RIPE NCC
RIPE NETWORK COORDINATION CENTRE

RIPE NCC

Internet Country Report: Mediterranean Europe

June 2021

Introduction

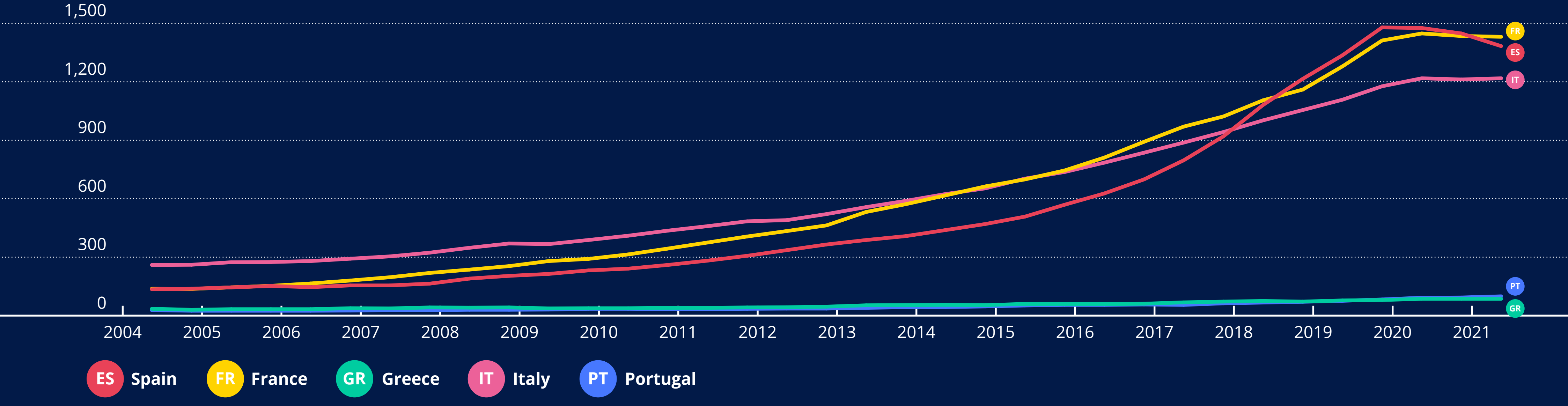
The Internet is a global network of networks, yet every country's relationship to it is different. This report provides an outlook on the current state of the Internet in Mediterranean Europe. We offer an analysis of the region's market landscape and its state of development, examine Internet routing within the region, take a close look at its access to the global domain name system, and investigate its connections to the global Internet. This analysis is based on what we can observe from the RIPE NCC's measurement tools as well as a few external data sources.

We focus the spotlight on five different countries in the RIPE NCC's service region – Portugal, Spain, France, Italy and Greece – and present a comprehensive analysis of the region's Internet development and potential for future growth in order to inform discussion, provide technical insight, and facilitate the exchange of information and best practices regarding Internet-related developments in this part of the world. (Note that we did not include the countries along the east coast of the Adriatic Sea, as they were covered in the RIPE NCC Southeast Europe Country Report in 2020.) This is the seventh such country report that the RIPE NCC has produced as part of an ongoing effort to support Internet development throughout our service region by making our data and insights available to local technical communities and decision makers.

Highlights

- These five countries all show a high level of Internet development, healthy market competition, and robust and resilient Internet infrastructure
- Although IPv4 shortage is less of an issue in this region than other parts of the world, further IPv6 deployment is still needed to achieve EU-wide connectivity goals as well as future growth
- The level of IPv6 deployment varies greatly in the region, with several countries at the forefront while others lag significantly behind
- Routing in the five countries is generally quite optimised, although there are a number of anomalies significant enough to affect response times
- The five countries have a diverse number of routes connecting them to the rest of the global Internet

Figure 1:
Number of Local Internet Registries over time



The Mediterranean Europe Market and Opportunity for Growth

The Market Landscape

The countries included in this report span a wide range of geographical sizes, populations and GDPs. As a result, their Internet landscapes also differ from each other. However, as part of the European Union (EU), all five countries have some shared ICT objectives, such as the EU's 2025 broadband goals,[1] and, to a large extent, share a common regulatory framework, being part of the EU internal market.

All five countries have a long history of Internet growth and development and although incumbent providers maintain a large footprint, the markets have evolved to be quite open and competitive, providing a good level of choice for enterprise and consumers. These countries benefit from robust infrastructure and high rates of Internet penetration. Some of the providers in this region are global players, such as France's Orange Group, which has significant presence across Europe, the Middle East and Africa. At the time of writing, four of the five counties have launched 5G networks, with the exception being Portugal.[2]

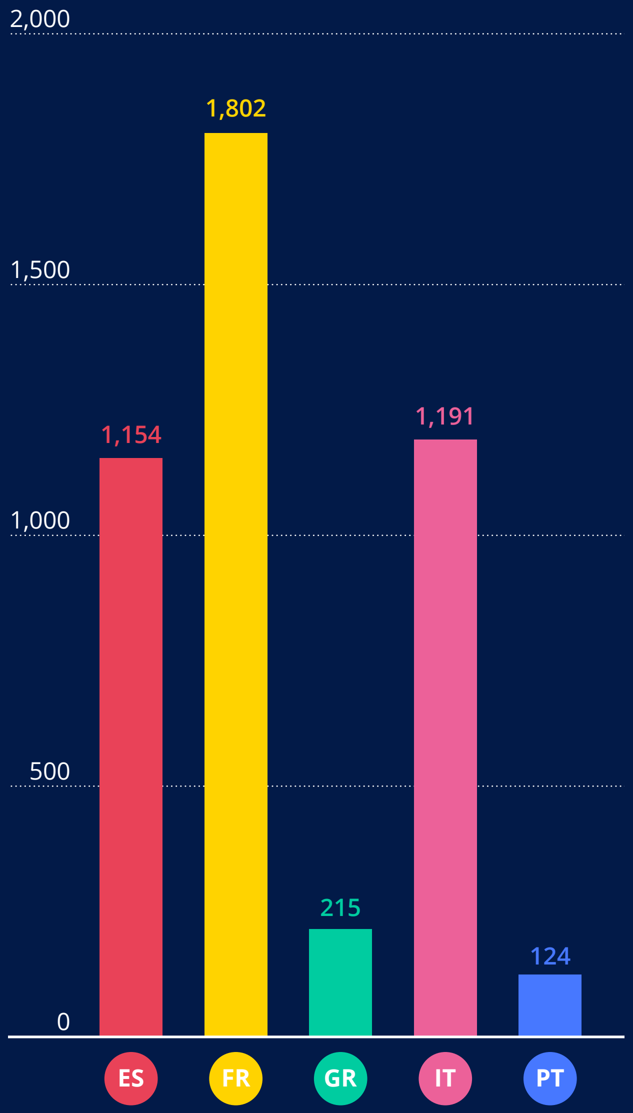
Number of Providers and Other Organisations Running Their Own Networks

As the Regional Internet Registry for Mediterranean Europe, the RIPE NCC can track the development of the local Internet over time through growth in the number of RIPE NCC members and Local Internet Registries (LIRs). Although growth in the three larger countries – Spain, France and Italy – is more obvious (and indeed, greater) in figure 1, the differences are not as striking when looking at percentage growth (rather than absolute numbers) in Greece and Portugal, which have still shown a significant increase in the number of LIRs.

It's interesting to note that the number of LIRs in Spain, after skyrocketing between 2016 and 2020, actually started to decline after 2020. Even so, the number remains on par with those of France and Italy, although the population of Spain is significantly smaller than those two countries. In general, a higher number of networks often signals a more diversified market, with a larger number of service providers operating their own networks; however, this is not always the case.

1 https://ec.europa.eu/digital-single-market/en/broadband-strategy-policy
2 European 5G Observatory

Figure 2:
Number of networks



RIPE NCC Members and Local Internet Registries (LIRs)

RIPE NCC members include Internet service providers, content hosting providers, government agencies, academic institutions and other organisations that run their own networks in the RIPE NCC's service region of Europe, the Middle East and Central Asia. The RIPE NCC distributes Internet address space to these members, who may further assign IP addresses to their own end users. It is possible for members to open more than one account, called a Local Internet Registry (LIR).

For a long time, the majority of RIPE NCC members were large Internet service and access providers. More recently, however, we've seen a significant increase in other types of organisations requiring IP addresses to run their own networks, including hosting providers, government agencies, universities, businesses, etc. This has allowed more organisations to exert more control over their Internet address resources and the ways in which they route their traffic. As a result, an increase in the number of LIRs doesn't necessarily translate into an increase in the number of Internet access providers.

In addition, it's possible for the same organisation to hold several LIR accounts. This practice became a significant trend after 2012, when the amount of IPv4 address space being allocated was restricted as the remaining IPv4 address pool became smaller and smaller (as explained in more detail in the IPv4 section below). Indeed, we see this taking place in Mediterranean Europe – especially in Spain, where 175 LIRs closed between the start of 2020 and the time of writing, 93 of which were "additional accounts" (those belonging to members with more than one account each). During the same period, only 81 new LIRs were opened in Spain, creating a downward trend in terms of overall growth. In total, Spain has 242 "additional" LIR accounts, France has 168, Italy has 77, Portugal has 16 and Greece has 5.

Network Growth and Diversity

In general, a larger number of Local Internet Registries corresponds to a larger number of independently operated networks called Autonomous Systems, each of which is represented by an Autonomous System Number, or ASN. (An Autonomous System is a group of IP networks that are run according to a single, clearly defined routing policy. There are currently about 70,000 active ASNs on the Internet today.)

The number of networks in a given country is one indication of market maturity. The greater the diversification, the more opportunity exists for interconnection among networks, which increases resiliency.

The RIPE NCC is responsible for the allocation of ASNs in its region. This provides us unique insight into the distribution and deployment of these networks across the Internet. Again, we see the larger countries dominating here, although with slightly different results than we saw in the number of LIRs. Although Italy has about 90% of France's population, it has only about 66% of France's number of networks. And while Greece and Portugal have comparable populations, Greece has far more networks than Portugal.

Interestingly, the diversity in networks we see in these five countries doesn't translate directly into more competition and lower access prices. In terms of mobile broadband prices, at least, Italy is one of the six least expensive countries in the EU, while France is one of 11 EU countries considered "relatively inexpensive". Spain, Greece and Portugal are three of the seven EU countries that fall into the "relatively expensive" category. None of the five countries are considered "expensive" by EU standards.[3]

3 https://ec.europa.eu/digital-single-market/en/broadband-connectivity

Figure 3:
IPv4 holdings

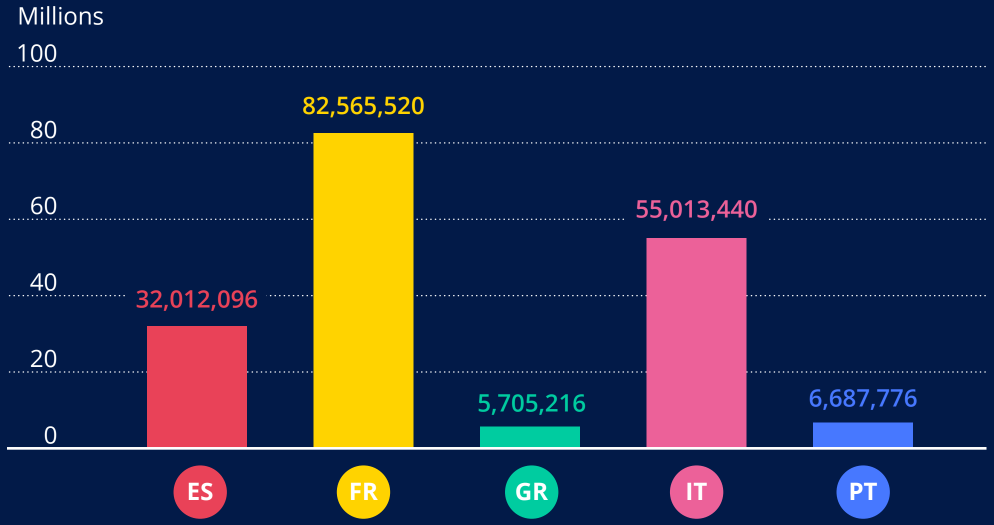
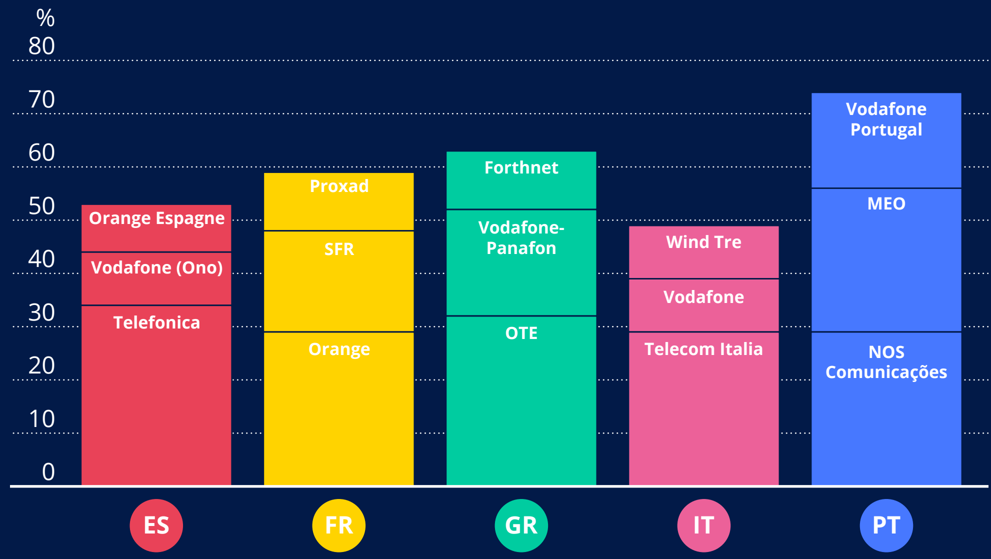


Figure 4:
IPv4 holdings by organisation



IPv4 Address Space in Mediterranean Europe

Until 2012, RIPE NCC members could receive larger 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 from a pool of recovered address space (occasionally member accounts are closed and address space is returned to the RIPE NCC).

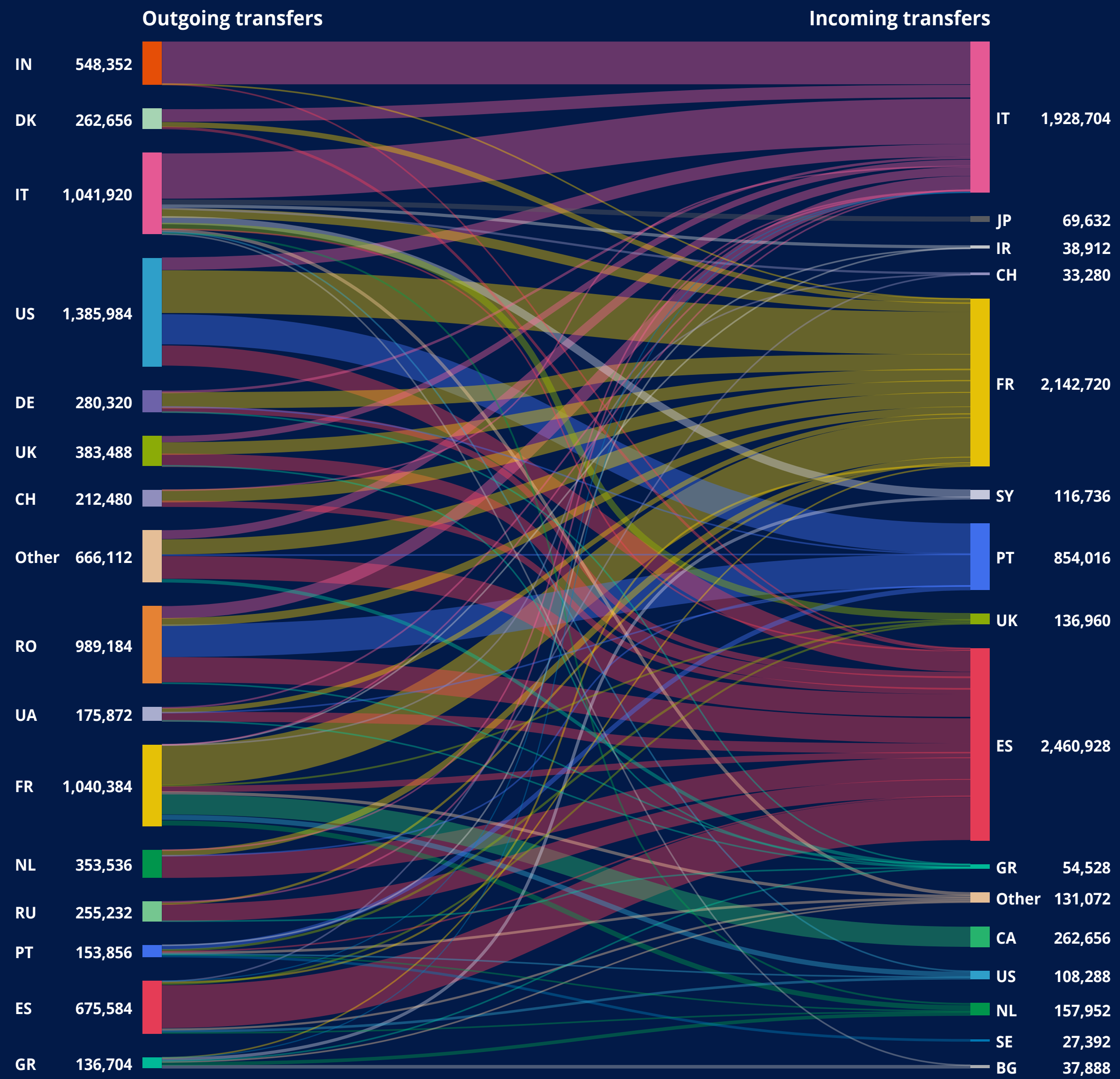
Indeed, none of the five countries included in this report continued to accrue any significant amounts of IPv4 address space after 2012. Even up until that time, we saw very little growth in the amount of IPv4 space in Portugal and Greece, while there was moderate growth in Spain, significant growth in Italy and the highest growth rate in France – all of which we see reflected in each country's IPv4 holdings today. Note that even in countries where a large number of organisations opened additional LIR accounts to receive further IPv4 allocations, the amounts were so small that they didn't significantly increase the countries' overall IPv4 holdings.

We also note a fairly high amount of IPv4 consolidation; in each of the five countries, between 50% and 75% of IPv4 addresses are held by just three organisations. While it was difficult to obtain clear and consistent data on market share, we believe these findings are generally representative in that these providers hold a significant share of the Internet access markets in these countries. Figure 4 shows the organisations with the three largest amounts of IPv4 in each country.

IPv4 Secondary Market

To fill the demand for more IPv4 address space, a secondary market has arisen in recent years, with IPv4 being bought and sold between different organisations. The RIPE NCC plays no role in these financial transactions, ensuring only that the RIPE Database – the record of which address space has been registered to which RIPE NCC members – remains as accurate as possible.

Figure 5:
IPv4 transfers within, into and out of Mediterranean Europe between December 2016 and May 2021



As demand for IPv4 continues despite the dwindling pool of available space, many providers and other organisations have turned to the secondary market. Figure 5 shows the IPv4 transfers that have taken place within, into and out of each country in the region since the market became active.

We can see an active secondary market in this part of the world, with IPv4 addresses being transferred both to and from each of the five countries. Unsurprisingly, the market is dominated by the three larger countries of Spain, France and Italy, all of which include a large number of domestic transfers (in which addresses are transferred between two parties in the same country). The biggest recipient organisations have been:

- OVH SAS (France): 917,504 addresses
- Vodafone Portugal: 720,896 addresses
- Vodafone España: 646,144 addresses
- Sky Italia: 524,288 addresses
- Orange España: 489,216 addresses

Of note is a /13 transfer from India to Italy (524,288 addresses) which took place between Reliance Communications Limited and Sky Italia in August 2018. While the commercial nature of this transaction is unknown, Reliance Communications filed for bankruptcy in February 2019.[4] However, the amount of IPv4 transferred into each of the five countries makes up only a small fraction of their total IPv4 holdings, so none are significantly reliant on the IPv4 secondary market.

Internet Penetration and Potential for Future Growth

All five countries included in this report have relatively large amounts of IPv4 space for their populations. In France especially, we see the unusual case of there being more IPv4 addresses than inhabitants, with 1.2 addresses per

4 *https://www.reuters.com/article/rcom-debt/rcom-goes-to-bankruptcy-court-to-resolve-debt-burden-idINKCN1PQ4WT?edition-redirect=in*

Figure 6:
Percentage of households with Internet access

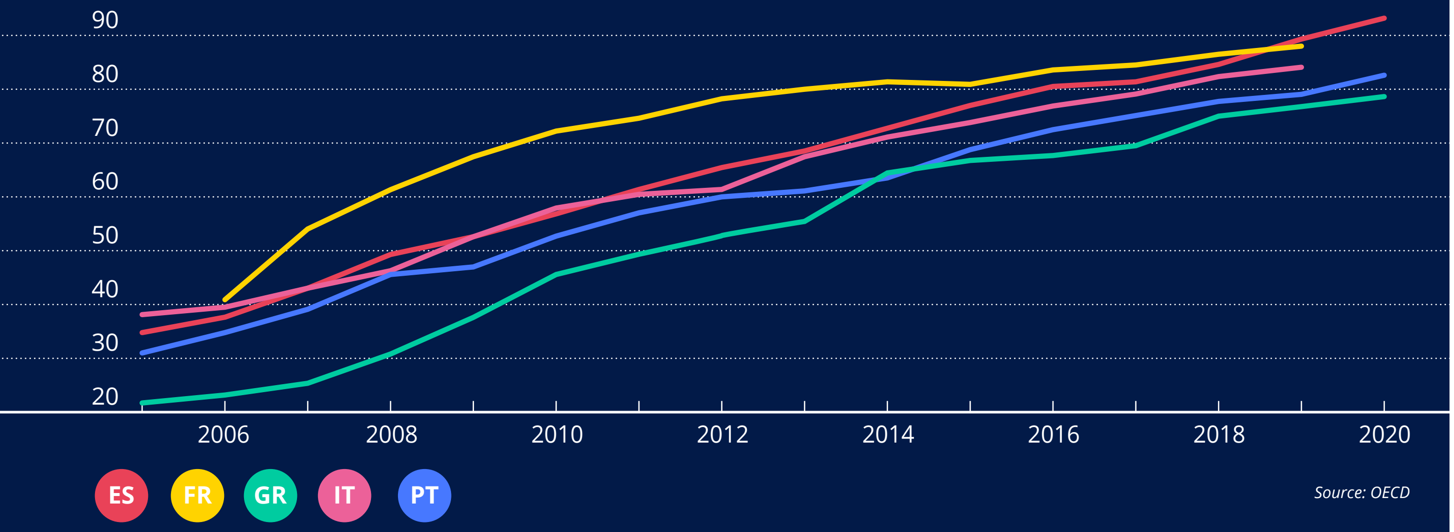
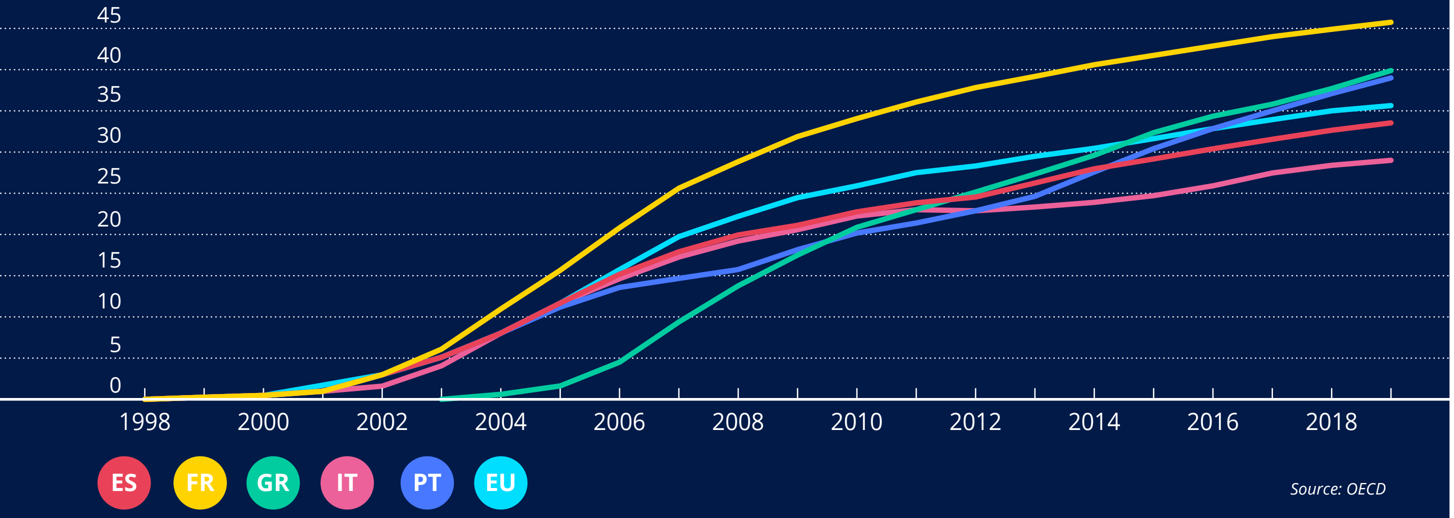


Figure 7:
Fixed broadband subscriptions per 100 people over time



capita. In the other countries, this figure ranges from 0.9 in Italy to 0.5 in Greece, with Spain and Portugal falling in between, each with 0.7 addresses per capita. This is one to two orders of magnitude more IPv4 addresses per capita than we've seen in some other countries in the RIPE NCC's service region, and can likely be attributed to the early Internet development that took place in Mediterranean Europe compared to many other parts of the world.

With such high address-to-population ratios throughout the region, first-rate connectivity coverage should be possible for these countries' populations. Indeed, this is what we see in figure 6. Although Portugal and Greece do have some of the lower Internet access rates in the EU, these percentages are still very high on a global scale, and we see that all five countries continue to improve connectivity.

Interestingly, rates for broadband subscriptions don't follow the same pattern. While Spain scores highest on Internet access, Greece and Portugal have higher rates of broadband subscriptions per capita than Spain (or Italy). This is probably explained, at least in part, by the fact that Spain and Italy have the most mobile subscriptions per capita, suggesting that people in those countries rely more on their mobile devices for Internet connectivity than fixed broadband subscriptions.

Figure 8:
Mobile subscriptions per 100 people over time

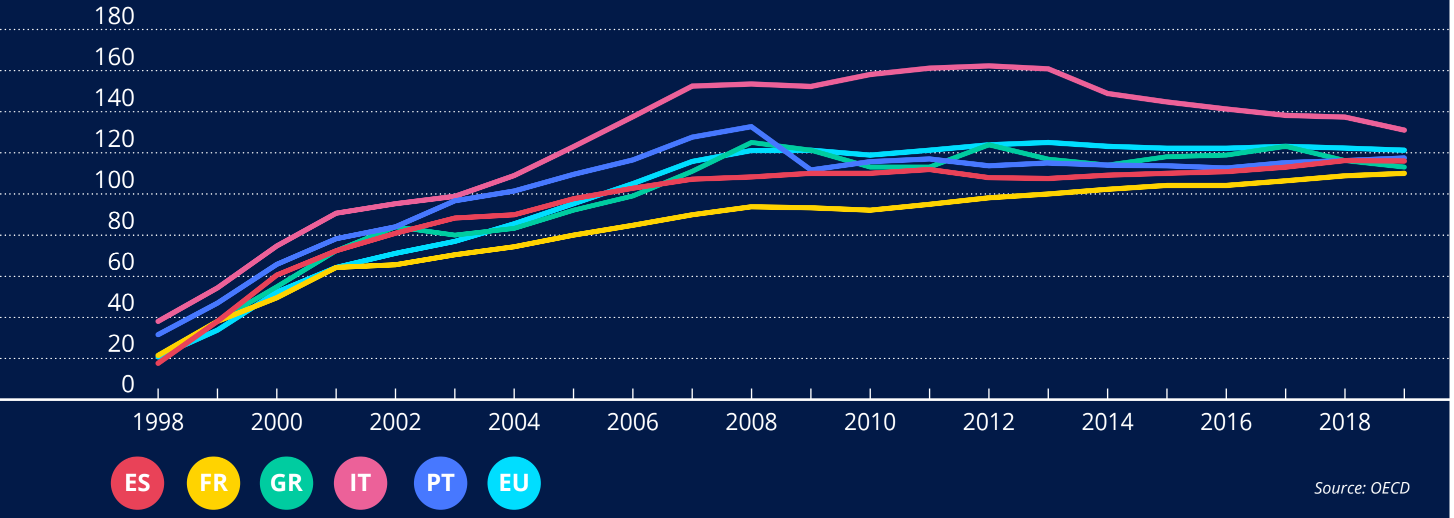
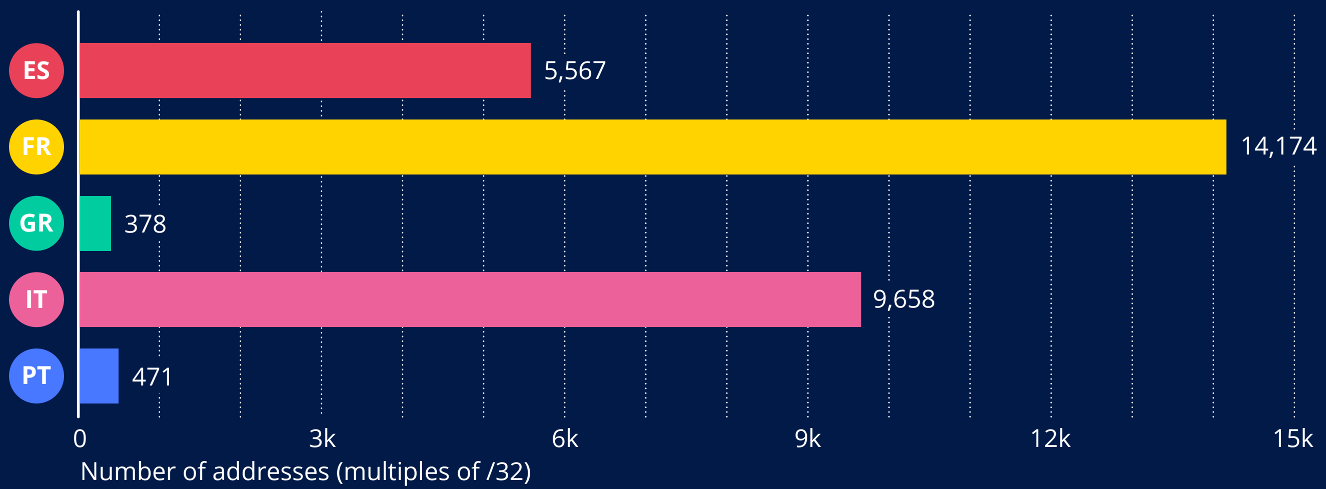


Figure 9:
IPv6 holdings



In particular, Italy's notably larger number of mobile subscriptions might be at least partially attributed to its inexpensive mobile broadband prices (as previously mentioned). All five countries have high mobile subscription rates, averaging more than one per person, even though most fall on the lower end of the EU average. We do see a slight decline in Italy in recent years, possibly signalling market saturation. We also see Portugal stand out in terms of broadband growth over the past 7-8 years. This may be due, at least in part, to a concerted effort on the part of its regulator and key operators, which have invested in shared infrastructure in a joint effort to expand coverage.[5]

Although all five countries have large amounts of IPv4 address space, the high rates of mobile subscriptions mean that mobile operators in particular are likely relying on address-sharing techniques 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 in mobile broadband connectivity. However, there are well-documented drawbacks to address-sharing technologies, and deploying IPv6 remains the only sustainable strategy for accommodating future growth and reaching the EU's goal of equipping every European household with a 100 Mbps connection by 2025[6] – not to mention supporting emerging technologies such as 5G, the Internet of Things and more.

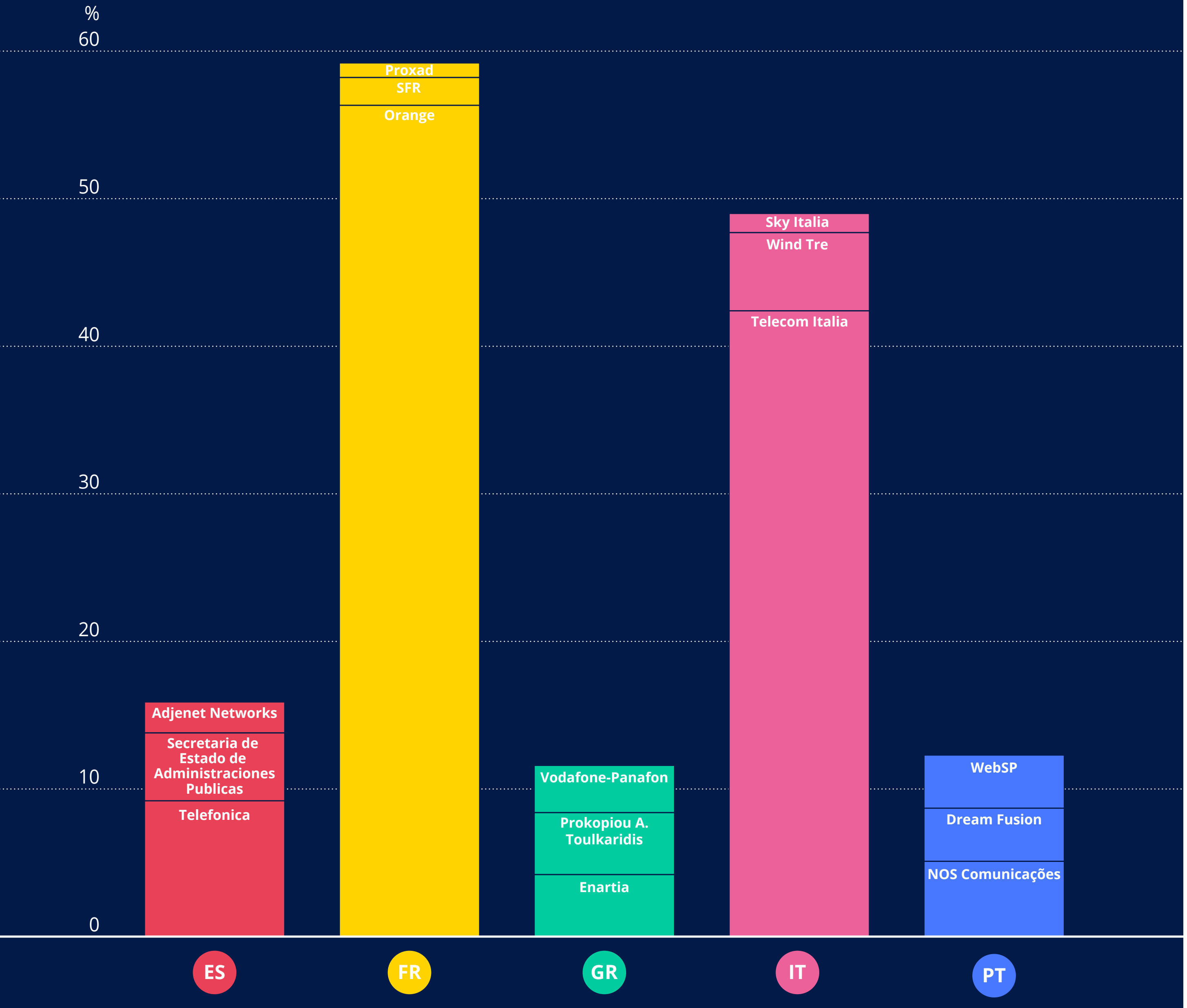
IPv6 in Mediterranean Europe

When it comes to IPv6 holdings, the five countries display a similar pattern to what we saw with IPv4. France dominates the region, followed by Italy and Spain, with Portugal and Greece holding just a fraction of the space that these larger countries have.

5 ITU background paper: Infrastructure sharing and co-deployment in Europe: good practices based on collaborative regulation

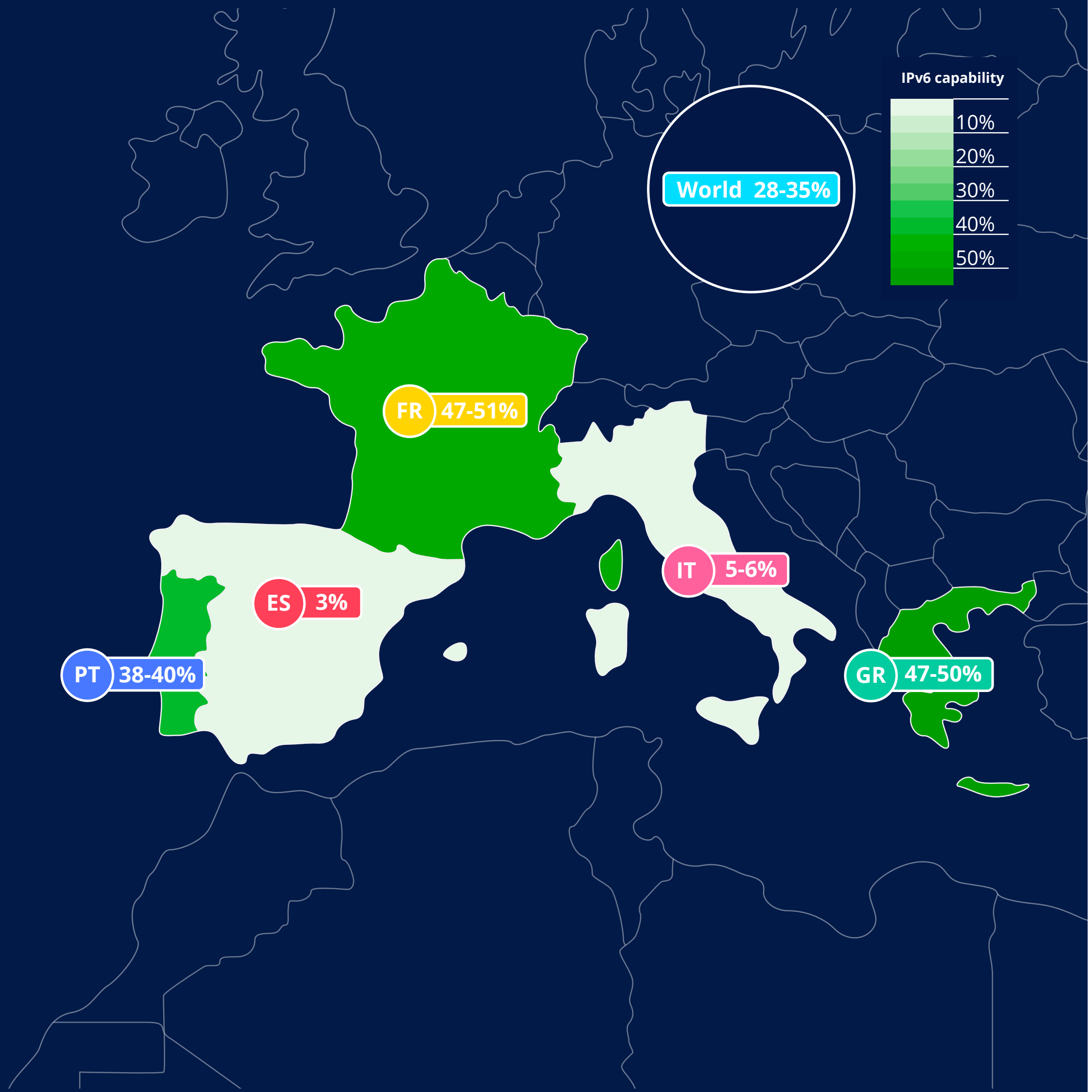
6 https://ec.europa.eu/digital-single-market/en/broadband-strategy-policy

Figure 10:
IPv6 holdings by organisation



In terms of distribution within the countries, figure 10 shows the organisations with the three largest amounts of IPv6 in each country. In both France and Italy, a single provider accounts for a large fraction (58% and 42% respectively) of the IPv6 addresses, whereas we see a much more even distribution in Portugal and Greece. Unlike IPv4, IPv6 addresses are widely available (although large allocations are based on demonstrated need), so hoarding is not a factor here. 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 have deployed IPv6 across entire networks and be able to serve their entire customer base with a relatively small allocation. This is the case with Sky Italia, for example, which holds just 1.33% of the IPv6 addresses registered in Italy, but has achieved more than 90% deployment within its network.

Figure 11:
IPv6 deployment rates



Sources: Akamai: https://www.akamai.com/us/en/resources/our-thinking/state-of-the-internet-report/state-of-the-internet-ipv6-adoption-visualization.jsp. 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.

Because larger IPv6 allocations are made according to need, we would expect to see deployment rates roughly reflect the different amounts of IPv6 address space we see in each country, yet this is definitely not the case. For example, Italy holds 68% of the amount of IPv6 address space as France, but its deployment rate is a small fraction of France's (5-6% versus 47-51% respectively). The situation is similar for Spain. (Note we include a range of data sources, as different organisations have different measurement methods that result in slightly different figures.)

In trying to better understand the situation, we look to the RIPE NCC Survey 2019,[7] which polled more than 4,000 network operators and other members of the technical community, including 674 total respondents from Portugal, Spain, France, Italy and Greece.

While only 40% of survey respondents in Portugal, France and Greece indicated that they believe their organisations will require more IPv4 in the next 2-3 years, 54% in Spain and Italy did the same (which is in line with the total average among all survey respondents of 53%). When asked about the current state of their networks' IPv6 deployment, 25% of respondents in Portugal, France and Greece said that they were fully deployed, compared to just 8% who said the same in Spain and Italy (the total average among all respondents was 22%). Additionally, 32% of respondents in Spain and Italy said they had no plans to deploy IPv6, compared to an average of 23% among all survey respondents. In looking at why respondents from Spain and Italy hadn't yet deployed IPv6, the top reasons given were a lack of business need or requirement, a lack of knowledge or expertise, and a lack of time. However, in addition to the 8% of respondents in Spain and Italy who said they were fully deployed, another 47% said they either had a plan, were currently testing IPv6 or had just started deployment, so perhaps we will see improvement in IPv6 deployment in these countries in the years ahead.

Governments, regulators, Internet exchange points (IXPs) and local network operator groups (NOGs) all have a role to play in IPv6 deployment. In France, for example, the telecommunications regulator, Arcep, has been active in pushing IPv6 deployment, launching an IPv6 task force in 2019 and publishing regulator reports on uptake. In Greece, where we also see a high level of IPv6 deployment, GR-IX, the country's main IXP, has also been very active in encouraging its members to deploy IPv6, and the local technical community, through GRNOG, is extremely active in supporting the country's network operators in their own IPv6 deployments. These factors can contribute significantly to a country's overall Internet development and the ability to transition to the next generation protocol.

7 RIPE NCC Survey 2019: https://www.ripe.net/survey

2. Domestic and International Connectivity

Domestic Connectivity Between Networks

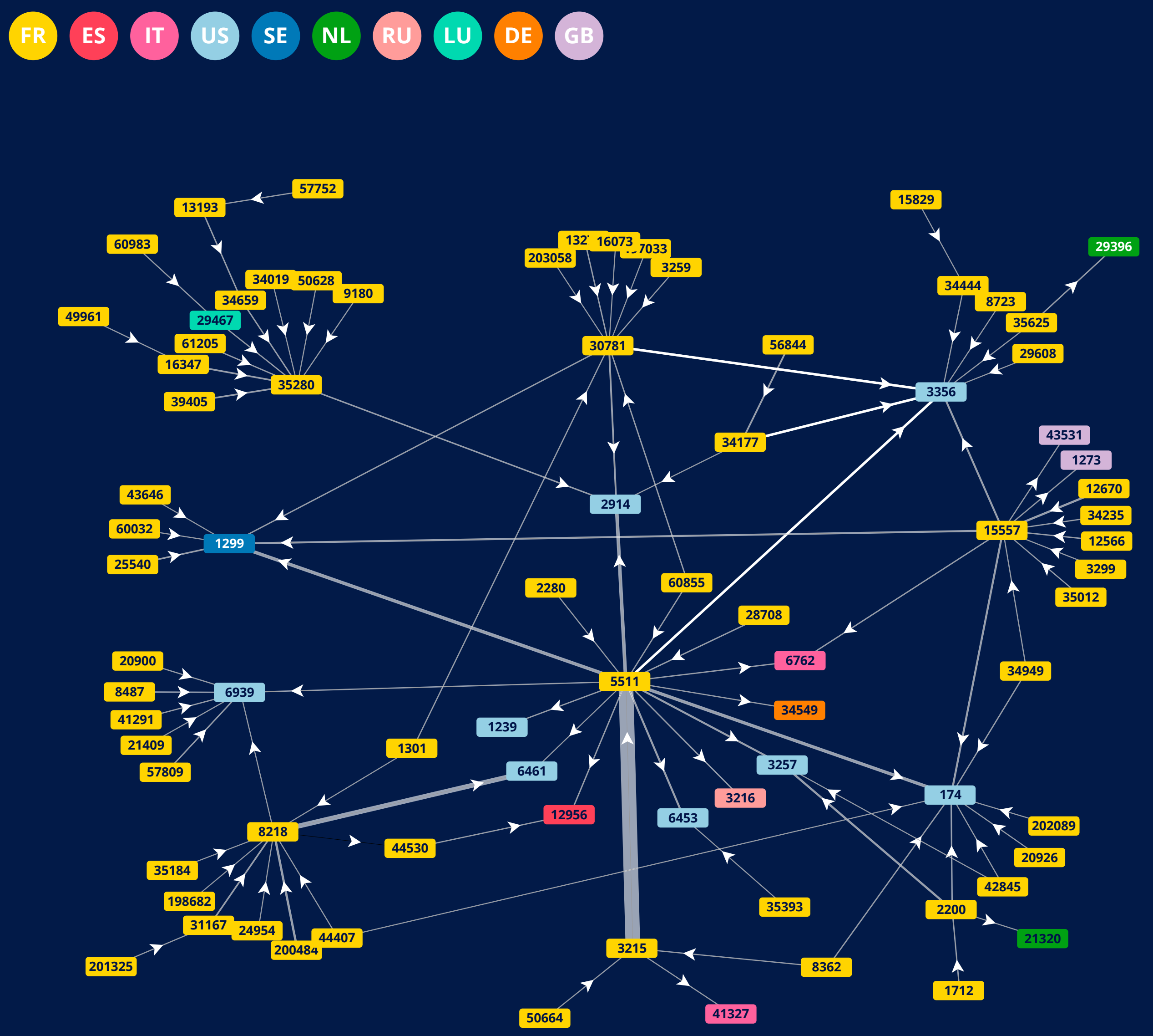
To understand the relationships that exist between different networks, we can investigate the interconnections within each of the countries using data from the RIPE NCC's Routing Information Service (RIS), which employs a globally distributed set of route collectors to collect and store Internet routing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

For each country, we plot how the routes propagate from one network to another (arrows indicate the direction of BGP flow, 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 in each figure are colour-coded according to the country where 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 the position of the different networks doesn't correspond to any kind of geographical layout; instead, these figures are merely a visual representation of the interconnections between the networks in each country.

Due to the nature of Border Gateway Protocol (BGP) and the 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.

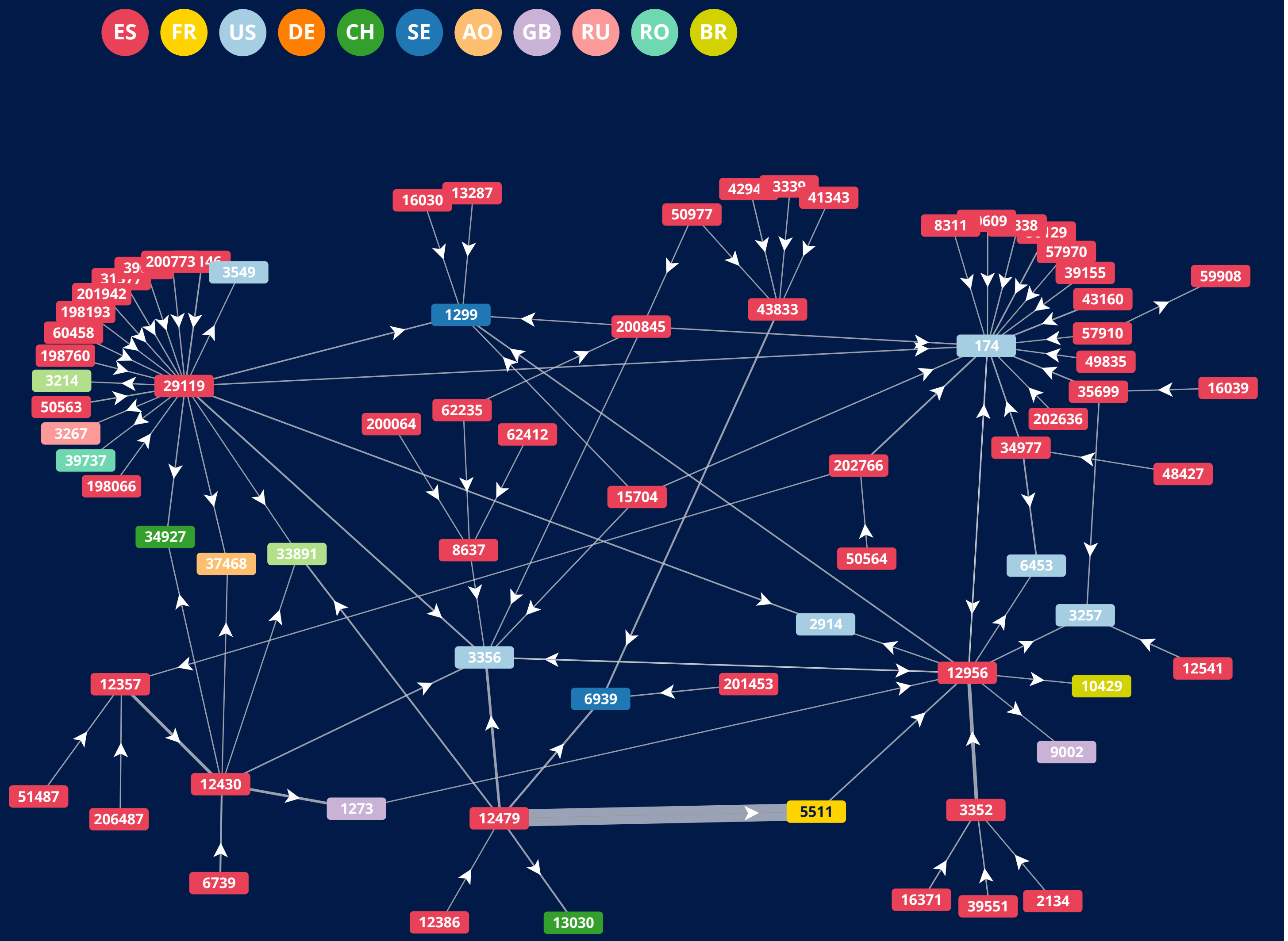
With more than a thousand ASNs registered in Spain, France and Italy, and one to two hundred in Portugal and Greece, it is unfortunately not possible to visualise all the connections between each network in these countries. To get a picture of high-level patterns, however, we restricted the following figures to include the top 100 most frequently observed segments in the BGP paths.

Figure 12:
Connectivity between networks in France



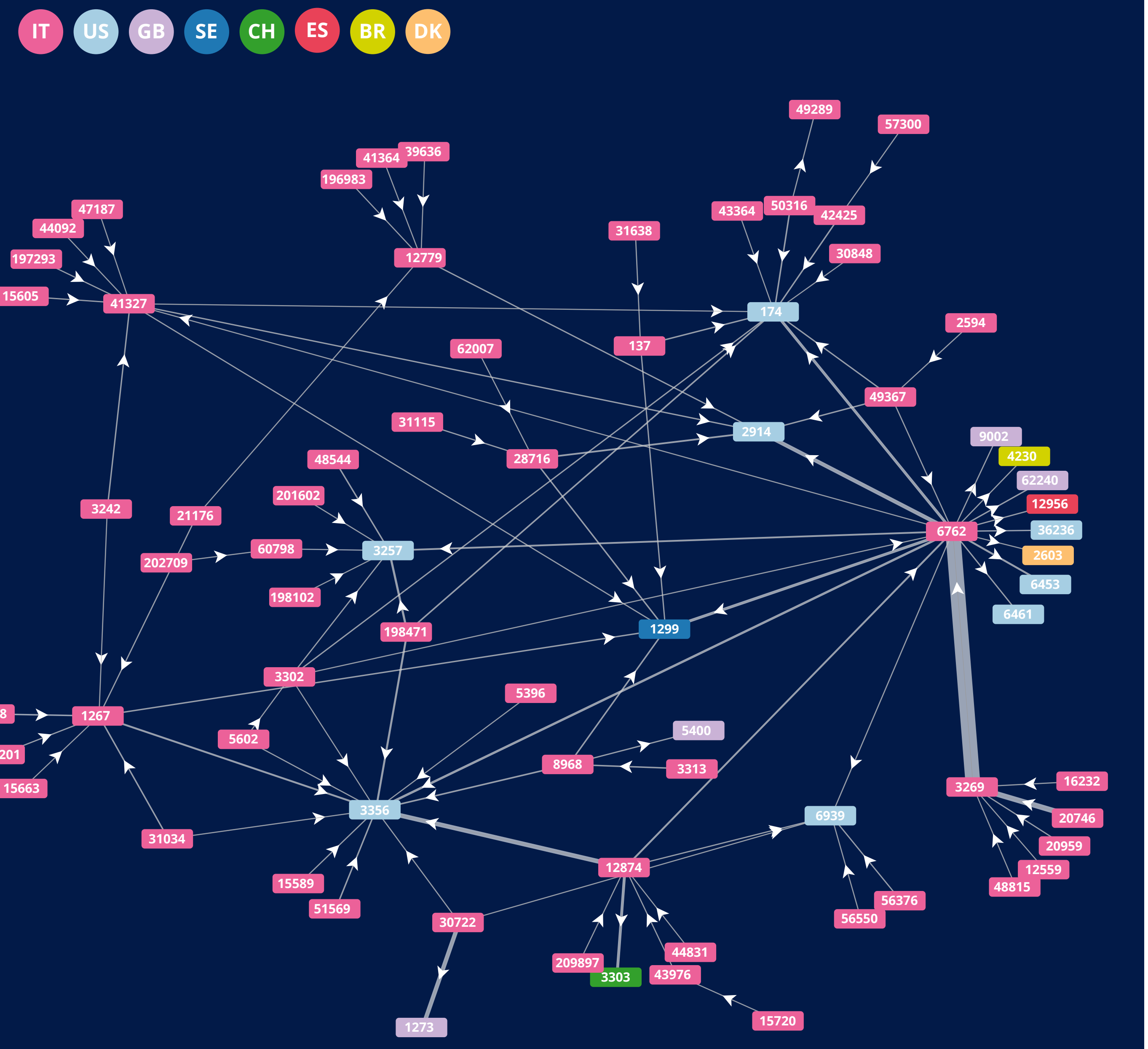
In France, we can see nine clusters around various networks, indicating the significant role they play in the country's domestic connectivity by connecting a number of other networks to the rest of the Internet. Five of these are registered to French organisations: Acorus (AS35280), Jaguar Network SAS (AS30781), Zayo France (AS8218), SFR (AS15557) and OpenTransit (AS5511). The other four are international providers with headquarters outside of France: Telia (AS1299), Hurricane Electric (AS6939), Level3 (AS3356) and Cogent (AS174). We can also clearly see how Orange's domestic network (AS3215), relies on OpenTransit – Orange's international backbone – for its main connectivity.

Figure 13:
Connectivity between networks in Spain



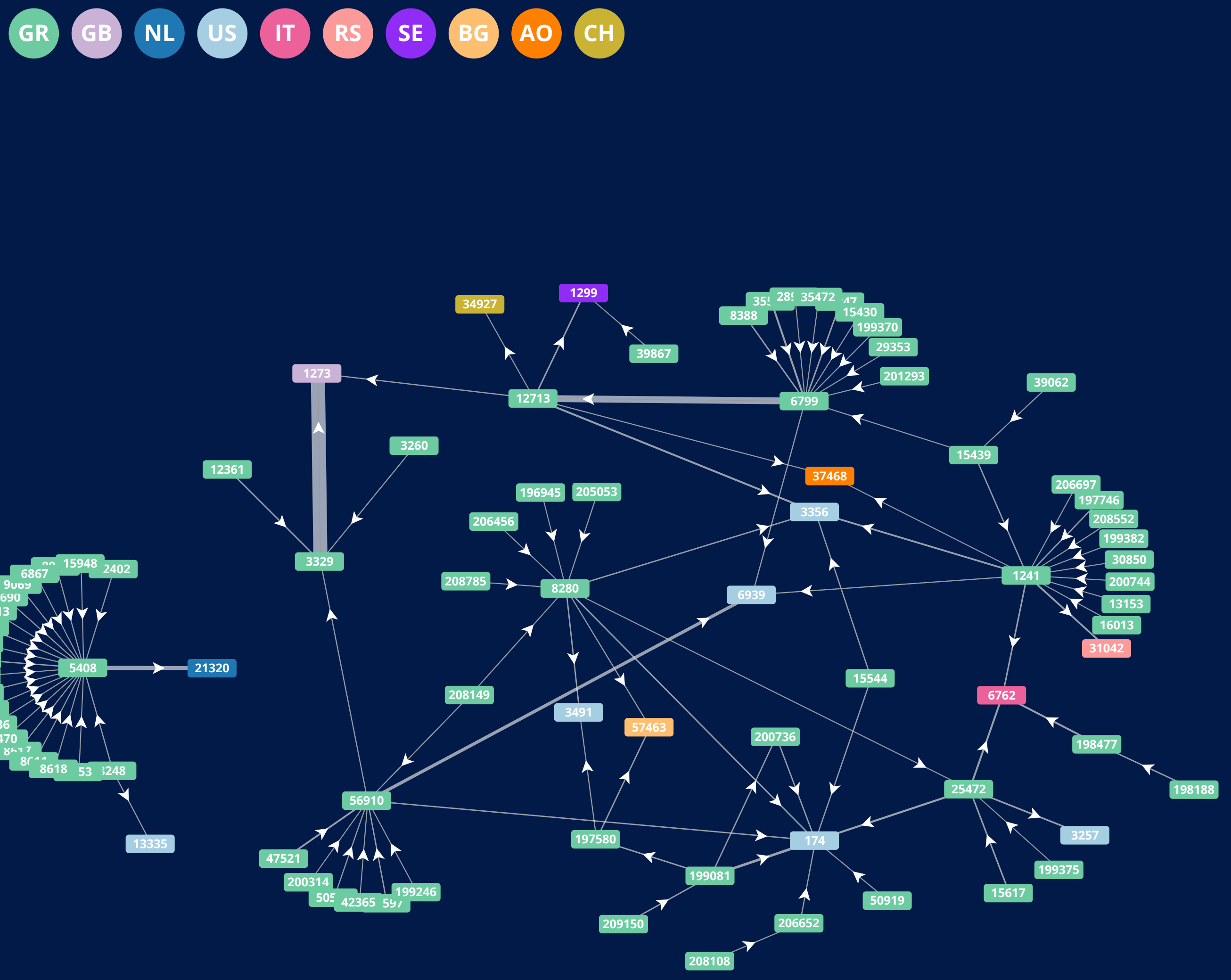
Spain's domestic connectivity is dominated by two networks: ServiHosting Networks (AS29119) and US-based Cogent (AS174). Many of Spain's networks receive connectivity via these providers. We also notice less prominent but still important clusters around Vodafone España (AS12430), Producmedia (AS43833) and Telefónica Global Solutions (AS12956), which is the upstream for Telefónica de España (AS3352) and the networks that it serves. Similar to the situation in France, we can also see how Orange España (AS12479) predominantly relies on OpenTransit (AS5511) for its international connectivity.

Figure 14:
Connectivity between networks in Italy



In Italy, we see Telecom Italia Sparkle (AS6762) serving many international connections. This network is also the main upstream provider for Telecom Italia's domestic network (AS3269). Smaller clusters around international operators Level3 (AS3356), GTT (AS3257), Cogent (AS174), NTT (AS2914), Telia (AS1299) and Hurricane Electric (6939) also stand out, in addition to Italian networks Wind (AS1267), Fiber Telecom (AS41327), IT.Gate (AS12779) and Fastweb (AS12874).

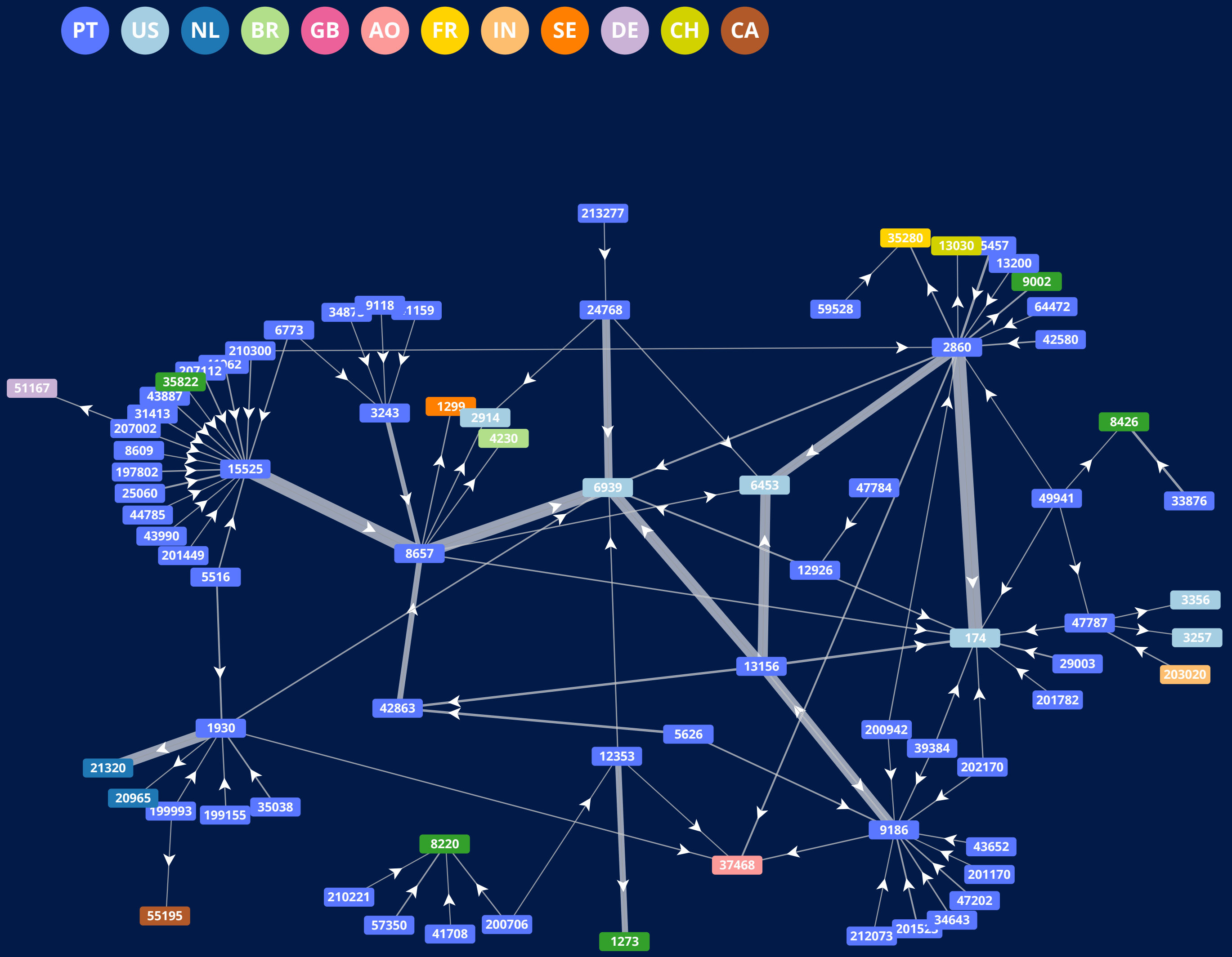
Figure 15:
Connectivity between networks in Greece



The role of GRNET, the national research and education network (NREN), stands out in Greece, where we see how GRNET (AS5408) connects many academic networks to the outside world via GÉANT (AS21320), the European research network that is based in the Netherlands.

We also see clusters around Forthnet (AS1241), OTE (AS6799) and Lambda Hellix (AS56910). Lambda Hellix gets connectivity from Hurricane Electric (AS6939) and Vodafone-Panafon (AS3329), which in turn relies on Vodafone GlobalNet (AS1273) for external connectivity. Also noteworthy is the cluster around Cogent (AS174), which is seen as a direct upstream provider for several Greek networks.

Figure 16:
Connectivity between networks in Portugal



In Portugal, the prominent position of Hurricane Electric (AS6939) also stands out. The network connects a substantial fraction of Portugal's networks to the rest of the Internet, both directly and indirectly, with most of the indirect connections passing through MEO Internacional (AS8657) and NOWO Communications (AS13156). MEO Internacional, in turn, is the exclusive upstream for other parts of MEO: MEO Residencial (AS3243), MEO Empresas (AS15525) and MEO Movel (AS42863). This illustrates how a single organisation can use multiple ASNs to structure its networks.

Other major players in connecting Portugal to the rest of the Internet include: NOS Comunicações (AS2860), with Cogent (AS174) and Tata Communications (AS6453) as primary upstreams; ONI Telecom (AS9186), receiving transit from NOWO Communications (AS13156); and RCCN (AS1930), the NREN which primarily relies on GÉANT (AS21320) for external connectivity, though some paths are also seen via Hurricane Electric (AS6939). Finally, we see how Cogent (AS174) provides transit not only to NOS Comunicações (AS2860) and its customers, but also directly to other Portugese networks.

A visualisation of Internet connectivity, like we see in these figures, should resemble a deeply interconnected web, with a large distribution of paths and interconnections that lack clear choke points or bottlenecks. Indeed, all five countries included in this report display a high level of interconnectivity among their domestic networks, indicating a mature, developed local landscape that provides a good level of redundancy and resiliency.

Figure 17:
France's international connectivity

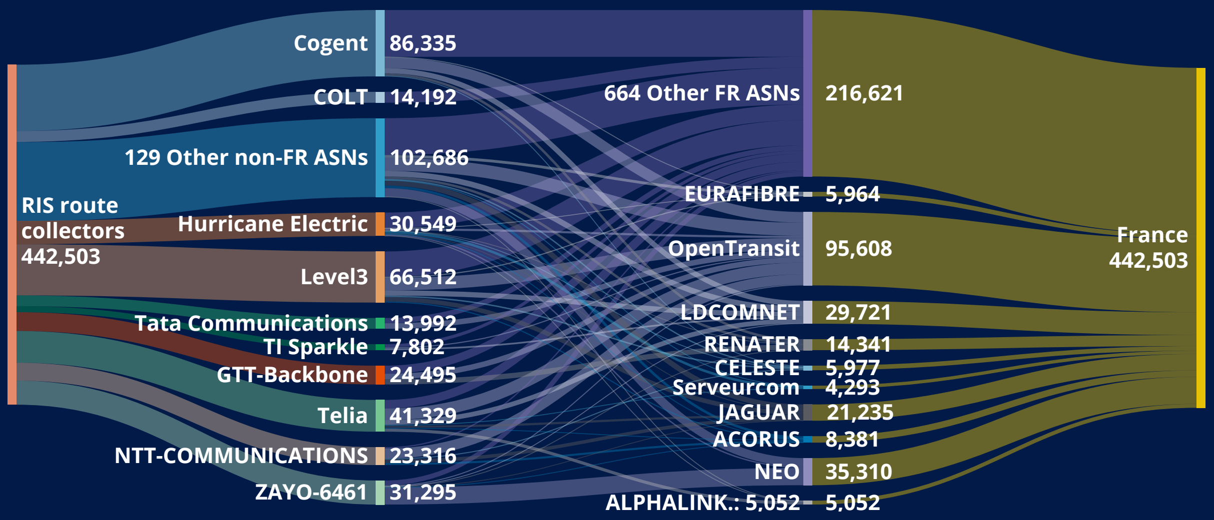
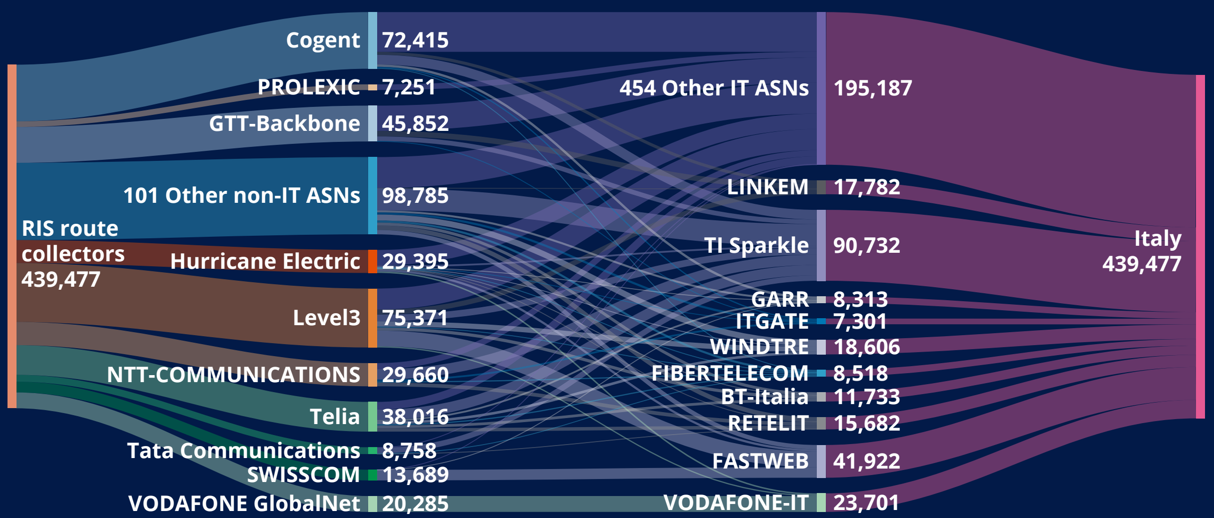


Figure 18:
Italy's international connectivity



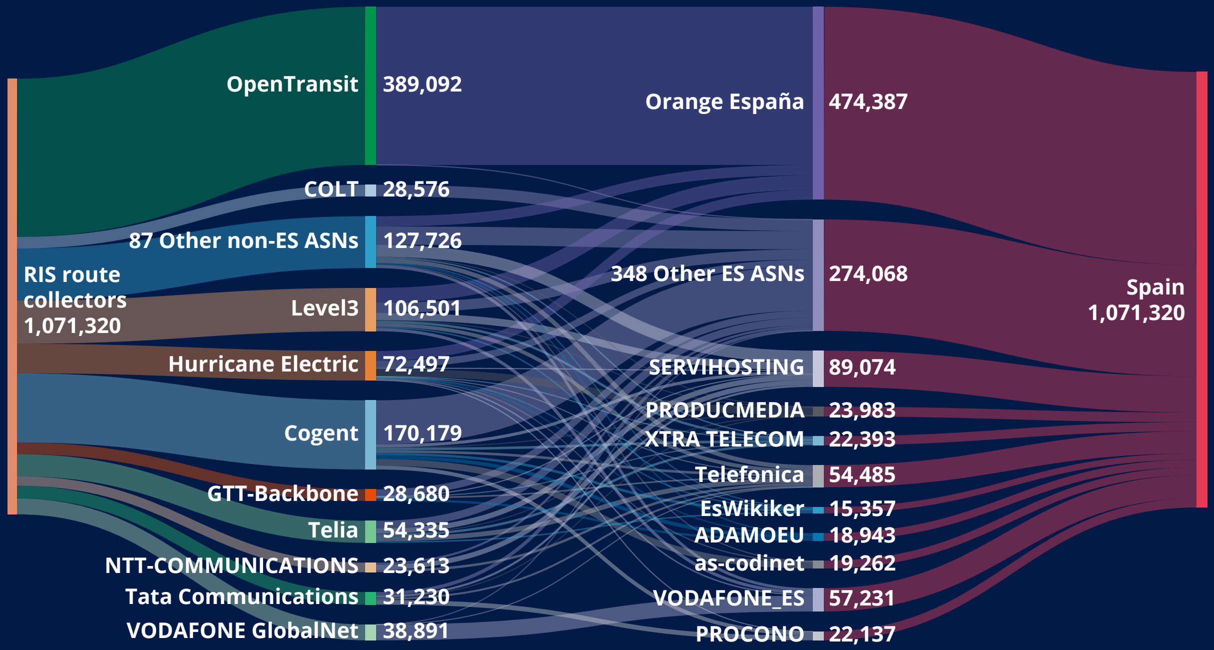
International Connectivity

Extending our view, we now look beyond domestic connectivity to examine how Mediterranean Europe connects to the rest of the world. To investigate this, we again turn to the RIPE NCC's Routing Information Service (RIS). We look at the routes collected by RIS for IP networks in each country and identify the last foreign and first domestic network encountered in these paths. This gives us an overview of which operators provide international connectivity into each country.

In France, we see OpenTransit, Orange's international backbone, in a large number of the paths connecting to French networks. However, we also see how large international players like Cogent, Level3, Telia and others directly serve hundreds of other French networks without going through the incumbent or a handful of large domestic providers. This is a sign of an open and competitive market.

Italy shows a similar pattern, with many different networks being served by different upstream providers, and a diverse choice of large upstream providers serving Italy's domestic networks directly.

Figure 19:
Spain's international connectivity



In Spain, international connectivity is dominated by the connection from Orange España via OpenTransit (Orange's backbone). However, while the relationship between the two is clear, the relative size is not representative of the real market share. The oversized representation in figure 19 is probably caused by Orange España announcing its address space in smaller fragments, creating a larger number of prefixes in the routing table and, therefore, more paths – despite the fact that Telefónica holds more announced IPv4 address space than Orange España does.

Figure 20:
Portugal's international connectivity

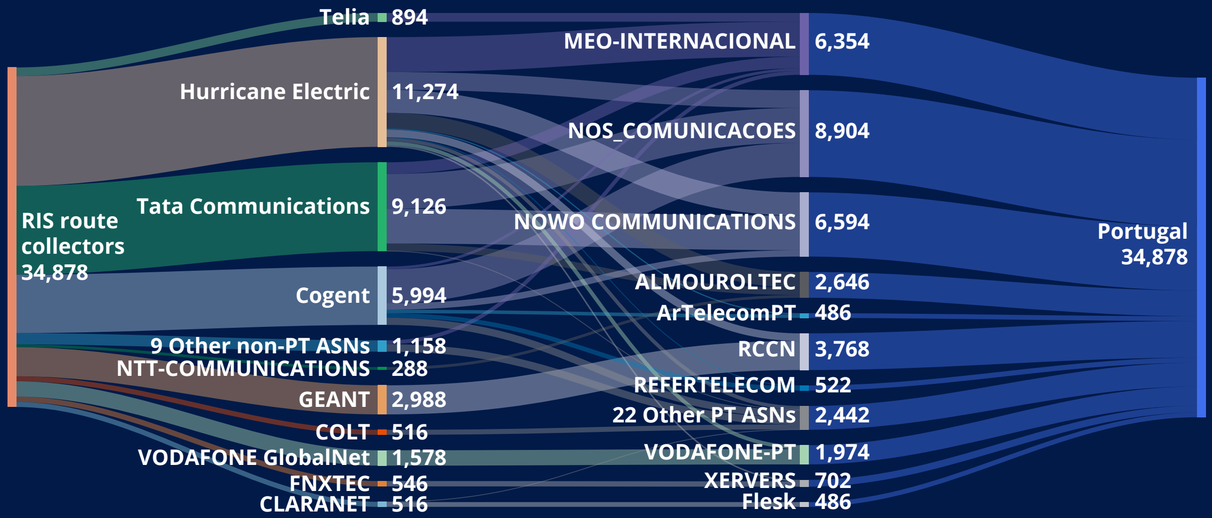
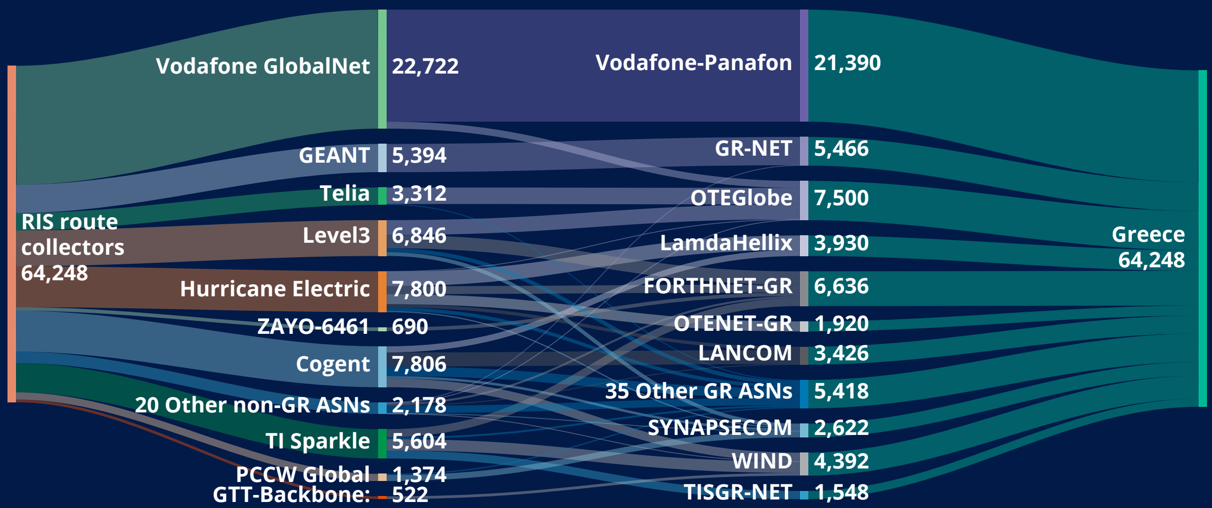


Figure 21:
Greece's international connectivity



In Portugal and Greece, the situation is different. As noted earlier, these countries have an order of magnitude fewer networks than the three larger countries. As a result, the main providers in Portugal and Greece play a role in a much larger fraction of the routing paths into and out of the country. In Greece, we see another case of Vodafone-Panafon being overrepresented in terms of its actual market share, as it simply has a larger number of announced prefixes, even though OTE has more total address space. While Vodafone GlobalNet is the only upstream provider for Vodafone-Panafon, the former likely has diverse peerings with other major networks. Depending on where the traffic handoff takes place between "local" and "global" Vodafone (i.e. how distant this is from the domestic network), this may still provide resilient connections to the global Internet.

In general, the higher the number of different available route paths we see into and out of a country, the better. This is because relying on a small number of dominant domestic providers to provide the vast majority of the connections into and out of a country creates the potential for bottlenecks and single points of failure, negatively impacting that country's Internet stability, regardless of how many upstream connections they have. In Mediterranean Europe, the visualisations of the countries' international connectivity paint a positive picture. In France, Spain and Italy we see an especially high level of diversity in international connections. While this is slightly less robust in Portugal and Greece, the interconnection environment is still relatively developed and diverse in these two countries.

3. 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 the region, we first examine which local instances of K-root are queried from requests originating in the different countries.

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.

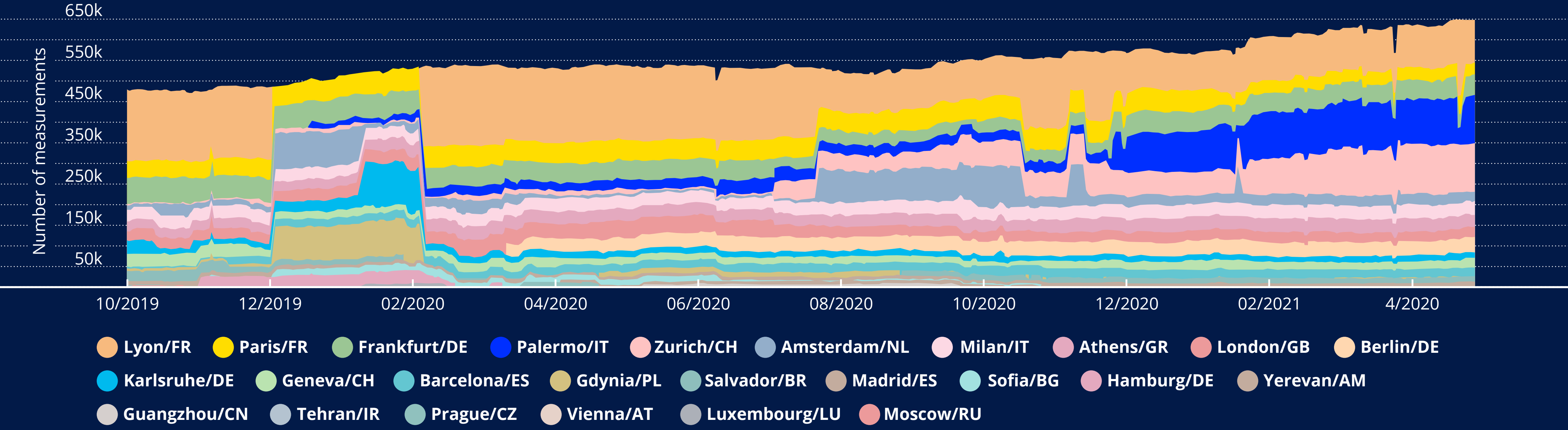
These measurements are based on the RIPE NCC's RIPE Atlas measurement platform, which employs a global network of probes to measure Internet connectivity and reachability (see the section on RIPE Atlas at the end of the report for more information about how to get involved). Note that K-root is just one of the world's 13 root name servers, and every domain name system (DNS) client will make its own decisions about which particular root name server to use. In cases where response times to K-root would be relatively slow, it is highly likely that clients would opt for faster alternatives among the other root name servers.

Even so, confining our measurements to look only at K-root and the choices that different RIPE Atlas probes in the region make about which K-root instance to query provides some insight into how the routing system considers the various options and decides which networks and locations will provide the best results.

Border Gateway Protocol and Anycast

The K-root name server, like many other DNS servers, uses a technique called anycast whereby each individual instance of K-root is independently connected to the Internet via a local Internet exchange point or any number of upstream networks available at its location. Each instance communicates using the Border Gateway Protocol (BGP), which is designed to select the best path out of all the available options. Initially, the most important criterion here is path length, and the system will choose the path with the lowest number of intermediary networks. However, network operators can override the BGP decision-making process, often for reasons relating to costs or ownership. It is not uncommon for networks to prefer routes that may be longer but are less expensive due to peering arrangements via an Internet exchange point or a parent company.

Figure 22:
K-root locations reached from within Mediterranean Europe (IPv4)

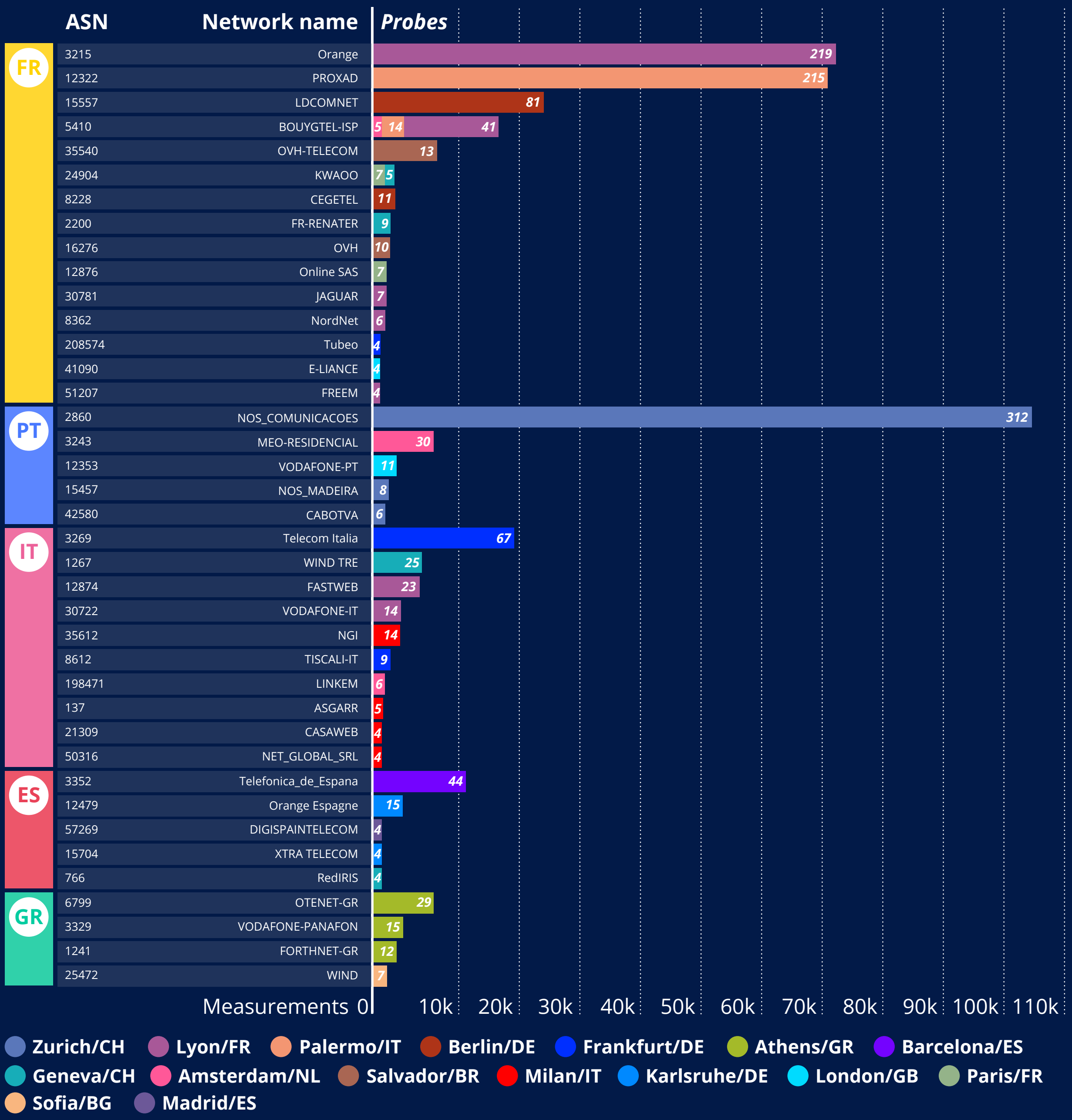


There are eight K-root instances hosted in this region, in Madrid, Barcelona, Lyon, Paris, Prato (just outside of Florence), Milan, Palermo and Athens. Figure 22 shows which K-root instances were reached by RIPE Atlas probes in the five countries in Mediterranean Europe from October 2019 until May 2021. Of the top 10 instances reached, half were located in the region, while the other half were located slightly farther afield but still within Europe, including Frankfurt, Amsterdam, London, Zurich and Berlin. We see seven of the eight K-root instances in the region being reached overall, with the exception of the instance in Prato, Italy. A small number of queries reached K-root instances as far away as Brazil, Armenia, China and Iran – all of which are suboptimal choices that will result in longer response times.

Figure 22 also showcases how dynamic the domain name system is, as we can see several changes that took place. From early December 2019 to early February 2020, the K-root instance in Lyon was unavailable as the host network was renumbered. Thanks to anycasting, this did not have an impact on the performance of the root name service, as the Border Gateway Protocol automatically found available alternatives in Amsterdam, Karlsruhe and Gdynia – all of which are close enough to maintain ideal round-trip times. Once the work was completed on the host network in Lyon, the K-root instance hosted there was re-enabled and DNS queries automatically resumed. These types of events illustrate the resiliency and flexibility of the root server system.

We also looked into which K-root instances were queried by RIPE Atlas probes in the different countries on a given day. In Portugal, which doesn't host a K-root instance, we saw the majority of probes reaching the instance in Zurich, while others reached Amsterdam, London and Geneva. The majority of probes in Spain reached the instances in Barcelona or Madrid, with a smaller number reaching Karlsruhe in Germany. In France, we saw more probes reaching the K-root instance in Lyon than any other instance; interestingly, however, far more probes reached the instance in Palermo than the one located in Paris. About half the probes in Italy reached instances in Milan or Palermo, but the majority of the remainder were sent to Frankfurt, with a smaller number reaching

Figure 23:
K-root locations reached from different networks throughout Mediterranean Europe (IPv4)



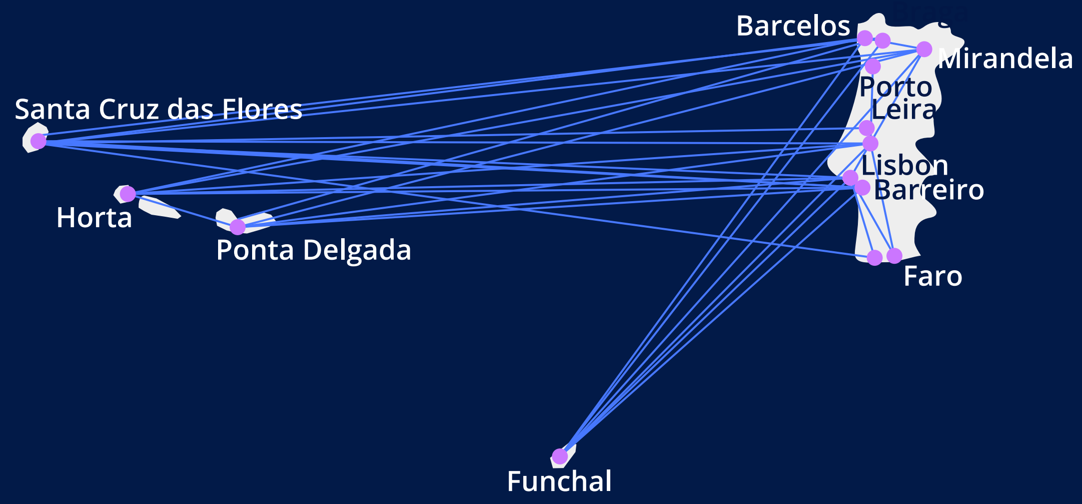
Geneva and Amsterdam. Finally, we saw the best optimisation in Greece, where the vast majority of probes reached the K-root instance in Athens. In general, the round-trip times throughout the region were reasonable, with a few exceptions of probes in France reaching an instance in Salvador, Brazil that resulted in longer response times and one case of a probe in Spain taking an unusually long time to reach an instance in Madrid, perhaps due to network congestion or suboptimal routing, although the exact reason is unknown.

We can also look at which K-root instances are queried by probes in different networks, as opposed to different countries. As we have RIPE Atlas probes in hundreds of networks in this region, a graph including every network would be illegible; as a compromise, we included networks that have at least four active probes.

Traditionally, the BGP decision-making process would ensure that once a particular path has been identified as being the best option, there is consistency across all the routers that are part of that particular network. Indeed, this is very much what we see in figure 23, where all the probes in almost every network end up querying the same K-root instance. However, there are quite a few cases in which we see networks favouring a K-root instance farther away than the closest (geographical) option, such as NOS Comunicações in Portugal favouring the K-root instance in Zurich over the instance in Madrid or Barcelona. In most cases, this is due to the peering arrangements or other relationships that exist between networks, including with their upstream providers. For example, we see the OVH Télécom network reaching a K-root instance in Salvador, Brazil, where OVH has a presence. Again, we see that Greece is particularly optimised, with all the probes reaching a K-root instance in Athens or nearby Sofia.

It's worth noting that the shortest path (from a routing perspective) for a network in Mediterranean Europe to a root name server might well be through Frankfurt or Zurich if the network peers at one of the exchanges in those locations. Smaller operators generally have less control over their routing and will be more

Figure 24:
Paths between origin and destination in Portugal (IPv4)



affected by the routing policies of their upstream providers, unless they make their own peering arrangements and individual routing decisions. For the most part, the additional distances we see here won't significantly affect response times; however, making use of local IXPs is generally preferred. It's also worth remembering that these results are for K-root only, and that DNS clients in the region are likely reaching other root name servers as well that may provide better response times.

We should also note that these results, while considered generally representative, offer only a snapshot of measurements made on a single day in May 2021. Given BGP's dynamic nature, results can change constantly due to subtle changes in routing.

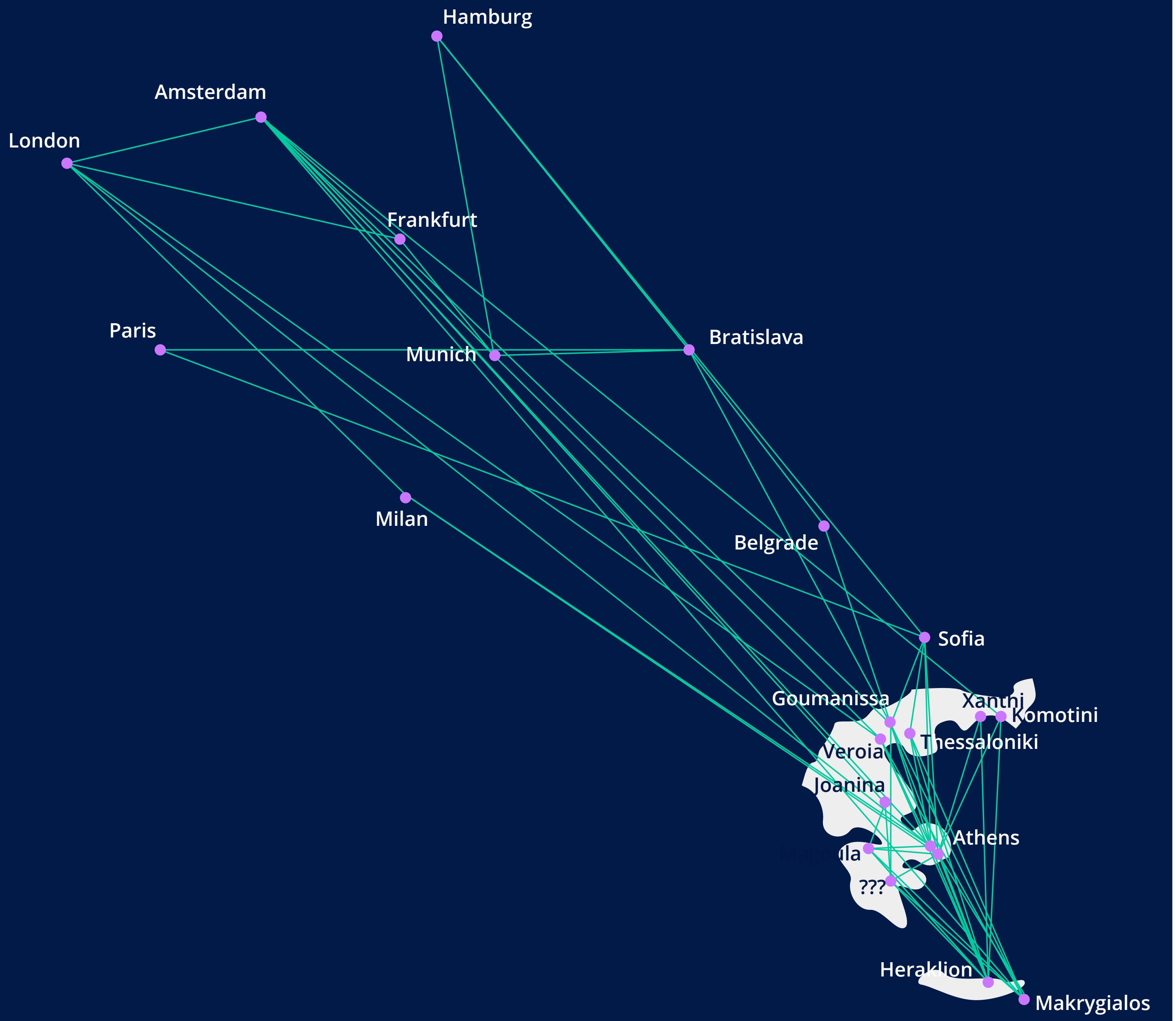
Regional Traffic Exchange

Again using data from the RIPE Atlas measurement network, we can investigate how some of the networks in the five countries exchange traffic with each other, and get some indication of where those exchanges take place. For this experiment, we performed traceroutes from each RIPE Atlas probe to every other probe in the country, for each of the five countries. Because those measurements disclose the IP addresses of the routers involved, we then used RIPE IPmap to geolocate those network resources. This gives some insight into the paths available to traffic, although it does not directly measure traffic.

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 all five countries, we see the majority of paths staying within a country's territory, and the role of local IXPs is visible. In Portugal, no foreign locations are detected. For the others, a

Figure 25:
Paths between origin and destination in Greece (IPv4)



subset of paths detour to locations outside of the country before returning to their domestic destination. Frankfurt, Amsterdam and London all host major IXPs and are understandable choices for traffic exchange, though from a performance point of view they are not necessarily the best. This is especially true for longer distances, as we see happening with local traffic in Greece that is exchanged at farther away locations, rather than relying more heavily on GR-IX, the Greek Internet Exchange.

With France, this is even more extreme. Although Paris and Marseille (both of which host major IXPs) are heavily used exchange points, some of the paths we observed are really suboptimal, extending as far away as San Francisco to the west and Kiev and Moscow to the east. This significantly increases round-trip times, although how significant this is for Internet users in France depends on the amount of traffic flowing over these paths, which is something we cannot 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 within the country.

Figure 26:
Paths between origin and destination in France (IPv4)

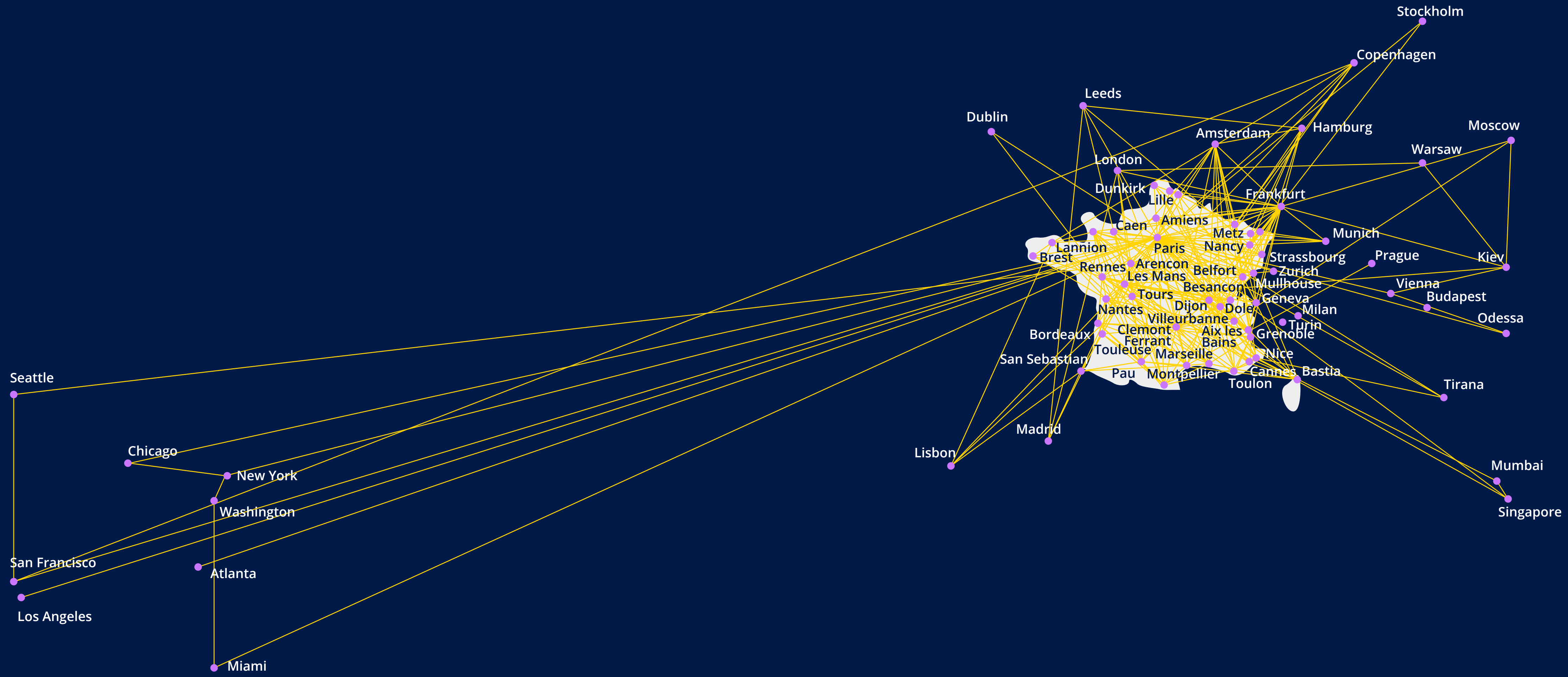


Figure 27:
Paths between origin and destination in Spain (IPv4)

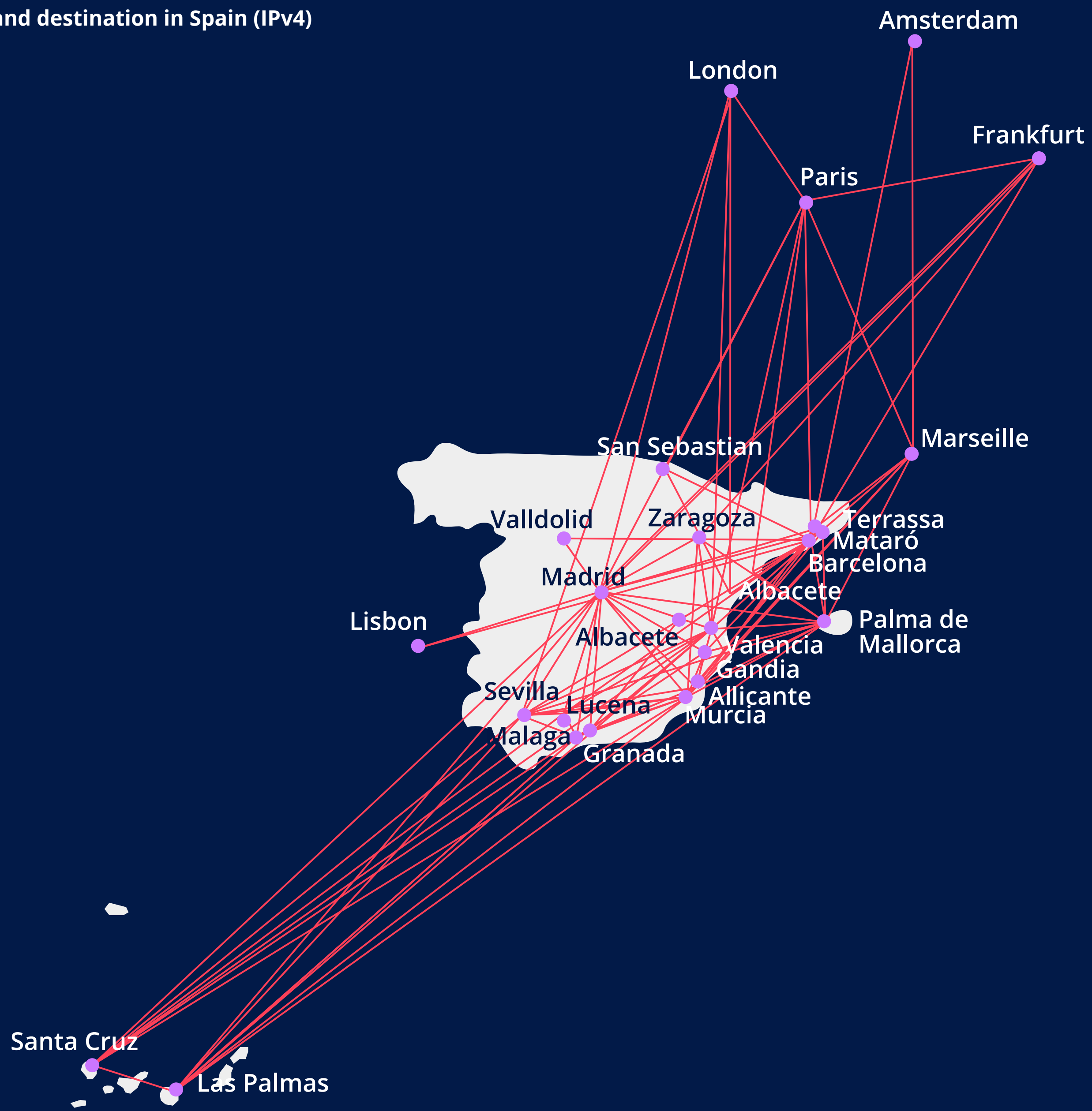


Figure 28:
Paths between origin and destination in Italy (IPv4)

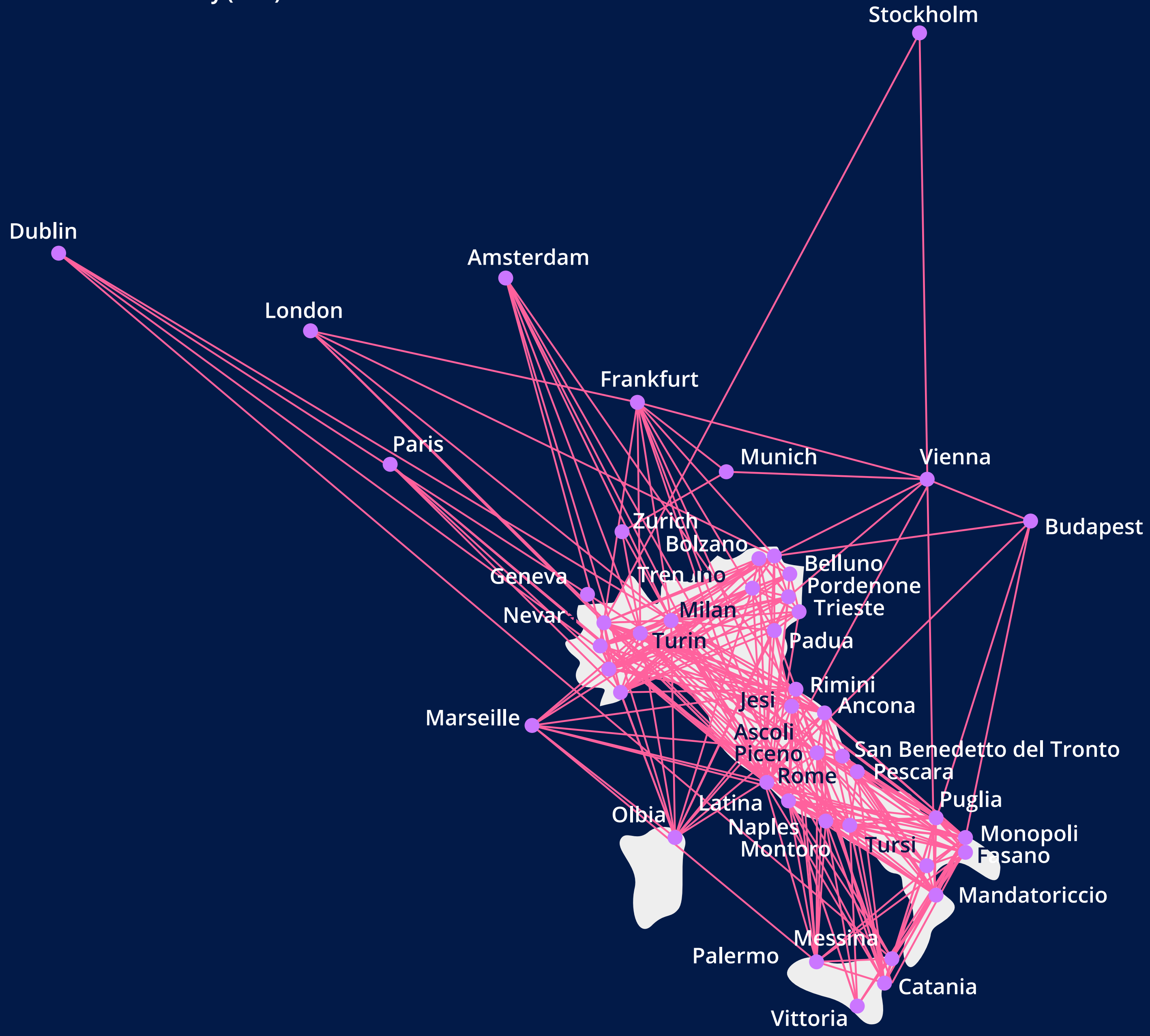
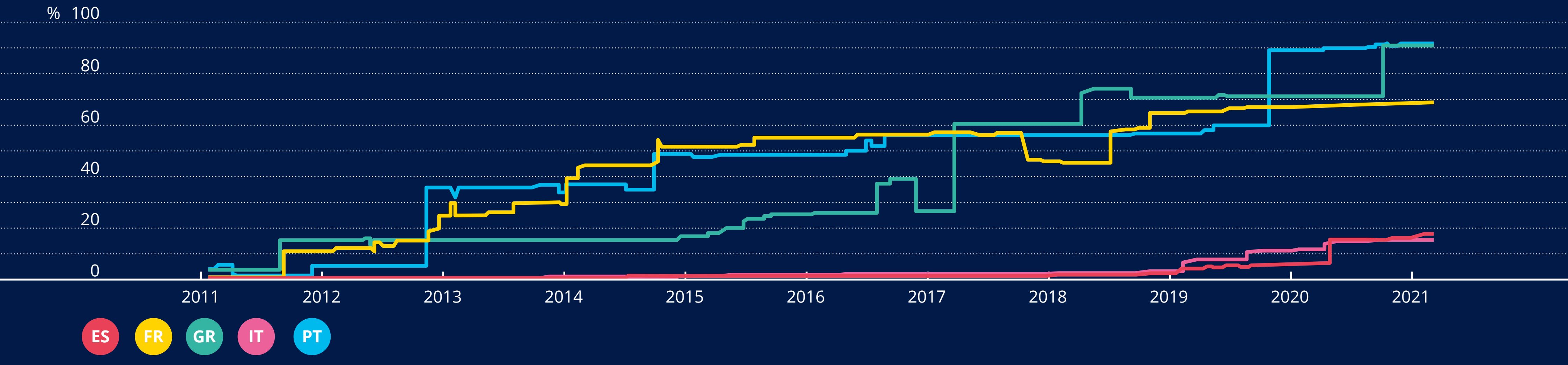


Figure 29:
IPv4 address space covered by RPKI



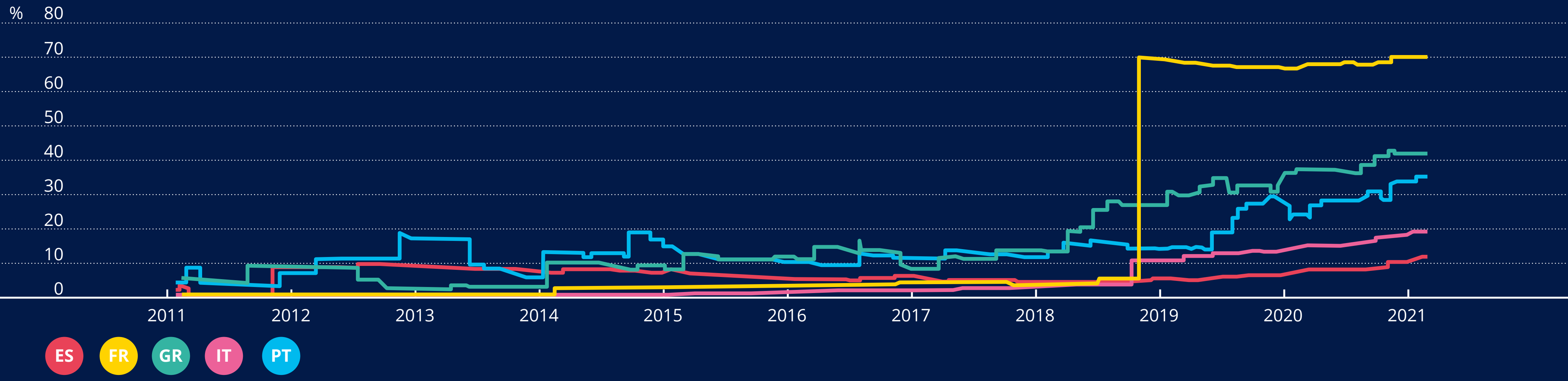
Routing Security

Beyond looking into the different routes available to traffic originating in the region, we can also investigate routing security in the five countries 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 the resource holder 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 Portugal and Greece, over 90% of the IPv4 address space registered to organisations in those countries is covered by ROAs. In the case of Greece, at least, we know that GR-IX strongly encourages its members to adopt RPKI and that most of the country's providers, even the smaller ones, are present at the IXP, which could help explain the high adoption rate we see for the country. The graph shows various sharp increases for all countries, which happen when a single, large provider adopts RPKI and creates ROAs for its address space. The latest example is Vodafone-Panafon in Greece creating ROAs, which shot the percentage up to more than 90%.

Figure 30:
IPv6 address space covered by RPKI



With IPv6 address space, the percentages covered by ROAs are significantly lower. France is the only exception, with around 70% covered – this was largely due to a single large provider, Orange, creating a ROA for its large /19 allocation of IPv6 address space.

Governments, regulators, IXPs and large service providers can all help encourage smaller players to certify their Internet number resources. They can also encourage best current operational practices around routing security in general to better safeguard the Internet and reduce the opportunity for bad actors to hijack resources and attack the routing system.

Conclusion

Mediterranean Europe has a long history of Internet development that is reflected today in the region's open, competitive markets, sophisticated infrastructure, skilled technical communities and high penetration rates. Enterprises and citizens alike have access to a wide range of digital services and largely affordable fixed broadband and mobile connectivity offered by a range of larger and smaller providers. Traffic flows between providers and through multiple exchange points – the result of regulators and operators working together and prioritising shared infrastructure and open access.

The domestic networks in each of the five countries are highly interconnected, providing a good level of resiliency and redundancy. Similarly, each country is connected to the rest of the global Internet by a large number of diverse routes into and out of the country, adding further stability and reducing the potential for disruptions or outages.

Routing is generally optimised for fast response times, although there are a number of cases where more distant exchange points seem to be favoured over domestic options, which unnecessarily increases costs, foreign dependencies and risk of disruption.

Countries in Mediterranean Europe enjoy high Internet penetration rates and large amounts of IPv4 address space. However, further IPv6 deployment will be crucial to connect the millions of remaining households that are yet to be connected as part of the EU's connectivity goals for 2025 and beyond. It will also be needed to support the roll-out of 5G and the development of IoT and other emerging technologies.

It's worth noting that all of the observations in this report are based on active paths, and we cannot know what "hidden" world of backups exists that would automatically take over in the case of any disruptions. Whatever redundancy does exist would provide the system with even more resiliency.

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 (ISPs) 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 is 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 at ways to get more RIPE Atlas probes connected and to find network operators willing to host RIS collectors. 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

External Data Sources

We would like to acknowledge Michalis Oikonomakos, Head of GR-IX and board member of Euro-IX and GRNOG, for providing background information included in this report around the Internet landscape in Greece.