Breaking Internet Routing (outages that didn’t happen)

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Agenda

- Introduction
- How does the global Internet routing system work?
  - Designed to grow
  - BGP
- Attempts to curb the unwieldy
  - IRR
  - RPKI
- How does RPKI work?
  - Imposing constraints on the chaos using a PKI
  - Technical details
  - RPKI-To-Router protocol (RTR)
- Known negative interactions between RPKI and BGP
  - Router bugs
  - Inefficient Routing Policies: grouping RPKI Validation States as BGP Communities considered Harmful
- Wrapping it up!
- Questions?
How does the Internet routing system work?

http://as2914.net/

RFC 4271
How to curb such an unwieldy system?

EBGP Routers tell each other what you can reach through them

Auxiliary systems to impose order required: first IRR, then RPKI

IRR is a plain-text system:

```bash
$ whois -h whois.ripe.net 2001:67c:208c::
```

```
route6:         2001:67c:208c::/48
descr:          NL-SNIJDERS-IT
origin:         AS15562
mnt-by:         SNIJDERS-MNT
created:        2015-08-31T14:16:27Z
last-modified:  2015-08-31T14:16:27Z
source:         RIPE
```
How to curb such an unwieldy system?

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source: RIPE
```
How to curb such an unwieldy system?

Downsides of Internet Routing Registry (IRR) system:

- No transport security (port 43!)
- No object security (gotta hope for the best at face value)
- No way of verifying the source’s authentication process
How to curb such an unwieldy system?

Downsides of Internet Routing Registry (IRR) system:

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How does RPKI work?

Overall architecture: RFC 6480

RPKI has *Object Security*!

A tree of X.509 certificates following address allocation

At the leaves of the tree *Route Origin Authorizations* exist
How does RPKI work? Every delegation is a “trap”

In the chain of certificates: You are *constrained* by the list of *subordinate* resources on your parent.
How does RPKI work? A Trust Anchor Certificate

RPKI Root Certificate
Location: ta/ripe/ripe-ncc-ta.cer
Subject key identifier:

Authority key identifier: Trust Anchor
Manifest: rpki.ripe.net/repository/ripe-ncc-ta.mft
CA Repository: rsync://rpki.ripe.net/repository/
Notification URL: https://rrrdp.ripe.net/notification.xml

Subordinate resources:
until: 2117-11-28T14:39:55Z
Resources:
1: AS: 0 – 4294967295
1: IP: 0.0.0.0/0
2: IP: ::/0

A RPKI intermediate cert operated by RIPE NCC

RPKI Certificate
Location: rpki.ripe.net/repository/aca/KpSo3VVK5wEHIJnHC2QHV3d5mk.cer

Manifest: rpki.ripe.net/repository/DEFAULT/KpSo3VVK5wEHIJnHC2QHV3d5mk.mft
CA Repository: rpki.ripe.net/repository/DEFAULT/
Notification URL: https://rrdp.ripe.net/notification.xml

Subordinate resources:
  until: 2023-07-01T00:00:00Z
  Resources:
  1: AS: 7
  2: AS: 28
  3: AS: 137
  4: AS: 224
  5: AS: 248 -- 251
  6: AS: 261
  ... etc etc ...

https://console.rpki-client.org/rpki.ripe.net/repository/aca/KpSo3VVK5wEHIJnHC2QHV3d5mk.cer.html
A RPKI CA certificate belonging to a RIPE member

RPKI Certificate

Location: rpki.ripe.net/repository/DEFAULT/00FPkv3HzPv8GCNhUjrifWl-LS8.cer

Manifest: chloe.sobornost.net/rpki/RIPE-nljobsnijders/00FPkv3HzPv8GCNhUjrifWl-LS8.mft
CA Repository: chloe.sobornost.net/rpki/RIPE-nljobsnijders/
Notification URL: https://chloe.sobornost.net/rpki/news.xml

Subordinate resources:

until: 2023-07-01T00:00:00Z

Resources:
1: AS: 15562
1: IP: 45.138.228.0/22
3: IP: 2a0e:b240::/29

https://console.rpki-client.org/rpki.ripe.net/repository/DEFAULT/00FPkv3HzPv8GCNhUjrifWl-LS8.cer.html
Zooming in on a ROA at a leaf of the RPKI

Route Origin Authorization

Location: chloe.sobornost.net/rpki/RIPE-nljobsnijders/8EjgZ6BLB_EFHp9nPxGx5icjjM.roa
asID: AS15562
Prefixes:
1: 2001:67c:208c::/48 maxlen: 48
2: 2a0e:b240::/48 maxlen: 48

https://console.rpki-client.org/chloe.sobornost.net/rpki/RIPE-nljobsnijders/8EjgZ6BLB_EFHp9nPxGx5icjjM.roa.html
Inspecting a RPKI ROA with OpenBSD rpki-client

```
$ firefox https://repology.org/project/rpki-client
$ sudo apt install rpki-client && sudo rpki-client       # now make coffee
$ rpki-client \
   -t /etc/rpki/ripe.tal \
   -f rsync://chloe.sobornost.net/rpki/RIPE-nljobsnijders/8EjgZ6BLB_EFHp9nPxEgX5icjjM.roa
```

File: chloe.sobornost.net/rpki/RIPE-nljobsnijders/8EjgZ6BLB_EFHp9nPxEgX5icjjM.roa
Authority info access: rsync://rpki.ripe.net/repository/DEFAULT/00FPkv3HzPv8GCNhUjrifWl-LS8.cer
ROA valid until: Jul 01 00:00:00 2022 GMT
AsID: 15562
  1: 2001:67c:208c::/48 maxlen: 48
  2: 2a0e:b240::/48 maxlen: 48
Validation: OK
How does RPKI apply to BGP?

BGP Prefix Origin Validation: RFC 6811
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BGP Prefix Origin Validation: RFC 6811

```
$ fgrep 193.0.0.0/21 /var/db/rpki-client/openbgpd
193.0.0.0/21 source-as 3333 expires 1648622587
```

```
$ bgpctl show rib 193.0.6.139
flags: * = Valid, > = Selected, I = via IBGP, A = Announced,
      S = Stale, E = Error
origin validation state: N = not-found, V = valid, ! = invalid
origin: i = IGP, e = EGP, ? = Incomplete

flags  ovs  destination          gateway          lpref   med aspath origin
I       V 193.0.0.0/21       165.254.255.1     100  1000 2914 12859 3333 i
```
How does RPKI apply to BGP?

BGP Prefix Origin Validation: RFC 6811

The validation algorithm has 3 possible outcomes:

- **Valid**: A ROA exists, and the BGP route conforms to the ROA
- **Invalid**: covering ROAs exist, but none of them permits the route
- **Not-Found**: no covering ROA exists for the BGP route
How does RPKI apply to BGP?

BGP Prefix Origin Validation: RFC 6811

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*THIS STATE IS WHAT NETWORK OPERATORS REJECT*
Contextual input validation – IMPORTANT! :-)

A RPKI ROA has the following datastructure layout:

```plaintext
RouteOriginAttestation: {
  - asID: INTEGER
  - ipAddrBlocks: {
    - ROAIPAddressFamily: {
      - addressFamily
        - ROAIPAddress: {
          - address: BIT STRING
            - maxLength: INTEGER
        }
    }
  }
}
```
Contextual input validation – IMPORTANT! :-)  

Zooming in on an 'openssl asn1parse' of the 2001:db8::/32 entry:

```
33:d=3  hl=2  l=  13  cons:    SEQUENCE
35:d=4  hl=2  l=  11  cons:    SEQUENCE
37:d=5  hl=2  l=   5  prim:      BIT STRING
    0000 - 00 20 01 0d b8
    .  .  .
44:d=5  hl=2  l=   2  prim:      INTEGER
    :81
```
Flow of information: validators are “firewalls”
Contextually overflowing maxlen: KABLOOEY!

Hostile RPKI Repositories

Normal RPKI Repositories

Router

EBGP routers

EBGP routers

EBGP routers

EBGP routers
Not a disaster when RTR sessions go down… right?

Expectation: all **Valid** BGP routes flip to **Not-Found**

Reality in the year 2020/2021 (*now fixed*):

- Some ISPs set/modify **BGP Communities** based on Validation state. Potential result: **33% of the BGP default-free zone churns**
- Some BGP Implementations have bugs: *briefly flip to invalid*
It is considered harmful to manipulate BGP Path Attributes (for example LOCAL_PREF or COMMUNITY) based on the RPKI Origin Validation state.

Making BGP Path Attributes dependent on RPKI Validation states introduces needless brittleness in the global routing system as explained here. Additionally, the use of RFC 8097 is STRONGLY ABSOLUTELY NOT RECOMMENDED. RFC 8097 has caused issues for multi-vendor network operators.

https://bgpfilterguide.nlnog.net/guides/reject_invalids/
Wrapping it all up!

Folks, always check your inputs!

Identifiers: CVE-2021-3761, CVE-2021-41531, etc

Full write-up:

http://sobornost.net/~job/invalid-maxlength-triggers-rtr-session-termination.txt
Questions?

Discussion?

Comments?

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