

# IP Technology Adoption in Bhutan

Geoff Huston  
APNIC Labs

# Why?

- Bhutan has a really high rate of adoption of DNSSEC in their recursive resolvers
- And a decent rate of RoV ROA filtering for BGP
- And a close to perfect rate of signed ROAs in their address infrastructure

Yet ...

- Not much IPv6!

# Bhutan is not that unusual

Many national environments have a unique technology adoption profile across these 4 technologies:

	<b>DNSSEC</b>	<b>IPv6</b>	<b>ROA Signing</b>	<b>RoV Filtering</b>
<b>Bhutan</b>	high	not much	perfect	decent
<b>Sweden</b>	high	not much	not really	good
<b>Brazil</b>	high	decent	nope	none
<b>Spain</b>	low	not much	decent	none
<b>India</b>	high	huge	decent	not much
<b>US</b>	so-so	good	decent	so-so
<b>Mongolia</b>	high	nope	perfect!	good

# Sameness and Differences

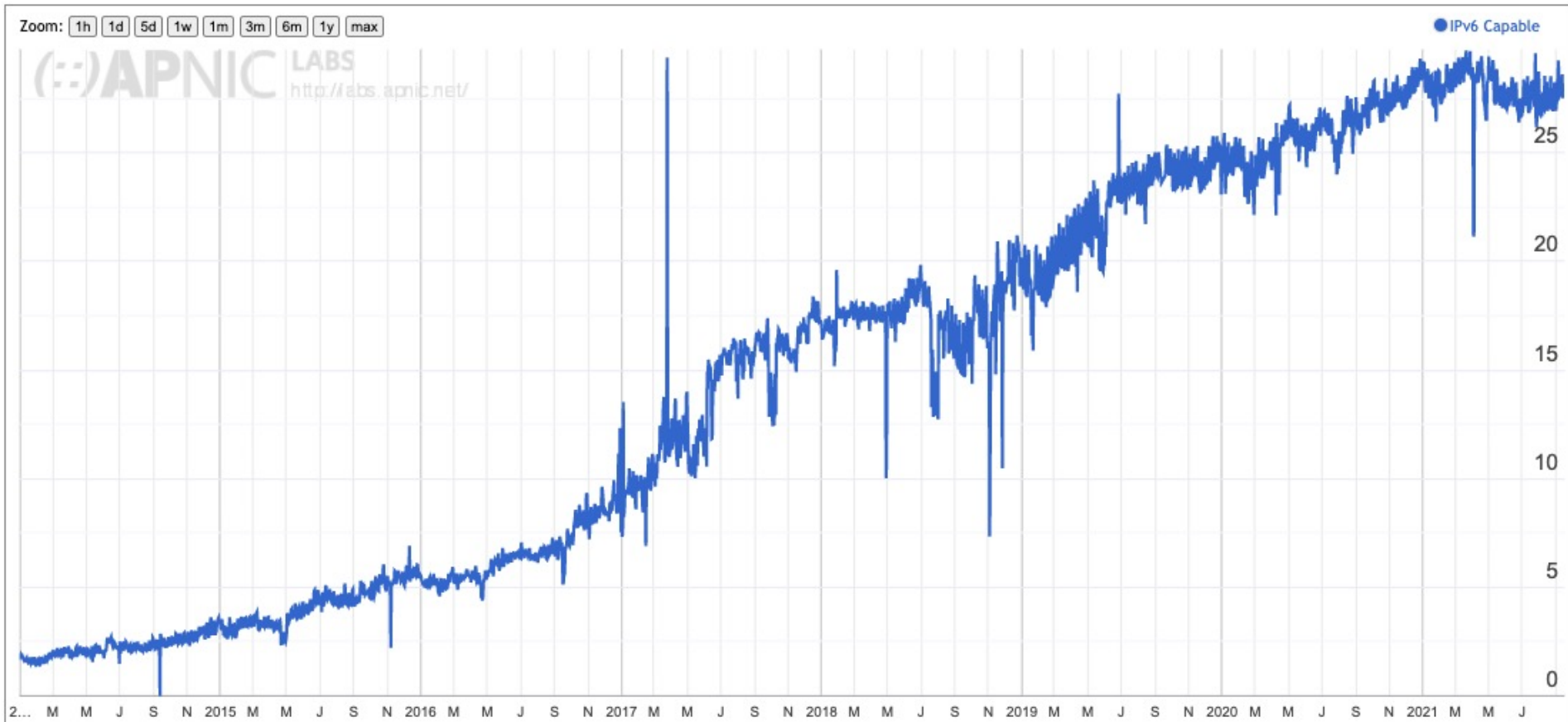
- All these markets have a similar technology base for consumers
- And they all use equipment drawn from a similar pool of vendors
- And the supply costs are largely the same across the entire network

Yet...

- They have different consumer “wealth” indicators
- There are different technology deployment models in each national market
- Though relative wealth and technology choices do not correlate well!

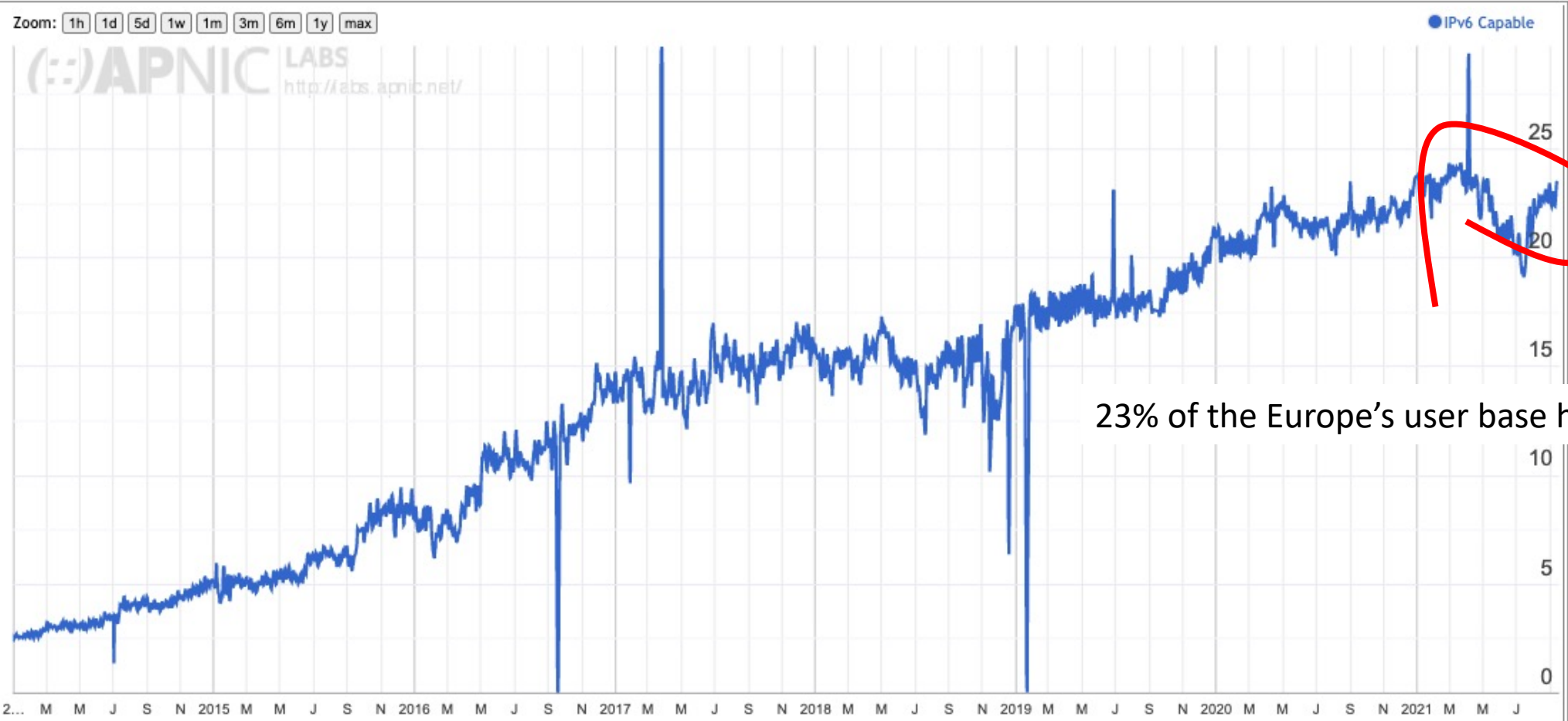
Lets look at each technology  
in a little more detail

# IPv6 Adoption - 2014 to Today



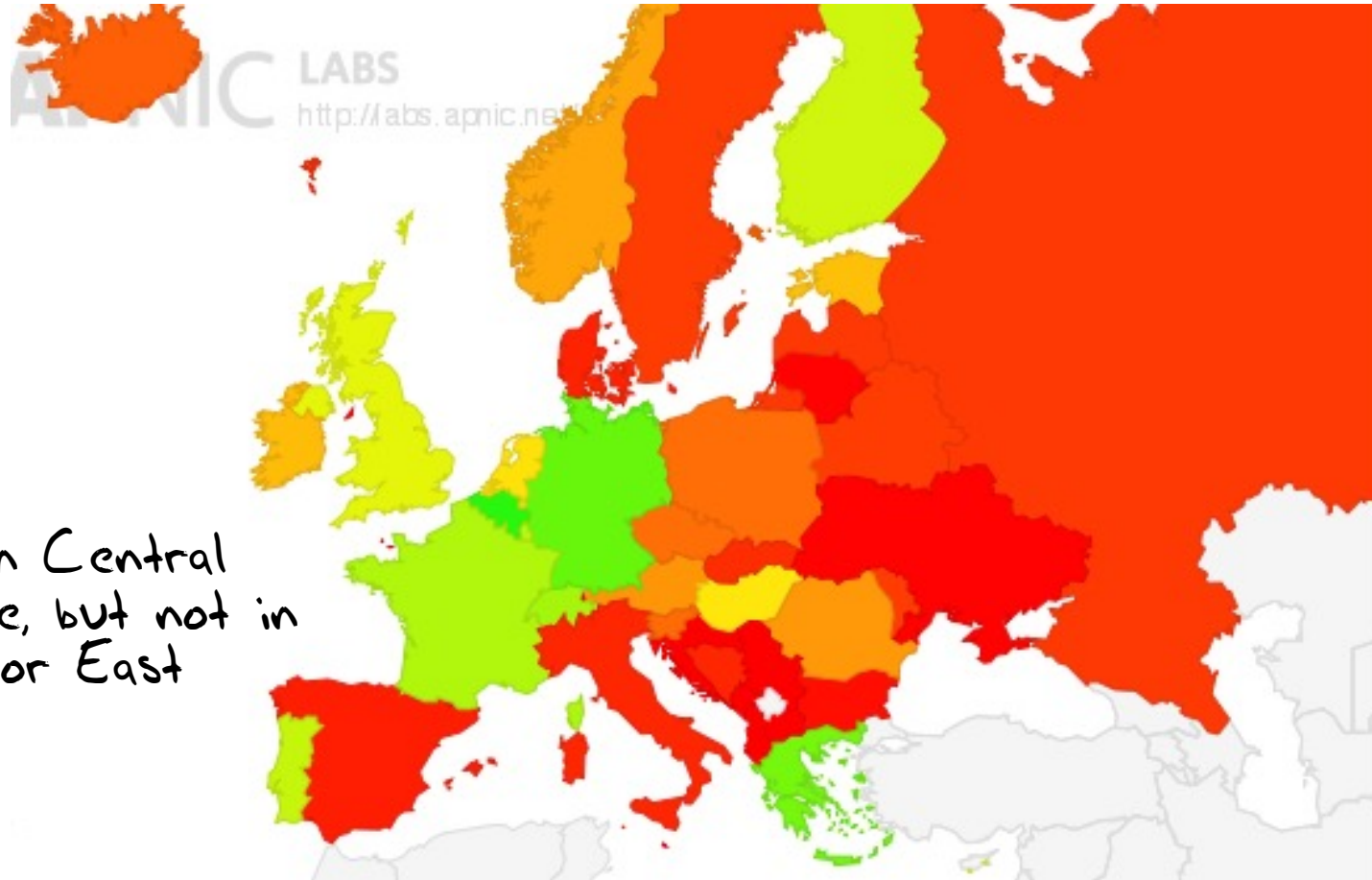
28% of the Internet's user base have IPv6 today

# Europe is (slightly) lagging...



23% of the Europe's user base have IPv6 today

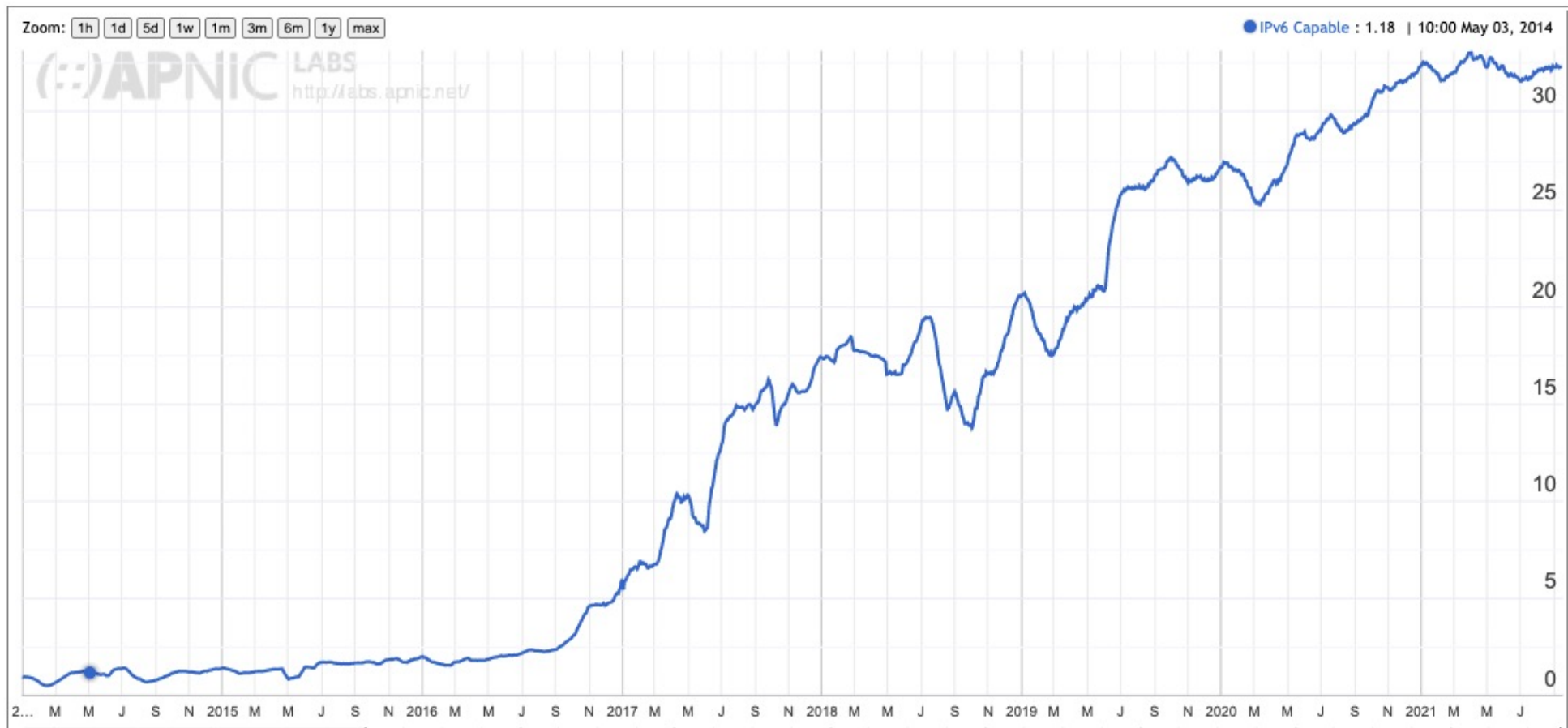
# And is very diverse



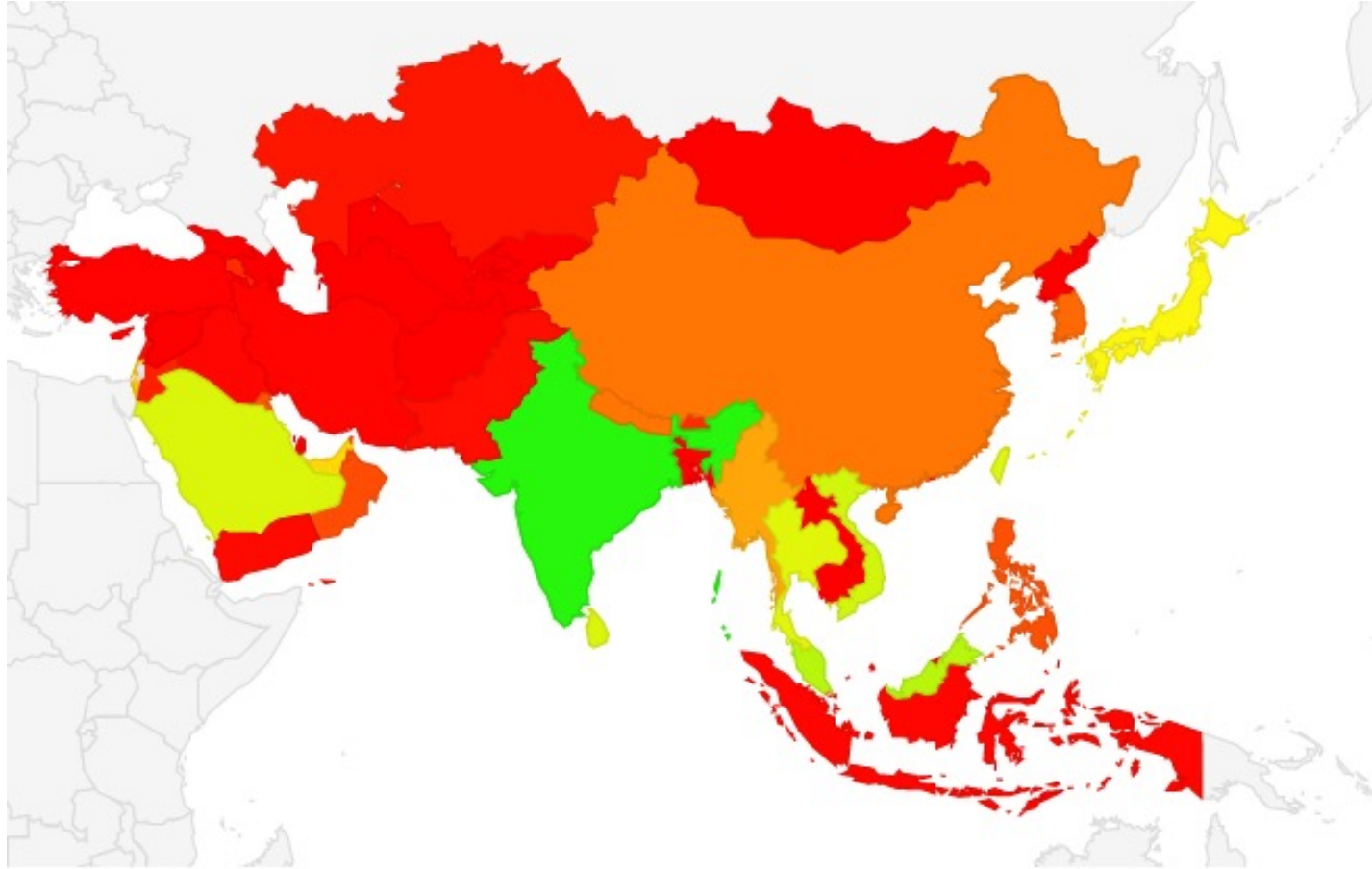
IPv6 is deployed in Central Europe and Greece, but not in the North, South or East



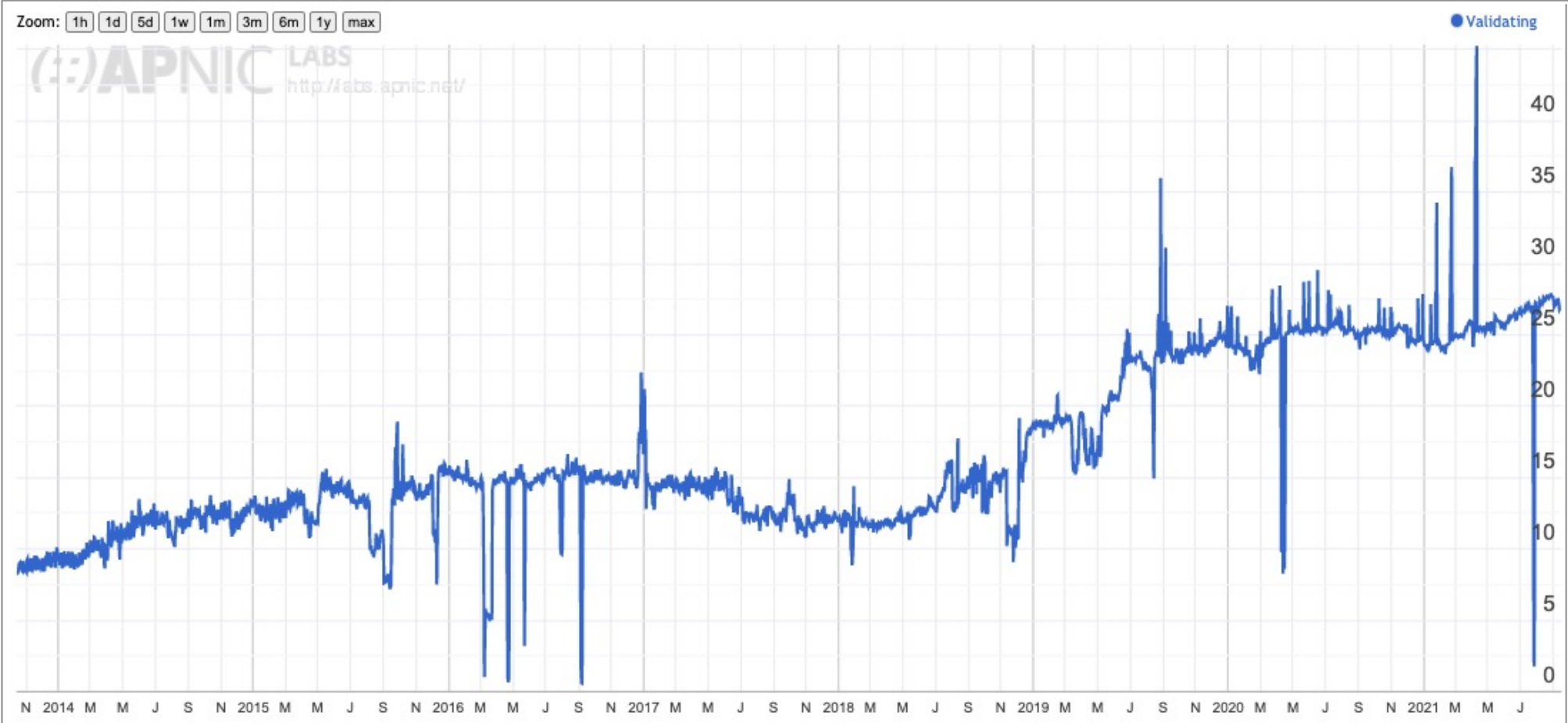
# Asia has better numbers



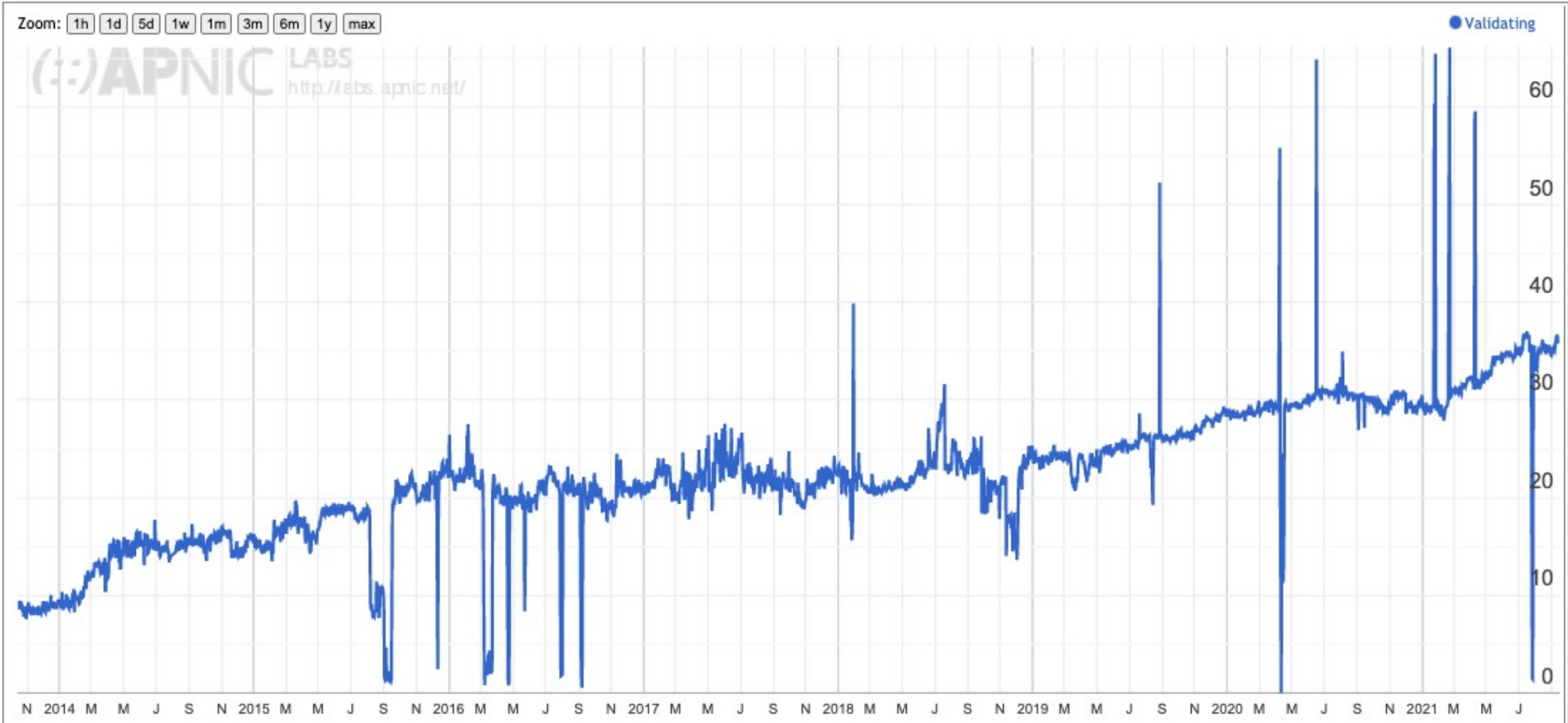
**And similar diversity**



# DNSSEC adoption

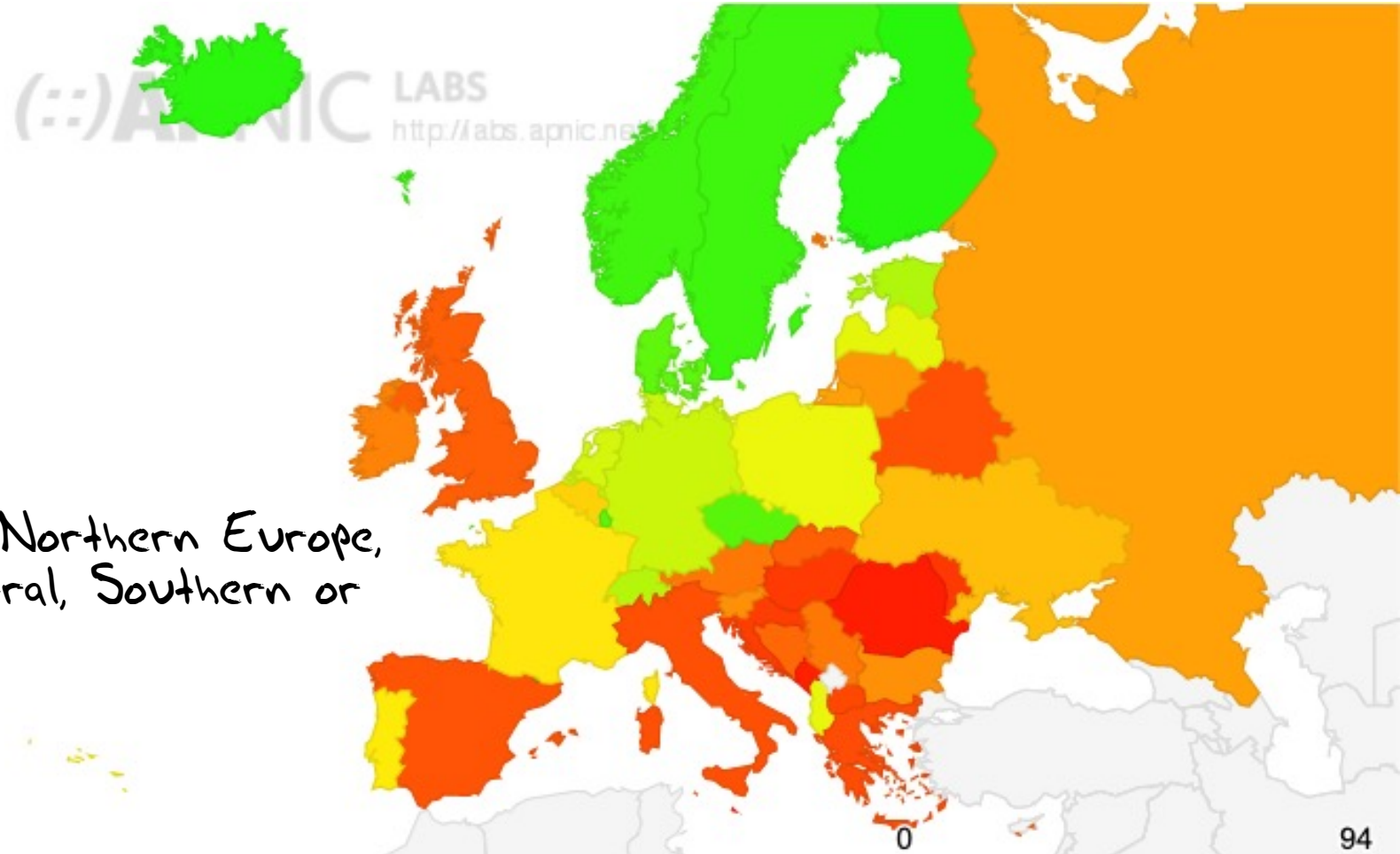


# Europe is (slightly) ahead

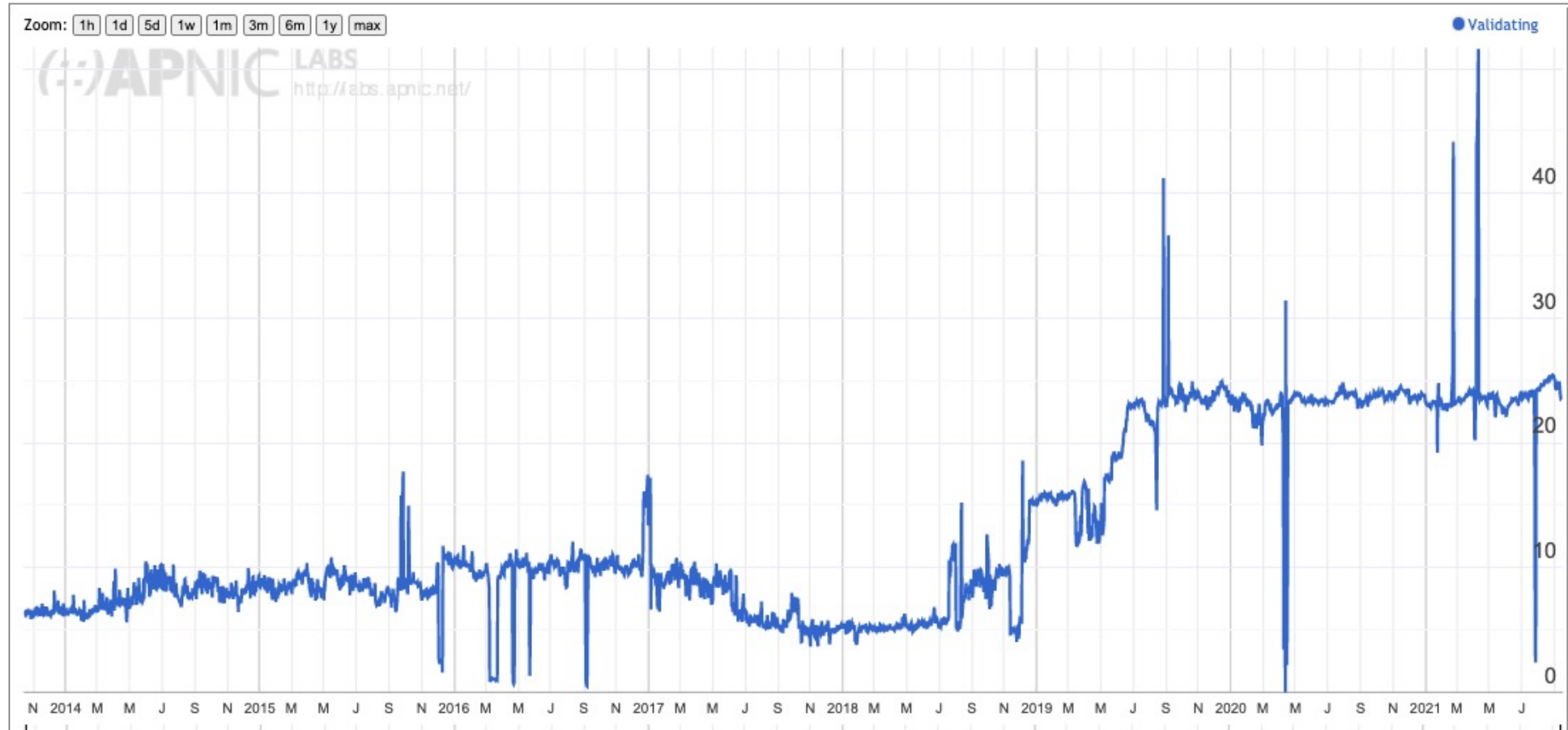


# Same (but different) diversity

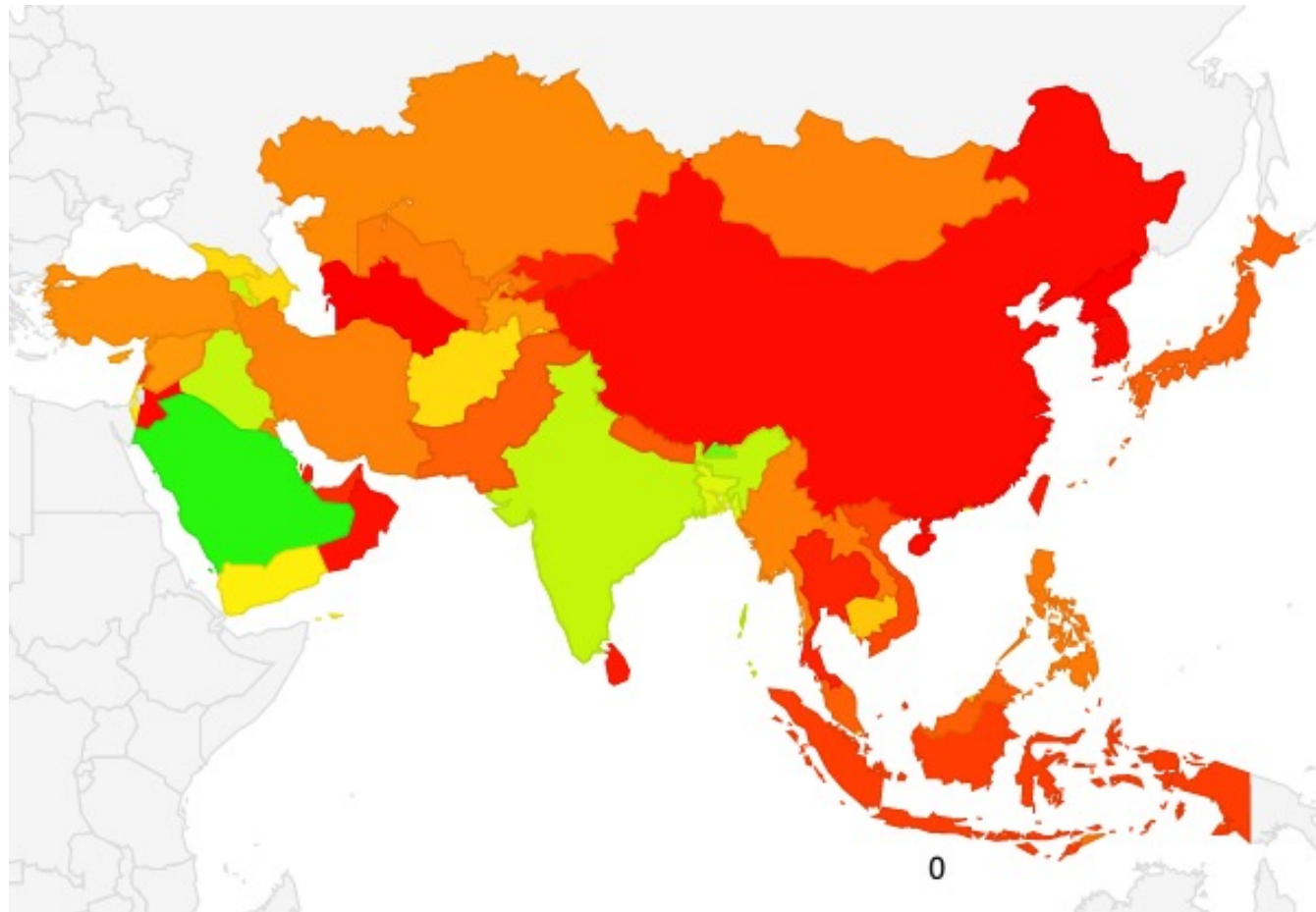
DNSSEC is deployed in Northern Europe, but not as much in Central, Southern or Eastern Europe



# Asia has been steady for 24 months



And again a diverse spread



# RPKI ROV Adoption

All End Users behind ROV-aware filters: **14%**

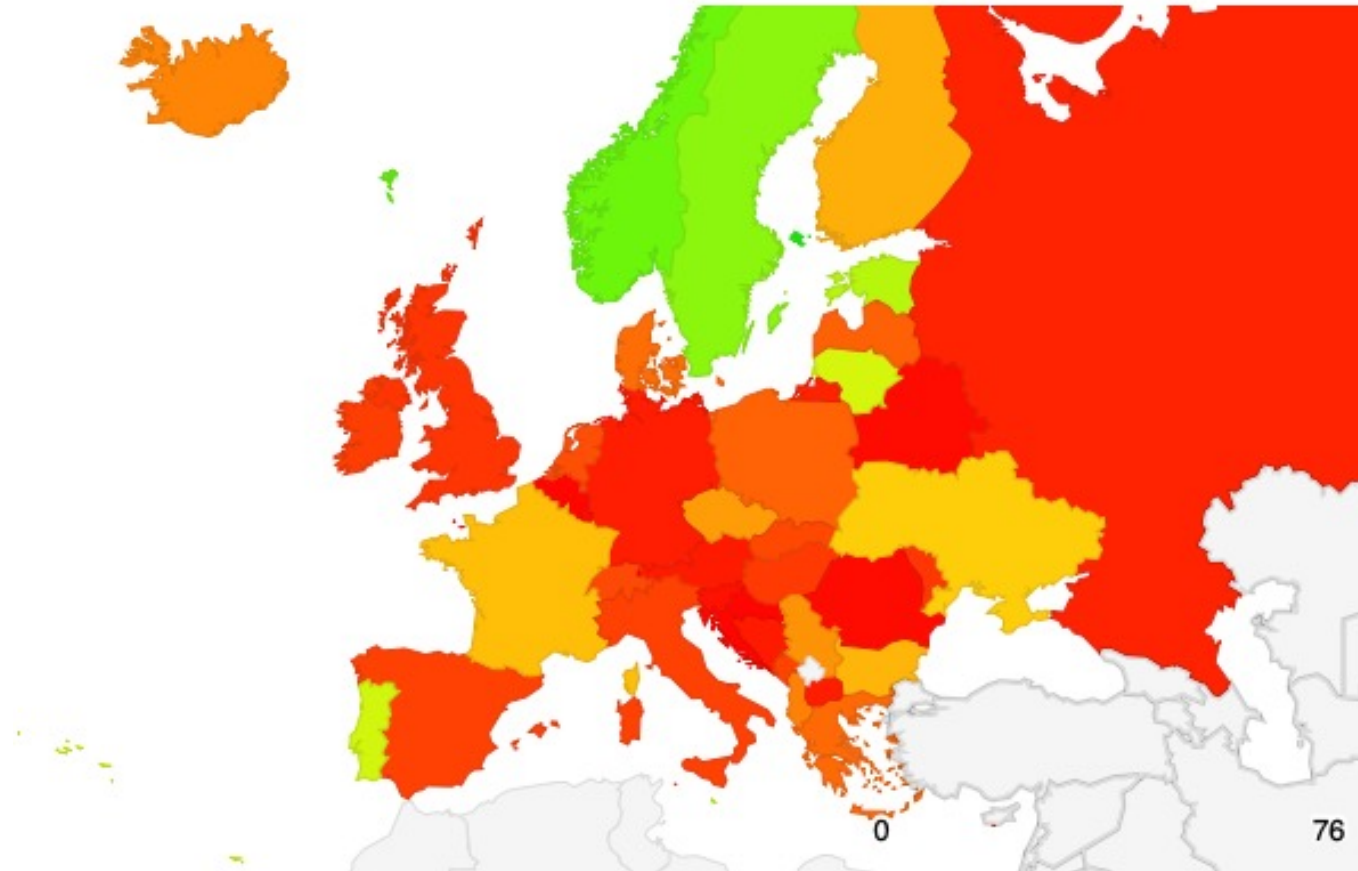
European users: **10%**

Asian users: **10%**



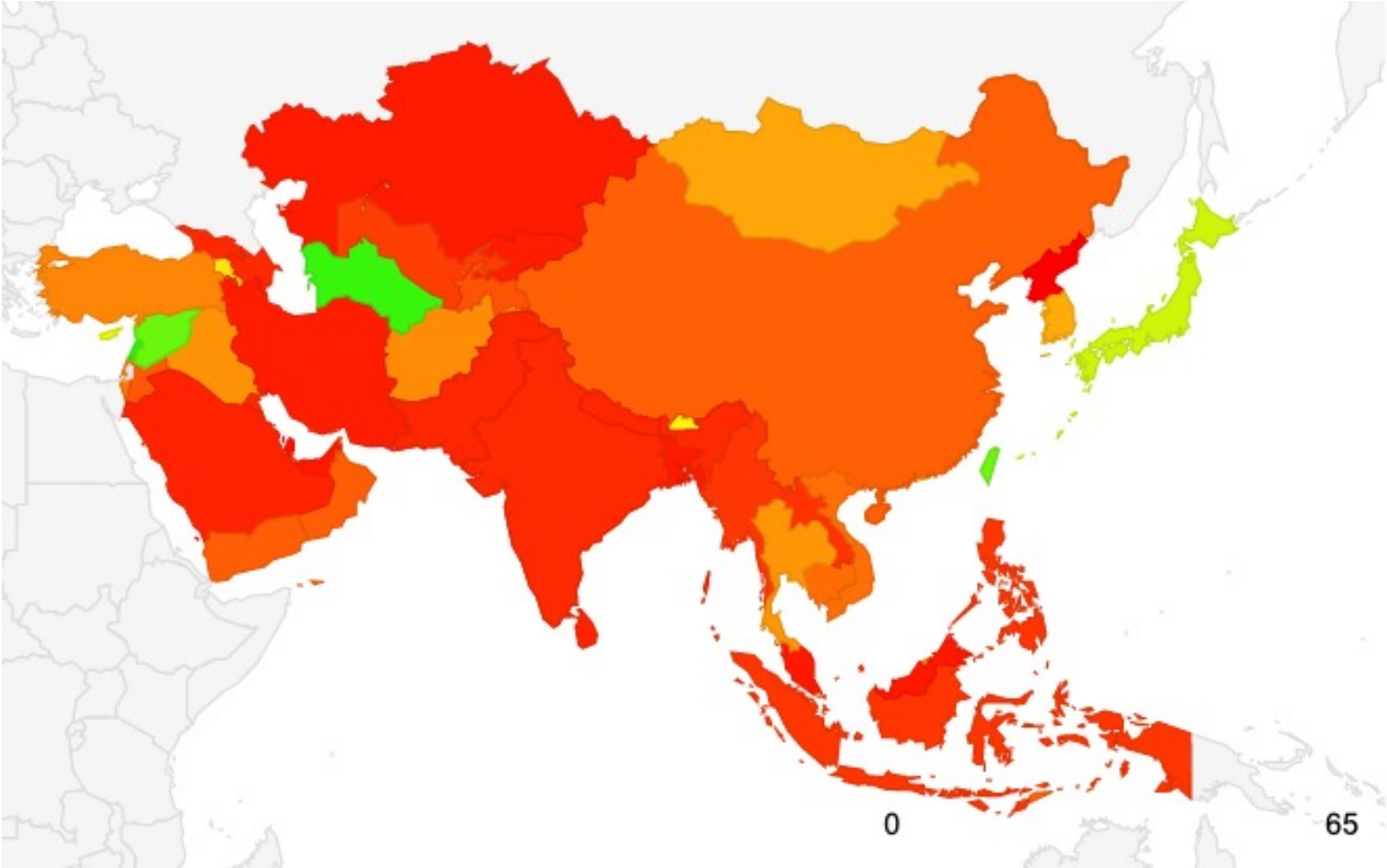
# RPKI ROV Adoption in Europe

Rate of RoV Filtering



# RPKI ROV Adoption in Asia

Rate of RoV Filtering



Why is there such diversity in deployment?

# Challenges for adoption:

1. This is a deregulated and competitive environment

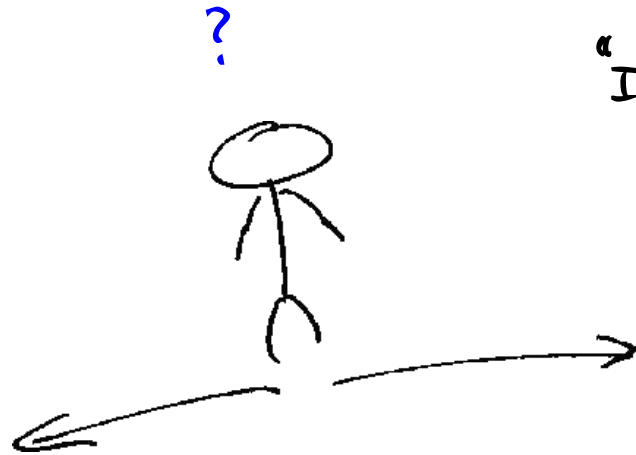
There are many different players  
Each with their own perspective



And all potential approaches will be explored!

# Challenges for adoption:

## 2. The myth of long-term planning



"IPv6 Transition will take many years...

5 years, maybe 10 years, maybe longer"

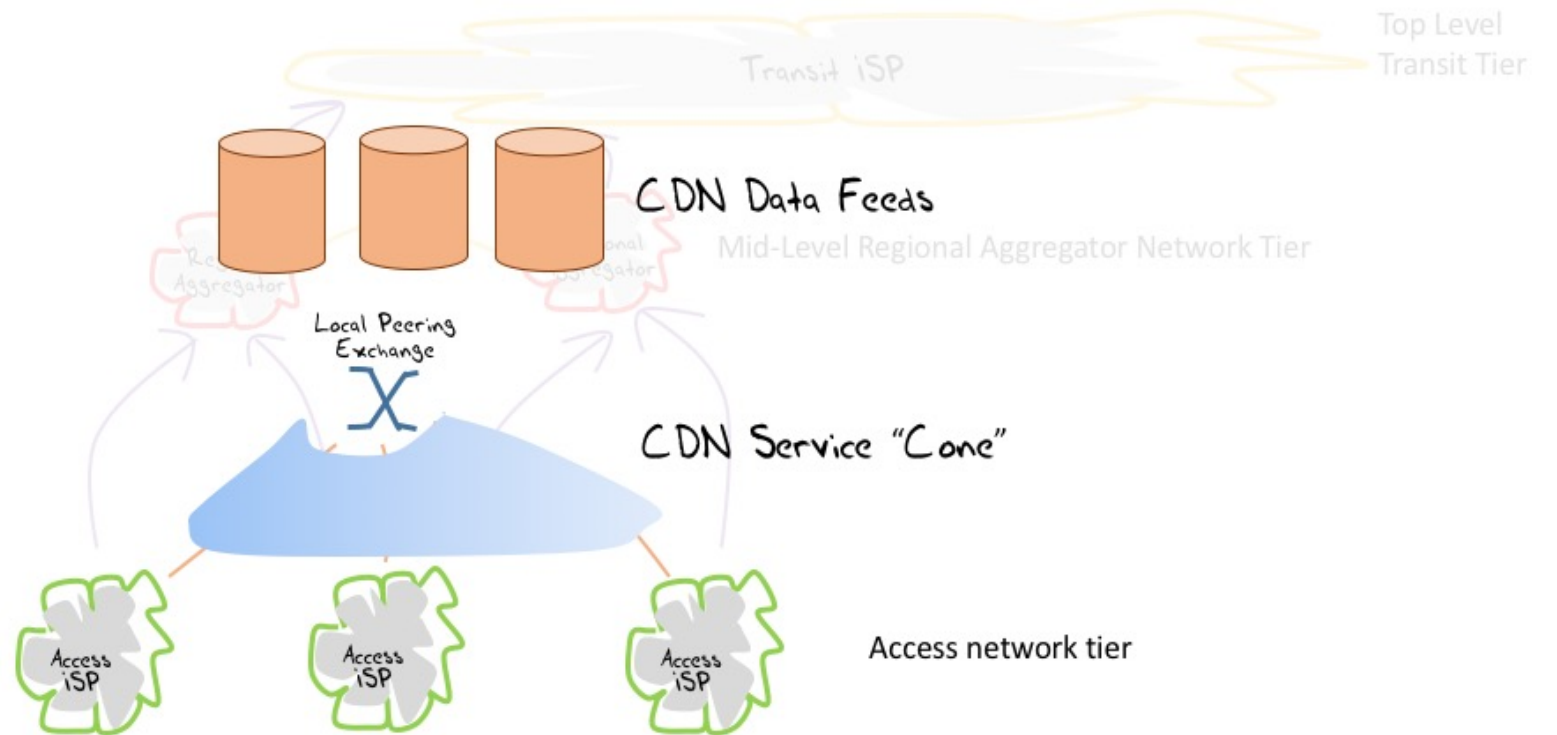
Are we still firmly committed to the plans we had 5 years ago? How about our 10-year-old plans?

The longer the period of transition, the higher the risk of completely losing the plot and heading into other directions!

# Challenges:

## 3. The Internet keeps changing

### Today's Internet Architecture



# Some providers see advantage in adoption

- Competitive positioning in a diverse market
- Early adoption of future mainstream technologies (first user advantage)
- Perception of enhanced utility, security and safety in these more recent technologies

# Others see reasons to wait ...

- **IPv6** is a 1990's technology solution to a 1980's networking architectural challenge – CDN feeder networks do not need globally unique address plans across every device all of the time
- **DNSSEC** is only partially-implemented. If we pushed DNSSEC validation to the edges of the network we're scared that the DNS will slow down to unacceptable levels.
- **RPKI Route Origin Validation** makes DNS route hijacking only slightly harder. More moving parts can introduce fragility, and not necessarily enhance operating stability

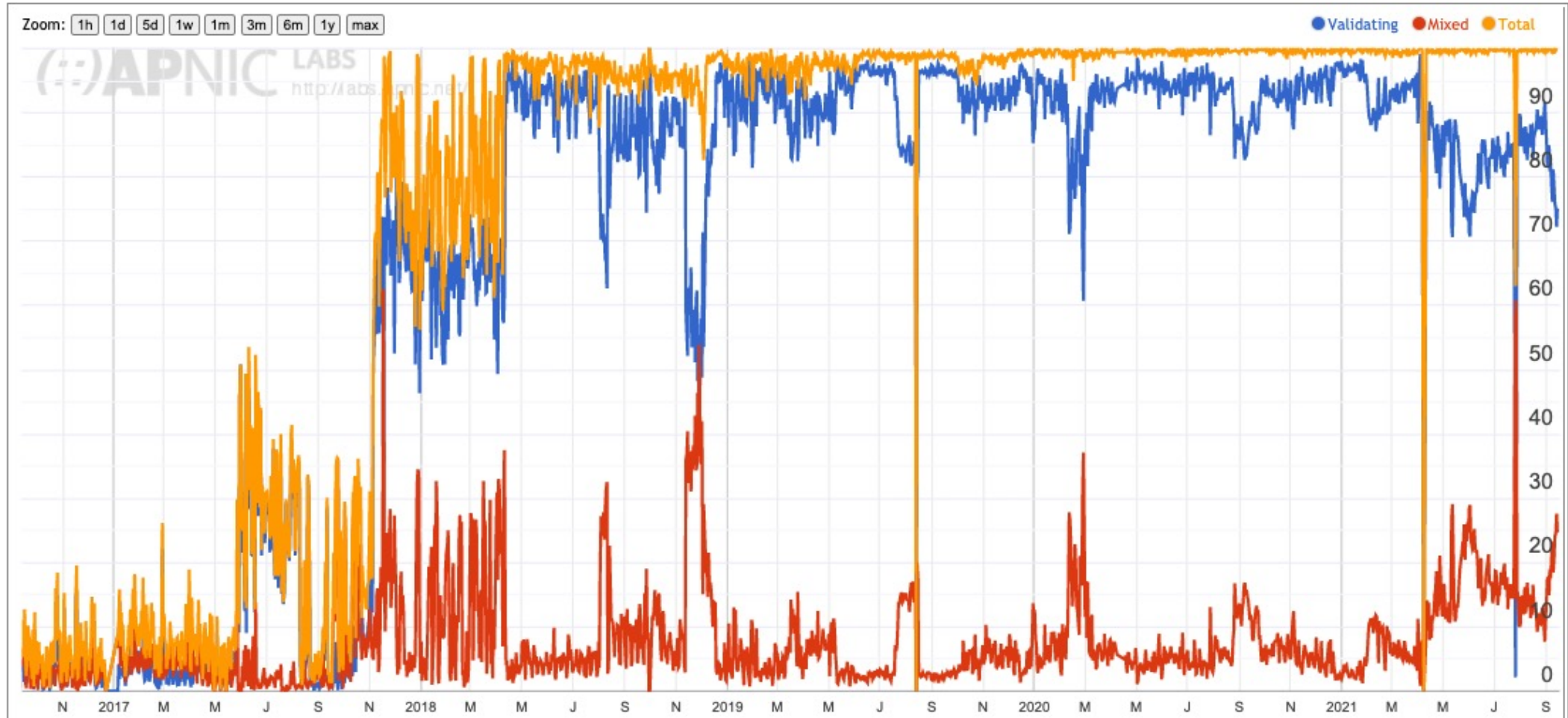


# Lets return to Bhutan

- And see which service providers have adopted each of these technologies

# Bhutan and DNSSEC

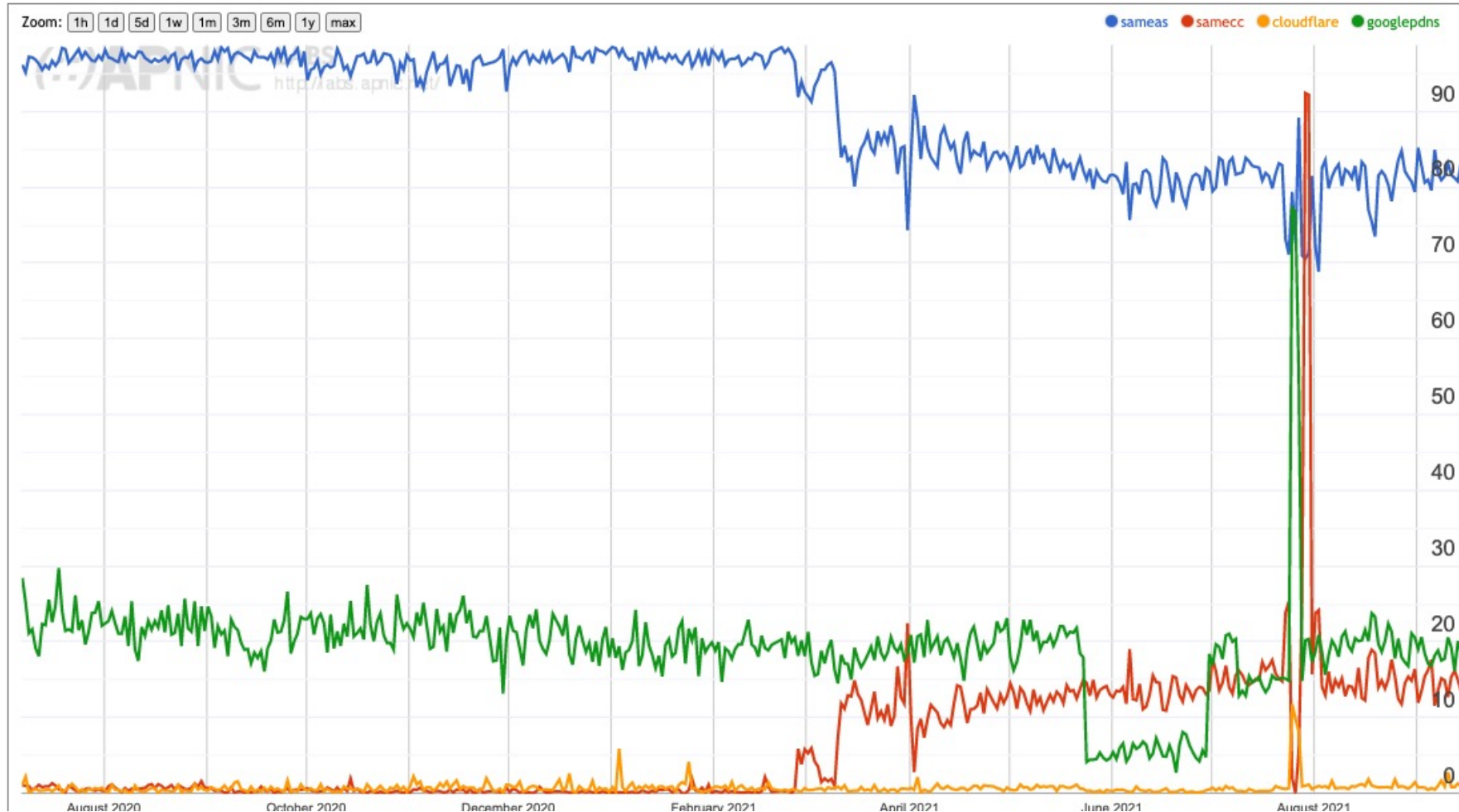
## Use of DNSSEC Validation for Bhutan (BT)



# Bhutan ISPs and DNSSEC

ASN	AS Name	DNSSEC Validates	Partial Validation	Samples
AS137412	TASHICELL-MOBILE-AS Tashicell Domestic AS Thimphu Bhutan	86.79%	13.18%	18,932
AS18024	BTTELECOM-AS-AP Bhutan Telecom Ltd	85.32%	14.42%	76,453
AS23955	TASHICELL-DOMESTIC-AS TashiCell Domestic AS, Thimphu, Bhutan	84.16%	15.73%	18,727
AS138529	DATANET-AS-AP DATANET WIFI	79.88%	20.02%	964
AS134715	DRUKREN-MOIC-AS Ministry of Information & Communications Thimphu, Bhutan	79.40%	15.33%	1,898
AS136039	NANO-AS-AP NANO, Bhutan	79.11%	20.57%	632
AS141680	SUPERNET1-AS-AP SuperNet Infocomm	60.17%	33.90%	236
AS38004	FASTLINK-ISP FastLink Wireless ISP, DrukCom Pvt. Enterprise.	14.29%	85.71%	203
AS9009	M247	10.81%	67.57%	74

# Bhutan and DNS Resolver Use



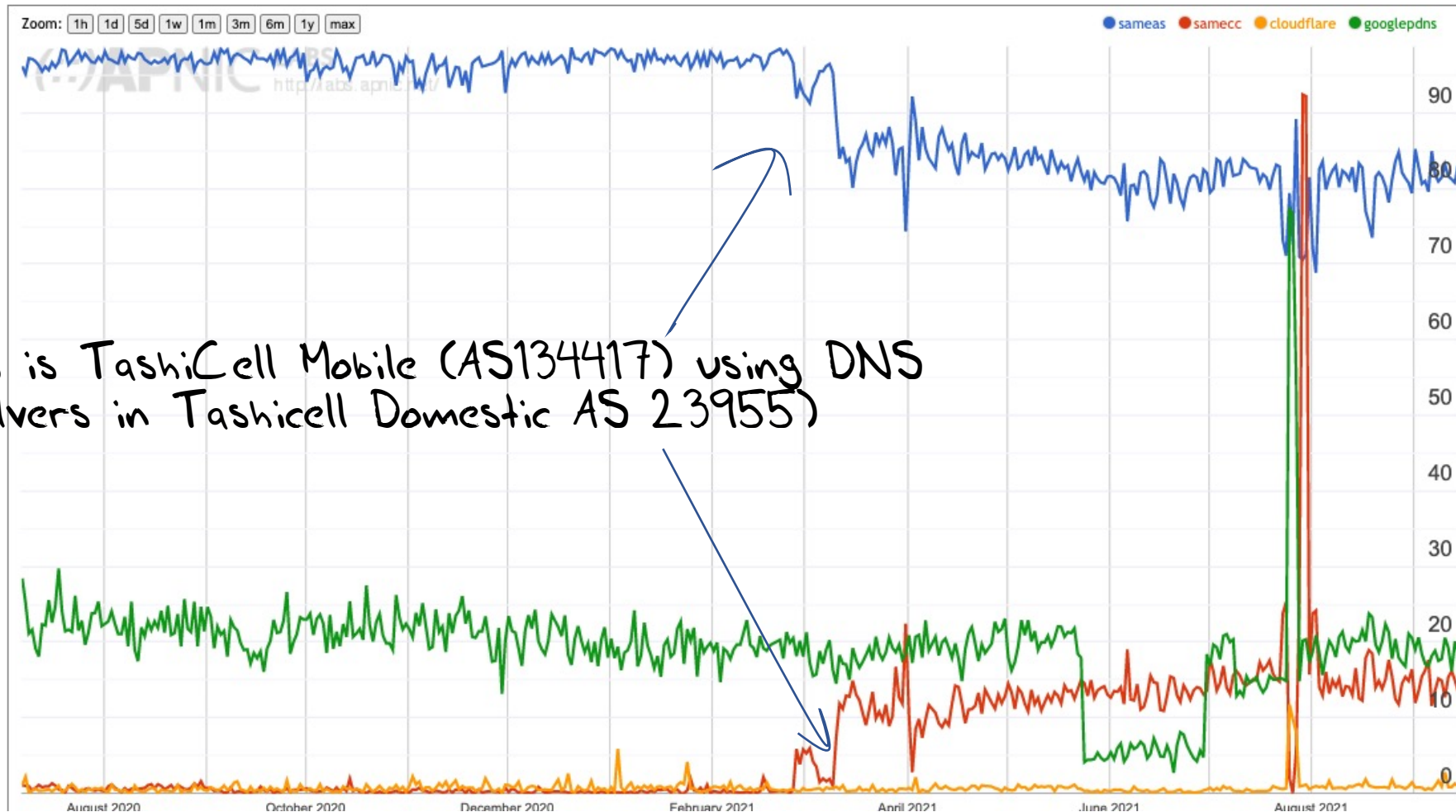
ISP Resolver

Google

Different AS, still in Bhutan

Cloudflare

# Bhutan and DNS Resolver Use



ISP Resolver

Google

Different AS, still in Bhutan

Cloudflare

This is TashiCell Mobile (AS134417) using DNS resolvers in Tashicell Domestic AS 23955)

# Bhutan and DNS Resolvers

ASN	AS Name	sameas	googlepdns	samecc	cloudflare	opendns	diffcc	quad9	level3	baidu	onedns	Samples
AS18024	BTTELECOM-AS-AP Bhutan Telecom Ltd	97.913%	17.994%	0.083%	0.390%	0.145%	0.165%	0.003%	0.202%	0.004%	0.002%	20,227
AS23955	TASHICELL-DOMESTIC-AS TashiCell Domestic AS, Thimphu, Bhutan	97.105%	19.011%	0.132%	0.264%	0.037%	0.671%	0.000%	0.131%	0.026%	0.013%	4,597
AS137412	TASHICELL-MOBILE-AS Tashicell Domestic AS Thimphu Bhutan	0.119%	12.185%	99.059%	0.037%	0.010%	0.045%	0.012%	0.000%	0.000%	0.000%	4,570
AS134715	DRUKREN-MOIC-AS Ministry of Information & Communications Thimphu, Bhutan	57.145%	63.984%	0.353%	19.422%	19.595%	0.187%	0.279%	0.056%	0.000%	0.000%	728
AS138529	DATANET-AS-AP DATANET WIFI	1.293%	92.779%	0.153%	0.000%	0.000%	28.536%	33.486%	0.349%	0.000%	0.000%	277
AS136039	NANO-AS-AP NANO, Bhutan	92.230%	40.246%	1.115%	13.846%	0.590%	4.929%	0.000%	0.251%	0.000%	0.000%	185
AS141680	SUPERNET1-AS-AP SuperNet Infocomm	0.000%	88.260%	10.900%	12.916%	0.000%	2.314%	12.089%	30.313%	0.000%	0.000%	48
AS38004	FASTLINK-ISP FastLink Wireless ISP, DrukCom Pvt. Enterprise.	86.988%	33.198%	0.000%	88.258%	92.830%	2.319%	0.000%	0.000%	1.159%	2.319%	41
AS9009	M247	100.000%	96.644%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	13
AS140695	BANKOFBHUTAN-AS-AP Bank of Bhutan Limited	92.634%	11.515%	0.000%	0.000%	96.820%	0.000%	0.000%	0.000%	0.000%	0.000%	11

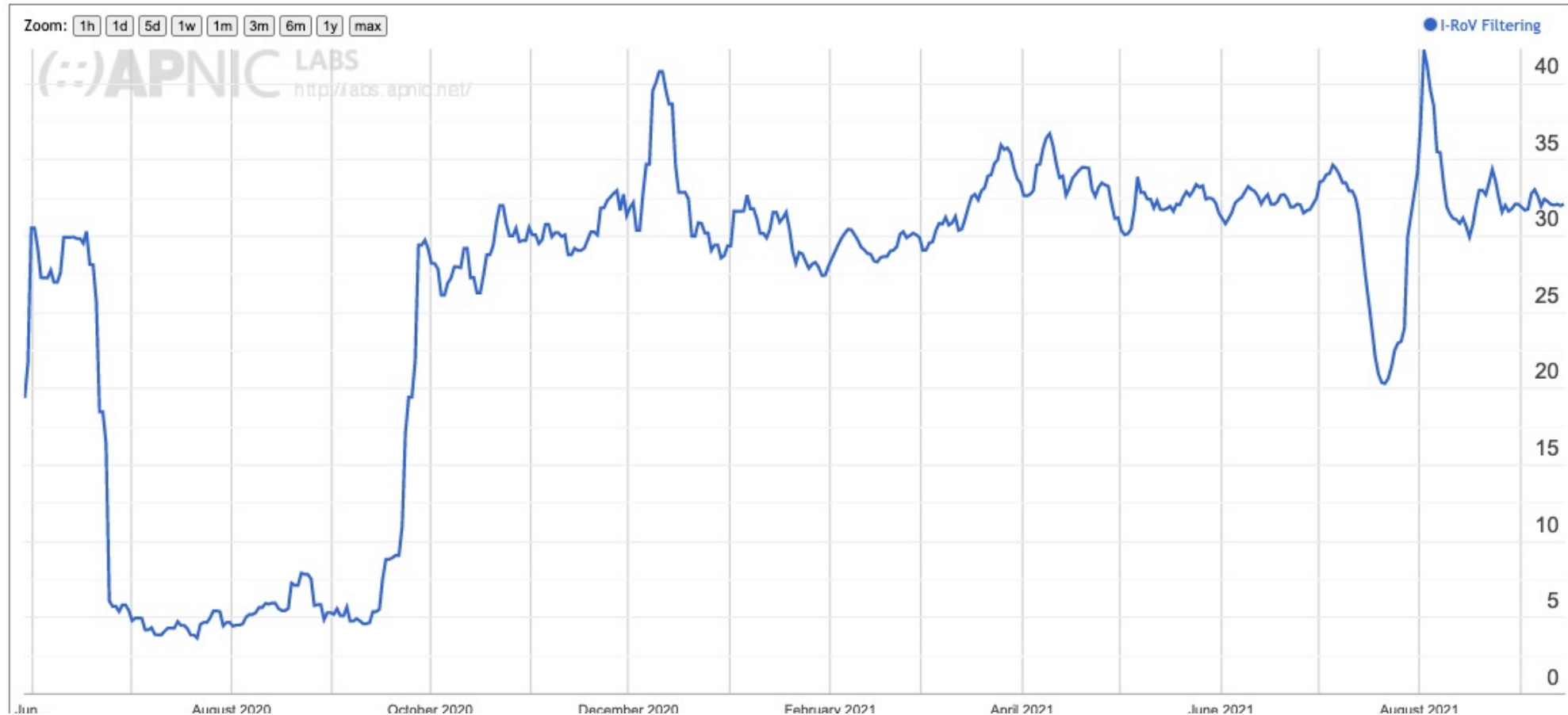
ISP Resolver

Other resolvers in Bhutan

Other resolvers not in Bhutan

Chinese open resolvers

# Bhutan and ROV Filtering



# Bhutan and ROV Filtering

This is impressive!

ASN	AS Name	RPKI Validates	Samples
AS141680	SUPERNET1-AS-AP SuperNet Infocomm	100.00%	55
AS23955	TASHICELL-DOMESTIC-AS TashiCell Domestic AS, Thimphu, Bhutan	99.41%	5,801
AS138529	DATANET-AS-AP DATANET WIFI	99.38%	321
AS137412	TASHICELL-MOBILE-AS Tashicell Domestic AS Thimphu Bhutan	99.16%	5,958
AS136039	NANO-AS-AP NANO, Bhutan	37.83%	230
AS18024	BTTELECOM-AS-AP Bhutan Telecom Ltd	4.13%	27,566
AS134715	DRUKREN-MOIC-AS Ministry of Information & Communications Thimphu, Bhutan	3.26%	920
AS38004	FASTLINK-ISP FastLink Wireless ISP, DrukCom Pvt. Enterprise.	1.75%	57

Obviously AS18024 (Bhutan Telecom) is not ROV filtering yet



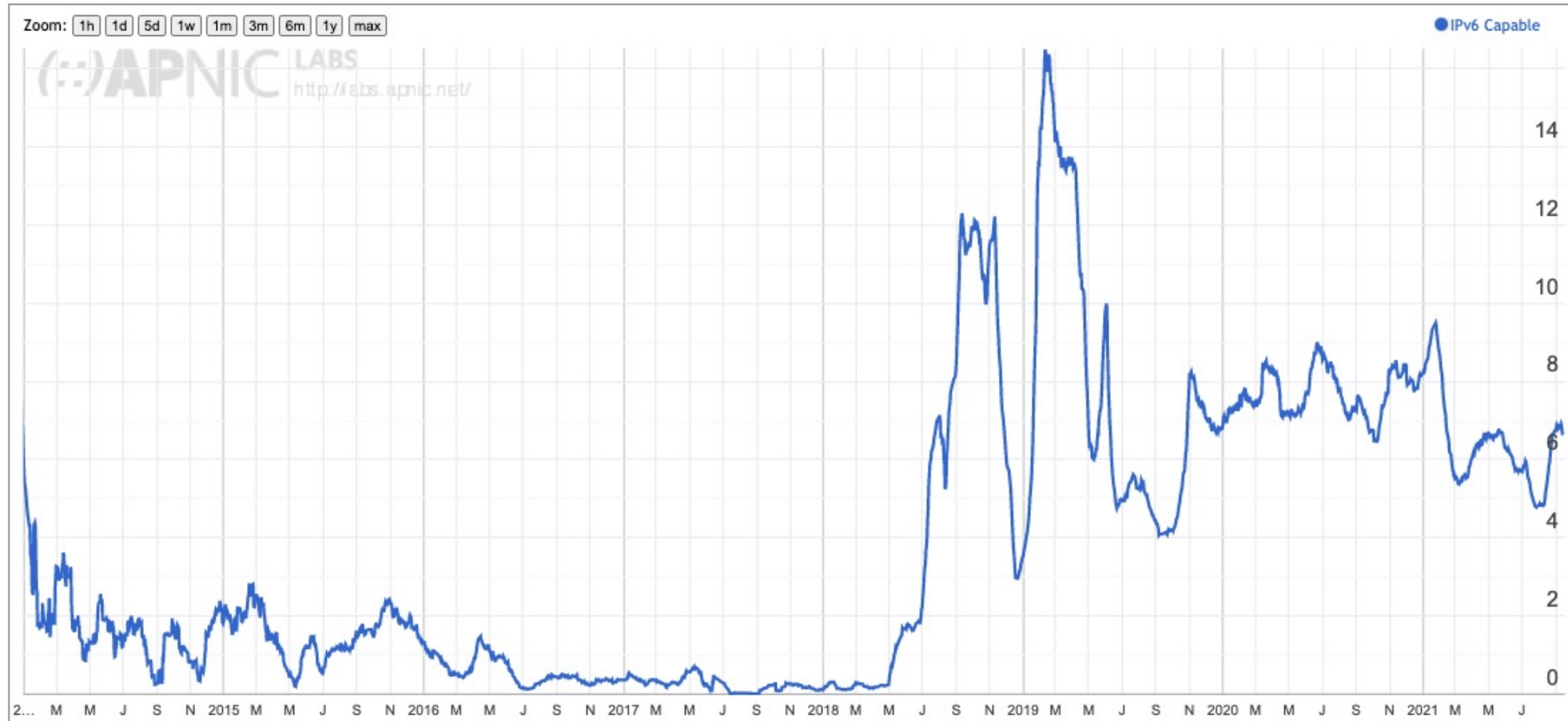
# Bhutan and ROA Production IPv4

AS	AS Name	V4 Valid	Pc	V4 Invalid	Pc	V4 Unknwn	Pc	V4 Total Routes
AS7615	BTIX-AS-AP Bhutan Internet Exchange	1	100.0%	0	0.0%	0	0.0%	1
AS9009	M247	1	100.0%	0	0.0%	0	0.0%	1
AS13335	CLOUDFLARENET	1	50.0%	0	0.0%	1	50.0%	2
AS17660	DRUKNET-AS DrukNet ISP	5	100.0%	0	0.0%	0	0.0%	5
AS18024	BTTELECOM-AS-AP Bhutan Telecom Ltd	7	100.0%	0	0.0%	0	0.0%	7
AS18025	BTTELECOM-AS-AP Bhutan Telecom Ltd	2	100.0%	0	0.0%	0	0.0%	2
AS23955	TASHICELL-DOMESTIC-AS TashiCell Domestic AS, Thimphu, Bhutan	11	100.0%	0	0.0%	0	0.0%	11
AS38004	FASTLINK-ISP FastLink Wireless ISP, DrukCom Pvt. Enterprise.	1	100.0%	0	0.0%	0	0.0%	1
AS44444	FORCEPOINT-CLOUD-AS	1	100.0%	0	0.0%	0	0.0%	1
AS132232	DCS-AS Data Centre Services	1	100.0%	0	0.0%	0	0.0%	1
AS134715	DRUKREN-MOIC-AS Ministry of Information & Communications Thimphu, Bhutan	10	100.0%	0	0.0%	0	0.0%	10
AS135666	MOIC-AS-AP Government Data Center DITTMoIC	4	100.0%	0	0.0%	0	0.0%	4
AS136039	NANO-AS-AP NANO, Bhutan	6	100.0%	0	0.0%	0	0.0%	6
AS137412	TASHICELL-MOBILE-AS Tashicell Domestic AS Thimphu Bhutan	1	100.0%	0	0.0%	0	0.0%	1
AS137925	GIC-BHUTAN-AS-AP GIC-Bhutan Reinsurance Co. Ltd.	1	100.0%	0	0.0%	0	0.0%	1
AS137994	BNBL-AS-AP Bhutan National Bank limited	1	100.0%	0	0.0%	0	0.0%	1
AS138529	DATANET-AS-AP DATANET WIFI	1	100.0%	0	0.0%	0	0.0%	1
AS140695	BANKOFBHUTAN-AS-AP Bank of Bhutan Limited	1	100.0%	0	0.0%	0	0.0%	1
AS141680	SUPERNET1-AS-AP SuperNet Infocomm	2	100.0%	0	0.0%	0	0.0%	2

# Bhutan and ROA Production IPv6

AS	AS Name	V6 Valid	Pc	V6 Invalid	Pc	V6 Unknwn	Pc	V6 Total Routes
AS7615	BTIX-AS-AP Bhutan Internet Exchange	1	100.0%	0	0.0%	0	0.0%	1
AS9009	M247	0	0.0%	0	0.0%	0	0.0%	0
AS13335	CLOUDFLARENET	0	0.0%	0	0.0%	0	0.0%	0
AS17660	DRUKNET-AS DrukNet ISP	2	100.0%	0	0.0%	0	0.0%	2
AS18024	BTTELECOM-AS-AP Bhutan Telecom Ltd	2	100.0%	0	0.0%	0	0.0%	2
AS18025	BTTELECOM-AS-AP Bhutan Telecom Ltd	0	0.0%	0	0.0%	0	0.0%	0
AS23955	TASHICELL-DOMESTIC-AS TashiCell Domestic AS, Thimphu, Bhutan	34	100.0%	0	0.0%	0	0.0%	34
AS38004	FASTLINK-ISP FastLink Wireless ISP, DrukCom Pvt. Enterprise.	1	100.0%	0	0.0%	0	0.0%	1
AS44444	FORCEPOINT-CLOUD-AS	0	0.0%	0	0.0%	0	0.0%	0
AS132232	DCS-AS Data Centre Services	1	100.0%	0	0.0%	0	0.0%	1
AS134715	DRUKREN-MOIC-AS Ministry of Information & Communications Thimphu, Bhutan	7	100.0%	0	0.0%	0	0.0%	7
AS135666	MOIC-AS-AP Government Data Center DITTMoIC	1	100.0%	0	0.0%	0	0.0%	1
AS136039	NANO-AS-AP NANO, Bhutan	1	100.0%	0	0.0%	0	0.0%	1
AS137412	TASHICELL-MOBILE-AS Tashicell Domestic AS Thimphu Bhutan	3	100.0%	0	0.0%	0	0.0%	3
AS137925	GIC-BHUTAN-AS-AP GIC-Bhutan Reinsurance Co. Ltd.	1	100.0%	0	0.0%	0	0.0%	1
AS137994	BNBL-AS-AP Bhutan National Bank limited	0	0.0%	0	0.0%	0	0.0%	0
AS138529	DATANET-AS-AP DATANET WIFI	0	0.0%	0	0.0%	0	0.0%	0
AS140695	BANKOFBHUTAN-AS-AP Bank of Bhutan Limited	1	100.0%	0	0.0%	0	0.0%	1
AS141680	SUPERNET1-AS-AP SuperNet Infocomm	1	100.0%	0	0.0%	0	0.0%	1

# And then there's IPv6



# And then there's IPv6

ASN	AS Name	IPv6 Capable	Samples
AS18024	BTTELECOM-AS-AP Bhutan Telecom Ltd	7.66%	36,388
AS137412	TASHICELL-MOBILE-AS Tashicell Domestic AS Thimphu Bhutan	4.65%	8,359
AS23955	TASHICELL-DOMESTIC-AS TashiCell Domestic AS, Thimphu, Bhutan	3.61%	8,247
AS134715	DRUKREN-MOIC-AS Ministry of Information & Communications Thimphu, Bhutan	15.37%	1,249
AS138529	DATANET-AS-AP DATANET WIFI	0.19%	515
AS136039	NANO-AS-AP NANO, Bhutan	0.93%	321
AS141680	SUPERNET1-AS-AP SuperNet Infocomm	1.16%	86
AS38004	FASTLINK-ISP FastLink Wireless ISP, DrukCom Pvt. Enterprise.	0.00%	77
AS140695	BANKOFBHUTAN-AS-AP Bank of Bhutan Limited	0.00%	22
AS137994	BNBL-AS-AP Bhutan National Bank limited	0.00%	7
AS9009	M247	0.00%	6
AS132232	DCS-AS Data Centre Services	0.00%	4
AS18025	BTTELECOM-AS-AP Bhutan Telecom Ltd	0.00%	3

# And then there's IPv6

ASN	AS Name	IPv6 Capable	Samples
AS18024	BTTELECOM-AS-AP Bhutan Telecom Ltd	7.66%	36,388
AS137412	TASHICELL-MOBILE-AS Tashicell Domestic AS Thimphu Bhutan	4.65%	8,359
AS23955	TASHICELL-DOMESTIC-AS TashiCell Domestic AS, Thimphu, Bhutan	3.61%	8,247
AS134715	DRUKREN-MOIC-AS Ministry of Information & Communications Thimphu Bhutan	15.37%	1,249
AS128522	DATA NET-AS-AP DATANET WIRELESS	0.19%	515
AS13669	NANO-AS-AP NANO, Bhutan	0.93%	321
AS14069	SUPERNET-AS-AP SuperNet Infocomm	1.16%	86
AS38004	FASTLINK-ISP FastLink Wireless ISP, DrukCom Pvt. Enterprise.	0.00%	77
AS140695	BANKOFBHUTAN-AS-AP Bank of Bhutan Limited	0.00%	22
AS137994	BNBL-AS-AP Bhutan National Bank limited	0.00%	7
AS9009	M247	0.00%	6
AS132232	DCS-AS Data Centre Services	0.00%	4
AS18025	BTTELECOM-AS-AP Bhutan Telecom Ltd	0.00%	3

WHY SO LOW?

Thanks!