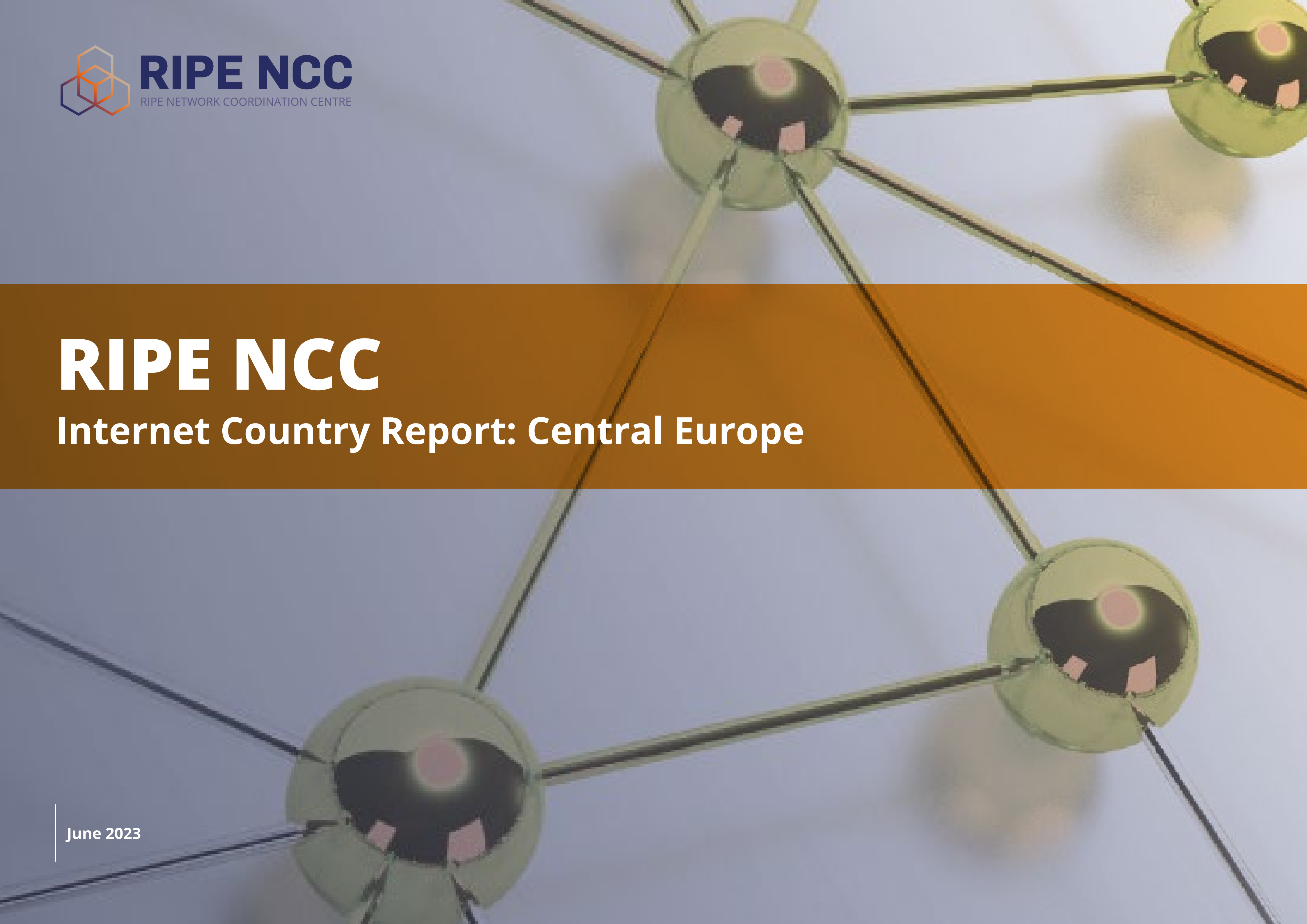

RIPE NCC
RIPE NETWORK COORDINATION CENTRE

RIPE NCC

Internet Country Report: Central Europe

June 2023

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Introduction

The Internet is a global network of networks, yet every country's relationship to it is different. In our latest country report, we provide an outlook on the current state of the Internet in four countries in Central Europe, including Czechia, Hungary, Poland and Slovakia. We offer an analysis of this region's market landscape and state of development, examine Internet routing within the region, take a close look at its 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. This analysis is based on what we can observe from the RIPE NCC's measurement tools as well as a few external data sources.

By focusing the spotlight on this part of the RIPE NCC service region, we can present a comprehensive analysis of its unique Internet ecosystem in order to inform discussion, provide technical insight, and facilitate the exchange of information and best practices. This is the 11th such country report 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 decision makers, local technical communities and policymakers.

Highlights

- The markets in these countries are well developed and competitive, with a large number of smaller providers in addition to the dominant players and incumbents
- Despite only modest amounts of IPv4 and a growing need for more addresses, IPv6 capability rates remain low in the region, with the exception of Hungary
- Access to the Domain Name System, via K-root, is very well optimised in the four countries
- International connectivity is quite resilient, with good diversity in upstream providers
- RPKI uptake, which is related to routing security, is very high in the region

The Market and Opportunity for Growth in Central Europe

The Market Landscape

Although the four countries in this report vary in terms of population, with Poland's 37.8 million dwarfing Czechia (10.5 million), Hungary (9.7 million) and Slovakia (5.5 million), they share many characteristics when it comes to their Internet landscapes, including overall level of development, challenges and opportunities for the future.

Several of the main Internet service providers are also common across the four countries. In Czechia, the main providers include O2 Czech Republic (fixed and broadband), T-Mobile Czech Republic (mobile), and Vodafone Czech Republic (fixed and mobile). In Hungary, the main providers include Magyar Telekom (fixed and mobile), Vodafone Hungary (fixed and mobile), DIGI (fixed and mobile) and Yettel Hungary (mobile). In Poland, the biggest providers by market share include Orange Polska (fixed and mobile), UPC Polska (fixed), T-Mobile Polska (mobile), Play (mobile) and Plus (mobile), which is the brand name for Polkomtel. In Slovakia, the main providers include Slovak Telekom (fixed and mobile), which used to operate under the T-Mobile and T-com brands, O2 Slovakia (mobile), Orange Slovensko (fixed and mobile), SWAN (fixed and mobile) and UPC Slovakia (fixed).

Many of the region's fixed and mobile Internet service providers are owned by large conglomerates. Deutsche Telekom owns T-Mobile Czech Republic, T-Mobile Polska and Slovak Telekom, and is the majority shareholder in Magyar Telekom.[1] PPF Telecom Group owns O2 Czech Republic and Yettel Hungary,[2] while 4iG owns both Vodafone Hungary[3] and DIGI.[4] UPC Slovakia is owned by Liberty Global, while Vodafone took over Liberty Global's operations in Czechia and Hungary in 2019, after which time UPC Czech Republic merged with Vodafone Czech Republic and UPC Hungary merged with Vodafone Hungary.[5] Liberty Global sold UPC Polska to Play, a mobile subsidiary of iliad S.A., in 2022.[6]

Despite the presence of these large multinational telecommunications companies, the four countries display open, competitive markets, with many smaller Internet Service Providers (ISPs) rounding out the market in Czechia and Poland especially. This competition may contribute to the fact that the region enjoys some of the lowest connectivity costs in Europe, as we'll examine in more detail later, and overall high Internet penetration rates. Despite this, these countries face some challenges when it comes to Internet development and reaching the EU's digital targets for 2030.[7]

The European Union's DESI (Digital Economy and Society Index) reports evaluate the EU countries' digital advancement by looking at factors including human capital, connectivity, integration of digital technology, and digital public services.

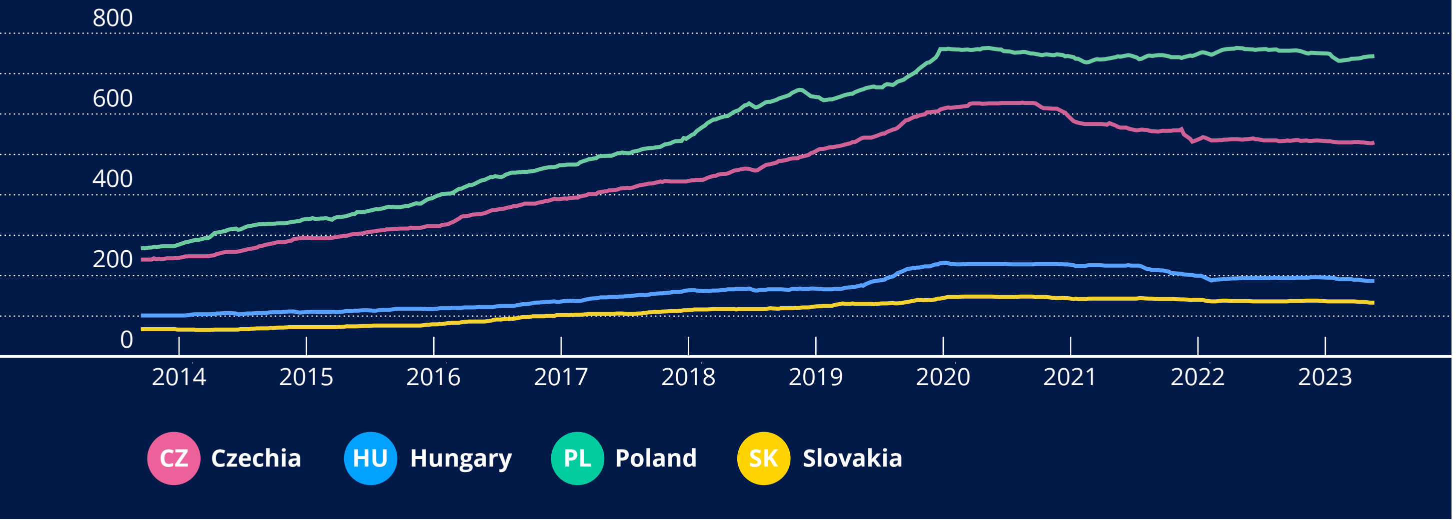
According to the 2022 DESI report, Poland ranked 24th out of 27 member states overall and 25th when it comes to connectivity.[8] However, Poland's score has been increasing at a faster pace than the EU average over the past five years, so it is making gains. Poland also ranks slightly better than the EU average when it comes to fixed broadband take-up of at least 100 Mbps and fibre-to-the-premise (FTTP) coverage, and significantly better than the EU average in the broadband price index. The areas in which it significantly lags are at least 1 Gbps take-up, 5G spectrum assignment and coverage and, to a lesser extent, overall fixed broadband take-up. With a geographically large country and 40% of the population living in rural areas, Poland struggles with rural access and the ability to attract infrastructure investment.

Czechia ranked 19th overall in the 2022 DESI report and 17th when it comes to connectivity.[9] However, Czechia ranks above the EU average when it comes to overall fixed broadband take-up, fast broadband coverage and 5G spectrum assignment. It also ranked 22nd in 2021, suggesting that it is making significant gains in digital development. Although its very high capacity network (VHCN) coverage is below the EU average of 70%, it substantially increased this percentage in just one year, from 33% in 2021 to 52% in 2022. It significantly lags behind the EU average in fast broadband (100 Mbps and 1 Gbps take-up), FTTP and 5G coverage.

Hungary ranked 22nd overall in the 2022 DESI report, yet 13th in connectivity.[10] It ranked above the EU average in every connectivity category except for 5G coverage (where it was well below the EU average of 66%, at only 18%) as well as mobile broadband take-up and broadband price index, both of which were just slightly below the average. In particular, it was well above the EU average in at least 100 Mbps fixed broadband take-up, at least 1 Gbps take-up, and FTTP coverage. In nearly every connectivity category,

1 https://report.telekom.com/annual-report-2021/notes/summary-of-accounting-policies/principal-subsidiaries.html
2 https://www.ppf.eu/en/our-companies/ppf-telecom-group
3 https://www.4ig.hu/vodafone-hungary-in-domestic-ownership
4 https://www.4ig.hu/new-chapter-in-the-telecommunications-market
5 https://en.wikipedia.org/wiki/UPC_Broadband
6 https://www.libertyglobal.com/liberty-global-and-iliad-complete-sale-of-upc-poland/
7 https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/europes-digital-decade-digital-targets-2030_en
8 https://ec.europa.eu/newsroom/dae/redirection/document/88719
9 https://ec.europa.eu/newsroom/dae/redirection/document/88698
10 https://ec.europa.eu/newsroom/dae/redirection/document/88704

Figure 1:
Number of Local Internet Registries over time



the country made significant gains between 2021 and 2022, but particularly in VHCN coverage. The country plans to use the European Regional Development Fund to support the deployment of broadband infrastructure in its rural areas.

Slovakia ranked 23rd overall and 21st in connectivity in the 2022 DESI report.[11] However, it scored slightly higher than the EU average in overall fixed broadband take-up and significantly higher in FTTP coverage, 5G spectrum assignment and broadband price index. The areas in which it significantly lagged behind the EU average include fast broadband and 5G coverage. Although there is a significant urban-rural divide in Slovakia when it comes to FTTP coverage, the country has been making gains in this area. With a relatively high percentage of 5G spectrum having been assigned and yet quite low coverage, further investment is also needed in building out the country's 5G infrastructure.

Fibre is the dominant fixed broadband connection in Hungary, Poland and Slovakia, while there are more DSL connections in Czechia.[12] While three of the four countries in this report are landlocked, Poland is connected via one submarine cable to Denmark, with another connecting Poland, Denmark and Sweden.[13] In terms of Internet speeds, the four countries are fairly average, with Hungary's fixed speeds ranking the highest of the four, at 20th place globally.[14]

Number of Providers and Other Organisations Running Their Own Networks

As the Regional Internet Registry for Europe, the Middle East and parts of Central Asia, the RIPE NCC can track the development of the local Internet over time by looking at the growth in the number of RIPE NCC members and Local Internet Registries (LIRs). In general, a higher number of LIRs often signals a more diversified market, with a larger number of service providers operating their own networks; however, this is not always the case.

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. As a result, an increase in the number of LIRs doesn't necessarily translate into an increase in the number of Internet access providers. However, it has allowed more organisations to exert more control over their Internet address resources and the ways in which they route their traffic.

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).

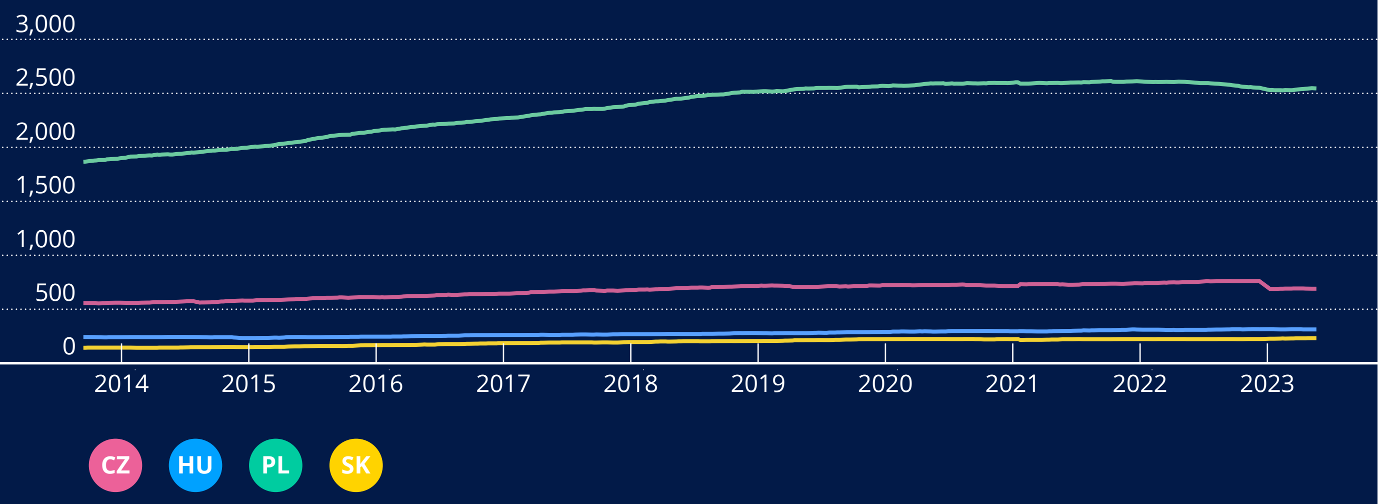
RIPE NCC Members and Local Internet Registries

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 service region of Europe, the Middle East and parts of Central Asia. The RIPE NCC distributes Internet address space to these members, who may further assign IP addresses to their own end users.

As seen in figure 1, all four countries show significant and steady growth in the number of LIRs until sometime around 2020, with Poland and Czechia displaying the fastest growth rate and Slovakia and Hungary experiencing more growth starting around 2016. Overall, Czechia has a higher number

11 https://ec.europa.eu/newsroom/dae/redirection/document/88712
12 https://www.oecd.org/digital/broadband/broadband-statistics-update.htm
13 https://www.submarinecablemap.com/
14 https://www.speedtest.net/global-index

Figure 2:
Number of networks over time



of LIRs relative to its population than the other countries, which may suggest a particularly diversified market – or possibly a wider range of different types of organisations running their own networks. Around 2020, we see the number of independent LIRs peak and then either plateau, as with Poland and Slovakia, or even decrease, as with Czechia and Hungary. This decline is something we've seen in other countries we've looked at in our reports, and is generally explained by IPv4 run-out and the consolidation or closure of multiple LIR accounts held by the same member that were originally opened in order to receive final /22 IPv4 allocations. In the case of Czechia, however, we also see a significantly smaller number of members in 2023 than we did in 2020.

Network Growth and Diversity

In general, a larger number of LIRs 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 resilience. The RIPE NCC is responsible for the allocation of ASNs in its service region. This provides us unique insight into the distribution and deployment of these networks across the Internet.

In figure 2, we can see more significant growth in the number of networks in Poland compared to the other three countries, although that growth also plateaued around 2020 and then declined slightly at the end of 2022. (Note that the sharp decrease we see for Czechia in December 2022 is purely administrative in nature; the RIPE NCC updated the records for these and other sponsored resources to reflect where the ASN holder is located, rather than the sponsoring LIR. With Czechia, about 70 ASNs "moved" out of the county without any actual change in the organisation that holds these ASNs. For the other countries, the changes were minimal.) Relative to their populations, Poland and Czechia are very similar in terms of the number of networks, while Slovakia and Hungary have much lower numbers, even relative to their smaller sizes. We see a slight decline in the number of networks in Poland in late 2022, which may have been the result of LIR accounts closing, as most of the ASNs were returned or reclaimed. The fact that we don't see the increase in LIRs from 2019 to 2022 reflected in an increase in networks adds further weight to the conclusion that multiple LIRs that were opened by the same member in order to receive a final /22 IPv4 allocation and were subsequently closed contributed significantly to the dynamics we see playing out here.

IPv4 in Central Europe

Until 2012, RIPE NCC members could receive larger blocks 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).

Figure 3:
IPv4 holdings

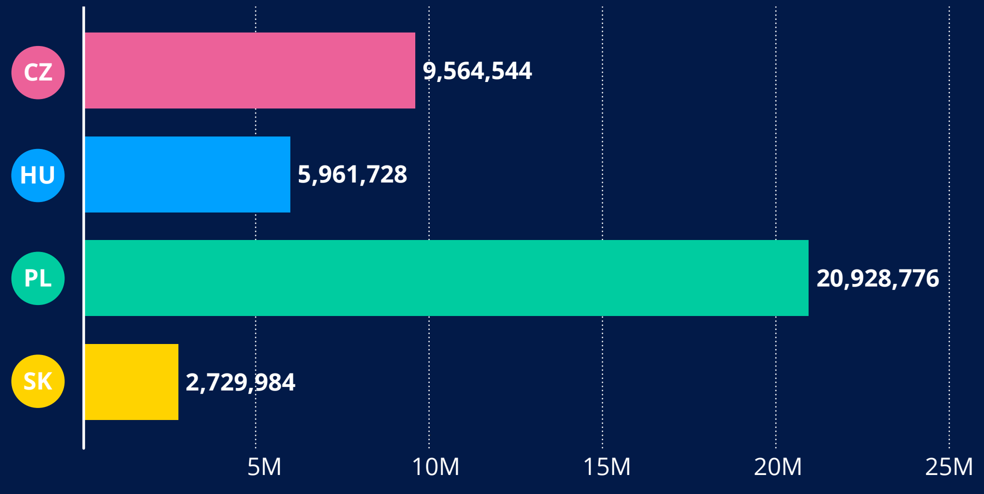
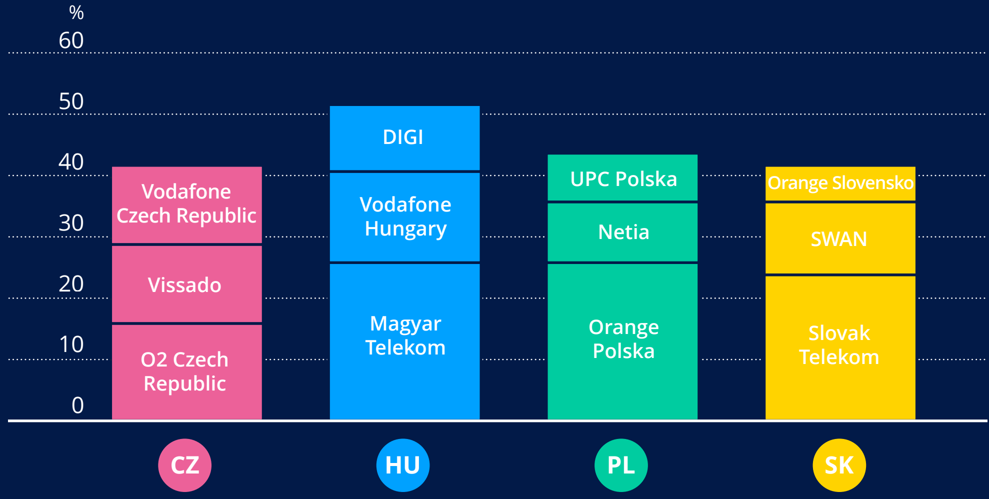


Figure 4:
Top 3 IPv4 holders



In figure 3, we show the current IPv4 address space held by each of the four countries, none of which have accrued significant amounts since the policy change in 2012. Poland's dominance is to be expected, given its much larger population, although Czechia actually has more IPv4 per capita (at 0.9 addresses per person) than Poland (0.6 per person), Hungary (0.6 per person) or Slovakia (0.5 per person). These figures are similar to other countries we've looked at in Europe (although we did see unusually high per capita figures in the Nordic region). Before the policy change in 2012, all four countries steadily increased their IPv4 holdings; between 2005 and 2012, they all saw increases of between 200-300%, indicating steady development over a sustained period of time.

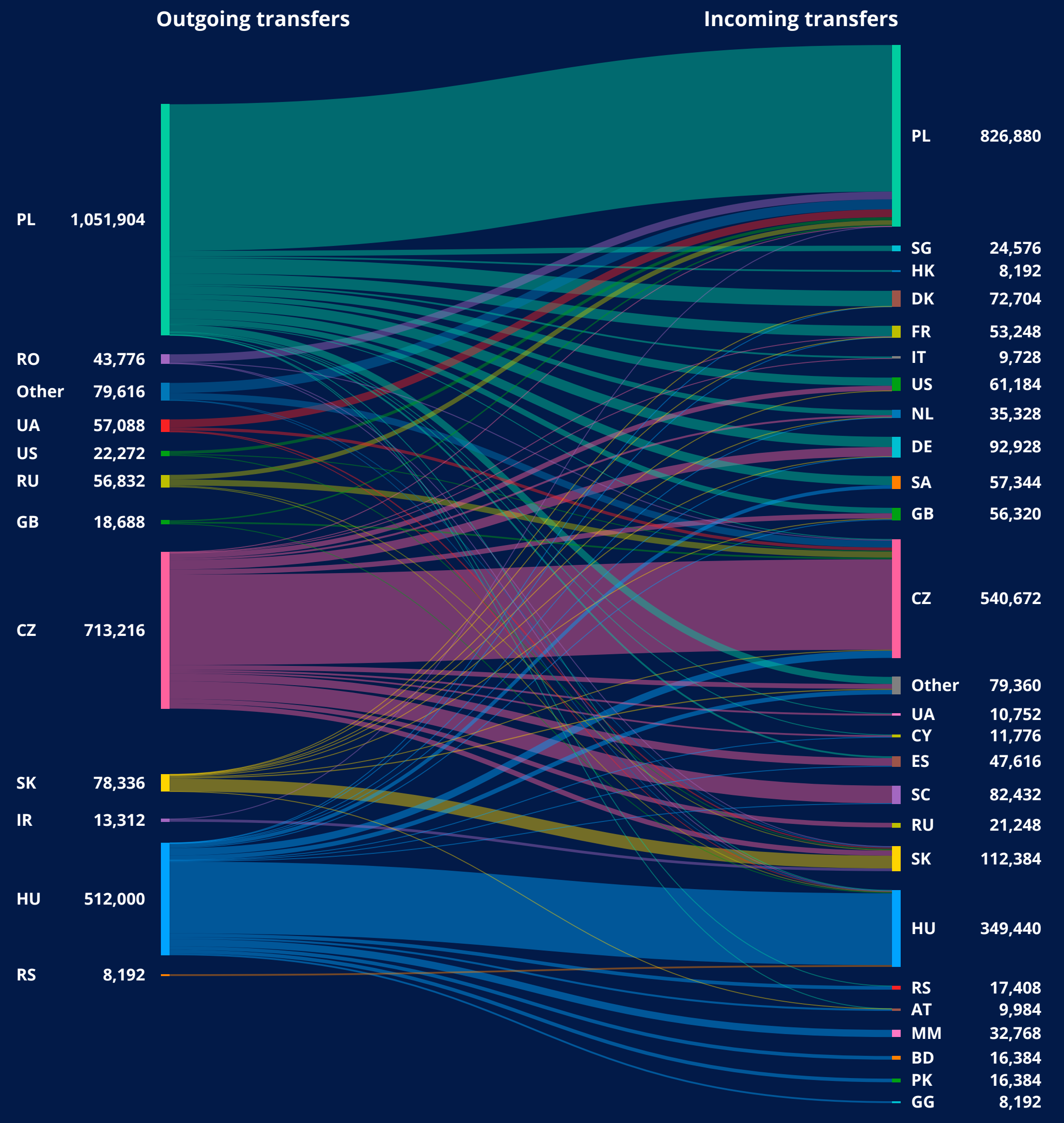
As seen in figure 4, there are quite low levels of consolidation in terms of the amount of IPv4 address space held by different companies in each of the four countries compared to many of the regions we've looked at. This is again suggestive that the markets in this region are diversified, with many smaller players offering Internet services. Apart from the main providers already mentioned, Vissado – a reseller that assigns IPv4 blocks from the RIPE NCC to smaller organisations – holds a significant portion of Czechia's IPv4 address space. In Poland, we see Netia – another large telecommunications company, which operates the second-largest fixed-line network in the country – as a significant IPv4 holder.

IPv4 Secondary Market

To fill the demand for more IPv4 address space, a secondary market has arisen in recent years, with IPv4 space being bought and sold by 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.

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. Note that these figures do not include resources that were obviously transferred as the result of mergers or acquisitions, or between related companies. For example, we see various transfers from UPC Polska to UPC Romania, from UPC Czech Republic to Liberty Global, and from Liberty Global to UPC Polska. These transfers may be related to Liberty Global's sale of the Czech, Hungarian and Polish UPC operations. They are not, however, considered transactions on the secondary market, as networks moved ownership with the customers. We also aggregate countries from or to which fewer than a /19 of IPv4 address space (8,192 addresses) were transferred into the category "other".

Figure 5:
IPv4 transfers within, into and out of Central Europe between October 2012 and April 2023



We can see that Poland, Czechia and Hungary have all been quite active in the IPv4 secondary market, while Slovakia has played a much less significant role. While Poland, Czechia and Hungary have all exported more addresses than they've imported, for a net loss, Slovakia has imported more than it's exported, for a net gain. In each of the four countries, we see domestic transfers – whereby addresses are transferred between two different entities within the same country – make up the majority of transfers. If we exclude the domestic transfers from the figures, we see that Czechia has exported more than two times the amount of IPv4 address space than it's imported, Poland has exported nearly two-and-a-half times the amount, and Hungary has exported more than eight times the amount than it's imported.

Looking at which organisations are responsible for the largest transfers, the top five organisations that were the biggest net importers of IPv4 address space via the secondary market across the four countries, and the number of addresses imported, include:

- Nej.cz (Czechia): 51,200
- Giganet (Hungary): 41,984
- OPC Networks (Hungary): 41,984
- Tarr (Hungary): 41,472
- Suntel Net (Czechia): 39,936

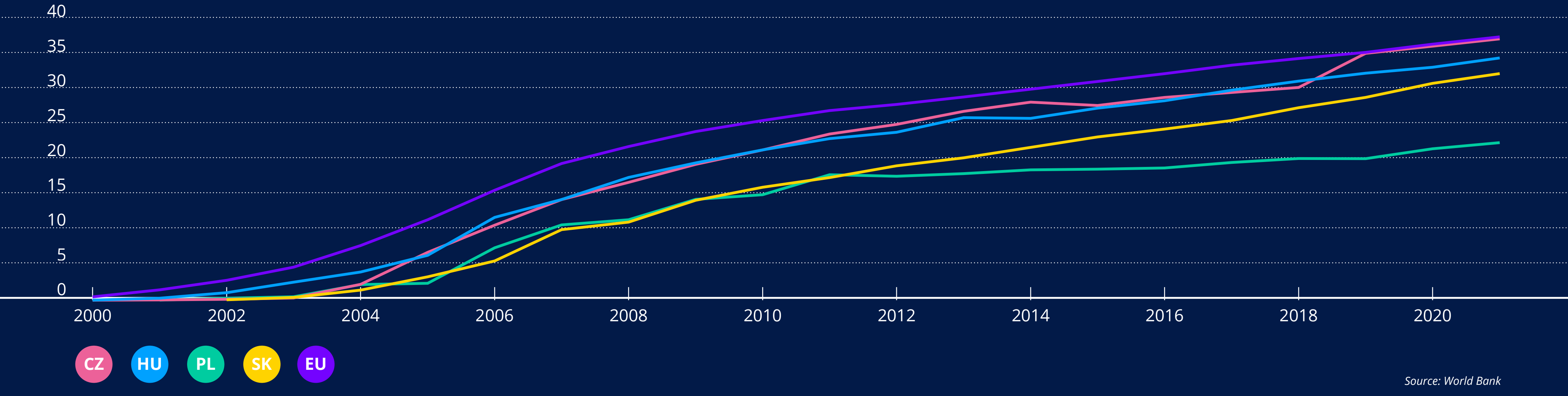
The top five organisations that were the biggest net exporters of IPv4 address space via the secondary market across the four countries, and the number of addresses exported, include:

- Hyperion (Poland): 150,272
- SoftNet Group (Poland): 98,304
- NTX Technologies (Czechia): 80,384
- Externet (Hungary): 69,632
- Telenor Hungary* (Hungary): 65,536

Nej.cz, Giganet, OPC Networks, Tarr and Externet are all ISPs and telecommunications companies, while Softnet is a banking software company and NTX Technologies is a computer systems design and services company.

**Now Yettel Hungary*

Figure 6:
Fixed broadband subscriptions per 100 people over time



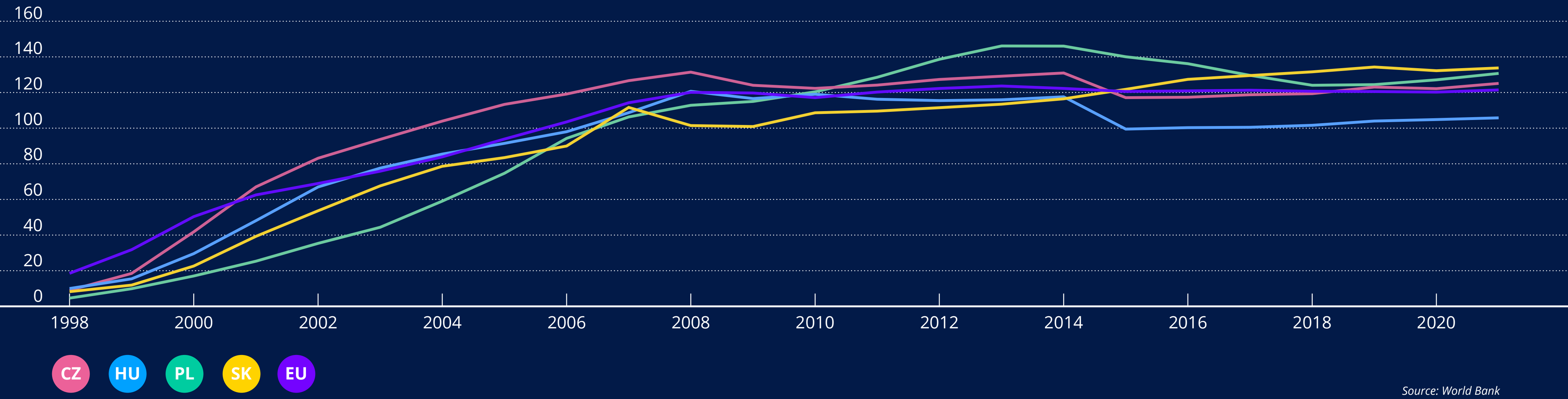
Internet Penetration and Potential for Future Growth

All four countries in this part of Central Europe have high Internet penetration rates, ranging from 90-92% of households having Internet access in Hungary, Poland and Slovakia, to 83% in Czechia.[15] Note that fixed broadband connections are generally shared among several people in the same household, and the numbers we see in figure 6 will therefore never approach 100.

In looking at the number of fixed broadband connections per 100 people in the four countries, we see Czechia at approximately the same level as the EU average, with Hungary and Slovakia not far below. Poland, however, lags significantly compared to the others. The gap between Poland and the other three countries may well be explained by its rural population; although an even higher percentage of Slovakia's population is rural (46% vs. Poland's 40%), Poland's much larger geographical spread likely contributes to the difficulty in connecting households in much of the country. (Czechia and Hungary share a similar, lower rural population of 26% and 28%, respectively.)[16] Despite Poland's lower rate of broadband subscriptions per capita, 93% of the country's urban households and 92% of its rural households have Internet access at home,[17] suggesting that perhaps a relatively large percentage of households rely on mobile data rather than a fixed broadband connection. When it comes to the cost of fixed broadband, the four countries covered in this report are among the least expensive in the EU.[18]

15 https://www.itu.int/en/ITU-D/Statistics/Dashboards/Pages/Digital-Development.aspx
16 https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS?locations=HU-CZ-PL-SK
17 https://www.itu.int/en/ITU-D/Statistics/Documents/DDD/ddd_POL.pdf
18 https://ec.europa.eu/newsroom/dae/redirection/document/88312

Figure 7:
Mobile subscriptions per 100 people over time



Source: World Bank

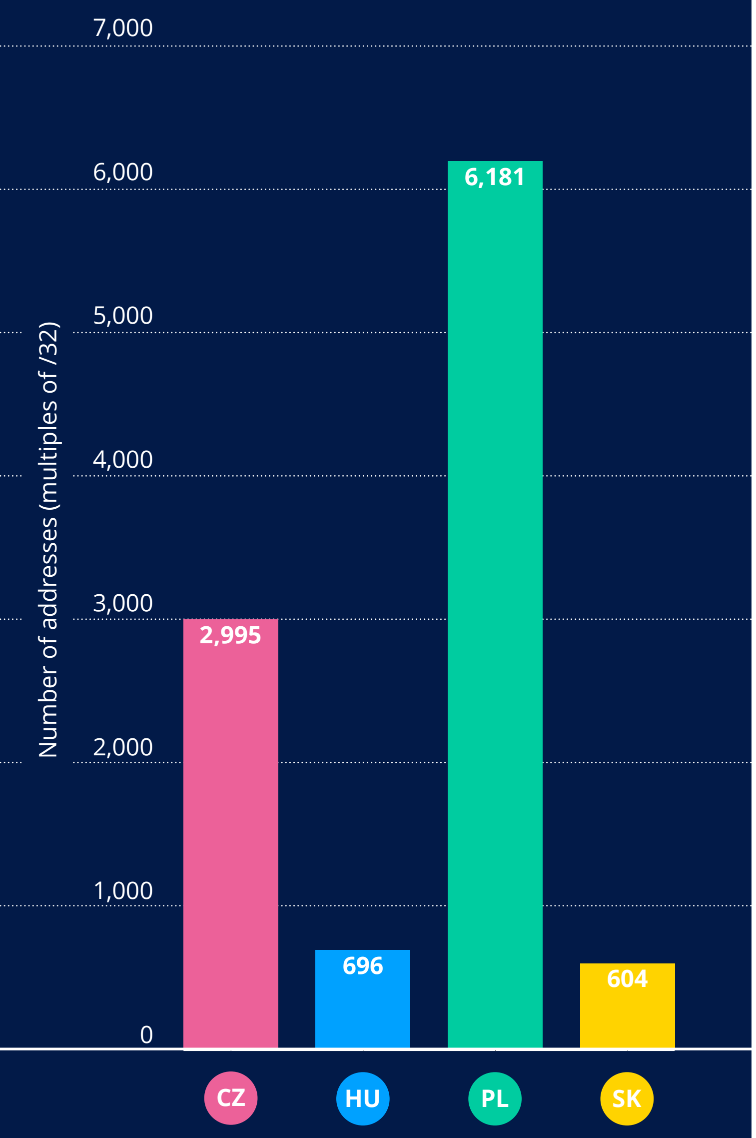
Despite a slower start compared to the other countries, Poland quickly caught up in the number of mobile subscriptions per 100 people and reached the highest peak of any of the four countries, at 148, in 2013. Since that time, its figure has fallen slightly along with Czechia and Hungary – a phenomenon we've seen in many of the developed countries we've looked at, as market saturation seems to have been achieved by the early 2010s. The market in Slovakia, on the other hand, continues to grow. Poland has the third least expensive mobile broadband in the EU, while Hungary has the fourth most expensive and Czechia has the most expensive. Slovakia falls in the middle, where it is classified as "relatively inexpensive" according to the EU's statistics on price indexes across the European Union.[19]

Interestingly, according to a report by the Polish government that compared the state of telecommunications in the country compared to the rest of Europe, Poland has the highest mobile penetration of any EU country while simultaneously having the lowest fixed Internet penetration.[20] Again, this may be an effect of a large rural population spread across a large area, making fixed-line infrastructure slow and expensive to develop compared to mobile infrastructure.

While the four countries in this report have moderate amounts of IPv4 address space to serve their populations, IPv4 run-out means that broadband providers will struggle to serve their growing numbers of customers and, with many more mobile customers than IPv4 addresses, mobile providers are likely relying on address-sharing techniques to meet current demand. 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. Slovakia, in particular, with the lowest IPv4 per capita of the four countries and yet a growing mobile customer base, may rely heavily on CGN. 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 2030 connectivity targets[21] – not to mention supporting emerging technologies such as 5G, the Internet of Things, smart cities and more.

19 https://ec.europa.eu/newsroom/dae/redirection/document/88312
20 https://www.uke.gov.pl/gfx/uke/userfiles/_shared/report_on_the_state_of_the_telecommunications_market_in_poland_in_2020.pdf
21 https://www.euractiv.com/section/broadband/news/connectivity-is-the-starting-point-for-the-2030-digital-targets/

Figure 8: IPv6 holdings



IPv6 in Central Europe

Given the importance of IPv6 in maintaining the Internet's growth and innovation, we now turn to look at the current state of IPv6 deployment in the four countries. (Because of the huge numbers involved in IPv6, we use the equivalent of a /32 of IPv6 in our calculations.)

Usually, we see the amount of IPv6 in a country roughly correspond to (though not equal) its IPv4, which is generally what we see in figure 8 with the exception of Hungary, which has much less IPv6 in comparison. All four countries have steadily increased their IPv6 holdings over the past decade, with Czechia and Poland accruing IPv6 at a faster rate than Hungary and Slovakia, although Czechia's growth started tapering off in the past two years.

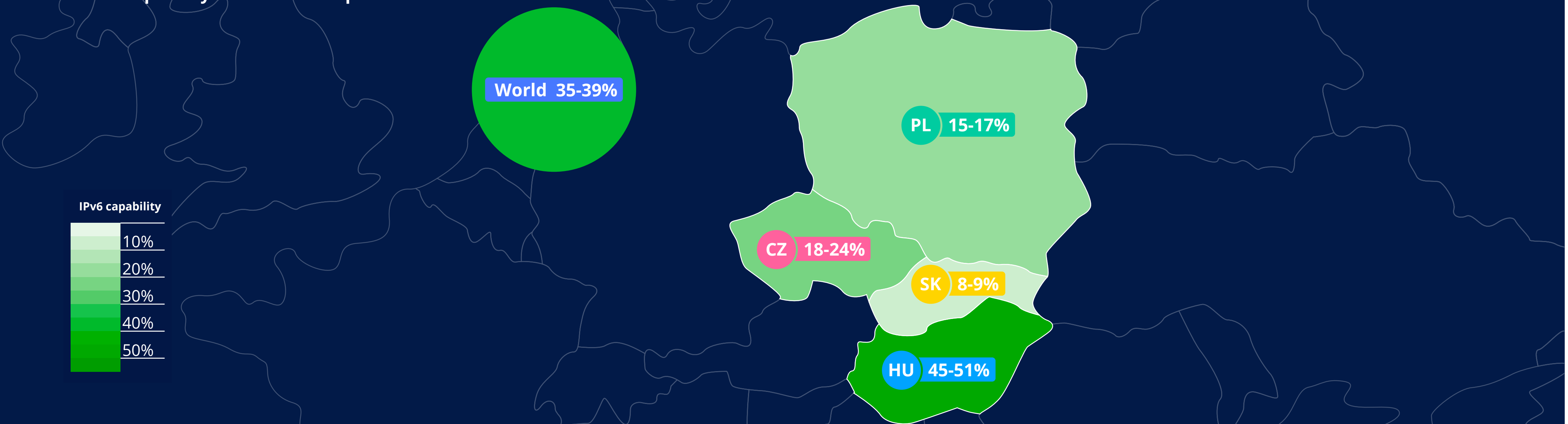
We see no evidence of any significant consolidation when it comes to IPv6 in these four countries. No organisation holds more than 10% of any of the countries' total IPv6 address space with the exception of Orange Polska, which holds 33% of Poland's IPv6 space.

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. Beginning in 2012, when the IPv4 policy change came into effect, LIRs began receiving an IPv6 allocation along with their final IPv4 allocation as standard practice. As such, just because an organisation holds IPv6 space doesn't necessarily mean that it has actually deployed IPv6 and that the addresses are in use.

We see this happening in the four countries, where only a fraction of the IPv6 space held by each country is actually being routed (i.e. being used). According to the RIPE NCC's Routing Information Service (RIS), which employs a globally distributed set of route collectors to collect and store Internet routing data, the following amounts of each country's IPv6 address space is being routed: 60% in Czechia, 41% in Hungary, 58% in Poland and 46% in Slovakia.

Some networks might hold a large amount of address space without using it (possibly having presented plans for future growth when requesting large allocations). Due to the nature of IPv6 networking, it's also possible for a provider to serve a large customer base with a relatively small allocation.

Figure 9:
IPv6 capability in Central Europe



Sources:
https://www.facebook.com/ipv6/?tab=ipv6_country
https://www.google.com/intl/en/ipv6/statistics.html#tab=per-country-ipv6-adoption
https://stats.labs.apnic.net/ipv6/
https://www.akamai.com/internet-station/cyber-attacks/state-of-the-internet-report/ipv6-adoption-visualization

IPv6 capability rates (which measure the percentage of users who can access content and services over IPv6) vary widely across this Central European region. While Hungary is the clear leader and even ranks 18th globally, according to Akamai, it is the only country in the region that ranks above the world average, with the other three lagging significantly behind. We know from the RIPE NCC Survey 2019[22] – which polled more than 4,000 network operators and other members of the technical community, including 273 respondents from Czechia, Hungary, Poland and Slovakia – that IPv4 scarcity is a major challenge in this region, yet (with the exception of Hungary), we still see relatively low levels of IPv6 deployment. A majority of survey respondents from the region (52%) said their organisations would require more IPv4 in the next two to three years (compared to the overall survey average of 46%), with only 12% saying they had enough IPv4 address space (compared to the survey average of 20%).

When it came to IPv6 deployment, 27% of respondents from the Central European region said they were fully deployed (surprisingly, this is actually significantly higher than the survey average of 19%), 20% had or were working on a plan, 15% were currently testing IPv6, 13% had just started deployment, and 12% had no deployment plans. The main reasons given for not deploying IPv6 included a lack of business need, followed by a lack of time and technical expertise. It's possible that the survey respondents disproportionately represented smaller organisations that are further ahead in IPv6 deployment than is generally reflected throughout the region. Looking to the different organisations that have deployed IPv6, we can get a more detailed picture of IPv6 deployment in this part of the world.

22 https://www.ripe.net/participate/member-support/surveys/ripe-ncc-survey-2019

Figure 10:
IPv6 capability by network

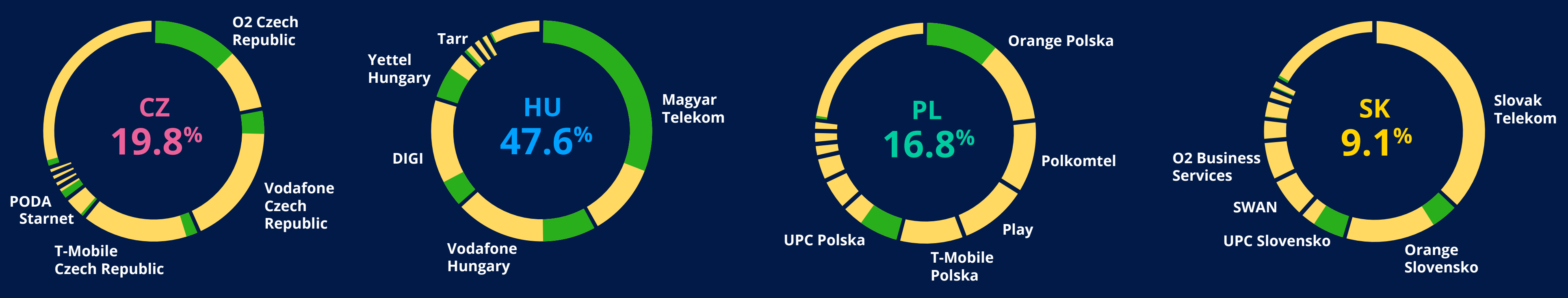


Figure 10 is a visual representation of IPv6 capability by network, according to APNIC measurements averaged over a 90-day period. Each arc segment represents one network (ASN), with the length of each arc corresponding to the percentage of the country's Internet users in that network. Only the five largest networks, by percentage of users, are labelled. Networks with fewer than 1% of users are aggregated into a single, thinner arc. For each arc, the green part shows what fraction is IPv6 capable, while the yellow section represents the fraction that is not IPv6 capable.

Despite the fact that Deutsche Telekom owns T-Mobile and Slovak Telekom, we see that the T-Mobile network in Czechia is 10% IPv6 capable, while the T-Mobile network in Poland and Slovak Telekom show no IPv6 capability. Even more striking is the fact that Magyar Telekom, also owned by Deutsche Telekom, is 73% IPv6 capable. We also see the Orange network in Poland with a higher IPv6 capability rate than in Slovakia, while Vodafone Hungary is more IPv6 capable than Vodafone Czech Republic.

We know that Hungary established a Hungarian IPv6 Forum in 2012, and that the country has made huge strides in recent years when it comes to IPv6 deployment. An IPv6 Education Lab was established at the Budapest University of Technology and Economics in 2011, and Magyar Telekom – which, with its approximately 40% market share, has had a significant impact on the IPv6 adoption rate of Hungary as a whole – started deploying IPv6 at the end of 2016.[23] Czechia had early ambitions with IPv6: in 2009, a government resolution decreed that all new networking equipment must be IPv6 compatible, and in 2013, Czechia was first among European countries in having the most websites available over IPv6.[24] The ccTLD for Czechia, administered by NIC.CZ, has also been active in IPv6 promotion, offering free courses in IPv6 implementation.

In past country reports, we've seen the positive effect that regulatory efforts can have on IPv6 uptake; however, in our work as a network coordination centre, we know how important bottom-up efforts are in deploying IPv6, too. There are active local technical communities in the four countries of this report, including a Czech and Slovak Network Operators Group (CSNOG), which started in 2018, a Polish Network Operators Group (PLNOG) dating back to 2008, and a newly established HUNOG that will hold its first meeting later in 2023. Governments, regulators, Internet exchange points (IXPs) and local network operator groups (NOGs) 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.

23 https://www.telekom.hu/about_us/ipv6_networks/what_does_magyar_telekom_offer
24 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELLAR:8daf9f3e-cc48-4dcd-aa24-b450373b8df7&from=FR

Domestic and International Connectivity

Domestic Connectivity Between Networks

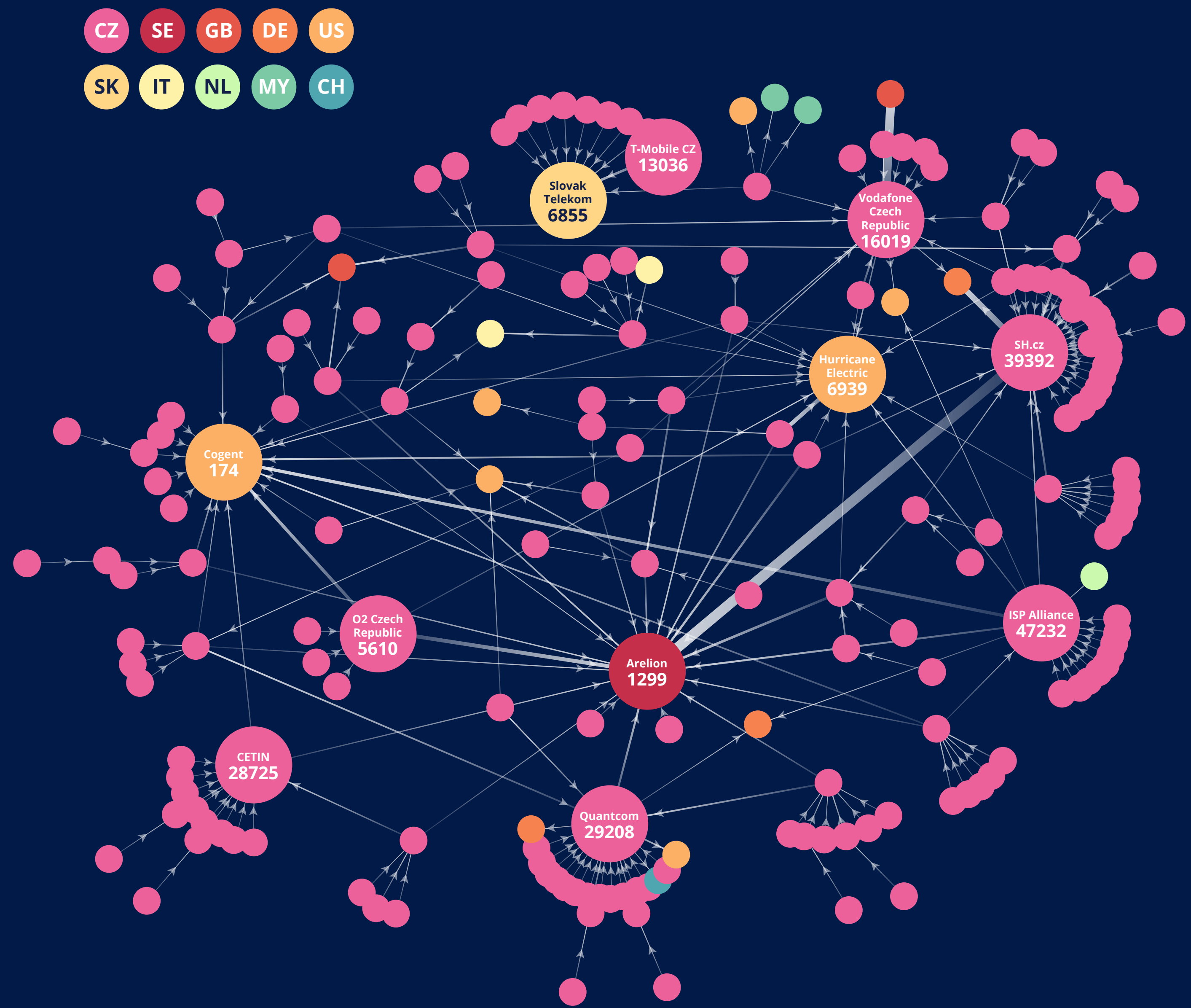
To understand the relationships that exist between different networks, we can investigate the interconnections within each of the countries using data from RIS. This shows us the available paths that exist between networks (as opposed to actual paths taken).

For each country, 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 in each figure 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, these figures are 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 the four countries in this report vary greatly in their number of ASNs, the following network diagrams have been restricted to the top 250 most observed links between ASNs. While this means that many smaller networks 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 11:
Connectivity between networks in Czechia

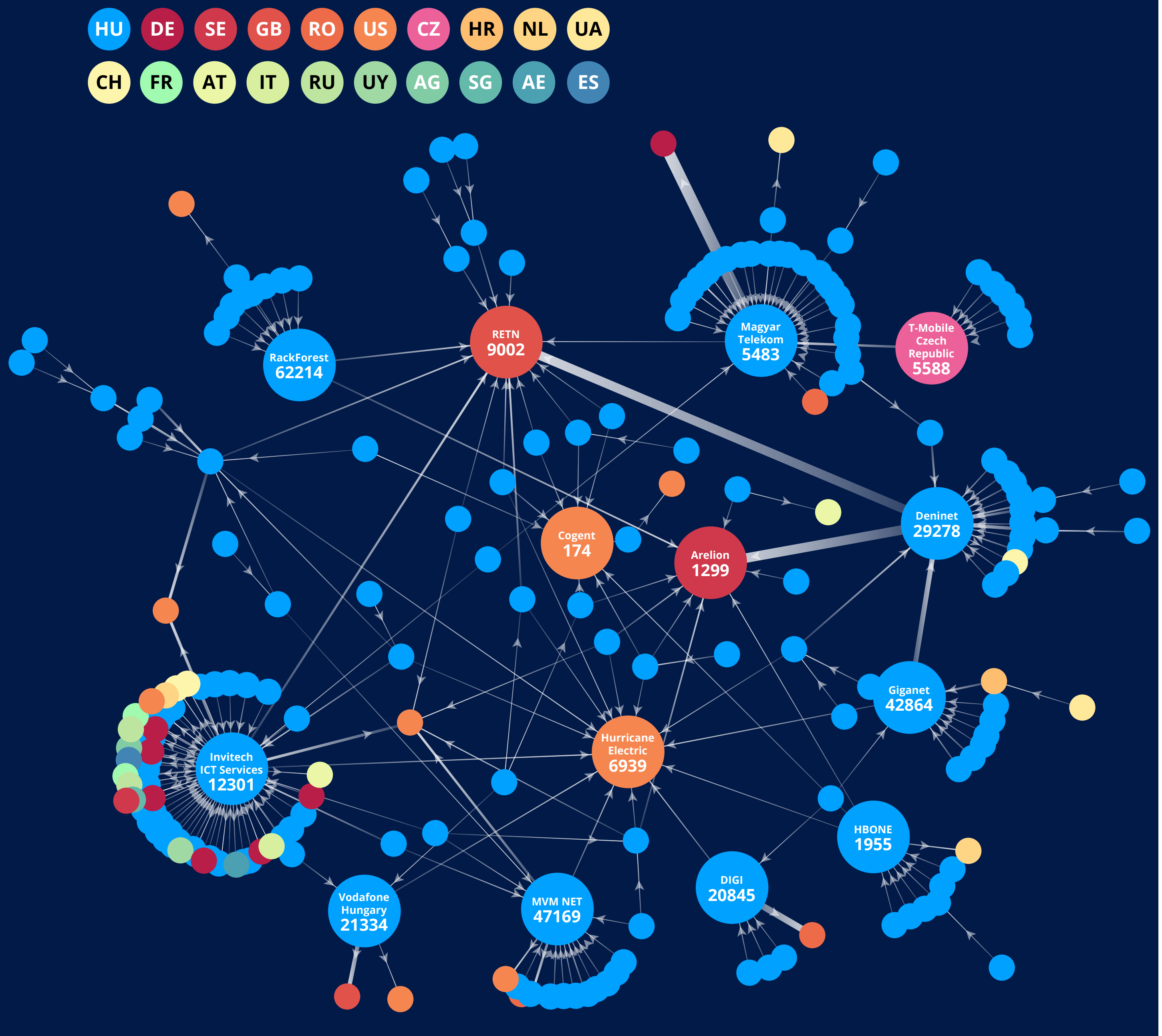


In Czechia, 504 of the 682 networks registered to entities in the country are seen in the RIS routing tables. With that number, it is no surprise we see many of the networks in Czechia connecting to two or more other domestic networks, even though we've restricted the graph to the 250 most observed connections. Another effect is that a sizable number of networks in Czechia connect directly to an international provider and therefore don't rely on a domestic party for Internet access. We can see significant clustering around Cogent (AS174), Arelion (AS1299) and Hurricane Electric (AS6939).

Vodafone Czech Republic (AS16019), SH.cz (AS39392), ISP Alliance (AS47232), Quantcom (AS29208) and CETIN (AS28725) are the major local players that provide connectivity to other domestic networks. O2 Czech Republic (AS5610), one of the largest networks in the country in terms of connected users, plays a more modest role when it comes to connecting domestic networks.

We can also see the role that AS6855 plays in connecting networks in Czechia to the rest of the Internet. Registered to Slovak Telekom, the ASN connects over 40 networks that are based in Czechia, including T-Mobile CZ (AS13036). Although this was surprising at first, we see that in the RIPE Database, the holder of AS6855 added the descriptive line "Slovak Telekom / T-Mobile CZ". This is a clear signal of the strong relationship between these two subsidiaries of Deutsche Telekom.

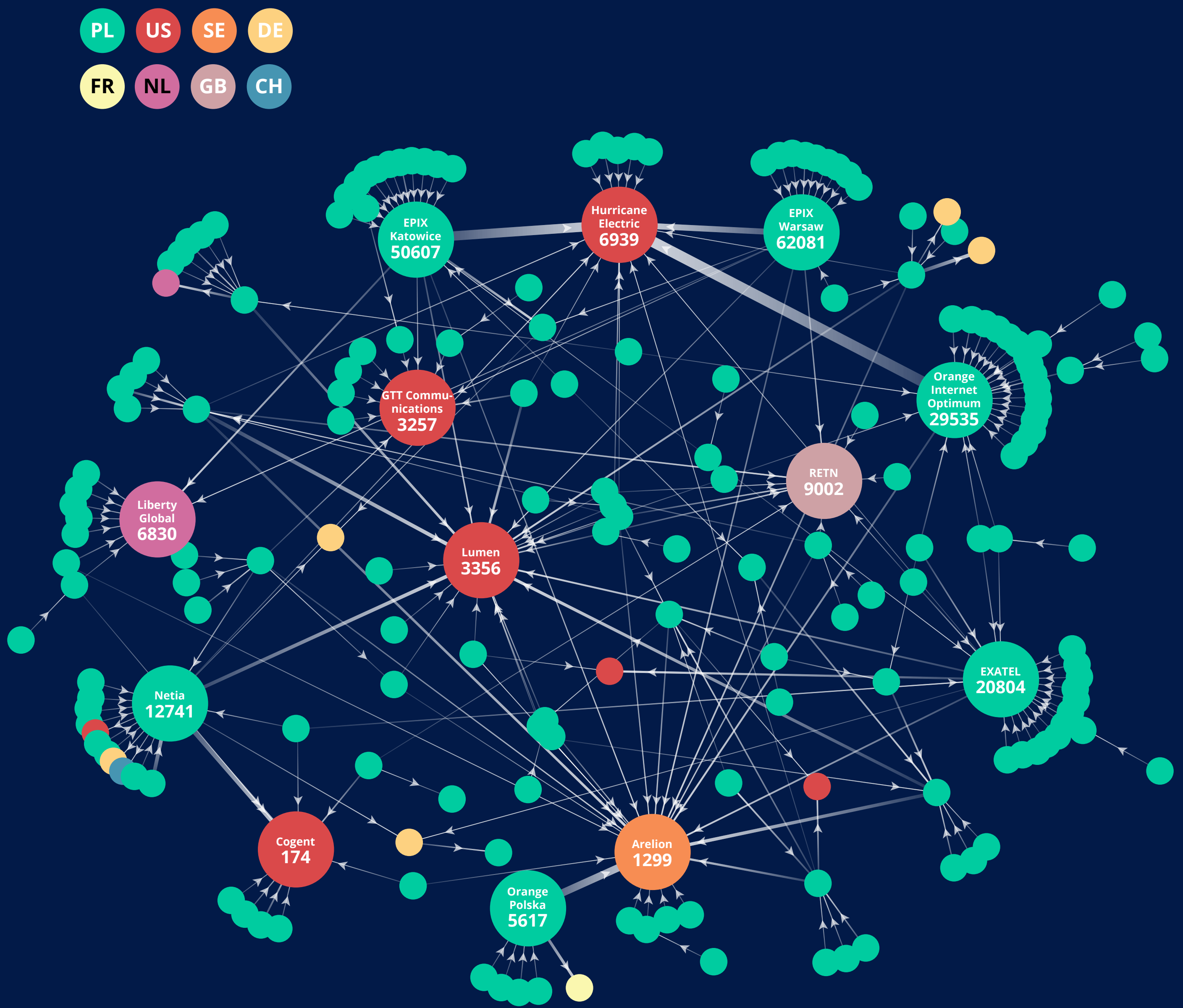
Figure 12:
Connectivity between networks in Hungary



In Hungary, we see many networks clustering around a single upstream provider, with only a modest number, in comparison, that have multiple upstream providers according to the RIS data. Magyar Telekom (AS5483) and Invitech ICT Services (AS12301) especially stand out. The relatively large number of foreign ASNs seen connecting to Invitech is due to the provider's presence at DE-CIX (a large IXP) in Frankfurt. Because that is one of the sites hosting a RIS route collector, we pick up routes which are a result of Invitech's peering. It is also interesting to see how a number of ASNs registered to entities within Hungary connect to Magyar Telekom via AS5588, which is registered to T-Mobile Czech Republic. The ASN was originally held by GTS Europe, a company that was bought by Deutsche Telekom (which owns T-Mobile Czech Republic) in 2014.

Other parties that connect a notable number of domestic networks to the rest of the Internet include MVM NET (AS47169), Giganet (AS42864), Deninet (AS29278) and RackForest (AS62214). For academic institutions, the HBONE network (AS1955) is the gateway to the global Internet. Lastly, the graph shows how DIGI (AS20845) and Vodafone Hungary (AS21334), which together connect roughly 40% of Hungary's Internet users, only connect a handful of other ASNs. Notable international players that provide connectivity to multiple ASNs within the country include Hurricane Electric (AS6939), Cogent (AS174), Arelion (AS1299) and RETN (AS9002).

Figure 13:
Connectivity between networks in Poland

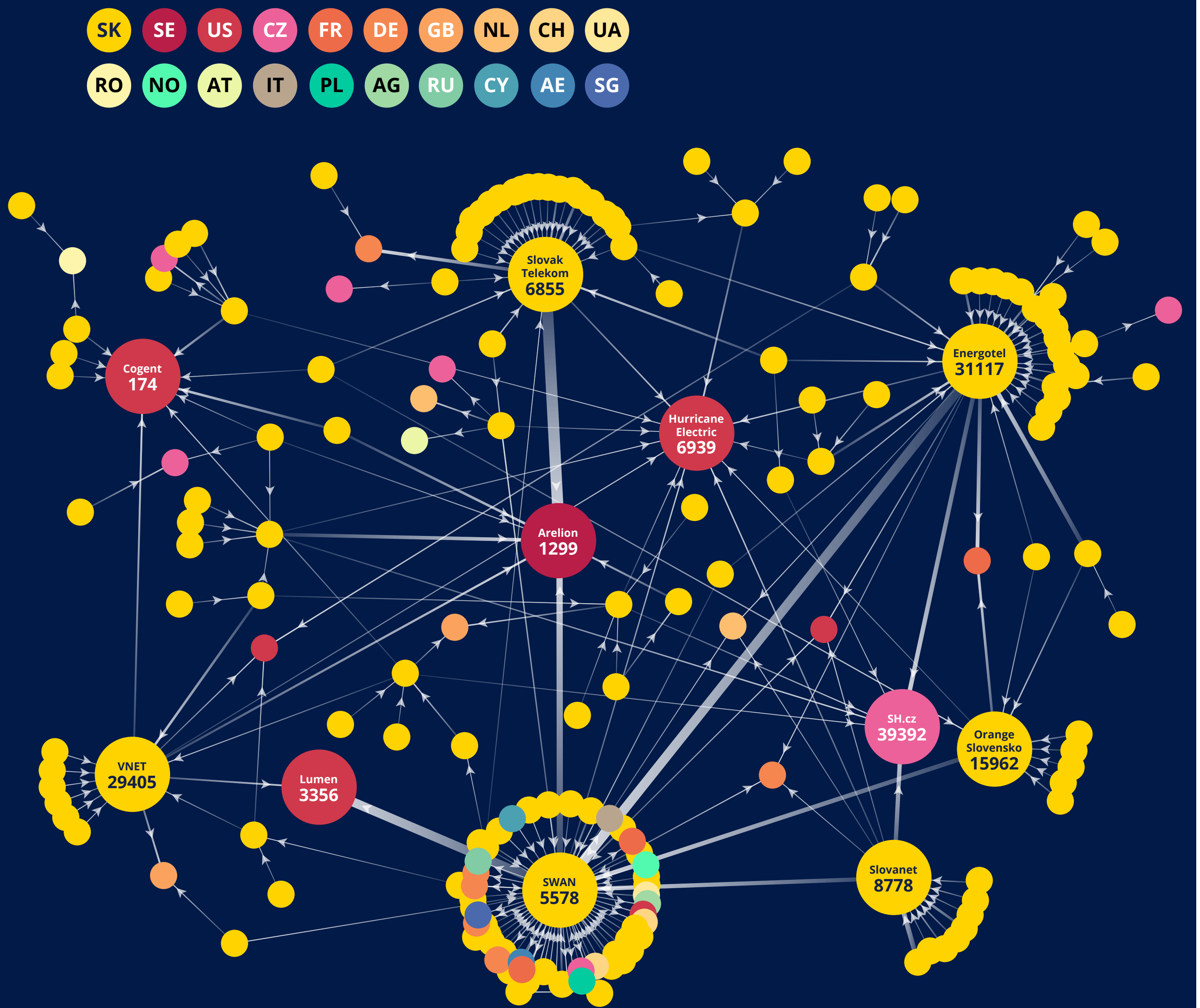


Because Poland has more than 2,000 ASNs in the routing system and 4,400 unique connections between them, no visualisation can reveal all the details of network connectivity within the country. Still, depicting the top 250 most observed segments provides some insight into which organisations play a major role in connecting Poland's networks to the rest of the Internet. We observe a good amount of multihoming, whereby networks connect to two or more upstream providers, as well as a notable number of networks that connect directly to an international provider, of which we see Arelion (AS1299), Cogent (AS174), GTT Communications (AS3257), Lumen (AS3356), Hurricane Electric (AS6939) and RETN (AS9002) playing a major role.

Domestic providers that play a prominent role in providing connectivity to networks within the country include Orange's Internet Optimum network (AS29535), EXATEL (AS20804), Netia (AS12741), EPIX Katowice (AS50607) and EPIX Warsaw (AS62081). Orange Polska's AS5617 does not stand out as much in this graph; however, in the full data set we do also see it connecting many other domestic networks.

Finally, AS6830, held by Liberty Global (which is registered in the Netherlands) is notable because the ASN is used to announce address space held by UPC Polska (which was sold by Liberty Global in April 2022) but it is also the ASN used for Liberty Global's Tier-1 services. From the routing data alone, we cannot tell whether connected networks are served by UPC Polska or by Liberty Global.

Figure 14:
Connectivity between networks in Slovakia



Looking at Slovakia, we see many neworks connected to SWAN (AS5578), several of which are foreign networks (i.e. registered to organisations outside Slovakia). As was the case with Invitech ICT Services in Hungary, this is a result of SWAN's presence at DEC-IX. Besides peering to improve regional connectivity, SWAN also gets transit from Lumen (AS3356) and Arelion (AS1299). Arelion is also the primary transit provider for Slovak Telekom (AS6855).

Energotel (AS31117), Orange Slovensko (AS15962) and Slovanet (AS8778), which also connect a notable number of ASNs registered in Slovakia, show a significant number of paths via SWAN, but the networks also have their own international upstream providers. VNET (AS29405), on the other hand, has no transit via SWAN or any other domestic network; instead, it connects to various international providers directly. Hurricane Electric (AS6939), Arelion (AS1299) and Cogent (AS174) stand out as connecting multiple ASNs in Slovakia to the wider Internet. Also of note is how SH.cz (AS39392), the major hosting provider in Czechia, also provides connectivity to various networks in Slovakia.

A visualisation of domestic 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. Although we see some significant clustering around a handful of domestic networks in all four countries, we also see good diversity as a result of multihoming among multiple networks.

International Connectivity

Extending our view, we now look beyond domestic connectivity to examine how the Central European countries connect to the rest of the world. Internet connectivity comes in two forms: peering and transit. Peering usually happens at Internet exchange points (IXPs) where parties exchange routes to their respective customers. This helps keep local traffic local, or at least regional. To reach other destinations beyond a regional scope, ISPs need transit agreements with one or more parties that will route traffic to the rest of the world. This usually involves some hierarchy. Like a regional peer, the first upstream will be happy to route traffic to its customers if the destination is in one of its networks; however, if the destination is not among its customers, the first upstream will in turn route the traffic to its own transit provider, which will apply the same process. Typically after two or three steps ("hops") from one network to another, traffic reaches a so-called Tier 1 network, which sits at the top of the hierarchy and requires no transit but has only peering relationships to other Tier 1 networks. Once traffic has been exchanged at the Tier 1 level, it goes down the chain on the other side to smaller ISPs until it reaches its final destination.

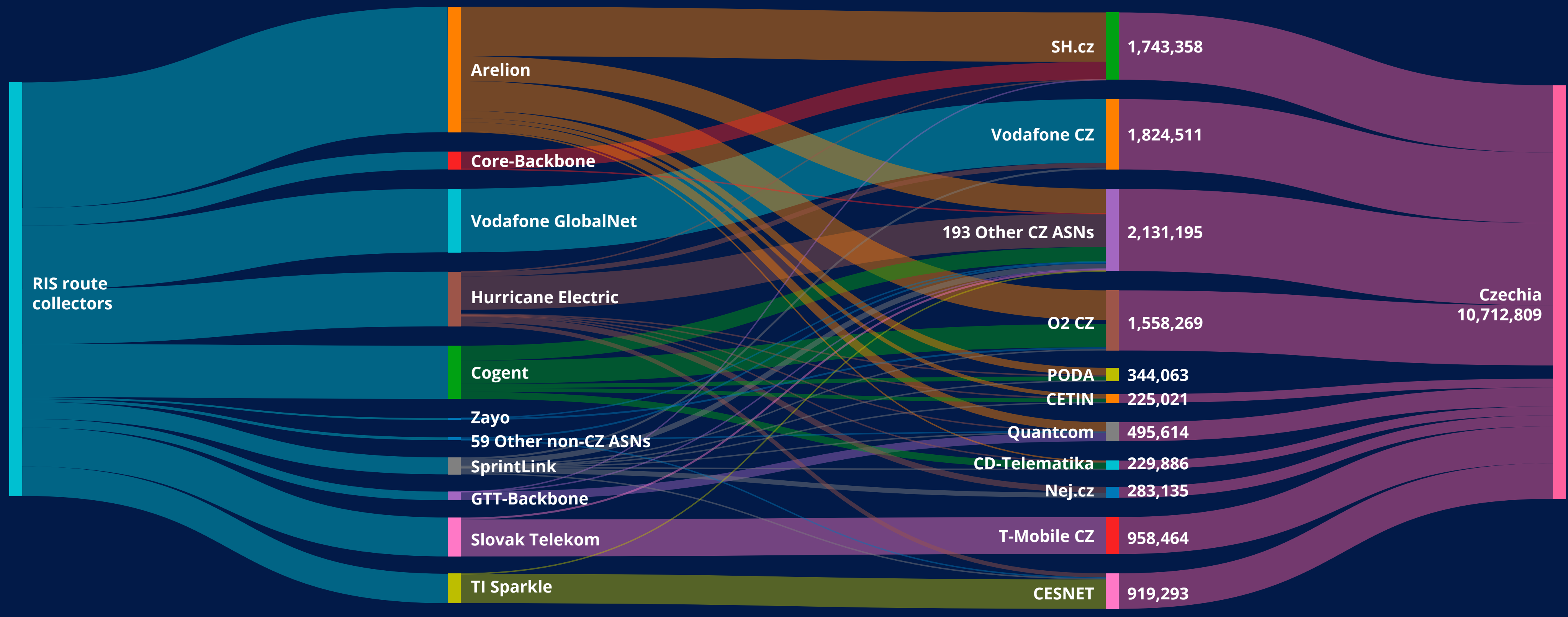
So while part of a network's international connectivity is taken care of via peering and medium-sized ISPs, the Tier 1 networks are instrumental in reaching all corners of the world. To assess which foreign ISPs are important in reaching a country, we again look to the RIPE NCC's Routing Information Service (RIS) to discover the AS paths that go through a Tier 1 network.[25] For each of these, we find the bordering network pair on either side of the Tier 1 network (i.e. the last network registered in a foreign country before the traffic enters the Tier 1 network, and the first network registered in the country of interest once the traffic has passed through the Tier 1 network).

The resulting figures are based on data that takes into account both the number of occurrences of each network pair, as well as the total size of the unique IP address space routed via each pair.

In the following figures, the organisations listed on the right are entry points to a country's IPv4 space. This includes both addresses held by the organisation itself as well as customers that operate their own networks. The numbers refer to the total number of IP addresses reached via this connection, and are therefore an indication of how many end users are served. As a result of multihoming, some IP networks may be reached via more than one entry point. The same is also true for the connections on the other end, between international and domestic networks. Only the top 10 transit providers and domestic providers are named; the rest are grouped into the category "other".

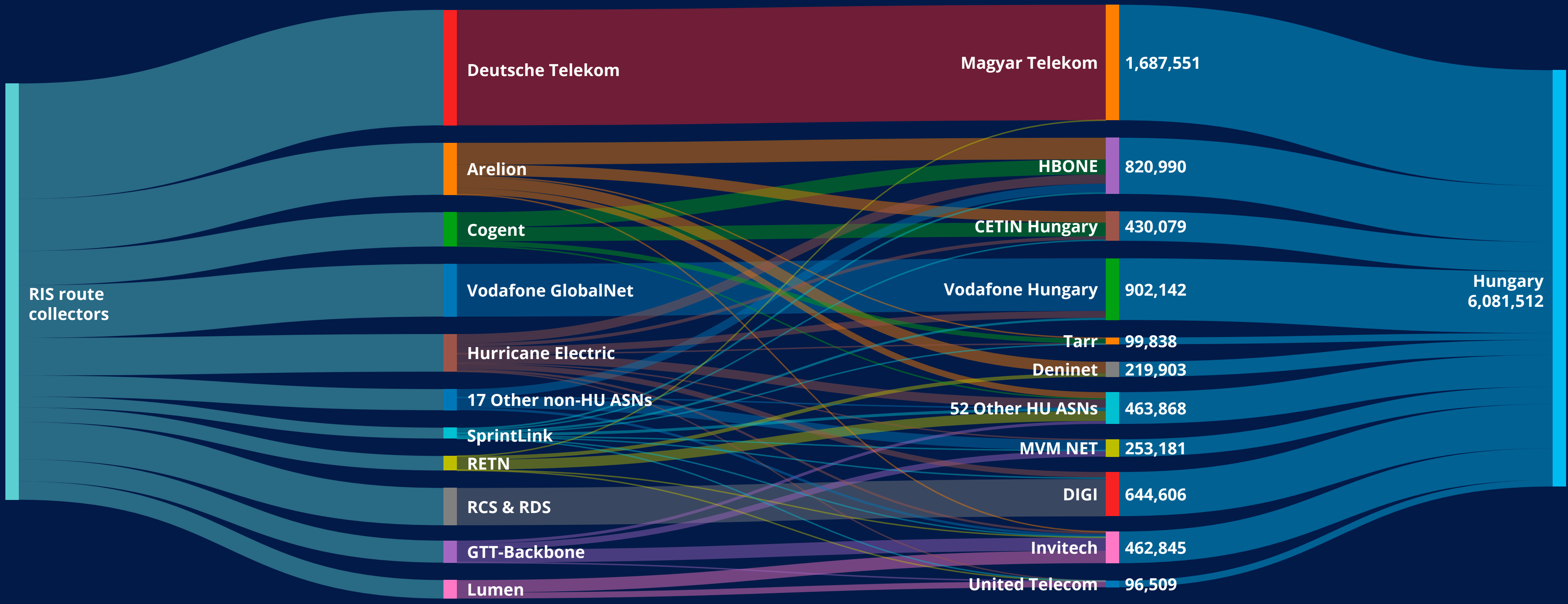
25 https://en.wikipedia.org/wiki/Tier_1_network#List_of_Tier_1_networks

Figure 15:
Czechia's international connectivity



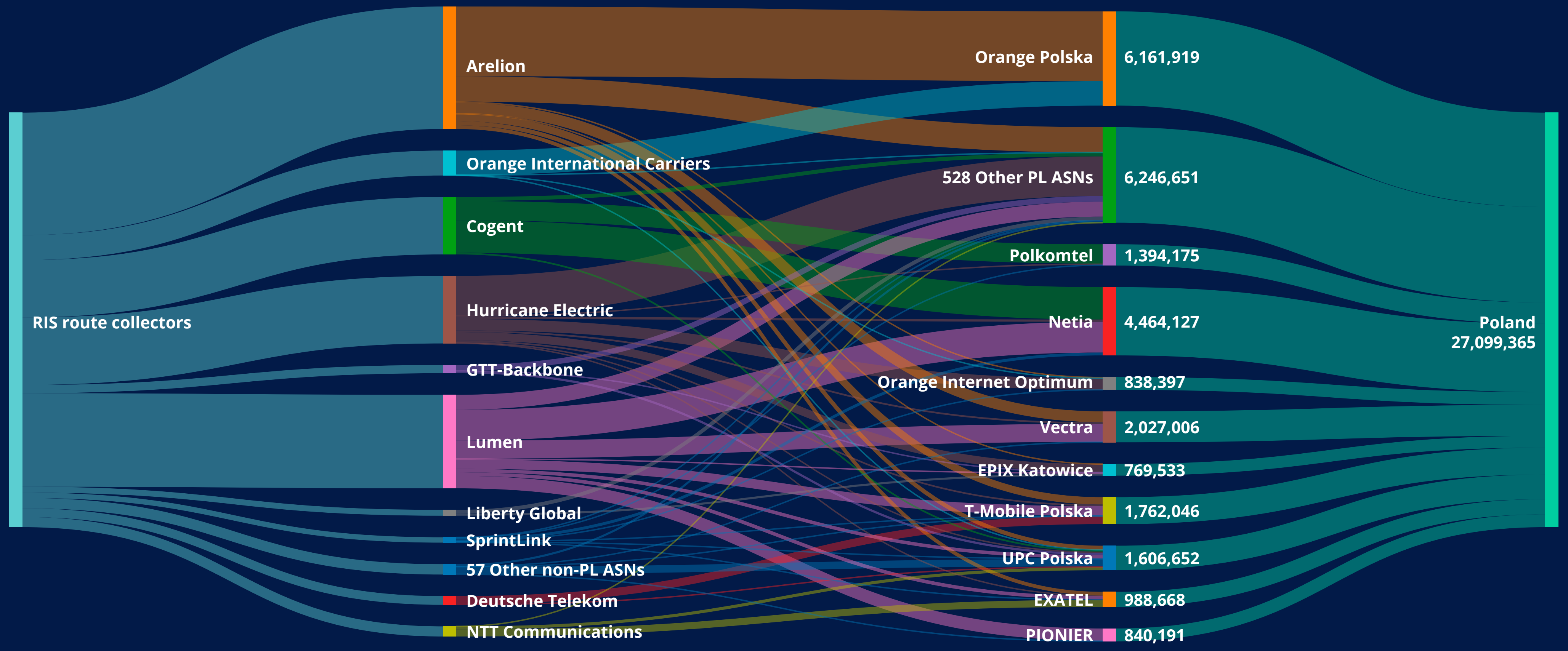
In looking at Czechia, the first thing that stands out is how 1.7 million IPv4 addresses are routed to the country via SH.cz. The hosting company itself only holds a modest 30,000 IPv4 addresses, but connects many other smaller players to the Internet. The other notable observation is that T-Mobile Czech Republic depends 100% on Slovak Telekom for connectivity, which was also apparent in the domestic connectivity graph, and which, again, reflects the close relationship between these two subsidiaries of Deutsche Telekom. Similar to T-Mobile, Vodafone Czech Republic has a strong dependency on Vodafone GlobalNet (although not 100%), while the academic network CESNET relies heavily on Telecom Italia Sparkle.

**Figure 16:
Hungary's international connectivity**



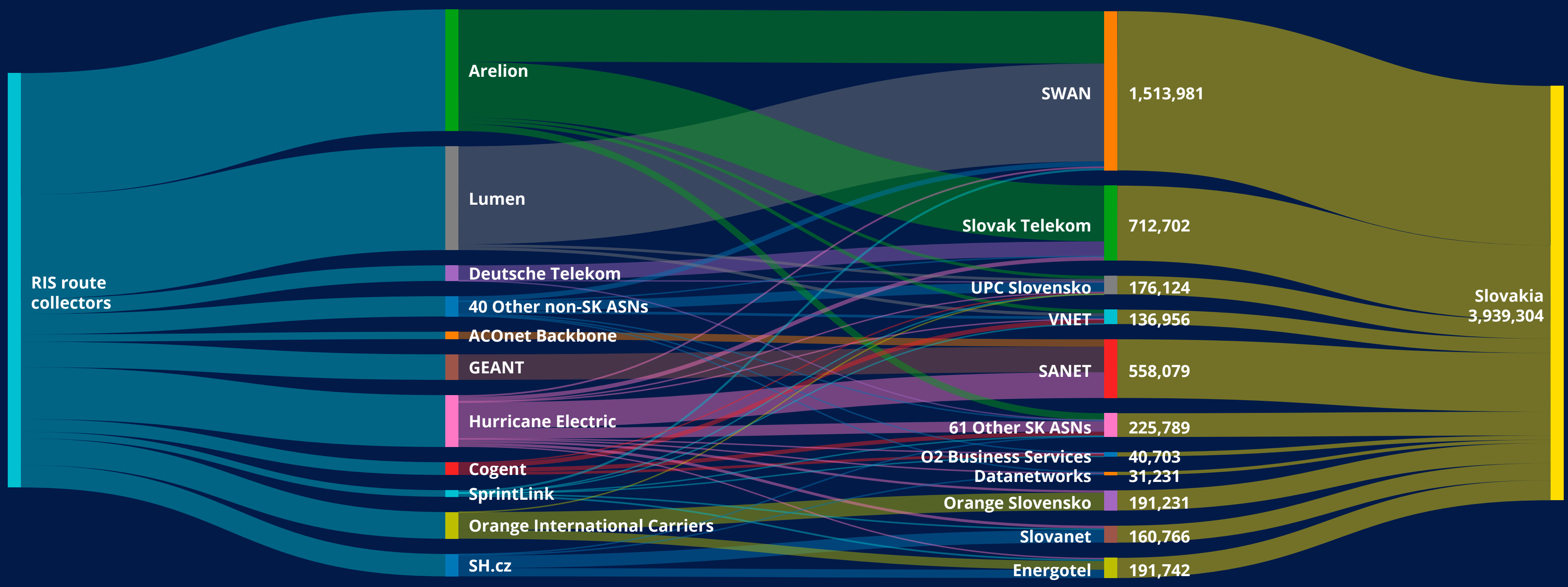
In Hungary, we see the main providers largely depend on their (former) parent companies for international transit. Magyar Telekom relies fully on Deutsche Telekom, while Vodafone Hungary and DIGI continue to predominantly be reached via former sibling/parent companies Vodafone GlobalNet and Romanian RCS & RDS, despite the fact that they've been owned by Hungarian 4iG since January 2023 and January 2022, respectively. The academic HBONE mostly obtains transit to the wider Internet via commercial providers Arelion, Cogent and Hurricane Electric. However, as HBONE is a member of the research association GÉANT, connectivity to other academic networks around the world is likely to pass through GÉANT's network.

Figure 17:
Poland's international connectivity



In Poland, the top 10 organisations that provide international connectivity all have diverse upstream providers, with Lumen serving as an upstream provider for eight of them. However, the largest IPv4 holder, Orange Polska, relies on Arelion and Orange International Carriers. We also see how more than 500 "other" ASNs, connecting 6.2 million IPv4 addresses in total, have a direct connection to an international provider. UPC Polska's networks, though acquired by Play in April 2022, are still routed as part of Liberty Global; because this is a Tier 1 provider, we see many connections to other international providers.

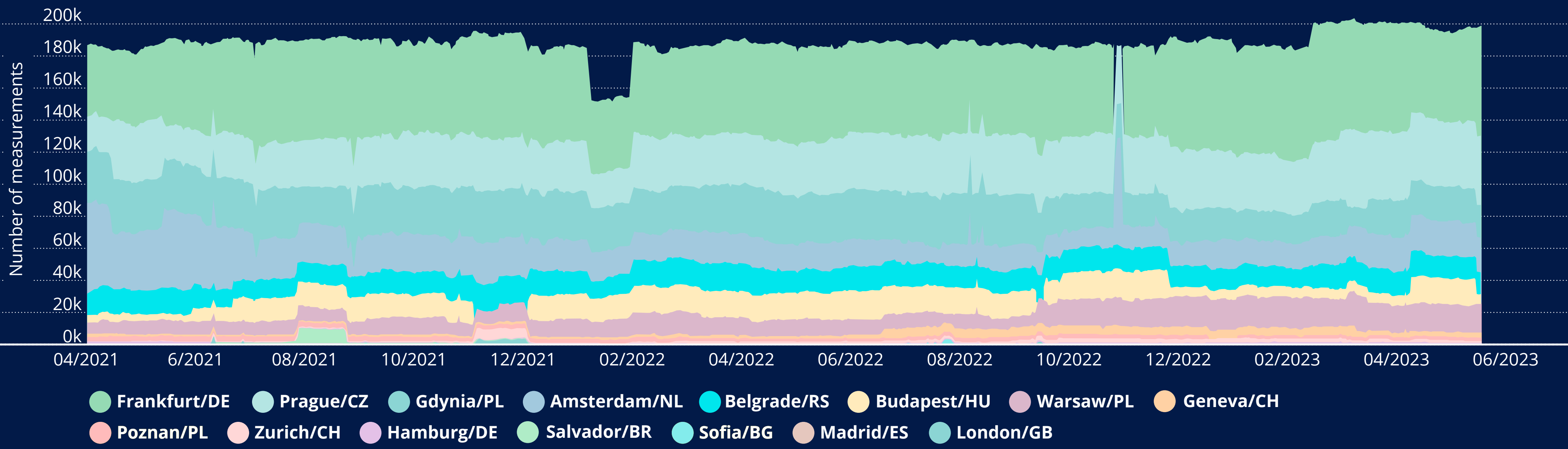
Figure 18:
Slovakia's international connectivity



With Slovakia, we see SH.cz as an upstream provider for two domestic networks: Energotel and Slovanet. The academic network SANET receives transit from GÉANT as well as from ACOnet (Austria's research network) and Hurricane Electric. SWAN is responsible for connecting a large number of IPs in Slovakia to the rest of the Internet. In turn, most international transit for SWAN passes through Lumen. Orange Slovensko receives international transit directly from Orange International Carriers, but also indirectly via SWAN. Slovak Telekom mostly relies on Arelion, and to a lesser extent on its parent company, Deutsche Telekom.

In general, the higher the number of different available 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 the four countries we looked at in Central Europe, we see a fairly healthy level of interconnection overall; most domestic providers receive transit from more than one upstream provider, with a few notable exceptions. This provides a good level of redundancy – and therefore stability – to the countries' international connectivity.

Figure 19:
K-root locations reached from requests originating in Central Europe over time (IPv4)



Domain Name System, Traffic Paths and Routing Security

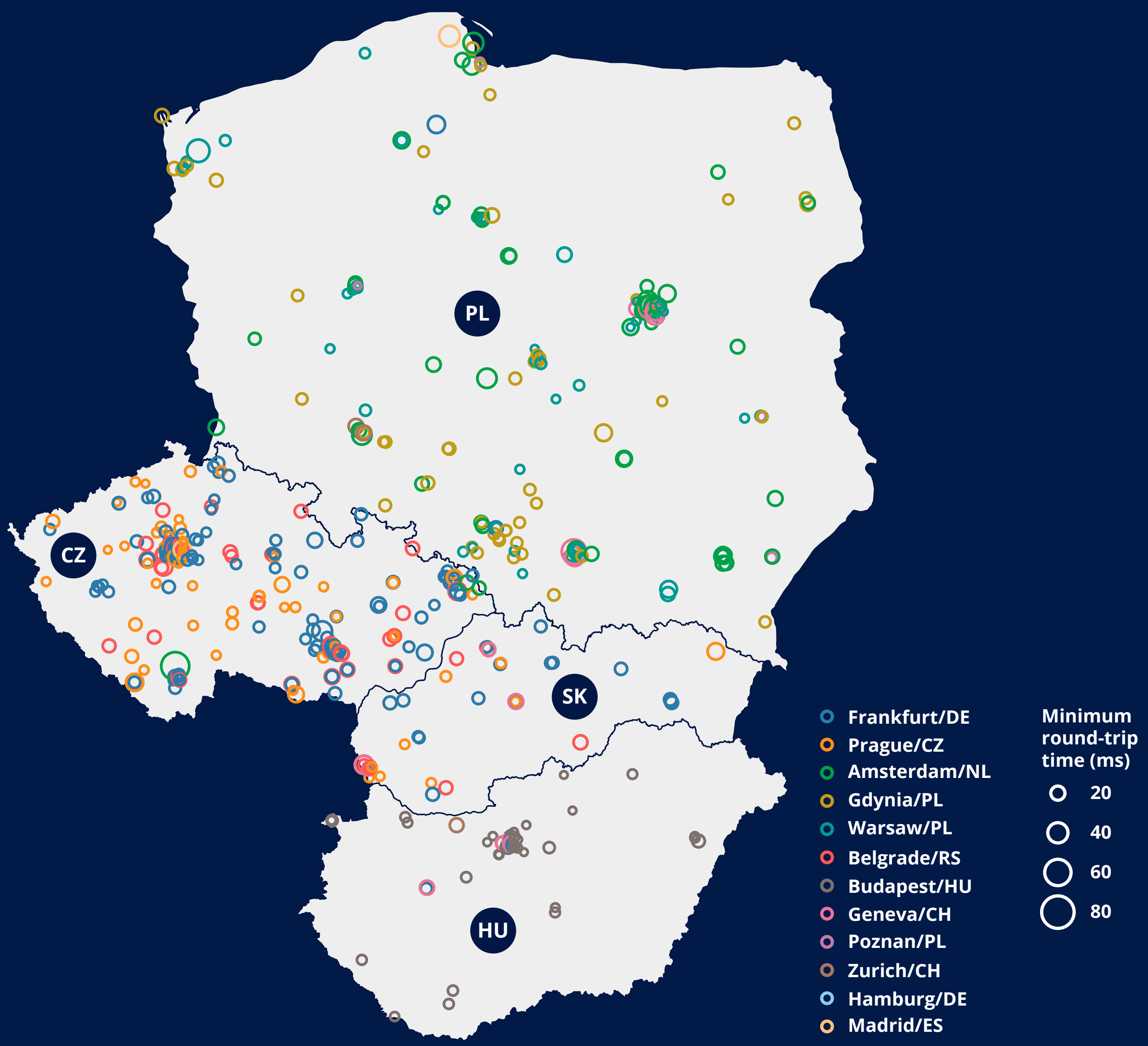
Reaching the Domain Name System

Turning now to investigate how traffic is routed to, from and within this part of Central Europe, we first examine which local instances of K-root are queried from requests originating in the different countries. 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, including 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 resilience and results in faster response times for DNS clients and, ultimately, end users.

There are five K-root instances in this part of Central Europe, including one in Czechia (Prague), one in Hungary (Budapest), and three in Poland (Warsaw, Gdynia and Poznan). In figure 19, we see how some of these instances are reached more often than others, and how some instances in more distant locations are favoured over the local instances. Although all five of the local instances appear in the data, only two of the top five instances reached are local instances (Prague and Gdynia). Frankfurt is the most reached K-root instance for queries originating in the region, with Amsterdam and Belgrade also playing a large role. We also see other countries throughout Europe relying heavily on K-root instances in Frankfurt and Amsterdam and, as these are not

Figure 20:
K-root locations reached from vantage points in Central Europe



geographically very far from the Central European countries, this is unlikely to significantly impact round-trip times.

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.

We also looked into which K-root instances were queried by RIPE Atlas probes throughout the region on a given day, as well as their round-trip times, as shown in figure 20. As expected, we see that many of the probes in Poland queried the K-root instances in Warsaw, Gdynia and Poznan (although we also see Amsterdam playing a significant role), while many of the probes in Czechia reached the instance in Prague (as well as Frankfurt). In particular, we see the probes in Hungary staying local, with the majority reaching the K-root instance in Budapest.

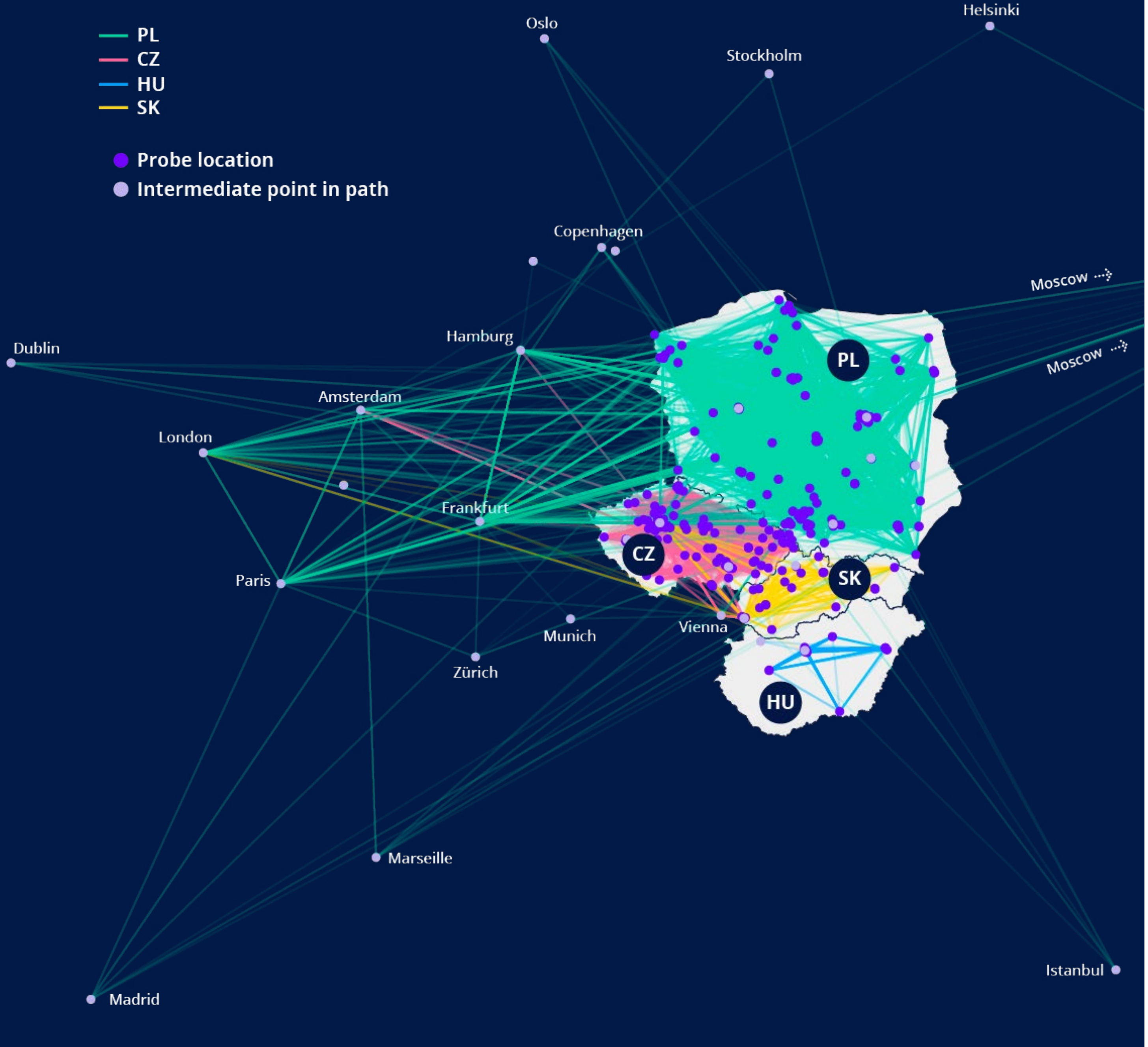
Finally, we looked at which K-root instances were queried by probes within different networks in each of the countries (for those networks that host at least one RIPE Atlas probe). Generally, most networks have a preference for a particular

K-root instance. Traditionally, the Border Gateway Protocol (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 generally what we see in the Central European countries, where all probes in a particular network end up querying the same root-server instance. We can see the effect of some of the upstream providers we looked at earlier in the report here as well; for example, the probes in the academic research networks HBONE in Hungary and SANET in Slovakia both reached the K-root instance in Amsterdam, which is home to the GÉANT network that routes many of Europe's research networks.

We should note that these results, while considered generally representative, offer only a snapshot of measurements made on a single day in April 2023. Given BGP's dynamic nature, results can change constantly due to subtle changes in routing. It's also worth remembering that these results are for K-root only, and every 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's likely that clients would opt for faster alternatives among the other root name servers.

The increase in round-trip times to K-root instances farther away (such as those in Amsterdam and Frankfurt) is obvious, yet all remain fast and it's unlikely that an end user would experience any noticeable delay. While we see the effect of certain probes reaching K-root instances at the larger IXPs in Europe (including AMS-IX in Amsterdam and DE-CIX in Frankfurt), we can say that, overall, access to K-root appears to be very well optimised in these Central European countries.

Figure 21:
Paths between origin and destination in the same country for Central Europe (IPv4)



Regional Traffic Exchange

Again using data from the RIPE Atlas measurement network, we can investigate how some of the networks in the three countries exchange traffic with each other, and get some indication of where those exchanges take place. For this experiment, we performed traceroutes between a subset of the RIPE Atlas probes in each country. Figure 21 shows the location of the probes (indicated by the light and dark purple dots) and the paths followed by the traceroutes (indicated by lines of a different colour for each country).

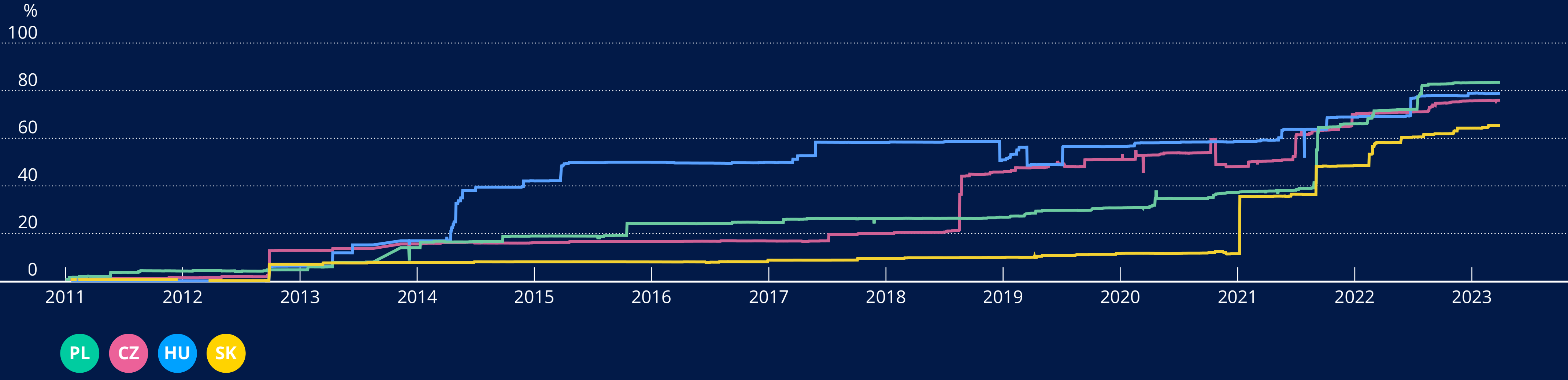
All four countries covered in the report host IXPs. EPIX in Poland is one of the largest IXPs in the world according to the number of networks connecting there, and Poland is one of the countries with the most IXP traffic in the world.[26] Yet we see more paths between probes in Poland passing through foreign IXPs than in the other countries. Looking at the results more closely, we discovered that these are largely the result of just a handful of probes for which traffic does not appear to pass through a local exchange point. When we look at the full picture, however, we see that the vast majority of paths between probes in Poland do make use of local exchanges to stay within the country.

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.

It's worth noting, however, that the impact of the longer routes we see here, which would result in longer response

26 *https://www.euro-ix.net/media/filer_public/35/73/3573f355-c90a-4b31-ae83-851b76cfa36b/ixp_report_2021.pdf*

Figure 22:
IPv4 address space covered by ROAs over time



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 within each country. The distances we see taken by the longest paths in this region are relatively short compared to what we've seen in many other countries; overall, routing appears to be quite efficient in this part of Central Europe.

Routing Security

Beyond looking into the different routes available to traffic originating in the region, we can also investigate routing security in the three 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.

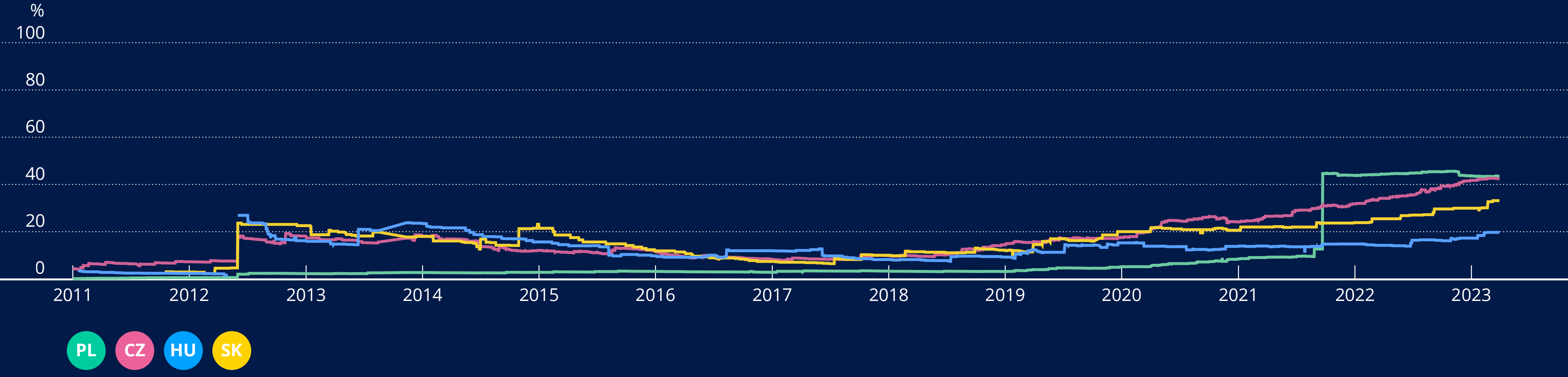
RPKI uses digital certificates called ROAs (Route Origin Authorisations) to prove a resource holder's right to announce IP prefixes (i.e. certifying that the resources were allocated or assigned to them by a Regional Internet Registry). This helps avoid the most common routing error on the Internet: 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 and IPv6 address space is covered by ROAs.

The big leaps we see in coverage are usually explained by large networks creating ROAs for their address space at a certain point in time. In mid-2014, Magyar Telekom and T-Mobile Hungary (which merged into Magyar Telekom five years later) added ROAs to their IPv4 blocks, boosting coverage from 16% to 38%. Other networks followed in recent years, and today 80% of Hungary's IPv4 space is secured.

In Czechia, the rate jumped from 21% to 44% in September 2018 thanks to the actions of O2, followed a few days later by CESNET, the academic network. CETIN also added ROAs at this time, but because it holds far less IPv4 space, its impact on the percentage covered was relatively small, contributing about 1.5% overall.

In Slovakia, RPKI coverage of IPv4 space got a significant boost in 2021 thanks to Slovak Telekom, followed shortly after by SWAN.

Figure 23:
IPv6 address space covered by ROAs over time



Poland saw a gradual increase in RPKI coverage until September 2021, when Orange Polska, by far the largest IPv4 holder, added ROAs, thereby boosting the country's coverage from 41% to 64%. About a year later, a final increase of 10% took place when Polkomtel and Multimedia Polska (which hold the fourth and sixth most IPv4 space in the country, respectively) added ROAs to their prefixes. Today, 84% of IPv4 is covered in Poland, which is an exceptionally high rate. Overall, RPKI coverage in this region is among the highest we've seen in the countries we've looked at in our country reports.

When it comes to IPv6, we consistently see lower rates of RPKI uptake. This is a result of the fact that less of the IPv6 that's been allocated is actually in use and being routed, as explained earlier. We see a steep increase in the amount of IPv6 covered by ROAs in Poland towards the end of 2021, when Orange Polska covered the /21 IPv6 allocation it holds. This allocation is 256 times larger than the normal /29 LIRs can get without providing detailed networking plans, and equaled 35% of Poland's IPv6 space at that time.

Earlier, in June 2012, Czechia, Hungary and Slovakia all reached levels of between 15% and 25% coverage when ROAs were added for the IPv6 prefixes held by the respective UPC branches. This also happened for UPC Polska's /27 IPv6 prefix, but due to the /21 allocation held (at that time) by Telekomunikacja Polska, the impact on Poland's total IPv6 coverage was only about 1.5%. This is a clear sign of RPKI configuration coordination among the different UPC subsidiaries. In subsequent years, the percentages in all three countries decreased to around 10%. This was the result of more and more IPv6 addresses being allocated to organisations that did not immediately add ROAs, so the overall percentage of the country's covered space slowly declined. It is not until 2018 that we see the trend reversed and the figures start to climb once again.

The rates of IPv6 coverage we see in these countries is fairly average across the other regions we've looked at in the country reports.

Conclusion

The four countries we looked at in Central Europe all display robust markets with healthy competition – despite some recent consolidation in the form of mergers and acquisitions – which likely contributes to the affordable connectivity rates. Internet penetration is high throughout the region, although Poland, especially, struggles with fixed connectivity for its rural population. However, high mobile subscriptions rates likely help to fill in the gap. Further investment in infrastructure will be needed for these countries to achieve the 2030 EU connectivity targets, yet all have made recent gains in their digital development.

We don't see a lot of IPv4 consolidation in this region, which reflects the diversified market. Overall, these countries hold modest amounts of IPv4 address space and, with the exception of Hungary, all are lagging far behind in IPv6 deployment. Even in Hungary, we saw how the country's high IPv6 capability rate can be largely attributed to a single large network, and it will be important for Hungary, too, but especially for Czechia, Poland and Slovakia, to improve their IPv6 capability in order to accommodate long-term growth as well as new and emerging technologies such as 5G, IoT, the Internet of Things, smart cities and more. Governments, IXPs, NOGs, network operators and decision makers all need to do their part to encourage IPv6 deployment more widely.

The networks in each of the five countries display a good level of interconnectivity, which keeps their domestic Internet connectivity landscapes stable and resilient. We also see a good amount of diversity in upstream providers, ensuring robust connections to the rest of the global Internet that mitigate against potential disruptions caused by bottlenecks or single points of failure.

The four countries all display highly optimised access to the DNS via K-root, and routing is quite efficient within the region, with a lot of paths available to keep domestic traffic local. We do see some of the larger European IXPs being used, but this is normal and not something that would result in noticeably longer response times. We also see a very high level of RPKI uptake (at least in IPv4 space), which helps ensure routing security.

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 resilience.

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