RIPE NCC
RIPE NETWORK COORDINATION CENTER

Ups and downs

BGP Security

Sweet memories (a short recap)

Original BGPv4

Late 1980s – early 1990s

The internet was still very small
Complete trust each other

The main goal is to turn the global network into a self-organizing one (no any security in mind)

The Internet was split into autonomous systems, and the open BGP protocol was born

Since then…

BGPv4 is still here

This technology proved to be a great success

This protocol is still in use today, 30 years after it was created

However, we can no longer trust just anyone on the internet

The protocol as it was originally created does not meet current security and operational standards

Issue statement

Some definitions for incidents

Prefix hijacks and route leaks

Prefix hijack

Originating an announcement by an unauthorized autonomous system

Route leaks

The propagation of BGP announcements beyond their intended scope

Other attributes modification

Real incidents

Stats and root causes

UNIQUE ROUTE LEAKER ASes	Q1, 2026	UNIQUE BGP HIJACKER ASes
1,823	January	9,432
1,960	February	6,294
1,955	March	7,130

Data from https://qrator.net/blog/details/Q1-2026-DDoS-bad-bots-and-BGP-incidents-statistics-and-overview/

Real incidents

Stats and root causes



In average, it is an incident every 4.5 minutes

And most of them happened due to the human mistakes

Data from https://qrator.net/blog/details/Q1-2026-DDoS-bad-bots-and-BGP-incidents-statistics-and-overview/

And now for something completely different

Money talks

But BGP's second main goal is to help operators make money

For 30 years, BGP has been refining ways to improve
our buying and selling traffic

BGP = “Money translated to the routers’ language”
You can't talk about inter-operator BGP without thinking about business

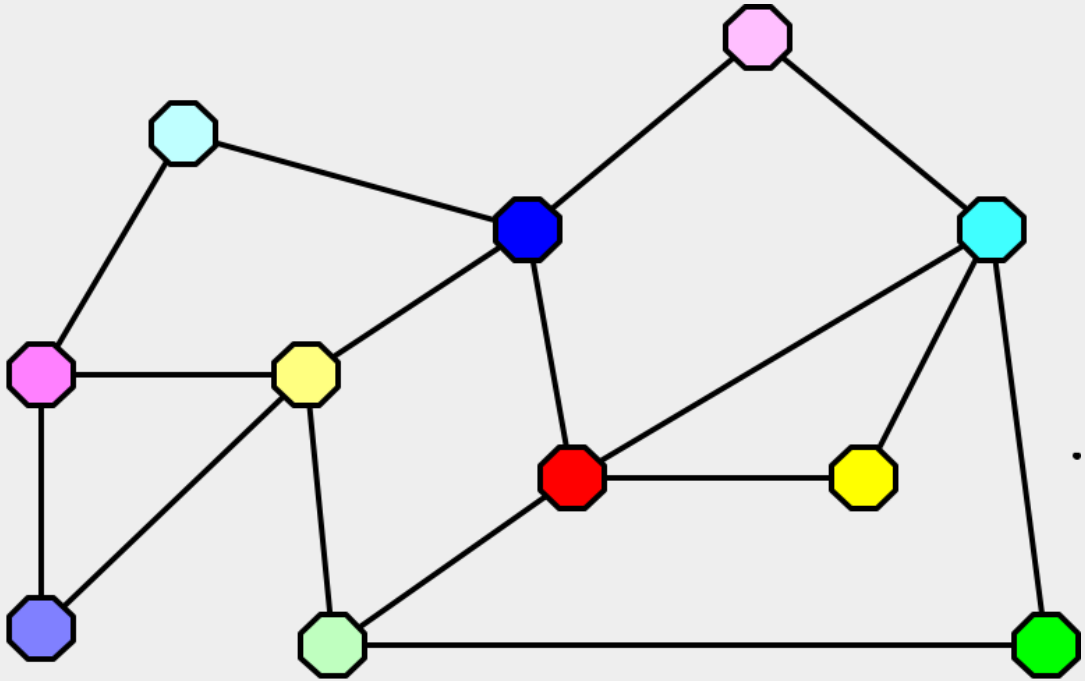
How did we start

Quite chaotic connections

Random traffic exchange

Complex interactions

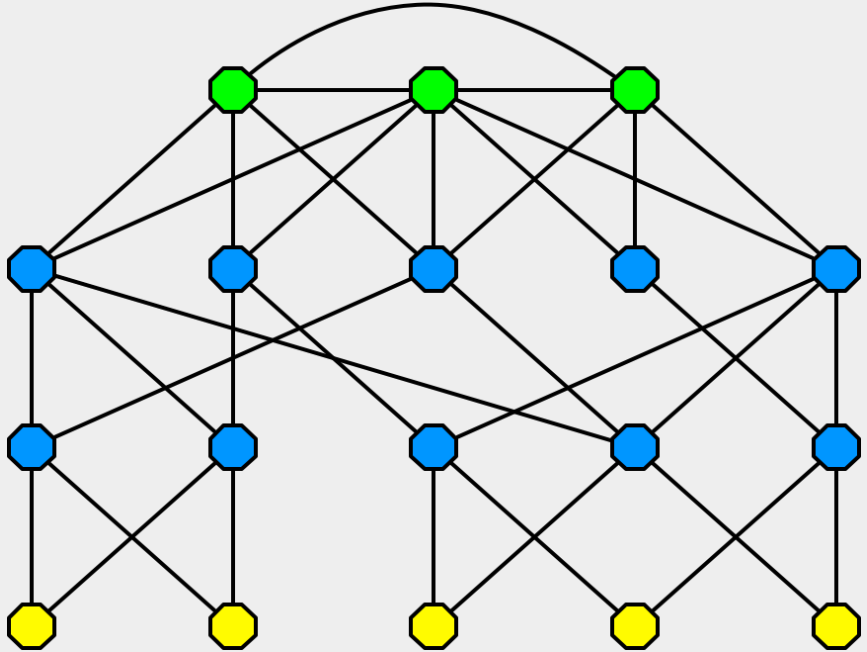
Often non-commercial



And where are we now?

The commercial hierarchy

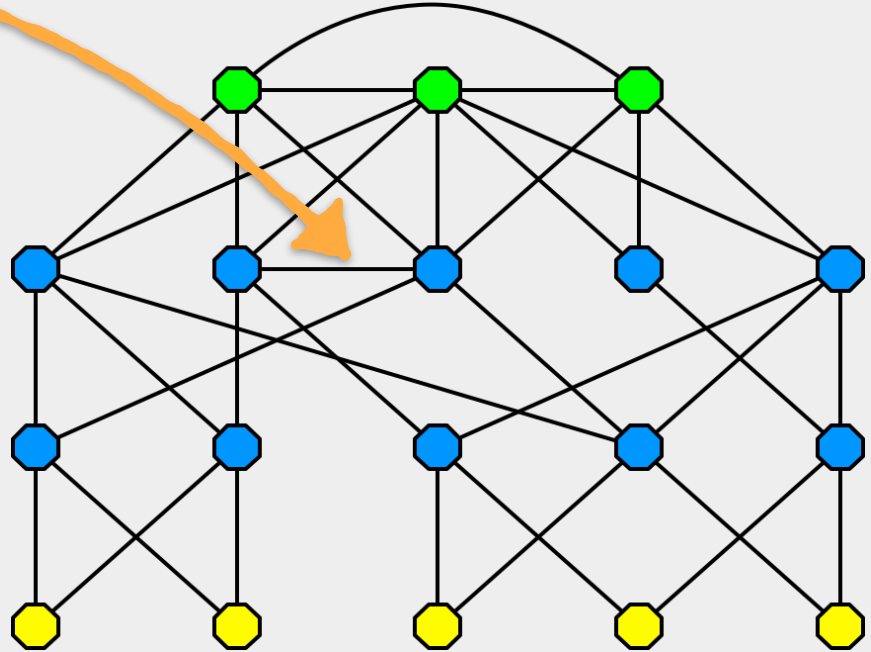
- Operator tiers based on their business model
  - Tier 1: Do not pay anyone for traffic
  - Tier 2: Pay upstream providers and receive revenue from downstream operators
  - Tier 3: Pay upstream providers



And where are we now?

Plus peering

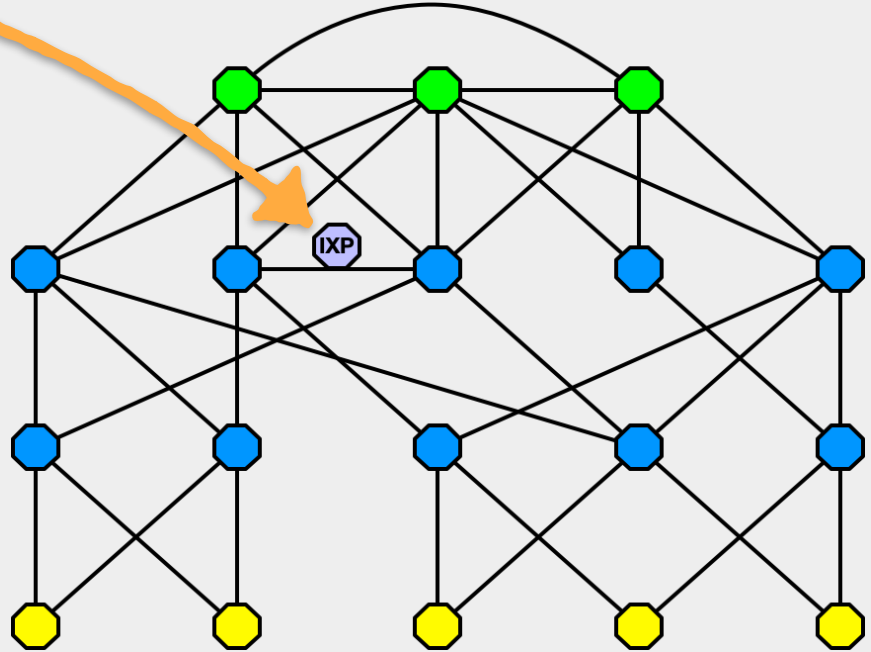
- Peering: exchanging your own traffic and traffic from your clients cone
- In fact, peering was already shown in this diagram
  - Between Tier 1 operators



And where are we now?

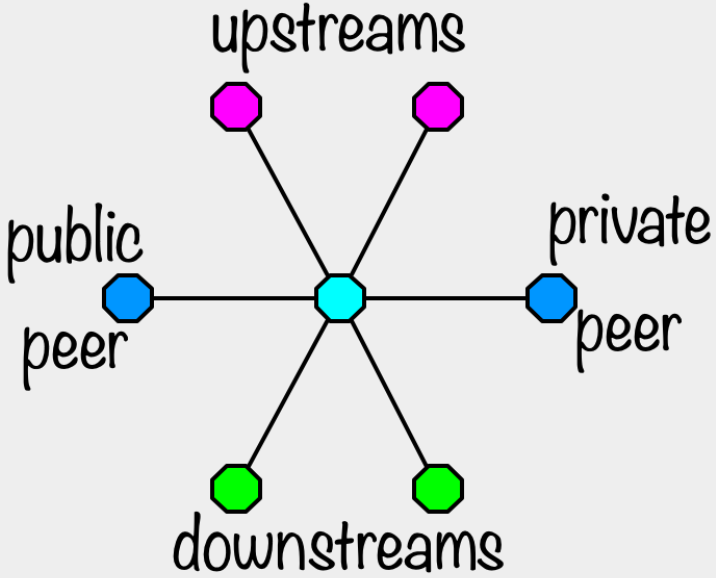
Plus IXP

- Peering at scale: Internet Exchange Points (IXPs)
- Payment is typically not based on traffic volume
- IXPs have their own autonomous system, which is not visible in the AS PATH



Gao-Rexford World

How to propagate announcements?



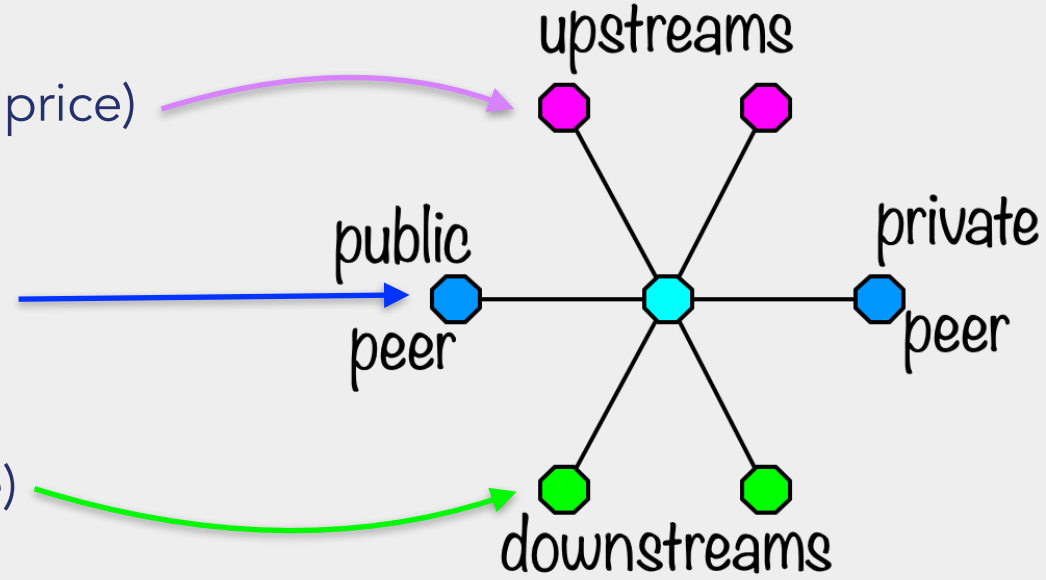
Gao-Rexford World

How to propagate announcements?

We buy traffic (wholesale price)

We do not pay for traffic

We sell traffic (retail price)

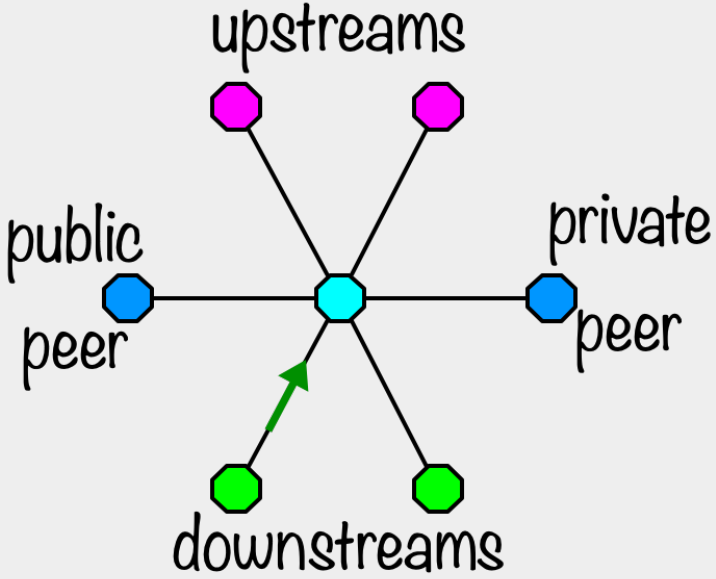


Gao-Rexford World

From a downstream

An announcement from the customer that pays us

So we want him to get a traffic



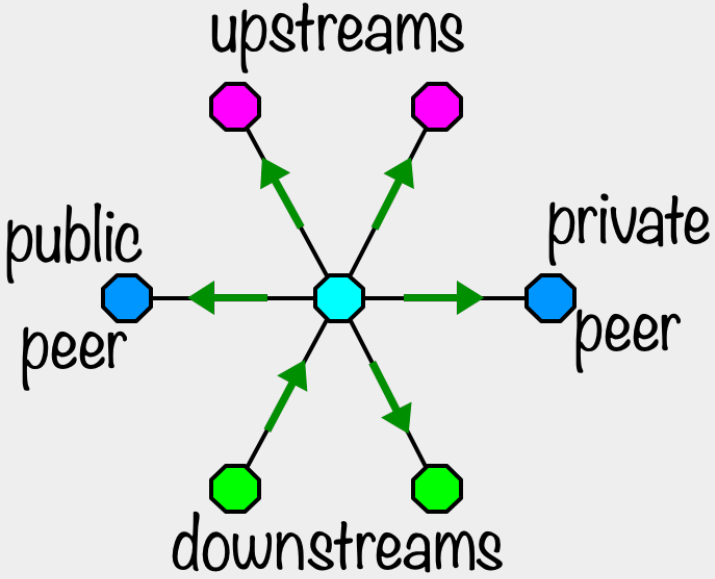
Gao-Rexford World

From a downstream - to anyone else

An announcement from the customer that pays us

So we want him to get a traffic

We are passing this announcement everywhere

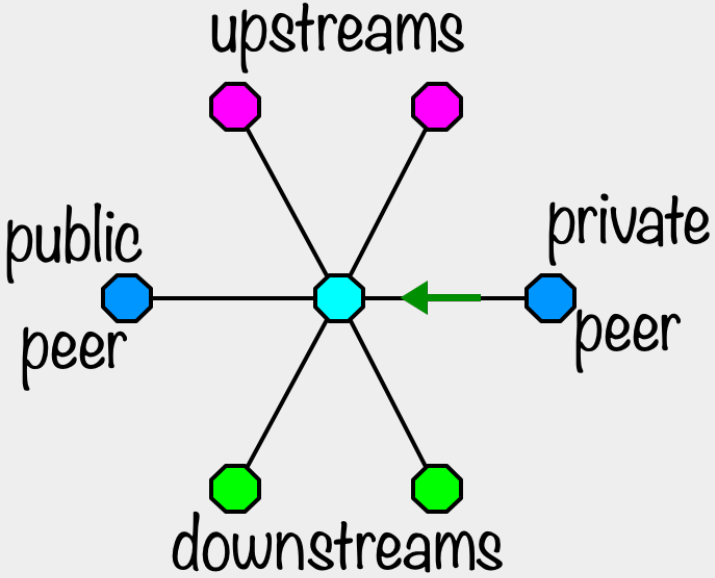


Gao-Rexford World

From a peer

An announcement from the peer that does not pay for traffic

We can earn only if someone else will



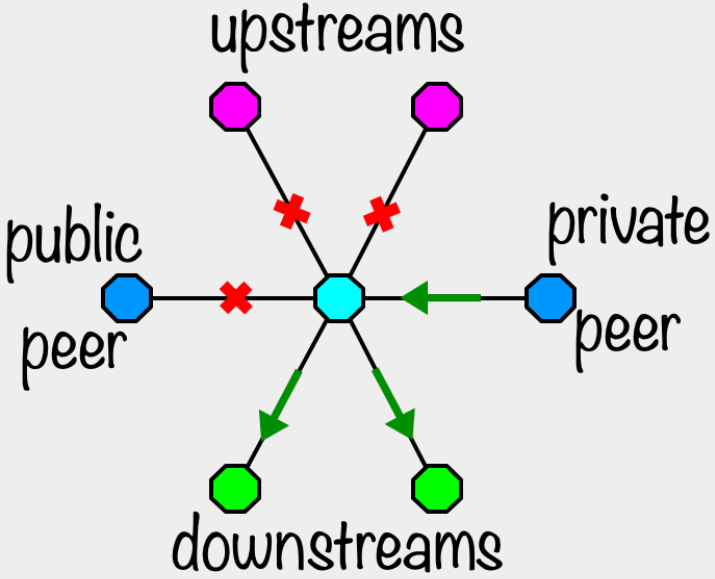
Gao-Rexford World

From a peer to downstreams only

An announcement from the peer that does not pay for traffic

We can earn only if someone else will

So we pass the announcement to downstreams

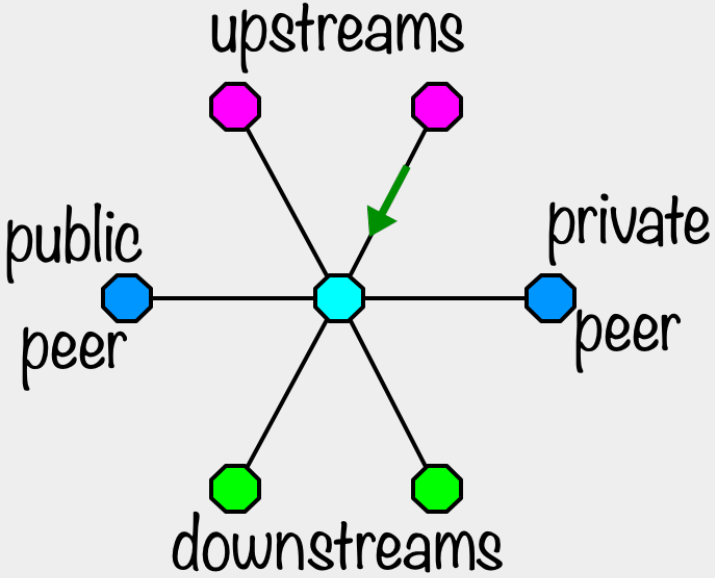


Gao-Rexford World

From an upstream

An announcement from the upstream to whom we pay for traffic

We can earn only if someone else will pay us more



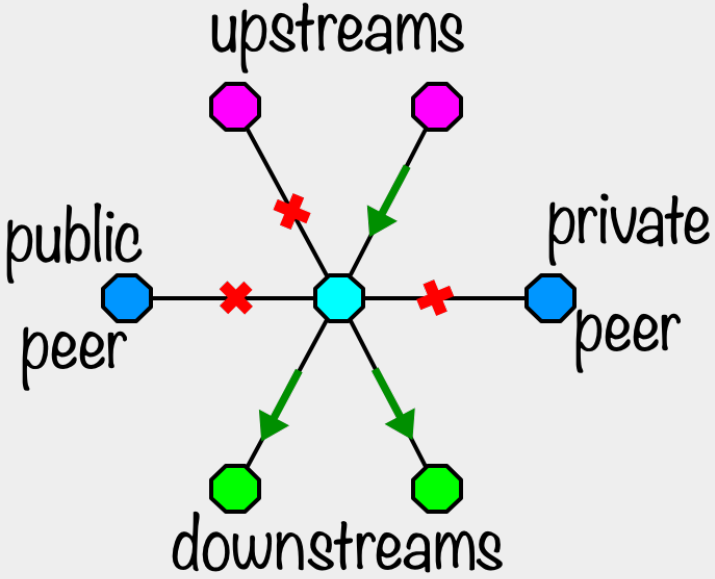
Gao-Rexford World

From an upstream to downstreams only

An announcement from the upstream to whom we pay for traffic

We can earn only if someone else will pay us more

So we pass the announcement to downstreams only



Long story short

The rule of thumb

Announcements coming **from below** are propagated **everywhere**

All other announcements are propagated **only downward**

An announcement resembles an avid mountaineer: it goes first up, then down - but never along a valley

How is it reflected in BGP?

How is it reflected in BGP?

It is not

The original BGP had absolutely no concept of “up” or “down”

Are we doomed?

No, we are not

Technologies aren't set in stone

For decades, the industry has been developing solutions within the IETF

Many of them proved unsuccessful and remained on paper

But not all of them!

RPKI
as a prerequisite

Principles to remember

Sources of trust external to BGP are required

Business relationships should be taken into account

Deployment should be gradual
(Interoperability with old realisations is a must)

Resource Private Keys Infrastructure (RPKI)

A framework

Not a single mechanism, but
an ***extensible* and *centralized* framework**
New “bricks” can be added
Now we have two: ROA and ASPA

Completely **external to BGP**
No new attributes, no new AFI/SAFI families

Authorisation is built-in and cannot be bypassed

Resource Private Keys Infrastructure (RPKI)

Two sides of the same coin

Ties entities cryptographically
E.g., an IP prefix and it's originating ASN

Relies on chains of trust
With trust anchors in RIRs

So there are two parts
one side is responsible for creating signed "statements" (**signing**),
and the other is responsible for using them with BGP (**validating**)

(old good)
RPKI ROA

Route Origin Authorisation in RPKI (RPKI ROA)

Fighting prefix hijacks

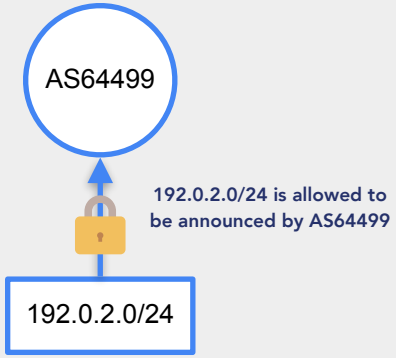
A popular technology that has been widely adopted around the world

A cryptographic binding is created **between an IP prefix and the autonomous system** authorized to originate traffic from that prefix

This binding is called a ROA; once created, it is published in a public repository (**signing**)

Validating networks download all ROAs, filter out the faulty ones, and use remaining **to match origins of incoming BGP announcements**

Invalid announcements are [to be] discarded



Route Origin Authorisation in RPKI (RPKI ROA)

Where to find out more

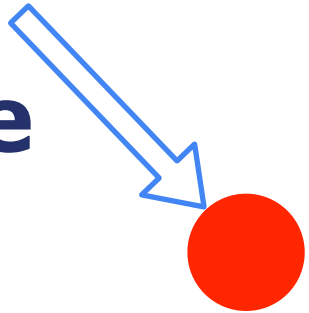
Our training courses

- Deploying RPKI Webinar
- Introduction to RPKI Webinar
- BGP Routing Security Training Course (face-to-face, 1 day)

Self-paced learning: RIPE Academy

- Microlearning course: Why RPKI?
  https://academy.ripe.net/mod/scorm/player.php?a=110&currentorg=articulate_rise&scoid=220
- Microlearning course: What is RPKI?
  https://academy.ripe.net/mod/scorm/player.php?a=116&currentorg=articulate_rise&scoid=232
- Full e-Learning course: BGP Security
  https://academy.ripe.net/course/view.php?id=15

You are here



BGP Roles

BGP Roles

“Let's color this page”

- For each session we are specifying **the role from our side**:
  - customer
  - provider
  - peer
  - RS
  - RS-client

- Our role should **match the role from the side of our neighbour**

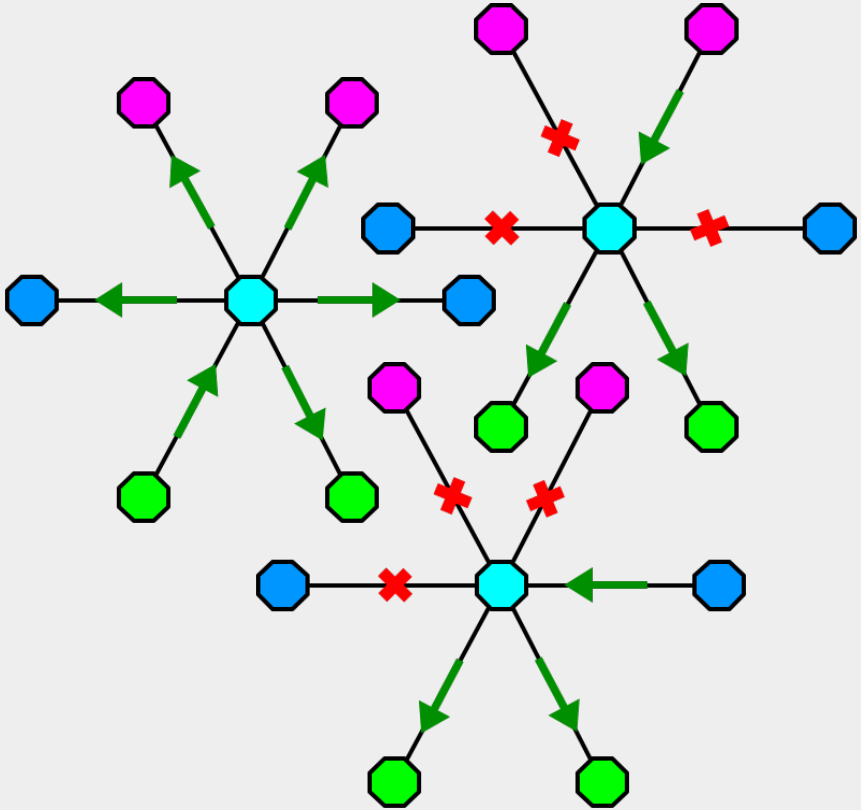
- When an announcement is first sent downward or to the side, the AS should add the **OTC (Only-To-Customer) attribute** with its ASN as the value
  - Transitive optional
  - Attribute Type Code 35

- An announcement not from customers (especially **with the OTC** attribute) can only be sent **via sessions with the local “provider” role**

BGP Roles

A familiar mountain landscape

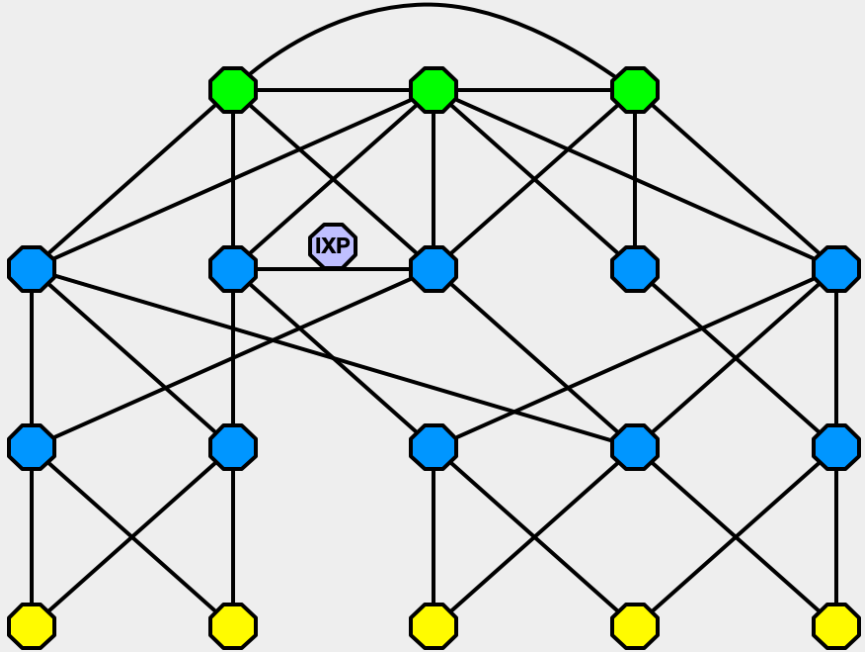
- Without the OTC attribute
  - Each node just follows Gao-Rexford rules locally



BGP Roles

A familiar mountain landscape

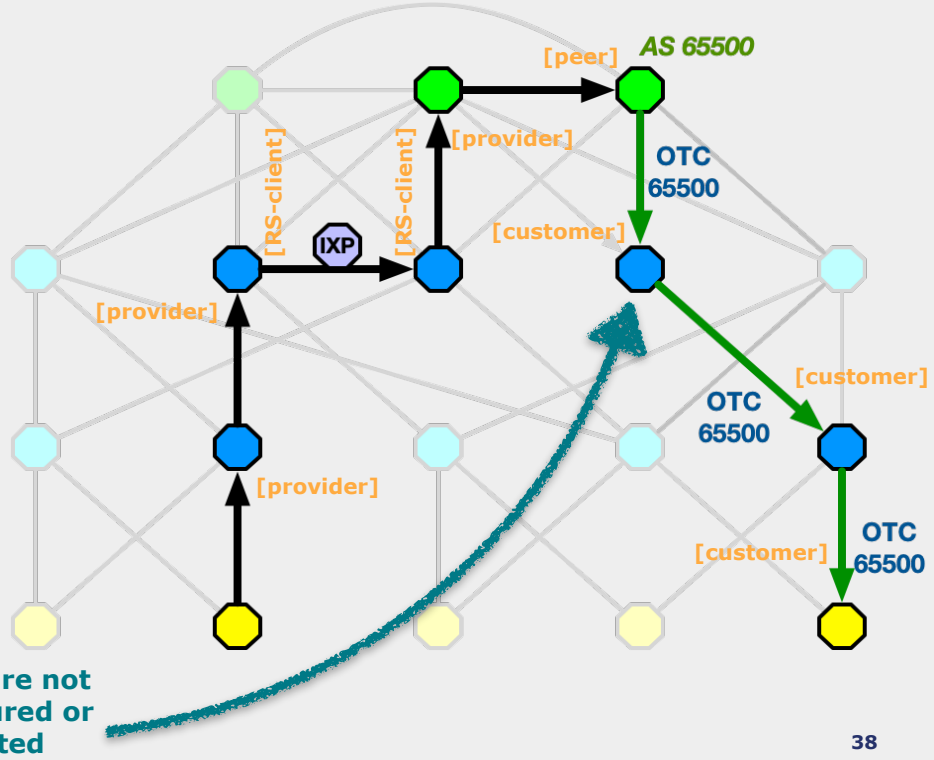
- Using the OTC attribute



BGP Roles

A familiar mountain landscape

- Using the OTC attribute
  - It doesn't matter how we climb
  - But we only make it down to the sessions with clients
  - It is transitive so if BGP Roles are not supported on some step, the logic can be restored after them



BGP Roles

Who is supporting?

Routing Software

BIRD
FRRouting
OpenBGPD
VyOS

Hardware

Juniper
Huawei
MikroTik (partially, no OTC support)

RFC 9234 - ask your manufacturer!

RPKI ASPA

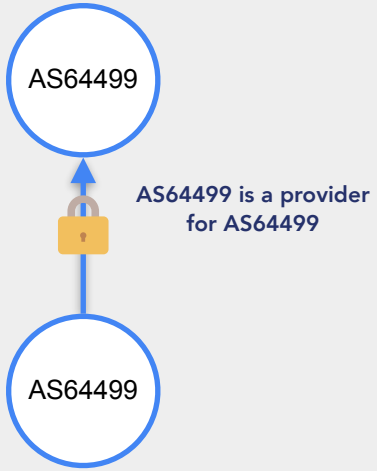
Autonomous System Provider Authorization (RPKI ASPA)

General principles

A cryptographic binding **between AS and and it's upstream:**
(Business relationships now are stored in the centralized way)

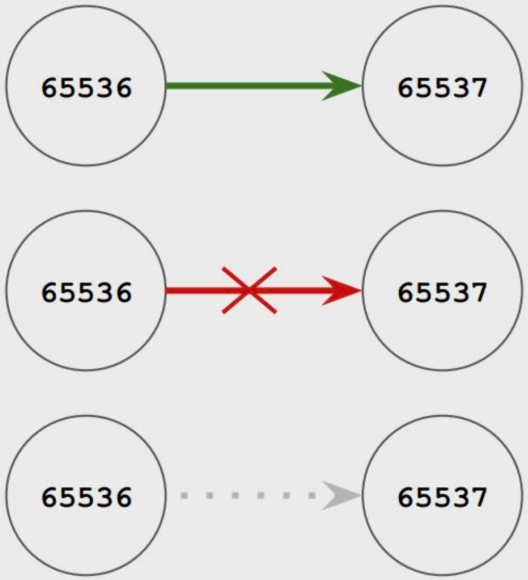
This binding is called an **ASPA**; once created, it is published in a public repository (**signing part**)

Validating networks download all ASPAs, filter out the faulty ones, and use remaining to **match AS PATH in incoming BGP announcements**



Provider Authorization Function

Fundamental Function to Evaluate AS Pairs



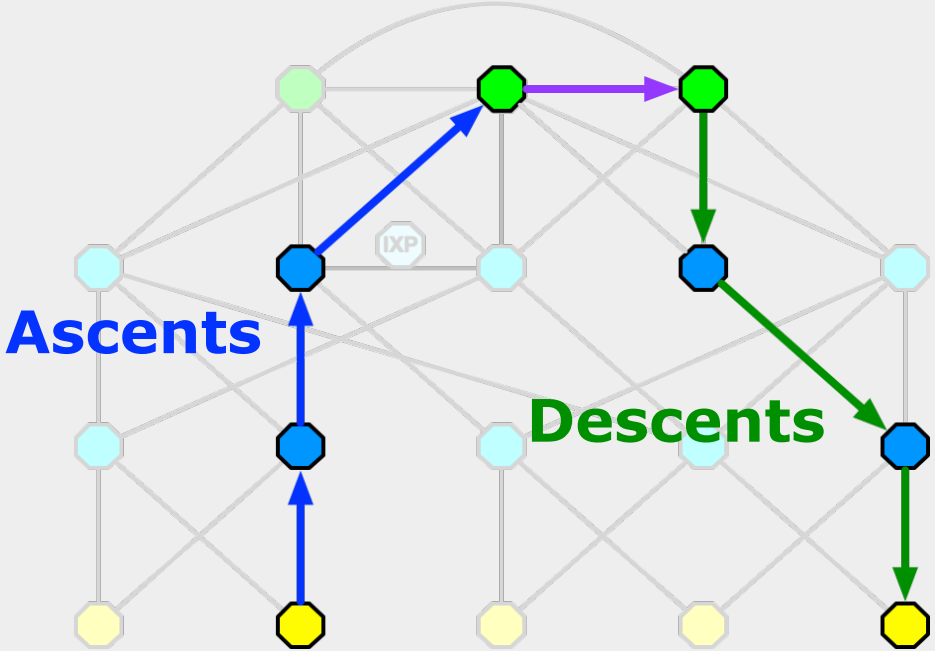
Provider	65536 has an ASPA including 65537
Not Provider	65536 has an ASPA without 65537
No Attestation	65536 has no ASPA

ASPA Rules

ASPA matching: no valleys in mountains of routing

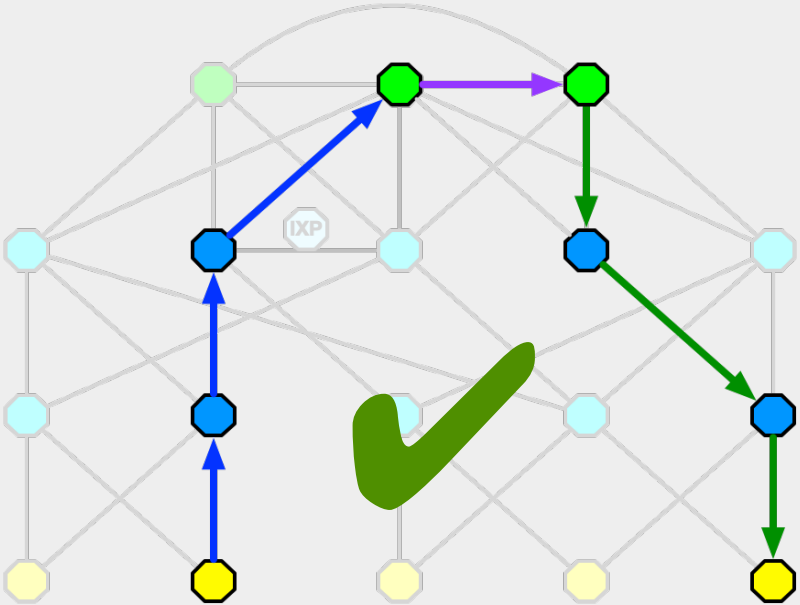
- **Ascent:** the **c ➤ p** segment
  Descent: the **p ➤ c** segment
  Valley: a node breaking Gao-Rexford rules

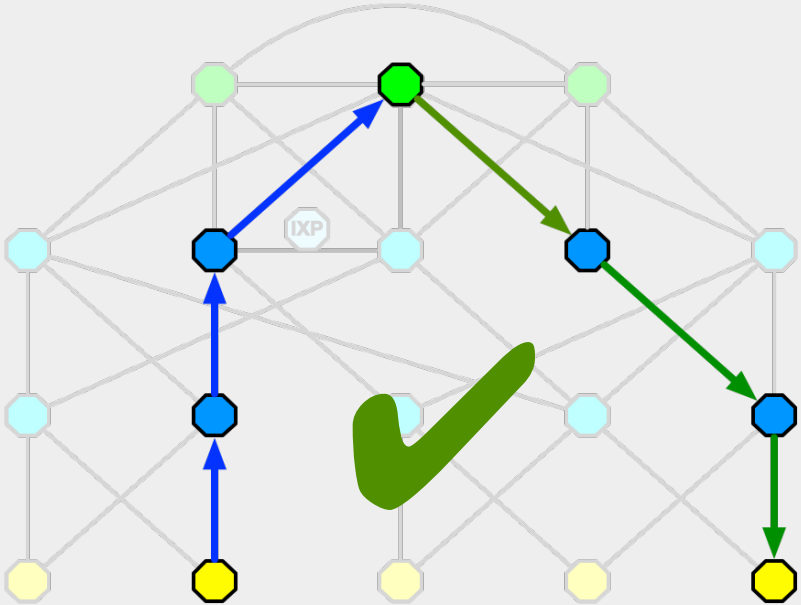
- The AS PATH:
  - only ascents at the beginning
  - only descents at the end
    - (no valleys)
  - not more than one horizontal segment in between



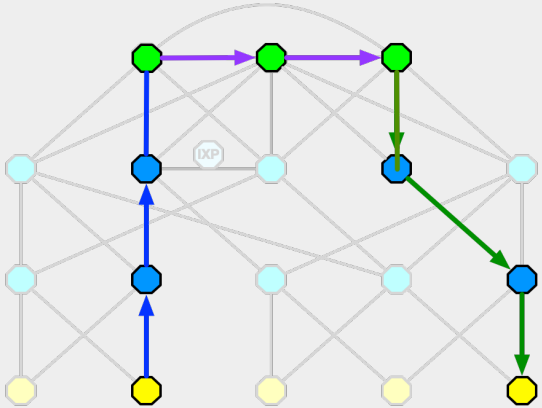
ASPA Rules: DOs

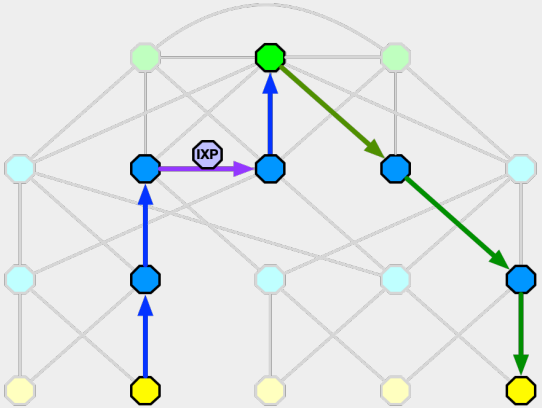
It’s easier to show: what is good

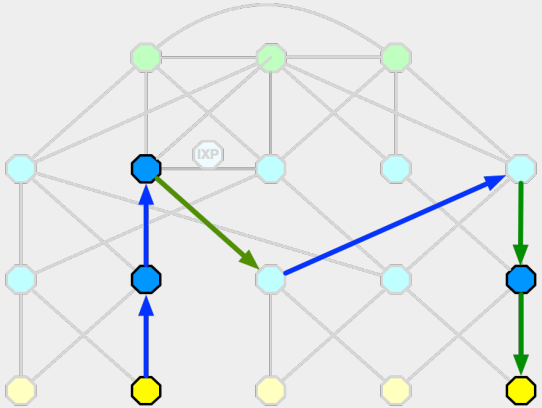




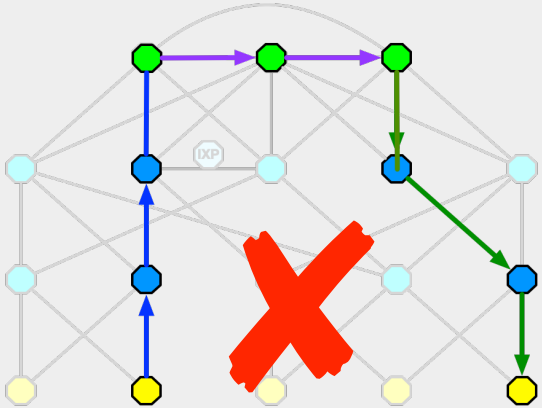
ASPA Rules

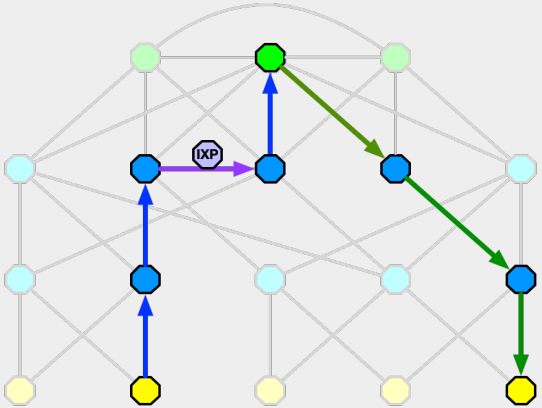


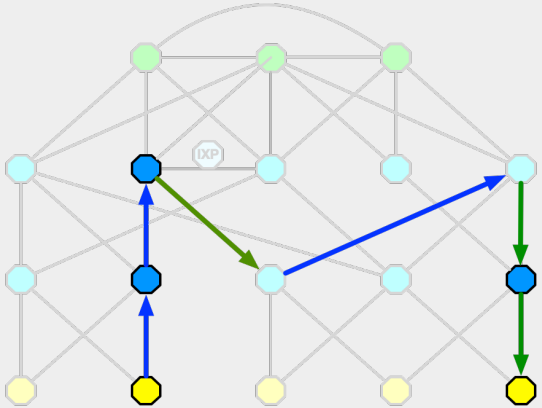




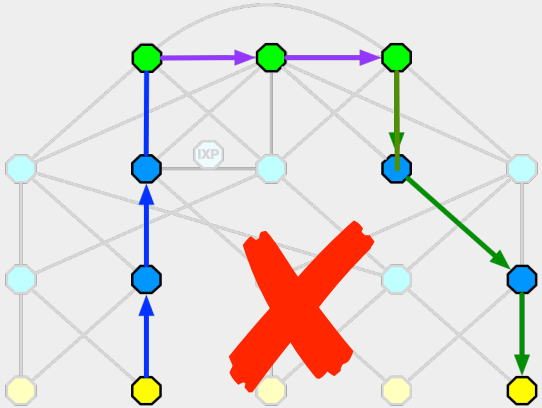
ASPA Rules: DONT

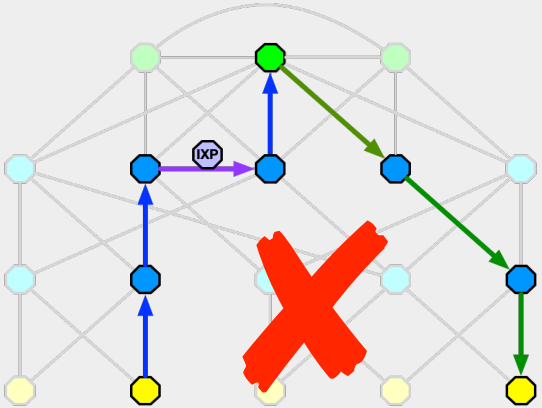


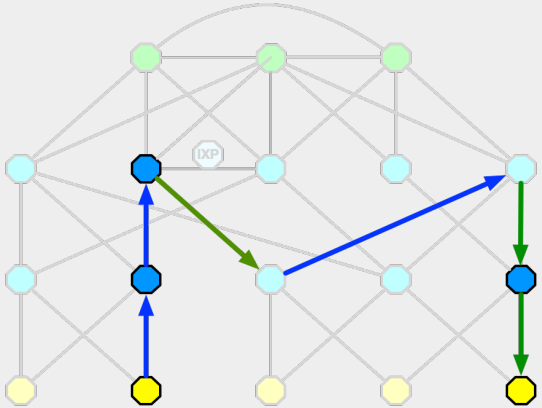




ASPA Rules: DONTs

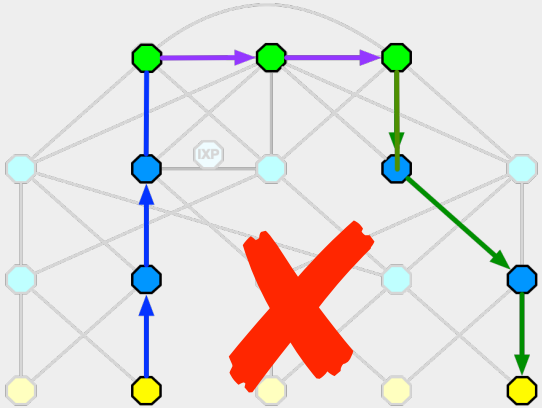


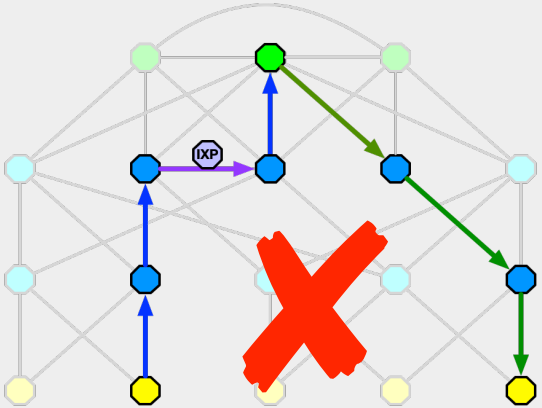


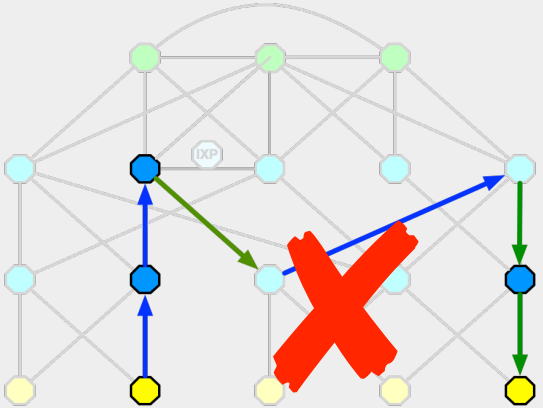


ASPA Rules: DONTs

It’s easier to show: what is bad







AS0 role

ASPA with non-existing provider?

AS0 is reserved and cannot be in the AS_PATH attribute… But can be in ASPA

AS0 is deliberately used as the provider if this autonomous system cannot have one

So any next AS gets “Not Provider” instead of “No Attestation”

Used by:

- Tier-1/Transit-free Networks
- Transparent Route Servers
- Route Collectors
- Or even unused ASNs

Autonomous System Provider Authorization (RPKI ASPA)

Who is supporting?

RIR Repositories (signing)
Production: RIPE NCC, ARIN
Planned: APNIC, LACNIC, AfriNIC

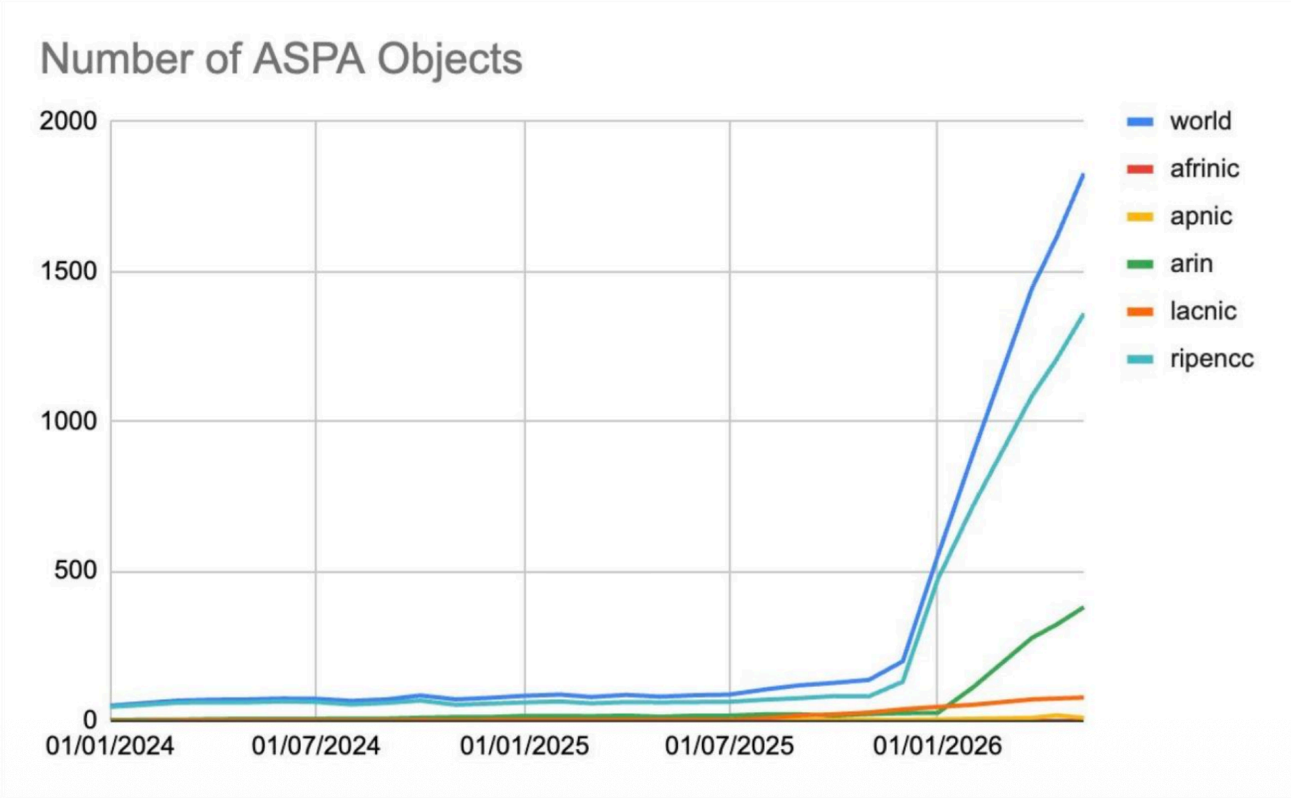
Who validates it
RIPE NCC
Cloudflare
Hurricane Electric
Cogent
(…)

Validators
Routinator
FORT Validator
rpki-client

Software routers
Bird
OpenBGPD
NIST BGP-SRx

Hardware routers
None at the moment
(Cisco, Huawei - test releases)

ASPA Signing Uptake



BGPSEC

New attribute

AS_PATH is no longer mandatory: **BGPsec_PATH** is used instead
They cannot be used together

Either BGPsec_PATH or AS_PATH should present

BGPsec_PATH is not transitive
If a next peer does not support BGPsec_PATH,
it MUST be converted to AS_PATH

BGPsec_PATH consists of two chains
Secure_Path: equivalent to AS_PATH
Signature_Block: signature sequence for Secure_Path segments

Signing: blockchain technologies in the world of routing

Each routers signs the whole Secure_Path and the previous Signature_Block

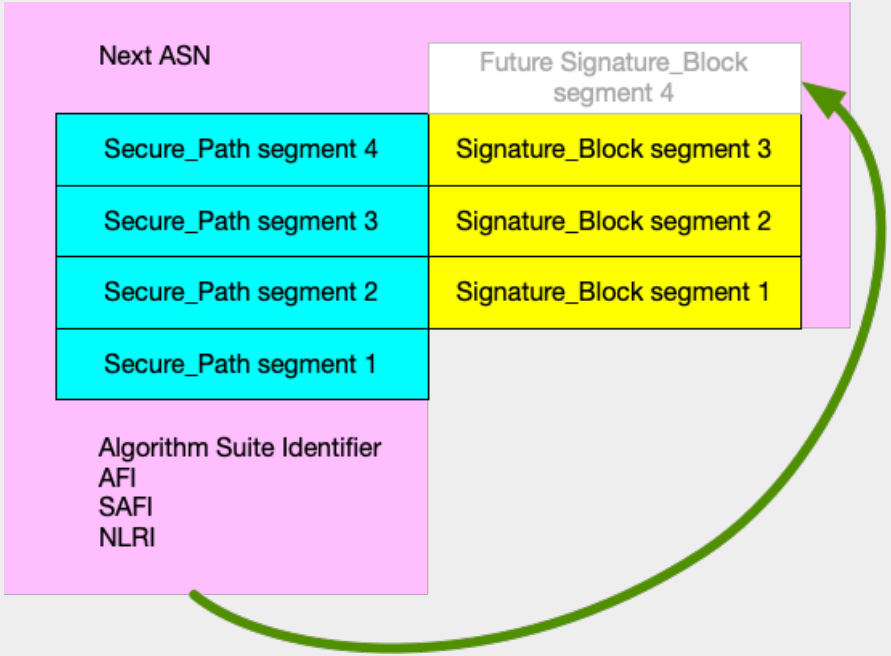
- use all signatures from the previous step in the new signature generation process

On the validation stage we **check all signatures** in the reverse order

BGPsec Router Certificates are used to verify signatures

- public RPKI repositories

Graphically



NLRI is used on each step

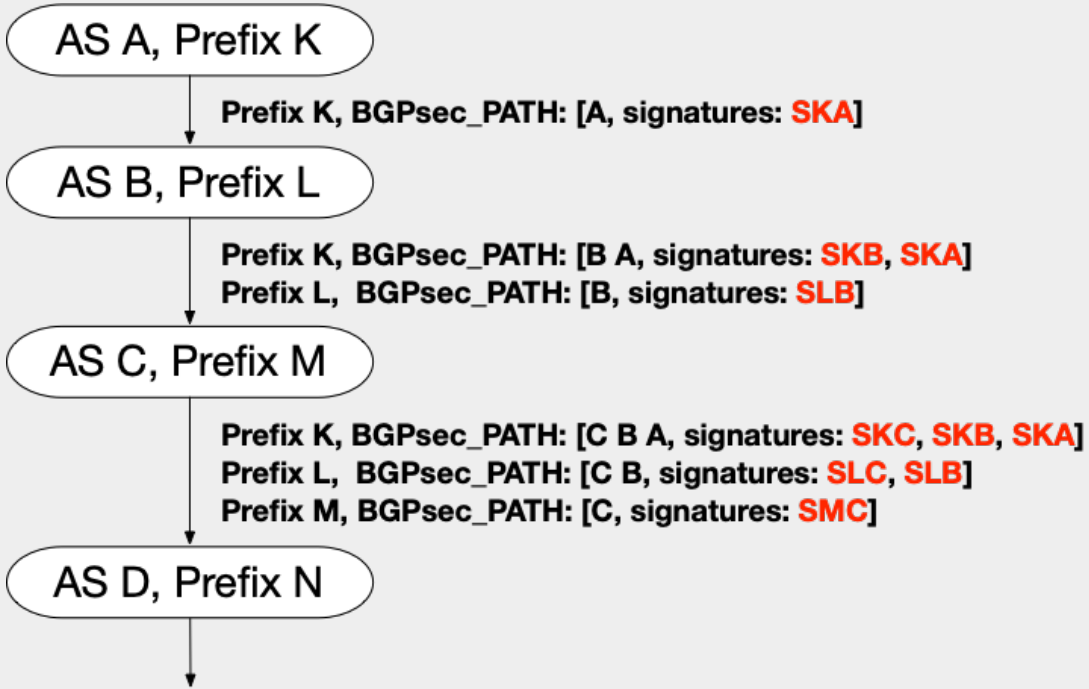
All previous signatures are used on each step

Not too much to cache

Cryptographic operations cannot be performed in advance

Validation

- All cryptographic checks must be performed **between** the receipt of the announcement and its processing
- As the network grows, the number of expensive operations increases **nonlinearly**



Surprise!

Have you seen how business relationships are described in BGPSEC?

Surprise!

Have you seen how business relationships are described in BGPSEC?

No, because they aren't described there at all

In its current form, it won’t anyhow help with route leaks

What ever can go wrong?



Partial control

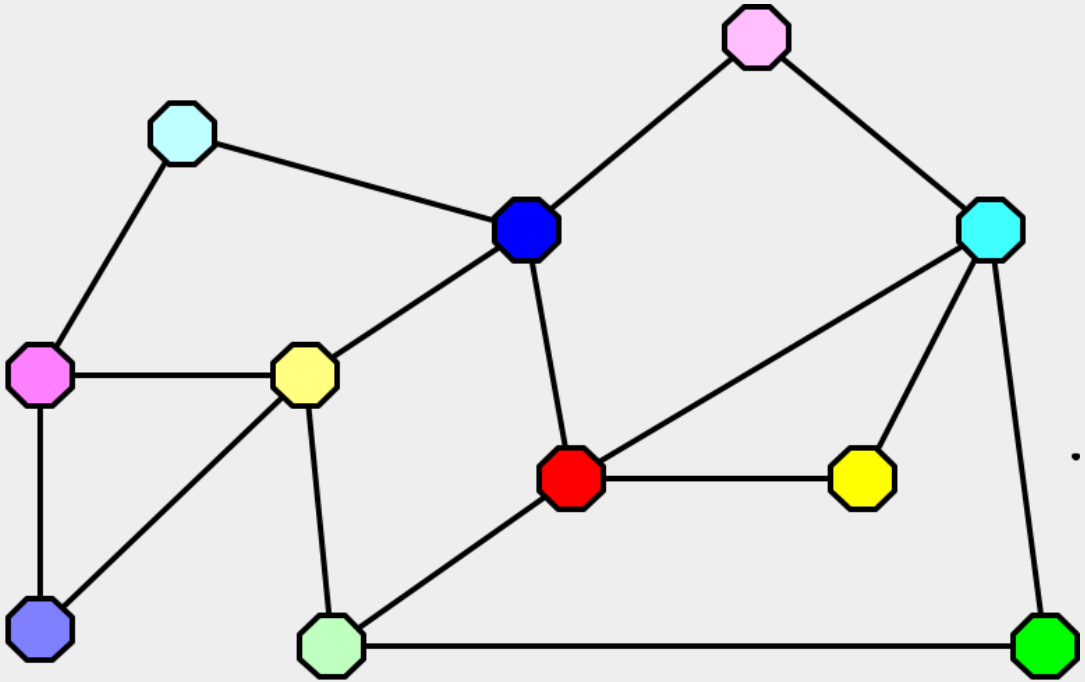
BGP Roles
Control only over the descent

ASPA
It might be difficult to judge the announcement when only part of the AS path is covered
(“a valley or a missing ASPA?”)

BGPSEC
No business relations reflected, so no leak control

Couple steps back (slides 9 and 10)

BGP = “Money translated to the routers’ language”



Complex scenarios

“You scratch my back, I'll scratch yours”?

Operators may have different roles:

- For different types of traffic
  (“you’re my upstream provider over IPv4, and I’m yours over IPv6”)
- For different regions
  (“I provide you with traffic in Asia, and you provide me with it in Europe”)

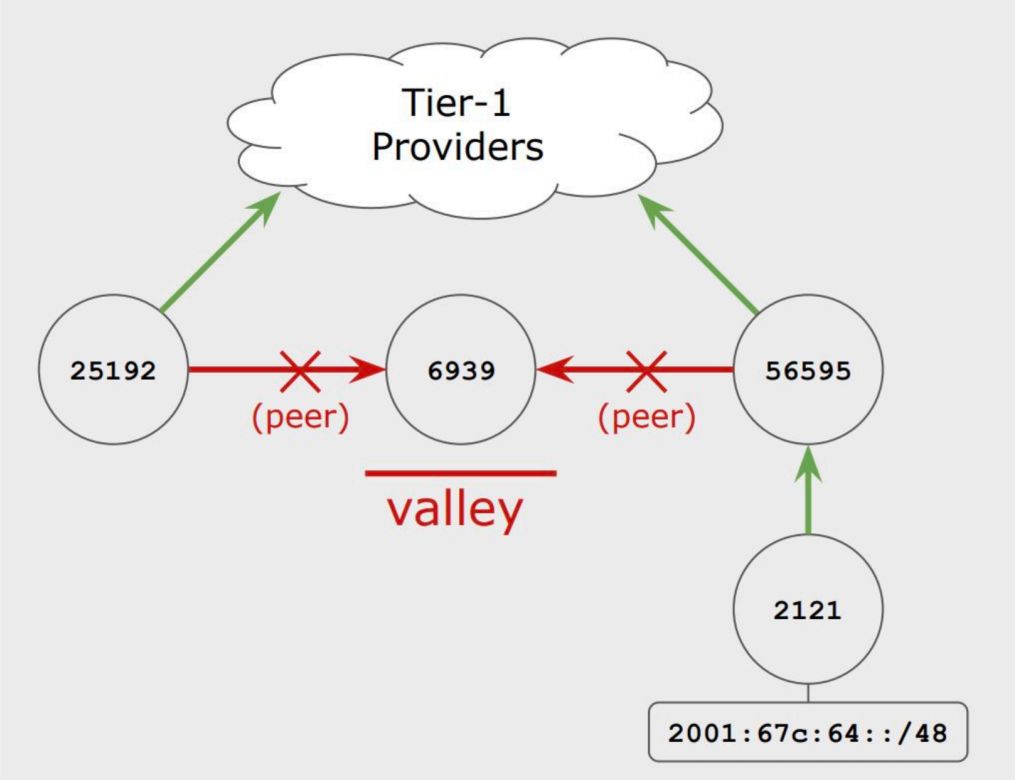
BGP Roles

- Can be solved with multiple BGP sessions

ASPA

- Everything is tougher, we need different ASNs and some additional BGP engineering

Real life: RIPE meeting validation case



RIPE Meeting network (2121) had one ISP (56595).

Both 56595 and 25192 consider 6939 a peer and issued ASPA objects, but 6939 provided IPv6 transit.

ASPA did the ASPA-right thing. Both 56595 and 25192 told us that 6939 is not a provider

Old techniques issues

Summarisation is not supported

ROA is not compatible with a tail AS_SET

- The announcement will be classified as INVALID if the covering ROA object is published

BGP Roles is not compatible with summarisation

- OTC will be lost

ASPA is not compatible with AS_SETs

- The announcement will be classified as INVALID if the ASPA object is published

Specific issues

A way too expensive computationally

For it to really work, 100% adoption is required

It doesn't solve every problem
Security is top-notch, but
operational errors (route leaks) aren't detected

Conclusions

Conslusions

There is no silver bullet

But there is **a lot that can and should be done** right now

You need to wash your hands, brush your teeth,
and use routing security mechanisms

Don't accumulate technical debt

RIPE NCC
RIPE NETWORK COORDINATION CENTER

Questions?
Comments?
Applause?

asemenyaka@ripe.net