

Loss of an RPKI Trust Anchor

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What's Being Covered Today

- Objective of the ARIN fail-open event
- Observations – Before, During and After
- Conclusions
- What are the next steps?

What Was the Objective

Why Did ARIN Run This Test?

- By simulating a failure of the ARIN RPKI Trust Anchor, ARIN and the RPKI community could measure our preparedness for an actual trust anchor failure. The RPKI is not infallible. RFC 7115 advises that in the event of an RPKI system disruption, network operators should revert to a routing state that depends on pre-established route policies and the BGP data within the global Internet routing table. Network operators who apply the practices outlined in RFC 7115 (BCP 185) best practices should experience little to no impact in the case of a genuine failure in the operations of an RIR trust anchor.
- ARIN took advantage of this event to gather information on the operational readiness of our own infrastructure when stressed by the expected heavy load of validators coming to fetch data from the RPKI repository.

Considering the RPKI Best Practices

- The IETF RFCs deal in MAY, SHOULD, and MUST
- The IETF BCPs are just best practices, there is no MUST
- BCPs are born out of lessons learned
- Be prepared for the unexpected

There are Many Moving Parts

- RIRs serve as Trust Anchor for resources in their respective regions.
- Most Relying Party and Certificate Authority software is developed RPKI by community participants.
- Technology vendors write code for their Internet connected devices enabling RPKI functionality.
- Network operator's routing security requirements and the decision use of RPKI data.

RPKI System Redundancy

- Traffic is load balanced to avoid direct single site communication
- Designed capacity N+2 for seamless maintenance and operation
- Geographically diverse installations
- Multiple connectivity partners
- Different power grids
- No single colocation provider
- Multi-vendor technology

External Goals

- Collect the number unique sources of incoming traffic
 - Track versions of the validators from each source
 - Identify outliers (non-supported, non-identifiable)
- Detect validator configuration settings
 - Protocol setup and failover
 - Abnormal fetch rates
 - Look for unusual software behavior
- Measure processes, volume, and patterns
 - Snapshots to set baseline
 - Track activity during incremental protocol shutdown
 - Compare differences after restoration

Internal Goals

- Evaluate RPKI service and hardware performance during protocol interruption (RRDP, rsync).
- Investigate any failed fetches to discern the causes between system performance or traffic volume issues.
- Assess recovery time to baseline traffic, memory usage, and CPU utilization.
- Monitor for any community impact reported through ARIN RSD (Registration Services Desk) channels or public forums such as mailing lists and message boards.

Pregaming

RPKI 'Fail Open'

Simulated a failure of the ARIN RPKI Trust Anchor took place on 24 October 2023.

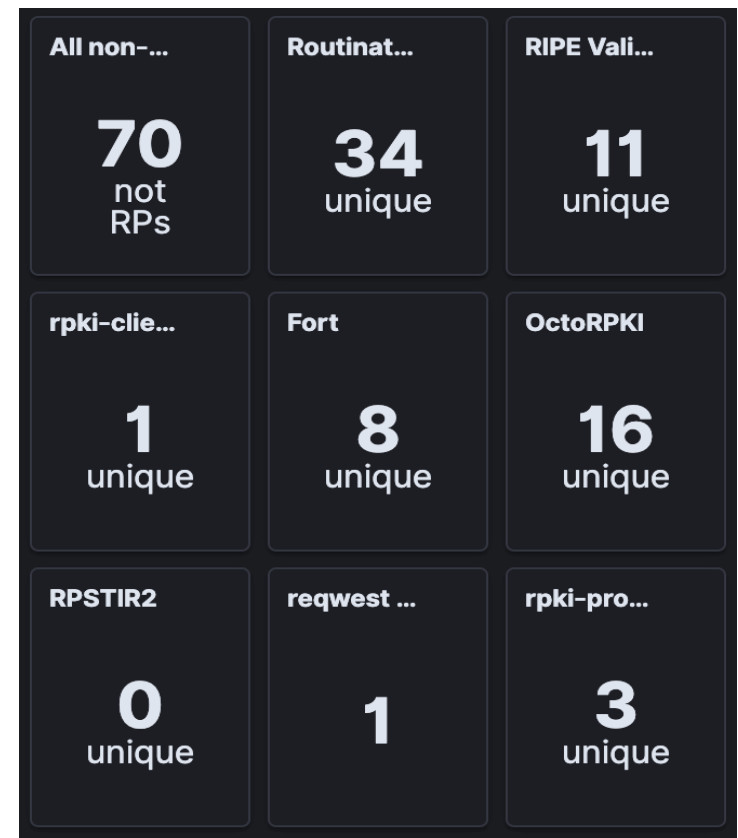
- Time window – 1400-1600 US Eastern
- Incremental loss of protocol connectivity
- Sixty-minute period of total 'darkness'
- Simultaneous restoration of access to ARIN infrastructure

Setting the Baseline

- The number of unique source IPs observed.
 - 3417 were establishing connections with RRDP
 - 308 of those also using RSYNC
- There were 75 different revisions of RP software identified.
 - Routinator, RIPE Validator, OctoRPKI, rpki-client, Fort, rpki-prover
- We logged 70 different 'versions' of incoming connection attempts that were not formatted for RPKI.
- Measured processes, requests, and CPU utilization.
- Active monitoring the community for messages related to the event.

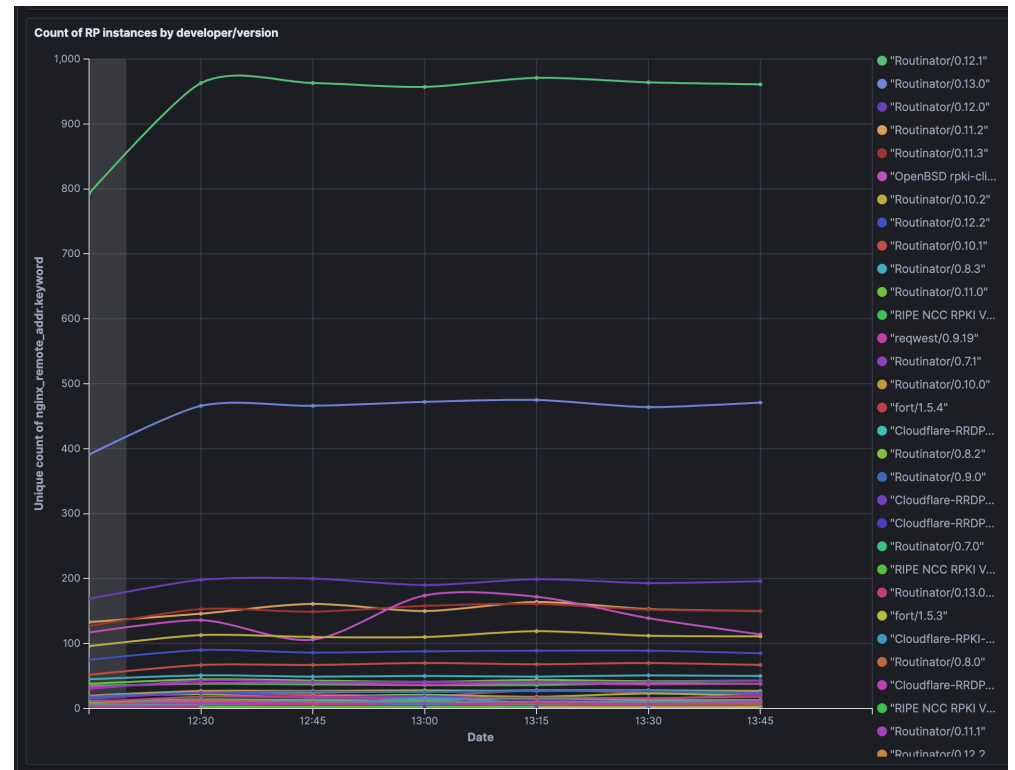
Count of Validators by Developer Name

- The developer community is actively writing and updating RP (validator) software.
- They remain vigilant in delivering new features and functionality while also maintaining standards conformance.
- This looks similar to operating systems running on computers today.



Validators by Revision

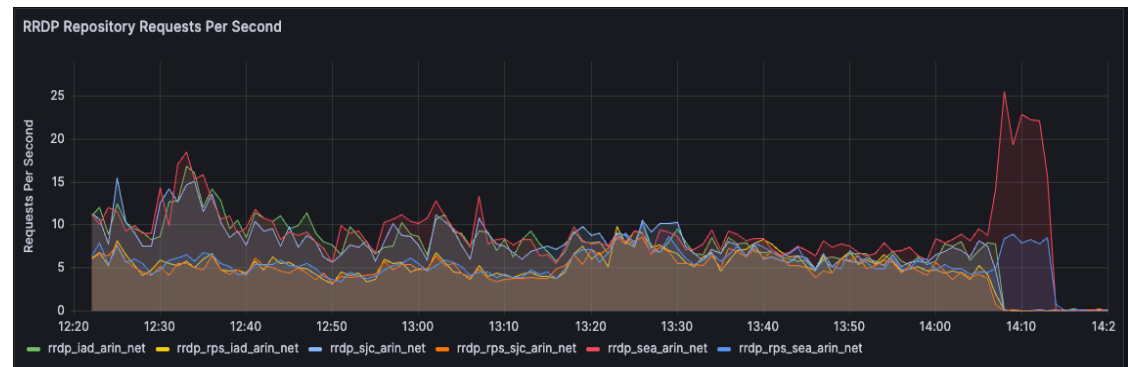
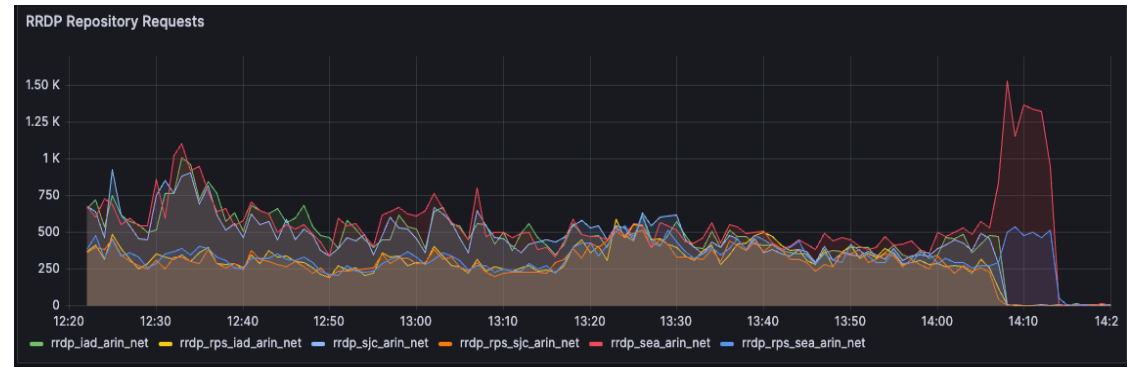
- The number of different validator revisions is higher than the typical RPKI community participant might expect.
- This can be viewed as a success since so many are actively in use today, but are we a victim of that same success?
- Are there systems running code that no longer conforms to standards or running without support?



RRDP Repository Requests by Site

- Sum of all connections
 - Hosted and RPS (Hybrid)
 - Reported every minute

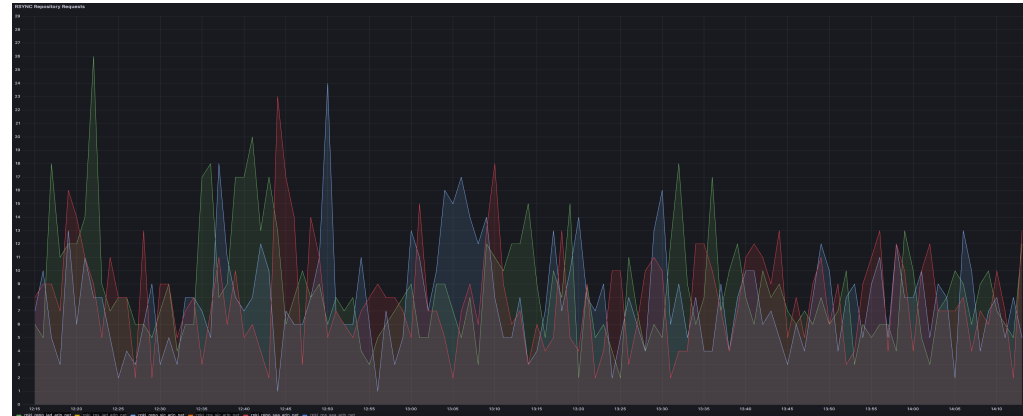
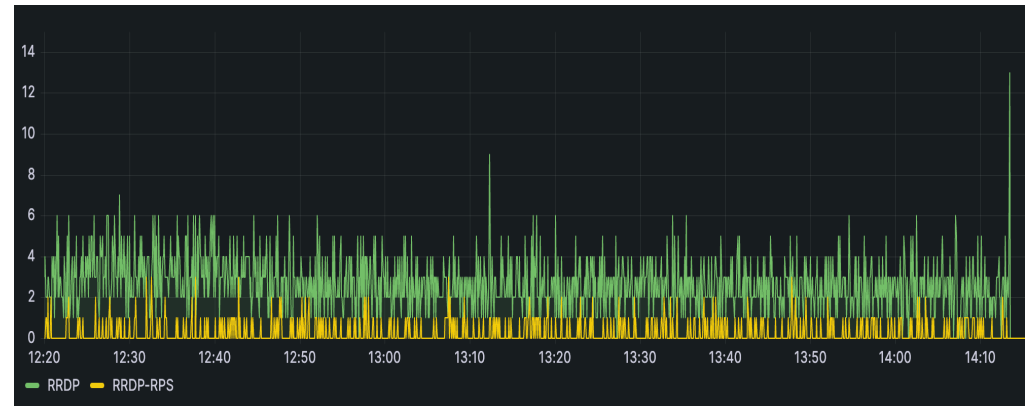
- Connections/sec
 - Hosted and RPS (Hybrid)
 - Calculated and reported every minute



RRDP Specific Requests

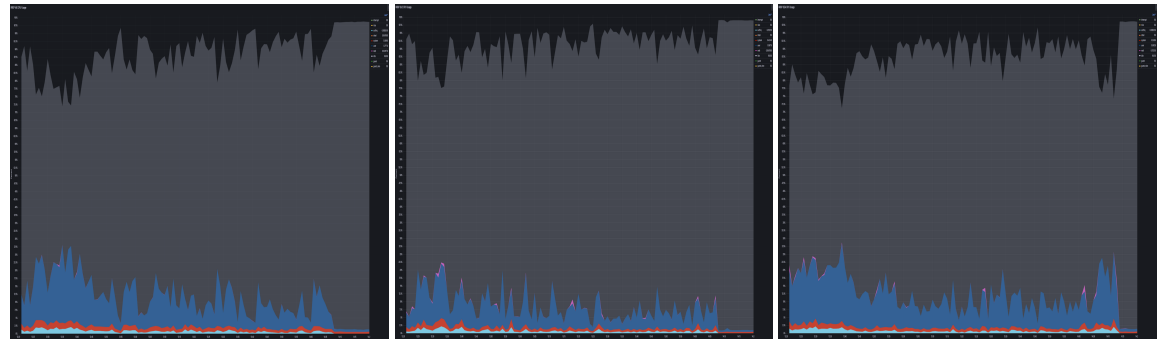
- Snapshot.xml requests
 - Hosted repository ~6/sec
 - Hybrid (RPS) ~2/sec

- rsync requests
 - Hosted repository ~20/sec
 - Hybrid (RPS) ~6/sec

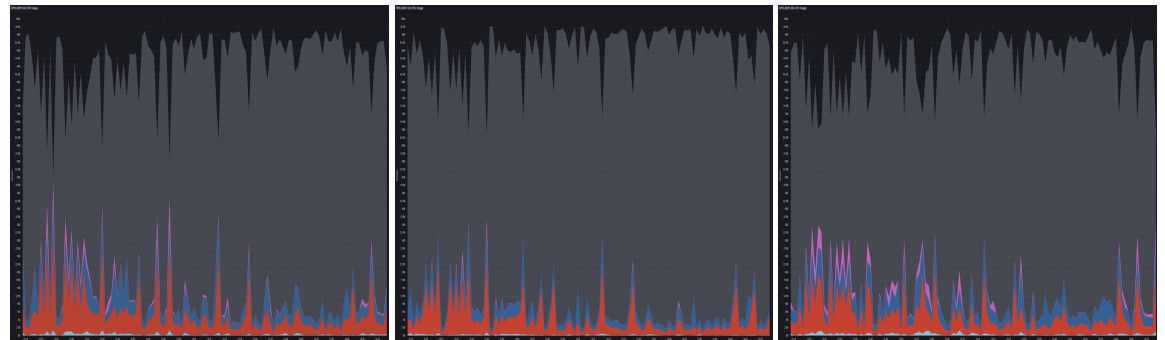


RRDP/rsync Systems CPU Usage

- RRDP Repository Sites
 - Idle ~ 92%



- Rsync Repository Sites
 - Idle ~70%



What We Found Was Surprising

Validator Use Patterns

We expected

- Multiple revisions of validator software
- Operators running multiple RP instances
- Operators with RPs of different developers

We didn't expect

- Old and non-supported versions in use
- User set parameters on validators
- Number of web crawlers and bots



Top Querier by User Agent & Request

| Querier (Remote Address) ▾ | Validator (User Agent) ▾ | Request ▾ | Count ▾ |
|----------------------------|---|--------------------------------|---------|
| 192.248.132 | "Routinator/0.8.0" | /arin-rpki-ta.cer | 3.21 K |
| 192.248.132 | "Routinator/0.8.0" | /notification.xml | 3.21 K |
| 192.66.68 | "Routinator/0.12.1" | /arin-rpki-ta.cer | 1.58 K |
| 192.66.68 | "Routinator/0.12.1" | /notification.xml | 1.58 K |
| 192.149.6 | "Routinator/0.12.1" | /notification.xml | 1.33 K |
| 192.191.16 | "Routinator/0.11.3" | /notification.xml | 938 |
| 192.149.6 | "Routinator/0.12.1" | /arin-rpki-ta.cer | 664 |
| 192.191.16 | "Routinator/0.11.3" | /arin-rpki-ta.cer | 560 |
| 192.66.68 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1a... | 477 |
| 192.66.68 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1a... | 218 |
| 192.1.255.100 | "Routinator/0.8.3" | /notification.xml | 180 |
| 192.136.44 | "Routinator/0.12.1" | /notification.xml | 171 |
| 192.184.10 | "Routinator/0.13.0" | /arin-rpki-ta.cer | 158 |
| 192.184.10 | "Routinator/0.13.0" | /notification.xml | 158 |
| 192.66.68 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1a... | 142 |
| 192.2.246.52 | "Routinator/0.13.0" | /notification.xml | 132 |
| 192.1.255.100 | "Routinator/0.8.3" | /arin-rpki-ta.cer | 90 |
| 192.136.44 | "Routinator/0.12.1" | /arin-rpki-ta.cer | 86 |
| 192.66.68 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1a... | 80 |
| 192.114.2 | "Routinator/0.12.1" | /notification.xml | 76 |
| 192.66.68 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1a... | 75 |
| 192.1.201.53 | "RIPE NCC RPki Validator/3.2-2020.10... | /notification.xml | 71 |

Validator Use – Typical Behavior

12:20-14:20 (before)

- Seeks update 22 times
- ~ 5 min interval
- Eight deltas were fetched once

16:20-18:20 (after)

- On par with pre-event activity
- Same ~5 min interval
- Deltas only fetched once

Overall expected activity

- Pulling deltas, only once
- Checking at regular intervals



Top Querier by User Agent & Request

| Querier (Remote Address) ▾ | Validator (User Agent) ▾ | Request ▾ | Count ↓ ▾ |
|----------------------------|--------------------------|---|-----------|
| 197.25 | "Routinator/0.10.2" | /notification.xml | 22 |
| 197.25 | "Routinator/0.10.2" | /arin-rpki-ta.cer | 11 |
| 197.25 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40598/delta.xml | 1 |
| 197.25 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40599/delta.xml | 1 |
| 197.25 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40600/delta.xml | 1 |
| 197.25 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40601/delta.xml | 1 |
| 197.25 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40602/delta.xml | 1 |
| 197.25 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40603/delta.xml | 1 |
| 197.25 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40604/delta.xml | 1 |
| 197.25 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40605/delta.xml | 1 |

Top Querier by User Agent & Request

| Querier (Remote Address) ↑ ▾ | Validator (User Agent) ▾ | Request ▾ | Count ▾ |
|------------------------------|--------------------------|---|---------|
| 197.25 | "Routinator/0.10.2" | /notification.xml | 19 |
| 197.25 | "Routinator/0.10.2" | /arin-rpki-ta.cer | 10 |
| 197.25 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40646/delta.xml | 1 |
| 197.25 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40645/delta.xml | 1 |
| 197.25 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40644/delta.xml | 1 |
| 197.25 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40643/delta.xml | 1 |
| 197.25 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40642/delta.xml | 1 |
| 197.25 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40641/delta.xml | 1 |
| 197.25 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40640/delta.xml | 1 |
| 197.25 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40639/delta.xml | 1 |

Validator Usage – Atypical Behavior

12:20-14:20 (before)



- Seeks update 2,820 times
- 255 ms interval



16:20-18:20 (after)

- Seeks update 3,390
- 212 ms interval

Denial of Service Attempt?

- No deltas or snapshots
- Routinator 0.8.0 ?

| Top Querier by User Agent & Request | | | |
|---|--------------------------|-------------------|-----------|
| Querier (Remote Address) ▾ | Validator (User Agent) ▾ | Request ▾ | Count ↓ ▾ |
|  248.132 | "Routinator/0.8.0" | /arin-rpki-ta.cer | 2.82 K |
|  248.132 | "Routinator/0.8.0" | /notification.xml | 2.82 K |

| Top Querier by User Agent & Request | | | |
|---|--------------------------|-------------------|-----------|
| Querier (Remote Address) ▾ | Validator (User Agent) ▾ | Request ▾ | Count ↓ ▾ |
|  248.132 | "Routinator/0.8.0" | /arin-rpki-ta.cer | 3.39 K |
|  248.132 | "Routinator/0.8.0" | /notification.xml | 3.39 K |

Validator Usage – Atypical Behavior

12:20-14:20 (before)

- Seeks update 1,690 times
- 426 ms interval

16:20-18:20 (after)

- Seeks update 522
- 725 ms interval

Intentional but misguided

- Multiple fetches of same snapshot
- 2/3 drop in requests, post event
- Only pulling Hosted repository



Top Querier by User Agent & Request

| Querier (Remote Address) ▾ | Validator (User Agent) ▾ | Request ▾ | Count ↓ ▾ |
|----------------------------|--------------------------|---|-----------|
| .66.68 | "Routinator/0.12.1" | /arin-rpki-ta.cer | 1.69 K |
| .66.68 | "Routinator/0.12.1" | /notification.xml | 1.69 K |
| .66.68 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40605/snapshot... | 465 |
| .66.68 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40603/snapshot... | 218 |
| .66.68 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40600/snapshot... | 173 |
| .66.68 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40604/snapshot... | 142 |
| .66.68 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40599/snapshot... | 87 |
| .66.68 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40601/snapshot... | 75 |
| .66.68 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40602/snapshot... | 68 |
| .66.68 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40598/snapshot... | 32 |

Top Querier by User Agent & Request

| Querier (Remote Address) ▾ | Validator (User Agent) ▾ | Request ▾ | Count ↓ ▾ |
|----------------------------|--------------------------|--|-----------|
| .66.68 | "Routinator/0.12.1" | /arin-rpki-ta.cer | 522 |
| .66.68 | "Routinator/0.12.1" | /notification.xml | 522 |
| .66.68 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40640/snapshot.xml | 29 |
| .66.68 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40642/snapshot.xml | 19 |
| .66.68 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40643/snapshot.xml | 13 |
| .66.68 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40645/snapshot.xml | 12 |
| .66.68 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40644/snapshot.xml | 11 |
| .66.68 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40639/snapshot.xml | 7 |
| .66.68 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40641/snapshot.xml | 5 |
| .66.68 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40646/snapshot.xml | 4 |

Validator Usage – Something is Not Quite Right

12:20-14:20 (before)

- rev 0.12.1
 - Polled 1,370 times
 - Every delta 50 times
 - Every 192 ms
- rev 0.10.2
 - 22 times
 - Once per delta
 - Every 5 minutes

Why the disparity of polling cycles based on validator revision?

| Querier (Remote Address) ▾ | Validator (User Agent) ▾ | Request ▾ | Count ↓ ▾ |
|----------------------------|--------------------------|---|-----------|
| .149.6 | "Routinator/0.12.1" | /notification.xml | 1.37 K |
| .149.6 | "Routinator/0.12.1" | /arin-rpki-ta.cer | 686 |
| .149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40598/delta.xml | 50 |
| .149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40599/delta.xml | 50 |
| .149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40600/delta.xml | 50 |
| .149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40601/delta.xml | 50 |
| .149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40602/delta.xml | 50 |
| .149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40603/delta.xml | 50 |
| .149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40604/delta.xml | 50 |
| .149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40605/delta.xml | 50 |
| .149.6 | "Routinator/0.10.2" | /notification.xml | 22 |
| .149.6 | "Routinator/0.10.2" | /arin-rpki-ta.cer | 11 |
| .149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40598/delta.xml | 1 |
| .149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40599/delta.xml | 1 |
| .149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40600/delta.xml | 1 |
| .149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40601/delta.xml | 1 |
| .149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40602/delta.xml | 1 |
| .149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40603/delta.xml | 1 |
| .149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40604/delta.xml | 1 |
| .149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40605/delta.xml | 1 |

Validator Usage – Something is Not Quite Right

16:20-17:20 (+1 hour)

- rev 0.12.1
 - fetch rate is dropping
 - Fewer multiple fetches
 - Starting to see deltas
 - ~ 500 ms
- rev 0.10.2
 - Hosted snapshots/RPS deltas
 - ~ 5 minutes

Why the disparity of polling cycles based on validator revision?

| Querier (Remote Address) ▾ | Validator (User Agent) ▾ | Request ▾ | Count ↓ ▾ |
|----------------------------|--------------------------|--|-----------|
| 149.6 | "Routinator/0.12.1" | /notification.xml | 536 |
| 149.6 | "Routinator/0.12.1" | /arin-rpki-ta.cer | 268 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40634/snapshot.xml | 50 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40632/snapshot.xml | 39 |
| 149.6 | "Routinator/0.10.2" | /notification.xml | 10 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40635/snapshot.xml | 9 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40633/snapshot.xml | 8 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40637/snapshot.xml | 7 |
| 149.6 | "Routinator/0.10.2" | /arin-rpki-ta.cer | 5 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40633/delta.xml | 5 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40634/delta.xml | 5 |
| 149.6 | "Routinator/0.10.2" | /222bc4dd-08cd-46c3-b744-f99835520fa4/14461/delta.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /222bc4dd-08cd-46c3-b744-f99835520fa4/14462/delta.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /222bc4dd-08cd-46c3-b744-f99835520fa4/14463/delta.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1addb69284ff/40630/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1addb69284ff/40631/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1addb69284ff/40632/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1addb69284ff/40634/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1addb69284ff/40635/snapshot.xml | 1 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1addb69284ff/40635/delta.xml | 1 |

Validator Usage – Something is Not Quite Right

17:20-18:20 (+2 hours)

- rev 0.12.1
 - fetch rate still dropping
 - Deltas for every snapshot
- rev 0.10.2
 - Hosted snapshots
 - RPS updated and cached

Why is 0.10.2 pulling older serials?

| Querier (Remote Address) | Validator (User Agent) | Request | Count |
|--------------------------|------------------------|--|--------|
| 149.6 | "Routinator/0.12.1" | /notification.xml | 1.07 K |
| 149.6 | "Routinator/0.12.1" | /arin-rpki-ta.cer | 533 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40644/delta.xml | 21 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40643/delta.xml | 20 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40644/snapshot.xml | 20 |
| 149.6 | "Routinator/0.10.2" | /notification.xml | 18 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40645/delta.xml | 17 |
| 149.6 | "Routinator/0.10.2" | /arin-rpki-ta.cer | 9 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40643/snapshot.xml | 8 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40645/snapshot.xml | 7 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40646/delta.xml | 5 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40646/snapshot.xml | 4 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40631/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40632/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40634/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40635/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40637/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40640/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40642/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40644/snapshot.xml | 1 |

Validator Usage – Something is Not Quite Right

18:20-19:20 (+3 hours)

- rev 0.12.1
 - fetch rate still dropping
 - Deltas for every snapshot
 - First signs of single snapshots
- rev 0.10.2
 - Hosted snapshots behind 0.12.1
 - Still looking for older serials

Why the disparity of serials based on validator revision?

| Querier (Remote Address) ▾ | Validator (User Agent) ▾ | Request ▾ | Count ↓ ▾ |
|----------------------------|--------------------------|--|-----------|
| 149.6 | "Routinator/0.12.1" | /notification.xml | 1.75 K |
| 149.6 | "Routinator/0.12.1" | /arin-rpki-ta.cer | 875 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40652/snapshot.xml | 46 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40653/delta.xml | 32 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40654/delta.xml | 32 |
| 149.6 | "Routinator/0.10.2" | /notification.xml | 30 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40651/delta.xml | 22 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40652/delta.xml | 20 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40654/snapshot.xml | 19 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40651/snapshot.xml | 18 |
| 149.6 | "Routinator/0.10.2" | /arin-rpki-ta.cer | 15 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40640/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40642/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40644/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40647/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40650/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40651/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40652/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40654/snapshot.xml | 1 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40653/snapshot.xml | 1 |

Validator Usage – Something is Not Quite Right

19:20-20:20 (+4 hours)

- rev 0.12.1
 - fetch numbers creeping up
 - Deltas are higher
 - single snapshots are more common
- rev 0.10.2
 - Snapshots caught up with 0.12.1
 - Still looking for older serials

Top Querier by User Agent & Request

| Querier (Remote Address) ▾ | Validator (User Agent) ▾ | Request ▾ | Count ↓ ▾ |
|----------------------------|--------------------------|--|-----------|
| 149.6 | "Routinator/0.12.1" | /notification.xml | 2.27 K |
| 149.6 | "Routinator/0.12.1" | /arin-rpki-ta.cer | 1.14 K |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40657/delta.xml | 46 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40656/delta.xml | 45 |
| 149.6 | "Routinator/0.10.2" | /notification.xml | 40 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40655/delta.xml | 39 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40658/delta.xml | 22 |
| 149.6 | "Routinator/0.10.2" | /arin-rpki-ta.cer | 20 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40655/snapshot.xml | 20 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40657/snapshot.xml | 3 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40654/snapshot.xml | 2 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40656/snapshot.xml | 2 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40650/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40651/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40652/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40655/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40656/delta.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40657/delta.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40658/delta.xml | 1 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40659/delta.xml | 1 |

Validator Usage – Something is Not Quite Right

20:20-21:20 (+5 hours)

- rev 0.12.1
 - fetch numbers creeping up
 - Deltas are creeping up
 - single snapshots common
- rev 0.10.2
 - Snapshots caught up with 0.12.1
 - More snapshots, fewer deltas
 - Still looking for older serials

Why the upturn in requests?

| Querier (Remote Address) ▾ | Validator (User Agent) ▾ | Request ▾ | Count ↓ ▾ |
|----------------------------|--------------------------|--|-----------|
| 149.6 | "Routinator/0.12.1" | /notification.xml | 2.27 K |
| 149.6 | "Routinator/0.12.1" | /arin-rpki-ta.cer | 1.14 K |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40657/delta.xml | 46 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40656/delta.xml | 45 |
| 149.6 | "Routinator/0.10.2" | /notification.xml | 40 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40655/delta.xml | 39 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40658/delta.xml | 22 |
| 149.6 | "Routinator/0.10.2" | /arin-rpki-ta.cer | 20 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40655/snapshot.xml | 20 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40657/snapshot.xml | 3 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40654/snapshot.xml | 2 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40656/snapshot.xml | 2 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40650/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40651/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40652/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40655/snapshot.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40656/delta.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40657/delta.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40658/delta.xml | 1 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40659/delta.xml | 1 |

Validator Usage – Something is Not Quite Right

21:20-22:20 (+6 hours)

- rev 0.12.1
 - fetch numbers creeping up
 - Deltas settling near 50/hr
 - snapshots almost gone
- rev 0.10.2
 - Only deltas, no snapshots
 - looking for more serials

Why does 0.10.2 look for more serials?

| Querier (Remote Address) | Validator (User Agent) | Request | Count |
|--------------------------|------------------------|--|--------|
| 149.6 | "Routinator/0.12.1" | /notification.xml | 3.36 K |
| 149.6 | "Routinator/0.12.1" | /arin-rpki-ta.cer | 1.68 K |
| 149.6 | "Routinator/0.10.2" | /notification.xml | 62 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40667/delta.xml | 50 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40668/delta.xml | 50 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40669/delta.xml | 50 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40664/delta.xml | 49 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40665/delta.xml | 49 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40666/delta.xml | 49 |
| 149.6 | "Routinator/0.10.2" | /arin-rpki-ta.cer | 31 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40662/delta.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40663/delta.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40664/delta.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40665/delta.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40666/delta.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40667/delta.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40668/delta.xml | 1 |
| 149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40669/delta.xml | 1 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40665/snapshot.xml | 1 |
| 149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40666/snapshot.xml | 1 |

Validator Usage – Something is Not Quite Right

21:20-22:20 (+7 hours)

- rev 0.12.1
 - fetch numbers still going up
 - Deltas settling near 50/hr
 - One lonely snapshot remains
- rev 0.10.2
 - Higher numbers than before counts
 - looking for more serials

| Querier (Remote Address) ▾ | Validator (User Agent) ▾ | Request ▾ | Count ↓ ▾ |
|----------------------------|--------------------------|--|-----------|
| 49.6 | "Routinator/0.12.1" | /notification.xml | 3.92 K |
| 49.6 | "Routinator/0.12.1" | /arin-rpki-ta.cer | 1.96 K |
| 49.6 | "Routinator/0.10.2" | /notification.xml | 72 |
| 49.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40667/delta.xml | 50 |
| 49.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40668/delta.xml | 50 |
| 49.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40669/delta.xml | 50 |
| 49.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40670/delta.xml | 50 |
| 49.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40671/delta.xml | 50 |
| 49.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40672/delta.xml | 50 |
| 49.6 | "Routinator/0.10.2" | /arin-rpki-ta.cer | 36 |
| 49.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40673/delta.xml | 34 |
| 49.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40666/delta.xml | 1 |
| 49.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40667/delta.xml | 1 |
| 49.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40668/delta.xml | 1 |
| 49.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40669/delta.xml | 1 |
| 49.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40670/delta.xml | 1 |
| 49.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40671/delta.xml | 1 |
| 49.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40672/delta.xml | 1 |
| 49.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40673/delta.xml | 1 |
| 49.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40666/snapshot.xml | 1 |

Validator Usage – Something is Not Quite Right

21:20-22:20 (+8 hours)

- rev 0.12.1
 - fetches 3x higher than before
 - Deltas stable at 50/hr
 - No more snapshots
- rev 0.10.2
 - fetches ~4x higher than before
 - Same number of serials

Why so long to settle down?

| Querier (Remote Address) ▾ | Validator (User Agent) ▾ | Request ▾ | Count ↓ ▾ |
|----------------------------|--------------------------|---|-----------|
| .149.6 | "Routinator/0.12.1" | /notification.xml | 4.45 K |
| .149.6 | "Routinator/0.12.1" | /arin-rpki-ta.cer | 2.22 K |
| .149.6 | "Routinator/0.10.2" | /notification.xml | 82 |
| .149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40669/delta.xml | 50 |
| .149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40670/delta.xml | 50 |
| .149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40671/delta.xml | 50 |
| .149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40672/delta.xml | 50 |
| .149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40673/delta.xml | 50 |
| .149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40674/delta.xml | 50 |
| .149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40675/delta.xml | 50 |
| .149.6 | "Routinator/0.10.2" | /arin-rpki-ta.cer | 41 |
| .149.6 | "Routinator/0.12.1" | /4a394319-7460-4141-a416-1adbb69284ff/40676/delta.xml | 16 |
| .149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40668/delta.xml | 1 |
| .149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40669/delta.xml | 1 |
| .149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40670/delta.xml | 1 |
| .149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40671/delta.xml | 1 |
| .149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40672/delta.xml | 1 |
| .149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40673/delta.xml | 1 |
| .149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40674/delta.xml | 1 |
| .149.6 | "Routinator/0.10.2" | /4a394319-7460-4141-a416-1adbb69284ff/40675/delta.xml | 1 |

RRDP/rsync Snapshot Requests

- **RRDP snapshot.xml**
 - No surprise, lots of snapshots
 - Somewhat surprised how long to settle
 - Really surprised, the new normal

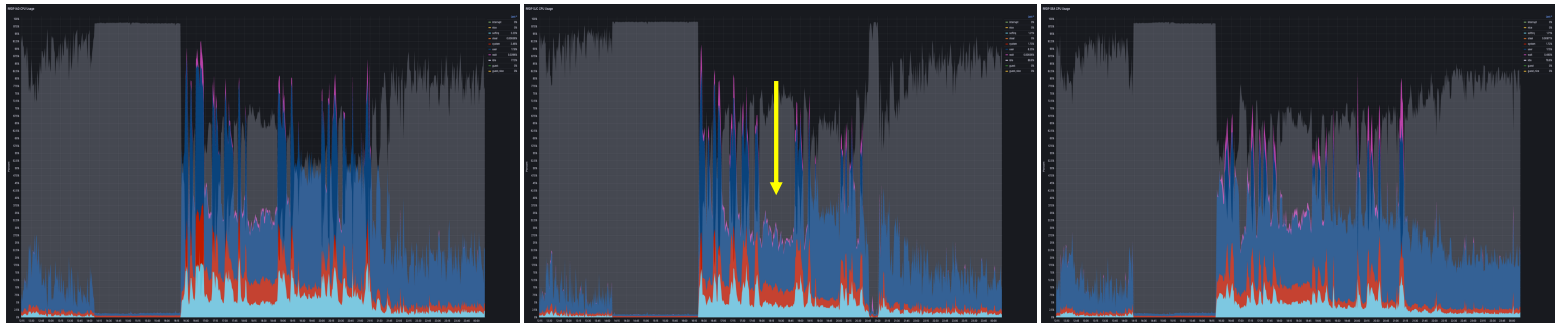
- **rsync**
 - Shutdown 1hr after RRDP
 - Same glidepath down

How are individual sites performing?

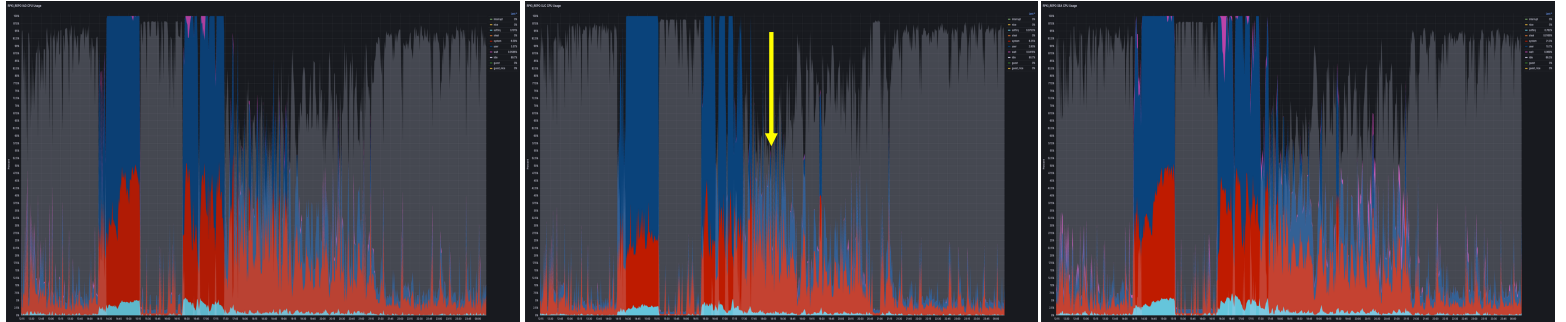


RRDP/rsync resource utilization by Site

RRDP

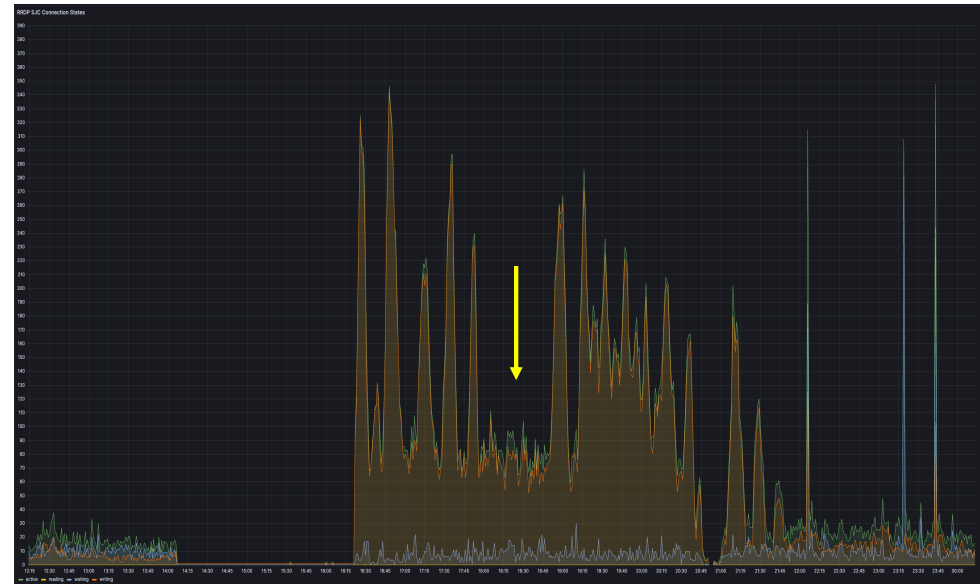


rsync



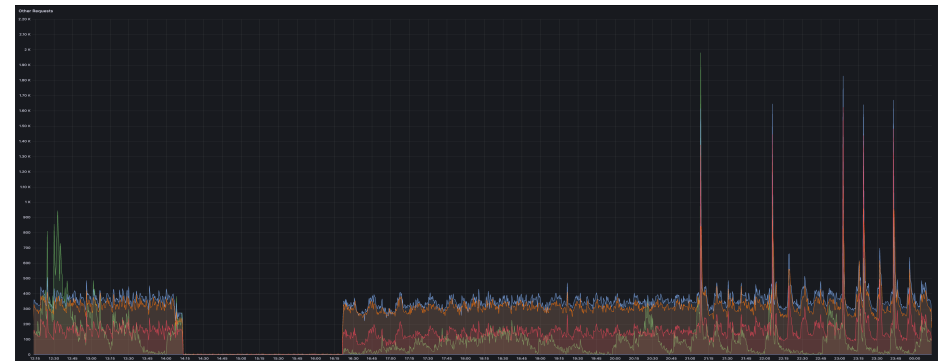
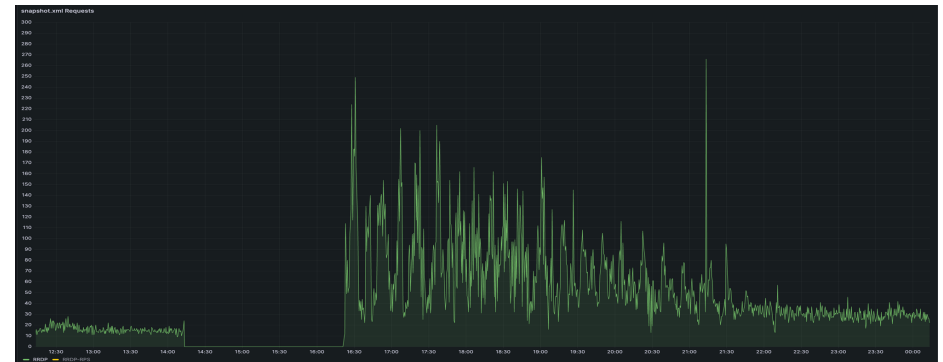
What's Behind These Dips??

- Time window 18:00-19:00
 - Drop inbound Internet traffic
 - Traffic shifted across providers and sites
 - Incoming requests kept constant
- When traffic returned
 - System resource demand had eased
 - More timely delivery of requested updates resulting in fewer retries
 - Infrastructure started catching up



Return to Baseline, Sort Of

- It took nearly eight hours before the RPKI system returned to pre-event performance.
- Snapshot.xml volume has not return to previous levels, there's a new normal.
- Slight increase in repository requests (delta.xml, notification.xml, ta.cer).
- Otherwise, all is as it should be.

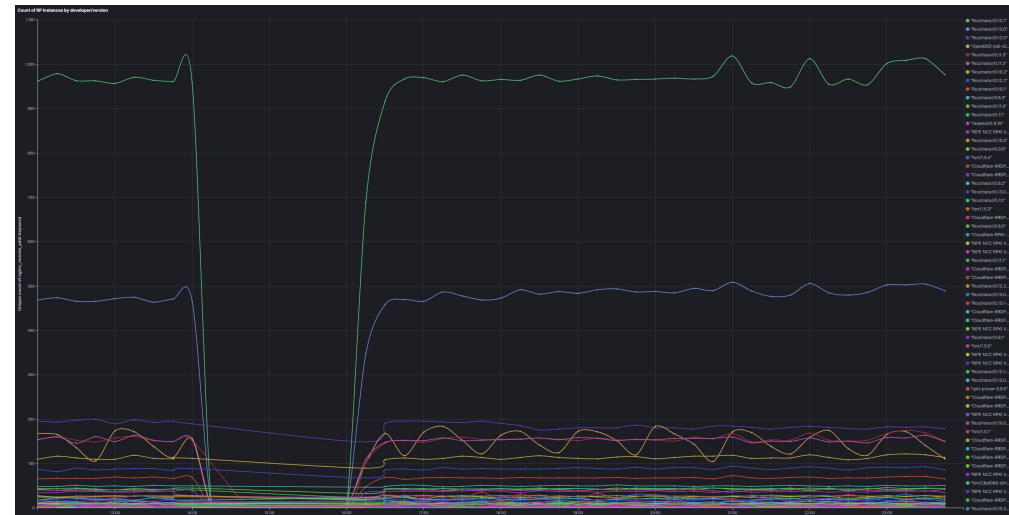


What's Been Changing

Validator Counts Effectively Unchanged

- Over time the number of validator revisions has remained fairly consistent.
- The top versions in use are changing as users are updating
 - Feature releases
 - Bug fixes
 - Early adopters?

| | | |
|----------------|------------------|---------------|
| All non-RPs | Routinator | RPE Validator |
| 147 not RPs | 34 unique | 11 unique |
| rpki-client | Fort | OctoRPKI |
| 1 unique | 8 unique | 16 unique |
| RPSTR2 | request versions | rpki-prover |
| 1 unique | 1 | 3 unique |



New Cast of Characters Are Stopping By

- New players are on the board.
- Some old friends have changed their ways, others not so much.
 - New validator revisions
 - Expected activity counts
 - Others are totally off the radar
 - Makes you wonder if they set up for the event and went on their way
- We'll keep an eye out for any notable changes.

| Client IP | Validator / version | Count ↓ |
|-----------|-----------------------|---------|
| 203.15 | "Routinator/0.11.2" | 41,451 |
| 25.62 | "Routinator/0.11.3" | 34,057 |
| 19.87 | "Routinator/0.13.0" | 32,478 |
| 19.6 | "Routinator/0.12.1" | 30,415 |
| 134 | "Routinator/0.13.0" | 18,631 |
| 91.16 | "Routinator/0.11.3" | 16,633 |
| 196.28 | "Routinator/0.11.2" | 15,614 |
| 108.57 | "Routinator/0.11.3" | 14,572 |
| 01.170 | "Routinator/0.10.2" | 9,436 |
| 98.217 | "Routinator/0.11.2" | 6,482 |
| 14.2 | "Routinator/0.12.1" | 5,822 |
| 109.79 | "Routinator/0.13.0" | 1,980 |
| 14.2 | "Routinator/0.12.0" | 1,684 |
| 14.72 | "Routinator/0.13.0" | 1,424 |
| 1.9 | "Routinator/0.13.0" | 1,284 |
| 14.72 | "OpenBSD rpki-client" | 895 |
| 240.245 | "Routinator/0.13.0" | 637 |
| 144.18 | "Routinator/0.11.3" | 619 |
| 241.35 | "Routinator/0.11.3" | 618 |
| 251.28 | "Routinator/0.11.3" | 616 |

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Systems Upgrades and Updates

- The RPKI repository sites are getting updated hardware.
 - One has been completed, others on schedule.
 - Investigating the option to build in the cloud.
- New resource allocation templates are being investigated.
 - Based on day of observations and ongoing monitoring.
- Modifications in monitoring based on lessons learned.
 - We are looking at more and different things.

Final Observations / Next Steps

What are We Doing with the Data Collected

- Communicate with the big number users to understand their requirements and why they are configured as such.
- Talk to the software development community.
 - Are there reasons for the usage patterns we observed?
 - Do they have a support plan for older and deprecated revisions?
- Confer amongst the RIR trust and see what lessons learned can be applied in all trust anchor deployments.
- Ask the RPKI community what they want us to do.
- What did YOU see during the event?

Ongoing Progress Requires Team Effort

- RPKI education is a MUST (not a SHOULD).
- Further testing and monitoring of RPKI performance .
- Tools development is an integral component and is a community sourced effort.
- RPKI standards and best practices are created through community participation.
- GET INVOLVED!

RPKI is Here to Stay – Embrace it

- As a networking community, the adoption of RPKI is accelerating.
- Global operators are making decisions based on RPKI validity.
- Service providers are requiring new and existing customers to make statements (create ROAs) for their resources.
- Examples of RPKI at work are not hard to find.



Thank you