RIPE NCC
RIPE NETWORK COORDINATION CENTRE

RIPE NCC

Internet Country Report: IPv6 in Sweden

May 2022

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Introduction

The Internet is a global network of networks, yet every country's relationship to it is different. Since 2019, the RIPE NCC has produced RIPE NCC Internet Country Reports as part of an ongoing effort to support Internet development throughout our service region by making our data and insights available to decision makers, local technical communities and policymakers. These reports analyse different countries' market landscapes and their state of development, examine their Internet routing and access to the global domain name system, and investigate connections between the major networks in each country as well as their connections to the global Internet. Our analysis is based on what we can observe from the RIPE NCC's measurement tools as well as a few external data sources.

This report is a smaller version of our full reports, this time focused specifically on IPv6 in Sweden. It was produced in response to a request by the Swedish Post and Telecom Authority (PTS) in relation to an IPv6 Forum that PTS held in May 2022. We hope it will serve to inform discussion, provide technical insight, and facilitate the exchange of information and best practices.

Highlights

- Sweden has an unusually large amount of IPv4 for its population, which likely contributes to its low IPv6 deployment rate
- The country's top Internet service providers vary greatly in terms of IPv6 capability, yet even the top IPv6 provider lags behind the world average
- There is a good level of interconnectivity between Sweden's networks, over both IPv4 and IPv6, resulting in healthy redundancy
- Domestic traffic paths tent to stay local over IPv6, and slightly less so over IPv4

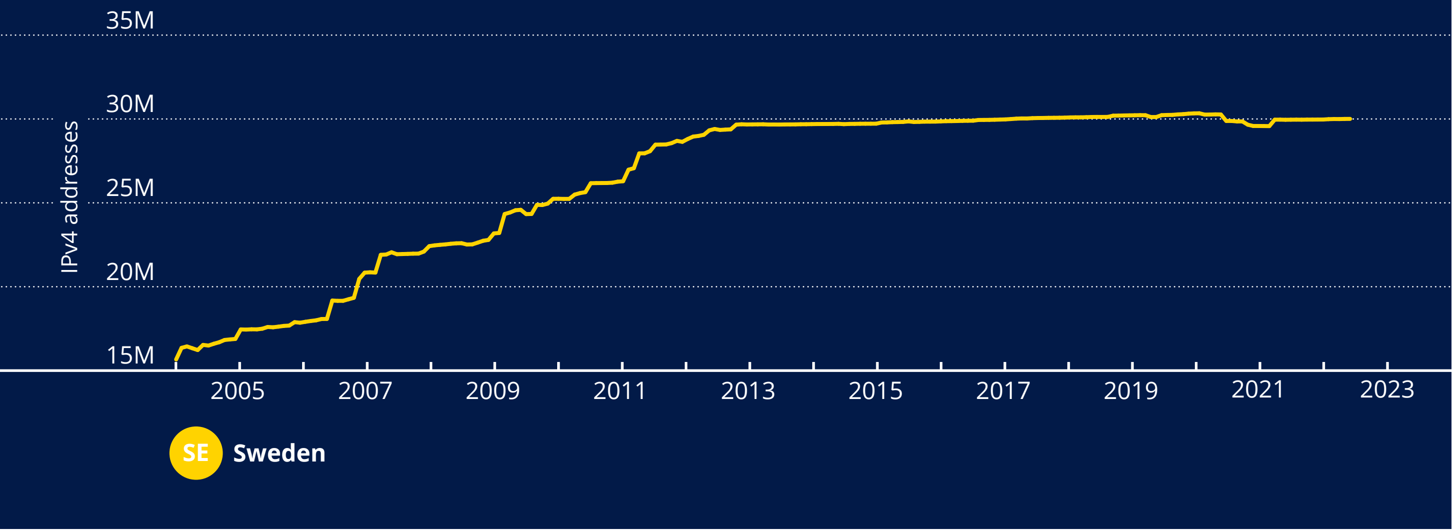
Market Landscape and Address Space

Sweden's Internet landscape is mature and well developed, with a number of different service providers and robust infrastructure in place. The country benefits from high Internet penetration rates and fast broadband and mobile Internet speeds. There has been a high level of investment in order to reach the 2025 broadband goals the country has set for itself, which include 98% of the population having broadband access of at least 1 Gbit/s at home and work by 2025.[1]

The most prominent Internet service providers in Sweden include: Telia, the former state telephony incumbent, which also operates in Norway, Denmark, Finland and the Baltics under different brands and accounts for approximately 33% of the Swedish broadband market and 35% of the mobile market;[2] Tele2, which is headquartered in Sweden and also operates in the Baltics, Germany, the Netherlands, Croatia and Russia; and Telenor, a majority state-owned Norwegian provider that also operates in Norway, Denmark, Finland and several countries in Asia. A number of other providers of varying sizes, both Swedish and international, also compete in the Swedish broadband and mobile markets, with Tre being the other large operator in the mobile sector.

In terms of the broader European landscape, Sweden ranks near the top of the EU's 2021 Digital Society and Economy Index (DESI), which takes into account factors including connectivity, digital skills, e-government and more. Sweden ranks third out of the 27 member countries in its overall ranking and fifth in connectivity. (While it ranks well above the EU average in many categories, including in overall fixed broadband take-up, it fell from 86% in 2020 to 84% in 2021 in this category.)[3] Broadband pricing is on par with the EU average, and the country ranks 17th globally for mobile Internet speeds and 23rd for broadband speeds.[4]

Figure 1:
IPv4 holdings over time



IPv4 and IPv6 in Sweden

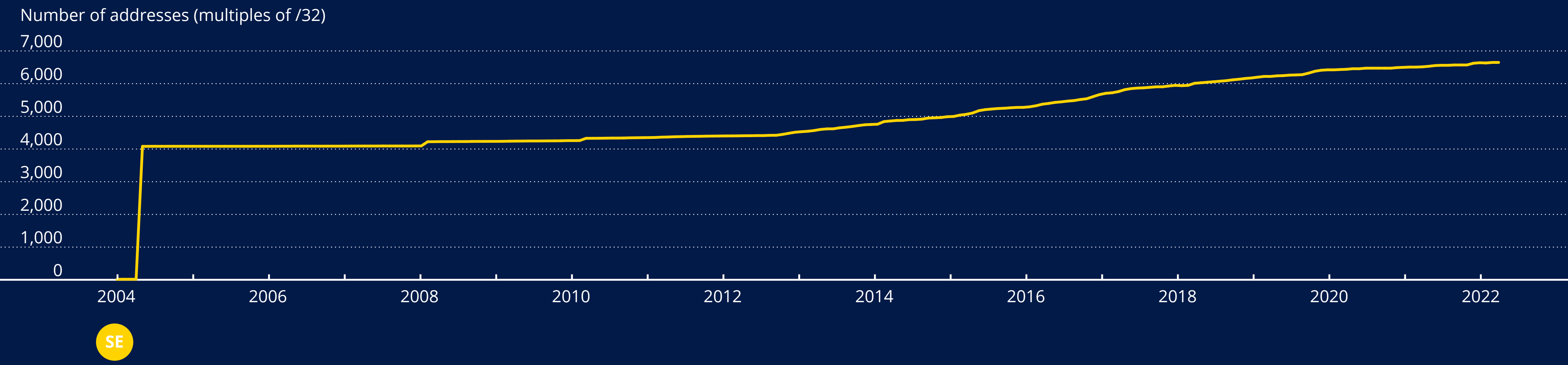
With 84% of households having a fixed broadband connection and 127 mobile subscriptions per 100 people,[5] a significant portion of Sweden's population is online and it therefore requires a substantial amount of IP address space to keep its population connected.

Until 2012, RIPE NCC members could receive large amounts of IPv4 address space based on demonstrated need. When the RIPE NCC reached the last /8 of IPv4 address space in 2012, the RIPE community instituted a policy allowing new LIRs to receive a small allocation of IPv4 (1,024 addresses) in order to help them make the transition to IPv6, the next-generation protocol that includes enough IP addresses for the foreseeable future. In November 2019, the RIPE NCC made the last of these allocations and a system now exists whereby organisations that have never received IPv4 from the RIPE NCC can receive an even smaller allocation (256 addresses), if available, from a pool of recovered address space (occasionally member accounts are closed and address space is returned to the RIPE NCC).

Similar to what we've seen in other countries within the RIPE NCC service region, Sweden continued to accrue significant amounts of IPv4 address space until the policy change in

1 https://www.government.se/496173/contentassets/afe9f1cfeaac4e39abcdd3b82d9bee5d/sweden-completely-connected-by-2025-eng.pdf
2 https://www.teliacompany.com/en/about-the-company/markets-and-brands/
3 https://ec.europa.eu/newsroom/dae/redirection/document/80480
4 https://www.speedtest.net/global-index
5 https://data.worldbank.org/indicator/IT.CEL.SETS.P2?locations=SE

Figure 2:
IPv6 holdings over time



2012, after which time growth plateaued and even dipped slightly in 2020.

In terms of which organisations hold the space, we see a moderate amount of IPv4 consolidation within the country, with the two largest IPv4 holders each accounting for more than 20% of the country's total IPv4 space:

- Telia Company 22.0%
- Tele2 21.1%
- Telenor 8.5%

Unlike IPv4, IPv6 addresses are widely available (although large allocations are based on demonstrated need), so hoarding tends not to play a role in the amount of space that organisations hold in the same way that it does when it comes to IPv4. However, it's worth noting that just because organisations hold large amounts of IPv6 address space does not mean they have actually deployed IPv6 and that the addresses are in use. Some networks might hold a large amount of address space without using it (possibly having presented plans for future growth when requesting large allocations), while others might be able to serve their entire customer base with a relatively small allocation.

While the same three organisations are also the three largest holders of IPv6 address space, we see much more consolidation when it comes to IPv6:

- Telia Company 61.4%
- Tele2 3.2%
- Telenor 1.0%

We clearly see Telia's dominance of Sweden's IPv6 address space in figure 2. Telia International Carrier was allocated a /20 of IPv6 space (equaling more than 4,000 /32s) in May 2004, which still accounts for 61.4% of the country's total IPv6 address space today. This large allocation may have been based on Telia Company's plans to "be the first in Europe to build a commercial network based on the latest Internet protocol, IPv6", as announced in 2001.[6]

After this huge allocation, growth in the amount of IPv6 space registered to Sweden was fairly stagnant until 2013, when it then picked up and enjoyed steady growth until 2020, before slowing somewhat.

With 2.9 IPv4 addresses per person, Sweden has more IPv4 per capita – by more than a factor of two – than any other country we've looked at in our RIPE NCC Internet Country

6 https://www.teliacompany.com/en/news/press-releases/2001/6/telia-to-build-new-generation-internet---first-in-europe-with-ipv6-in-commercial-network/

Figure 3:
IPv6 capability over time

Source: Compiled from APNIC data

Reports. This could help explain Sweden's comparatively low IPv6 deployment rate, which stands between 12-14% as of May 2022,[7] despite its relatively large amount of IPv6. For comparison, IPv6 deployment rates across Europe range from virtually zero to more than 60%.

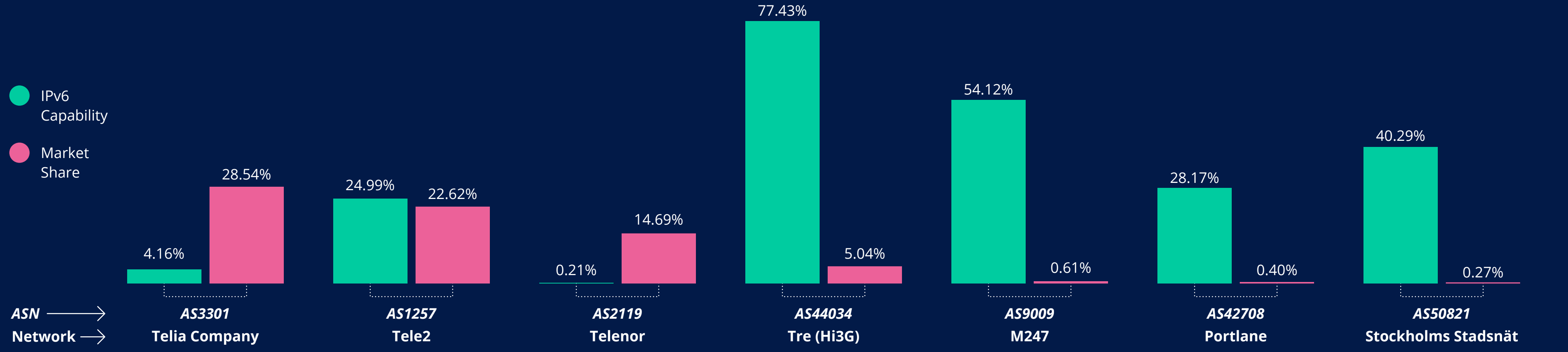
In figure 3, we can see that Sweden's IPv6 capability roughly followed the world average until around 2018, when it plateaued as the world average continued its upward trajectory. (Note that we don't have any information about the temporary spikes seen in Sweden's rate, which are likely artefacts in the data.)

Clearly, a significant amount of Sweden's IPv6 space is not actually in use. Of the 806 IPv6 blocks registered to organisations in Sweden, 451 are completely routed, while portions of another 72 are routed. There are usually several reasons for this. For one, nearly all organisations that became a RIPE NCC member in order to obtain a final IPv4 allocation received an IPv6 allocation at that time (which is standard procedure), even if they had no immediate plans for deployment. Additionally, address space may be registered to an international organisation with headquarters in one country but used in that organisation's international operations. Finally, there are different stages of deployment and different ways to measure IPv6 deployment. Large allocations are made to large, complex networks to facilitate address management, and the fraction of an IPv6 allocation that will be used to number connected devices is much lower than with IPv4.[8] Deploying IPv6 in a backbone carrier network, for example, is different to rolling it out to the edges, or individual end users – which is what's measured in most IPv6 capability statistics.

7 *Note that exact figures differ between organisations, which use different measurement methodologies. Sources: APNIC: https://stats.labs.apnic.net/ipv6 Facebook: https://www.facebook.com/ipv6 Google: https://www.google.com/intl/en/ipv6/statistics.html#tab=per-country-ipv6-adoption*

8 *See RFC 3194 for a technical explanation: https://datatracker.ietf.org/doc/html/rfc3194*

Figure 4:
IPv6 capability by network



Source: APNIC

In looking at IPv6 capability rates by network in figure 4, we see a striking difference between Sweden's top three Internet service providers. However, even at 25% IPv6 capability, Tele2 still falls below the world average of 30-37%. In addition to the top three providers, we also include any network with an IPv6 capability rate over 10%.

RIPE NCC Survey on IPv6

In trying to gain further insight, we look to the RIPE NCC Survey 2019,[9] which polled more than 4,000 network operators and other members of the technical community, including 78 respondents from Sweden.

Compared to the average responses across all survey respondents, we see that in Sweden, only 36% answered that they believe their organisation will require more IPv4 in the next two to three years, versus the average survey response of 46%. Additionally, only 18% in Sweden said they would buy IPv4 address space on the secondary market, compared to the average response of 28% across all respondents. These responses perhaps aren't surprising, given the country's large amount of IPv4 per capita. In looking at the ways in which organisations will obtain more IPv4 address space, 17% of respondents from Sweden said they will instead move to IPv6, which was also the average response across all survey respondents.

Among respondents from Sweden who claimed they *wouldn't* require more IPv4, 21% said they will deploy IPv6, which is higher than the survey average of 14% across all respondents. Interestingly, 36% of respondents from Sweden answered that their networks had fully deployed IPv6 (compared to the survey average of 19%), while a further 45% said they were either currently testing, had a plan or had just started deployment. Only 5% said they had no IPv6 deployment plans – far below the 20% of all survey respondents who said they had no plans. In comparison to the 35% of all survey respondents who identified IPv6 deployment as the main operational challenge facing their organisation's Internet-related services, that answer didn't even show up in the responses from Sweden.

Clearly, there is a discrepancy between the survey answers from Swedish operators and the current deployment rates in the country. While we do see a lack of urgency when it comes to obtaining further IPv4 space, we also see strong stated support for current IPv6 deployment plans. When it comes to IPv6, the size of the network obviously matters in terms of overall country deployment rates, and it's possible that the survey respondents who had made progress with IPv6 deployment were from organisations with smaller networks that didn't have a large effect on the country's overall standing.

9 https://www.ripe.net/survey

Domestic and International Connectivity

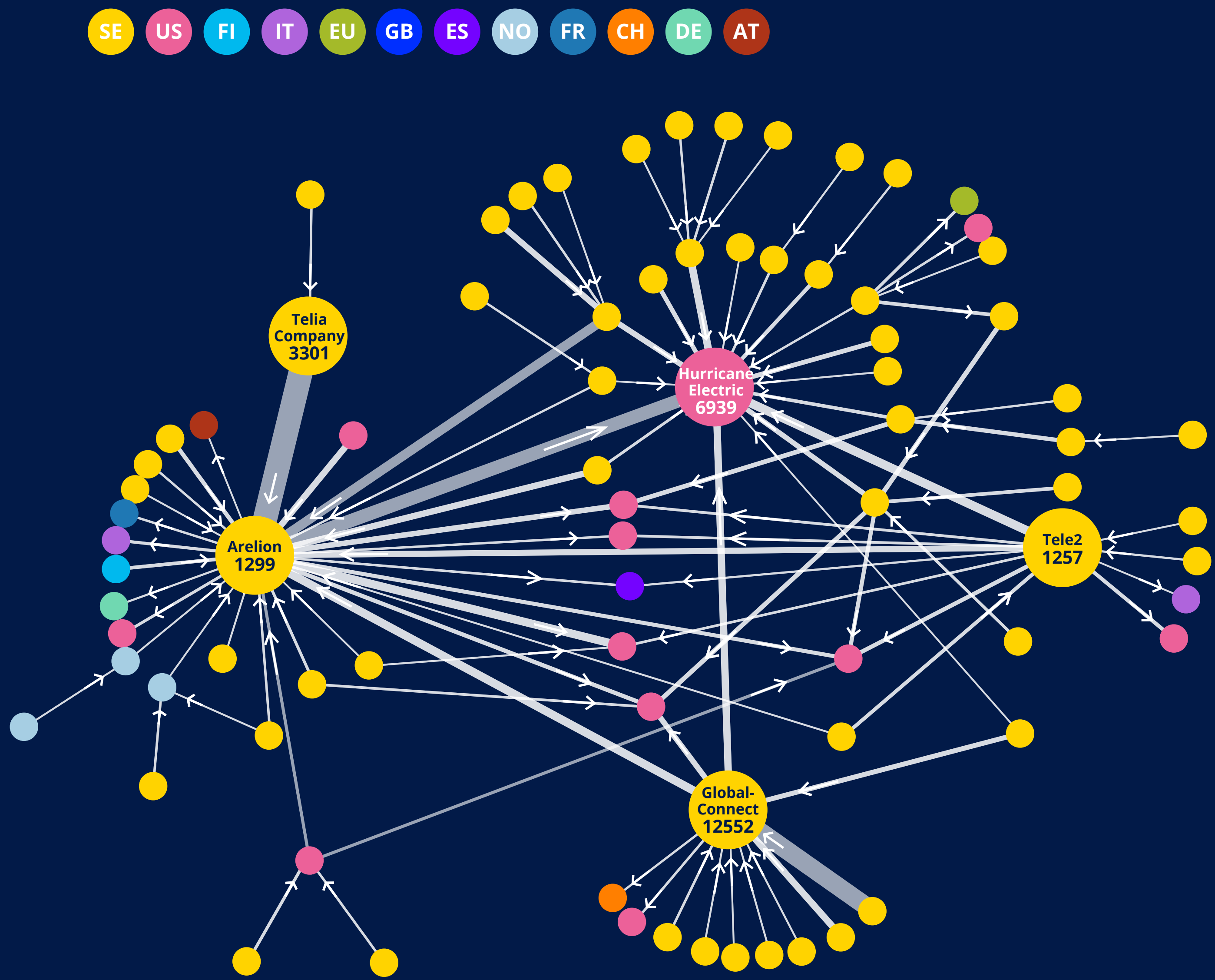
To understand the relationships that exist between different networks, we can investigate the interconnections within Sweden using data from the RIPE NCC's Routing Information Service (RIS), which employs a globally distributed set of route collectors to collect and store Internet routing data. This shows us the available paths that exist between networks (as opposed to actual paths taken).

In the following figure, we plot how routes propagate from one network to another (arrows indicate the direction of BGP announcements, which is opposite to traffic flow) up to the point where the path reaches a foreign network. For each path, we discard the first few hops that detail how routes propagate through international networks; our focus is on routing inside each country and the connections to the outside world. The nodes are colour-coded according to the country in which the network (ASN) is registered, and the width of the lines is determined by the number of paths in which we see the connection between the different ASNs. Note that we only label the ASNs that we specifically mention in the text, and that the position of the different networks doesn't correspond to any kind of geographical layout; instead, this is a visual representation of the relationships between the networks in each country.

Due to the nature of Border Gateway Protocol (BGP) and RIS route collection processes, our view is limited to the routes followed by international traffic. We will only observe peering relationships between two service providers in a country when one or both partners announce the other's routes to a third party that further propagates the route. Most notably, we will not see peerings at regional IXPs, where the intention is to keep local traffic within the country or region. Nevertheless, graphing the connections that we can detect provides valuable insight into domestic connectivity.

Because Sweden has a large number of ASNs, the figure has been restricted to the top 100 most observed links between ASNs. While this means that many smaller ASNs have been left out, as well as some less frequently seen paths between ASNs, the result still provides a view of the overall picture.

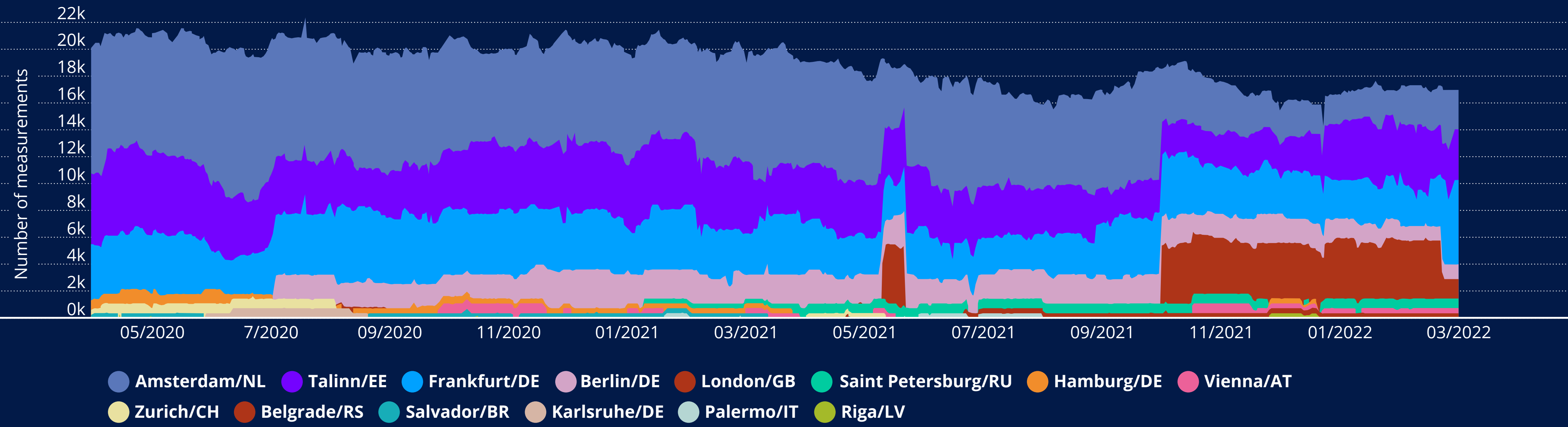
Figure 5:
Connectivity between networks in Sweden (IPv6)



Hurricane Electric (AS6939) stands out as a focal point of international IPv6 connectivity for many Swedish networks – both directly and indirectly. Telia Company (AS3301) relies exclusively on its former Telia Carrier subsidiary, now Arelion (AS1299). Arelion is well connected in its own right, but also has a significant number of paths passing through Hurricane Electric, which could be due to peering arrangements between the two. With Tele2 (AS1257), we observe fewer international connections; instead, we see a notable dependency on both Hurricane Electric and Arelion. Finally, we see how GlobalConnect (AS12552) provides connectivity to various Swedish networks and in turn is connected to Arelion, Hurricane Electric and, to a smaller extent, other international networks.

The only major difference we see when looking at connectivity over IPv4 is that Hurricane Electric plays a lesser role, connecting fewer networks over fewer paths. Over both IPv4 and IPv6, we see a healthy level of multi-homing without any obvious bottlenecks or single points of failure.

Figure 6:
K-root requests reached from requests originating in Sweden over time (IPv6)



Domain Name System, Traffic Paths and Routing Security

Reaching the Domain Name System

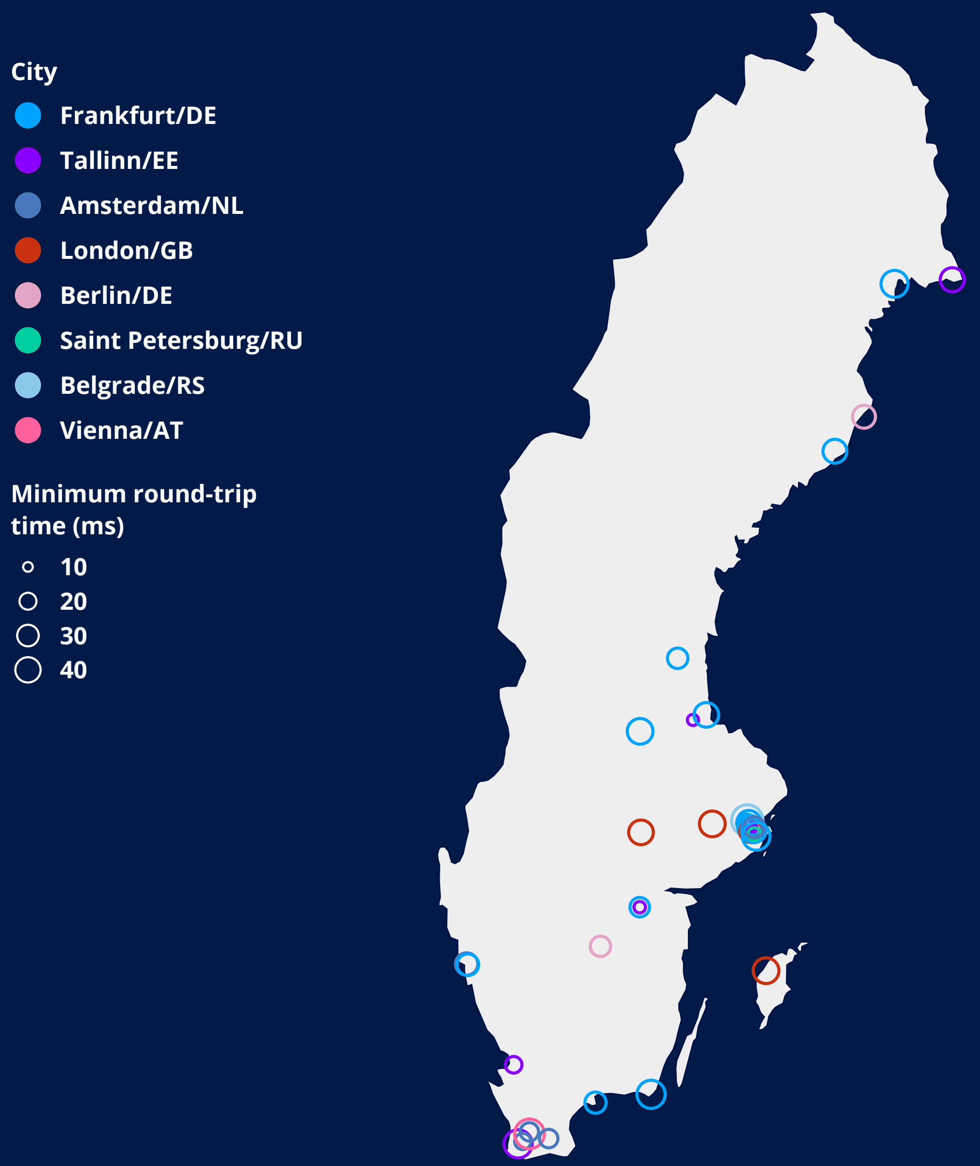
Turning now to investigate how traffic is routed to, from and within Sweden, we first examine which instances of K-root are queried over IPv6 from requests originating in the country. This gives us some insight into how the routing system considers the various options and decides which networks and locations will provide the best results. These measurements are based on the RIPE NCC's RIPE Atlas measurement platform, which employs a global network of probes to measure Internet connectivity and reachability (see the section on RIPE Atlas at the end of the report for more information about how to get involved).

K-root and DNS

K-root is one of the world's 13 root name servers that form the core of the domain name system (DNS), which translates human-readable URLs (such as https://www.ripe.net) into IP addresses. The RIPE NCC operates the K-root name server. A globally distributed constellation of these root name servers consists of local "instances" that are exact replicas. This set-up adds resiliency and results in faster response times for DNS clients and, ultimately, end users.

Sweden doesn't host a local instance of K-root. The most frequently reached K-root instances over IPv6 were those in Amsterdam, Tallinn, Frankfurt, Berlin and, more recently, London. These locations accounted for the vast majority of all requests. Other, much less used instances include Saint Petersburg, Hamburg, Vienna, Zurich, Belgrade, Palermo and Salvador (Brazil). The latter is far from an optimal choice, but it stopped being used by the RIPE Atlas probes more than a year ago, and even when this instance was reached, the impact would have been limited. As there are 12 other root name servers, one of which is operated by Netnod in Sweden, it's likely that when K-root would have

Figure 7:
K-root locations reached from vantage points in Sweden (IPv6)



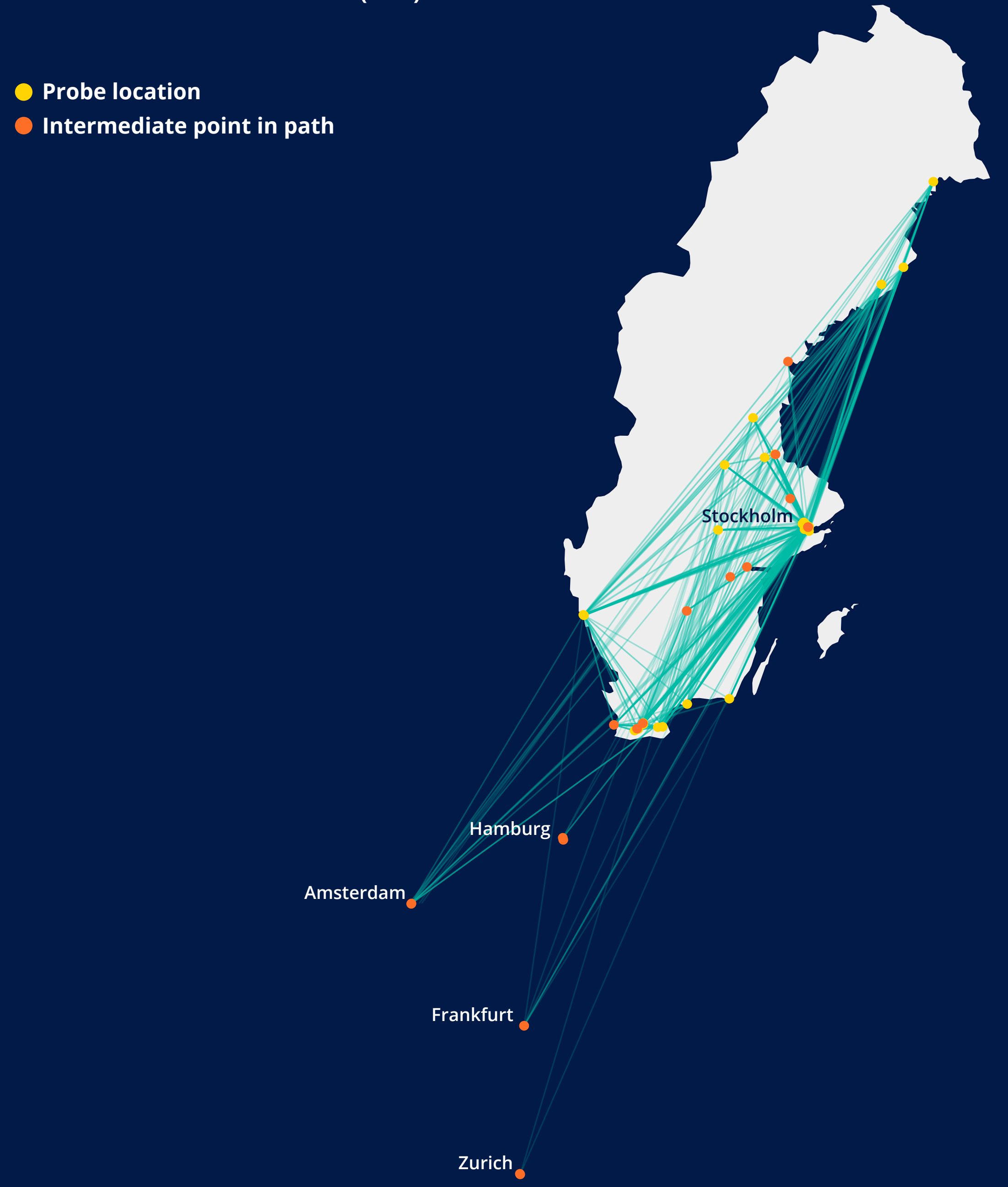
proved to be a sub-optimal choice, this or another root name server would have been queried instead. We didn't see big differences when looking at IPv4; Amsterdam, Tallinn, Frankfurt and Saint Petersburg were the most queried locations in recent months, while Zurich was a strong choice in 2020 but hasn't been seen in more than a year.

We also looked into which K-root instances were queried by RIPE Atlas probes over IPv6 on a given day, as shown in figure 7. All of the resulting round-trip times were quite favourable, and no probes were seen reaching very distant instances. In looking at individual networks, we generally expect to see networks reaching the same K-root instance, because once a particular path has been identified as being the best option according to the BGP decision-making process, there is usually consistency across all the routers that are part of that particular network.

This is generally what we see with Sweden's networks reaching K-root over IPv6, although we did note that Telia reached instances in both London and Frankfurt, Bahnhof reached instances in Tallinn, Frankfurt and London, and Sunet (the Swedish academic research network) reached instances in both Tallinn and Amsterdam. It's not unusual to see networks overriding the BGP decision-making process and reaching various K-root instances that are hosted in parent companies, at exchange points or with organisations with which the network has a peering arrangement.

We should note that these results, while considered generally representative, offer only a snapshot of measurements made on a single day in April 2022. Given BGP's dynamic nature, results can change constantly due to subtle changes in routing.

Figure 8:
Paths between domestic traffic (IPv6)



Domestic Traffic Exchange

Again using data from the RIPE Atlas measurement network, we can investigate how some of the networks in Sweden exchange traffic with each other, and get some indication of where those exchanges take place. For this experiment, we performed traceroutes between the RIPE Atlas probes in Sweden. Figure 8 shows the location of the probes (indicated by the yellow dots), the intermediate points detected in the traceroutes (indicated by the orange dots) and the paths followed by the traceroutes.

Routing packets a long way to an exchange point, only to have them travel back to a destination close to the origin, is referred to as "tromboning". The farther a path extends from the origin/destination, the more inefficient the path is. In addition, these detours generally increase costs for the network operator and, more importantly, the additional distance travelled unnecessarily increases the risk of disruptions. It also creates additional dependencies on external providers, which could have regulatory implications.

In Figure 8, we can see that most of the domestic traffic stays within the country, with a few paths detouring to Amsterdam, Frankfurt, Hamburg and Zurich. It's likely that traffic is being exchanged at the major IXPs in those locations, which is not unusual. We can also see the role that Netnod IX and, to a lesser extent, other IXPs play in exchanging local traffic in Stockholm. The picture is very similar for IPv4, although there we also see some paths extending as far away as New York.

It's worth noting that the impact of the longer routes we see here, which would result in longer response times, is impossible to ascertain directly because it depends on how much traffic is actually flowing across them, which is not something we can measure. Instead, we can only discover which route traffic *would* take if a device in one network wanted to reach a device in another network.

Figure 9:
IPv4 address space covered by ROAs over time

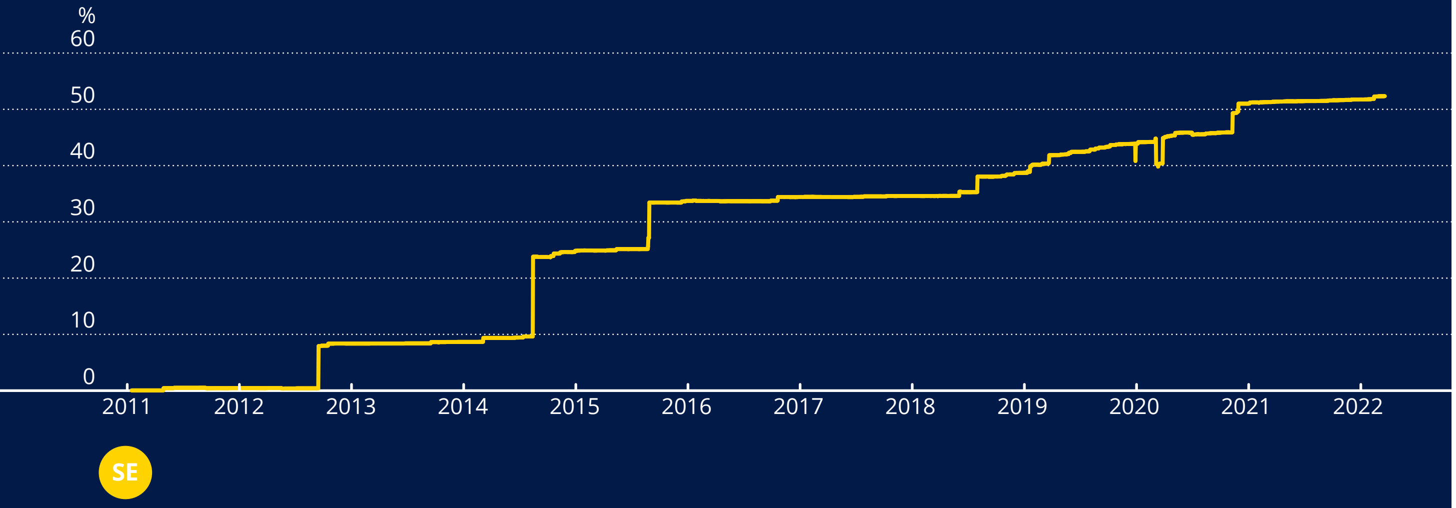
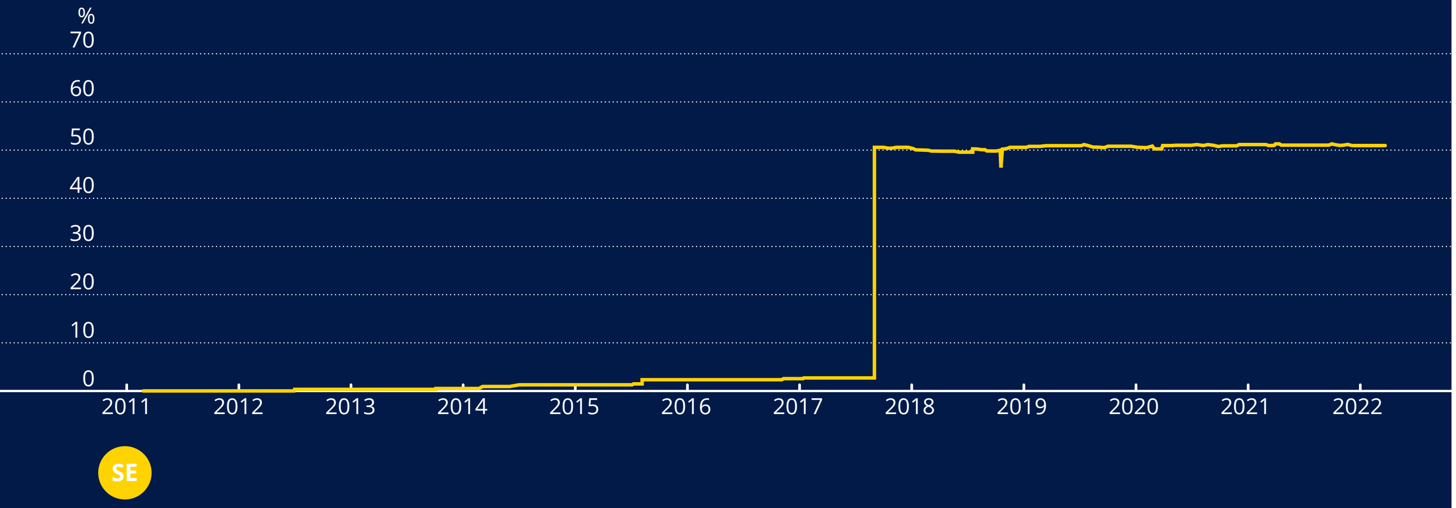


Figure 10:
IPv6 address space covered by ROAs over time



Routing Security

Beyond looking into the different routes available to traffic originating in the region, we can also investigate routing security in the country by looking at how effectively IP address space is protected by Resource Public Key Infrastructure (RPKI), a security framework that helps network operators make more secure routing decisions.

RPKI uses digital certificates called ROAs (Route Origin Authorisations) to prove a resource holder's right to announce IP prefixes (i.e. certifying that the resources were allocated or assigned to them by a Regional Internet Registry). This helps avoid the most common routing error on the Internet: the accidental announcement of an IP prefix by someone who is not the legitimate holder of that address space. Using the RIPE NCC's RIPEstat tool – which provides all available information about IP address space, ASNs, and related information for hostnames and countries – we can see what percentage of a country's IPv4 address space is covered by ROAs.

In Sweden, we see the unusual case of a higher percentage of the country's IPv6 address space being covered by ROAs than its IPv4 address space. The sudden jump in Sweden's IPv6 RPKI coverage in late 2017 was caused by Telia, which created ROAs for its /20 – as mentioned previously, this corresponds to 61% of the total IPv6 address space allocated to Sweden.

The Need for IPv6

While Sweden has an unusually large amount of IPv4 address space to serve its population, it cannot rely on IPv4 forever. IPv4 run-out means that, eventually, even the large broadband and mobile providers will struggle to serve their growing numbers of customers. Technical workarounds that allow multiple users to share a single IP address, such as carrier-grade network address translation (CGN), are in widespread use, especially in mobile broadband connectivity; however, there are well-documented drawbacks to address-sharing technologies. The price of IPv4 on the secondary market currently stands at around $50 USD per address and is only projected to continue increasing.[10] In addition, a healthy market with open competition requires that new service providers have the address space they need to carve out a place for themselves.

Deploying IPv6 remains the only sustainable strategy for accommodating future growth and reaching the EU's 2030 connectivity targets[11] – not to mention supporting emerging technologies such as 5G, the Internet of Things, smart cities and more.

Governments, regulators, Internet exchange points and local network operator groups all have a role to play in IPv6 deployment. As we've seen in other countries we've looked at, active support among these actors can contribute significantly to a country's overall Internet development and the ability to transition to the next-generation protocol.

10 https://auctions.ipv4.global/prior-sales
11 https://www.euractiv.com/section/broadband/news/connectivity-is-the-starting-point-for-the-2030-digital-targets/

About the RIPE NCC

The RIPE NCC serves as the Regional Internet Registry for Europe, the Middle East and parts of Central Asia. As such, we allocate and register blocks of Internet number resources to Internet service providers and other organisations.

The RIPE NCC is a not-for-profit organisation that works to support the open RIPE community and the development of the Internet in general.

Data Sources

The information presented in this report and the analysis provided are drawn from several key resources:

RIPE Registry

This is the record of all Internet number resources (IP addresses and AS Numbers) and resource holders that the RIPE NCC has registered. The public-facing record of this information is contained in the RIPE Database, which can be accessed from https://www.ripe.net

RIPE Atlas

RIPE Atlas is the RIPE NCC's main Internet measurement platform. It is a global network of thousands of probes that actively measure Internet connectivity. Anyone can access this data via Internet traffic maps, streaming data visualisations, and an API. RIPE Atlas users can also perform customised measurements to gain valuable information about their own networks. https://atlas.ripe.net

Routing Information Service (RIS)

The Routing Information Service (RIS) has been collecting and storing Internet routing data from locations around the globe since 2001.
https://www.ripe.net/ris

The data obtained through RIPE Atlas and RIS is the foundation for many of the tools that we offer. We are always looking to improve our measurement platforms by expanding the diversity of the networks they cover and would like to have RIPE Atlas probes or RIS peers in networks that aren't already included. Please see the RIPE Atlas and RIS websites to learn more.

Other RIPE NCC Tools and Services

- RIPEstat: https://stat.ripe.net/
- RIPE IPmap: https://ipmap.ripe.net/
- K-root: https://www.ripe.net/analyse/dns/k-root