BGP Origin Validation

ISP Workshops

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Last updated 16th November 2021

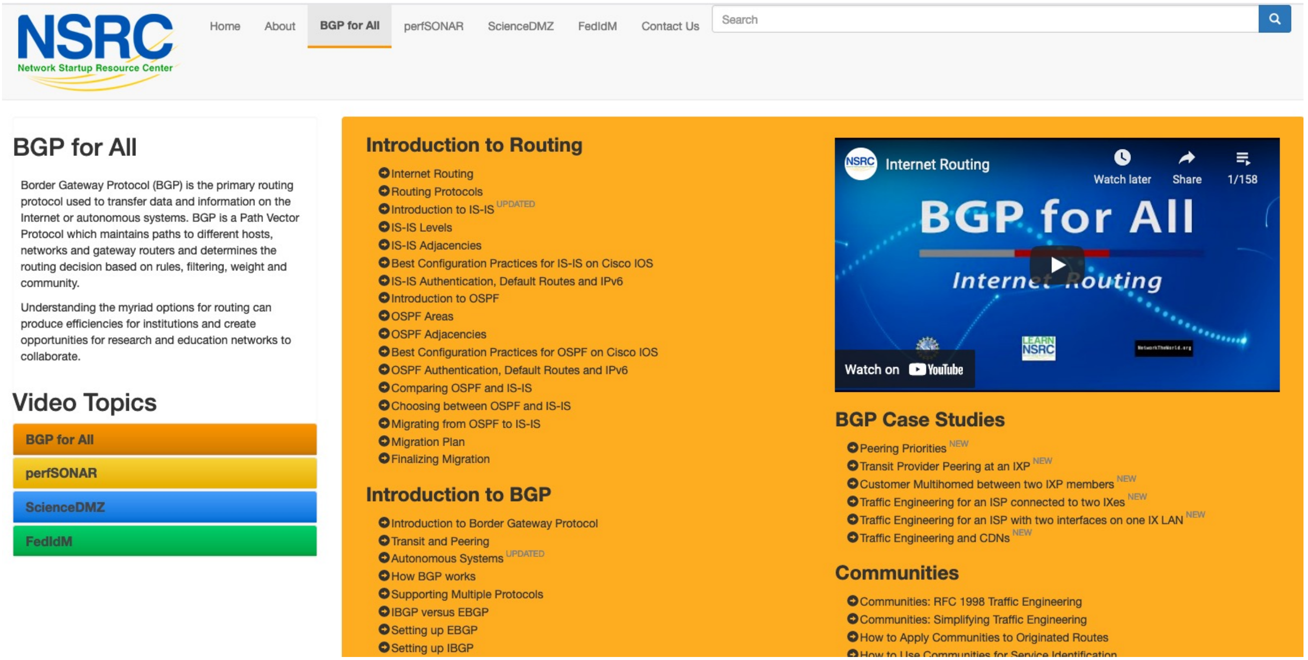
Acknowledgements

- This material was built from contributions by Randy Bush, Mark Tinka, Aftab Siddiqui, Tashi Phuntsho and others
- Use of these materials is encouraged as long as the source is fully acknowledged and this notice remains in place
- Bug fixes and improvements are welcomed
  - Please email *workshop (at) bgp4all.com*

Philip Smith

BGP Videos

- NSRC has produced a library of BGP presentations (including this one), recorded on video, for the whole community to use
  - https://learn.nsrc.org/bgp



Validating BGP Route Announcements

- How do we know that an AS is permitted to originate the prefix it is originating?
- Implicit trust?
- Because the Internet Routing Registry says so?
  - The Internet Routing Registry (IRR) only documents routing policy
  - And has a large amount of outdated/incorrect information
- Is there something else?
  - Yes: Route Origin Authorisation

RPKI

- RPKI – Resource Public Key Infrastructure, the Certificate Infrastructure for origin and path validation
  - We need to be able to authoritatively prove who owns an IP prefix and which AS(s) may announce it
  - Prefix ownership follows the allocation hierarchy (IANA → RIRs → ISPs → etc)
  - Origin Validation
    - Using the RPKI to detect and prevent mis-originations of someone else's prefixes (early 2012)
  - AS-Path Validation, in other words, BGPsec
    - Prevent Attacks on BGP (future work)

BGP – Why Origin Validation?

- Prevent YouTube accident & Far Worse
- Prevents most accidental announcements
- Does not prevent malicious path attacks
- That requires 'Path Validation' and locking the data plane to the control plane, the third step, BGPsec

What is RPKI?

- Resource Public Key Infrastructure (RPKI)
  - A security framework for verifying the association between resource holder and their Internet resources
  - Created to address the issues discussed in RFC 4593 "Generic Threats to Routing Protocols" (Oct 2006)
- Helps to secure Internet routing by validating routes
  - Proof that prefix announcements are coming from the legitimate holder of the resource
  - RFC 6480 – An Infrastructure to Support Secure Internet Routing (Feb 2012)
  - RFC 7115 – Origin Validation Operation Based on the Resource Public Key Infrastructure (RPKI)

Benefits of RPKI for Routing

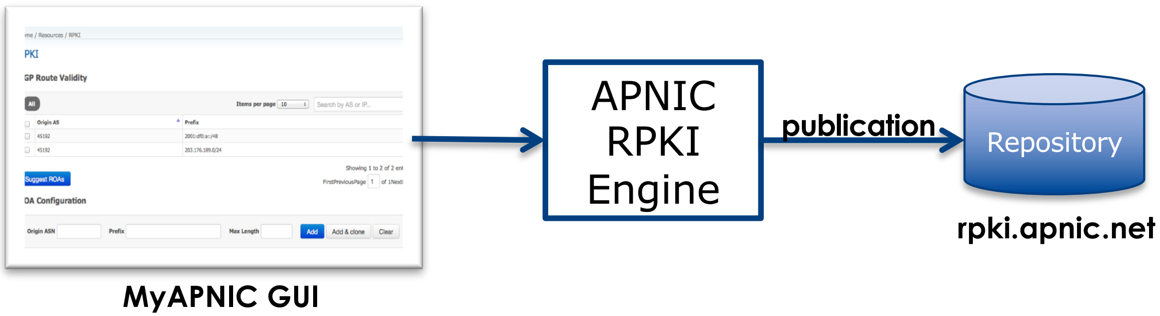
- Prevents route hijacking
  - A prefix originated by an AS without authorisation
  - Reason: malicious intent
- Prevents mis-origination
  - A prefix that is mistakenly originated by an AS which does not own it
  - Also route leakage
  - Reason: configuration mistake / fat finger

BGP Security (BGPsec)

- Extension to BGP that provides improved security for BGP routing
- Being worked on by the SIDR Working Group at IETF
- Implemented via a new optional non-transitive BGP attribute that contains a digital signature
- Two components:
  - BGP Prefix Origin Validation (using RPKI)
  - BGP Path Validation

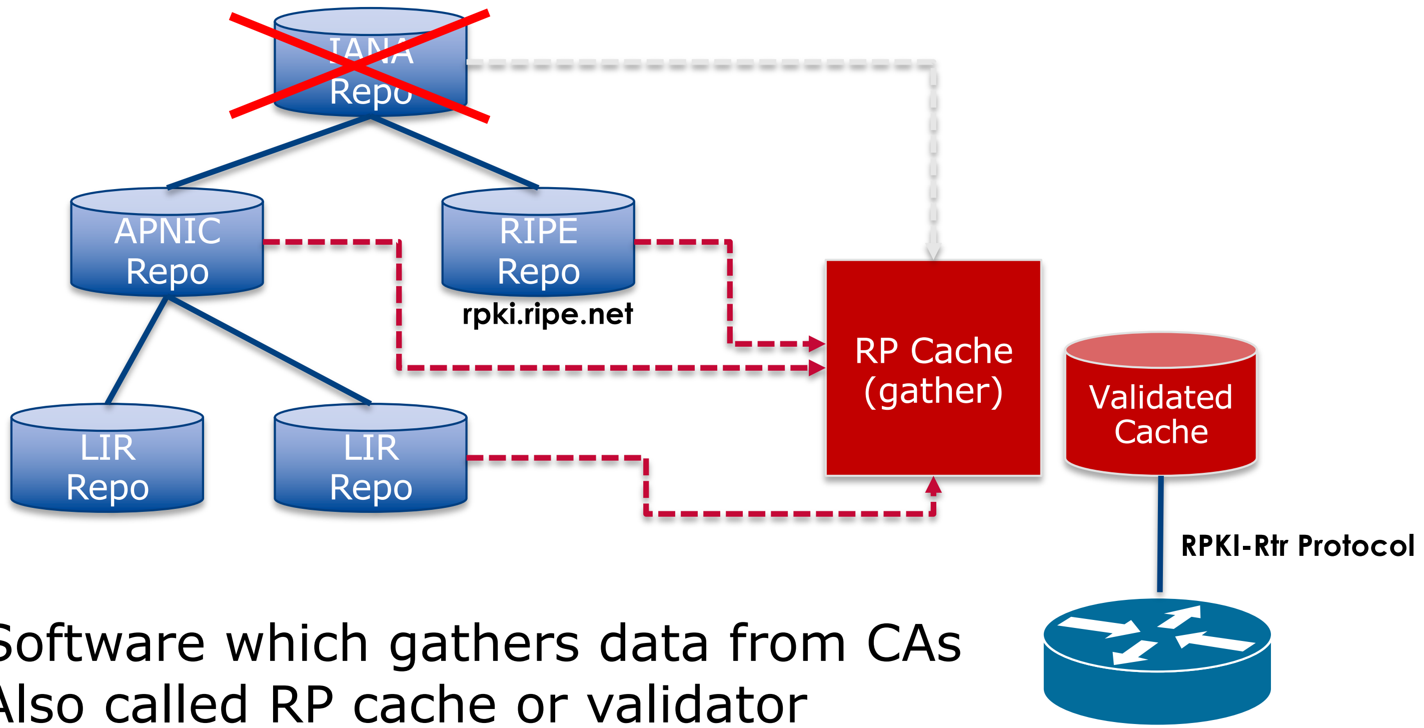
Issuing Party

- Internet Registries (RIR, NIR, Large LIRs)
- Acts as a Certificate Authority and issues certificates for customers
- Provides a web interface to issue ROAs for customer prefixes
- Publishes the ROA records



Courtesy of APNIC: https://apnic.net

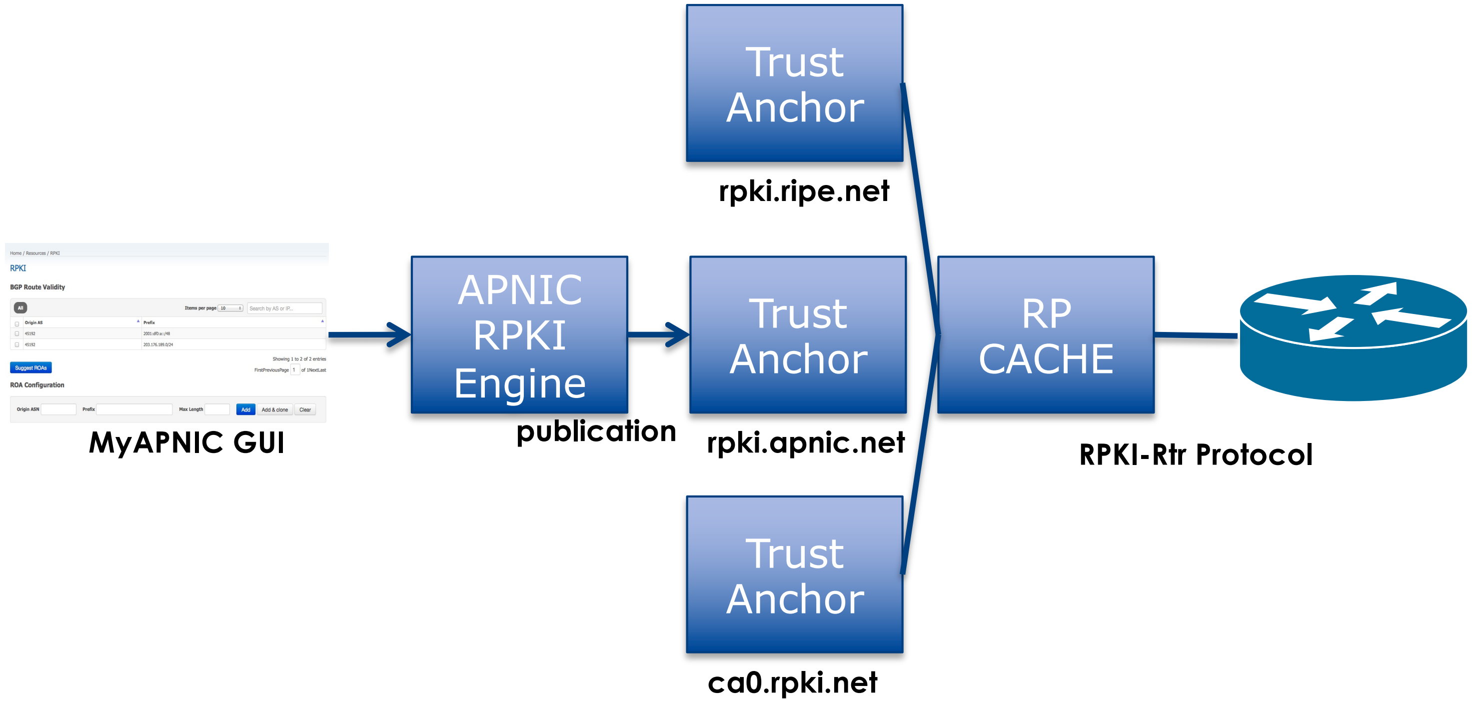
Relying Party (RP)



Software which gathers data from CAs
Also called RP cache or validator

Courtesy of APNIC: https://apnic.net

RPKI Components



Courtesy of APNIC: https://apnic.net

RPKI Service Models

- Hosted Model:
  - The RIR runs the CA on behalf of its members
    - Manage keys, repository, etc
    - Generate certificates for resource certifications
- Delegated Model:
  - Member becomes the CA, delegated from the parent CA (the RIR)
    - Operates the full RPKI system
    - Several entities now operating delegated CAs
  - CA Software
    - NLnetLabs Krill: https://www.nlnetlabs.nl/projects/rpki/krill/

Route Origin Authorisation (ROA)

- A digital object that contains a list of address prefixes and one AS number
- It is an authority created by a prefix holder to authorise an AS Number to originate one or more specific route advertisements
- Publish a ROA using your RIR member portal
  - Consult your RIR for how to use their member portal to publish your ROAs

Route Origin Authorisation

- A typical ROA would look like this:

Prefix	10.10.0.0/16
Max-Length	/18
Origin-AS	AS65534

- There can be more than one ROA per address block
  - Allows the operator to originate prefixes from more than one AS
  - Caters for changes in routing policy or prefix origin

Creating ROAs

- Only create ROAs for the aggregate and the exact subnets expected in the routing table
- Examples:

Prefix	Max Length	Origin AS	Comments
10.10.0.0/16	/24	65534	ROA covers /16 through to /24 – any announced subnets to /24 will be Valid if from AS65534
10.10.0.0/16	/16	65534	ROA covers only /16 – any announced subnets will be Invalid
10.10.4.0/22	/24	65534	ROA covers this /22 through to /24
10.10.32.0/22	/24	64512	Valid ROA covers /22 through to /24 announcements from AS64512

Creating ROAs – Important Notes

- Always create ROAs for the aggregate and the individual subnets being routed in BGP
- Example:
  - If creating a ROA for 10.10.0.0/16 **and** "max prefix" length is set to /16
    - There will only be a valid ROA for 10.10.0.0/16
    - If a subnet of 10.10.0.0/16 is originated, it will be state Invalid

Creating ROAs – Important Notes

- Avoid creating ROAs for subnets of an aggregate unless they are actually being actively routed
  - If ROA exists, but subnet is not routed, it leaves an opportunity for someone else to mis-originate the subnet using the valid origin AS, resulting in a hijack

- https://datatracker.ietf.org/doc/draft-ietf-sidrops-rpkimaxlen/ has a good description of the care needed when creating ROAs
  - Recommendations:
    - Avoid using maxLength attribute unless in special cases
    - Use minimal ROAs wherever possible – only for prefixes that are actually being announced
  - Also a discussion about ROAs for facilitating DDoS Services
  - There is even a strong suggestion that "maxLength" should be deprecated

Creating ROAs – Important Notes

- Some current examples of problematic ROAs:

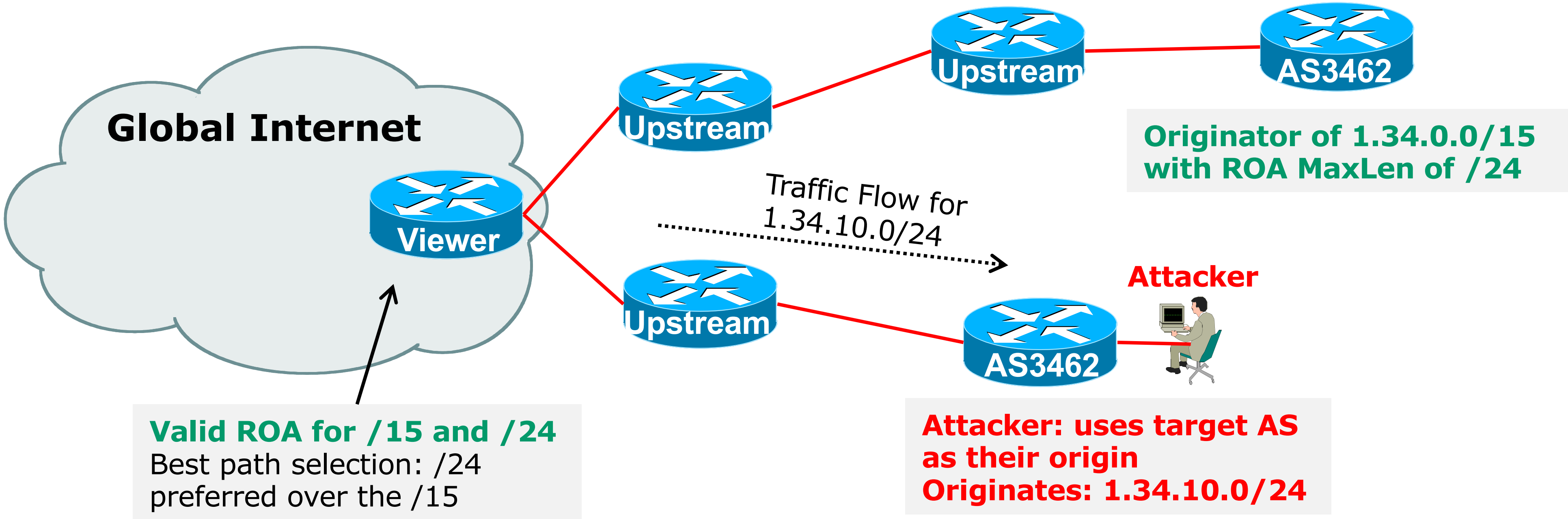
328037	2c0f:f0c8::/32	128

  - This means that any and every subnet of 2C0F:F0C8::/32 originated by AS328037 is valid
    - An attacker can use AS328037 as their origin AS to originate 2C0F:F0C8:A0:/48 to deny service to that address block
    - Known as a validated hijack!

3462	1.34.0.0/15	24

  - This means that any subnet of 1.34.0.0/15 down to a /24 as originated by AS3462 is valid
    - An attacker can use AS3462 as their origin AS to originate 1.34.10.0/24 to deny service to that address block

Creating ROAs: "Validated Hijack"



- If the 1.34.10.0/24 prefix had had no ROA, route origin validation would have dropped the invalid announcement at the upstream AS

Creating ROAs: pre-RIR Address Space

- Some entities were assigned address space by InterNIC
  - This is prior to the existence of the RIRs
- How to sign ROAs for these resources?
- Some RIRs will support the signing of legacy address space ROAs
  - If there is documentation proving the holding
  - If there is some service agreement for resources allocated by the RIR
  - Or by some other arrangement
  - Example, APNIC:
    - https://www.apnic.net/wp-content/uploads/2018/02/APNIC-AR-2017.pdf
  - Example, RIPE NCC:
    - https://www.ripe.net/manage-ips-and-asns/resource-management/certification/resource-certification-rpki-for-provider-independent-end-users

Route Origin Validation

- Router must support RPKI
- Checks an RP cache / validator
  - Uses RtR protocol, described in RFC8210
- Validation returns 3 states:

State	Description
Valid	When authorisation is found for prefix X coming from ASN Y
Invalid	When authorisation is found for prefix X but **not** from ASN Y, or **not** allowable subnet size
Not Found	When no authorisation data is found for prefix X

Route Origin Validation – AS0

- RFC6483 also describes "Disavowal of Routing Origination"
  - AS 0 has been reserved for network operators and other entities to identify non-routed networks
  - Which means:
    - "A ROA with a subject of AS0 (AS0 ROA) is an attestation by the holder of a prefix that the prefix described in the ROA, and any more specific prefix, should not be used in a routing context"
- Any prefixes with ROA indicating AS0 as the origin AS need to be dropped
  - If these prefixes appear with any other origin, their ROAs will be invalid, achieving this goal

Route Origin Validation – AS0

- Possible use cases of AS0:
  - Internal use of a prefix that should not appear in the global BGP table
  - Internet Exchange Point LAN must never appear in the global BGP table
  - Private Address space (IPv4) and non-Global Unicast space (IPv6)
  - Unassigned address space
    - This is under discussion within the various RIR policy fora
  - IPv4 and IPv6 address resources which should not appear in the global BGP table
    - For example, the special use address space described in RFC6890

Route Origin Validation – AS0

- APNIC & LACNIC have now published their AS0 TALs
  - Operated separately from the regular TAL
    - https://www.apnic.net/community/security/resource-certification/trust-anchor-locator/
    - https://www.lacnic.net/4984/2/lacnic/rpki-rpki-trust-anchor
  - Simply add to the TAL folder in the validator cache
- Some examples of AS0 being used today:

```
RPKI/RTR prefix table
Prefix                                  Prefix Length  Origin-AS
2.57.180.0                                 22 -   24            0
5.57.80.0                                  22 -   22            0
23.4.85.0                                  24 -   24            0
23.173.176.0                               24 -   24            0
23.211.114.0                               23 -   24            0
45.12.44.0                                 22 -   22            0
58.181.75.0                                24 -   24            0
109.122.244.0                              22 -   22            0
```

Route Origin Validation – Implementations

- Cisco IOS – available from release 15.2
- Cisco IOS/XR – available from release 4.3.2
- Juniper JunOS – available from release 12.2
- Nokia – available from release R12.0R4
- Huawei – available from release V800R009C10
- FRR – available from release 4.0
- BIRD – available from release 1.6
- OpenBGPD – available from OpenBSD release 6.4
- GoBGP – available since 2018
- VyOS – available from release 1.2.0-RC11
- Mikrotik ROS – available from release v7
- Arista EOS – available from release 4.24.0F

RPKI Validator Caches

- NLnet Labs Routinator 3000
  - https://www.nlnetlabs.nl/projects/rpki/routinator/
  - https://github.com/NLnetLabs/routinator
- LACNIC/NIC Mexico validator (FORT)
  - https://fortproject.net/en/validator
  - https://nicmx.github.io/FORT-validator/
- RPKI-client
  - https://www.rpki-client.org/
- StayRTR
  - https://github.com/bgp/stayrtr
- RPKI-Prover
  - https://github.com/lolepezy/rpki-prover

Package available for Debian/Ubuntu, CentOS/RHEL & FreeBSD

RPKI repository query system (output for OpenBGPD, BIRD, json)

RPKI to Router protocol implementation (input JSON formatted VRP exports)

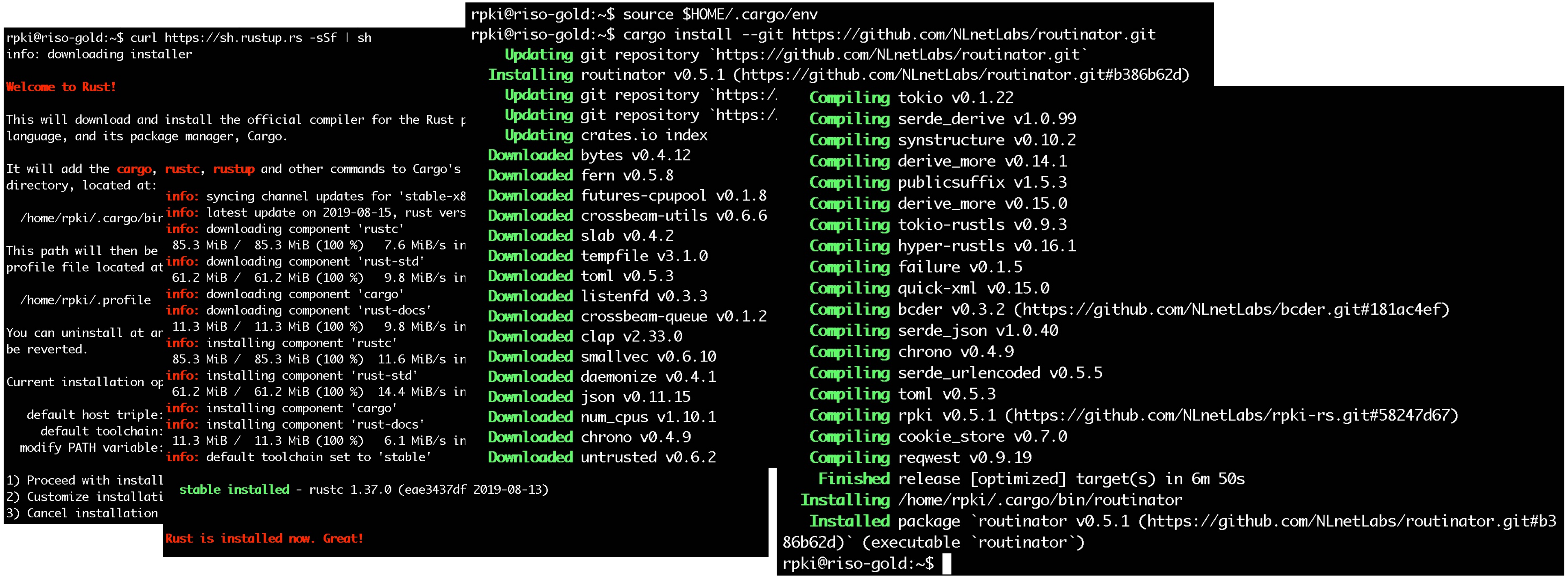
- Cloudflare validator (OctoRPKI) & RIPE NCC validator
  - Both discontinued and no longer maintained

Installing a validator – Routinator

- If using Ubuntu/Debian, then simply use the package manager, as described:
  - https://github.com/NLnetLabs/routinator#quick-start-with-debian-and-ubuntu-packages
- In summary:
  - Get the NLnetLabs public key
  - Add the repo to the sources lists
  - Install routinator
  - Initialise
  - Run

Installing a validator – Routinator

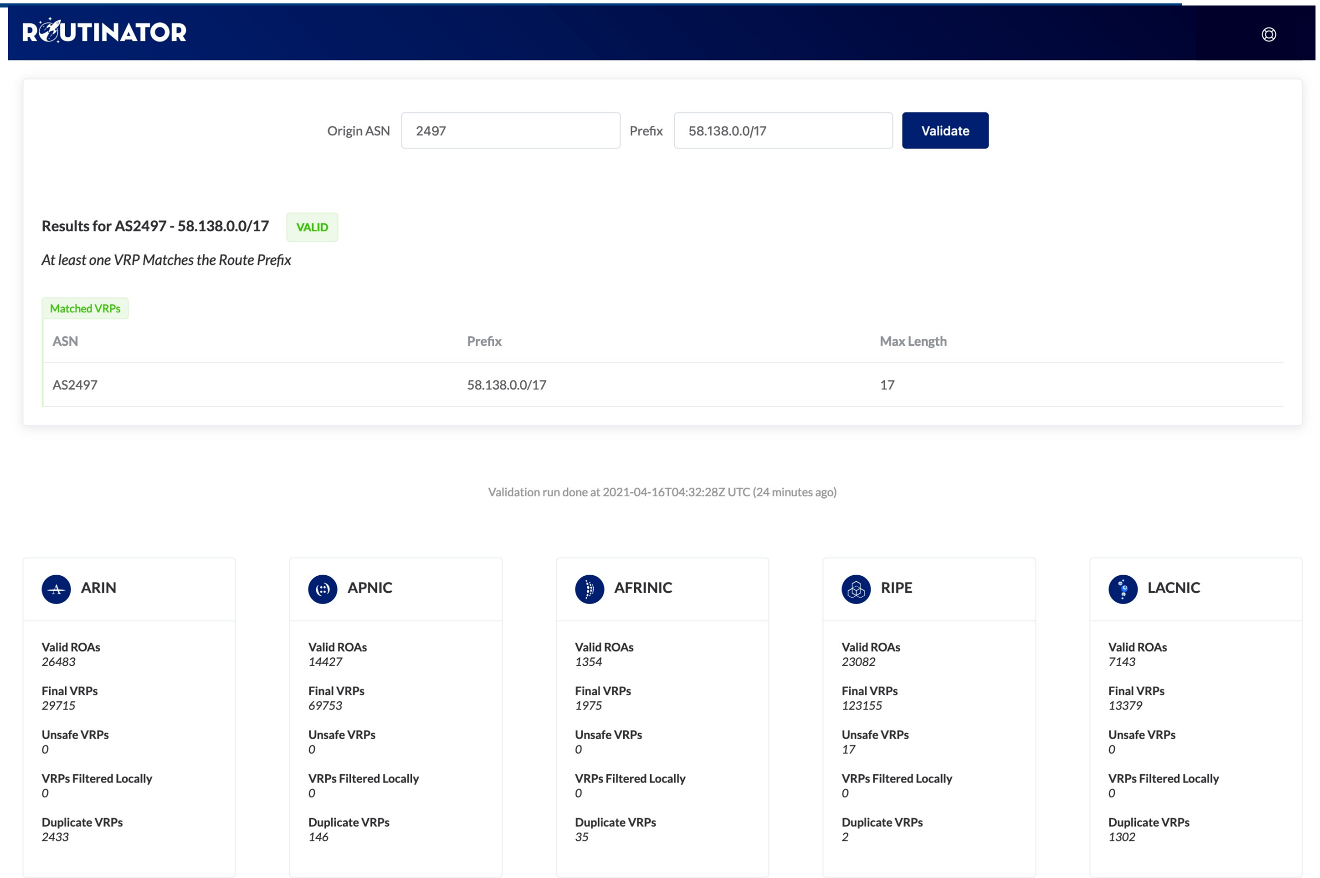
- If building it from source, consult instructions at:
  - https://github.com/NLnetLabs/routinator



Routinator 3000 web interface

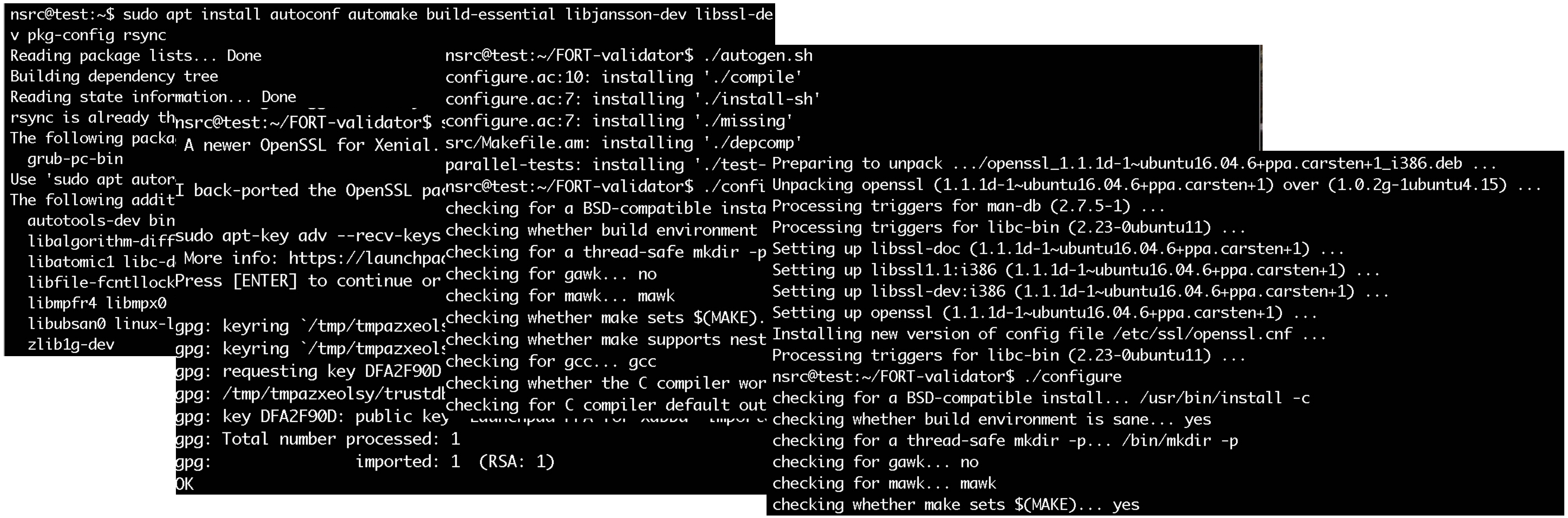
- User interface of Routinator accessed by enabling http option in the server configuration
  - Listens on port 8323

/etc/routinator/routinator.conf



Installing a validator – FORT

- If building from source, consult instructions at:
  - https://nicmx.github.io/FORT-validator/installation.html
  - Note: Needs OpenSSL >=1.1



RP Cache Deployment

- Network Operator design advice:
  - Deploy at least two Validator Caches
  - Geographically diverse
  - Perhaps two different implementations
    - For software independence
  - Implement on a Linux container so that the container can be moved between different server clusters as required
  - Configure validator to listen on both IPv4 and IPv6
    - Configure routers with both IPv4 and IPv6 validator connections
  - Securing the validator: Only permit routers running EBGP to have access to the validators

RP Cache Deployment: Open Questions

- Consider two different validator cache implementations
  - Gives software independence
  - What happens if the different cache implementations contain different VRPs?
  - Scenario 1:
    - Cache 1: route X is valid
    - Cache 2: route X is invalid
  - Scenario 2:
    - Cache 1: route X is valid
    - Cache 2: route X is NotFound
  - Answer: depends on router vendor implementation?!

Configure Router to Use Cache: Cisco IOS

- Point router to the local RPKI cache
  - Server listens on port 3323
  - Cache refreshed every 60 minutes (RFC8210 recommendation)
  - Example:

```
router bgp 64512
 bgp rpki server tcp 10.0.0.3 port 3323 refresh 3600
```

  - Once the router's RPKI table is populated, router indicates validation state in the BGP table

Cisco IOS status commands

- **`show ip bgp rpki servers`**
  - Displays the connection status to the RPKI caches
- **`show ip bgp rpki table`**
  - Shows the VRPs (validated ROA payloads)
- **`show ip bgp`**
  - Shows the BGP table with status indication next to the prefix
- **`show ip bgp | i ^V`**
  - Shows the status ”valid” prefixes in the BGP table

Configure Router to Use Cache: JunOS

1. Connect to validation cache:

```
routing-options {
  validation {
    group ISP {
      session 10.0.0.3;
      port 3323;
      refresh-time 600;
      hold-time 3600;
    }
  }
}
```

- (using same parameters as for the Cisco IOS example)

Configure Router to Use Cache: JunOS

2. Configure validation policies:

```
policy-options {
  policy-statement RPKI-validation {
    term VALID {
      from {
        protocol bgp;
        validation-database valid;
      }
      then {
        validation-state valid;
        next policy;
      }
    }
    term INVALID {
      from {
        protocol bgp;
        validation-database invalid;
      }
      then {
        validation-state invalid;
        next policy;
      }
    }
```

```
(continued)...

    term UNKNOWN {
      from {
        protocol bgp;
        validation-database unknown;
      }
      then {
        validation-state unknown;
        next policy;
      }
    }
  }
}
```

Configure Router to Use Cache: JunOS

3. Apply policy to eBGP session:

```
protocols {
  bgp {
    group EBGP {
      type external;
      local-address 10.0.1.1;
      neighbor 10.1.15.1 {
        description ”ISP Upstream";
        import [ RPKI-validation Upstream-in ];
        export LocalAS-out;
        peer-as 64511;
      }
    }
  }
}
```

- Note that policy options *Upstream-in* and *LocalAS-out* are the typical inbound and outbound filters needed for an eBGP session

JunOS status commands

- `show validation session detail`
  - Display the details of the connection to the RPKI caches
- `show validation replication database`
  - Shows the VRPs (validated ROA payloads)
- `show route protocol bgp`
  - Shows the BGP table with status indication next to the prefix

  `show route protocol bgp validation-state valid`
  - Shows the status ”valid” prefixes in the BGP table

Configure Router to Use Cache: FRrouting

- Point router to the local RPKI cache
  - Server listens on port 3323
  - Cache refreshed every 60 minutes (RFC8210 recommendation)
  - Example:

```
rpki
  rpki polling_period 3600
  rpki cache 10.0.0.3 3323 preference 1
  rpki cache 10.0.1.2 3323 preference 2
exit
```

  - Two caches specified for redundancy

FRrouting status commands

- `show rpki cache-connection`
  - Displays the connection status to the RPKI caches
- `show rpki prefix-table`
  - Shows the VRPs (validated ROA payloads)
- `show ip bgp`
  - Shows the BGP table
- `show ip bgp rpki valid`
  - Shows the status ”valid” prefixes in the BGP table
  - (There are also options for “invalid” and “notfound”)

Configure Router to Use Cache: BIRD v2

- Point BIRD to the local RPKI cache
  - Server listens on port 3323
  - Cache refreshed every 60 minutes (RFC8210 recommendation)
  - Two caches specified for redundancy

```
roa4 table r4;
roa6 table r6;

protocol rpki validator1 {
    roa4 { table r4; };
    roa6 { table r6; };
    remote 10.0.0.3 port 3323;
    retry 300;
}

protocol rpki validator2 {
    roa4 { table r4; };
    roa6 { table r6; };
    remote 10.0.1.2 port 3323;
    retry 300;
}
```

BIRD v2 status commands

- `show protocols validator1`
  - Displays the connection status to the RPKI cache "*validator1*"
- `show route table r4`
  - Shows the IPv4 VRPs (validated ROA payloads)

  `show route table r6`
  - Shows the IPv6 VRPs (validated ROA payloads)
- `show route protocol <name>`
  - Shows the BGP table

Implementation notes

- Cisco IOS/IOS-XE
  - Invalid prefixes are dropped by default
    - The operator does not need to define a policy based on validation state
  - Prefixes originated locally into IBGP are automatically marked as Valid
    - There is no check against the cached validation table
    - Allows operator to originate non-signed address blocks or other entity address space inside their own IBGP
- JunOS
  - Complete separation between validation table and what happens in BGP
    - There has to be a specific policy statement for any action based on validation state

Implementation notes

- Cisco IOS/IOS-XE/IOS-XR
  - Every VRP change causes a route-refresh with its BGP neighbours
    - Even though VRP change only affects valid/invalid/notfound status
  - Big impact for BGP sessions carrying a large or the full BGP table
    - Especially for BGP peers with weak control planes!
  - Transit providers need to be cautious:
    - BGP customer doing ROV on Cisco router will cause significant impact on the Access Router CPU
  - Cisco's recommended workaround:
    - Turn on "Soft Reconfiguration"
    - Which has memory implications, and blocks access to the route refresh CLI
  - Summary: think carefully about using Cisco routers for Route Origin Validation

Implementation notes

- Other router implementations
  - Most modern implementations save the incoming BGP table prior to policy application (ADJ-RIB-IN)
  - Changes in VRPs are applied to this stored BGP table
  - Similar behaviour to Cisco's soft-reconfiguration

- NB: It's important not to rely on Route Refresh to implement VRP changes
  - More and more frequent changes cause more and more refresh requests to peers, consuming peer CPU resources – potentially a denial of service attack on the peer
  - Recommended reading:
    - https://datatracker.ietf.org/doc/draft-ymbk-sidrops-rov-no-rr/

Implementation notes

- What happens when router cannot contact any validator cache?
  - Cisco IOS/IOS-XE – empties the VRP table within 5 minutes
  - Juniper & Nokia – keeps VRPs until their preconfigured expiry (default 60 minutes)
  - Other vendors – behaviour untested

- Design advice:
  - It is important to ensure that EBGP speaking routers can always remain connected to a validator cache
    - **Minimum of two independent caches recommended!**

Check Server

```
lg-01-jnb.za>sh ip bgp rpki servers
BGP SOVC neighbor is 105.16.112.2/43779 connected to port 43779
Flags 64, Refresh time is 300, Serial number is 1463607299
InQ has 0 messages, OutQ has 0 messages, formatted msg 493
Session IO flags 3, Session flags 4008
 Neighbor Statistics:
  Prefixes 25880
  Connection attempts: 44691
  Connection failures: 351
  Errors sent: 35
  Errors received: 0

Connection state is ESTAB, I/O status: 1, unread input bytes: 0
Connection is ECN Disabled
Mininum incoming TTL 0, Outgoing TTL 255
Local host: 105.22.32.2, Local port: 27575
Foreign host: 105.16.112.2, Foreign port: 43779
Connection tableid (VRF): 0
```


Courtesy of SEACOM: http://as37100.net

Check Server

```
philip@DREN-THIMPHU-BR> show validation session detail
Session 103.197.176.141, State: up, Session index: 2
  Group: DrukREN, Preference: 100
  Local IPv4 address: 103.197.176.5, Port: 3323
  Refresh time: 600s
  Hold time: 1800s
  Record Life time: 3600s
  Serial (Full Update): 0
  Serial (Incremental Update): 1
    Session flaps: 1
    Session uptime: 00:19:11
    Last PDU received: 00:00:34
    IPv4 prefix count: 94329
    IPv6 prefix count: 15992
```

Courtesy of DrukREN, Bhutan

RPKI Table (IPv4) – October 2021

```
217259 BGP sovc network entries using 34761440 bytes of memory
239398 BGP sovc record entries using 7660736 bytes of memory

Network                  Maxlen  Origin-AS  Source  Neighbor
1.0.0.0/24               24      13335      0       192.168.1.225/3323
1.0.4.0/24               24      38803      0       192.168.1.225/3323
1.0.4.0/22               22      38803      0       192.168.1.225/3323
1.0.5.0/24               24      38803      0       192.168.1.225/3323
1.0.6.0/24               24      38803      0       192.168.1.225/3323
1.0.7.0/24               24      38803      0       192.168.1.225/3323
1.1.1.0/24               24      13335      0       192.168.1.225/3323
1.1.4.0/22               22      4134       0       192.168.1.225/3323
1.1.16.0/20              20      4134       0       192.168.1.225/3323
1.2.9.0/24               24      4134       0       192.168.1.225/3323
1.2.10.0/24              24      4134       0       192.168.1.225/3323
1.2.11.0/24              24      4134       0       192.168.1.225/3323
1.2.12.0/22              22      4134       0       192.168.1.225/3323
1.3.0.0/16               16      4134       0       192.168.1.225/3323
1.6.0.0/22               24      9583       0       192.168.1.225/3323
1.6.4.0/22               24      9583       0       192.168.1.225/3323
```

RPKI Table (IPv6) – October 2021

```
43391 BGP sovc network entries using 7983944 bytes of memory
46341 BGP sovc record entries using 1482912 bytes of memory

Network                Maxlen  Origin-AS  Source  Neighbor
2001:200::/32          32      2500       0       192.168.1.225/3323
2001:200:136::/48      48      9367       0       192.168.1.225/3323
2001:200:1BA::/48      48      24047      0       192.168.1.225/3323
2001:200:900::/40      40      7660       0       192.168.1.225/3323
2001:200:E00::/40      40      4690       0       192.168.1.225/3323
2001:200:8000::/35     35      4690       0       192.168.1.225/3323
2001:200:C000::/35     35      23634      0       192.168.1.225/3323
2001:200:E000::/35     35      7660       0       192.168.1.225/3323
2001:218:3002::/48     48      1613       0       192.168.1.225/3323
2001:240::/32          32      2497       0       192.168.1.225/3323
2001:260::/32          48      2518       0       192.168.1.225/3323
2001:288::/32          32      1659       0       192.168.1.225/3323
2001:2F0::/32          128     7514       0       192.168.1.225/3323
2001:300::/32          32      2497       0       192.168.1.225/3323
2001:360::/32          32      135887     0       192.168.1.225/3323
2001:360:12::/48       48      135887     0       192.168.1.225/3323
```

BGP Table (IPv4)

```
RPKI validation codes: V valid, I invalid, N Not found

Network          Metric LocPrf Path
N*>  1.0.4.0/24       0        37100 6939 4637 1221 38803 56203 i
N*>  1.0.5.0/24       0        37100 6939 4637 1221 38803 56203 i
...
V*>  1.9.0.0/16       0        37100 4788 i
N*>  1.10.8.0/24      0        37100 10026 18046 17408 58730 i
N*>  1.10.64.0/24     0        37100 6453 3491 133741 i
...
V*>  1.37.0.0/16      0        37100 4766 4775 i
N*>  1.38.0.0/23      0        37100 6453 1273 55410 38266 i
N*>  1.38.0.0/17      0        37100 6453 1273 55410 38266 {38266} i
...
I*   5.8.240.0/23     0        37100 44217 3178 i
I*   5.8.241.0/24     0        37100 44217 3178 i
I*   5.8.242.0/23     0        37100 44217 3178 i
I*   5.8.244.0/23     0        37100 44217 3178 i
...
```

Courtesy of SEACOM: http://as37100.net

BGP Table (IPv6)

```
RPKI validation codes: V valid, I invalid, N Not found

Network                Metric LocPrf Path
N*>  2001::/32              0        37100 6939 i
N*   2001:4:112::/48        0        37100 112 i
...
V*>  2001:240::/32          0         37100 2497 i
N*>  2001:250::/48          0         37100 6939 23911 45
N*>  2001:250::/32          0         37100 6939 23911 23910 i
...
V*>  2001:348::/32          0         37100 2497 7679 i
N*>  2001:350::/32          0         37100 2497 7671 i
N*>  2001:358::/32          0         37100 2497 4680 i
...
I*   2001:1218:101::/48     0         37100 6453 8151 278 i
I*   2001:1218:104::/48     0         37100 6453 8151 278 i
N*   2001:1221::/48         0         37100 2914 8151 28496 i
N*>  2001:1228::/32         0         37100 174 18592 i
...
```

Courtesy of SEACOM: http://as37100.net

RPKI BGP State: Valid

```
BGP routing table entry for 2001:240::/32, version 109576927
Paths: (2 available, best #2, table default)
  Not advertised to any peer
  Refresh Epoch 1
  37100 2497
    2C0F:FEB0:11:2::1 (FE80::2A8A:1C00:1560:5BC0) from
                                 2C0F:FEB0:11:2::1 (105.16.0.131)
      Origin IGP, metric 0, localpref 100, valid, external, best
      Community: 37100:2 37100:22000 37100:22004 37100:22060
      path 0828B828 RPKI State valid
      rx pathid: 0, tx pathid: 0x0
```

Courtesy of SEACOM: http://as37100.net

RPKI BGP State: Invalid

```
BGP routing table entry for 2001:1218:101::/48, version 149538323
Paths: (2 available, no best path)
  Not advertised to any peer
  Refresh Epoch 1
  37100 6453 8151 278
    2C0F:FEB0:B:3::1 (FE80::86B5:9C00:15F5:7C00) from
                                              2C0F:FEB0:B:3::1 (105.16.0.162)
      Origin IGP, metric 0, localpref 100, valid, external
      Community: 37100:1 37100:12
      path 0DA7D4FC RPKI State invalid
      rx pathid: 0, tx pathid: 0
```


Courtesy of SEACOM: http://as37100.net

RPKI BGP State: Not Found

```
BGP routing table entry for 2001:200::/32, version 124240929
Paths: (2 available, best #2, table default)
  Not advertised to any peer
  Refresh Epoch 1
  37100 2914 2500
    2C0F:FEB0:11:2::1 (FE80::2A8A:1C00:1560:5BC0) from
                                 2C0F:FEB0:11:2::1 (105.16.0.131)
      Origin IGP, metric 0, localpref 100, valid, external, best
      Community: 37100:1 37100:13
      path 19D90E68 RPKI State not found
      rx pathid: 0, tx pathid: 0x0
```

Courtesy of SEACOM: http://as37100.net

Using RPKI

- Network operators can make decisions based on RPKI state:
  - Invalid – discard the prefix – many do this now!
  - NotFound – let it through (maybe low local preference)
  - Valid – let it through (high local preference)
- Some operators even considering making “Not Found” a discard event
  - But then Internet IPv4 BGP table would shrink to about 220000 prefixes and the IPv6 BGP table would shrink to about 43000 prefixes!

Deploying RPKI within an AS

- For fully supported Route Origin Validation across the network:
  - All EBGP speaking routers need talk with a validator
    - Supporting ROV means dropping **invalid**s as they arrive in the network
    - EBGP speaking routers are part of the operator IBGP mesh
  - IBGP speaking routers do not need to talk with a validator
    - Only **valid** and **NotFound** prefixes will be distributed from the EBGP speaking routers
    - The validation table is not distributed from router to router
- Remember:
  - Cisco IOS/IOS-XE drops **invalid**s by default – to allow **invalid**s to be distributed by IBGP, use the per address-family command:

```
bgp bestpath prefix-validate allow-invalid
```

Propagating validation state

- RFC8097 describes the propagation of validation state between iBGP speakers
  - Defines an opaque extended BGP community

Extended Community	Meaning
0x4300:0:0	Valid
0x4300:0:1	NotFound
0x4300:0:2	Invalid

  - These extended communities can be used in IBGP to allow distribution of validation state along with the prefix if desired
  - On Cisco IOS/IOS-XE:

```
neighbor x.x.x.x announce rpki state
```

  - For JunOS, policy needs to be explicitly configured

Propagating validation state

- There are two important caveats when propagating validation state:
  - Interoperability – is the defined opaque extended community supported on all vendor equipment in a multi-vendor network?
    - Until recently JunOS would not allow the required opaque extended communities to be configured at the command line
  - Cisco IOS/IOS-XE behaviour:
    - Adds a step to the best path selection algorithm: checks validation state (***valid*** **preferred over** ***not found***) before checking local preference
      - This cannot be turned off 🤯🤬

JunOS: opaque extended community

- Supported only in most recent JunOS releases
  - Fixed from 17.4R3, 18.2R3, 18.4R2…

```
policy-options {
    community RPKI-VALID members 0x4300:0:0;
    community RPKI-UNKNOWN members 0x4300:0:1;
    community RPKI-INVALID members 0x4300:0:2;
}
```

JunOS: opaque extended community

- And we can now set policy to detect these communities being sent from Cisco IOS/IOS-XE routers
  - Under "policy-options":

```
policy-statement PEER-in {
    term VALID {
        from community RPKI-VALID;
        then {
            validation-state valid;
            next policy;
        }
    }
    term INVALID {
        from community RPKI-INVALID;
        then {
            validation-state invalid;
            next policy;
        }
    }
    term UNKNOWN {
        from community RPKI-UNKNOWN;
        then {
            validation-state unknown;
            next policy;
        }
    }
}
```

Propagating validation state: Cisco IOS

- Cisco IOS/IOS-XE behaviour – example:
  - Prefix learned via two paths via two separate EBGP speaking routers
  - Prefix and validation state distributed by IBGP to core router (route reflector):

```
     Network          Next Hop     Metric LocPrf Weight Path
V*>i 61.45.249.0/24   100.68.1.1        0     50      0 121 20 135534 i
N* i                  100.68.1.3        0    200      0 20 135534 i
V*>i 61.45.250.0/24   100.68.1.1        0     50      0 121 30 135535 i
N* i                  100.68.1.3        0    150      0 30 135535 i
V*>i 61.45.251.0/24   100.68.1.1        0     50      0 121 122 40 135536 i
N* i                  100.68.1.3        0    150      0 40 135536 i
```

  - One EBGP speaking router talks with validator
  - The other EBGP speaking router does not (due to error or design)
  - Core router best path selection prefers *valid* path over *not found* even if the latter has higher local preference

Propagating validation state: Cisco IOS

- Looking at the path detail:

```
BGP routing table entry for 61.45.249.0/24, version 32
BGP Bestpath: deterministic-med
Paths: (2 available, best #1, table default)
  Not advertised to any peer
  Refresh Epoch 1
  121 20 135534, (Received from a RR-client)
    100.68.1.1 (metric 2) from 100.68.1.1 (100.68.1.1)
      Origin IGP, metric 0, localpref 50, valid, internal, best
      Extended Community: 0x4300:0:0
      path 67A585D0 RPKI State valid
  Refresh Epoch 1
  20 135534, (Received from a RR-client)
    100.68.1.3 (metric 2) from 100.68.1.3 (100.68.1.3)
      Origin IGP, metric 0, localpref 200, valid, internal
      Community: 10:1100
      Extended Community: 0x4300:0:1
      path 67A58918 RPKI State not found
```

Note best path

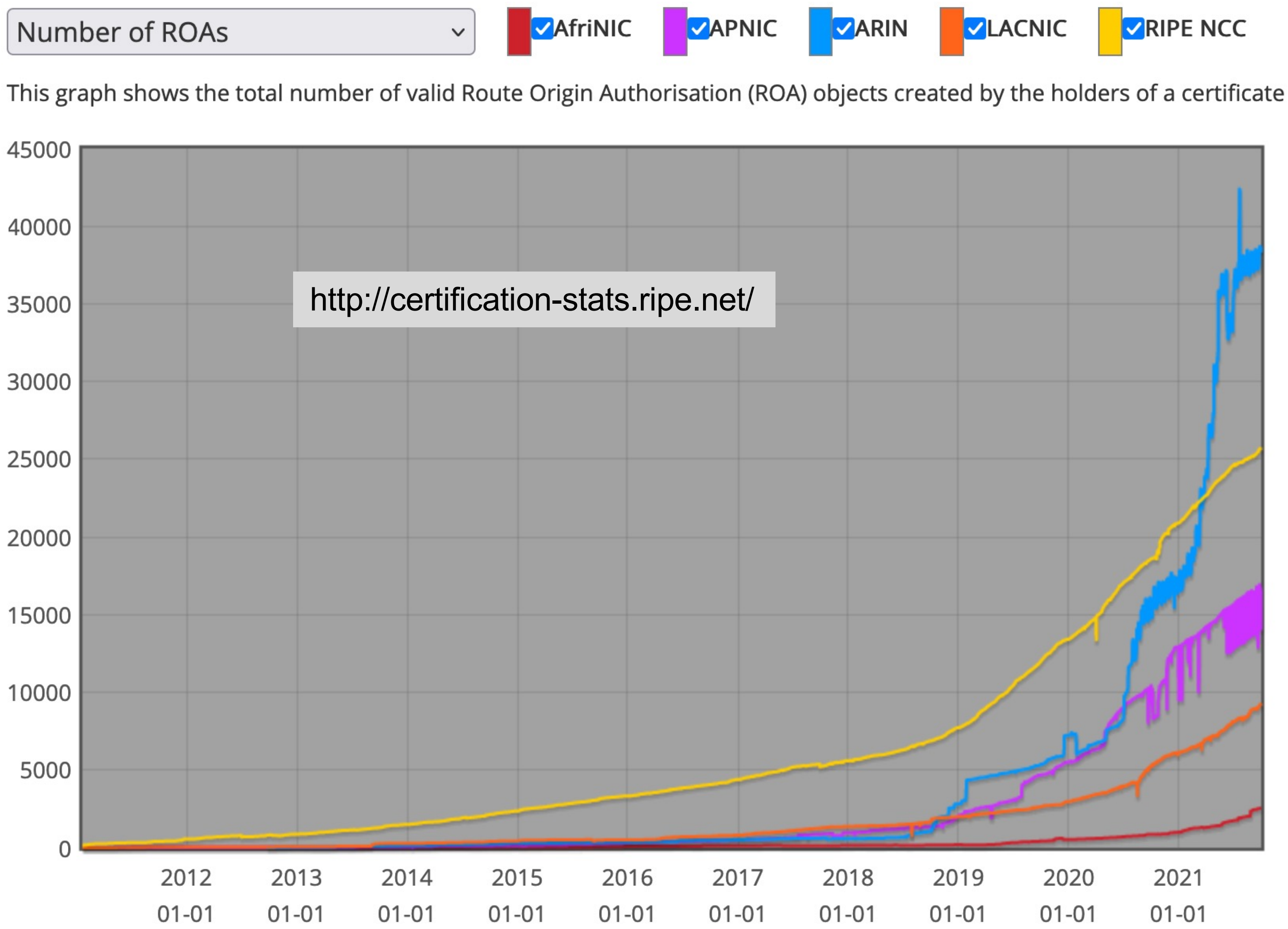
Propagating validation state

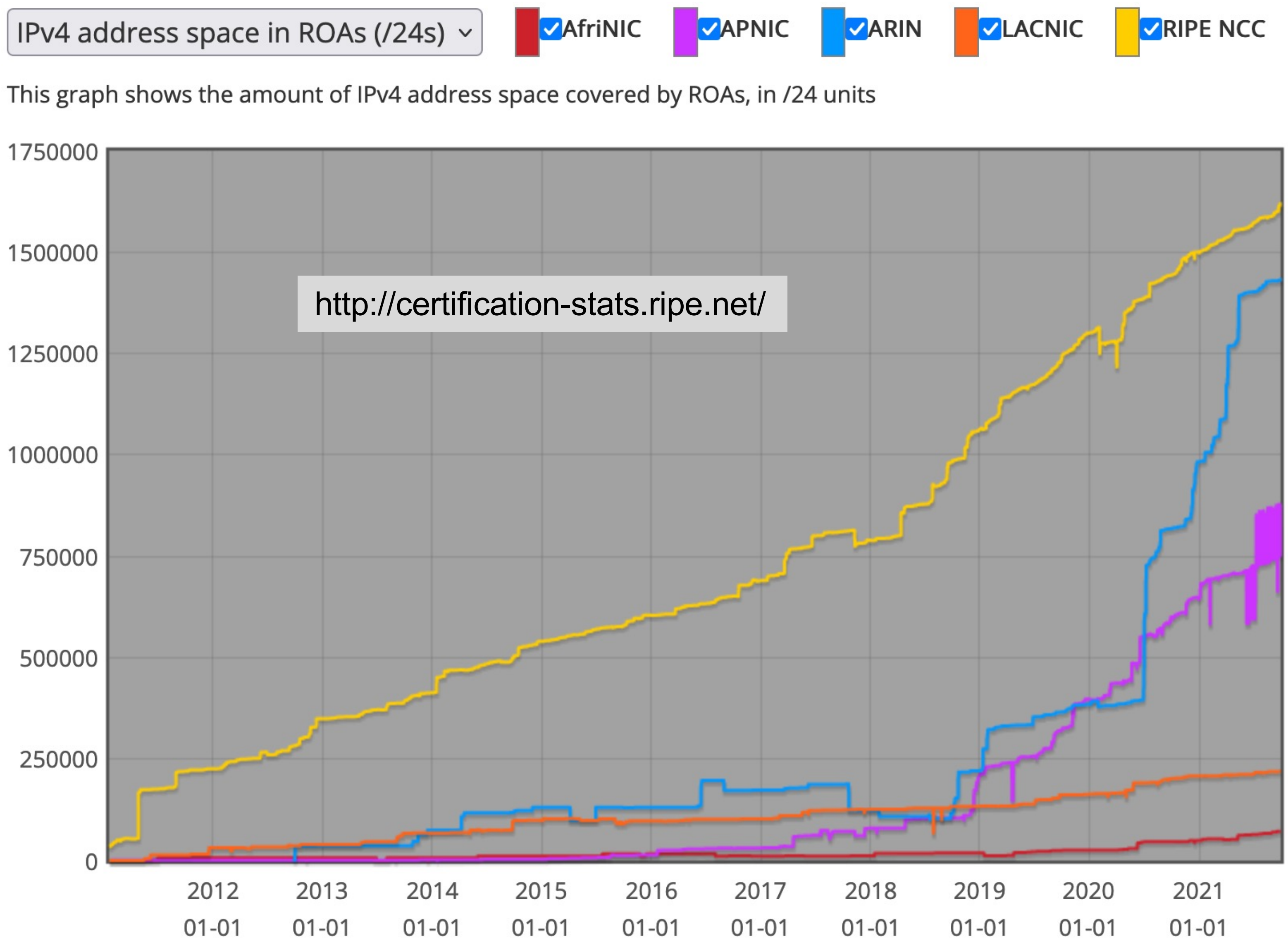
- Consider carefully if this is desired
- Current standard practice is to:
  - EBGP speaking routers have session with two diverse/redundant validators
  - Check validation state on EBGP speaking routers
  - Drop invalids on EBGP speaking routers
  - Distribute remaining prefixes by IBGP
  - Avoid propagating validation state (at least in Cisco IOS)

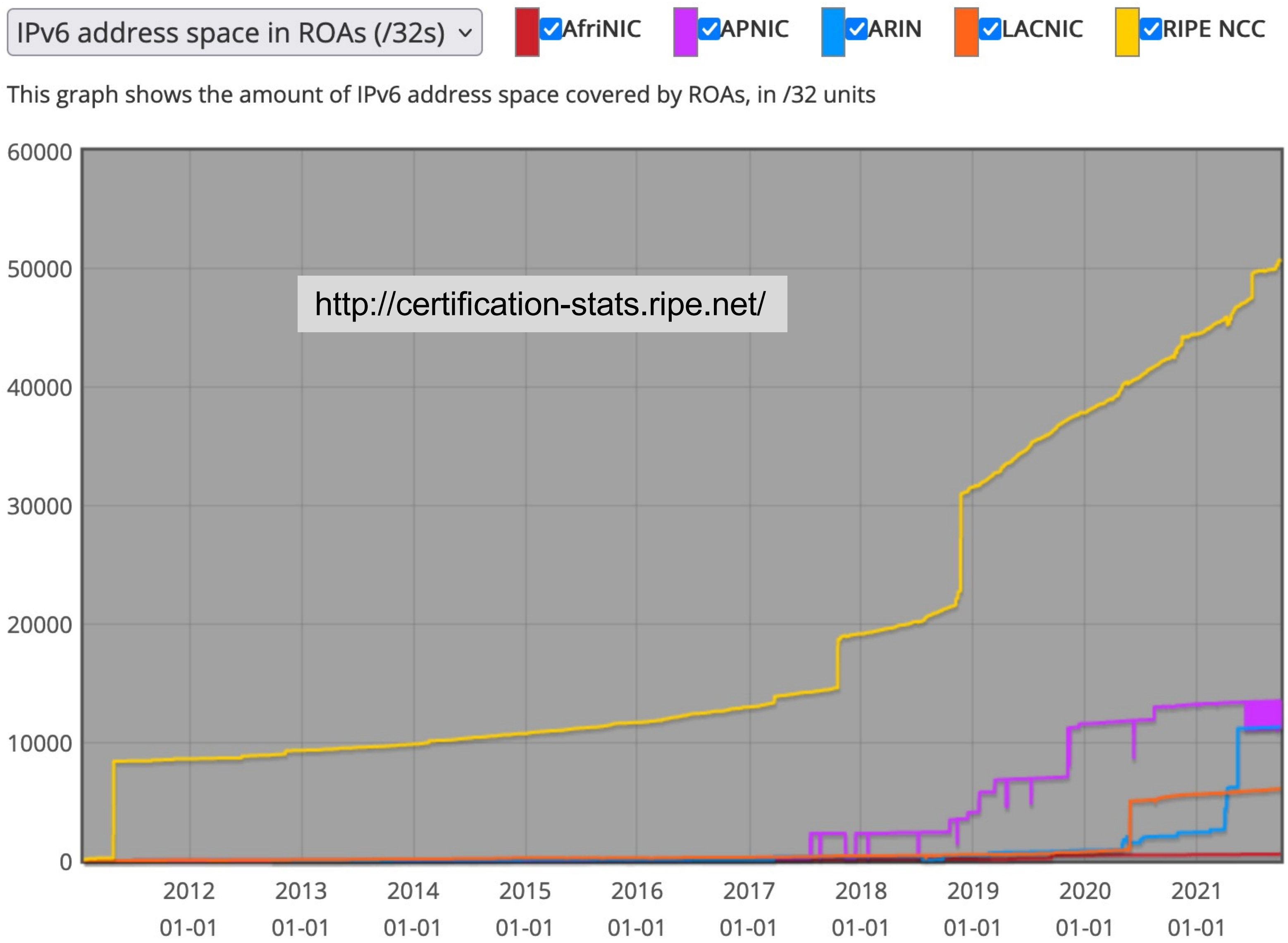
    -or-
  - Make sure that EBGP speaking routers never lose their connectivity to validators

RPKI Summary

- All AS operators must consider deploying:
  - **Signing ROAs**
  - **Dropping Invalids** (ROV)
- An important step to securing the routing system
- Doesn’t secure the path, but that’s the next important hurdle to cross
- With origin validation, the opportunities for malicious or accidental mis-origination are considerably reduced
- FAQ:
  - https://nlnetlabs.nl/projects/rpki/faq/


Number of ROAs
AfriNIC
APNIC
ARIN
LACNIC
RIPE NCC
This graph shows the total number of valid Route Origin Authorisation (ROA) objects created by the holders of a certificate
http://certification-stats.ripe.net/
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
2012 01-01
2013 01-01
2014 01-01
2015 01-01
2016 01-01
2017 01-01
2018 01-01
2019 01-01
2020 01-01
2021 01-01


IPv4 address space in ROAs (/24s)
AfriNIC
APNIC
ARIN
LACNIC
RIPE NCC
This graph shows the amount of IPv4 address space covered by ROAs, in /24 units
1750000
1500000
1250000
1000000
750000
500000
250000
0
http://certification-stats.ripe.net/
2012 01-01
2013 01-01
2014 01-01
2015 01-01
2016 01-01
2017 01-01
2018 01-01
2019 01-01
2020 01-01
2021 01-01


IPv6 address space in ROAs (/32s)
AfriNIC
APNIC
ARIN
LACNIC
RIPE NCC
This graph shows the amount of IPv6 address space covered by ROAs, in /32 units
http://certification-stats.ripe.net/
60000
50000
40000
30000
20000
10000
0
2012 01-01
2013 01-01
2014 01-01
2015 01-01
2016 01-01
2017 01-01
2018 01-01
2019 01-01
2020 01-01
2021 01-01

RPKI Deployment Status

- NIST keeps track of deployment status for research purposes:
  - https://rpki-monitor.antd.nist.gov/
- RIPE NCC statistics:
  - http://certification-stats.ripe.net/
- APNIC R&D ROA status:
  - RIPE NCC Validator running at APNIC
  - http://nong.rand.apnic.net:8080/roas

Major Operators deploying RPKI and ROV

- Telia

```
aut-num:        AS1299
org:            ORG-TCA23-RIPE
as-name:        TELIANET
descr:          Telia Carrier
<snip>
remarks:        AS1299 is matching RPKI validation state and reject
remarks:        invalid prefixes from peers, and are currently extending
remarks:        this to our customer connections.
remarks:
remarks:        Our looking-glass at https://lg.telia.net/ marks
remarks:        validation state for all prefixes.
remarks:
remarks:        Please review your registered ROAs to reduce number
remarks:        of invalid prefixes.
```

Major Operators deploying RPKI and ROV

- More and more operators are deploying RPKI and ROV
- Not just transit providers!
- But also:
  - Content providers
  - IXPs
  - R&E networks
  - Access providers

- Telia
- NTT
- Lumen (ex L3)
- HE
- GTT
- Workonline
- SEACOM
- Cloudflare
- AMS-IX
- LINX
- DE-CIX
- Terrehost
- Vocus
- Telstra
- REANNZ
- Cogent
- GR-IX
- Swisscom
- Netflix
- UAE-IX
- …

Routing Security

- Implement the recommendations in https://www.manrs.org
  1. Prevent propagation of incorrect routing information
     - Filter BGP peers, in & out!
  2. Prevent traffic with spoofed source addresses
     - BCP38 – Unicast Reverse Path Forwarding
  3. Facilitate communication between network operators
     - NOC to NOC Communication
     - Up-to-date details in Route and AS Objects, and PeeringDB
  4. Facilitate validation of routing information
     - Route Origin Authorisation using RPKI

MANRS

Summary

- Deploy RPKI
  - It is in the Internet's best interest
- With wide deployment of RPKI it becomes possible to only allow validated prefix announcements into the Internet Routing System
  - Prevents mis-originations
  - Prevents prefix hijack
  - Makes the Internet infrastructure more reliable and more stable
  - Allows the next step: AS-PATH validation

BGP Origin Validation

ISP Workshops