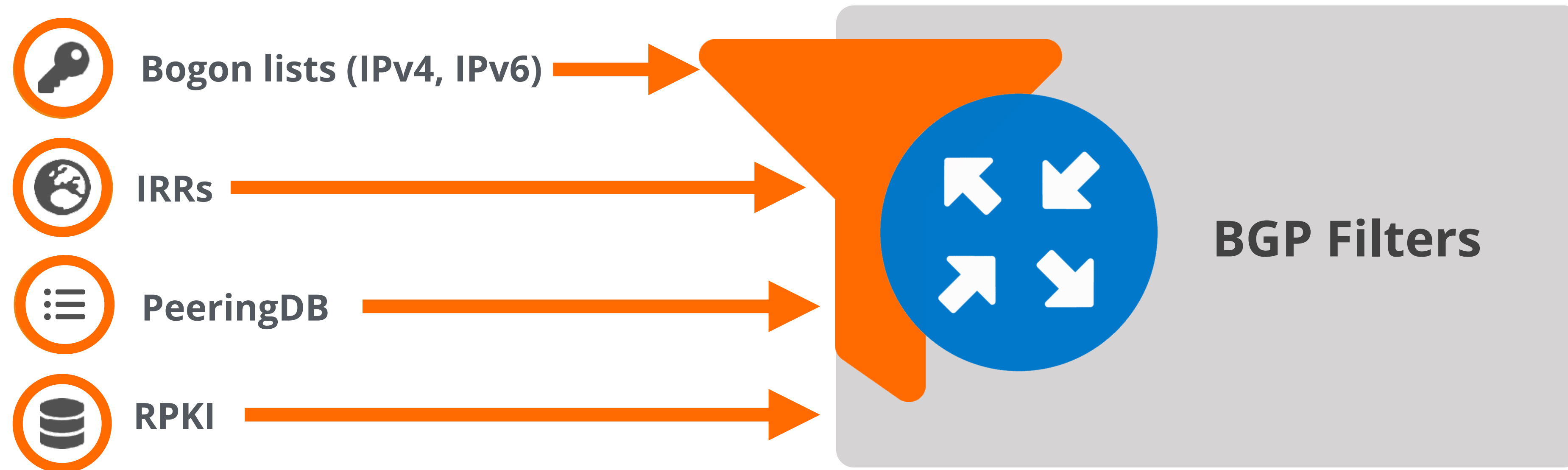


BOGON ASN filtering



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



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	<input checked="" type="checkbox"/> Unicast IPv4 <input type="checkbox"/> Multicast <input checked="" type="checkbox"/> IPv6 <input type="checkbox"/> 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	<input checked="" type="checkbox"/>
AMS-IX 80.249.208.71	3333 2001:7f8:1::a500:3333:2	10G	<input checked="" type="checkbox"/>
NL-ix 193.239.117.25	3333 2001:7f8:13::a500:3333:1	10G	<input checked="" type="checkbox"/>
NL-ix 193.239.118.84	3333 2001:7f8:13::a500:3333:2	10G	<input checked="" type="checkbox"/>

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



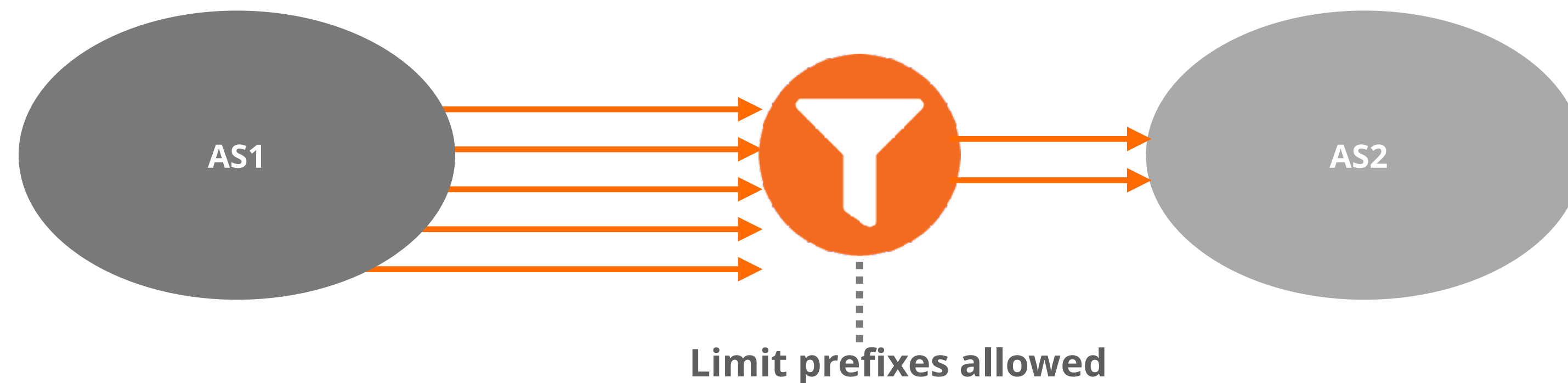
BGP Security

<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





Questions



Lab 3 - Filtering AS-Path and Number of Prefixes

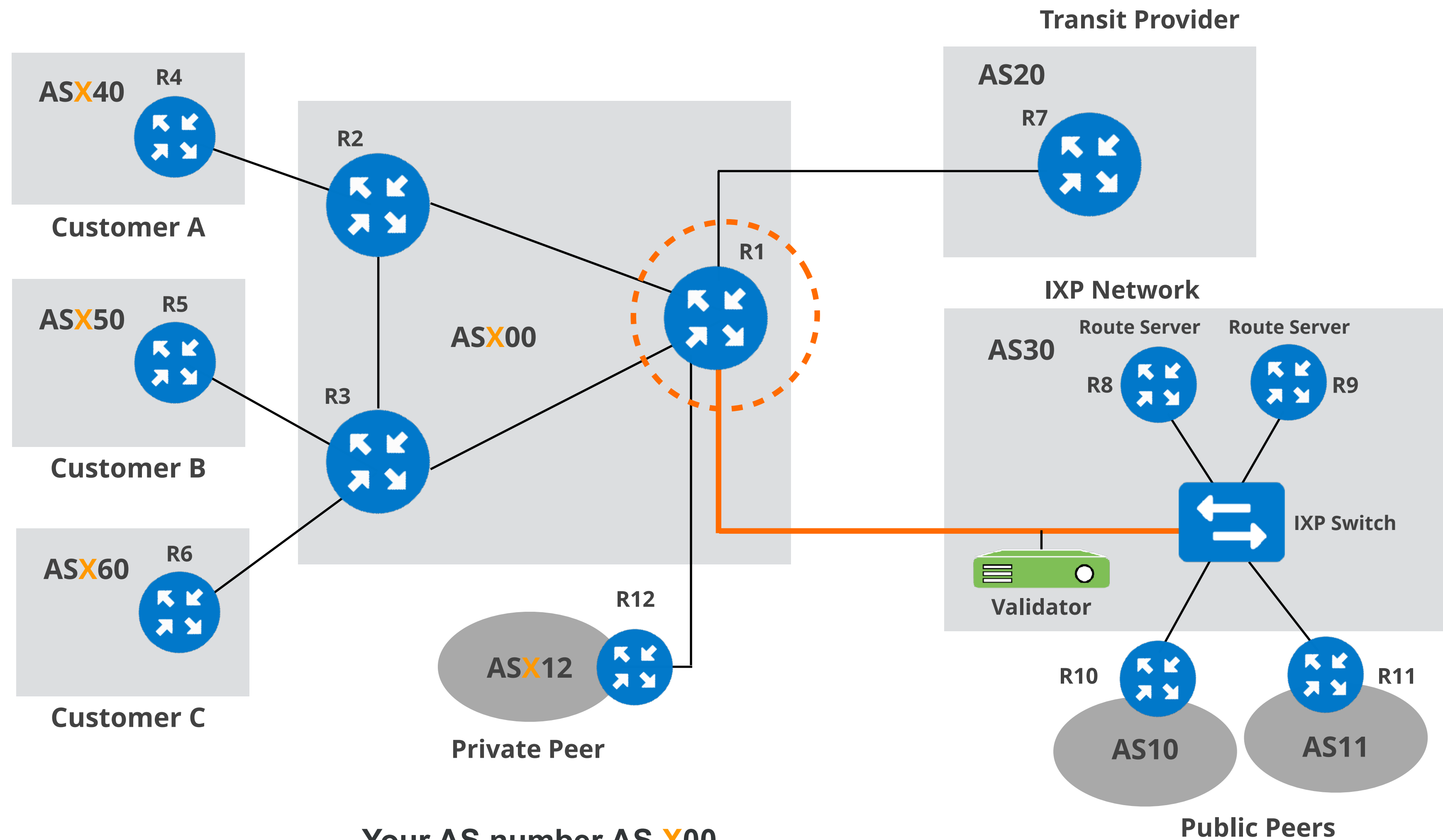


20 min



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



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

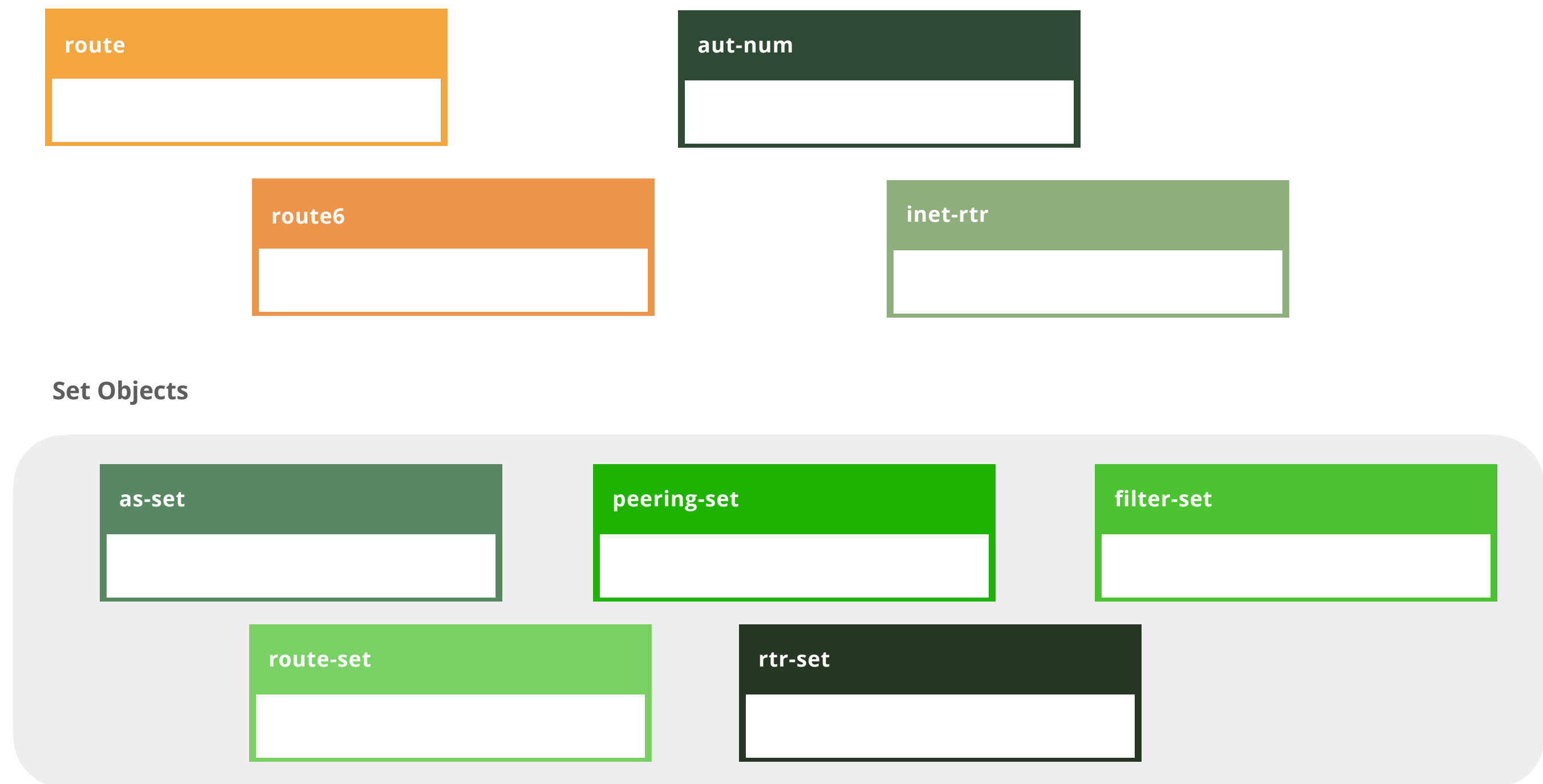


- Many transit providers and IXPs **require** it
 - They build their filters based on the Routing Registry



The RIPE Routing Registry

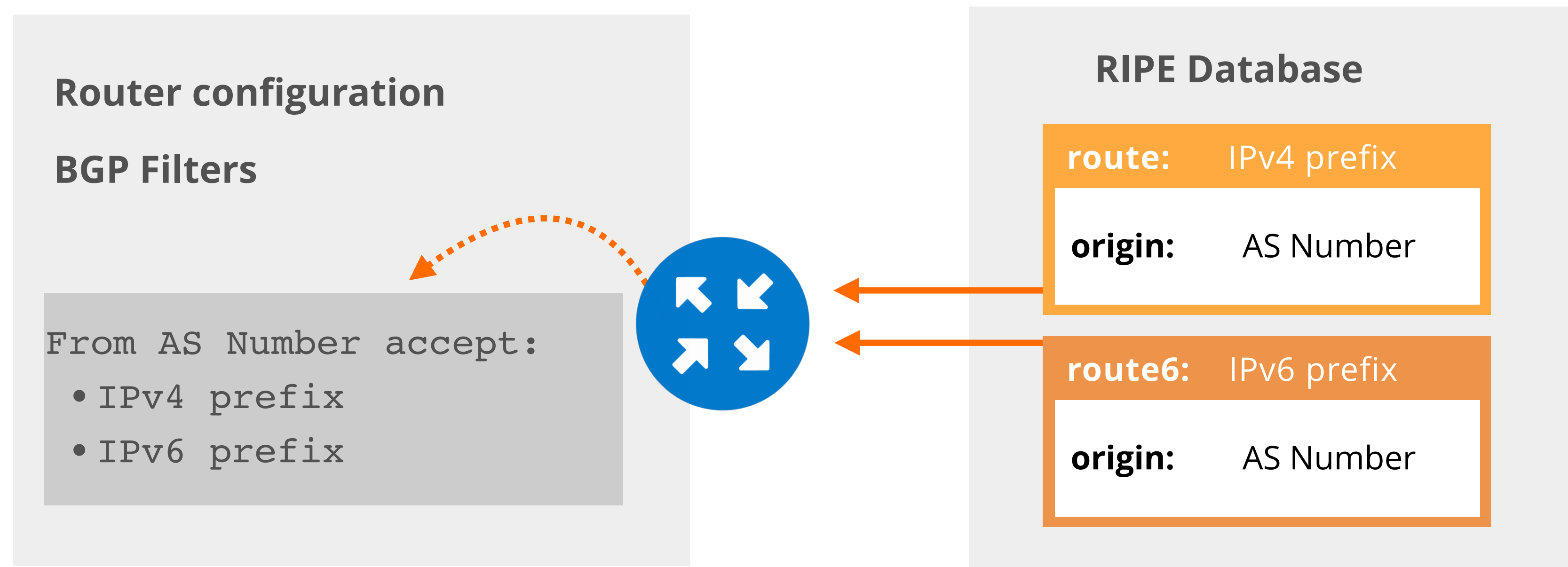
- A subset of the RIPE Database and part of the global IRR
- Used for registering **routing policy information**
- Includes several objects





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

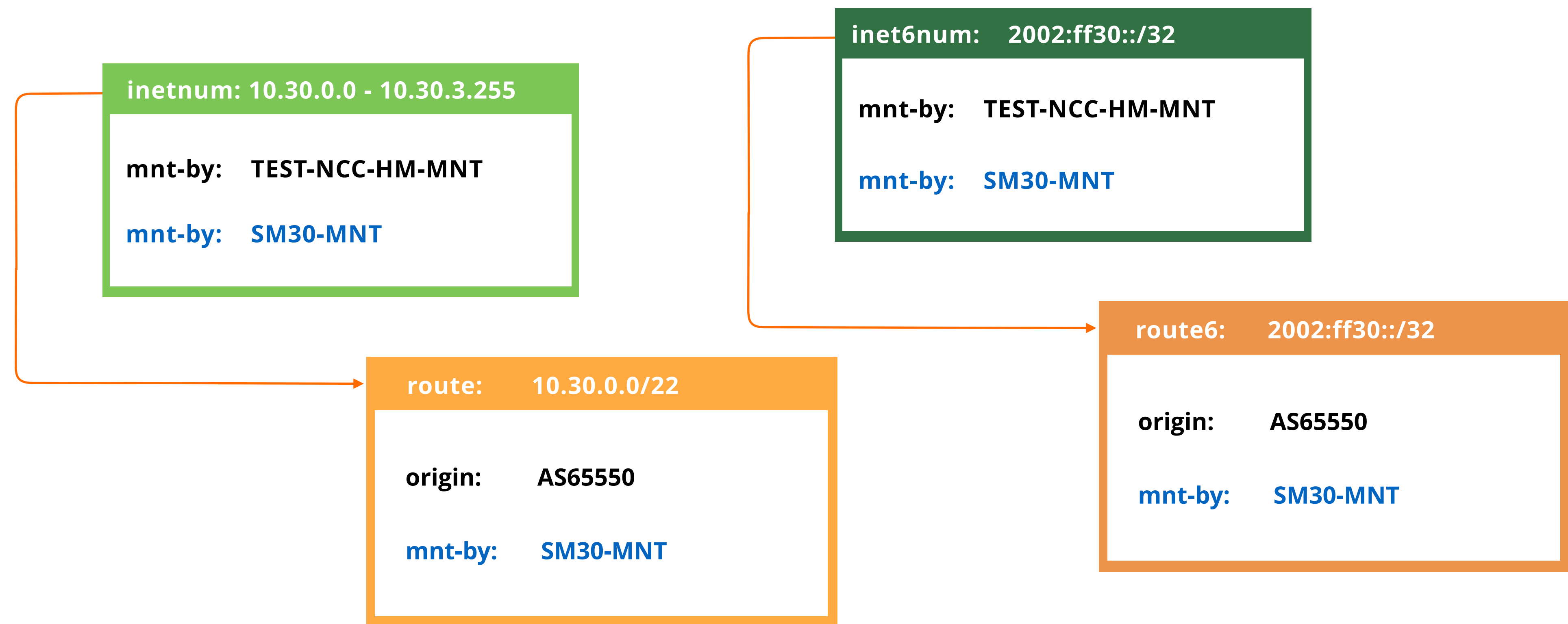
2

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 AS64494 accept ANY
export: to AS64494 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

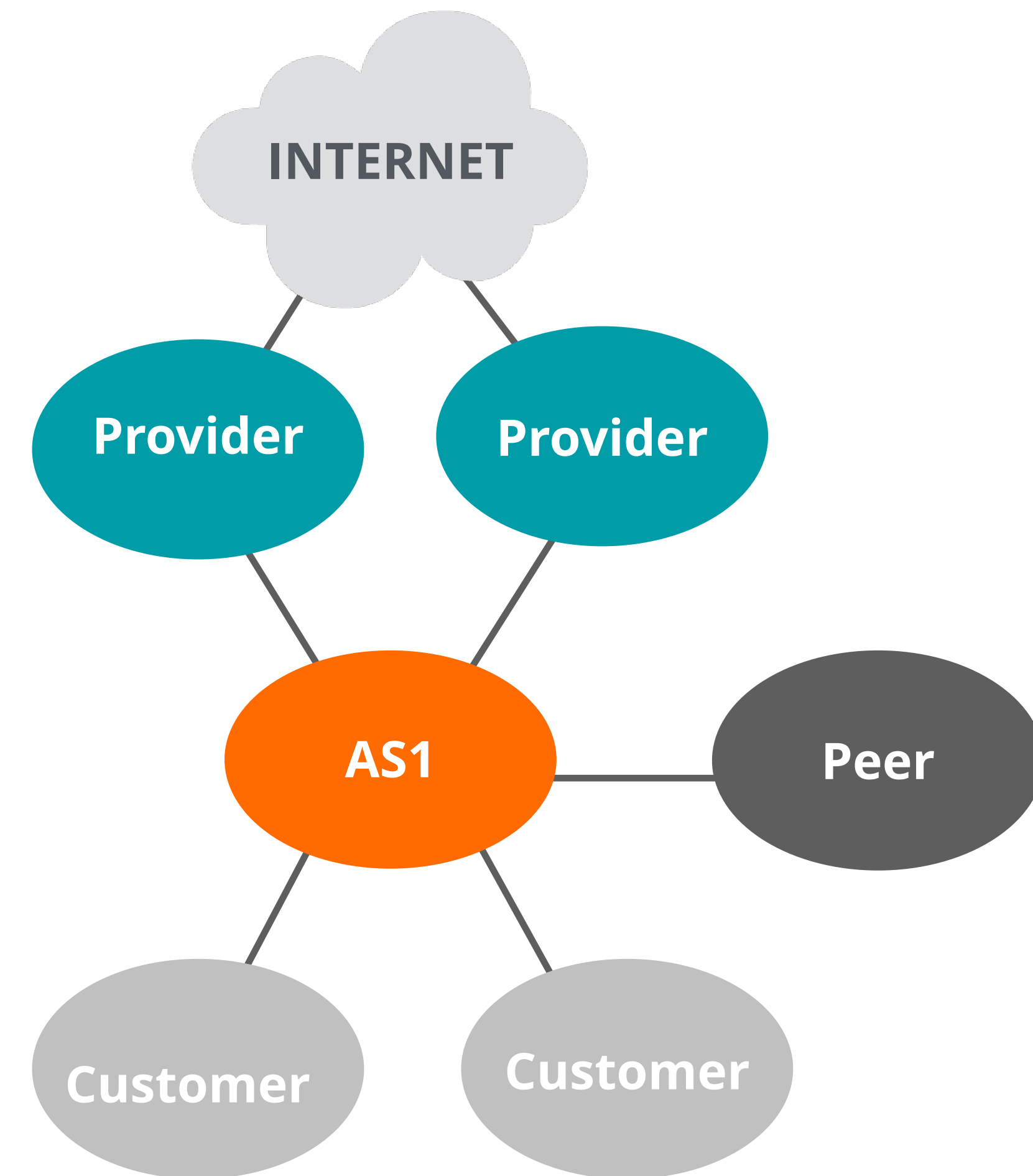
Defines the routing policy for an AS

- **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?





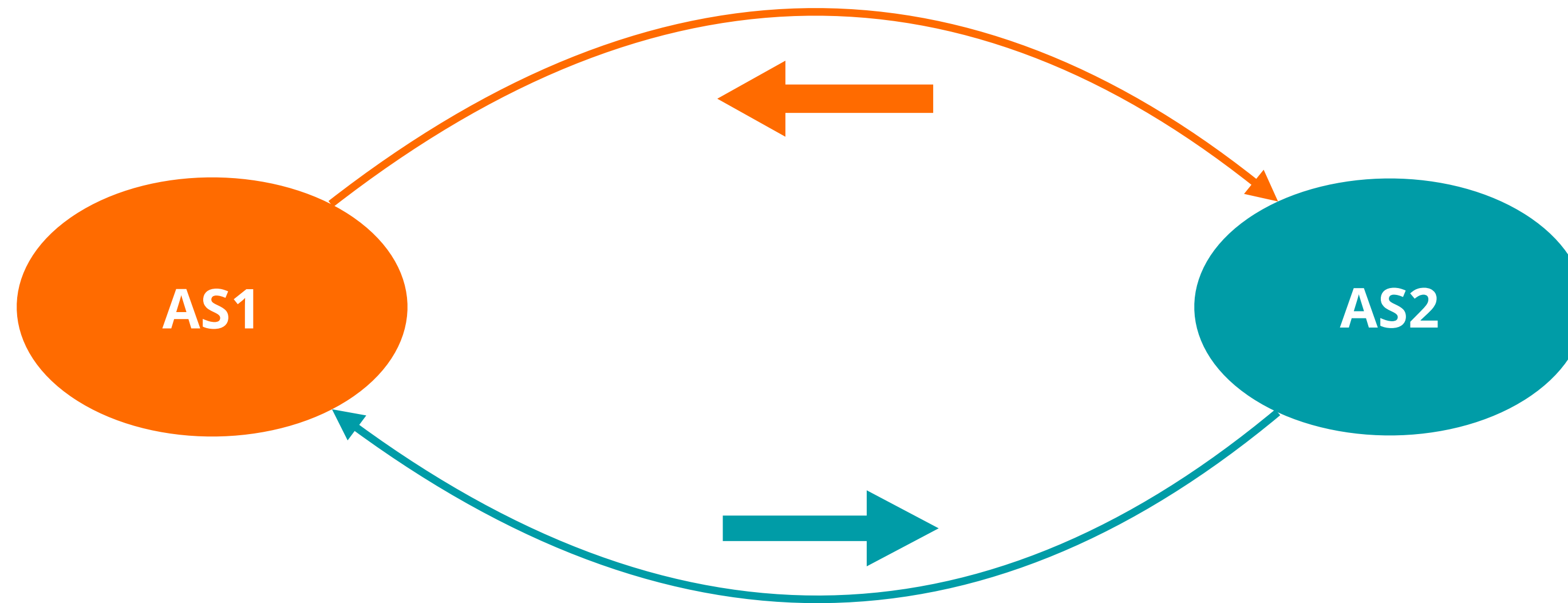
IRRs use RPSL Language

- **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

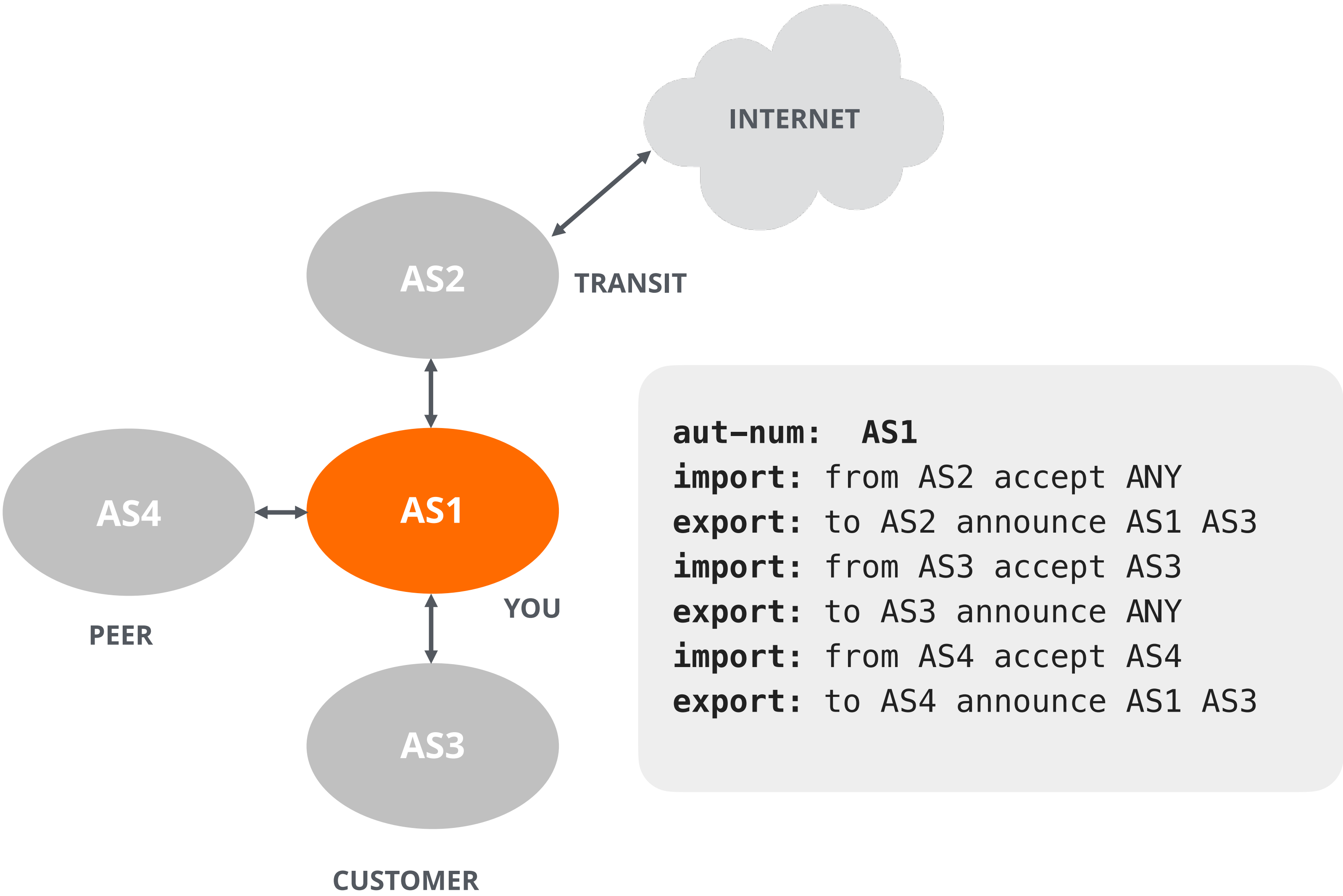
RFC 2650 - Using RPSL in Practice

Defining Routing Policy in RPSL



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

Routing Policy Example





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
```


Tools to check IRR status



Routing Consistency i				
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://irrexplorer.nlnog.net/>

<http://stat.ripe.net>



Reality Check

- The IRR system has limitations
 - Conflicting data, no central authority, no holdship 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



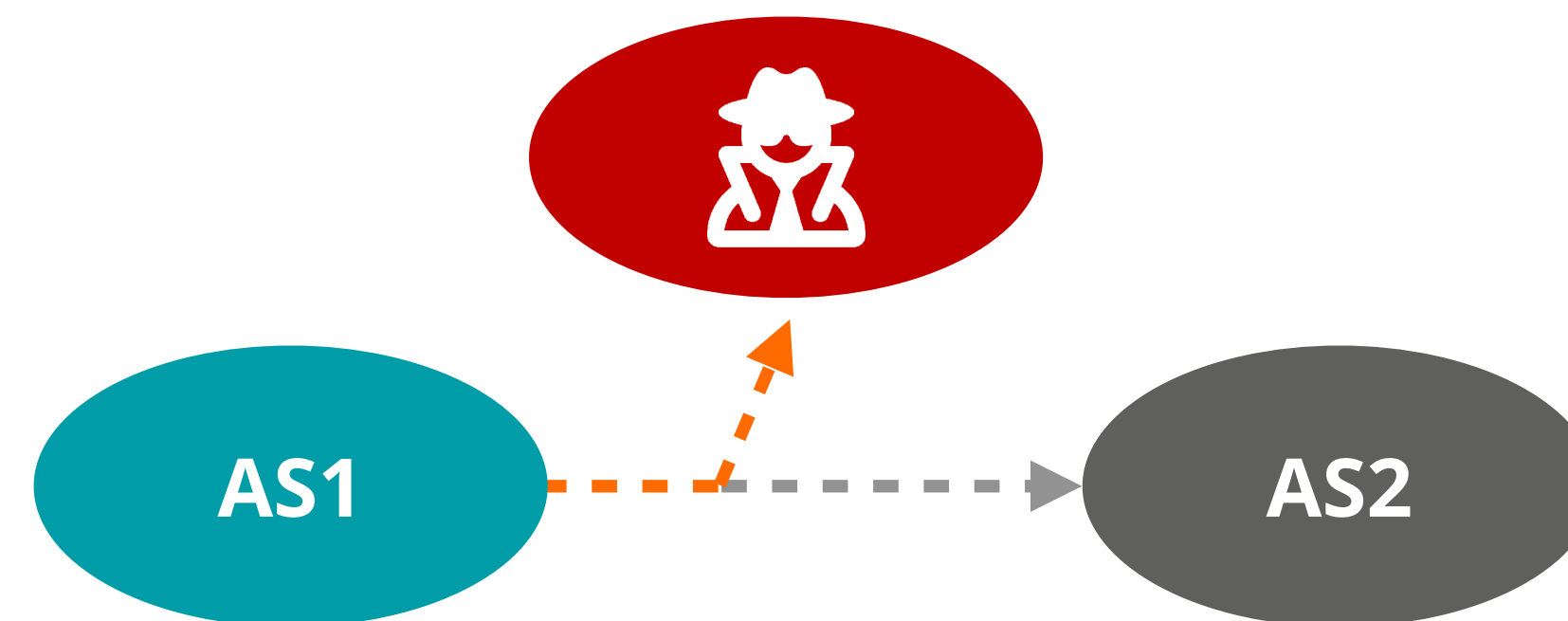
Implementing RPKI

Section 3.5

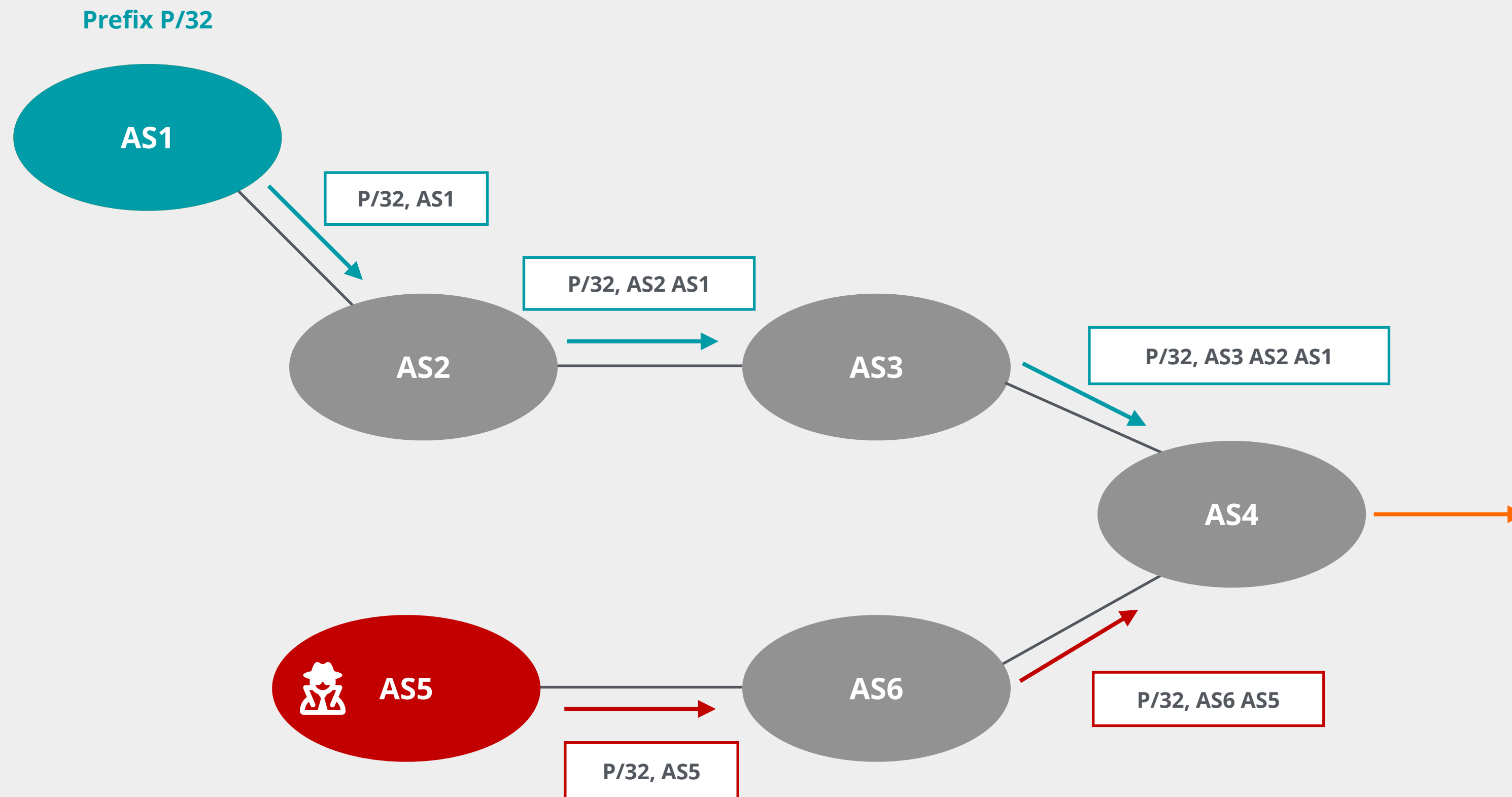


BGP Origin Hijacks

- 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)



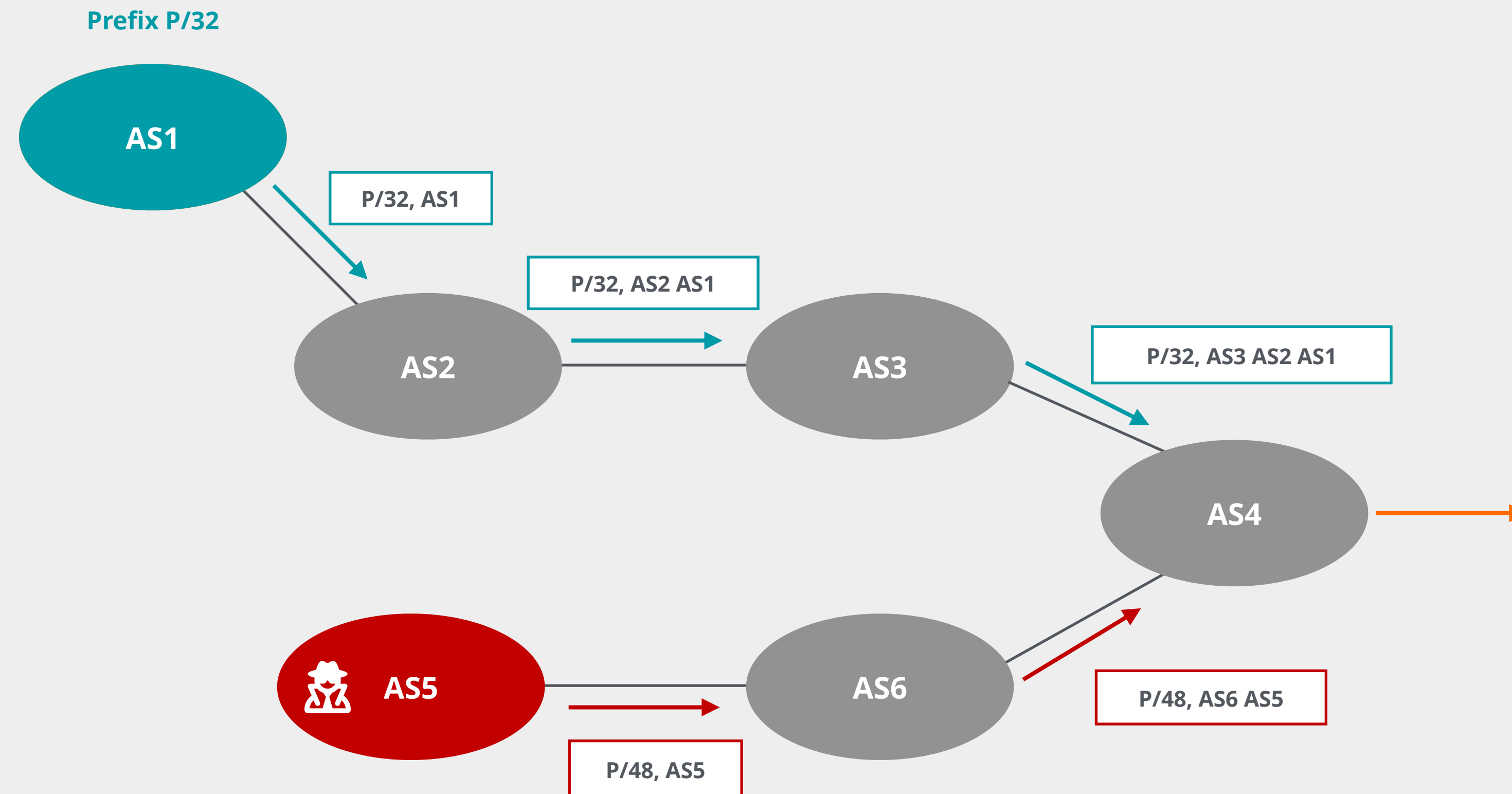
Prefix Hijack



This is a **local hijack**!

Only some networks are affected based on BGP path selection process

Sub-prefix Hijack (Subnet Attack)



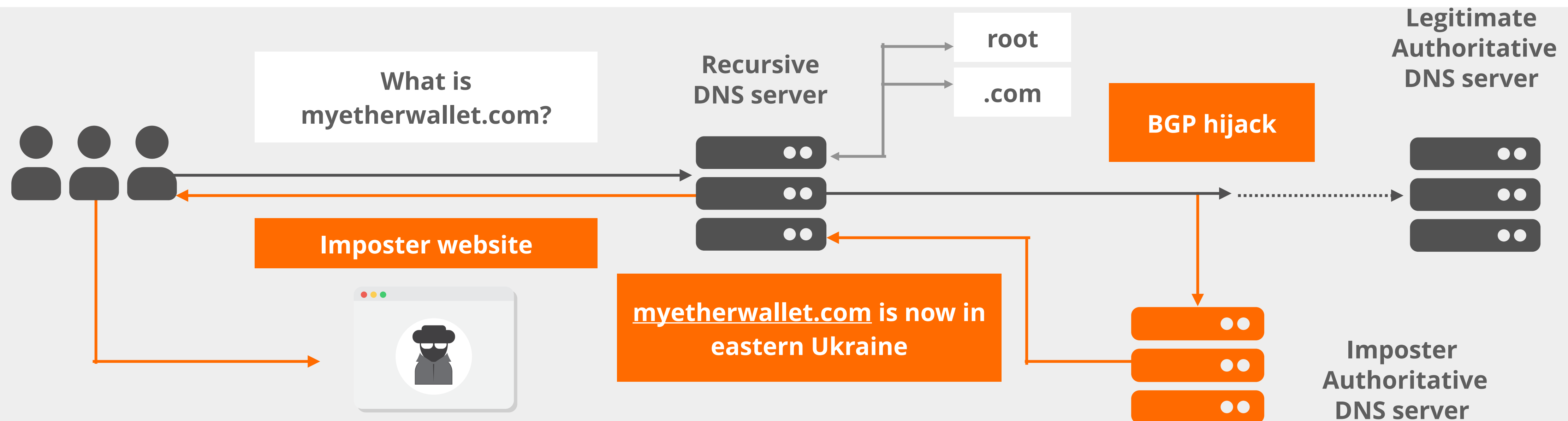
This is a **global hijack!**

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



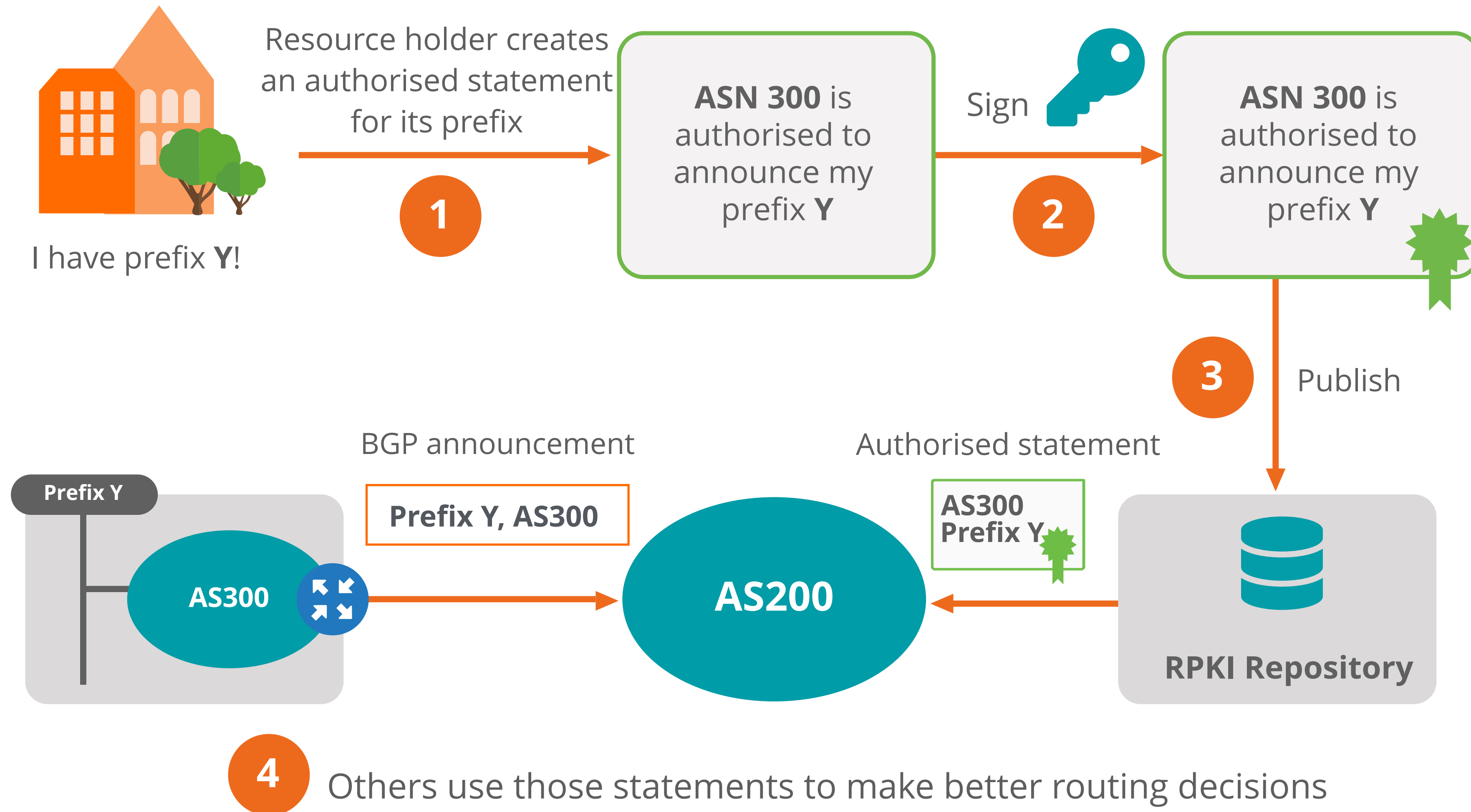


What is RPKI?

- 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**



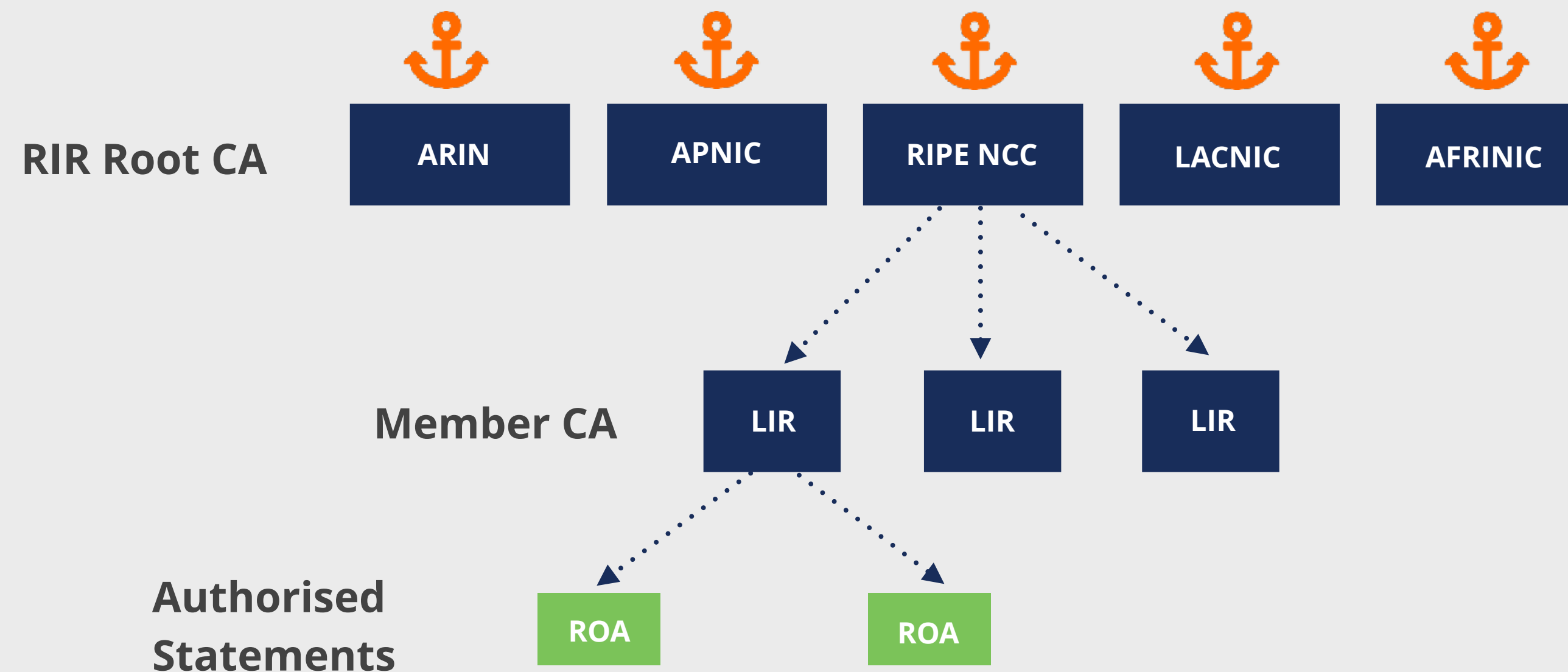
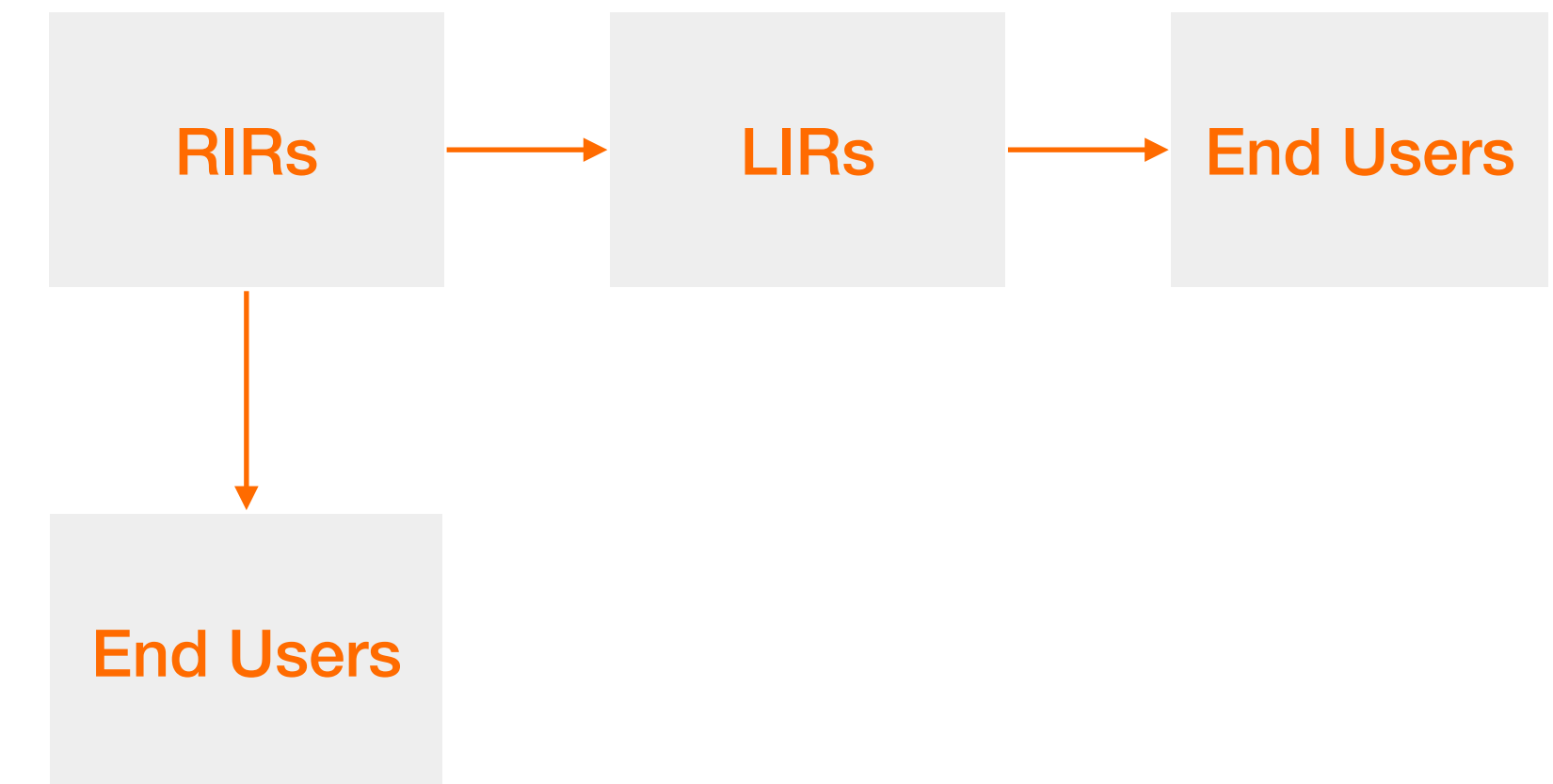
How Does RPKI Work?



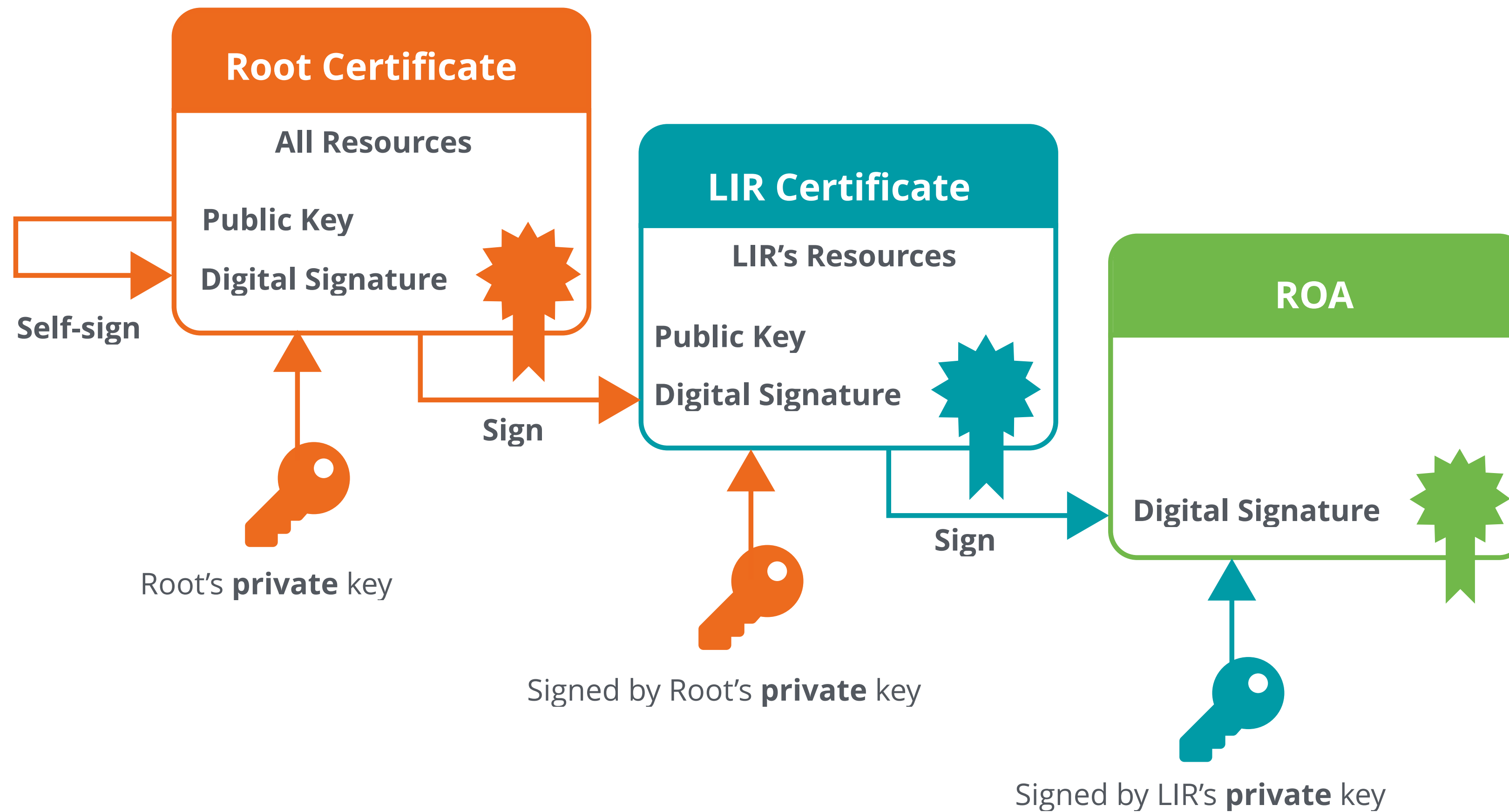
Trust in RPKI



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



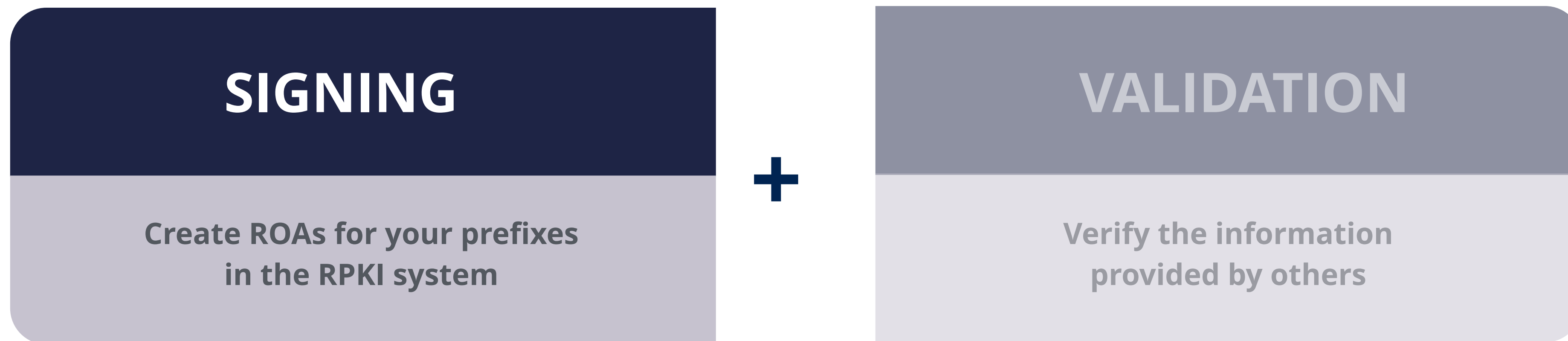
RPKI Chain of Trust





Elements of RPKI

- The RPKI system consists of two parts:

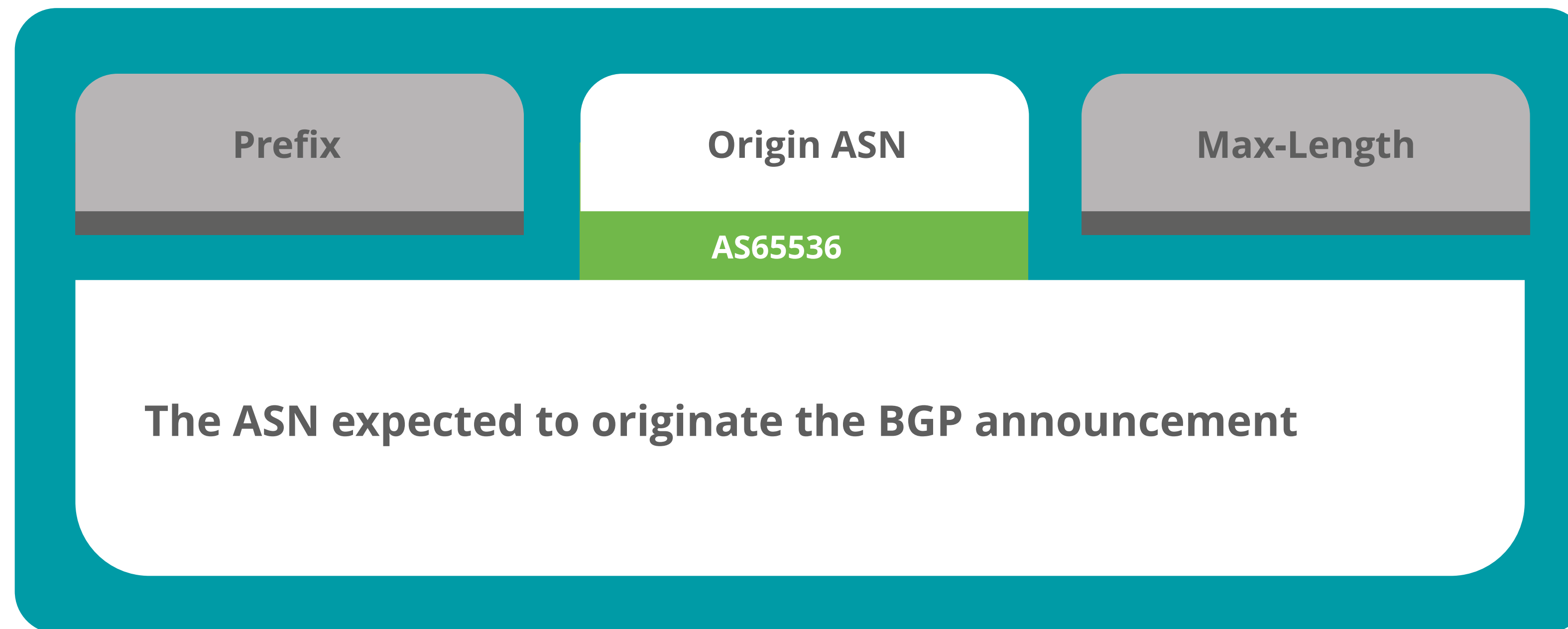


What is in a ROA?

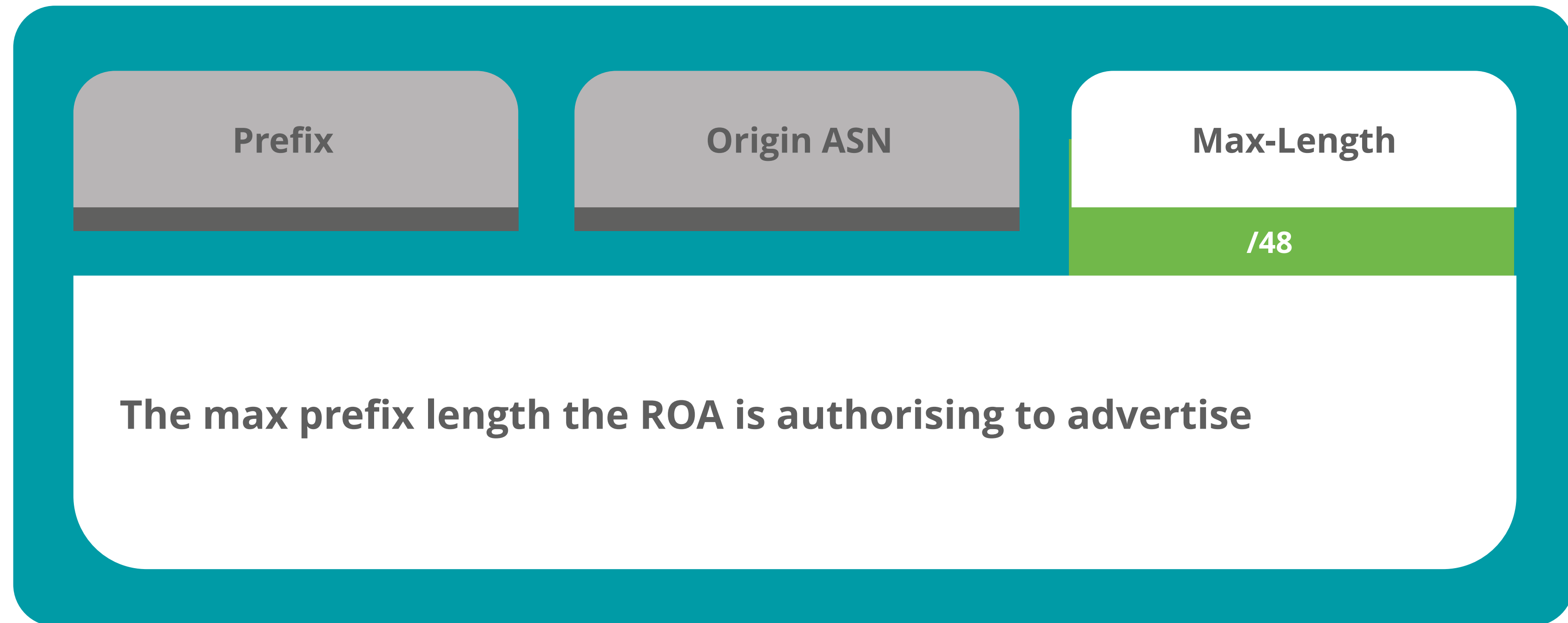


Prefix	Origin ASN	Max-Length
2001:db8::/48		
The network for which you are creating the ROA		

What is in a ROA?



What is in a ROA?



Max-Length

RIPE NCC (AS3333) has an IP address allocation

RIPE NCC creates this ROA

193.0.0.0/21

ROA

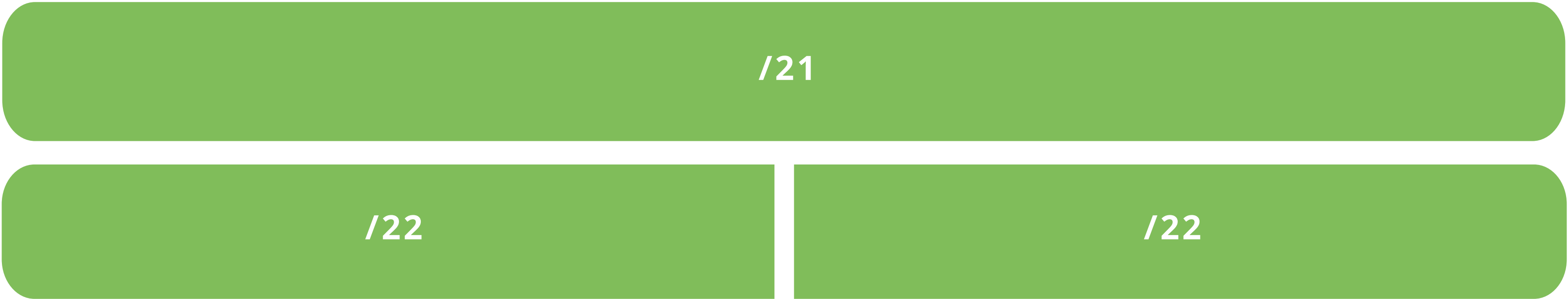
Prefix	193.0.0.0/21
Max Length	/22
Origin ASN	AS3333

Max-Length

RIPE NCC (AS3333) has an IP address allocation

RIPE NCC creates this ROA

According to the ROA:

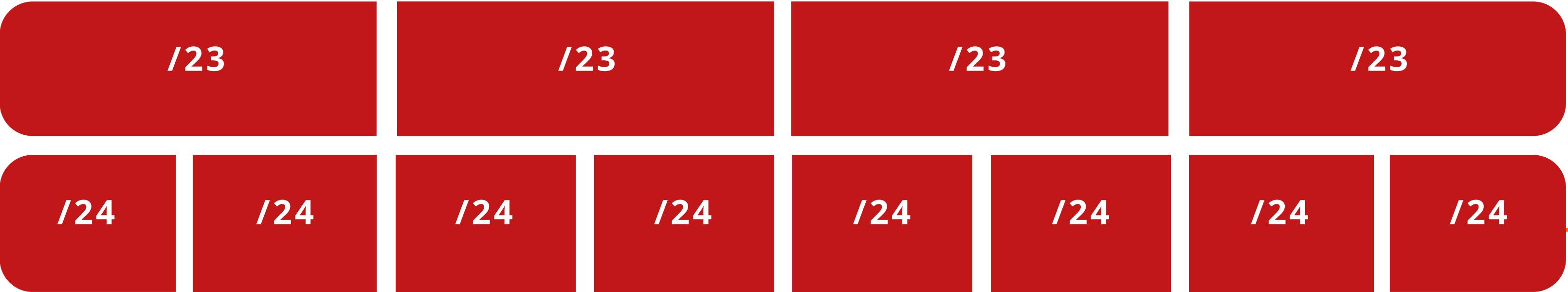
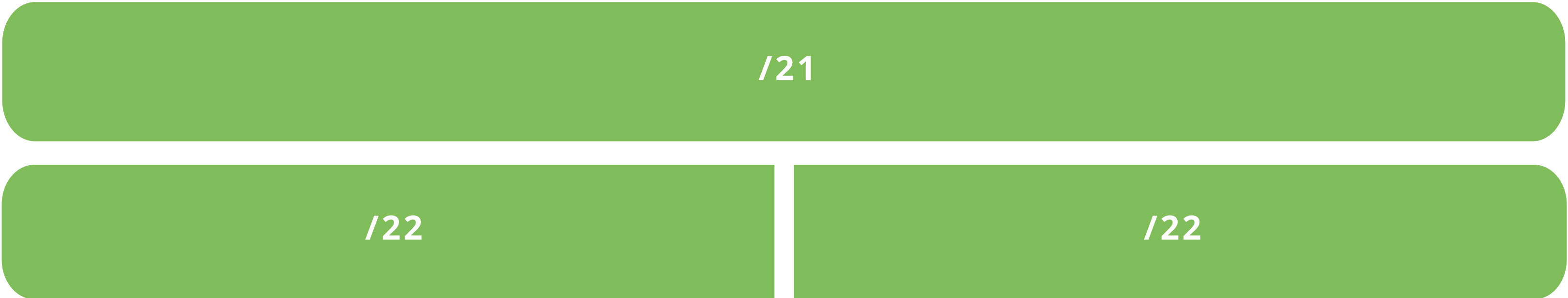


193.0.0.0/21

ROA	
Prefix	193.0.0.0/21
Max Length	/22
Origin ASN	AS3333

Max-Length

- RIPE NCC (AS3333) has an IP address allocation
- RIPE NCC creates this ROA
- According to the ROA:



193.0.0.0/21

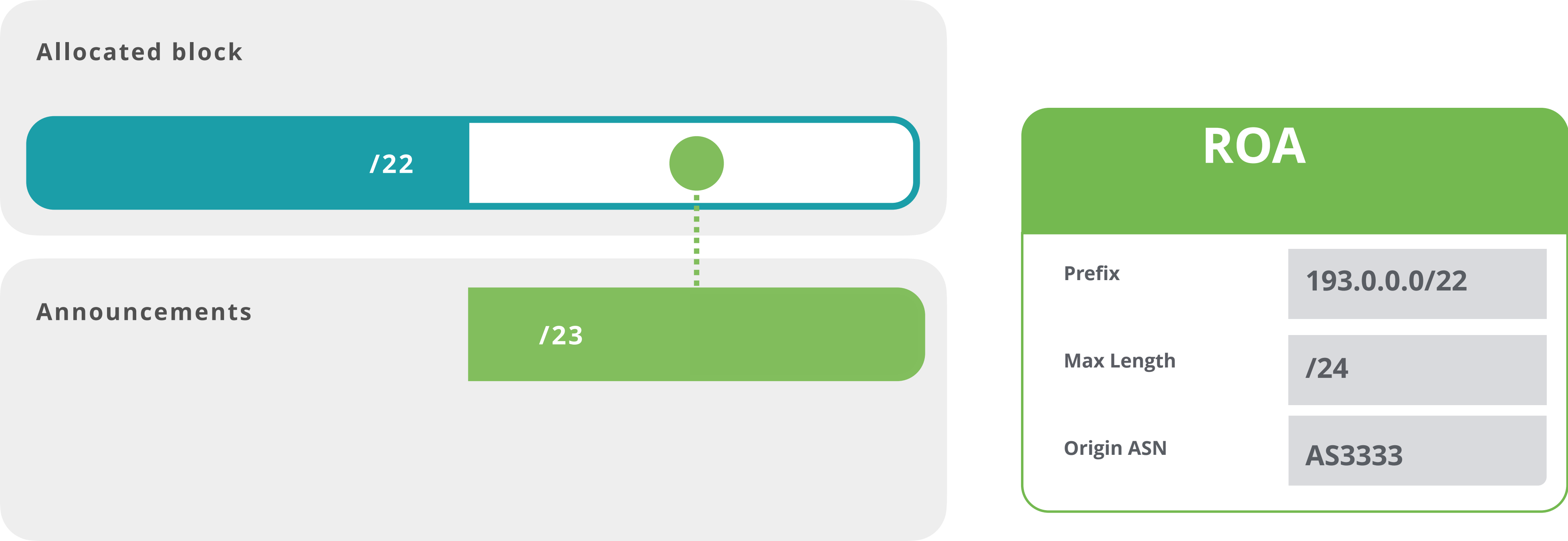
ROA	
Prefix	193.0.0.0/21
Max Length	/22
Origin ASN	AS3333

Any other more specific announcements are unauthorised by the ROA

How Should We Use Max-Length?



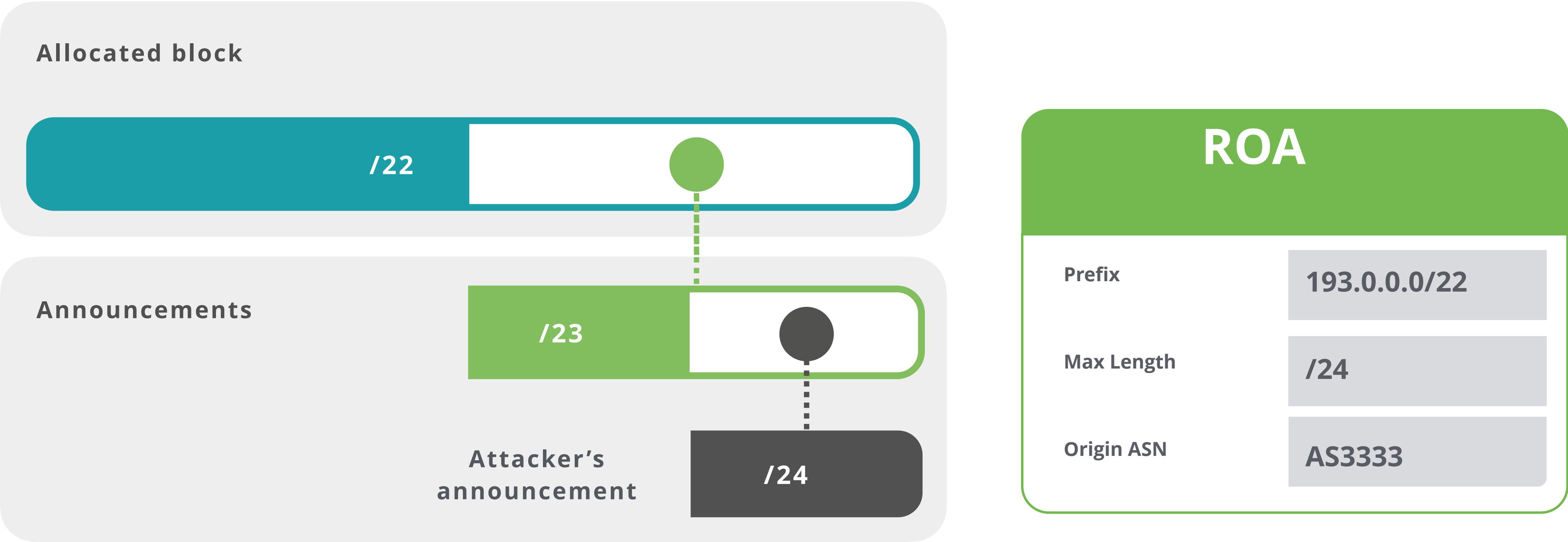
Case 1: You create a single ROA authorising the entire /22



How Should We Use Max-Length?



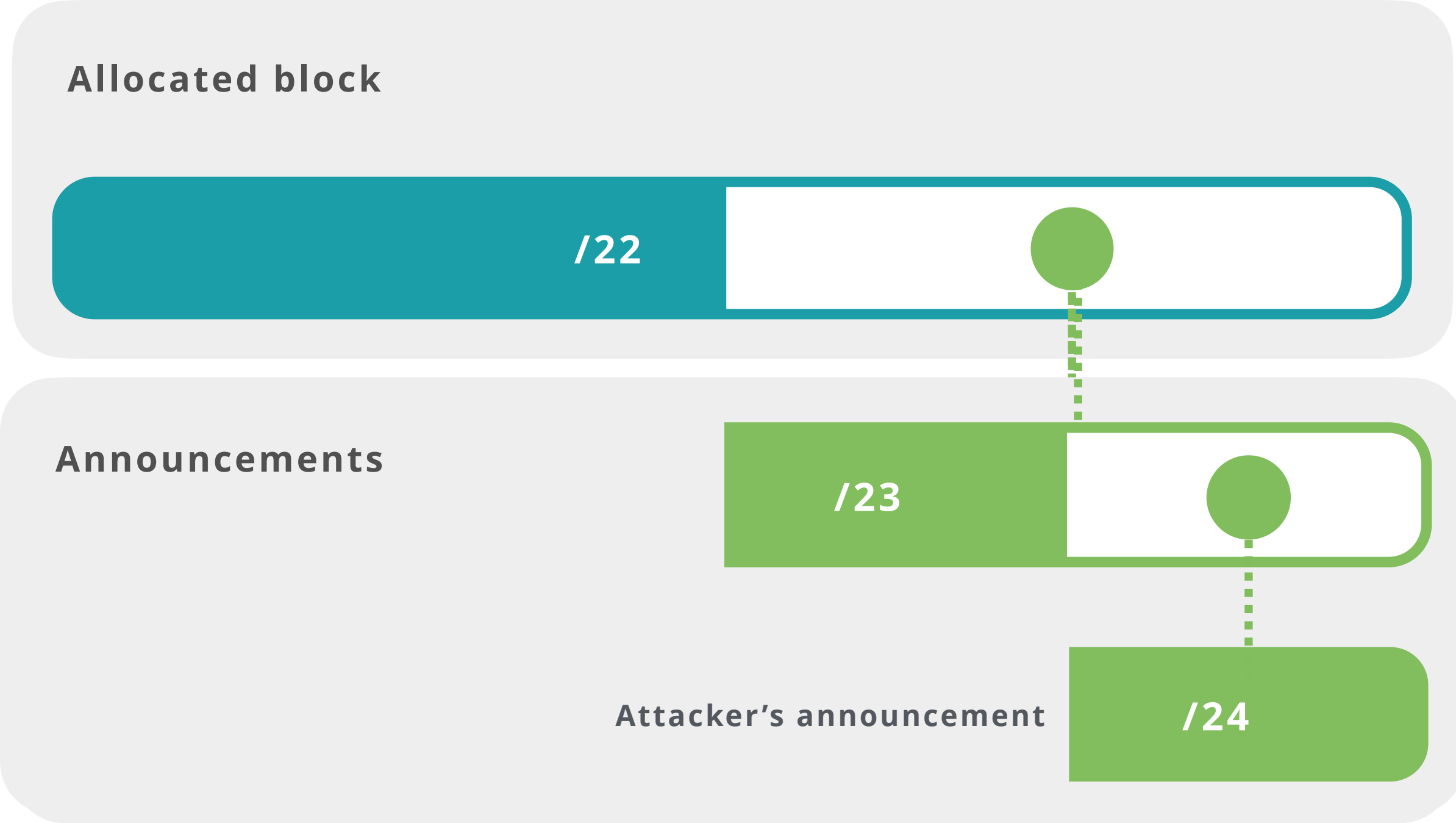
Case 1: You create a single ROA authorising the entire /22



How Should We Use Max-Length?



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



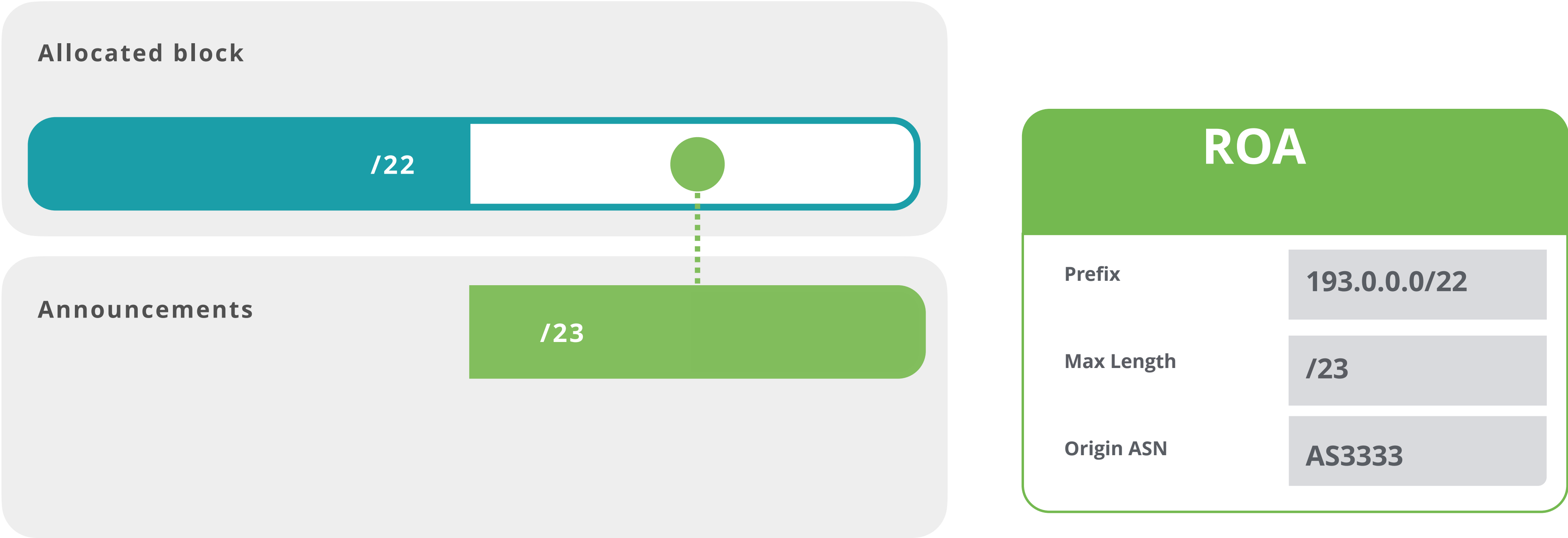
VALID

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

How Should We Use Max-Length?



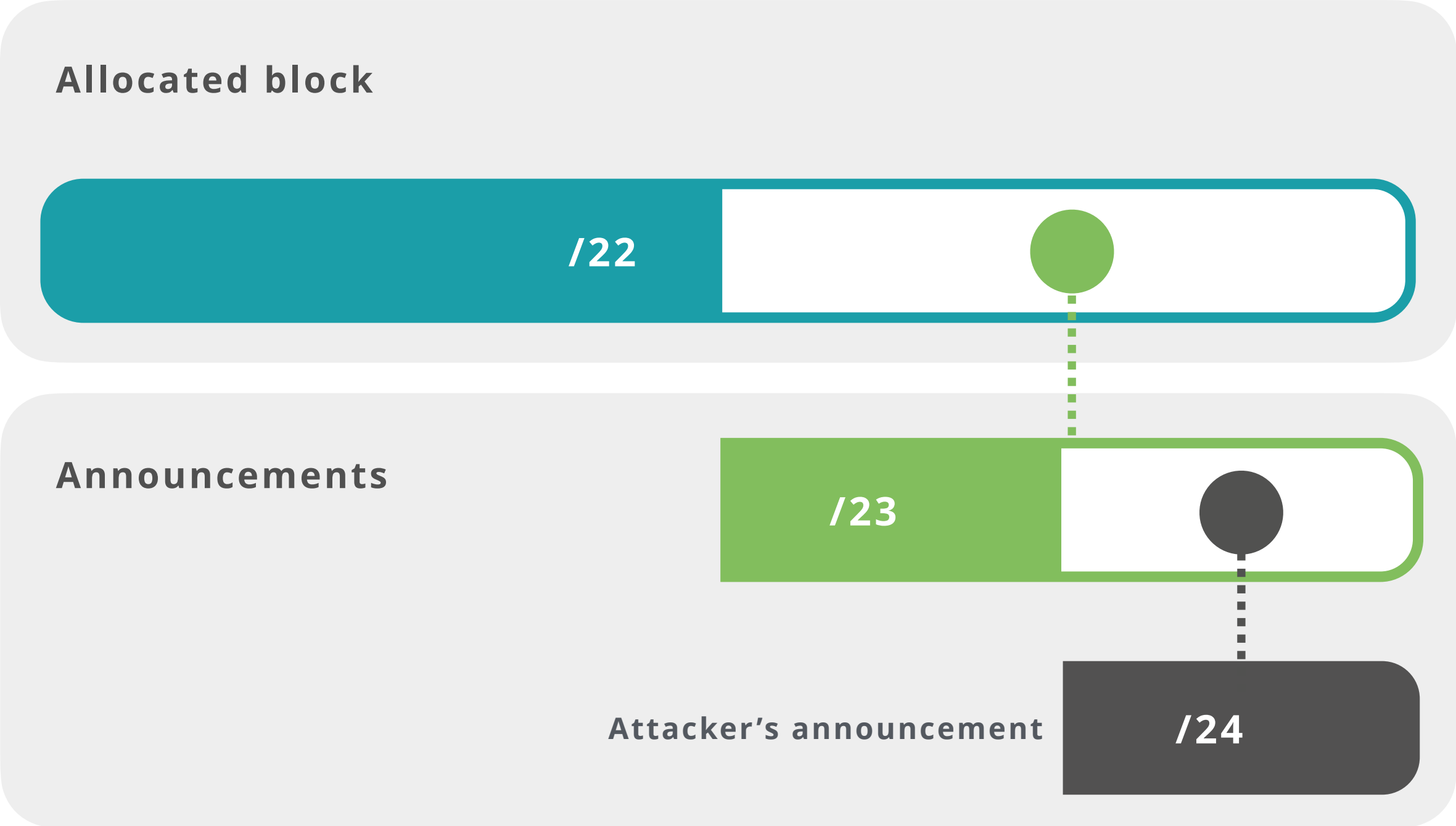
Case 2: You create ROAs only for your BGP announcement



How Should We Use Max-Length?



Case 2: You create ROAs only for your BGP announcement

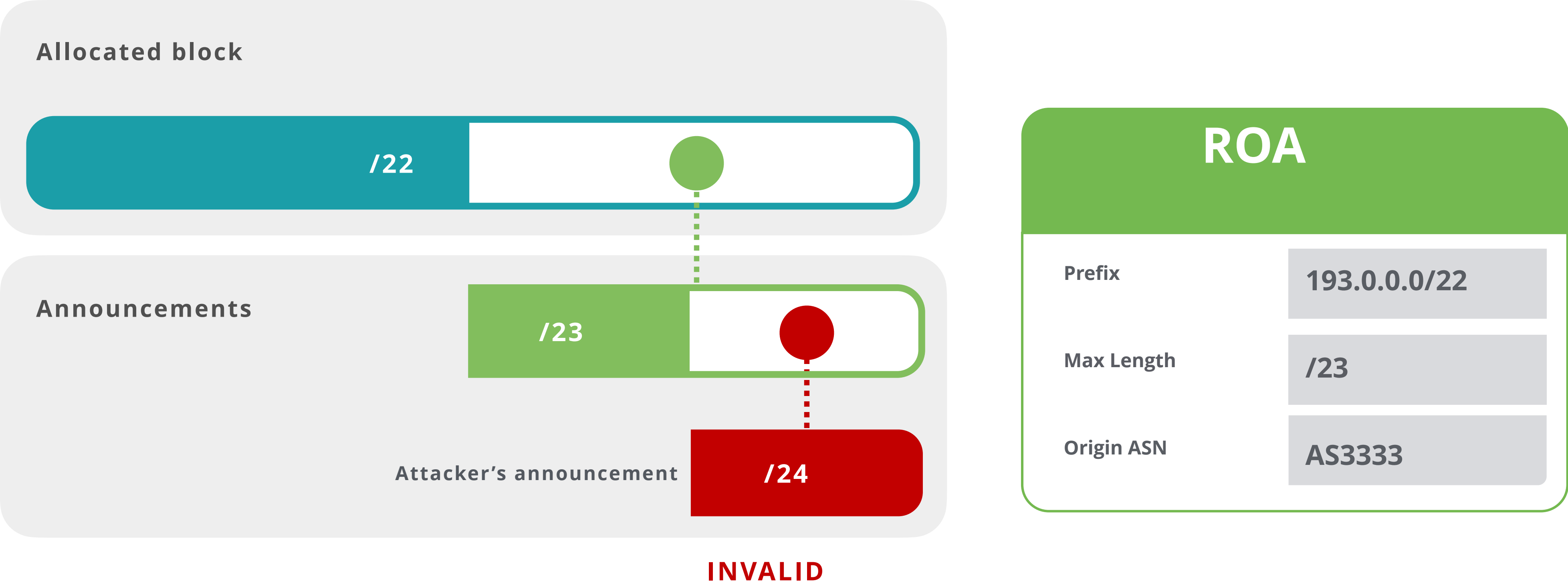


ROA	
Prefix	193.0.0.0/22
Max Length	/23
Origin ASN	AS3333

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

The screenshot shows the LIR Portal interface. On the left is a dark sidebar with a menu. The 'RPKI RPKI Dashboard' item is circled in orange. An orange arrow points from this menu item to the 'Hosted' radio button in the main content area. The main content area is titled 'Create a Certificate Authority for bh.viacloud' and contains the 'RIPE NCC Certification Service Terms and Conditions'. Under 'Article 1 - Definitions', there is a section 'Type of Certificate Authority' which explains the difference between 'Hosted' and 'Delegated' RPKI. At the bottom, there are two radio buttons: 'Hosted' and 'Delegated', with 'Hosted' being selected. The 'Hosted' button is also enclosed in an orange box.

LIR Portal

- My LIR
LIR Account, Billing, Users, General Meeting...
- Requests
Tickets, Resources, Updates, Transfers
- Resources
My Resources, Sponsored Resources
- RIPE Database
- RPKI**
RPKI Dashboard

Create a Certificate Authority for bh.viacloud

RIPE NCC Certification Service Terms and Conditions

Introduction

This document will stipulate the Terms and Conditions for the RIPE NCC Certification Service. The RIPE NCC Certification Service is based on Internet Engineering Task Force (IETF) standards, in particular RFC3647, "Internet X.509 Public Key Infrastructure Certificate Policy and Certification Practices Framework", RFC3779, "X.509 Extensions for IP Addresses and AS Identifiers", and the "Certificate Policy (CP) for the Resource PKI (RPKI)".

Article 1 - Definitions

Type of Certificate Authority

You can choose between asking the RIPE NCC to host your RPKI Certificate Authority (Hosted RPKI) or running your own Certificate Authority (Delegated RPKI).

Select "Hosted" if you would like the RIPE NCC to host your Certificate Authority keys, ROAs, manifests etc. and publish the information in our repository. You will only need to maintain your ROAs in our dashboard. This is the recommended option if you are not an RPKI expert.

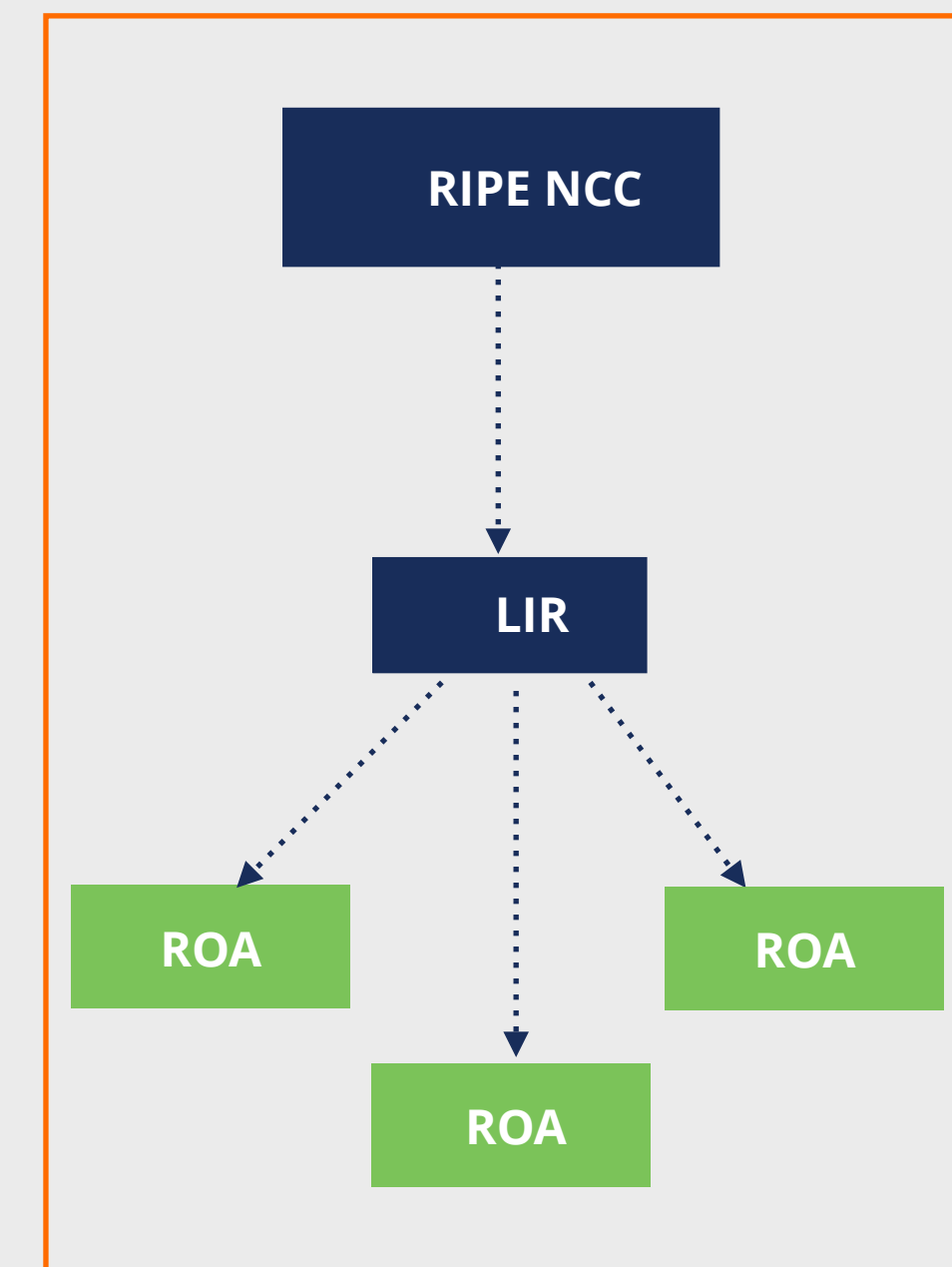
Select "Delegated" to run your own Certificate Authority and to host your own keys, ROAs, manifests etc. you will need to run additional software to proceed.

☒ Hosted
☐ Delegated

Hosted RPKI

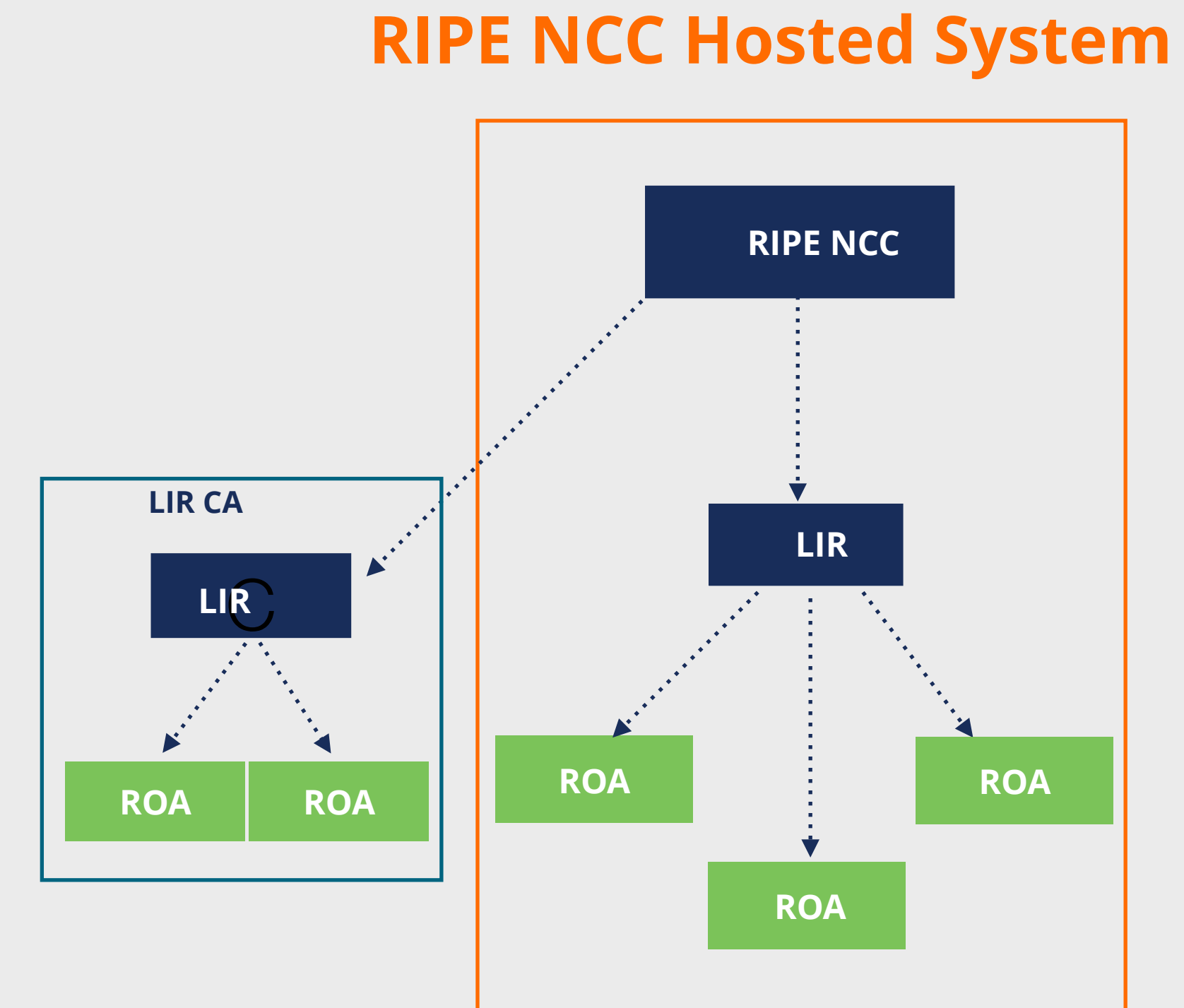
- ROAs are created and published using the **RIR's member portal**
- RIR hosts a CA for LIRs and signs all ROAs
- Automated signing and key rollovers
- Allows LIRs to focus on creating and publishing ROAs

RIPE NCC Hosted System



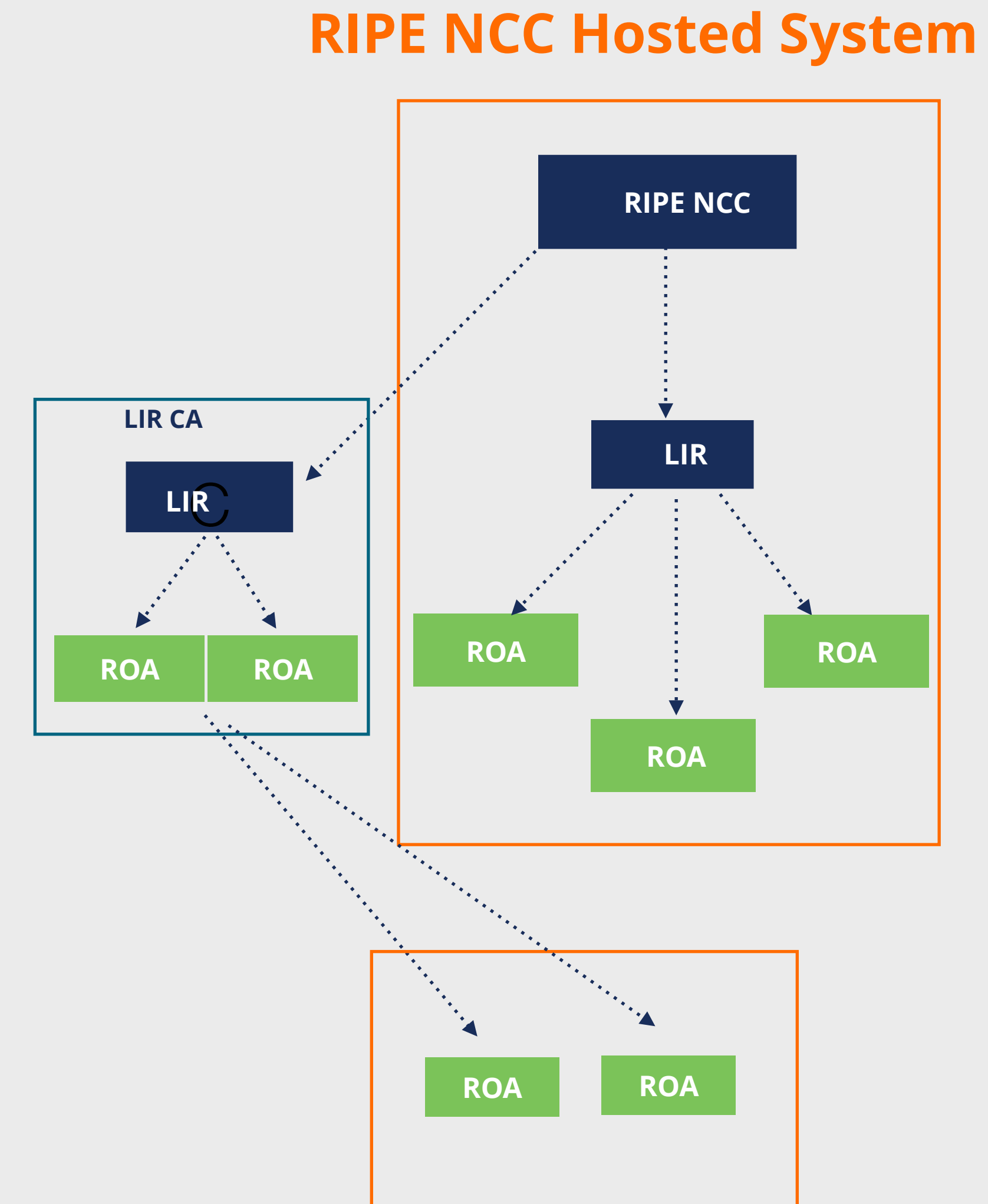
Delegated RPKI

- 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



2 BGP Announcements

0 Valid

0 Invalid

2 Unknown

0 ROAs

0 OK

0 Causing problems

BGP Announcements

Route Origin Authorisations (ROAs)

History

Create ROAs for selected BGP Announcements

<input type="checkbox"/> Origin AS	Prefix	Current Status
<input checked="" type="checkbox"/> AS2121	193.0.24.0/21	UNKNOWN
<input checked="" type="checkbox"/> AS2121	2001:67c:64::/48	UNKNOWN

Show 25

✓ Apply the changes

↺ Discard the changes

Cancel

Staged ROAs

AS2121 ≡ 193.0.24.0/21 ↔ 21

AS2121 ≡ 2001:67c:64::/48 ↔ 48

Affected announcements

AS2121 ≡ 193.0.24.0/21 UNKNOWN →

AS2121 ≡ 2001:67c:64::/48 UNKNOWN →

Review and publish changes

2

Looking for ROA Certification for PI resources?



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

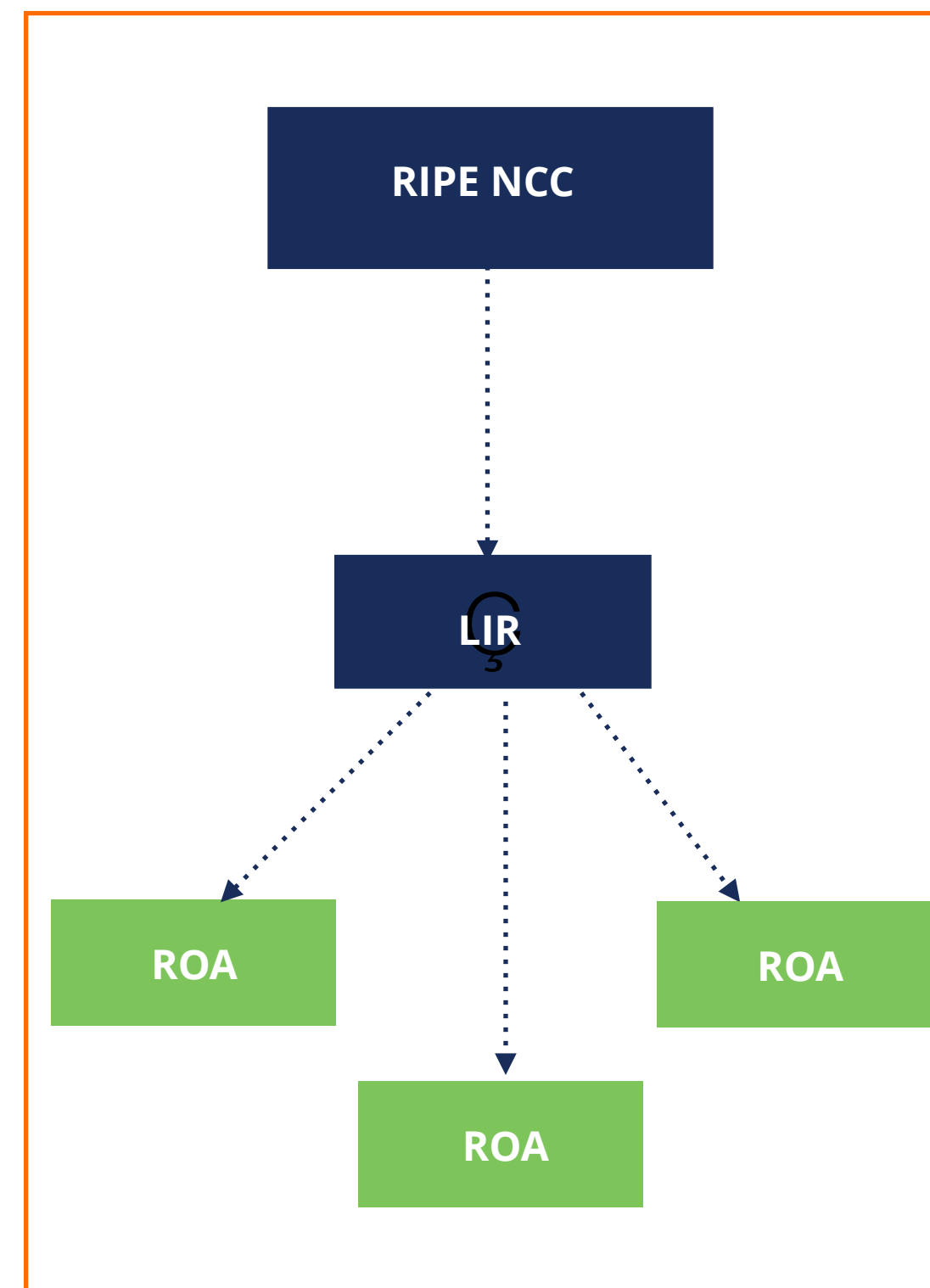
- **Description:** Create (see demo) ROAs in the test RPKI Dashboard
- **Goals:**
 - Identify elements of the RPKI infrastructure
 - Register routing information in the RPKI dashboard by creating a ROA
- **Time:** 15 minutes
- **Tasks:**
 - 5.1 Check your BGP announcements
 - 5.1 Create (or see a demo)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

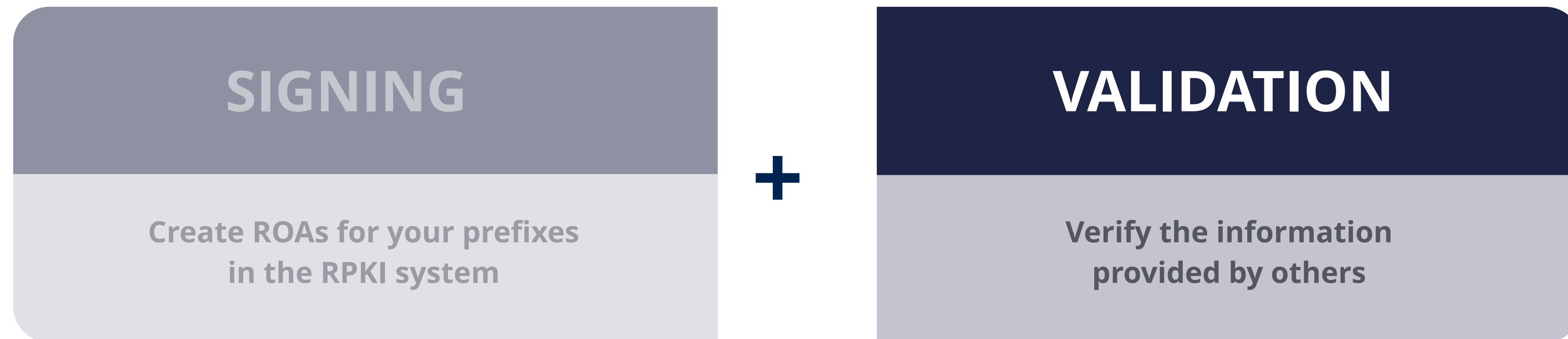
RIPE NCC Hosted System





Elements of RPKI

- The RPKI system consists of two parts:





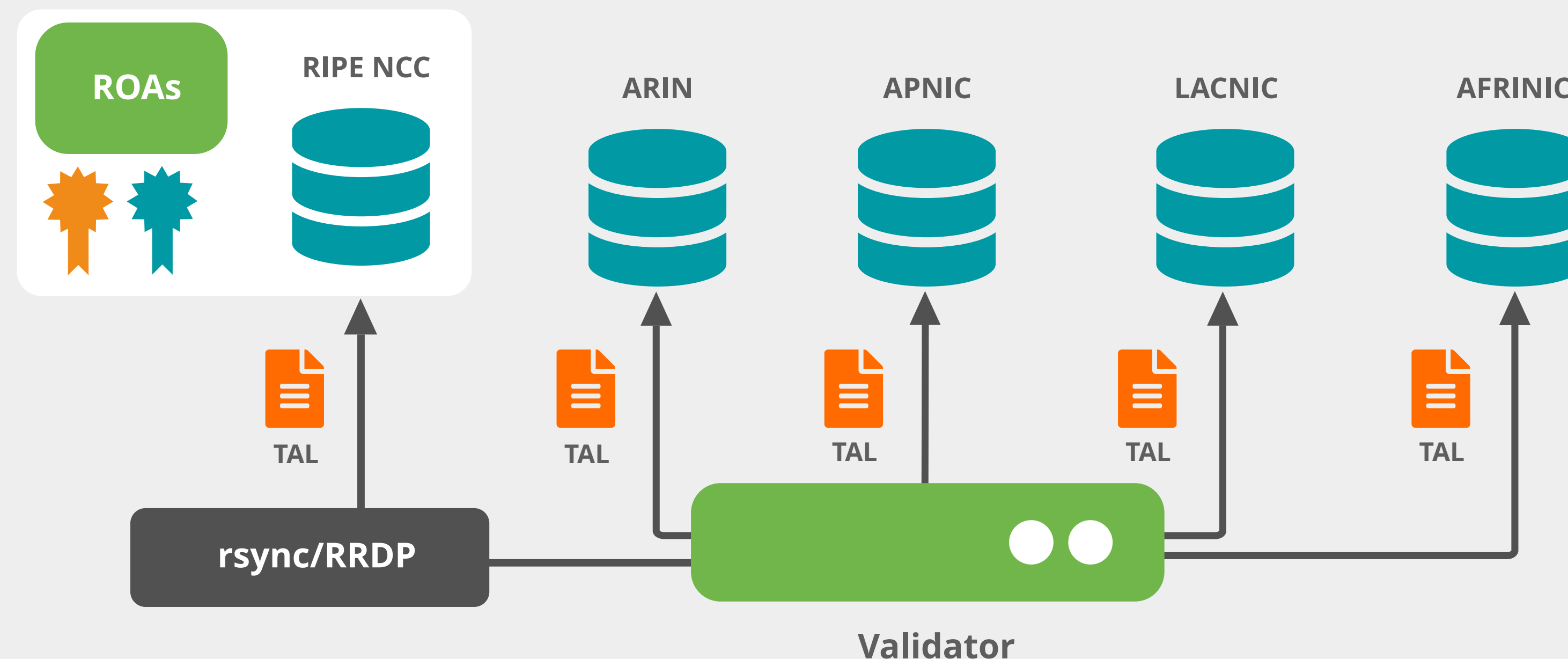
RPKI Validation

- Verifying the information provided by others
- First, **validate the RPKI data**
 - Install a **validator software** locally in your network
 - Verify holdings 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

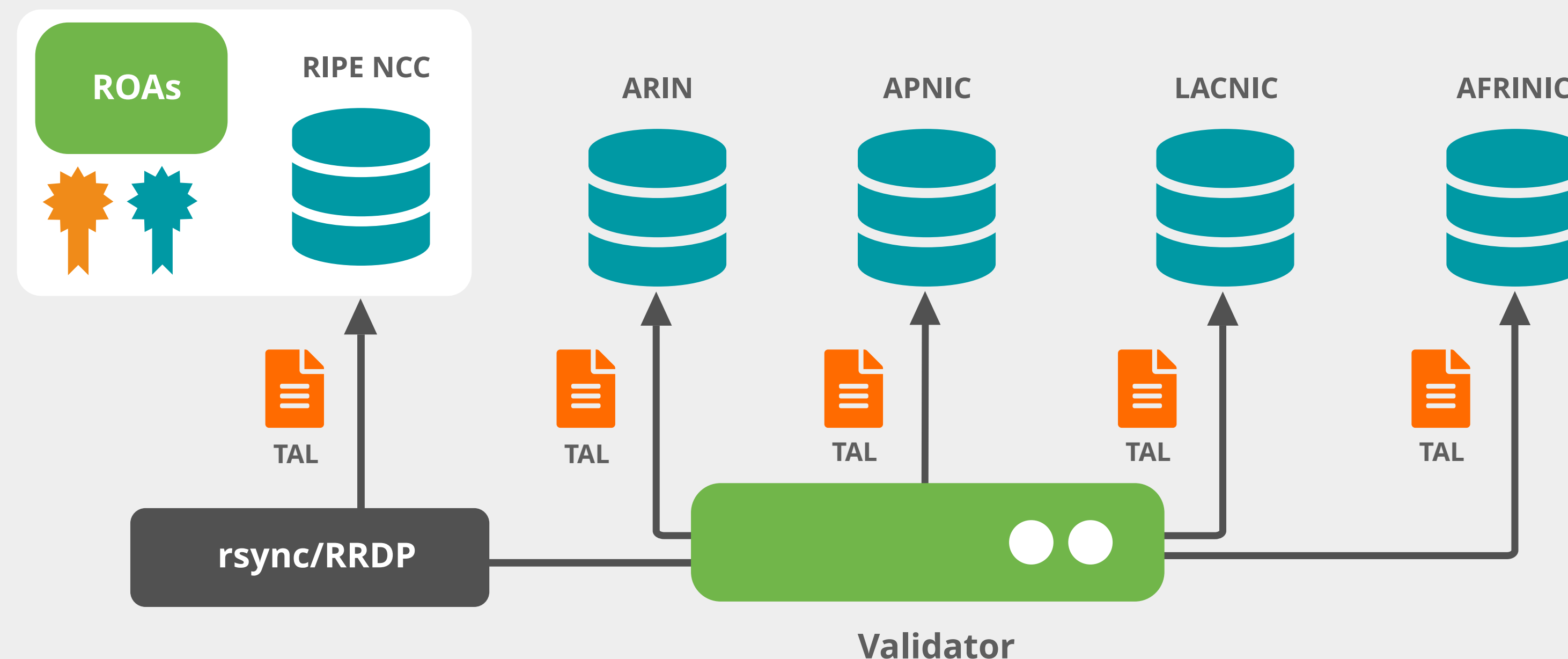
- Also known as **Relying Party (RP)** software
- Connects to RPKI repositories via **rsync** or **RRDP** protocol
- Uses information in TALs to connect to the repositories





RPKI Validator

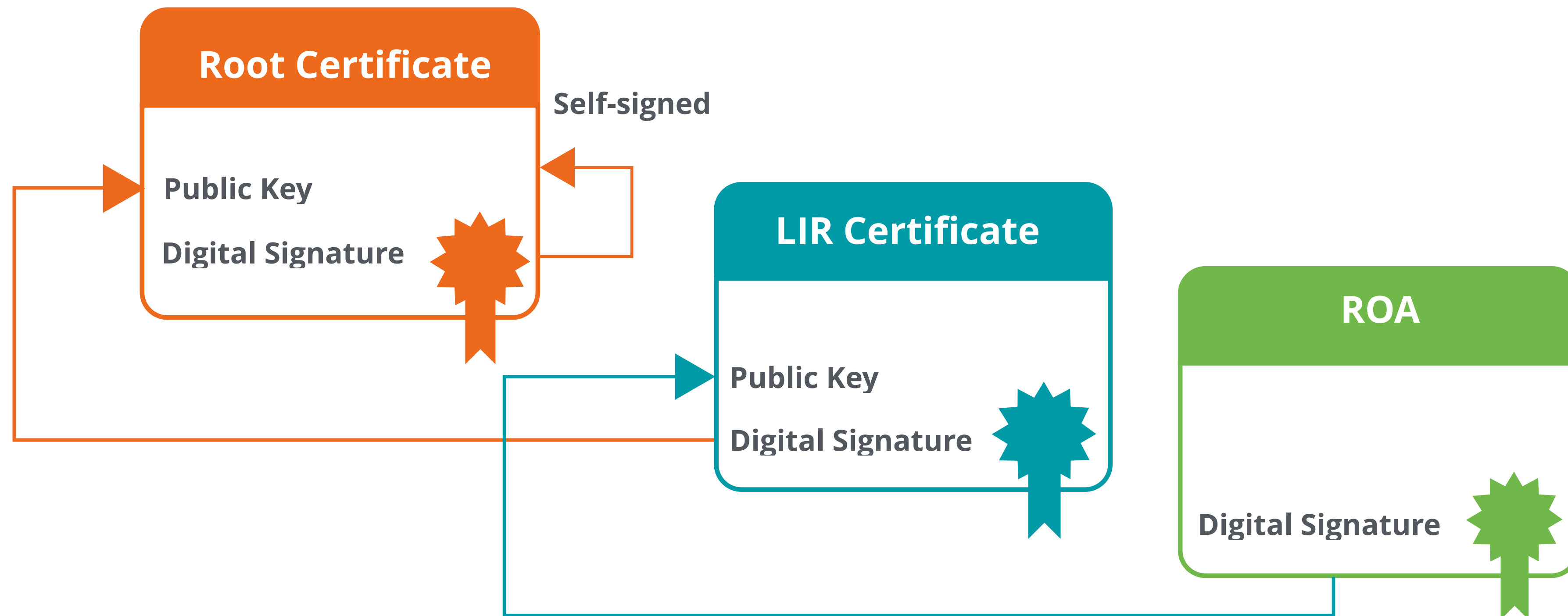
- Downloads ROAs from RPKI repositories
 - From RIRs and external repos
- Validates the chain of trust for all ROAs and associated CAs
 - Creates a local “**validated cache**” with all the **valid ROAs**



ROA Validation Process



- ✓ IF chain is complete ==> ROA is **VALID!**
- ✗ ELSE validation is unsuccessful ==> ROA is **INVALID!**





RPKI Validator Options

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

Links for RPKI Validators:

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

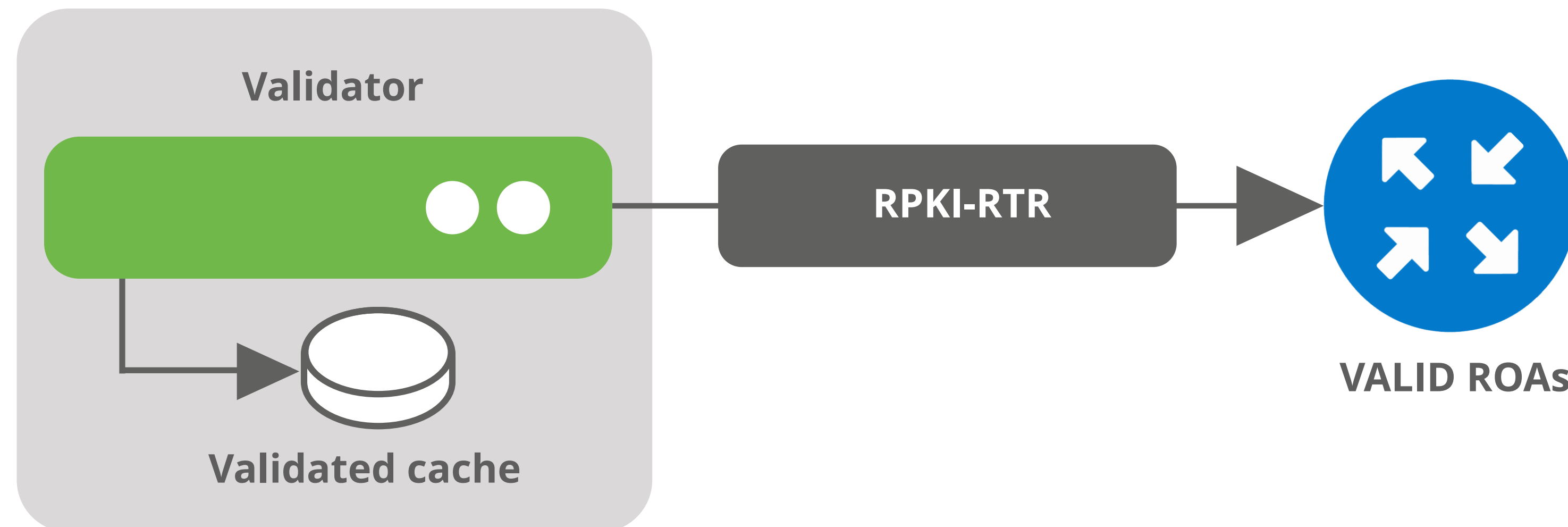
<https://github.com/NICMx/FORT-validator/>

<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!



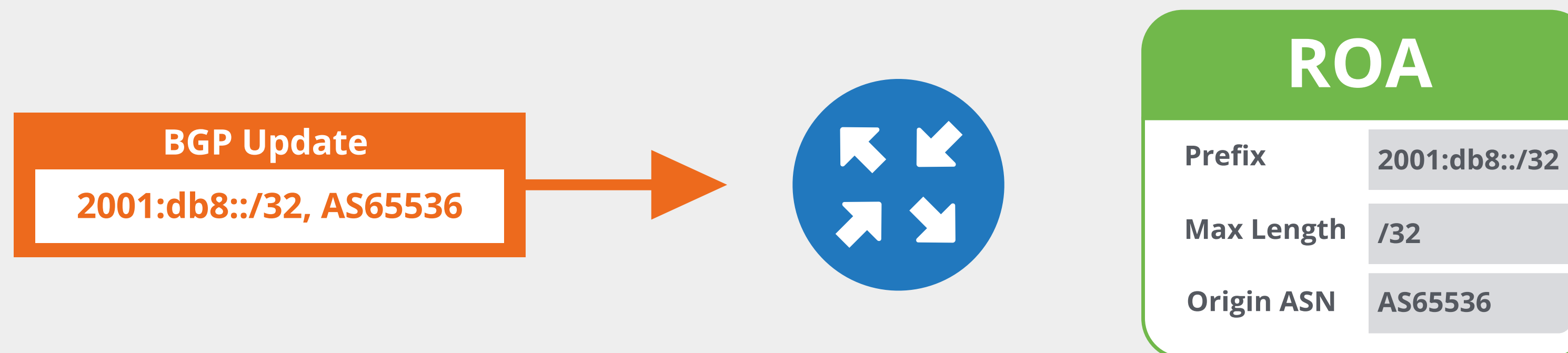
OR



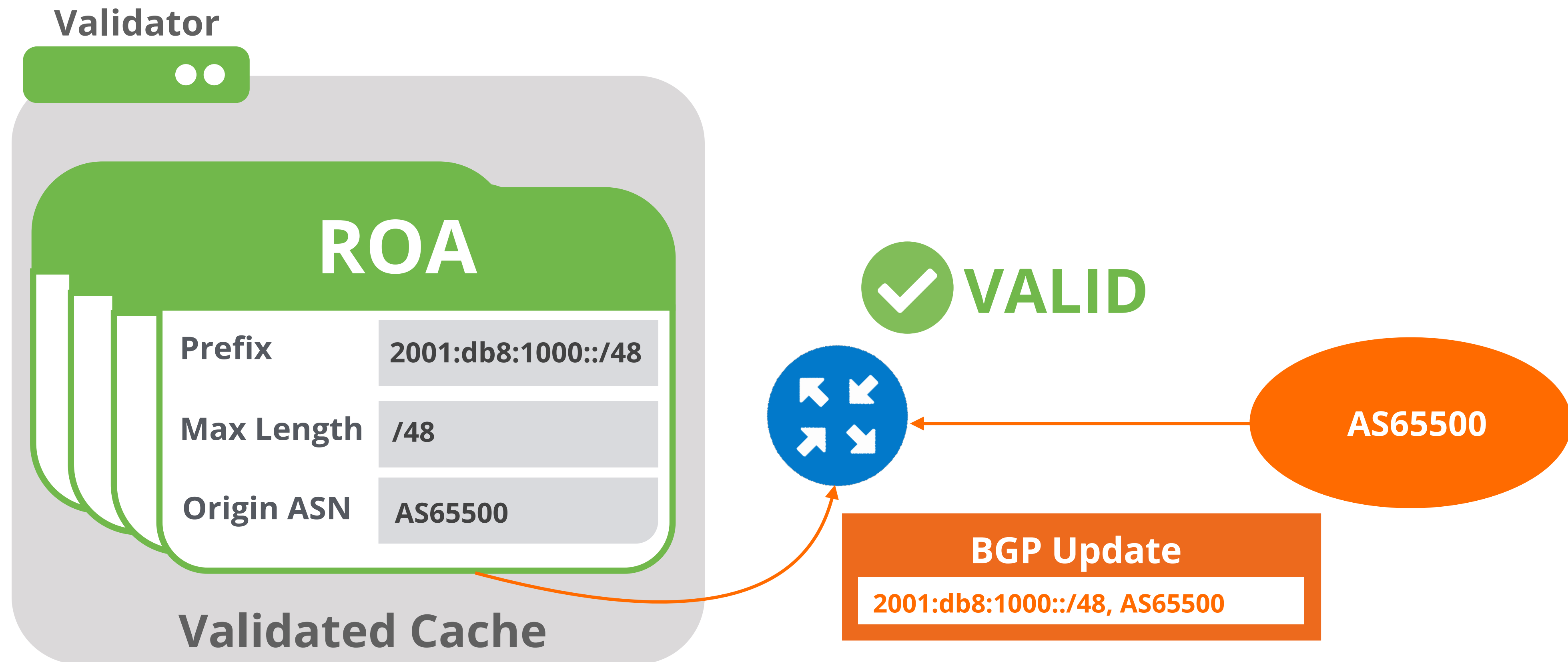


BGP Origin Validation (BGP OV)

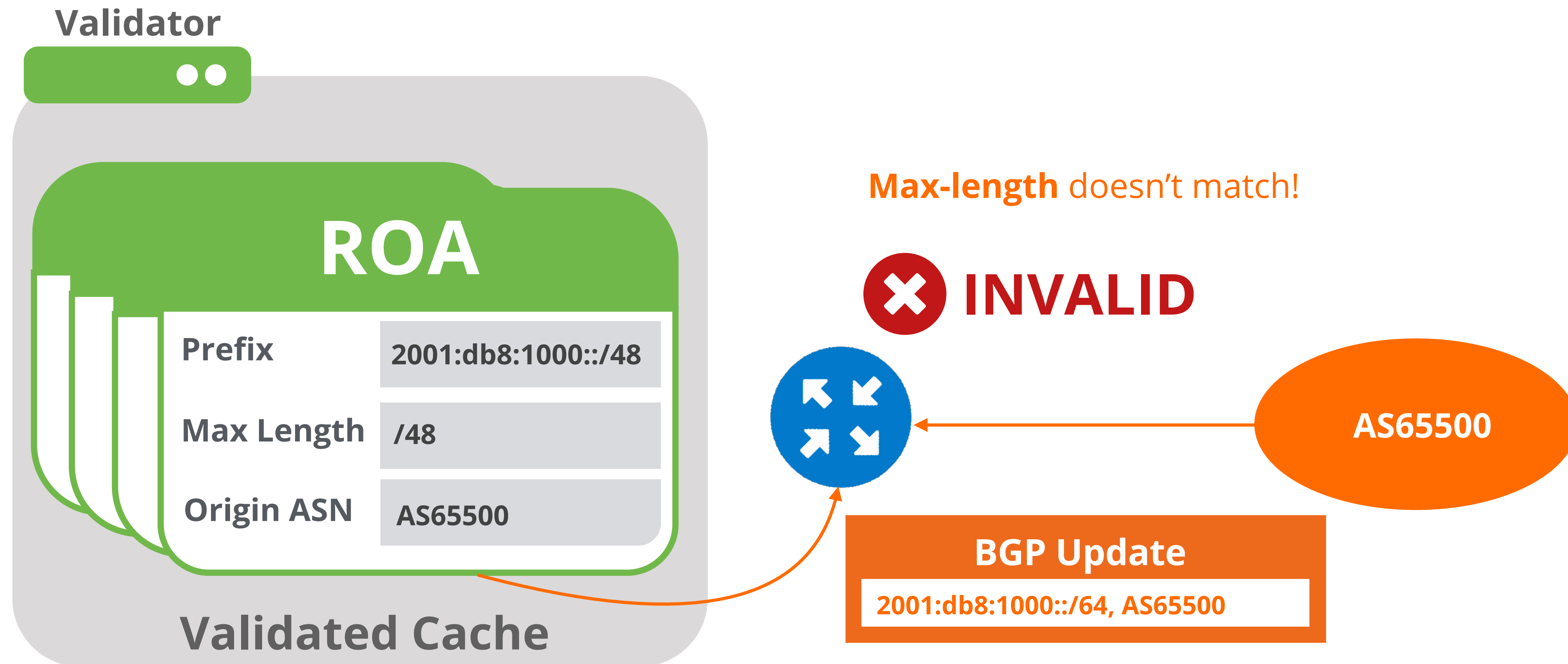
- RPKI based route filtering
- BGP announcements are compared against the **valid** ROAs
 - **Origin ASN** and **max-length** must match!
- Router decides the validation states of **routes**:
 - **Valid**, **Invalid** or **Not-Found**



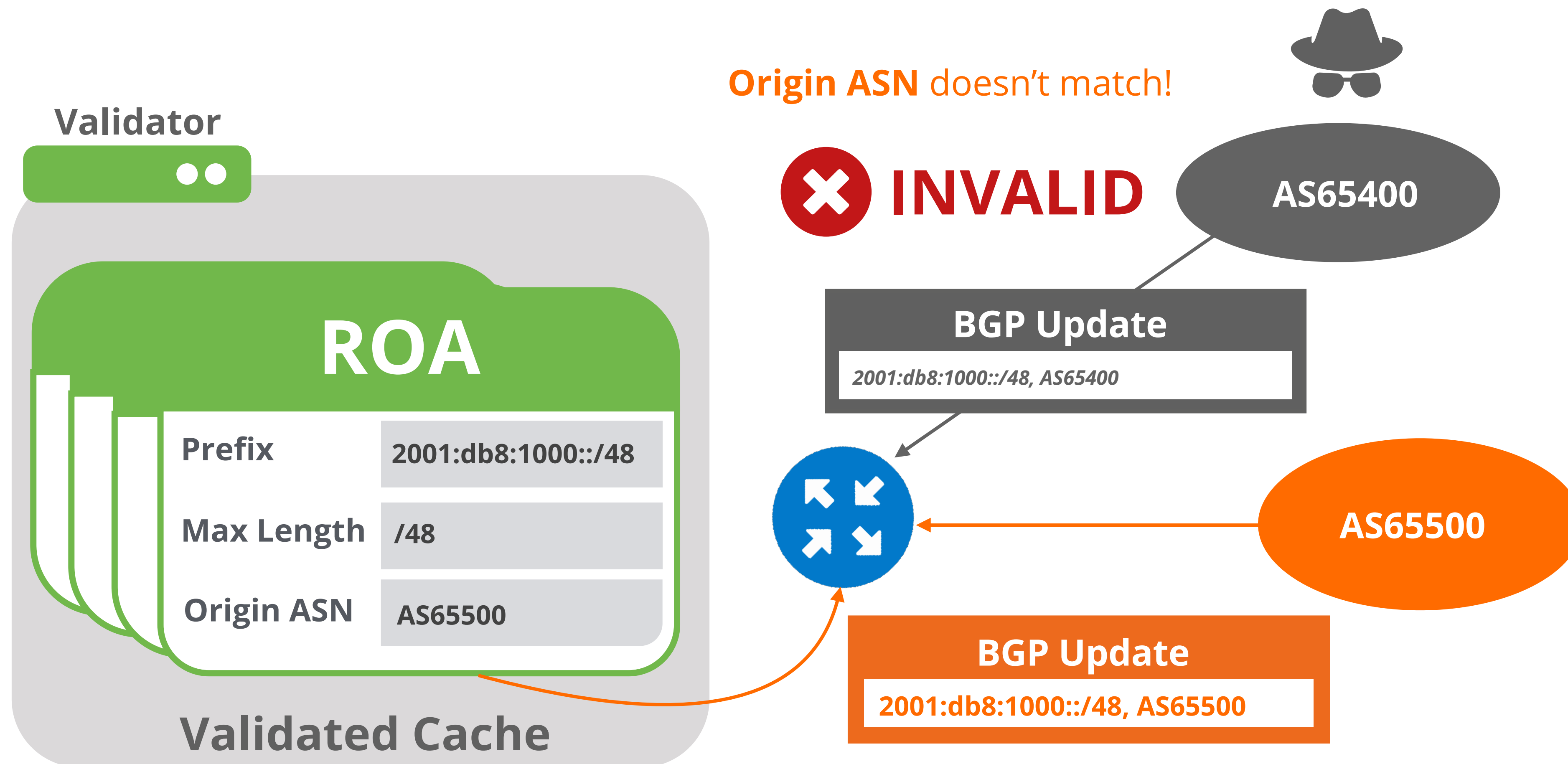
How Does RPKI Validate the Origin?



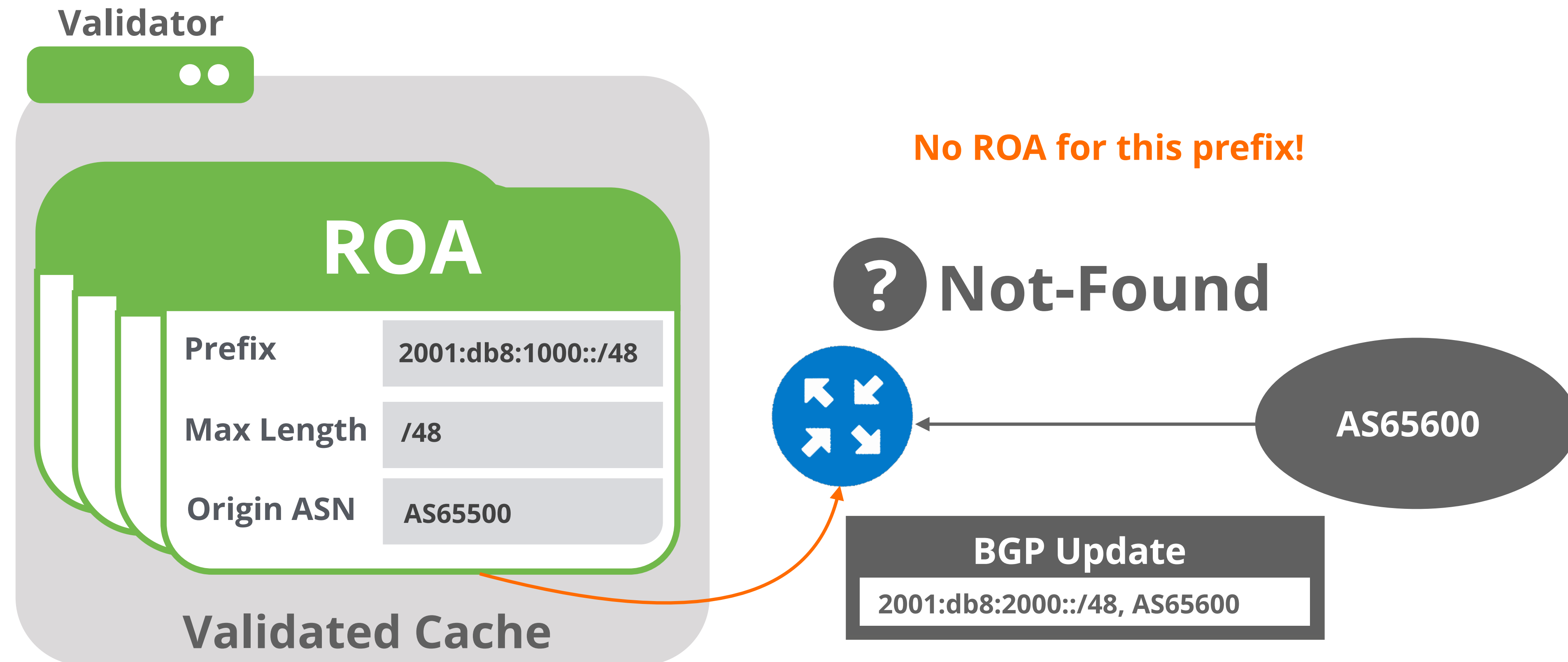
How Does RPKI Validate the Origin?



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

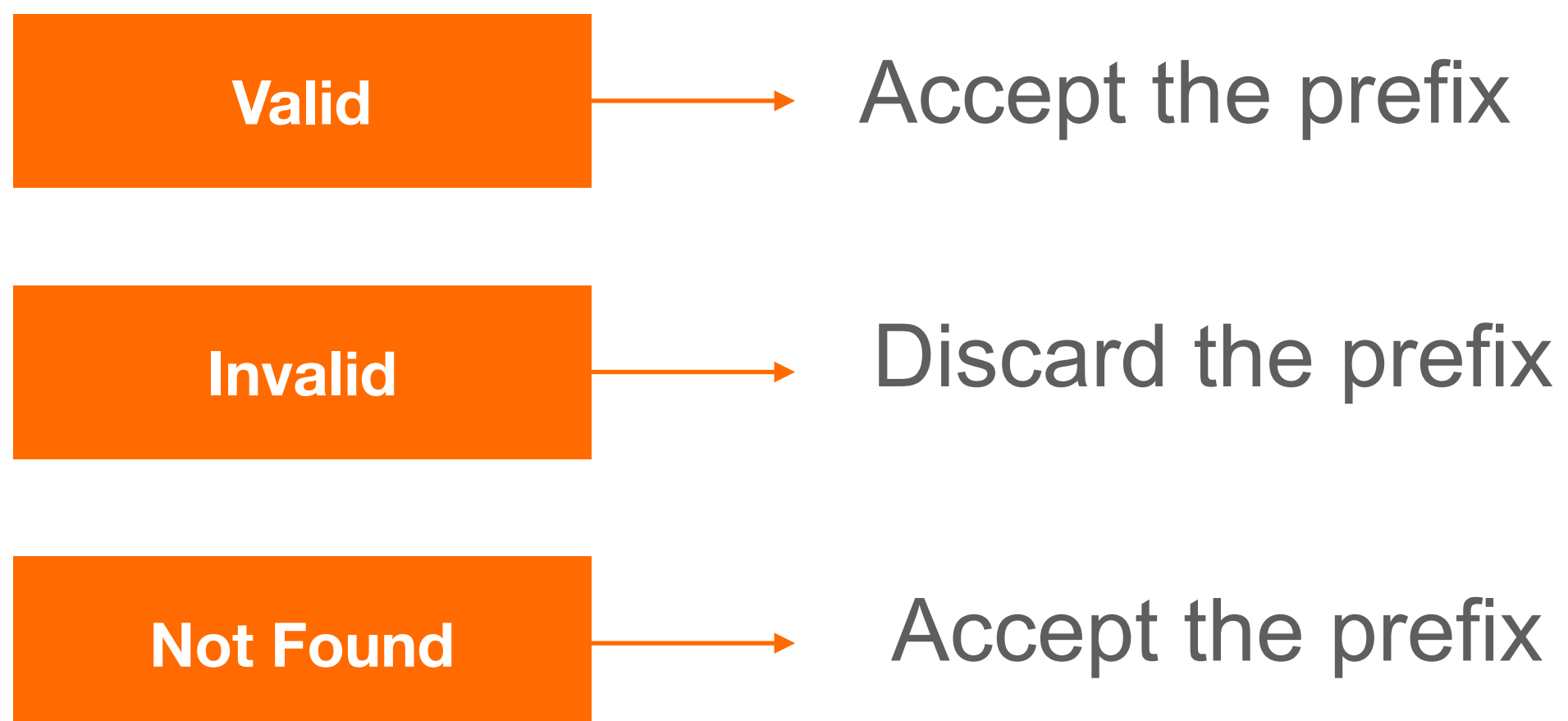


The prefix I not found



After Validating

- You have to make a decision: Accept or Discard



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



Major Networks and RPKI Invalids

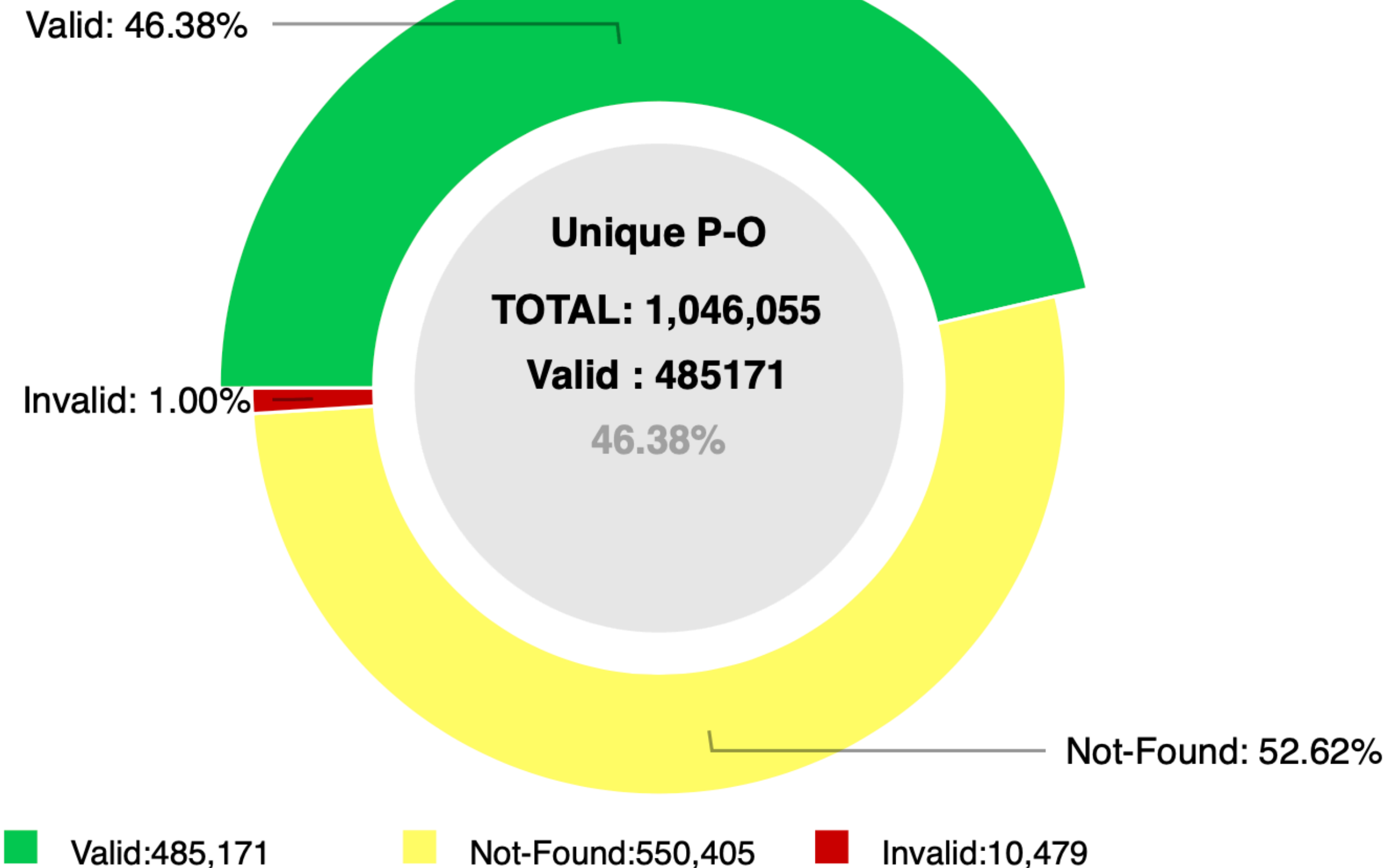
- Major networks are dropping invalids
 - Telia, AT&T, Cloudflare, Netflix, Swisscom, Cogent etc
- They follow a phased approach: First peers, then customers
 - Tag invalids on all peers, then on all customers
 - Drop invalids for all peers, then for all customers

RPKI-ROV Analysis Globally (IPv4)



RPKI-ROV Analysis: Global Analysis

RPKI-ROV Analysis of Unique Prefix-Origin Pairs (IPv4)



NIST RPKI Monitor: RPKI-ROV Analysis

Protocol: IPv4

RIR: All

Date: 2023-11-02 00:00

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



Questions



Lab 5 - RPKI

5.2 - BGP Origin Validation with RPKI

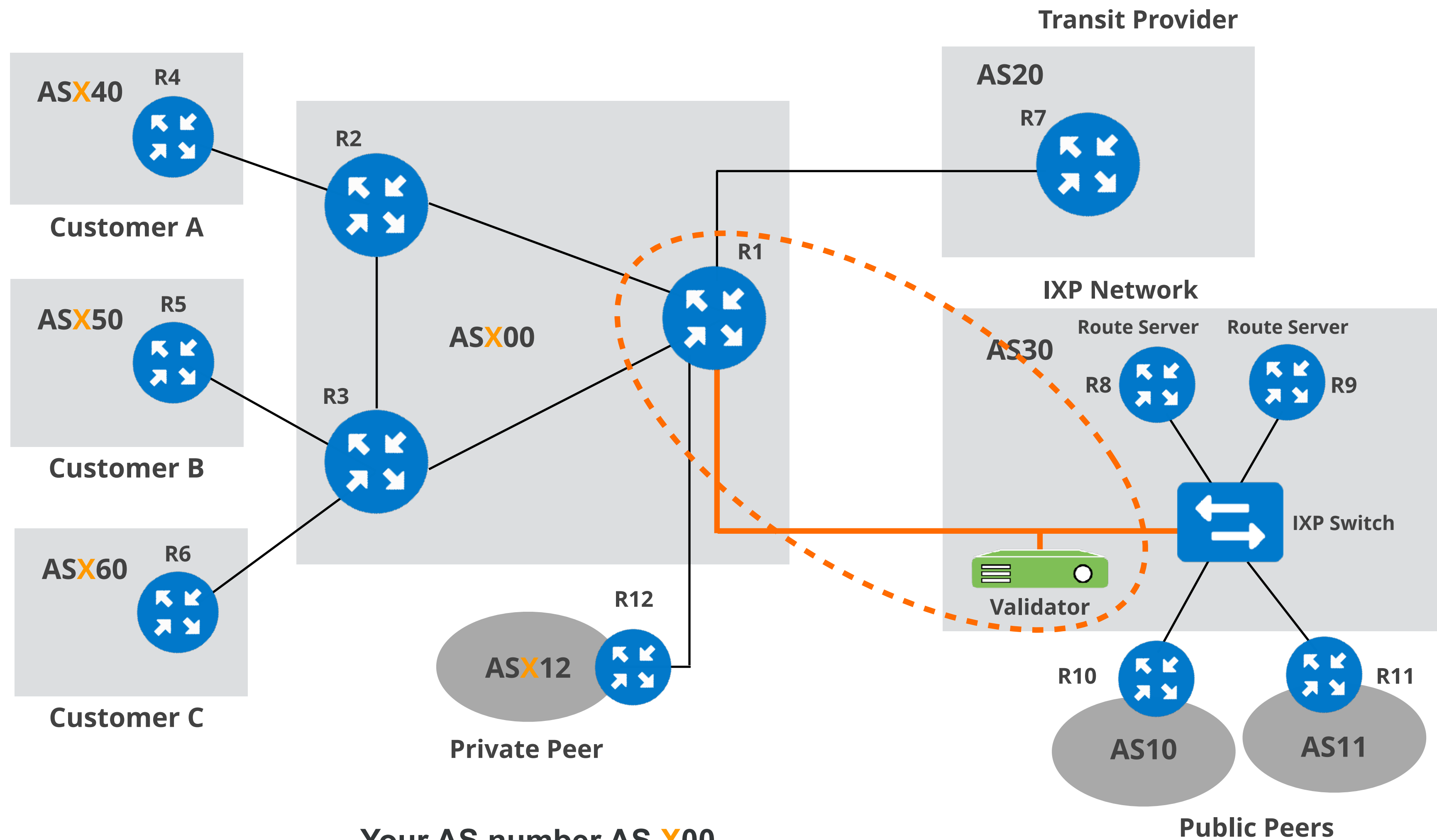


20 min



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
 - 5.2 Discard BGP RPKI Invalids



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?

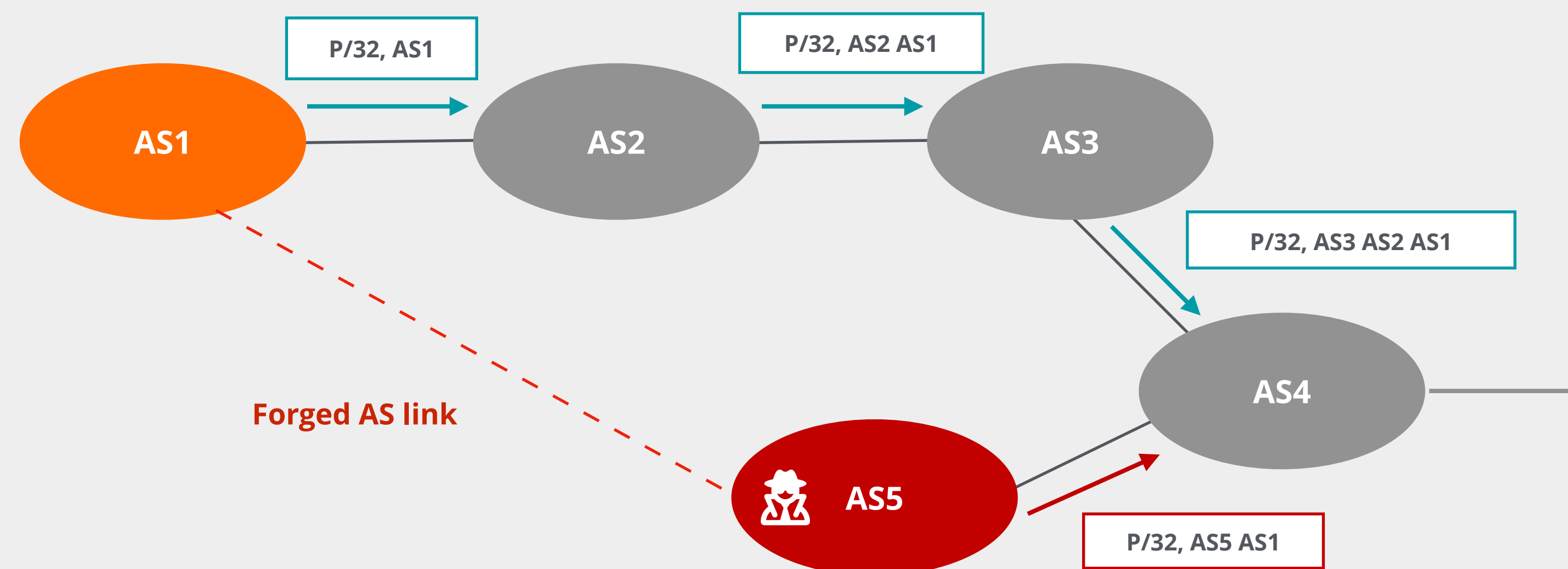


Dealing with Path Hijacks...



Fake Path with Correct Origin

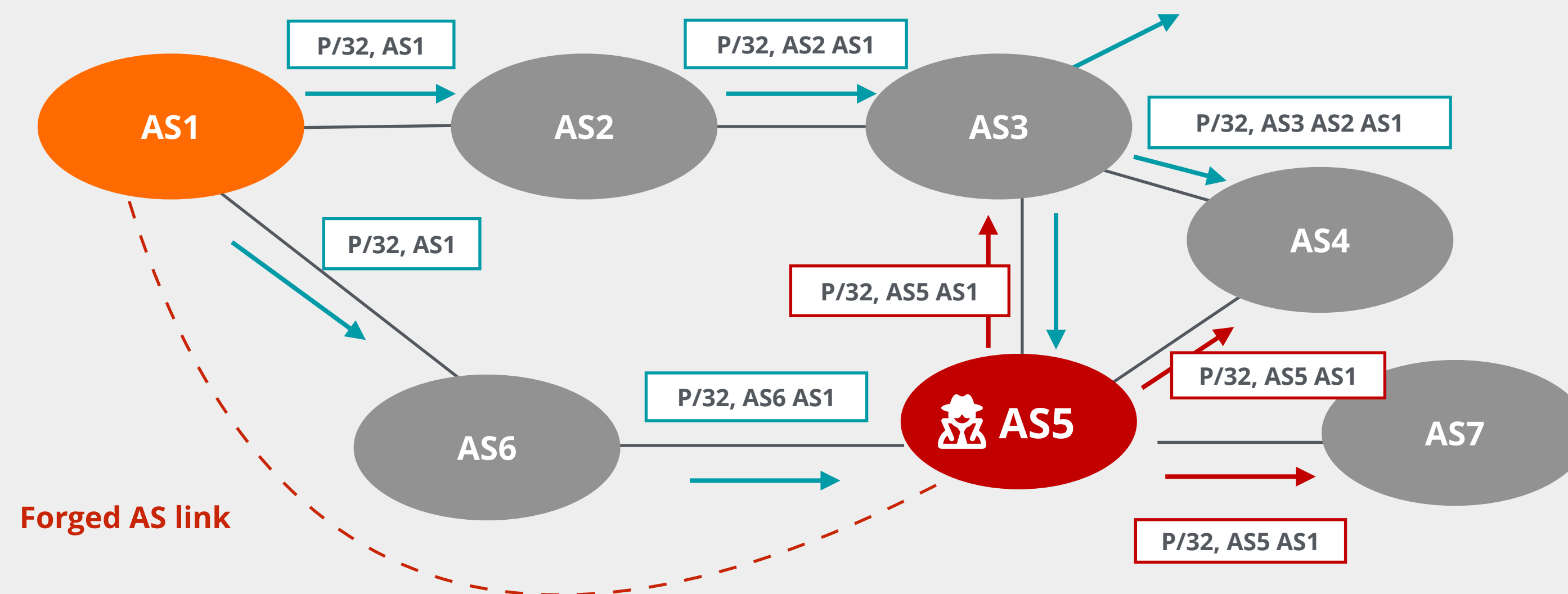
- The origin of the path does not change!
- The attacker:
 - Creates a forged AS link between two ASes
 - Reroutes the traffic to itself





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!**



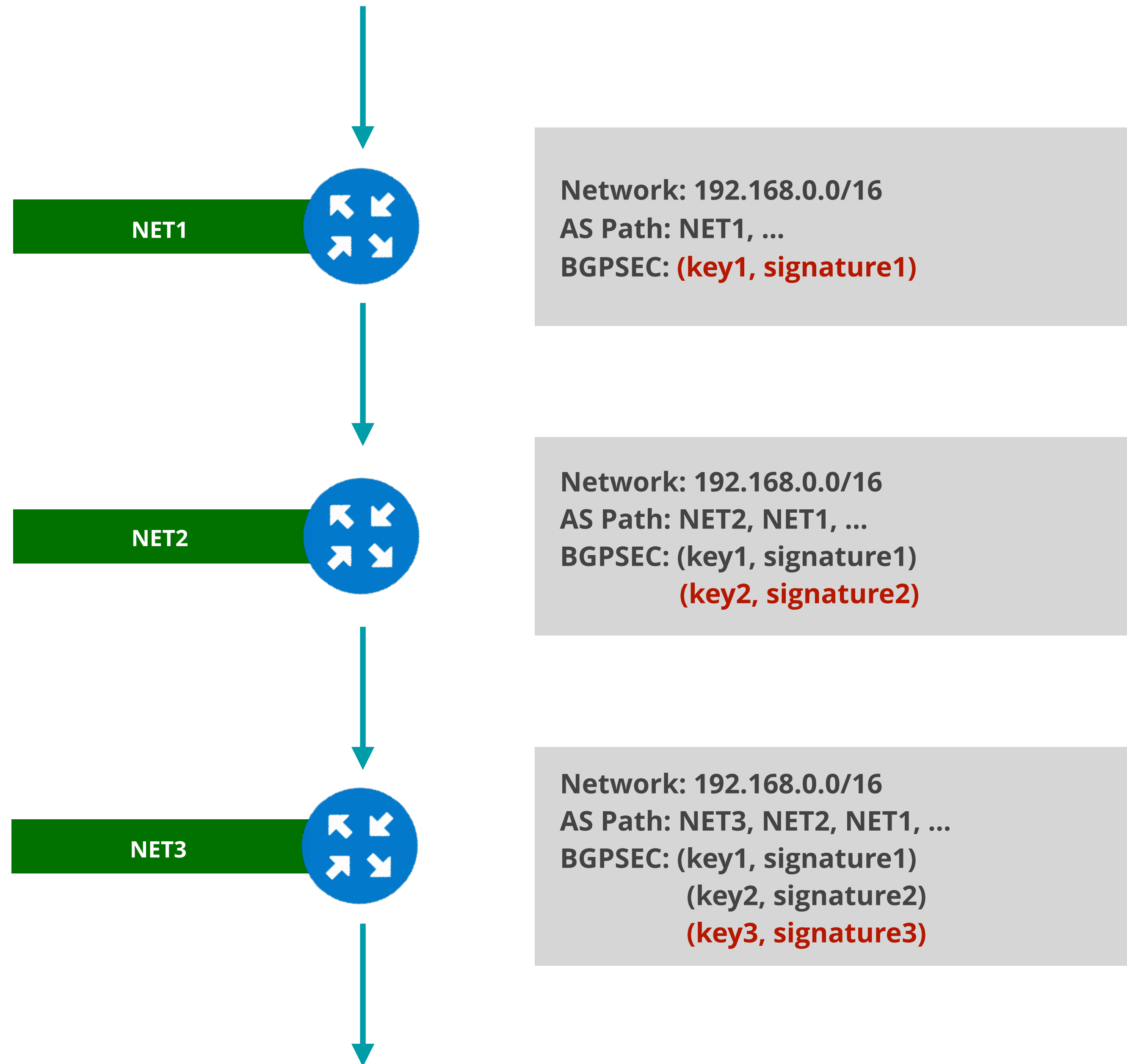
BGPsec

- 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





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

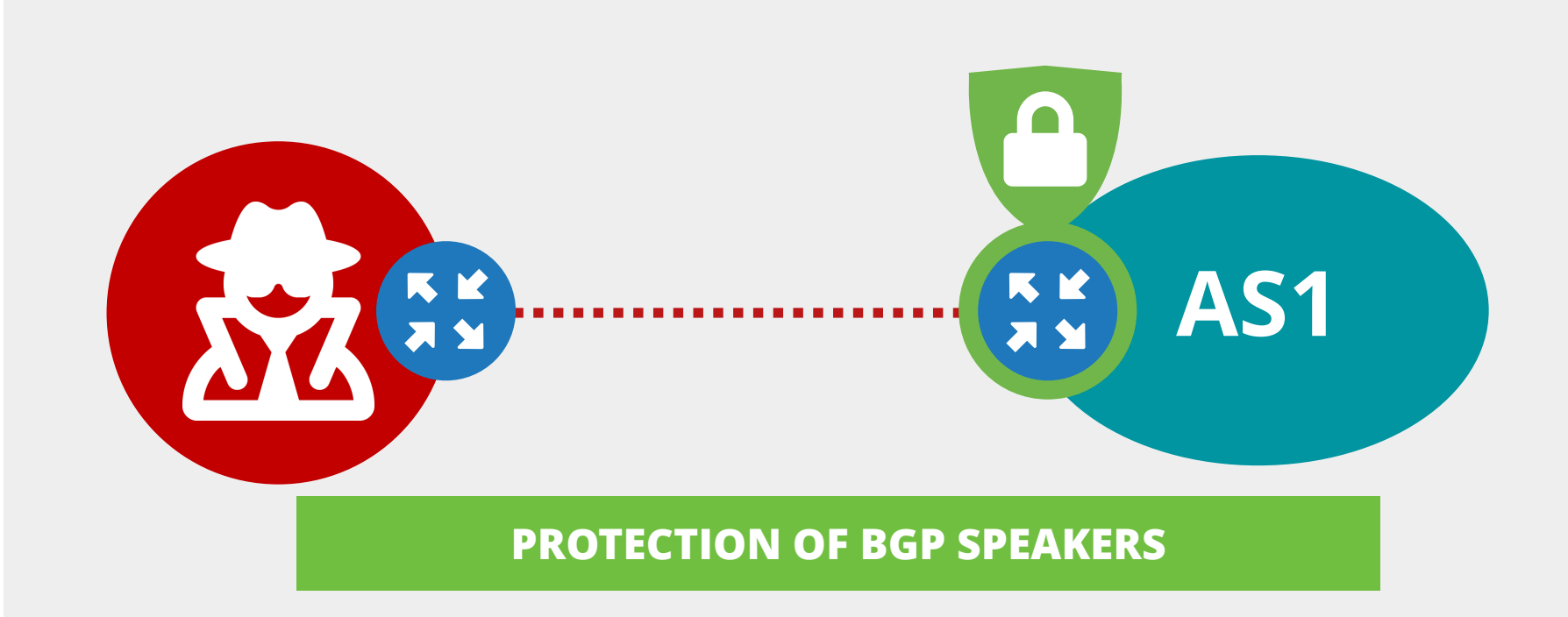
Section 5



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

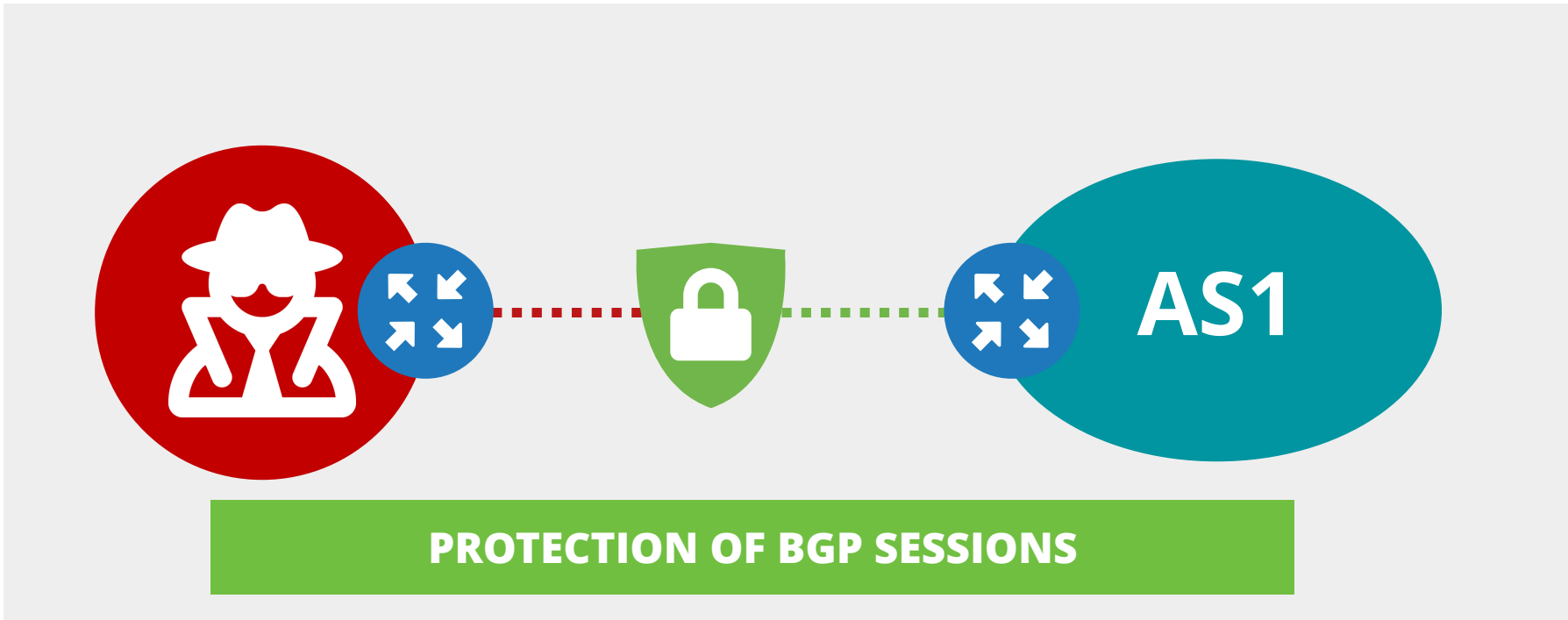
BGP Security Measures



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

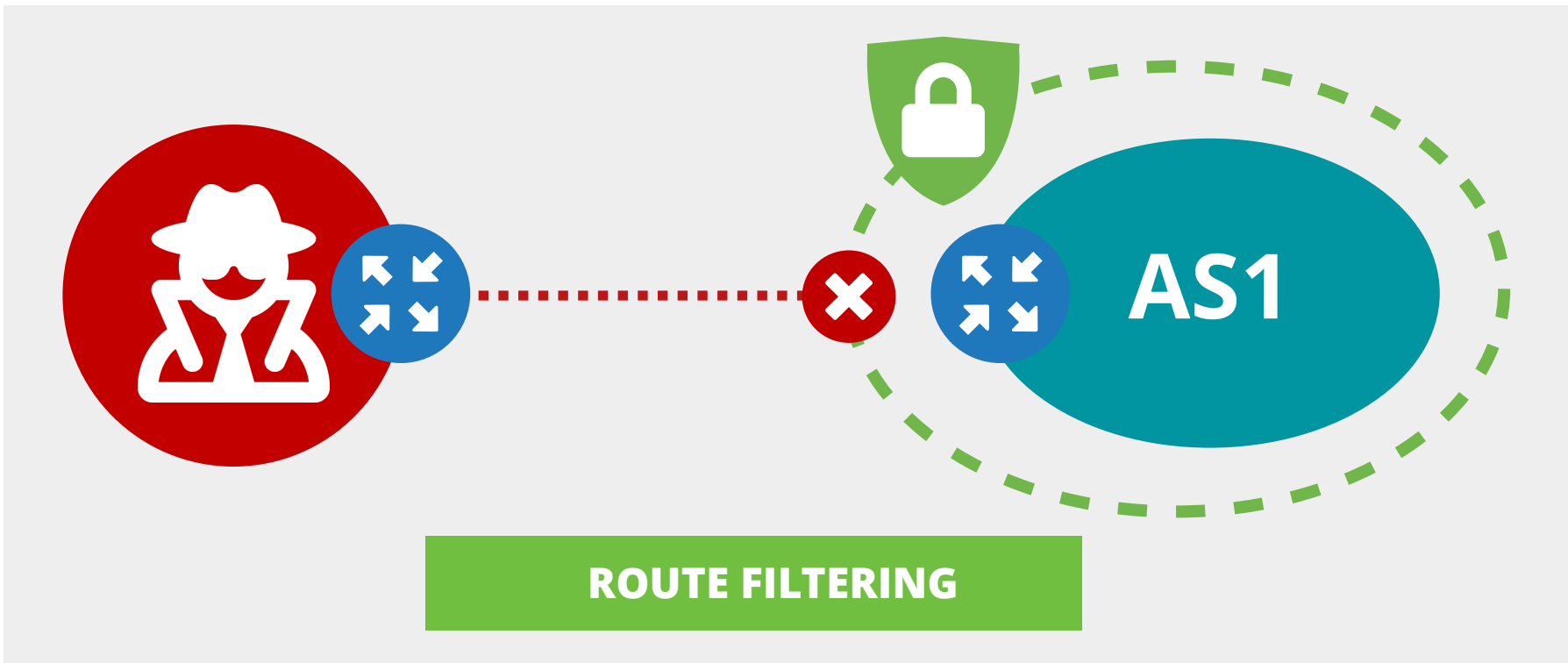


MD5



TCP-AO

BGP TTL Security (GTSM)



Inbound/outbound filters by type of peer

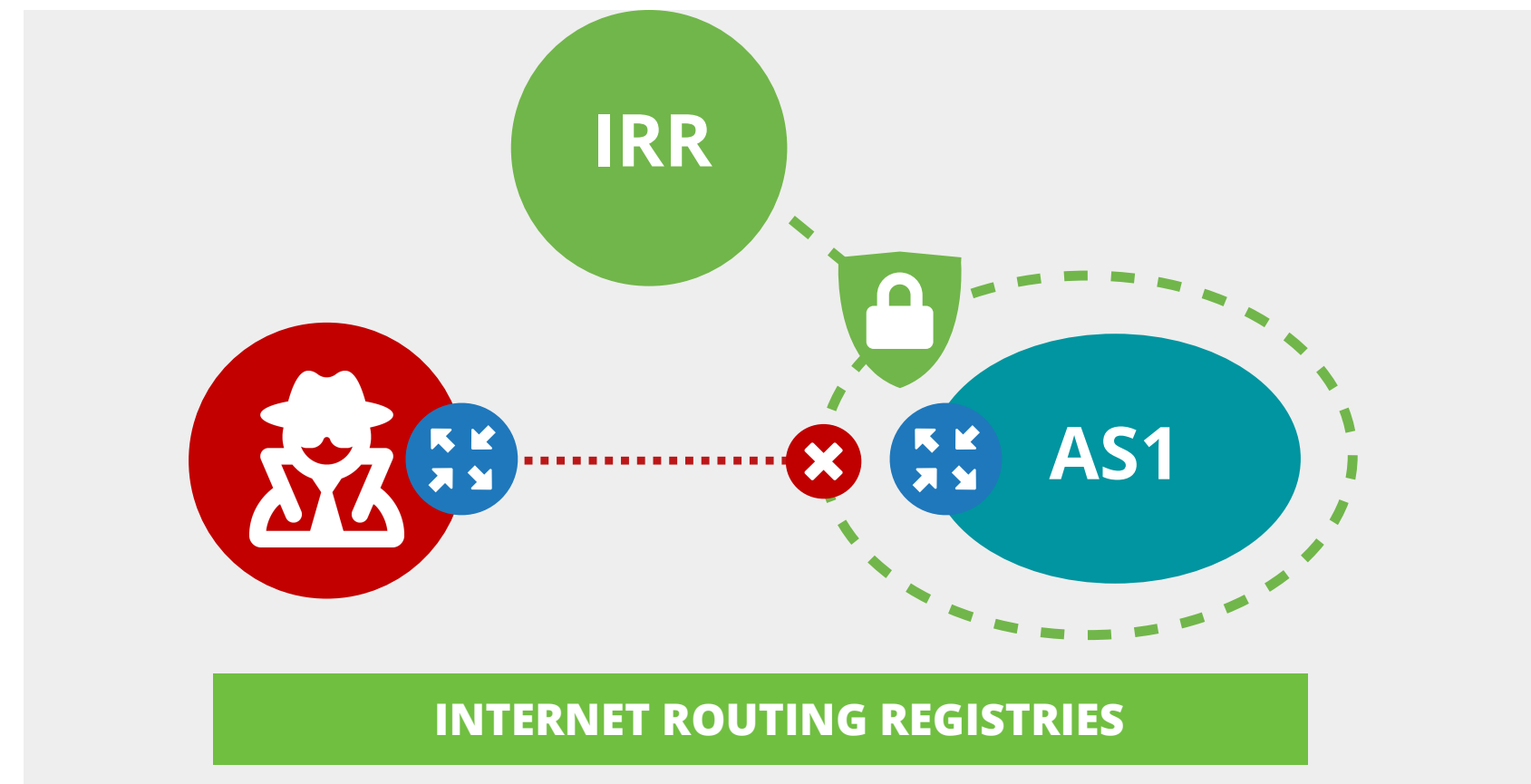


Filtering based on prefixes and/or AS Path



Manual or Automatic (IRRs) configuration

BGP Security Measures



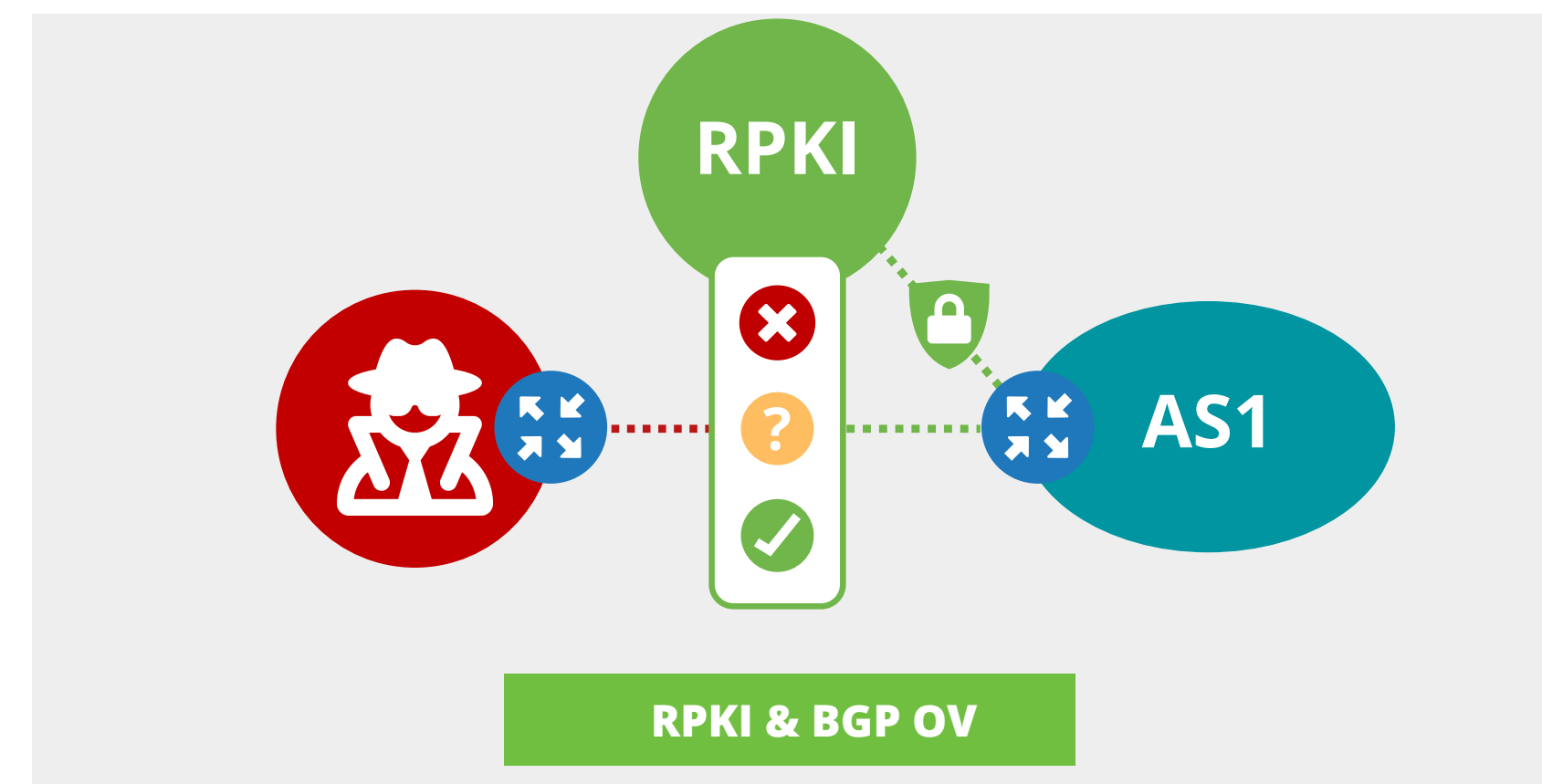
Create your route(6) objects in IRR



Update your IRR info regularly

Automate filters creation (IRR) (double check)

Document your Routing Policy



Create ROAs for your address space



max-length considerations (your most specific)

or, one ROA per prefix and more-specific

Implement BGP Origin Validation (OV)



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



We want your feedback!



What did you think about this session? Take our survey at:

<https://www.ripe.net/feedback/bgp/>



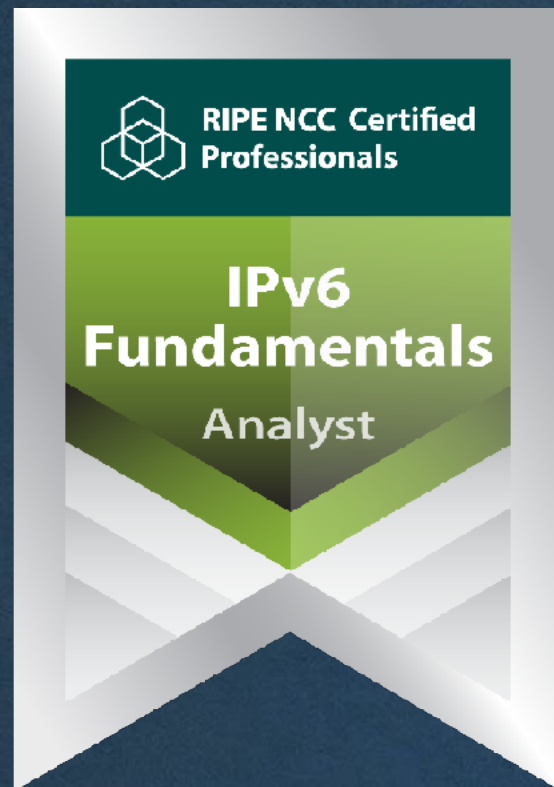


Learn something new today!
academy.ripe.net





RIPE NCC Certified Professionals















<https://getcertified.ripe.net/>



What's Next in BGP?



 Webinars	 Face-to-face	 E-learning	 Examinations
<p>Attend another webinar live wherever you are.</p> <ul style="list-style-type: none">❖ BGP Filtering (1 hr)❖ Deploying RPKI (2 hrs)❖ Introduction to RPKI (1 hr)❖ Internet Routing Registry (1 hr) <p> For more info click the link below</p> <div>learning.ripe.net</div>	<p>Meet us at a location near you for a training session delivered in person.</p> <ul style="list-style-type: none">❖ BGP Routing Security (6.5 hrs) <p> For more info click the link below</p> <div>academy.ripe.net</div>	<p>Learn at your own pace at our online Academy.</p> <ul style="list-style-type: none">❖ BGP Security (10 hrs) <p> For more info click the link below</p> <div>academy.ripe.net</div>	<p>Learnt everything you needed? Get certified!</p> <ul style="list-style-type: none">❖ BGP Security Associate <p> For more info click the link below</p> <div>getcertified.ripe.net</div>

Ěnn	Соңы	An Críoch	پایان	Ende	Y Diwedd
Vége	Endir	Finvezh	վերջ	Кінець	Koniec
Son	დასასრული	הסוף	Tmíem	Liðugt	Finis
Lõpp	Amaia	Loppu	Slutt	Kraj	
Kraj	Sfârșit	النهاية	Конец	Konec	Fund
Fine	Fin	Einde	Fí	Край	Beigas
					Τέλος
Fim	Slut				Pabaiga



Copyright Statement

[...]

The RIPE NCC Materials may be used for **private purposes, for public non-commercial purpose, for research, for educational or demonstration purposes**, or if the materials in question specifically state that use of the material is permissible, and provided the RIPE NCC Materials are not modified and are properly identified as RIPE NCC documents. Unless authorised by the RIPE NCC in writing, any use of the RIPE NCC Materials for advertising or marketing purposes is strictly forbidden and may be prosecuted. The RIPE NCC should be notified of any such activities or suspicions thereof.

[...]

Find the full copyright statement here:

<https://www.ripe.net/about-us/legal/copyright-statement>

