

Measuring the Effectiveness of  
Route Origin Validation  
Filtering via Drop Invalids from  
the perspective of the End User  
using a Technique of Broad Scale  
Reachability Measurement

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# Measuring RPKI

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# Routing Security



What's “the objective” of routing security?

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- Protect the routing system from all forms of operator mishaps?
- Protect the routing system from some forms of operator mishaps?
- Protect the routing system from all hostile attacks?
- Protect the routing system from some hostile attacks?
- Prevent the routing of bogus address prefixes?
- Prevent the use of bogus AS's in the routing system?
- Prevent all forms of synthetic routes from being injected into the routing system?
- Prevent unauthorised route withdrawal?
- Protect users from being directed along bogus routing paths?

# Routing Security



Enforcing rules to ensure that the routes carried in BGP are both protocol-wise accurate and policy-wise accurate is well beyond the capabilities of BGP and viable BGP control mechanisms \*

Route Origin Validation is designed to prevent BGP speakers from learning and preferring routes that are not authorised by the prefix holder

The intent of not preferring unauthorised routes is to prevent users' traffic from being steered along these bogus routes

\* BGP is not a deterministic protocol, but more of a negotiation protocol that attempts to find meta-stable 'solutions to importer / export policy preferences simultaneously. Where the policies are incompatible the BGP "solution" is not necessarily reached deterministically and different outcomes will be seen at different times – see "BGP Wedgies" for an illustration of this form of indeterminism

# Routing Security



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# Our Objective



- To measure the “impact” of invalid route filtering on users
- The question we want to answer here is user-centric:
  - What proportion of users can’t reach a destination when the destination route is invalid according to ROV?
- We’d like to continue this as a long term whole-of-Internet measurement

# Measurement Approach



If we are looking at the effectiveness of the secure routing system in blocking the ability to direct users along bogus routing paths, then this suggests a measurement approach:

- Set up a bogus (RPKI RoV-invalid) routing path as the only route to a prefix
- Direct a very large set of users from across the Internet to try to reach a web server located at this prefix
- Use a 'control' of a valid routing path to the same destination
- Measure and compare





# Methodology

- Set up a prefix and AS in a delegated RPKI repository
  - We used the Krill package to achieve this
  - It Just Worked!™



## RPKI TOOLS

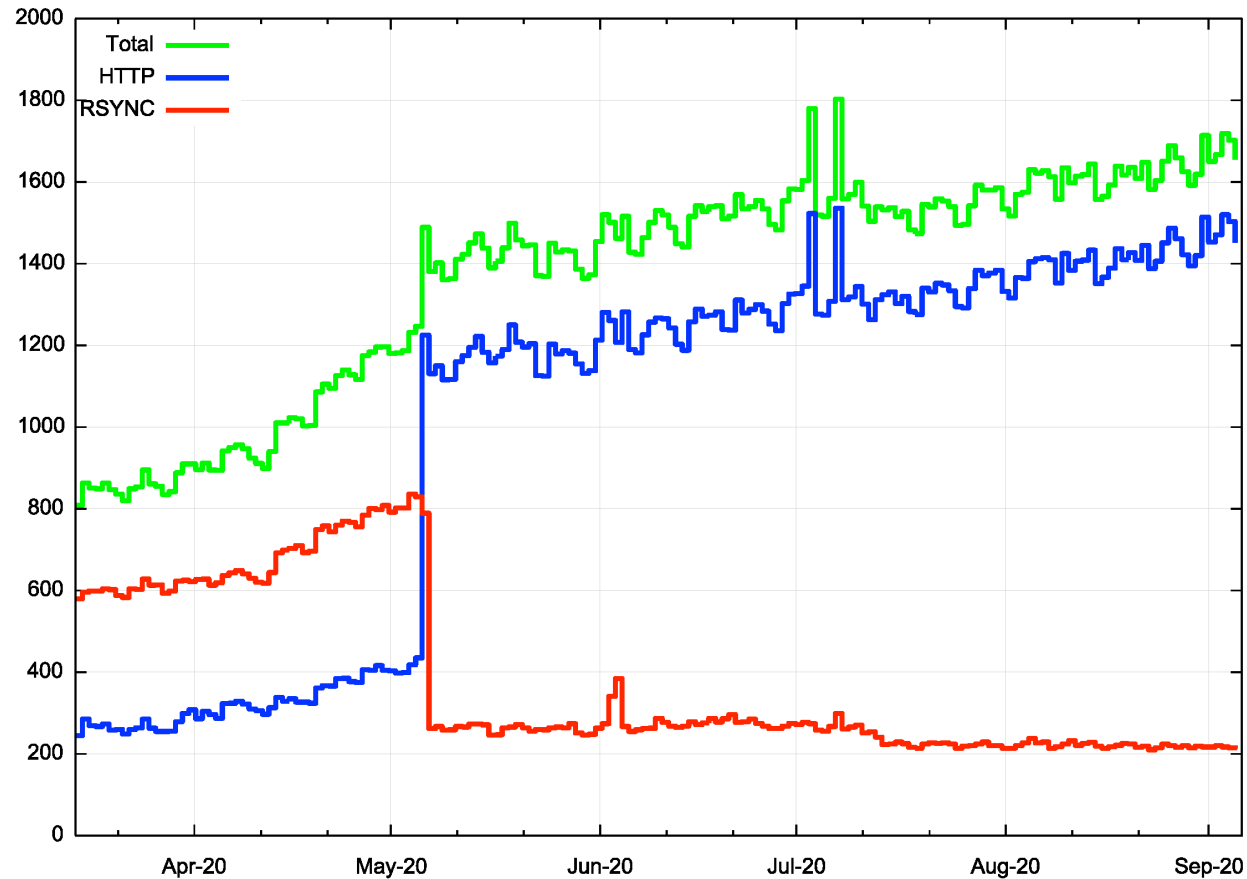
[About](#) | [Krill](#) | [Routinator](#) | [Support](#) | [FAQ](#) | [Security Advisories](#) | [Analytics](#) | [Funding](#)



Krill is a free, open source RPKI Certificate Authority that lets you run delegated RPKI under one or multiple Regional Internet Registries (RIRs). Through its built-in publication server, Krill can publish Route Origin Authorisations (ROAs) on your own servers or with a third party.

<https://www.nlnetlabs.nl/projects/rpki/krill/>

# Counting RPKI Clients



Number of Unique IP addresses per day performing a fetch from our RPKI repository



# Methodology

- ❑ Set a prefix and AS in a delegated RPKI repository
- ❑ Regularly revoke and re-issue ROAs that flip the validity state between valid and invalid states

```
# Flip to "good" at 00:00 on Fri/Mon/Thu
```

```
0 0 * * 1,4,5 /home/krill/.cargo/bin/krillc roas update --delta ./delta-in.txt > /tmp/krillc-in.log 2>&1
```

```
# Flip to "bad" at 12:00 on sat/Tue/Thu
```

```
0 12 * * 2,4,6 /home/krill/.cargo/bin/krillc roas update --delta ./delta-out.txt > /tmp/krillc-out.log 2>&1
```

These two scripts flip the ROA valid state between 'good' and 'bad' origin ASNs for the prefix



# Methodology

- ❑ Set a prefix and AS in a delegated RPKI repository
- ❑ Regularly revoke and re-issue ROAs that flip the validity state between valid and invalid states
- ❑ Anycast the prefix and AS pair in a number of locations across the Internet
  - We are using 3 locations: US (LA), DE (FRA), SG
  - We are using 3 transit providers
  - The server at this location delivers 1x1 blots
  - This is IPv4-only at this point



# Methodology

- ❑ Set a prefix and AS in a delegated RPKI repository
- ❑ Regularly revoke and re-issue ROAs that flip the validity state between valid and invalid states
- ❑ Anycast the prefix and AS pair in a number of locations across the Internet
- ❑ Load a unique URL that maps to the destination into a measurement script
  - The DNS component uses HTTPS and a unique DNS label component to try and ensure that the HTTP FETCH is not intercepted by middleware proxies



# Methodology

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- ❑ Load a unique URL that maps to the destination into a measurement script
- ❑ Feed the script into the advertising systems
  - This is part of the larger APNIC Labs ad-based measurement system – this test is one URL in a larger collection of URLs



# Methodology

- ❑ Set a prefix and AS in a delegated RPKI repository
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- ❑ Anycast the prefix and AS pair in a number of locations across the Internet
- ❑ Load a unique URL that maps to the destination into a measurement script
- ❑ Feed the script into the advertising systems
- ❑ Collect and analyse data
  - We use the user record of successful fetch to avoid zombies and stalkers

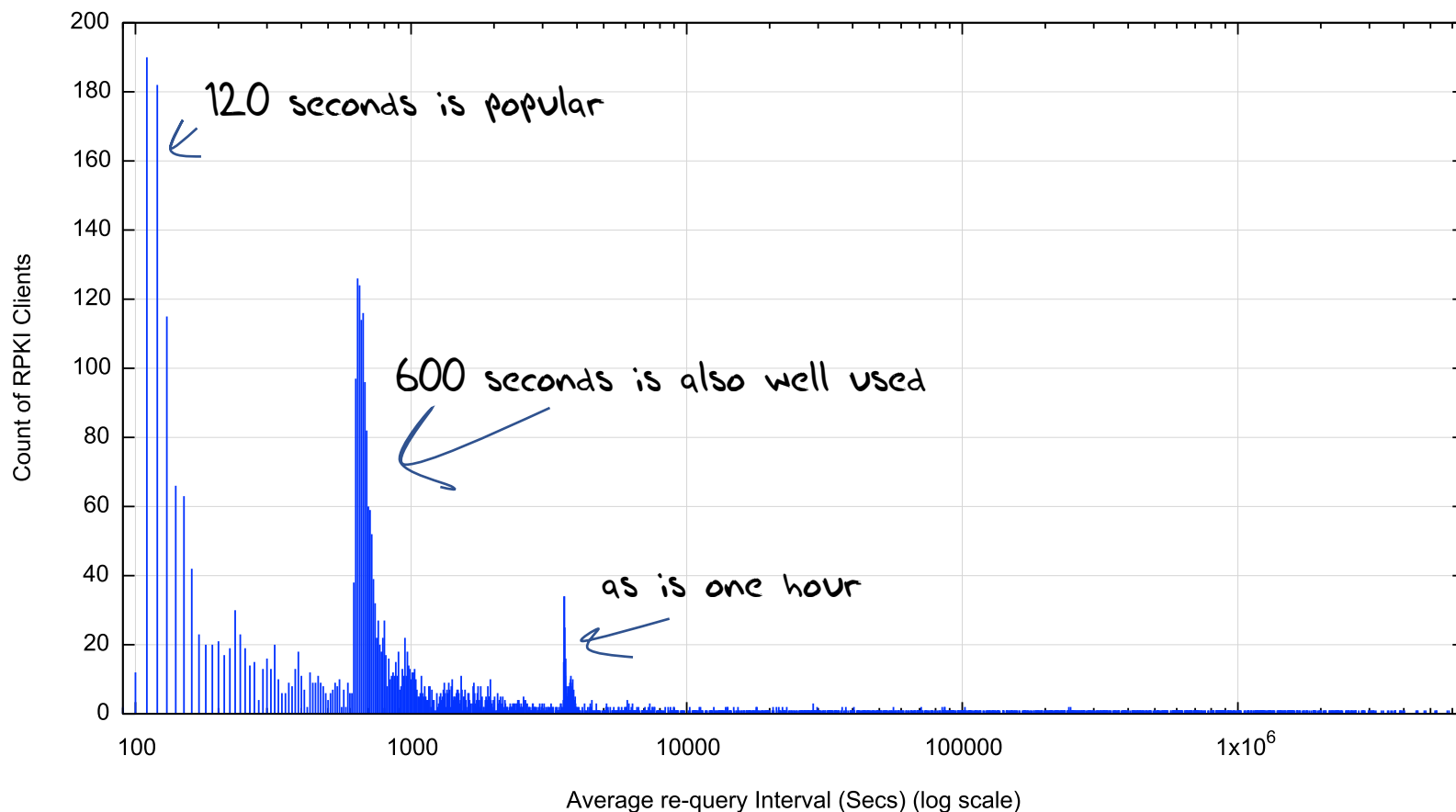
# Flipping ROA states

- What's a good frequency to flip states?
  - How long does it take for the routing system as a whole to learn that a previously valid route is now invalid? And how long for the inverse invalid to valid transition
- Validity / Invalidity is determined by what is published at the RPKI publication point
  - Each transition is marked by revocation of the previous ROA's EE certificate and the issuing of a new ROA and EE certificate
- What's the re-query interval for clients of a RPKI publication point?
  - There is no standard-defined re-query interval so implementors have exercised their creativity!

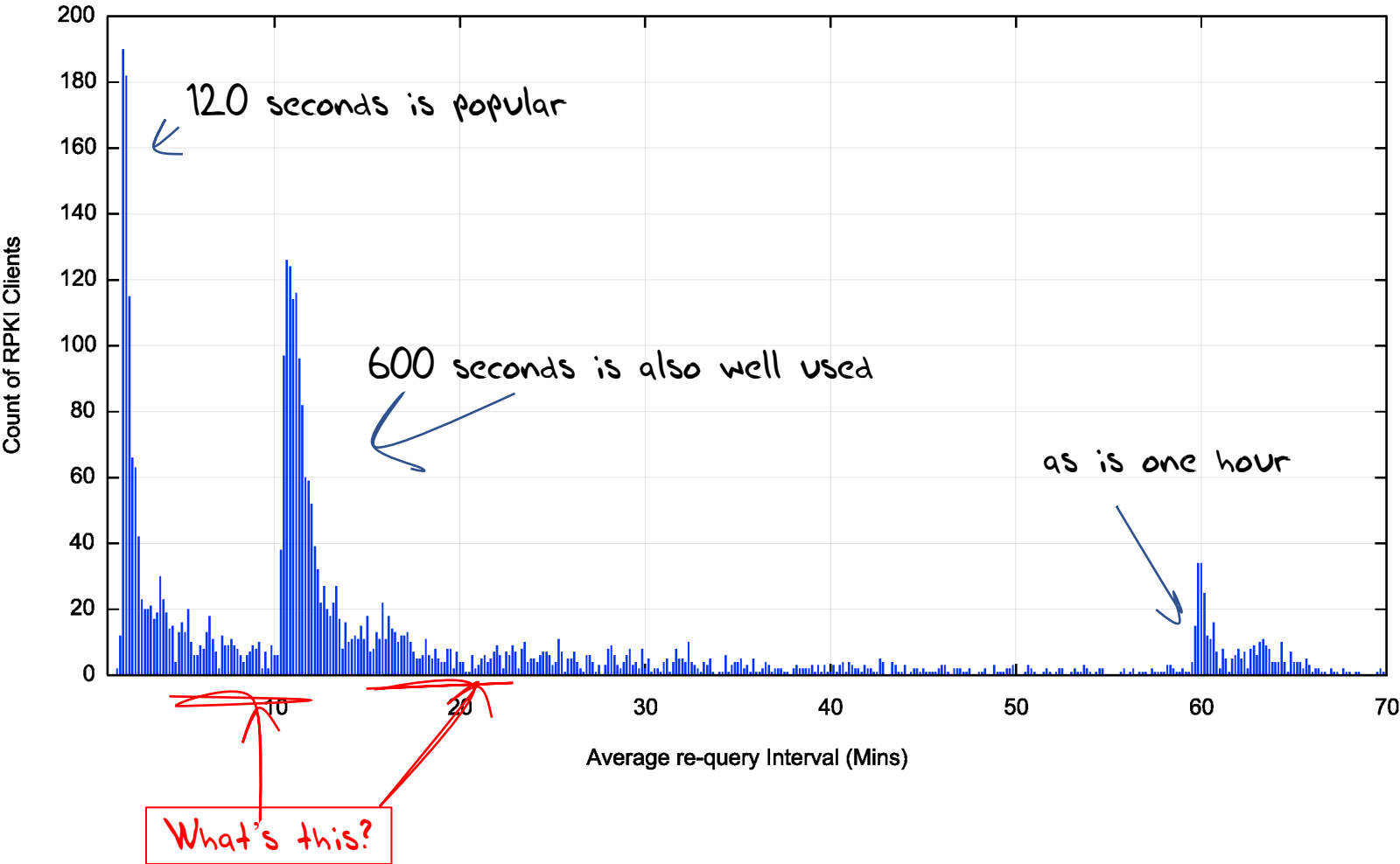


# RPKI Pub Point Re-Query Intervals

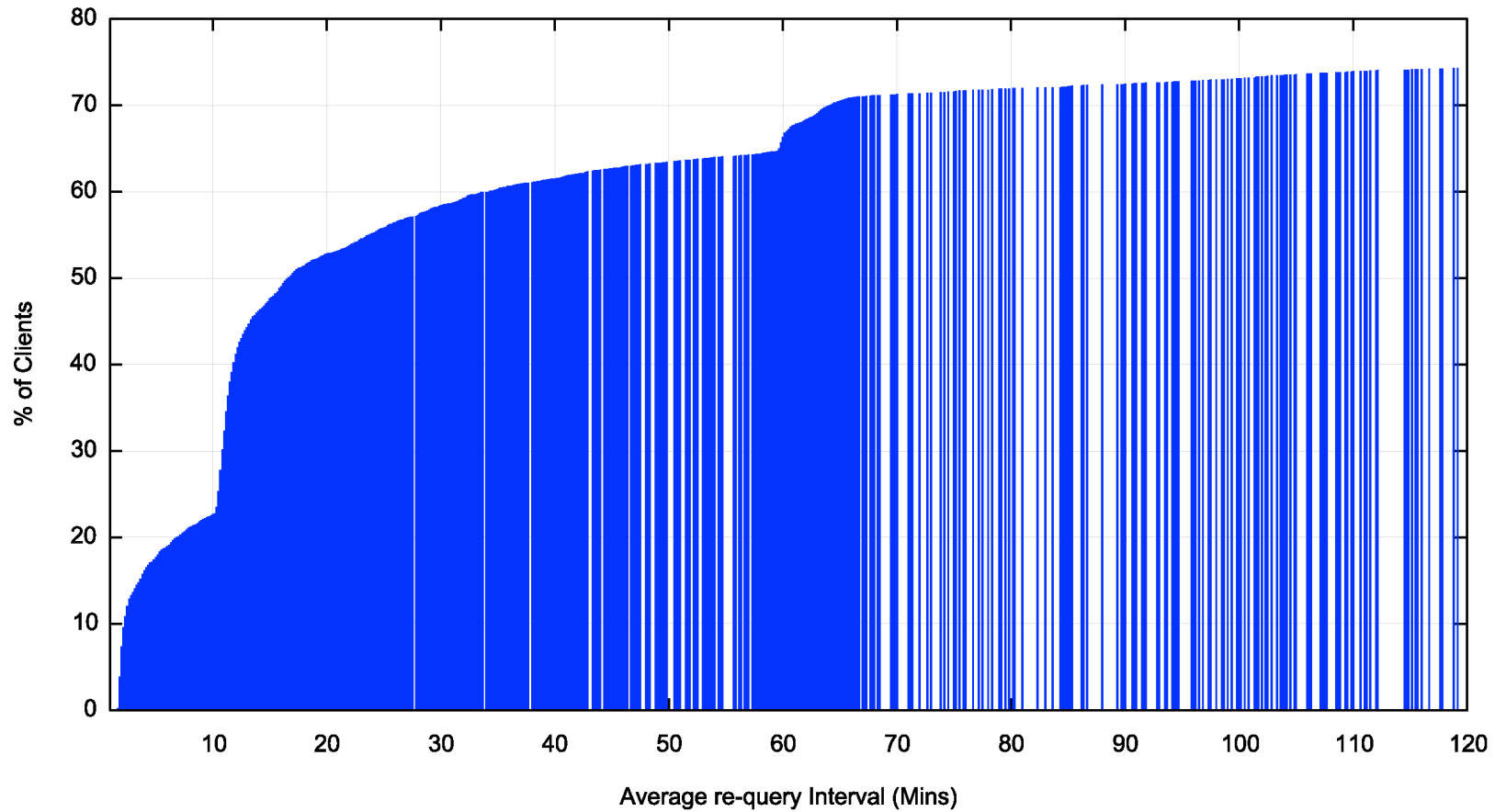
We are looking here at the average elapsed time between successive visits to the RPKI publication point server from the same IP address (krill logs)



# RPKI Pub Point Re-Query Intervals (first hour)

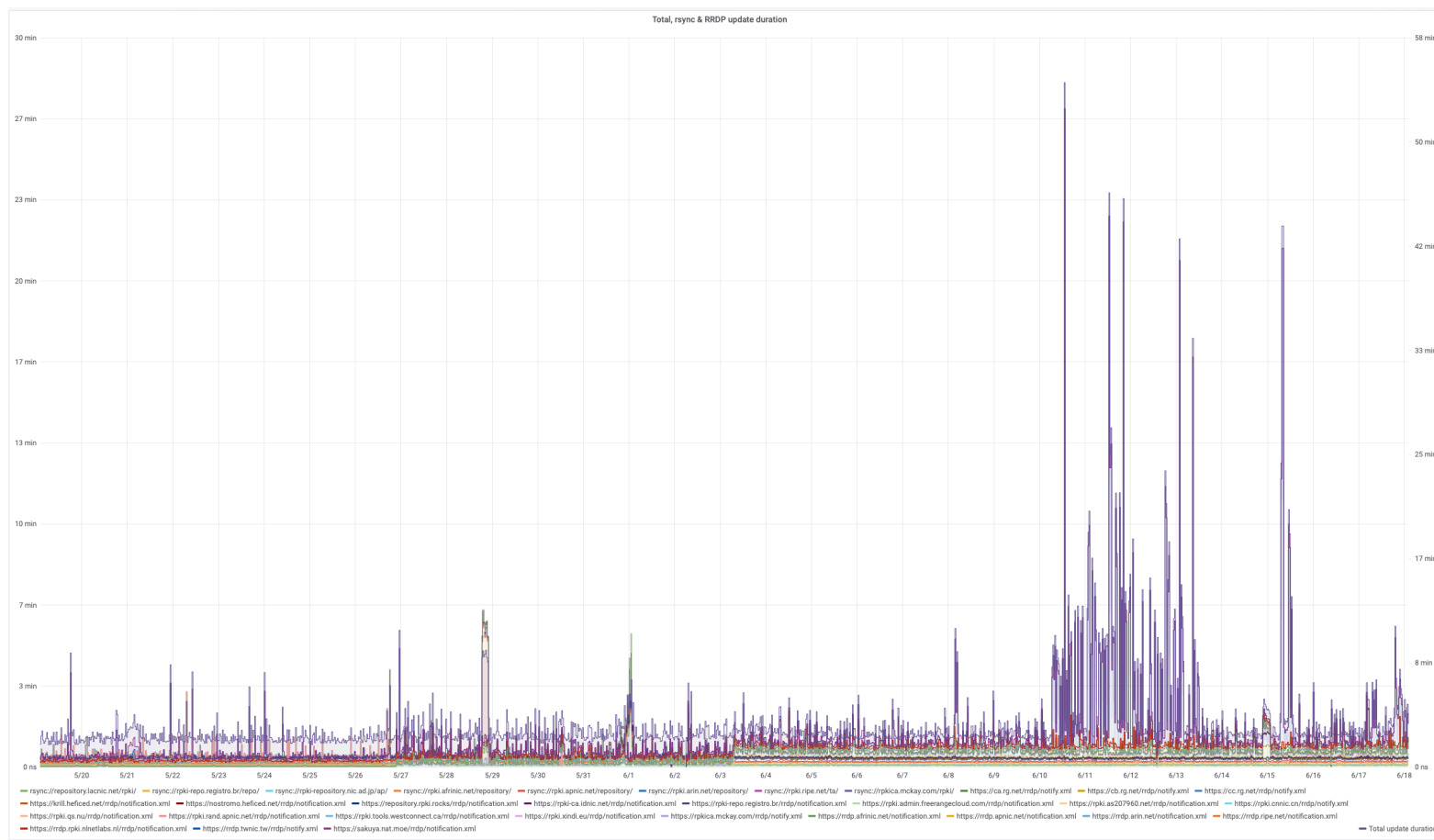


# Re-Query - Cumulative Distribution



Within 2 hours we see 75% of clients perform a requery

# Why the lag?



Clients can take a significant amount of time to complete a pass through the entire RPKi distributed repository set, which makes the entire system sluggish to respond to changes

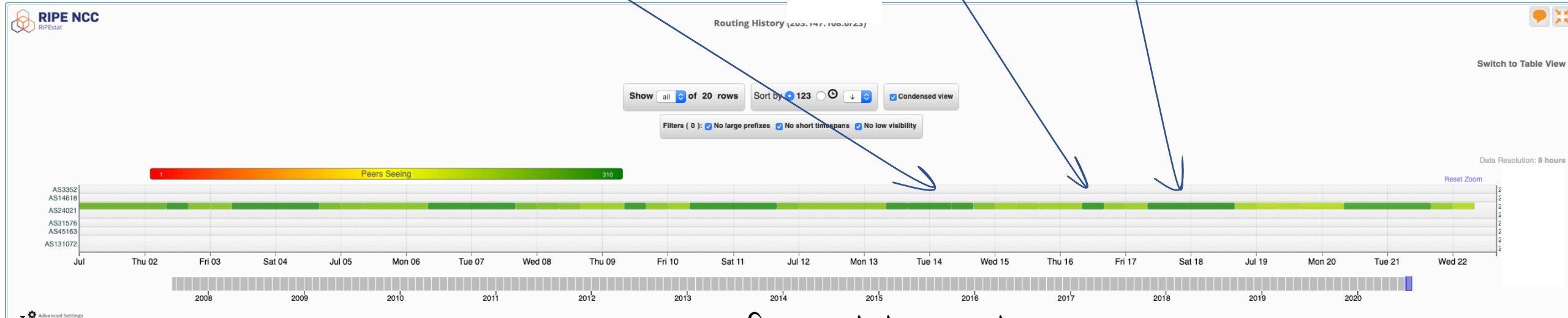
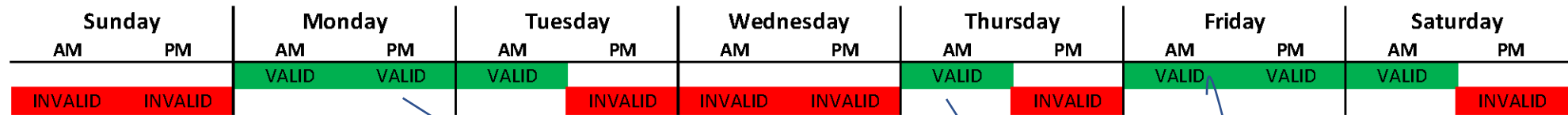
<https://grafana.wikimedia.org/d/UwUa77GZk/rpki?panelId=59&fullscreen&orgId=1&from=now-30d&to=now>

# We use 12 and 36 hour held states for ROA validity

Sunday		Monday		Tuesday		Wednesday		Thursday		Friday		Saturday	
AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
INVALID	INVALID	VALID	VALID	VALID	INVALID	INVALID	INVALID	VALID	INVALID	VALID	VALID	VALID	INVALID

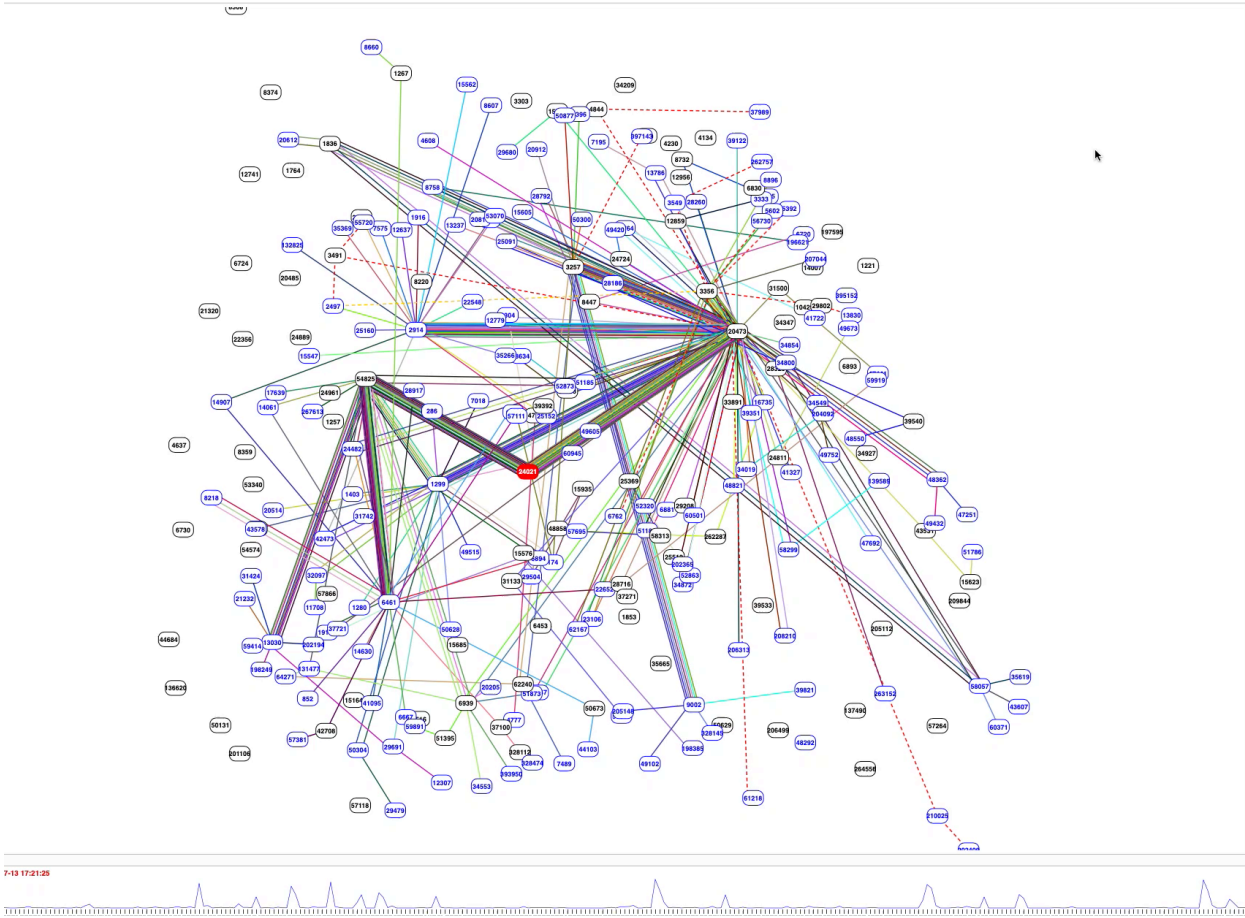
The route object validity state cycles over a 7 day period in a set of 12 and 36 hour intervals

# We use 12 and 36 hour held states



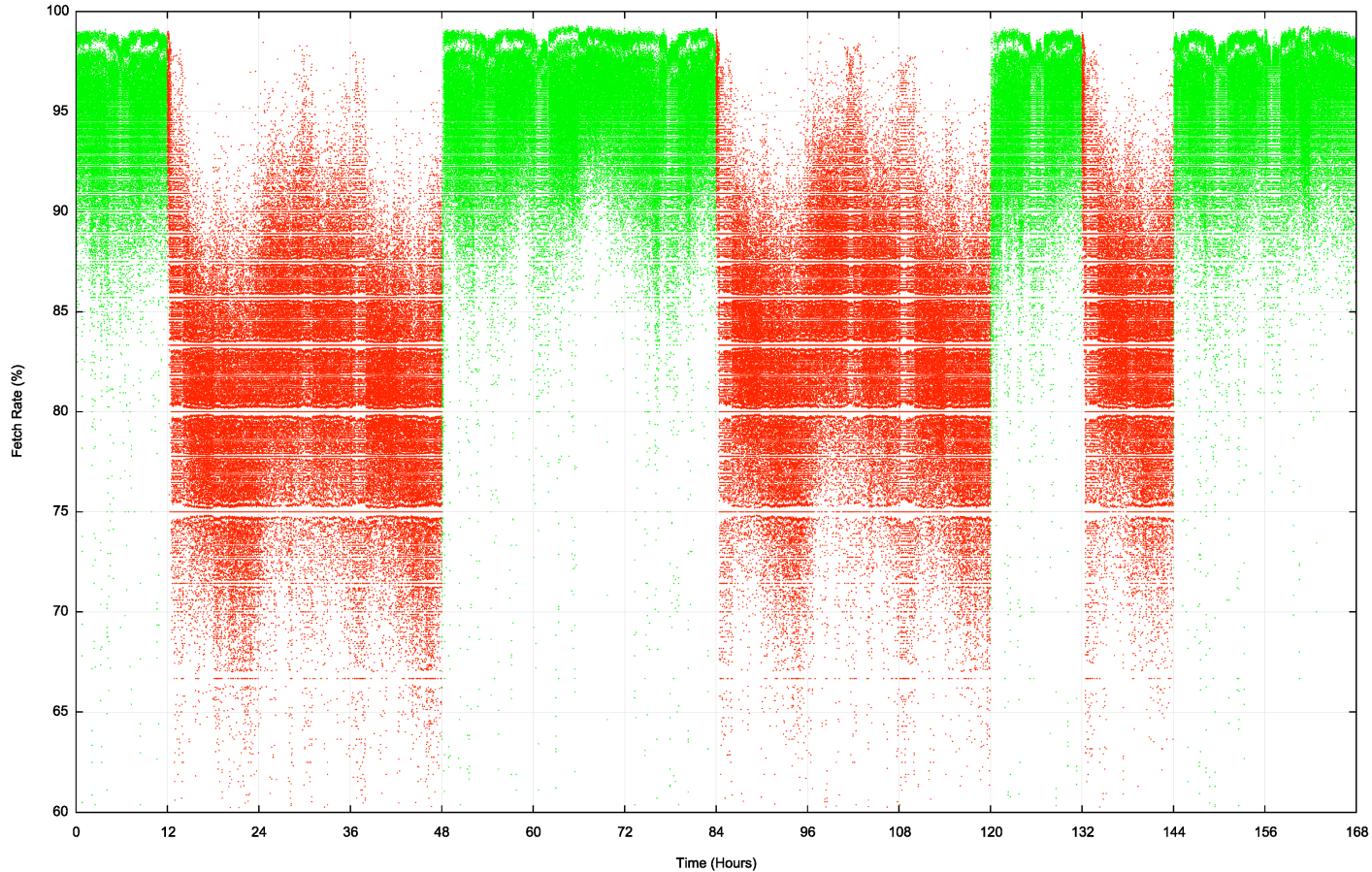
view from stat.ripe.net

We use 12 and 36 hour held states



BGP Play view of the routing changes

# We used 12 and 36 hour states

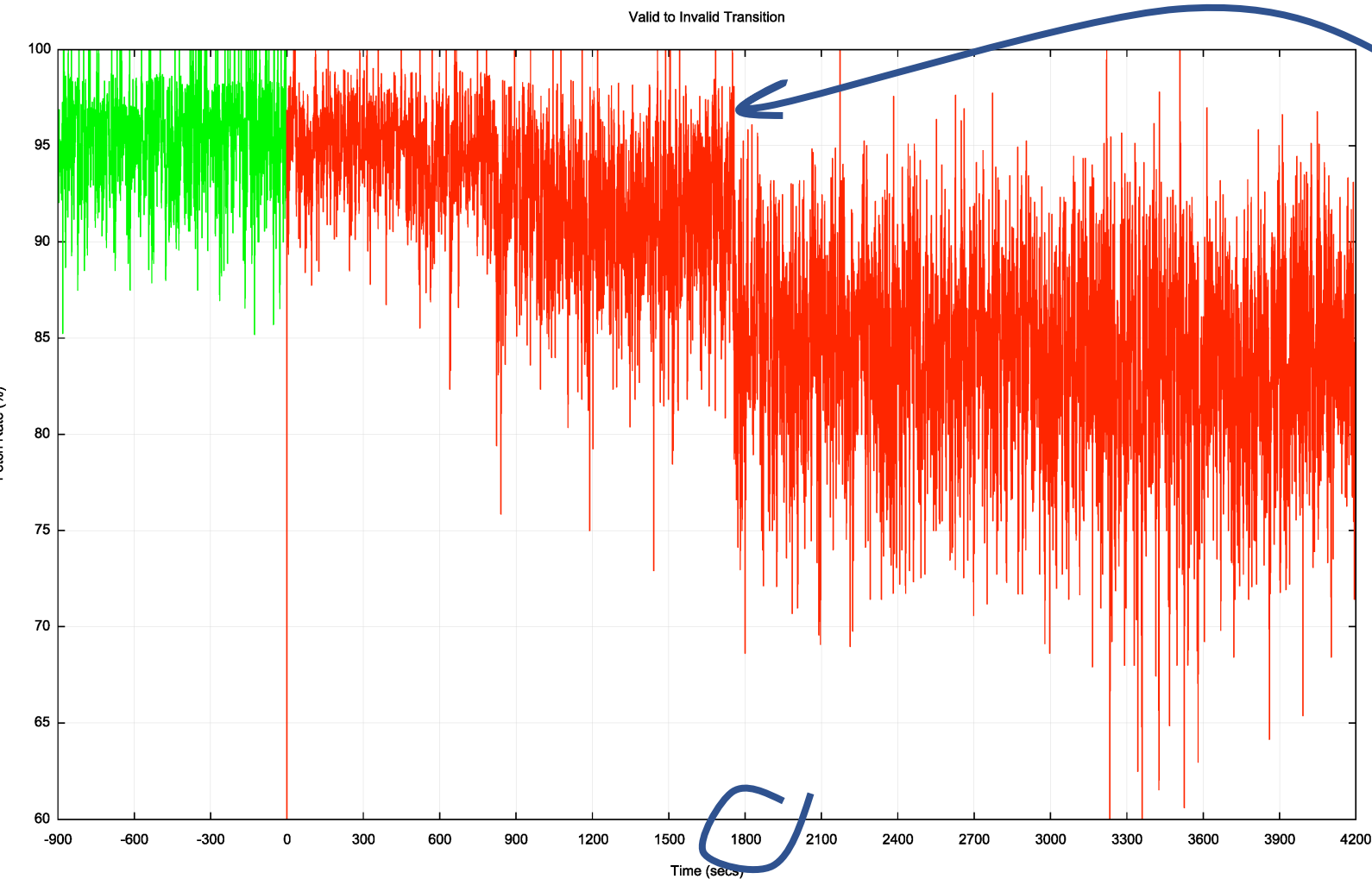


This shows the per-second fetch rate when the route is valid (green) and invalid (red) over a 7 day window

The route validity switches are clearly visible



# Transition - Valid to Invalid

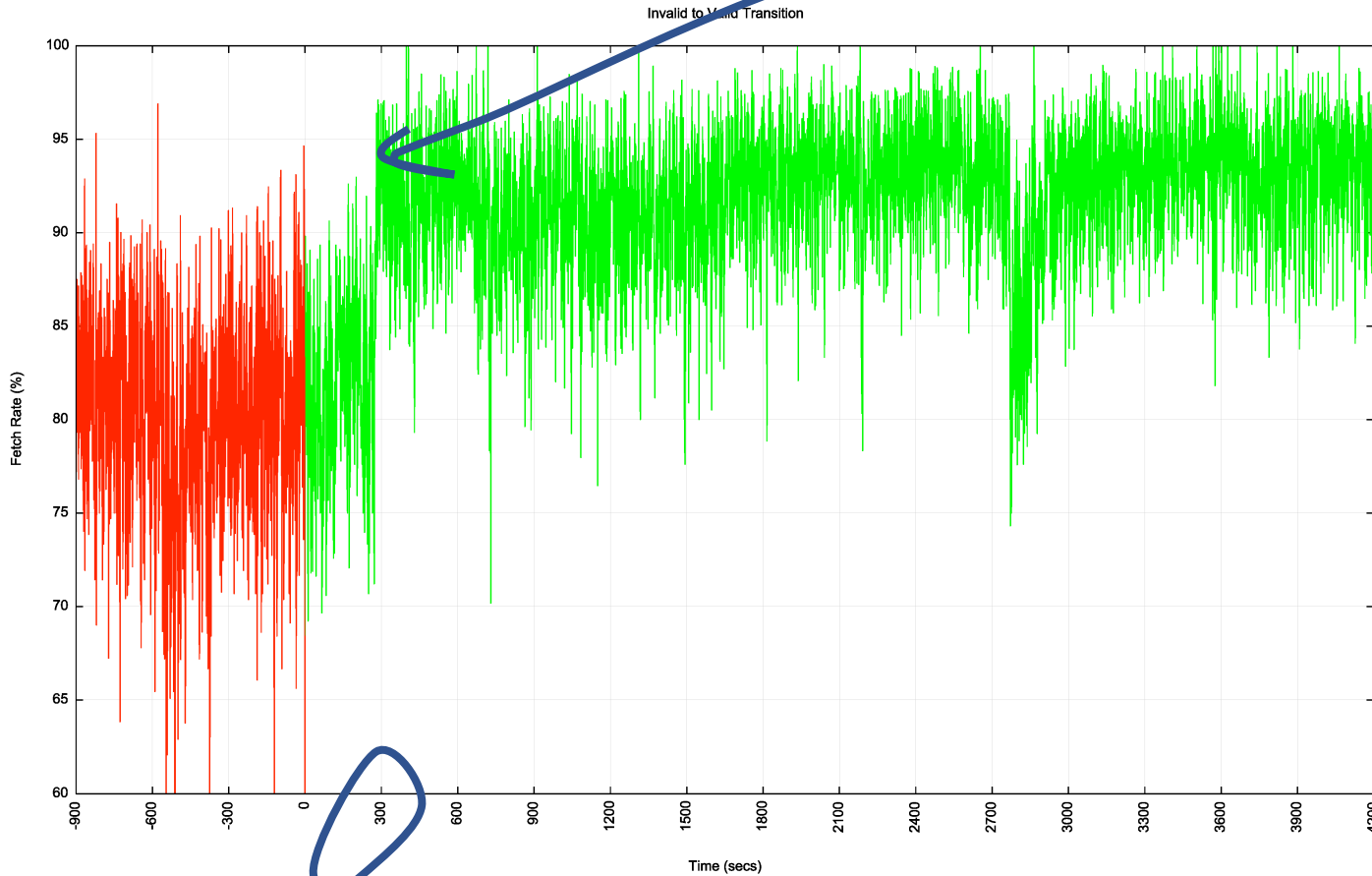


It takes some **30 minutes** for the valid to invalid transition to take effect in this measurement

It appears that this is a combination of slow re-query rates at the RPKI publication point and some delays in making changes to the filters being fed into the routers

This system is dependant on the last transit ISP to withdraw

# Transition - Invalid to Valid



It takes some **5 minutes** for the invalid to valid transition to take effect in this measurement

This system is dependant on the first transit ISP to announce, so it tracks the fastest system to react

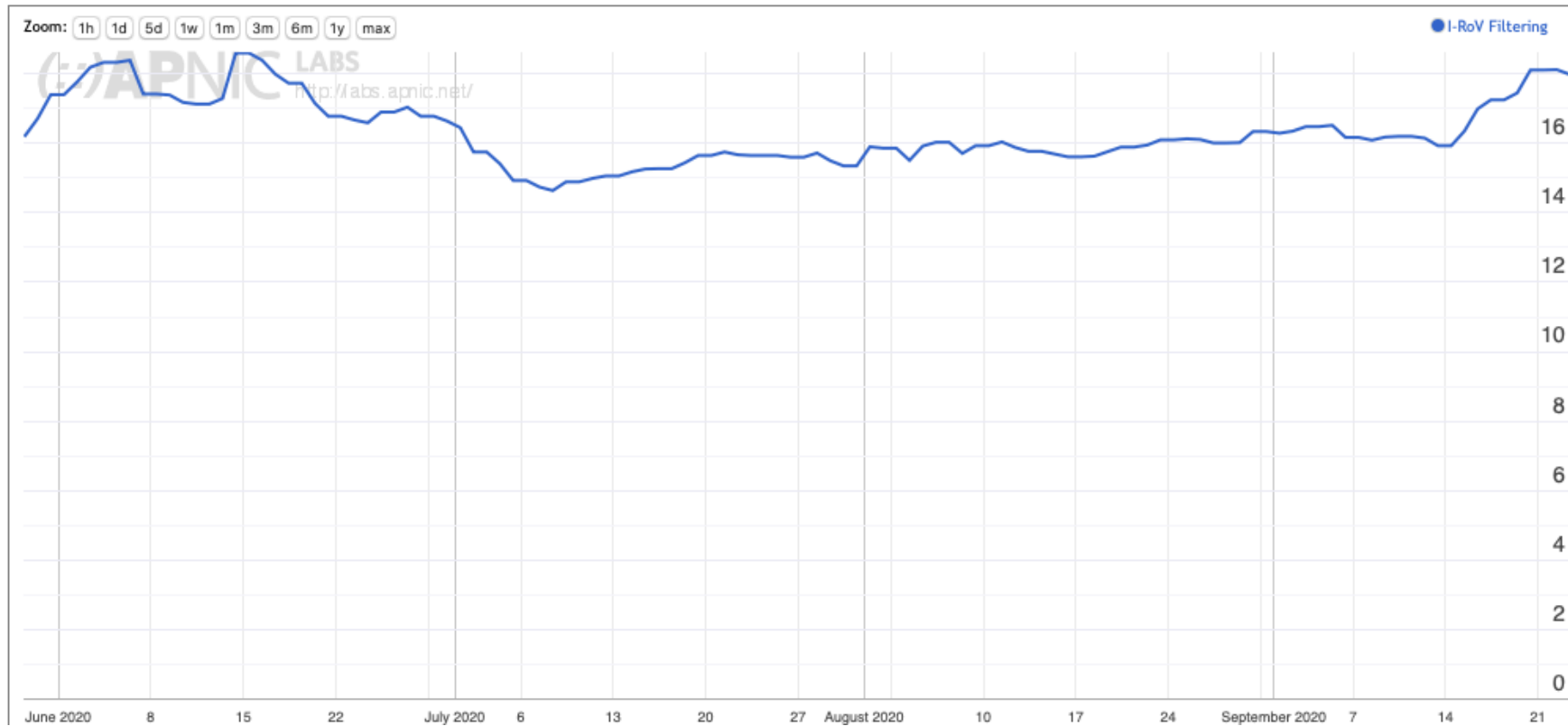
# RPKI "sweep" software

- There is a mix of 2, 10 and 60 minute timers being used
- 2 minutes seems like a lot of thrashing with little in the way of outcome – the responsiveness of the system is held back by those clients using longer re-query timers
- 60 minutes seems too slow

*(I'd go with a 10 minute query timer as a compromise here)*

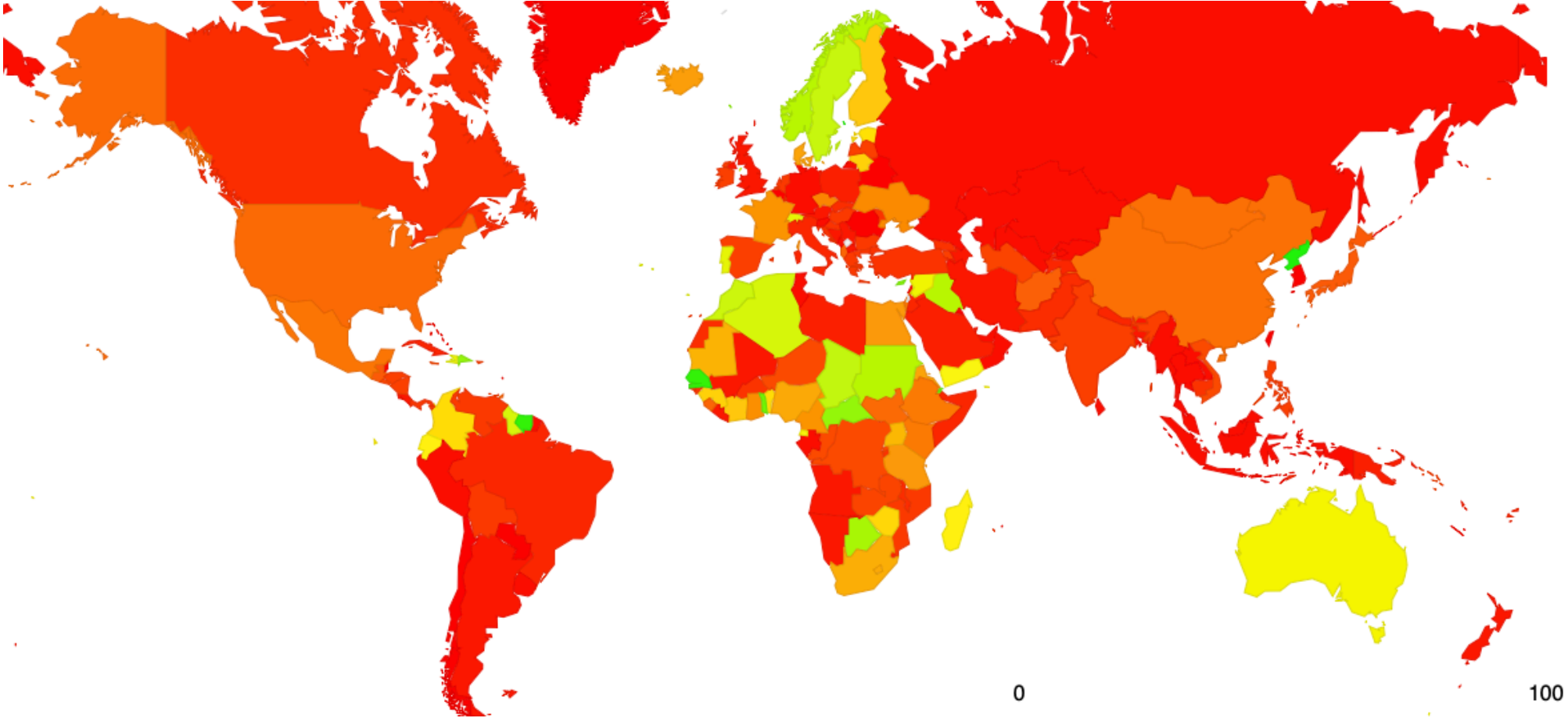
# User impact of RPKI filtering

## Use of RPKI Validation for World (XA)



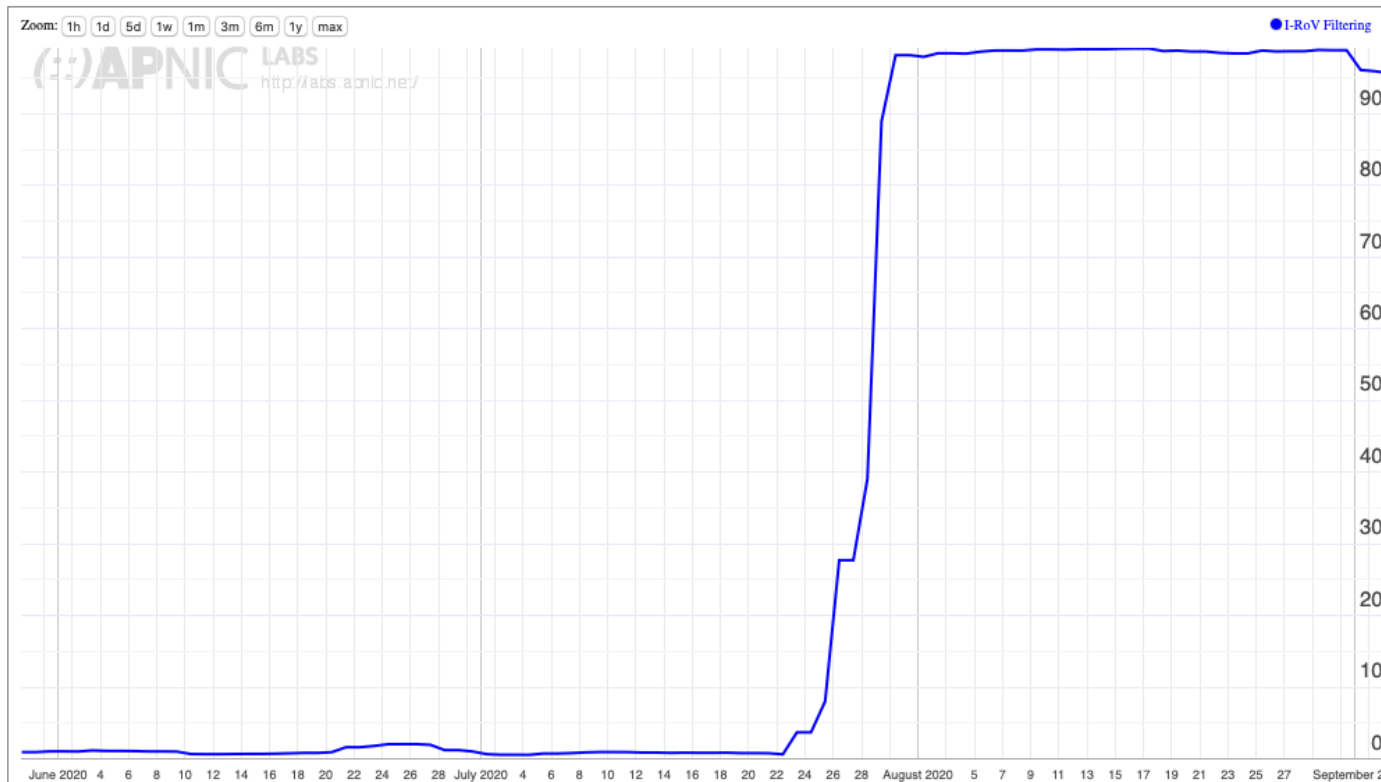
At 17% of users that's a surprisingly large impact for a very recent technology

# User impact of RPKI filtering

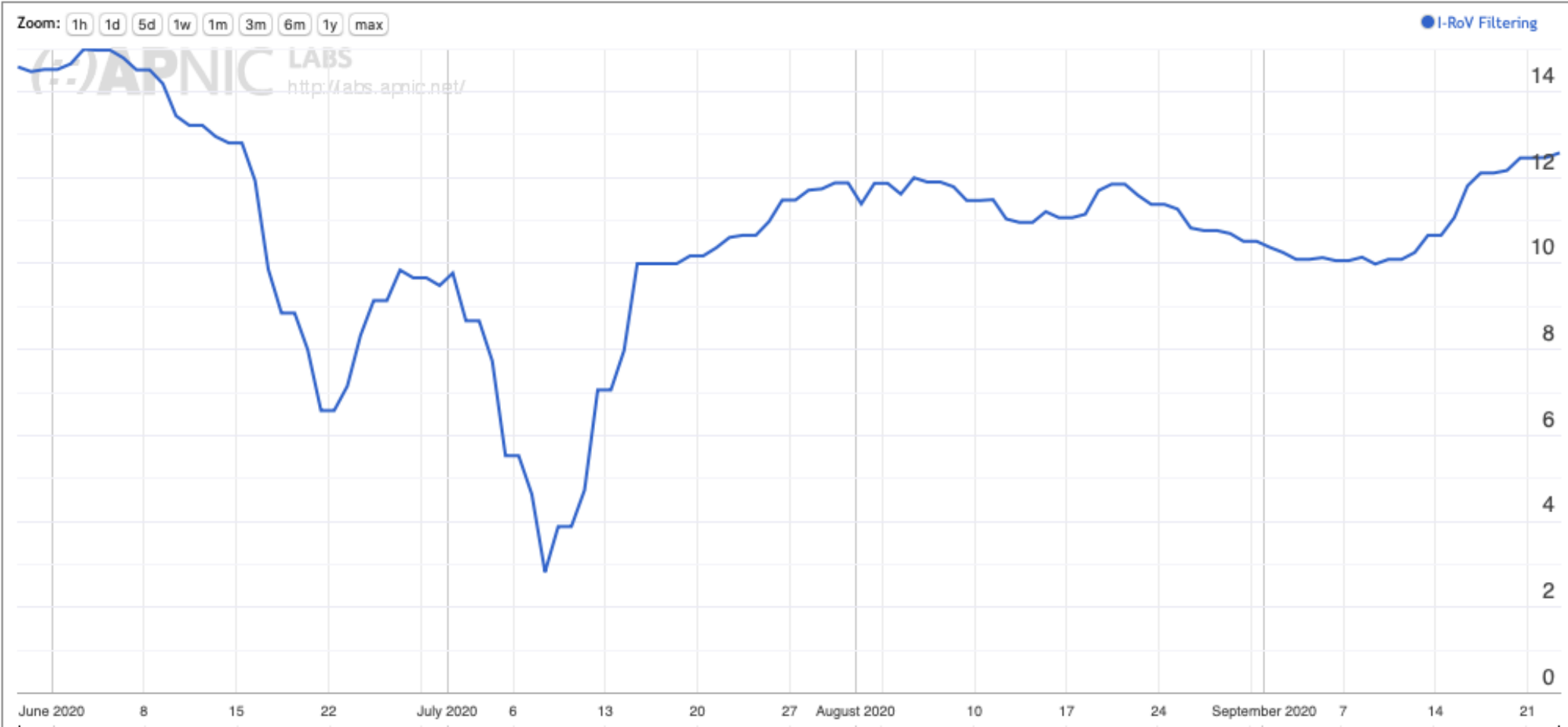


# Turning on Drop Invalid Filtering

**RPKI I-ROV Per-Country filtering for AS1221: ASN-TELSTRA Telstra Corporation Ltd, Australia (AU)**



# Hong Kong



# Hong Kong

ASN	AS Name	RPKI Validates	Samples ▼
AS4760	HKTIMS-AP HKT Limited	4.18%	20,186
AS9269	HKBN-AS-AP Hong Kong Broadband Network Ltd.	2.74%	17,208
AS38819	HKCSL-AS-AP HKCSL GPRS NETWORK	1.45%	10,382
AS9231	IPEOPLESNET-AS-AP China Mobile Hong Kong Company Limited	1.34%	8,074
AS17924	SMARTONE-MB-AS-AP SmarTone Mobile Communications Ltd	2.41%	5,233
AS9304	HUTCHISON-AS-AP HGC Global Communications Limited	95.62%	4,131
AS10118	HTCL-IAS-HK-AP Hutchison Telephone Company Limited	3.17%	3,465
AS9908	HKCABLE2-HK-AP HK Cable TV Ltd	6.63%	2,533
AS18116	HGC-AS-AP HGC Global Communications Limited	94.73%	2,295
AS9381	HKBNES-AS-AP HKBN Enterprise Solutions HK Limited	6.13%	962
AS8075	MICROSOFT-CORP-MSN-AS-BLOCK	16.99%	671
AS45102	CNNIC-ALIBABA-US-NET-AP Alibaba (US) Technology Co., Ltd.	20.04%	559
AS10099	UNICOM-GLOBAL China Unicom Global	1.65%	423
AS13335	CLOUDFLARENET	96.97%	363
AS4515	ERX-STAR HKT Limited	4.85%	330
AS10103	HKBN-AS-AP HK Broadband Network Ltd.	24.84%	318
AS63888	TISP-AS TISP LIMITED	97.90%	286

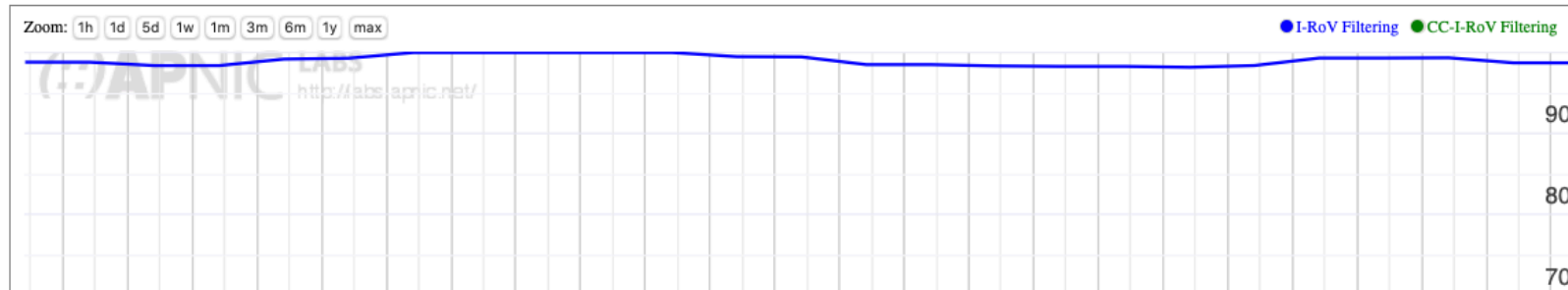


# Why?

There are two factors at play:

- Networks that perform invalid route filtering

## RPKI I-ROV Per-Country filtering for AS37100: SEACOM-AS, South Africa (ZA)



## RPKI I-ROV Per-Country filtering for AS7018: ATT-INTERNET4, United States of America (US)



# Why?

There are two factors at play:

- Networks that perform invalid route filtering  
and
- Network that do not filter themselves, but are customers of transit providers who filter

In either case the basic RPKI RoV objective is achieved, in that the users within these ISP networks are not exposed to invalid route objects

# Next Steps for Measurement

- Could we attempt selective traceroute from the anycast servers to identify the networks that are performing the RoV invalid filter drop?
- Should we perform further analysis of BGP route updates in route collectors to determine route withdrawal and announcement patterns when RPKI validity changes?

# Questions we might want to think about

- Is it necessary for every AS to operate RPKI ROV infrastructure and filter invalid routes?
- If not, what's the minimal set of filtering networks that could provide similar levels of filtering for the Internet as a whole
- What's the marginal benefit of stub AS performing RPKI ROV filtering?
- Should a stub AS RPKI ROV only filter its own announcements?
  - What's more important: protecting others from your operational mishaps or protecting yourself from the mishaps of others?

# What are we trying to achieve here?

- If this is a routing protection measure then what are you trying to protect? From whom? From what threat?
- If this is a user protection measure then the issue of route filtering is an issue for transit providers, not stub networks
  - A stub network should generate ROAs for its routes, but there is far less of an incentive to perform RoV invalid filtering if the stub's upstreams / IXs are already performing this filtering
  - Is it more important for IXs and Transits to perform drop-invalids than for stubs?

Thanks!