2018 Compendium Study

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Abstract

The GÉANT Compendium provides an authoritative reference source for anyone with an interest in the development of research and education networking in Europe and beyond. Published since 2000, the Compendium provides information on key areas such as NREN users, services, traffic, budget and staffing. This document covers the period January to December 2017. The GÉANT NREN Compendium may be found online at: https://compendium.geant.org/

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1 A Guide to the GÉANT Compendium of NRENs

1.1 About the Compendium

The GÉANT Compendium of National Research and Education Networks in Europe (the Compendium) is the result of a broad, collective effort to portray the networks of the research and education community in Europe.

National research and education network (NREN) organisations run special communication networks dedicated to supporting the needs of the scientific and academic community within a country. In Europe, NRENs are interconnected by the pan-European GÉANT network, the largest and most advanced R&E network in the world.

The Compendium is a living picture of what NRENs do every day to meet users' requirements and help them in their research, teaching and learning activities. The annual NREN Compendium survey invites Europe's NRENs to provide detailed information about their network, equipment and users. The survey conducted in 2018 focused on the period from January to December 2017. It requested information relating to seven areas of interest to NRENs including: network, service portfolios, and budgets. The survey questions were drafted under the guidance of subject specialists from within the GN4-2 project. This same group also led the analysis of the respondents' data. The results from this survey are summarised in this document.[1] Reports compiled from NREN data may also be generated from the online version of the Compendium [COMPENDIUM].

The diversity and complexity of the different NRENs can make comparisons challenging, but it is the Compendium's ambition to help to provide an insight into this thriving community.

This Compendium is a community-led document, created by the NREN community, for the NREN community, as a means to understand the status of the collective as a whole, as well as of each NREN. It is a dataset with and on which NRENs can inform and build their strategy decisions.

[1] The 2017 edition of this document included sections reporting the results of a separate survey on security and T&I services; the 2019 edition will also do so. However, work on the 2018 surveys was out of sync, meaning it has not been possible to include those results in this Compendium Study.

Notes for the Reader

When reading the data, keep in mind that NRENs are a large and diverse family. Each national organisation reflects the specific environment in which it grew, with country-specific particularities, such as the political situation, the history of the organisation and its relations with user groups, funding agencies, and the status of research and education in that country, all woven into its fabric. Another important aspect is the difference between the leading communities that formed the first NRENs: each NREN was set up in a form that suited a country's needs and background. In articulating these particularities, the aim is to show that although all of the survey respondents were NRENs, they are far from being a homogeneous community. It is important to remember this when comparing results.

It is also important to understand the variations in NREN infrastructure and the reasons why an NREN is or is not connecting a specific institution. Infrastructure choice has an impact on all aspects of NREN operations, including the reach of the network, connection possibilities, and selection of equipment/technology. The development and support of this infrastructure is often determined by the vision, resource and funding levels in a given country, and this differs between national authorities. As well as infrastructure limitations, whether an NREN is or is not connecting a specific institution is also dependent upon an acceptable use policy, which varies by NREN; some can connect schools, while other mandates may extend to private R&D firms.

To provide an example of infrastructure difference: some NRENs have a hierarchical architecture that includes a national backbone, which interconnects a number of separately managed regional networks, which, in turn, connect end users. Such an NREN will have an indirect view of the organisations connected to its network. By contrast, some networks do not have regional branches, and connect institutions directly, giving the NREN a more direct view of its connected institutions.

Such diversity, although puzzling at times, is an inherent characteristic that it is important to respect and preserve, because the current shapes in which NRENs have grown come from their unique environments, which have fostered their scientific, educational and cultural communities.

The Compendium shows what NRENs are doing to meet users' requirements and to help them in their research, teaching and learning activities. It has been compiled from information provided by the people who carry out this work, from the executive directors, to technical officers, to service portfolio strategists and many more professionals. Subject matter experts reviewed all of the responses within a given area and summarised the main data points in this document.

A massive thank you to the NRENs that took the time to complete the survey and provide their views.

2 About GÉANT

In Europe, NRENs are interconnected by the pan-European GÉANT network, which, funded by the GN4-n project with 40 partners during GN4-2, the phase of the project to which this edition of the Compendium relates, is the largest and most advanced R&E network in the world.

GÉANT is a fundamental element of Europe's e-infrastructure provider landscape, delivering the pan-European GÉANT network for scientific excellence, research, education and innovation [GÉANT]. Through its integrated catalogue of connectivity, collaboration and identity services, GÉANT, together with its National Research and Education Network (NREN) partners, provides users with highly reliable, unconstrained access to communication, computing, analysis, storage, applications and other resources, whenever and wherever needed. Through the network's connections to similar infrastructures, both in Europe and across all continents, the GÉANT partnership ensures that Europe remains at the forefront of research.

GÉANT's world-class, high-speed backbone provides seamless and secure connectivity with 42 NRENs during GN4-2, reaching tens of millions of users in 10,000 institutions across Europe, and more than 100 countries worldwide through links with other regions. The core backbone is capable of multiple 100 Gbps over each fibre link, and Terabit connectivity can be achieved by a single node.

Safe and rapid connection of users to each other, to the increasing amounts of data generated by science and to the high-performance computing capacity required by collaborative research forms the foundation of the GÉANT partnership.

The focus of the GN4 Phase 2 (GN4-2) project [GN4-2] was to raise European research to the next level, promoting scientific excellence, access and re-use of research data. It also aimed to drive European-wide cost efficiencies in scientific infrastructure through the promotion of interoperability on an unprecedented scale with other e-infrastructures. GN4-2 was funded by the EC's Directorate-General for International Cooperation and Development (DG DEVCO) and ran from 2016 till the end of 2018. It has now been succeeded by the GN4-3 projects [GN4-3].

It should also be emphasised that while the GÉANT network provides mainly pan-European coverage, the project and its members currently also fund GÉANT´s international connectivity to the R&E networking partners in North America (Internet2, ESnet and CANARIE) as well as to China and Latin America (BELLA) [Internet2; ESnet; CANARIE; BELLA]. Other world regions are also connected to GÉANT, thanks to support received over the past 15 years from DG DEVCO [DGDEVCO]. Through these projects, and with the support of the GÉANT community, the GÉANT network today connects to 68 NRENs beyond its European footprint. The projects include: AfricaConnect2, supporting pan-African connectivity and interconnections to Europe; TEIN4, which interconnects the Asia–Pacific region and South Asia; EaPConnect, for the Eastern Partnership countries; as well as CAREN, in Central Asia, and EUMEDCONNECT3, in the eastern Mediterranean region [AfricaConnect2; TEIN4; EaPConnect; CAREN; EUMEDCONNECT3].

The overall objective for the GÉANT partnership is to contribute to the effective European Research Area by making Europe the best-connected region in the world. To achieve this, GÉANT must offer European researchers the network, communications facilities and application access that ensure the digital continuum necessary to allow them to conduct world-class research in collaboration with their peers around the world.

3 Key Findings

Figure 3.1 below shows the countries represented in the 2018 Compendium (i.e. whose NREN responded to the 2018 Compendium survey).

Figure 3.1: Countries represented in the 2018 Compendium (in green)

Like past Compendium surveys, the 2018 results reveal changes in the NREN landscape, although the changes are mostly gradual.

In terms of tangible resources available to NRENs, the budget they have for their activities has decreased by 2% since the last survey. One-fifth of respondents observed no change to their activity budget, and one-fifth witnessed a budget decrease. Possibly reflecting the slight decrease in NRENs' activity budgets, the overall number of personnel decreased slightly by 5%.

The expansion into the primary and secondary education sector by some NRENs has resulted in schools (mainly primary schools) now representing four-fifths of the NRENs' user base. This overall average, however, hides a large variance between the European NRENs.

The survey also covered the quality and development of the core service – connectivity – the NRENs are providing and how users take advantage of it. The typical connectivity available to universities is increasing, but year on year the changes are small. The capacities range between 1 Mbps and 100G, with over half of the respondents indicating 1G as the typical capacity for connected universities and research institutions. These two institution types are the best connected and some boast connectivity well above the typical 1G, 10G or even higher speeds being the rule in several countries.

Similarly, the actual use of the available connectivity, indicated by the volume of traffic NRENs carry, continues to increase. About a third of NRENs reported a rise in traffic, and the data highlights the wide variation in traffic from GÉANT partner NRENs. Overall, the GÉANT network recorded growth in traffic of 43% in 2018. Furthermore, this trend will likely continue: more than half of the NRENs who provided a forecast for the average traffic expected a growth of 47% by 2021, across all organisations within the NRENs' remit. Most of this traffic growth is expected in the traditional domain of the NRENs, i.e. universities and research. However, the highest growth (though small in absolute numbers) for any single user group, even before universities and research institutions, will likely come from schools, with 57% anticipated traffic growth.

Constant changes in national networks and take-up of new technologies are needed to support dynamic and growing user needs and this also is reflected in the results. Network services are an important part of any NREN's purpose, though the exact content of each NREN's service portfolio will vary. The survey registered some changes here. The number of services offered has declined (not necessarily their use, which was not part of the survey), especially in areas such as multimedia applications and web conferencing. Another finding is that the adoption of technologies such as software-defined networks or virtualisation has flatlined among NRENs compared to 2017.

On the other hand, cloud services are offered or enabled by an increased number of NRENs. An important tool here was the GÉANT IaaS Framework [IaaS Framework], which indeed saw increased use by the NRENs in 2018.

4 NREN Organisations

Outreach to end users is essential for NRENs, not only to connect research communities and offer network support, but also to provide a feedback mechanism that can inform future service development in a way that accurately reflects the end users' needs.

In recent years, NRENs have been adding new activities and services to their portfolios to support their constituencies. These new activities and services need dedicated effort and an expanded skill set not traditionally found within NREN organisations. This expansion in activity is juxtaposed with national organisations coming under increased funding pressure.

This section provides an overview of NRENs as organisations by considering changes in annual budgets and funding, staffing, participation in projects, and by looking at what has changed in NRENs' policies and portfolios.

4.1 Budget Dedicated to NREN Activities

Figure 4.1 shows the budget dedicated to the NRENs' activities. The size of the budget reflects the extent of the tasks an NREN must fulfil but also the size of the country. In addition, one-off investments can result in short-term budget expansion. As shown in Figure 4.1, the amount of budget NRENs have for activities such as networking, trust and identity, and security saw a 2% decrease in 2018, about €8 million.

One fifth of respondents observed no change to their budget (GRENA, SANET, RoEduNet, EENet, Funet, RedIRIS, KIFÜ), and another fifth witnessed a budget decrease (CARNet, UNINETT, HEAnet, BASNET, RENAM, DFN, IUCC, SWITCH).

Not all NRENs reported a decreased or flat budget in 2018. Some respondents had notable budget increases. The highest growth rates were seen in Cyprus (CyNet: 365%), Portugal (FCCN: 76%), Luxembourg (RESTENA: 69%) and Armenia (ASNET: 66%) – possibly due to infrastructure investments which inflate the budget temporarily. Increases above 10% were also noted in Ukraine (URAN), Slovenia (ARNES), the Czech Republic (CESNET), France (RENATER), Serbia (AMRES), Turkey (ULAKBIM), and Lithuania (LITNET).

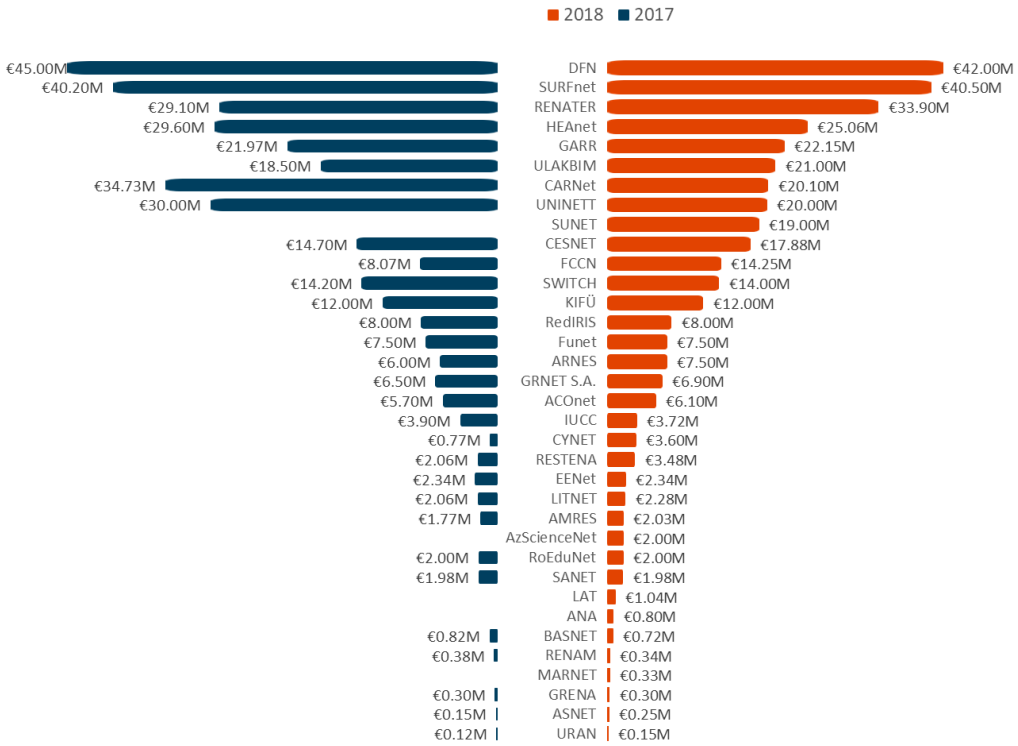


Figure 4.1: Organisation budget, 2018 vs. 2017

4.2 Income Sources

NREN funding mechanisms vary greatly: some receive all of their funding directly from the national government; others are financed entirely by their users; still others have a model based on multiple sources. Ultimately, the majority of their income derives, directly or indirectly, from public sources.

That said, some NRENs receive income from the commercial services they offer (such as domain registration fees and security). However, with the exception of MARnet, RESTENA and SWITCH, this is not a huge source of income.

While overall, the 2018 Compendium data shows there is little change in the funding sources compared with 2017, some NRENs have undergone significant change. For example, CyNet changed their funding model from a mostly client-funded approach to being funded mostly through direct government grants.

Additional detail of income source per NREN is shown in Table 4.1 below.

	CLIENT INSTITUTIONS	EUROPEAN FUNDING	GOV/ Public BODIES	COMMERCIAL	OTHER
ACOnet					
AMRES					
ANA					
ARNES					
ASNET-AM					
AzScienceNet					
BASNET					
Belnet					
BREN					
CARNET					
CESNET					
CYNET					
DeIC					
DFN					
EENet					
FCCN					
Funet					
GARR					
GRENA					
GRNET S.A.					
HEAnet					
IUCC					
Jisc					
KIFU (NIIF)					
LITNET					
MARnet					
MREN					
PIONIER					
RedIRIS					
RENAM					
RENATER					
RESTENA					
RoEduNet					
SANET					
LAT					
SUNET					
SURFnet					
SWITCH					
ULAKBIM					
UNINETT					
URAN					

OVER 75% | 25% TO 75% | LESS THAN 25%

Table 4.1 Estimated income sources per NREN, 2018

4.3 Staffing

The data presented in this section shows the staff engaged in NREN activities in full-time equivalents (FTE), for both permanent and subcontracted staff.

For the countries where results for both 2017 and 2018 surveys are available, the number of personnel decreased slightly, by about 5%, in 2018, possibly reflecting the reduction in NRENs' budget covered in Section 4.1.

The number of subcontracted staff grew by 15% compared with 2017 – again, this could reflect a less secure budget situation.

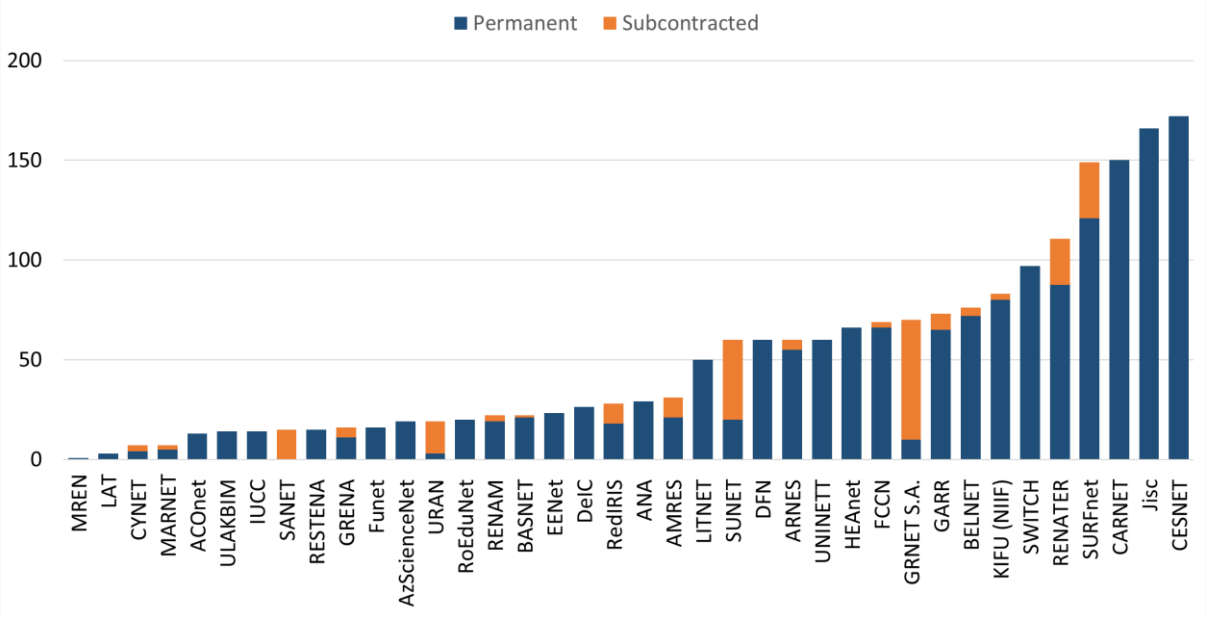


Figure 4.2 Number of staff engaged in NREN activities

Figure 4.3 provides information on the number of staff engaged in NREN activity by function. The data shows considerable differences in skill sets from NREN to NREN but generally, not unexpectedly, a high ratio of technical staff (Information Security, IT/Software development, NOC+engineering).

NRENs perform different tasks. Some provide extensive support to individual end users at institution level, some provide limited customer support, and many have service levels that are somewhere in between. These factors can have a significant effect on staff levels and functions.

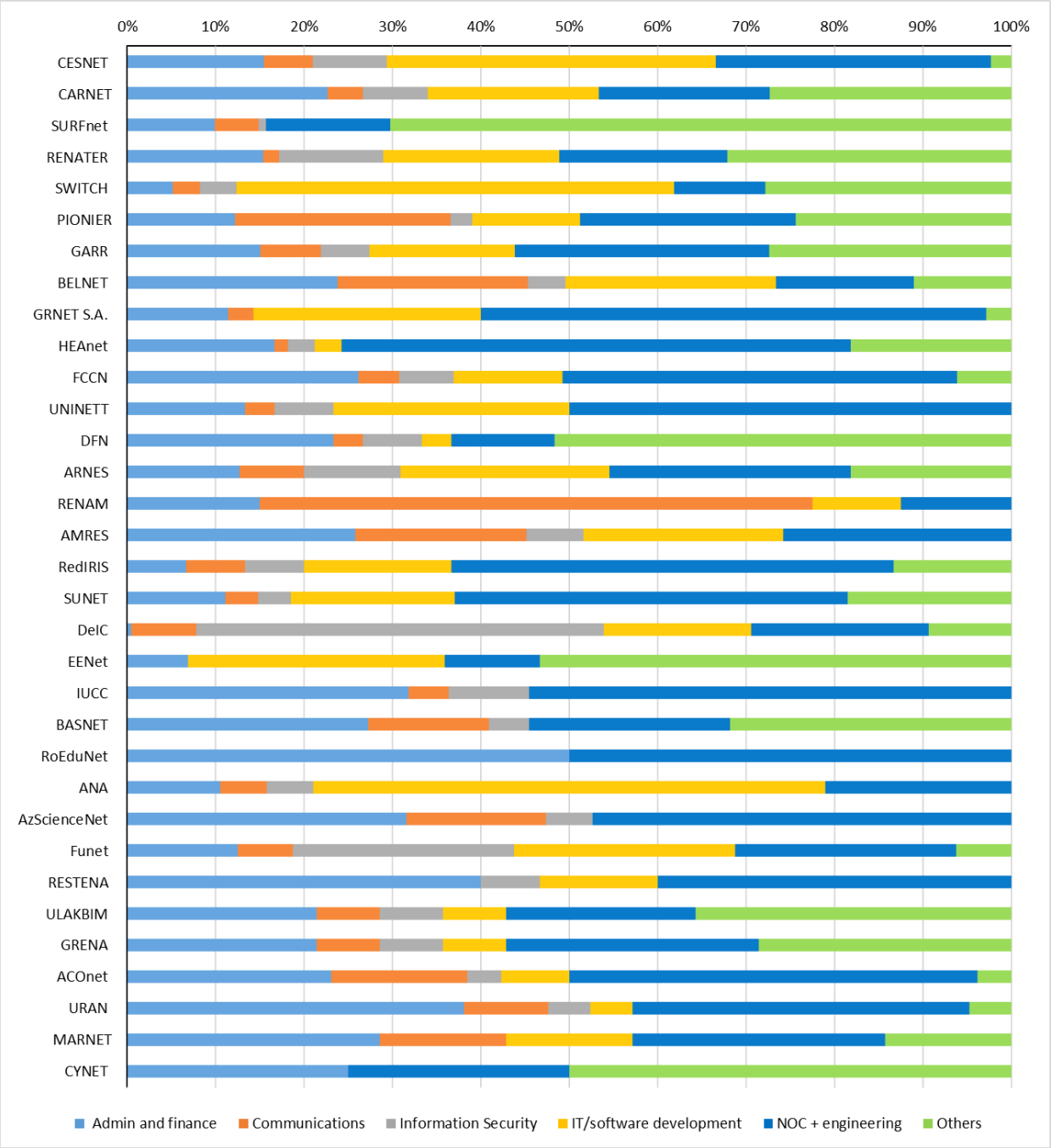


Figure 4.3 NREN staff FTE by function

4.4 Policies

Table 4.2 below gives an overview of NRENs' corporate and other policies. The 2018 Compendium shows that 36 NRENs already have an acceptable use policy, and, out of 37 respondents, 30 have a connectivity policy in place. Thirteen NRENs updated their corporate strategy over the last year.

	Acceptable Use Policy	Environmental Policy	Connectivity Policy	Updates made in corporate strategy over the last year?
ACOnet	■			
AMRES	■	■	■	
ANA	■	■	■	■
ARNES	■		■	
ASNET-AM	■	■	■	
AzScienceNet	■		■	
BASNET	■			
BELNET	■	■	■	■
CARNET	■		■	■
CESNET	■	■	■	
CYNET	■	■	■	
DeIC	■		■	
DFN	■			
EENet	■		■	■
FCCN	■		■	
Funet	■	■	■	
GARR	■		■	
GRENA	■		■	
GRNET S.A.	■	■	■	
HEAnet	■	■	■	■
Jisc	■	■	■	■
KIFU (NIIF)	■	■	■	■
LITNET	■		■	■
MARnet	■	■	■	
MREN	■		■	
PIONIER	■			
RedIRIS	■		■	■
RENAM	■	■	■	■
RENATER	■		■	
RESTENA	■			■
RoEduNet	■		■	
SANET	■		■	
SUNET	■		■	
SURFnet		■	■	
SWITCH	■			■
ULAKBIM	■			■
UNINETT	■		■	
URAN	■		■	

Table 4.2 NRENs corporate and other policies, 2018

5 End Users

The NREN end-user landscape (that is, the "end users" of the GÉANT network: universities, research institutions, etc.) has broadened considerably in recent years. Many NRENs now go beyond their traditional remit of providing connectivity to researchers and university students by also offering networking, trust and identity (T&I), mobility, security and cloud services to schools, public institutions and commercial organisations. There are many reasons for this development, including desire for better utilisation of the purchased infrastructure, expansion of value-added services that are of interest to others, and the facilitation of public–private partnerships between publicly funded and commercial research facilities.

This section provides an overview of the NRENs' formal remit, including the users and organisations that are able to connect, and current market shares of the institutions connected to each NREN. As in previous years, in order to allow a consistent categorisation across different national education systems, the classification in this section follows the ISCED 2011 classification system (the UNESCO scheme for International Standard Classification of Education) [ISCED 2011].

5.1 Who Can Connect? NRENs' Acceptable Use Policy

NRENs have different funding structures, organisational set-up and business models that define their scope and service offerings. The acceptable use policy (AUP) is a key element used to define the formal remit of NRENs, in terms of which institutions they are eligible to connect. According to the latest 2018 Compendium data, there has been a 10 percentage point reduction in the number of NRENs permitted to connect commercial (for-profit) organisations to the network (23%, down from 33% in 2017) and a further increase of 6 percentage points in those permitted to provide connectivity services to educational institutions other than universities (96%, up from 85% in 2017).

An overview of acceptable use policies for each country, including (where available) a link to the AUP, can be found in the online version of the Compendium [COMPENDIUM].

All NRENs connect universities and research institutions. Nearly all are permitted to connect institutes of further education, libraries and museums.

Connectivity to for-profit organisations is part of the remit of only about a quarter of the NRENs. Where it takes place, it often involves restrictions such as connectivity being limited to a specific research project or connectivity allowed only with the endorsement of an already connected research institution. Figure 5.1 gives an overview who can connect to NRENs.

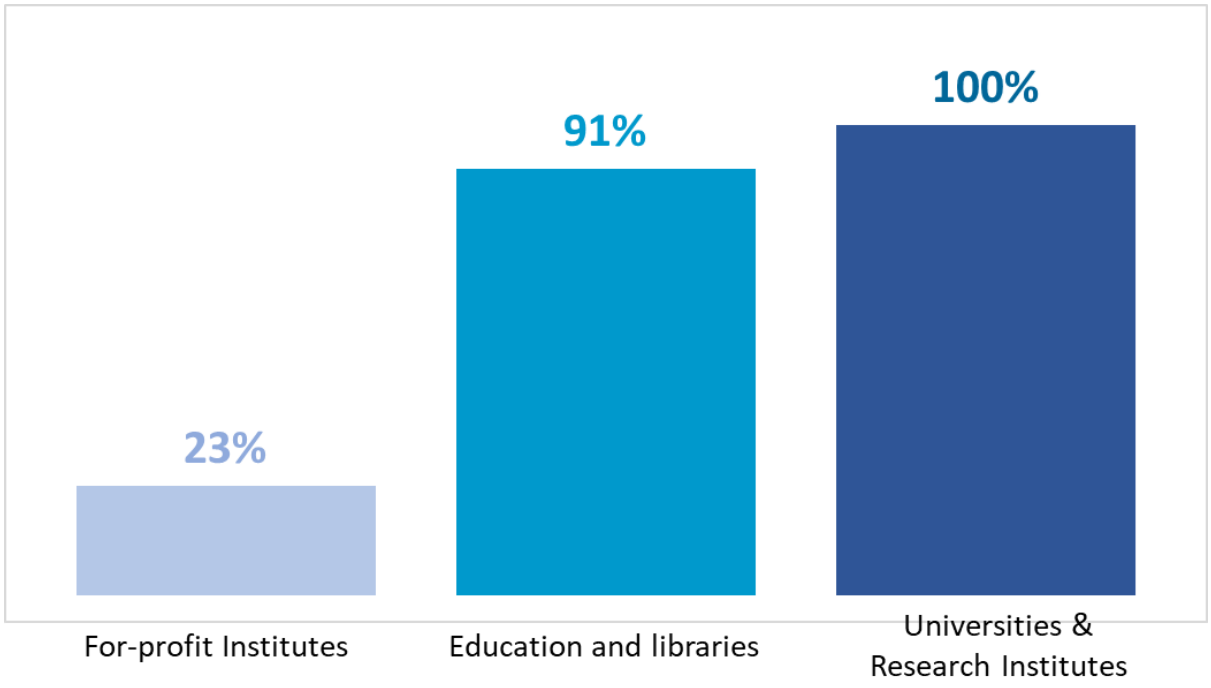


Figure 5.1: NRENs' connectivity remit

5.2 NRENs Users Landscape

The 2018 Compendium survey shows no significant changes in the make-up of the NREN user landscape, as illustrated in Figure 5.2 below.

While universities and researchers are the traditional remit of NREN activity, many NRENs provide connectivity to schools, which now represent about 80% of the NRENs' user base (mainly primary schools).

From 36 respondents, the number of schools connected to the NREN network grew slightly, by about 5%, from 32,543 (2017) to 34,357 (2018).

Some significant changes can be found in the drop of the number of connected government institutions (-14%), for-profit organisation (-16%) and hospitals (-37%).

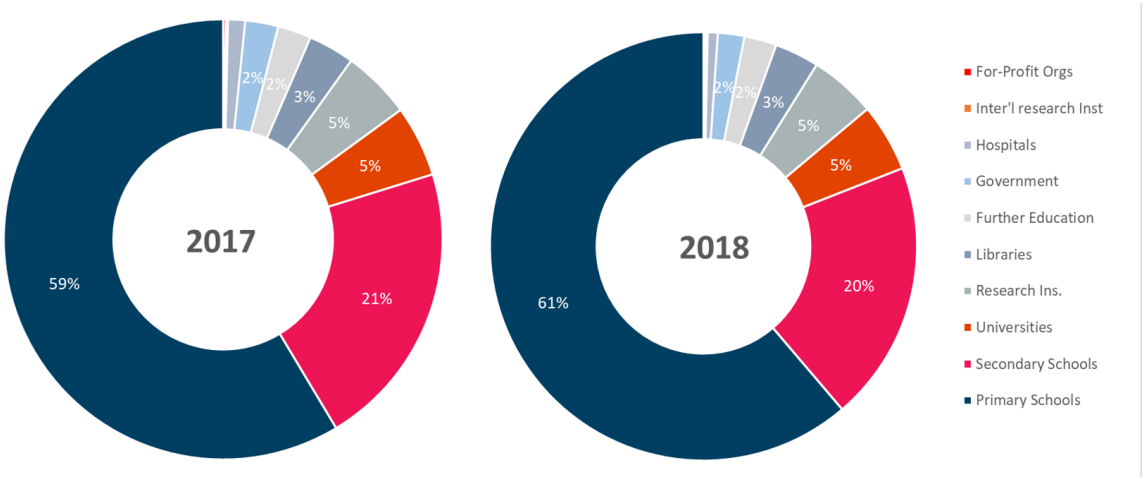


Figure 5.2 Ratio of number of institutions connected to NREN networks

5.3 Approximate Market Shares

This section covers the estimated market share per institution type, per NREN. Overall market share distribution in 2018 is comparable to that of 2017. Universities and research institutions represent the largest market share, with full or nearly full coverage across most NRENs. This reflects the formal remit of the NRENs. Where schools fall into the NRENs' remit, the NREN's market share is usually very high and the same is true for institutions of further education.

	OVER 75%			25% TO 75%					LESS THAN 25%	
	For-Profit Orgs	Further Education	Government	Inter'l research Inst	Libraries	Hospitals	Primary Schools	Research Ins.	Secondary Schools	Universities
ACOnet			60		40	60	90		90	80
AMRES		90	2		50	3	97	80	97	80
ANA			7		4			13		74
ARNES		90	10		85		93	90	90	100
ASNET-AM										
AzScienceNet								90		26
BASNET										
BELNET		1	25	1	1	5	5		5	90
BREN										
CARNet	1	5	16		1	90	95	98	95	100
CESNET		10	10	90	1	20	1	95	5	95
CYNET		50						70		100
DeIC	1	25	6	100	2			50		100
DFN										
EENet		56	4		6		7	5	28	75
FCCN										
Funet										
GARR				20	0.5	4.4	0.8	80	4.7	60
GRENA								1		
GRNET S.A.							100	100	100	100
HEAnet		5	5				98	50	100	100
IUCC										50
Jisc		100								100
KIFU (NIIF)	1	75	9		20	10	20	100	52	86
LITNET										40
MARnet										
MREN			5		90	5	90	99	90	72
PIONIER										
RedIRIS						20	55			90
RENAM		11	5		9	7		80	0.01	72
RENATER					20			100		100
RESTENA							85	96	100	80
RoEduNet		50	10		60		50	80	30	90
SANET		95	5		10	5	10	70	50	98
LAT										
SUNET		100								100
SURFnet	2	90		20	5	6	8	90	8	100
SWITCH										100
ULAKBIM		20	2		0.1					93
UNINETT		100			10			80		100
URAN	1	10	5	10	5	6		10	5	35

Table 5.1: Approximate market shares (%)

5.4 Typical and Highest Capacity of Connected Institutions

Overall, there has not been a major change in the typical connectivity to universities from 2017. The common capacity ranges from 1 Mbps up to 100G. Over half of respondents indicate 1G as typical capacity for connected universities and research institutions. These two institution types are the best connected, with the largest share of typical connectivity of 10G.

Figure 5.3 and Figure 5.4 show the typical and the highest capacity of institutions connected to those GÉANT partner NRENs who responded.

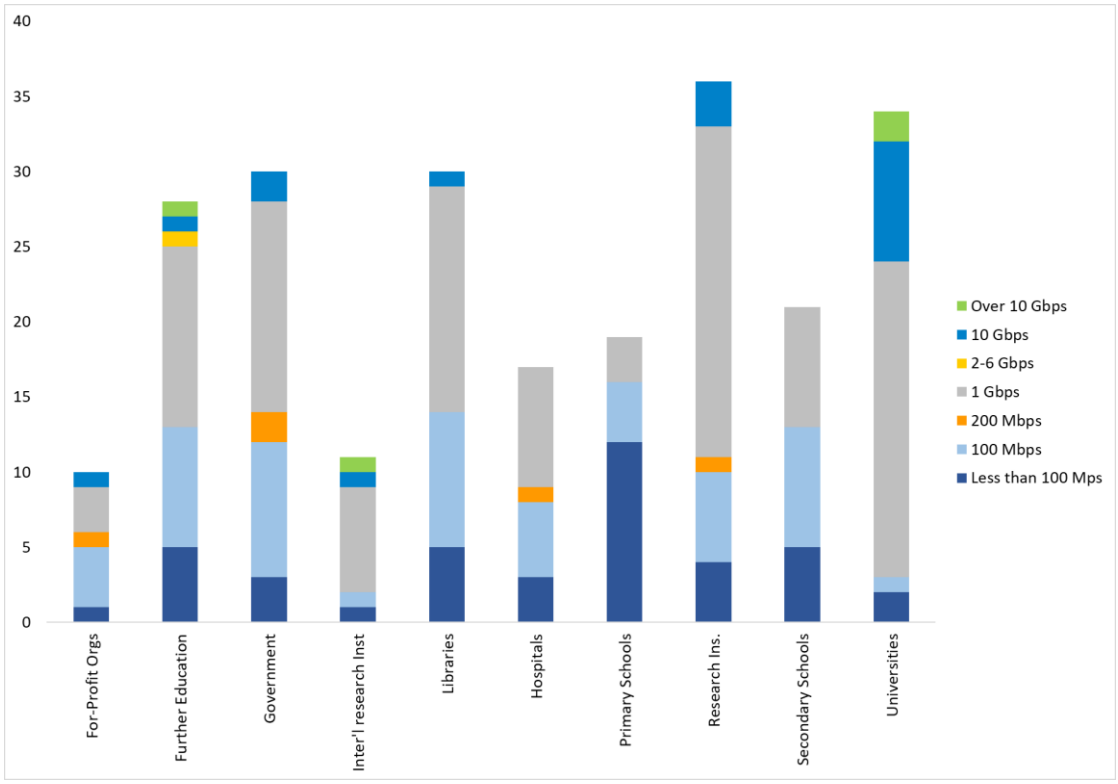


Figure 5.3: Typical capacity of connected institutions – GÉANT partner countries

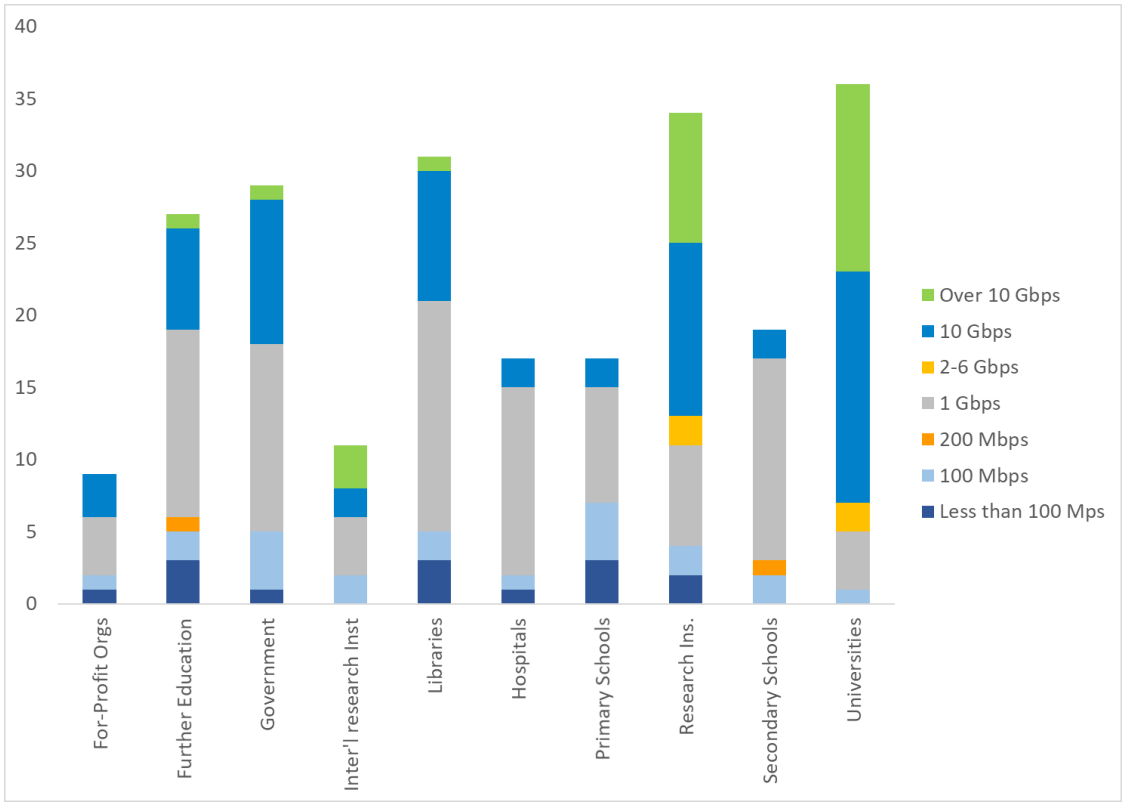


Figure 5.4: Highest capacity of connected institutions – GÉANT partner countries

5.5 Connectivity to and for Commercial Organisations

In 2018, as in previous years, a number of NRENs were connecting commercial institutions. As mentioned in Section 5.1 and shown in Figure 5.5 below, many acceptable use policies (AUPs) do not allow such connections, or limit them to specific cases, and overall the number of NRENs that can connect commercial organisations has decreased somewhat (33% of responding NRENs in 2017, 23% in 2018). However, where such connections are allowed, some NRENs actively seek to expand their user base, and view the services and collaboration potential of these other organisations as a means to do so.

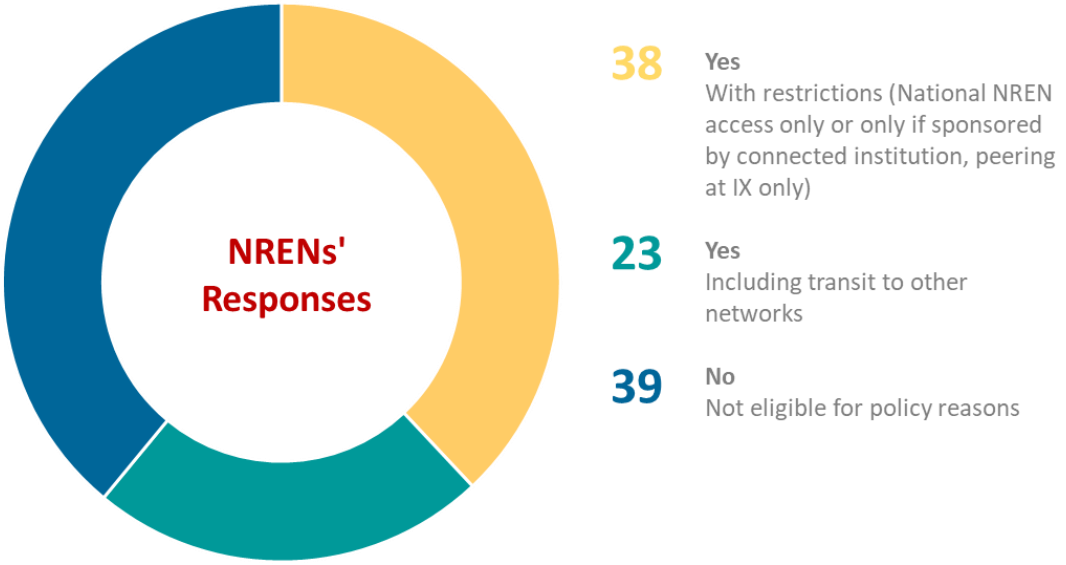


Figure 5.5 Percentage of NRENs linking to for-profit entities

Some NRENs see this expansion as a clear opportunity to secure long-term sustainability; others stress the need for a clear positioning of the NREN to not depart from their core function within a country. Figure 5.6 shows an overview of the different types of relationships NRENs are supporting with for-profit entities.

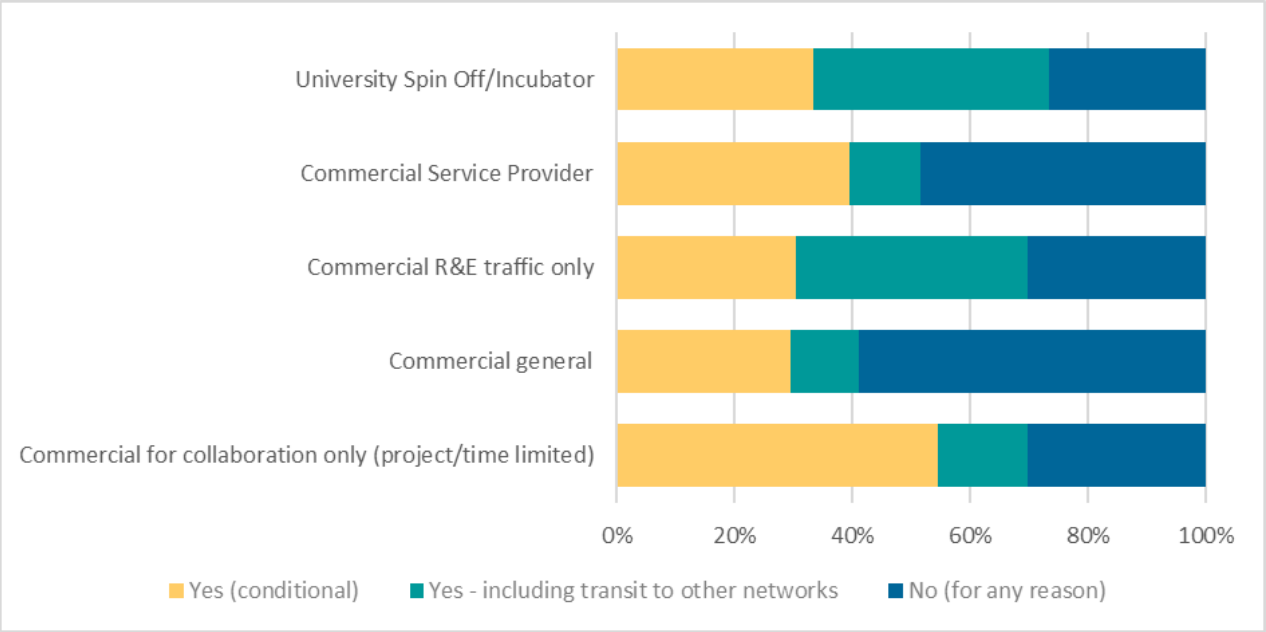


Figure 5.6 Connectivity policy for commercial entities

6 Involvement in EC Projects

6.1 NRENs' Interaction with EC Projects

In addition to the GÉANT project, there are a number of other international collaborations, particularly scientific collaborations, that bring together researchers from around the world to work together on a common research topic. These also include European projects that provide infrastructure and services to the research community. Such projects are based on the concept of providing shared ICT infrastructure, essentially centralised computing and storage facilities, which generally interact with GÉANT as a network service provider, enabling remote access from researchers to the centralised facilities.

Figure 6.1 gives an overview of NRENs' interaction with EC projects other than GN4-2. The data shows 67% of NRENs participating in a total of 56 unique EC projects. Interestingly, more NRENs were engaged in European projects in 2018 (27) than in 2017 (19), though the number of unique projects with NREN contributions was almost the same (56 and 57, respectively).

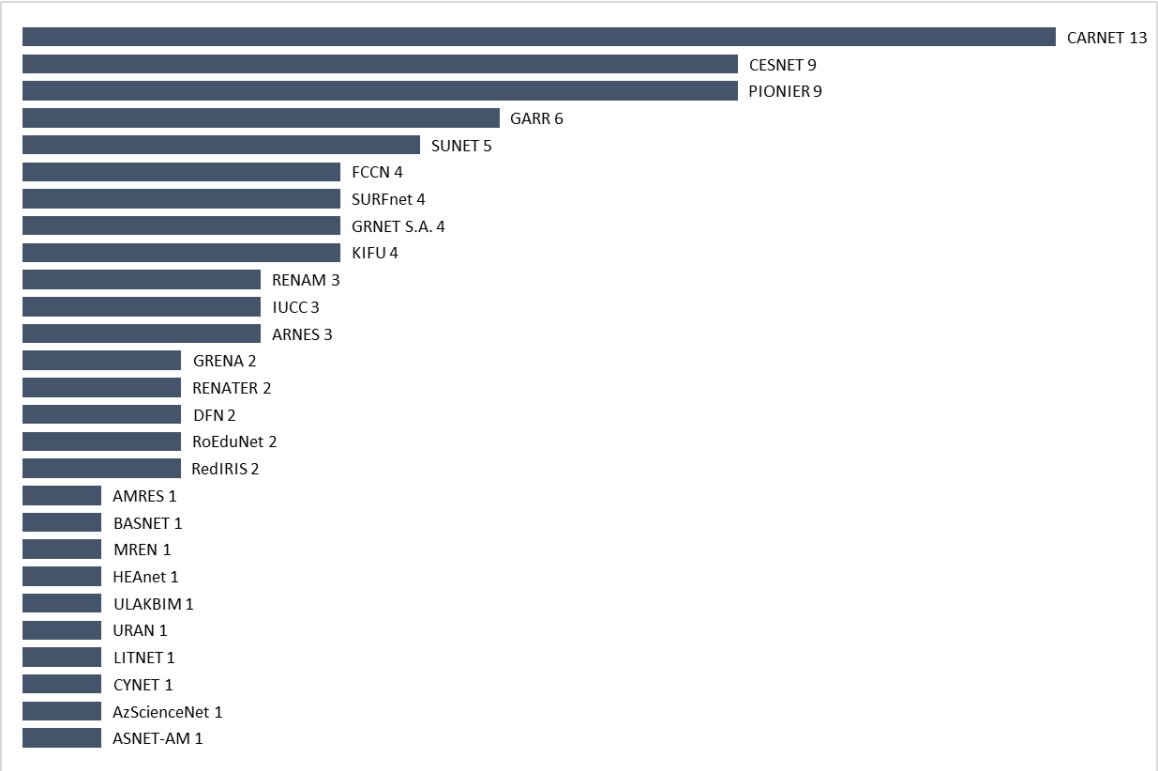


Figure 6.1: NRENs' interaction other European projects – total projects per NREN

6.2 International Research Projects

NRENs also support pan-European user communities, usually working closely with GÉANT.

Interactions between a lead NREN, users, GÉANT account managers, and the relevant subject matter expert teams define the requirements of a potential new service. Proposals are then jointly reviewed with the involved NRENs to ensure the service is fit for purpose and all the parties involved have operational visibility.

A range of user communities and projects in a number of areas around the world are supported in this way, including:

- **Energy**: Nuclear power, future energy research, anything to do with the science that keeps the lights and computers turned on around the world. An example would be International Thermonuclear Experimental Reactor (ITER) [ITER].
- **Earth and Environmental Sciences**: Earth observation, climate monitoring, water quality, volcanoes, and sustainable development are some of the subject areas that are covered, assisting organisations such as: Group on Earth Observations, WMO, ESA, EUMETSAT and the COPERNICUS project [GEO; WMO; ESA; EUMETSAT; COPERNICUS].
- **Social Sciences**: Examples from the social sciences, including music, art and languages, include CLARIN, DARIAH [CLARIN; DARIAH].
- **Physical Sciences**: Projects include SKA, JIVE, NEXPReS, LIGO-Virgo for observational science [SKA; JIVE; NEXPReS; LIGO-Virgo], but also the likes of CERN [CERN] and the High-Energy Physics community (LHC, BELLE2, NOvA, etc.[LHC; BELLE2; NOvA]).
- **e-infrastructures**: Assist and provide services to the infrastructures who deliver complementary services to research communities, including PRACE, EUDAT, EGI and others [PRACE; EUDAT; EGI].

Future challenges will be in the areas of High-Performance Computing or large-scale data distribution, which will need a powerful network and services infrastructure able to support them.

7 NREN Service Portfolio

In recent years, the role of NRENs has become more than just connectivity and commodity provider. Constant changes in national networks and take-up of new technologies are needed to support dynamic and growing user needs. NRENs therefore need to have the ability not only to satisfy the current requirements of their user communities, but also to look ahead and develop a service portfolio that will meet future requirements.

This section gives an overview of the services NRENs offer their end users. There have been some changes in the numbers of these since the previous survey. Overall, the number of NREN services offered to end users decreased by 9%; this follows an overall increase of 22% in 2017. The decrease is mostly due to a drop in the number of multimedia services (a 58% decrease, following an increase of over 100% in 2017). Network services increased by 25%, continuing the trajectory of 2017, which saw a 42% increase. Security and T&I services dropped slightly (by 5%, after an 11% increase in 2017), and professional services such as Web/desktop conferencing, user conferences, consultancy and training decreased by 25% (after an increase of 9% in 2017).

A table showing all services on offer across GÉANT partners is available on the Compendium website [SERVICES].

Figure 7.1: NRENs' end-user services

8 Network

The term “network” can cover a broad spectrum of infrastructure and communications technologies at varying levels of granularity and complexity. Within this section, the term refers to a snapshot of the services, infrastructure and monitoring tools that GÉANT and the NRENs use to connect their users.

NREN networks, like the countries in which they reside, are each unique and are tailored to fit the community they serve, within the limits of the resources at their disposal. This section presents an overview of NREN network traffic, infrastructure and services.

8.1 Network Traffic

This section considers the rate of growth of NREN traffic and how the traffic type and destination have changed over time. Figure 8.1 and Figure 8.2 show the total amount of traffic per NREN, from external networks and from NREN end users, respectively, for 2016 to 2018. The numbers provided in this section have been augmented with data from GÉANT’s Deepfield application, to provide a deeper understanding of traffic patterns, traffic growth and other sources and types of data on the network.

The volume of traffic that NRENs carry continues to rise. About a third of NRENs reported an increase in traffic, and the data highlights the wide variation in GÉANT partner NRENs’ traffic volumes: from Jisc, with more than 470,000 Tbytes of data from outside the NREN to ANA/RASH, with 65 Tbytes.

“External networks” (Figure 8.1) denotes sources that are outside the NREN’s domain, such as GÉANT, general/commercial Internet, Internet exchange, peerings, other NRENs.

“NREN end users” (Figure 8.2) denotes sources that are part of the remit of an NREN’s domains.

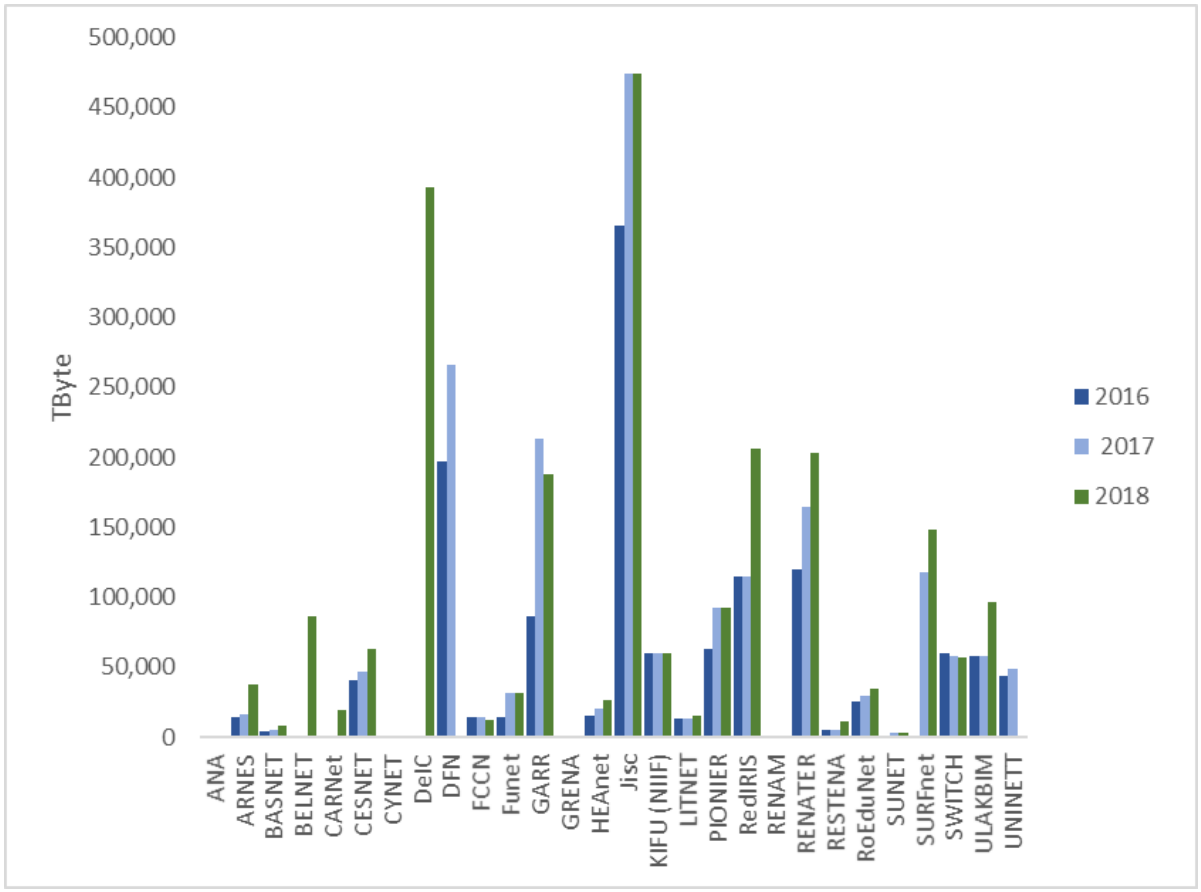


Figure 8.1: NRENs' traffic from external networks – January to December 2016 to 2018

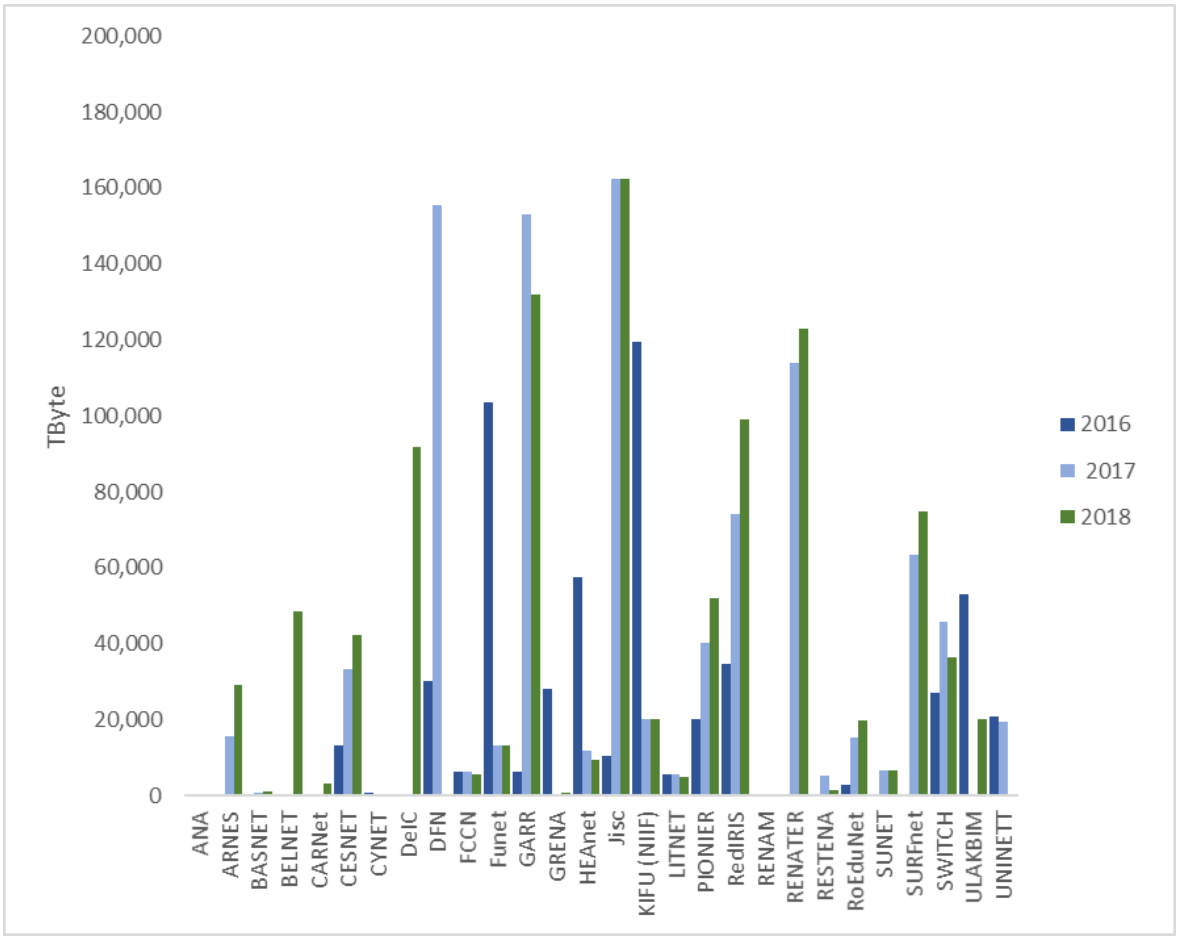


Figure 8.2: NRENs' traffic from NREN end users – January to December 2016 to 2018

8.2 Traffic Growth Forecast

The 2018 Compendium survey again asked the NRENs what they anticipate the growth in their traffic to be, by institution type, over the next three years, a question first introduced in 2017.

The data indicates that over half of the 27 NRENs who responded forecast the average traffic growth to be circa 46% by 2021, across all institution types within the NREN's remit. The equivalent figure in the 2017 survey was 49%.

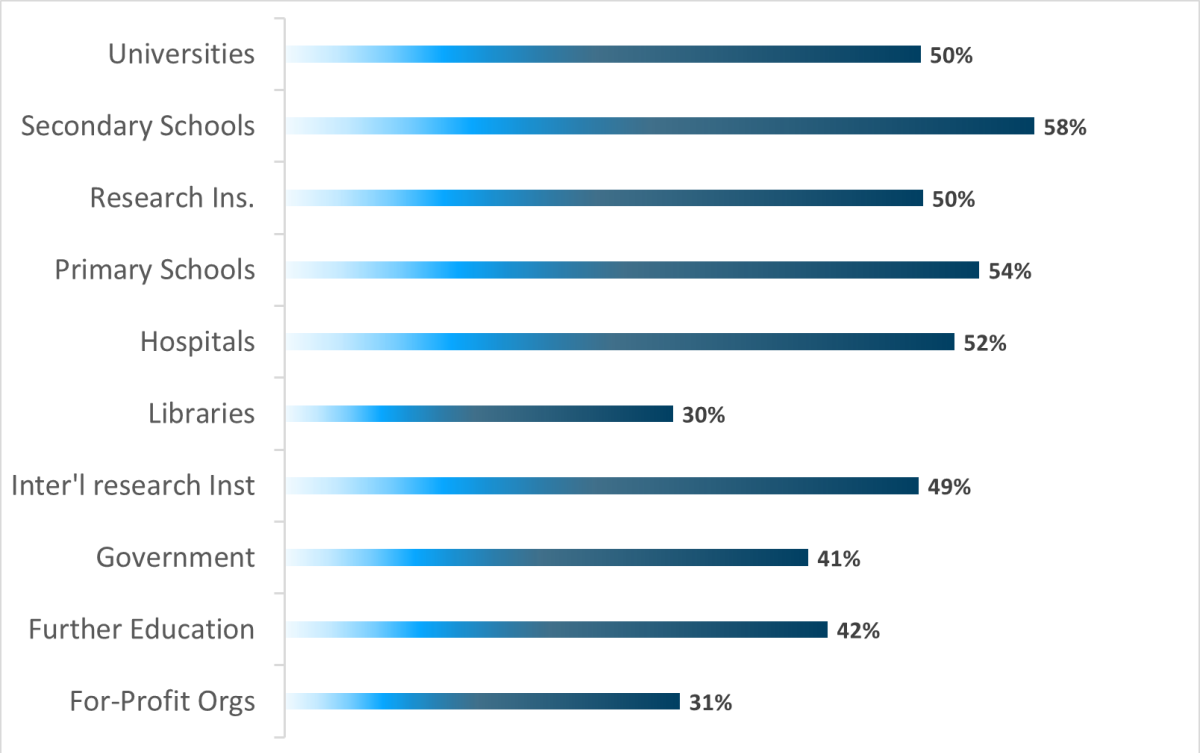


Figure 8.3: NRENs' forecast traffic growth by institution type (based on 27 responses)

The highest anticipated growth rates are in the school sector. This is in line with the NRENs' expansion into this sector, as discussed in Section 5.2 and Section 5.3, but the forecast traffic growth rate in other categories of institutions is not far behind. Note, however, that these growth numbers are percentages – the actual traffic volume is vastly bigger for universities and research institution than it is for schools, the latter having much more modest needs.

Table 8.1 below gives an overview of the expected traffic growth over the three-year period 2018 to 2021, by NREN and by institution type.

	For-Profit Orgs	Further Education	Government	Inter'l research Inst	Libraries	Hospitals	Primary Schools	Research Ins.	Secondary Schools	Universities
ACOnet		50	50		50	50	100	50	100	50
ANA		20	10		10			30		40
ASNET-AM								80		80
AzScienceNet					40			50		50
CESNET		5	5	10	5	5	5	10	5	10
CYNET		25						20		25
DeIC		30	30		30			30		30
EENet		30	15		35		30	50	40	30
FCCN			50	20				50	99	70
Funet			100		31			60		31
GARR	20		20	100	20	100	100	100	100	100
GRENA			80	100	100	100		100		100
GRNET S.A.		40	10		10	40	40	30	40	30
HEAnet		30					40	30	41	30
IUCC					20			20		1
Jisc	50	90	50	50	50	50	90	90	90	
KIFU (NIIF)		100	100	100	50		100	100	100	100
MARnet										100
MREN			10		10			10		30
RedIRIS		75	30		40		90	60	90	70
RENAM		10								20
RoEduNet		20			30		20	100	20	30
SigmaNET		20						20		20
SUNET		90						99		99
SWITCH	35	35	35	35	35	35	35	35	35	35
ULAKBIM		50	50		50			50		60
UNINETT										8
URAN	80		90	30	20	90		20		90
	OVER 40		LESS = 40							

Table 8.1: Forecast traffic growth by NREN and institution type 2018 to 2021

8.3 IPv6

IPv6 became a draft RFC in 1998. However, adoption was initially very slow. IPv6 remains the most recent version of the internet protocol (IP) and its continued take-up is important to network evolution as IPv6 simplifies routing and supports further growth of the number of connected hosts, as well as transmitted data traffic.

The deployment of IPv6 among network providers in general has reached an estimated 80–90% within their networks (usually running in parallel with "traditional" IPv4 networking). R&E networks are no exception, with close to 80% of NRENs offering IPv6, while GÉANT has implemented IPv6 across the whole network, with 100% of the network now fully IPv6-enabled.

However, the data volumes using IPv6 over commercial networks are still quite low. As an example, the Amsterdam Internet Exchange (IX) transfers an average of 3.7 Terabits per second of which less than 3% is IPv6 traffic.

By contrast, as can be seen in Figure 8.4, R&E networks have seen substantial increases in traffic using IPv6 in 2018/19.

In April 2018 the GÉANT network was transferring an average of 20 Gbps of IPv6 traffic (approximately 6% of total traffic) and only 12 months later this has increased to an average of 110 Gbps or 22% of total traffic – an increase of 5.5 times.

Detailed analysis of this increase is still ongoing, but there are some indications that this traffic is associated with the many "big science" projects that use GÉANT's network to transfer and share data. Figure 8.4 shows the IPv6 traffic average into GÉANT from its NREN partners during December 2018. A large part of the IPv6 traffic into the NRENs originates from CERN. Overall, about 25% of GÉANT traffic is now IPv6. This large growth is a positive sign that the R&E community is leading the field in IPv6 adoption. GÉANT believes that this will bring benefits to the community and ensure sustainability and robustness of the networking infrastructure.

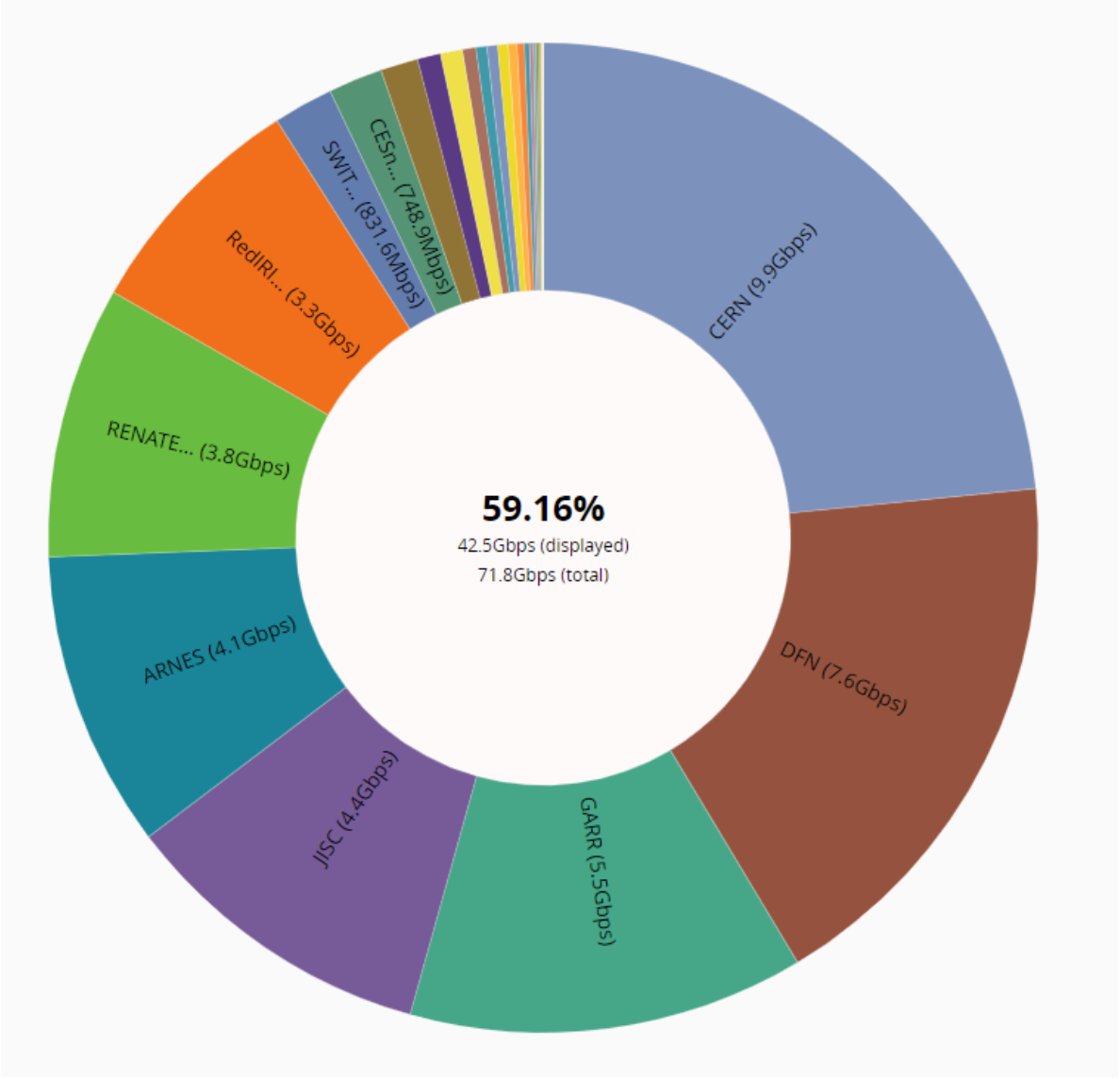


Figure 8.4: GÉANT IPv6 – top NREN traffic sources December 2018 [Source: GÉANT Deepfield tool]

8.4 Network Infrastructure: Dark Fibre

Dark fibre refers to fibre leased or purchased from another supplier in the dark (i.e. unlit state), hence the name “dark” fibre. The fibre is then lit by the NREN using dense wavelength division multiplexing (DWDM) transponders and amplifiers.

The NREN community has substantially increased its ownership of dark fibre over recent years. In 2018, the NRENs reported a total of around 150,000 km of dark fibre, 20,000 km more than in 2017. Together with the GÉANT install base of around 11,000 km of intercity dark fibre, this forms a strong community infrastructure.

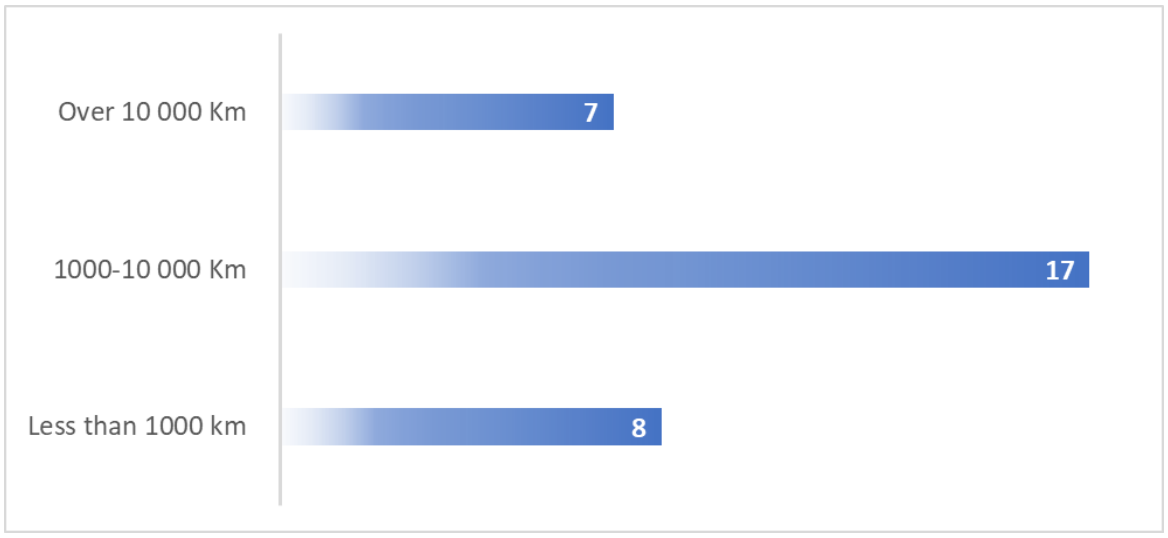


Figure 8.5: Number of respondent NRENs / length of dark fibre

GÉANT’s dark fibre infrastructure remained the same in 2018/19 compared to previous years. However, GÉANT is in the process of procuring a new dark fibre footprint to replace the existing fibre leases, which expire in 2020. The new fibre will provide access to nearly every country in Europe and

the upgrade will result in around twice as much dark fibre as the current network.

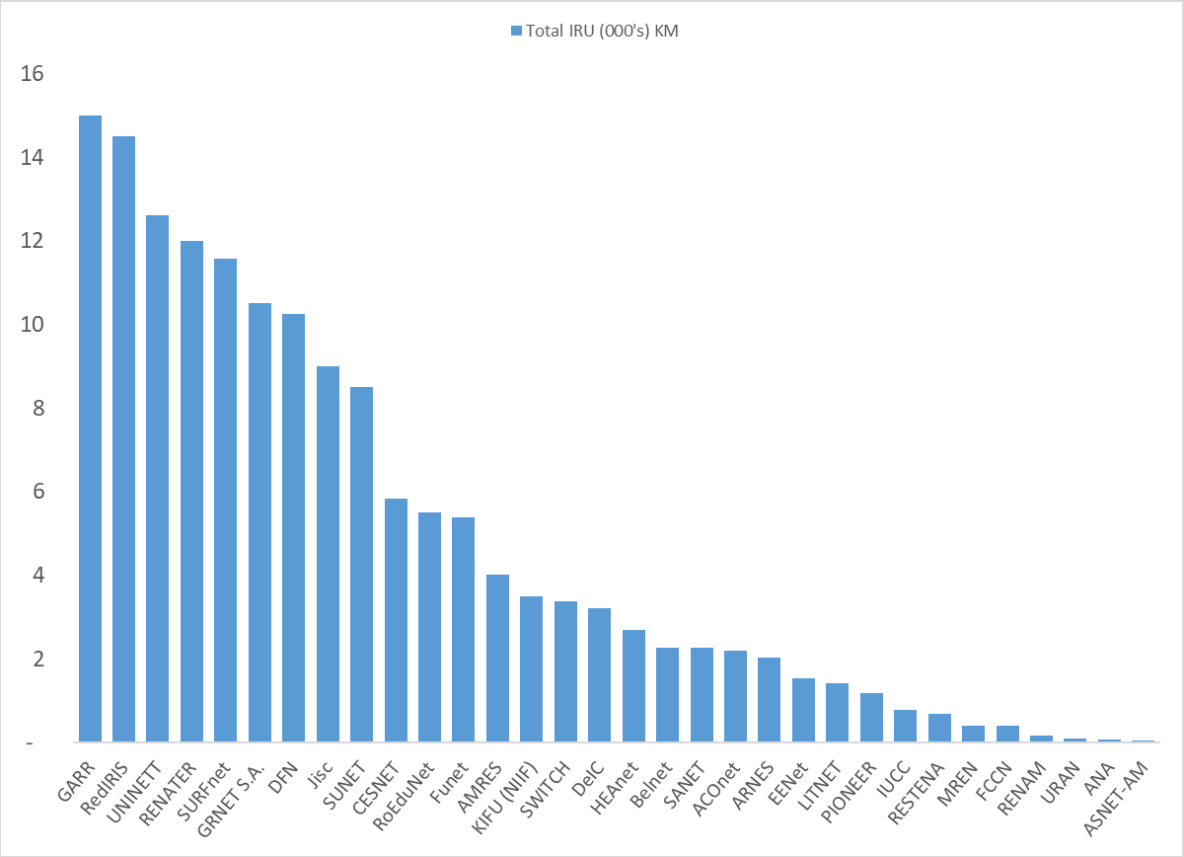


Figure 8.6: Number of kilometres of NREN IRU network

Figure 8.6 below shows the number of kilometres of fibre (also known as indefeasible rights of use (IRU)) each NREN reported in its own network.

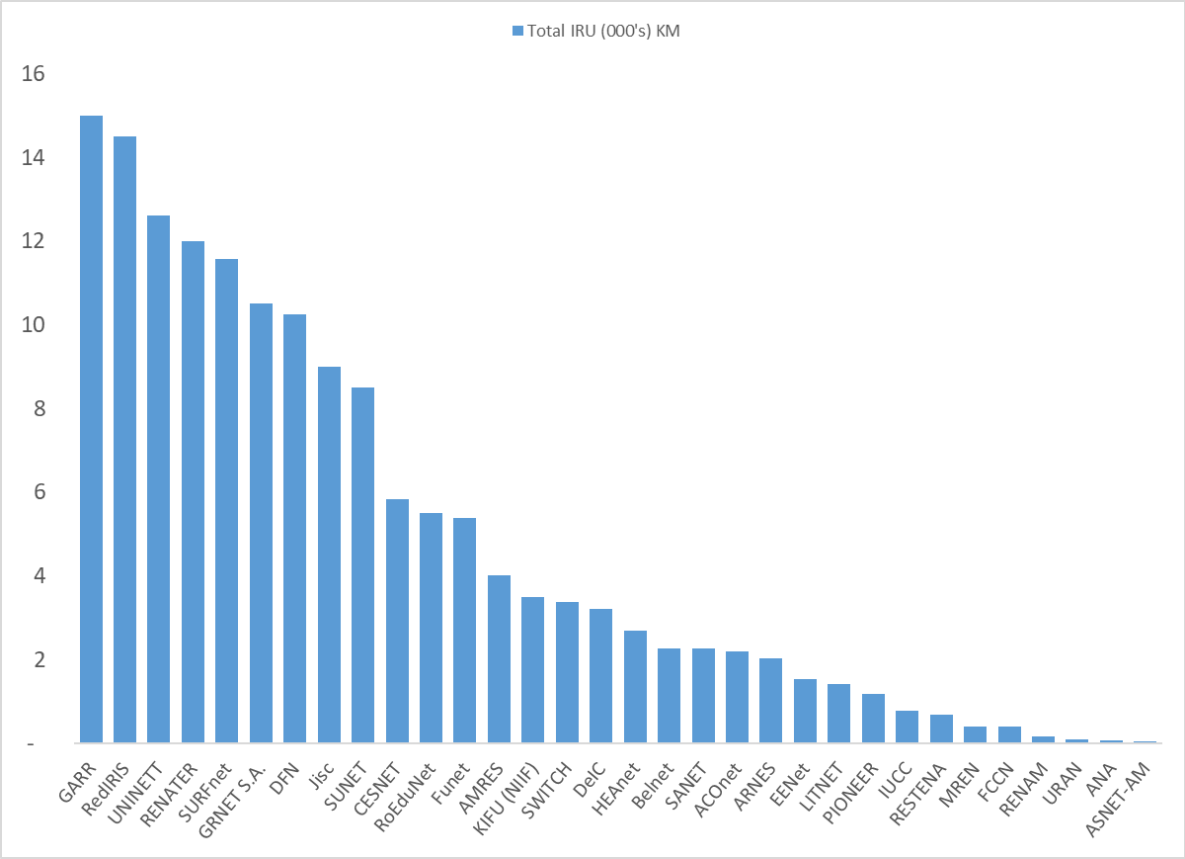


Figure 8.6: Number of kilometres of NREN IRU network

8.5 Alien Waves

In the optical transport world, the term “alien wavelength” or “alien wave” (AW) is used to describe wavelengths in a DWDM line system that traverse the network but are not sourced/terminated by the line-system operator’s equipment. This setup is in contrast to traditional DWDM systems, where the DWDM light source (transponder) operates in the same management domain as the amplifiers.

Alien waves are an important part of infrastructure sharing as the use of this technology is an important prerequisite for dark fibre spectrum to be shared between multiple research network providers.

According to the survey results, the number of NRENs making use of alien waves (5) is the same as in 2017. The majority of European NRENs who responded (29) are currently not using alien waves but some (7) plan to do so soon.

In 2019 GÉANT and the NRENs will be working together to pool their dark fibre resources through the Spectrum Connection Service sub-task in GN4-3 WP7. This Task aims to build on the work in JRA1 T1 in GN4-2 which fostered spectrum sharing. WP7 will formalise a service within GÉANT and the NRENs that will allow NRENs to get alien wave or spectrum services from GÉANT to build their own international services.

Examples of spectrum sharing currently in use in the NREN community include:

- NORDUnet has taken steps towards building its entire network using spectrum provided by its local NREN members.
- GÉANT will offer a new service in GN4-3 called the Spectrum Connection Service. This service will allow NRENs to inject coloured DWDM light directly into the GÉANT network without the cost of OEO conversion at the GÉANT/NREN interface.
- GÉANT will make use of as much NREN spectrum as possible when building the new network in 2020–2022. For example, the GÉANT link from Copenhagen to Helsinki is planned to make use of spectrum provided by NORDUnet/SUNET.

8.6 IP Trunks

NREN fibre is increasingly being lit using 100G technology. Twelve NRENs have reported having IP trunks of 100 Gbps or above (compared with 10 in 2017). As can be seen in Figure 8.7, from the 38 NRENs respondents, 13% posted an increase in usable backbone capacity from 2017.

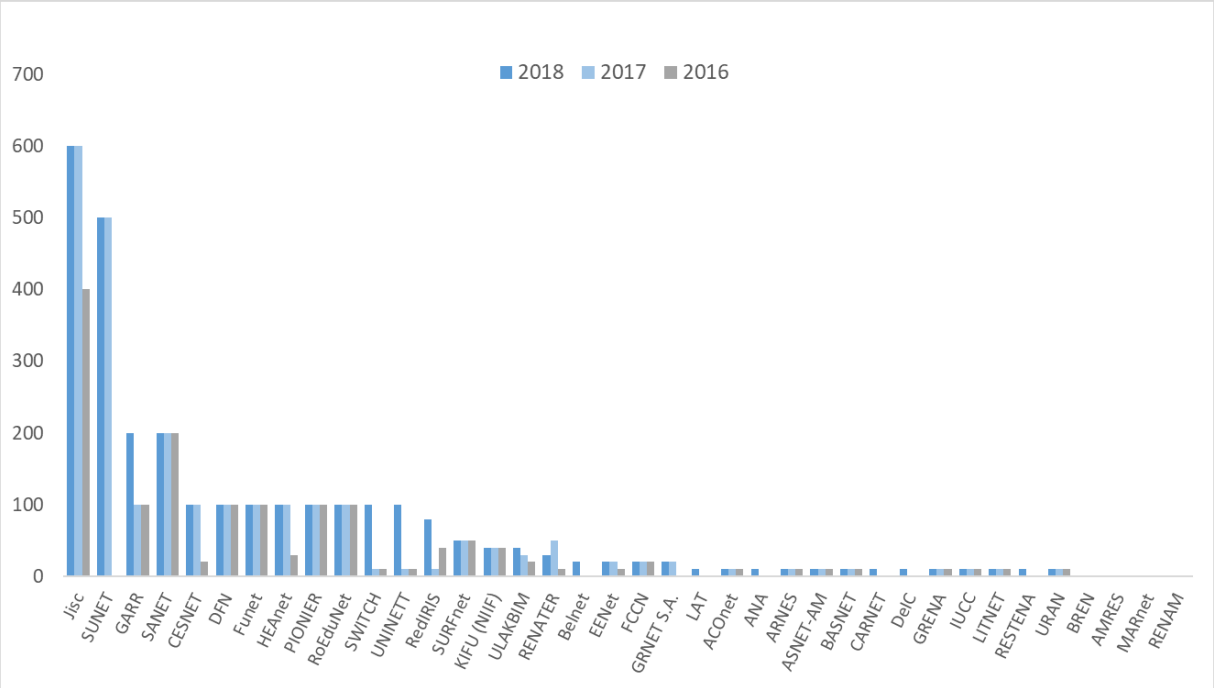
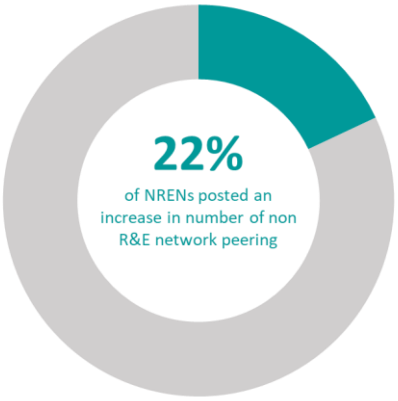


Figure 8.7: NRENs' typical core usable backbone IP trunk in Gbps 2016 to 2018

8.7 Network Peering

"Network peering" refers to the direct exchange of Internet traffic between two networks. Most NRENs have at least some direct peering with commercial networks and content providers. Settlement-free peering offers the possibility of saving fees for upstream traffic but has the added cost of a presence in an Internet exchange.



Overall, the number of non-R&E peering networks is higher than in the 2017 survey (2,504 in 2018 compared with 2,225 in 2017, an increase of 13%). However, while many NRENs reported small increases in peering numbers, the main reason for the increase is the higher response rate (36 NRENs reported their non-R&E peering network numbers in 2018 while only 30 NRENs did so in 2017).

Of the 36 NREN respondents, 8 (22%) posted an increase in the number of non-R&E peering networks. The steep drop in peering numbers in the case of the Ukrainian NREN, URAN, reflects a more accurate data collection method rather than a dramatic loss of peering partners.

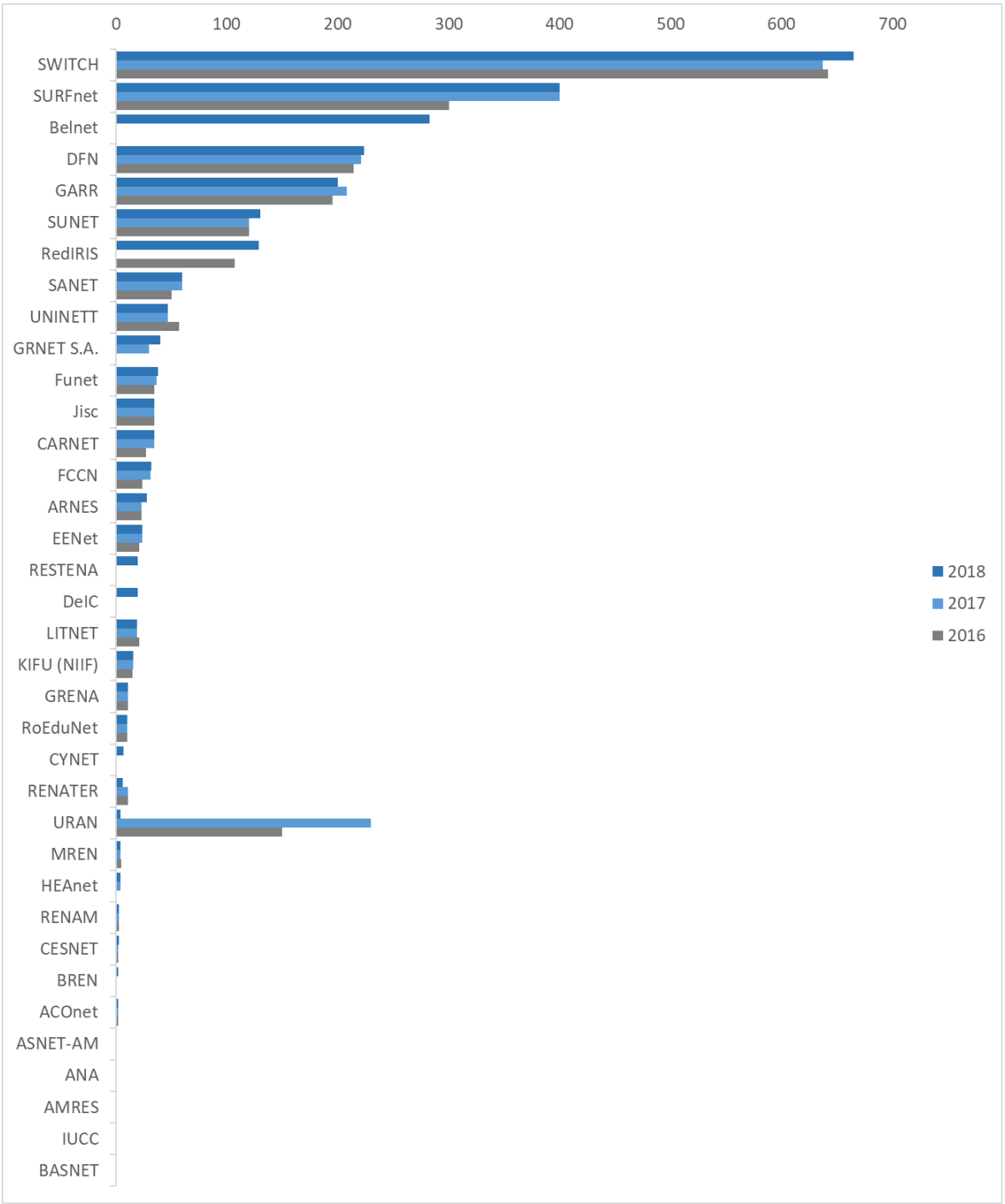


Figure 8.8: Number of non-R&E peering networks 2016 to 2018

8.8 Network Innovation: SDN and NFV

8.8.1 SDN

As in previous years, NRENs are actively deploying software-defined networking (SDN) in their networks. Of the 41 NRENs that responded on SDN, 10 are using it and 13 are planning to use it. The majority are using either NETCONF or OpenFlow APIs [NETCONF; OpenFlow]. The preferred SDN controller is ONOS (5 NRENs) [ONOS].

Among the 23 respondents, SDN is intended to be used as follows (note the figures total >100% as some NRENs are using SDN for multiple purposes):

Pilot services	35%
Production services	30%
Testbed facility for researchers	61%
To provide/support other operational services	30%
Other	13%

These responses show that SDN is still a matter of interest to the NREN community. It should be noted that SDN seems to have found some specialised uses, in particular as testbeds. This use is also the only one where a noticeable increase has been recorded (61% in 2018 vs. 47% in 2017); the other uses plateaued or showed only minor changes.

8.8.2 NFV

Network Function Virtualisation (NFV) is the process of moving network functions (such as firewalls) off bespoke hardware and into software. In this model, new functions can be rapidly instantiated when needed by the customer.

In the 2018 Compendium survey, 20 NRENs responded that they are either using or planning to deploy NFV in their network. The responses were divided up as follows (note the figures total >100% as some NRENs are using NFV for multiple purposes):

Firewalls	70%
Load balancers	30%
Routers/switches	65%
VPN concentrator services	50%
Other	14%

As with SDN, changes in the use of NFV compared to 2017 were minor, though mostly showing slight decreases.

8.9 GÉANT Network Updates

8.9.1 GÉANT Network and Statistics

The GÉANT network interconnects 44 networks in Europe and has 31 active routers and 19 Infinera nodes. This section presents a snapshot of the GÉANT network, including statistics such as IP/MPLS traffic growth.

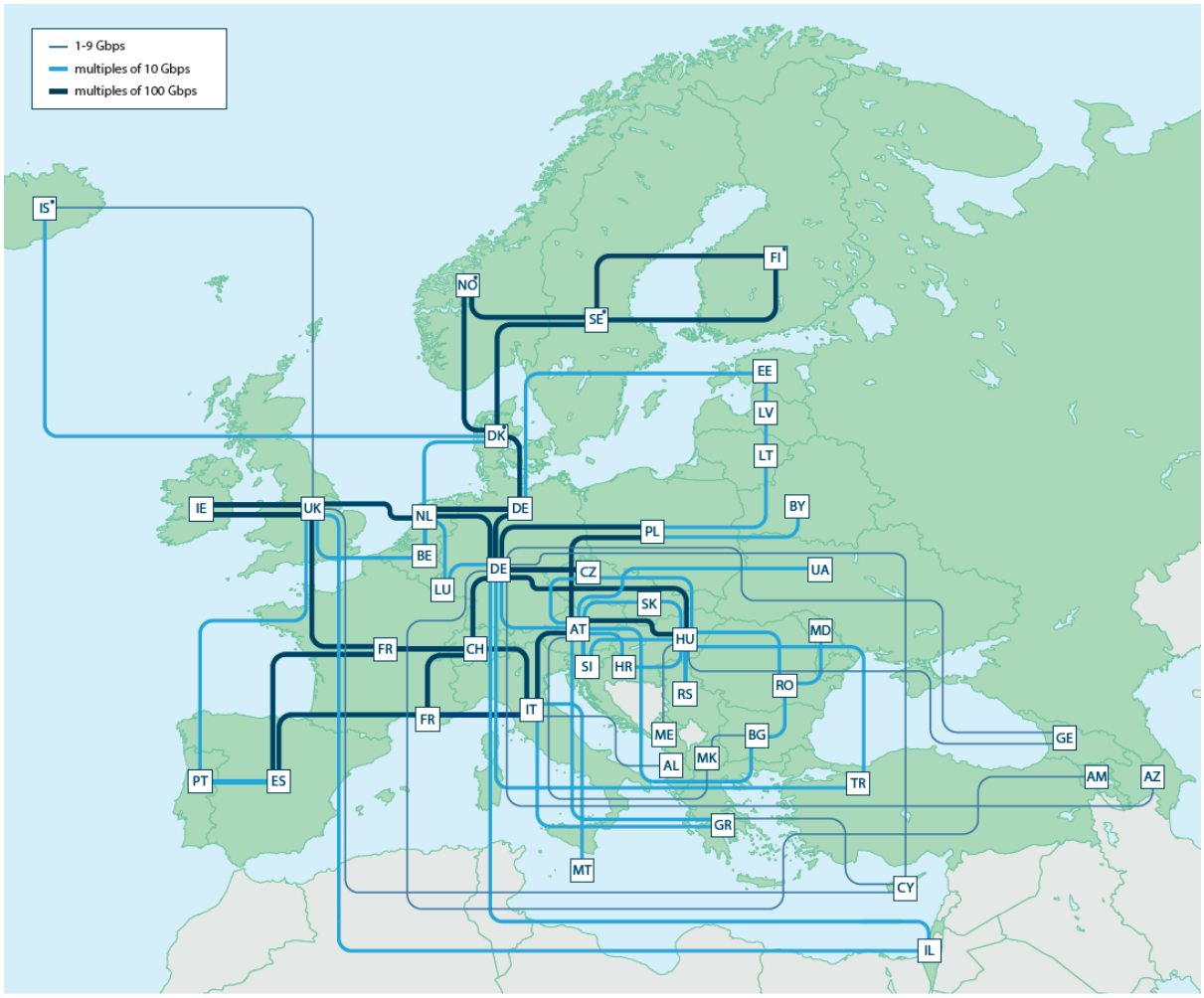


Figure 8.9: GÉANT pan-European network topology map (December 2018)

The GÉANT network is divided into two parts: the Infinera dense wavelength division multiplexing (DWDM) network and the Juniper-based internet protocol/multiprotocol label switching (IP/MPLS) network [Infinera; Juniper]. The Infinera DWDM runs on dark fibre, providing 10G and 100G lambdas, either for use as links on the IP/MPLS network or to be sold as lambda services. The IP/MPLS network provides all other GÉANT services. Of the two, there is more extensive traffic information for the IP/MPLS network.

The IP/MPLS network received over 750 Gbps of traffic at peak time, with a daily average of over 470 Gbps towards the end of the year. The year-on-year (YoY) growth rates on the IP/MPLS network

slowed down further in 2018 to 30%, vs. the 33% recorded for 2017 and the 64% for 2016. Science data growth was still faster than the Internet service, with 32.5% vs. 22.5%. IP/MPLS YoY averaged growth rate for the rolling three-year period for which data is available is at 31% (down from 47% for the period to 2017).

The busiest part of the network is still the Western Ring, where IP/MPLS links are currently at 300G, with daily peaks now reaching 150 Gbps, 200+ Gbps when rerouting (an increase of 50 Gbps compared with 2017). In terms of the daily average for 2018, the IP/MPLS network received 4.06 PB of data (up by .93 PB on 2017). The total, including lambda services, is 6.6 PB (up by 1.81 PB on 2017).

8.9.2 GÉANT Evolution

8.9.2.1 *Transmission*

The GÉANT network is primarily an IP backbone to interconnect the NRENs, built on a combination of dark fibre and lease circuits. At the heart of the network is the objective to achieve an uncongested capacity and high-availability network. With the projected exponential traffic growth driven by the requirements of big science projects such as LHC, SKA and others that have large – and sometimes unpredictable – requirements, and the desire to provide a platform for the integration of e-infrastructures, GÉANT has been reviewing its transmission technology.

In 2018 GÉANT has made use of the PRISM framework contract, in place since 2015, to procure Infinera's Groove Data Centre Interconnect (DCI) equipment. This equipment has been used to add new IP trunks to the GÉANT network. The Western Ring of the GÉANT network now uses the Grooves to deliver 300G IP trunk circuits between all routers. The cost savings of using this equipment have been significant and in the second half of 2019 it is planned to deploy the Groove equipment in the Eastern part of the network as and when increased capacity is needed.

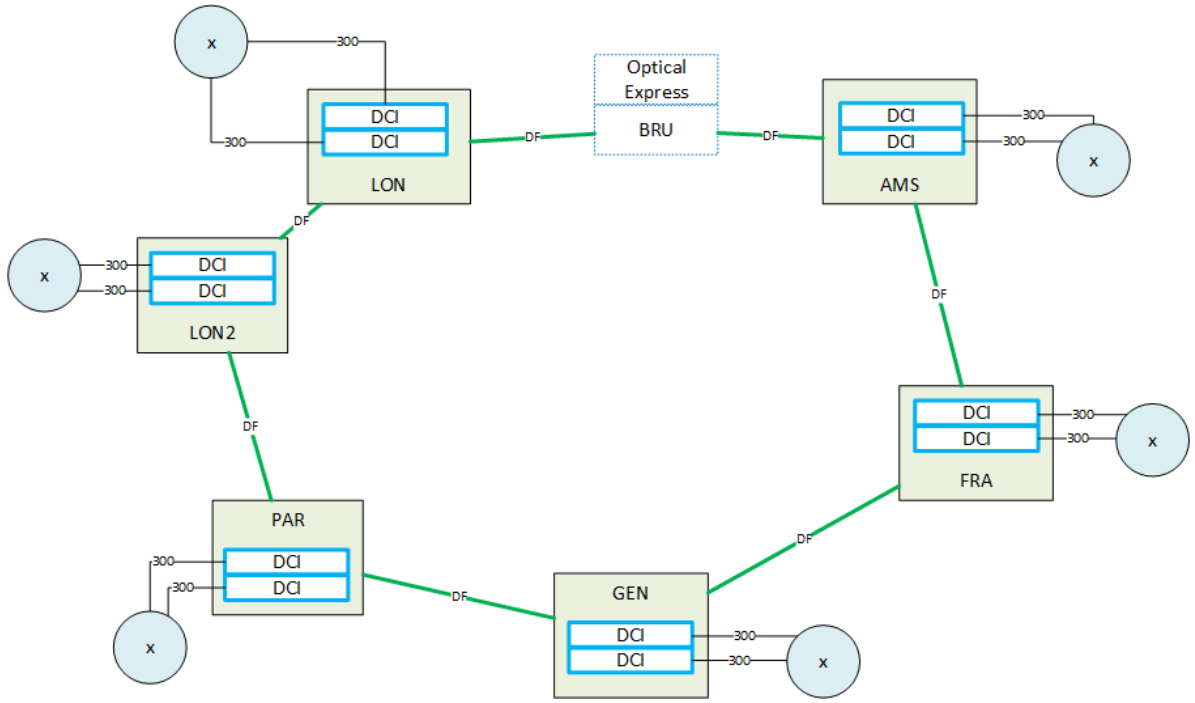


Figure 8.10: GÉANT IP trunks on Western Ring, now built using Groove DCI equipment

The current GÉANT optical network is based on the Infinera DTN-X platform and is managed by Infinera DNA [Infinera-DNA]. This network infrastructure does not support disaggregation of the optical layer – the entire transport network acts as one "black box" network – and is reaching end-of-life. Therefore although this platform delivers fast turn-up of carrier-grade services, lambda services and IP trunks between GÉANT routers, the lack of disaggregation means that GÉANT needs to carry out an equipment upgrade starting in 2020.

At the transmission layer the plans for the GÉANT network take advantage of the developments in Open Line System (OLS) principles. In 2020–2022 GÉANT will upgrade the network to be OLS compliant, which will allow use of any future transponder technology across such a system, effectively future-proofing the lowest layers of the infrastructure. The upgrade is planned to coincide with the renewal of the core fibre that will take place in 2020–2021.

Figure 8.11 below shows the plan for the expanded GÉANT optical footprint. This will be financed using the €50 million of funding available in GN4-3N. The aim is to purchase fifteen-year IRUs for fibre and spectrum, as shown in Figure 8.11. The dark-blue lines show where GÉANT plans to use dedicated dark fibre; the orange lines show where GÉANT aims to make use of spectrum on third-party dark fibre. The light-blue lines indicate leased capacity.

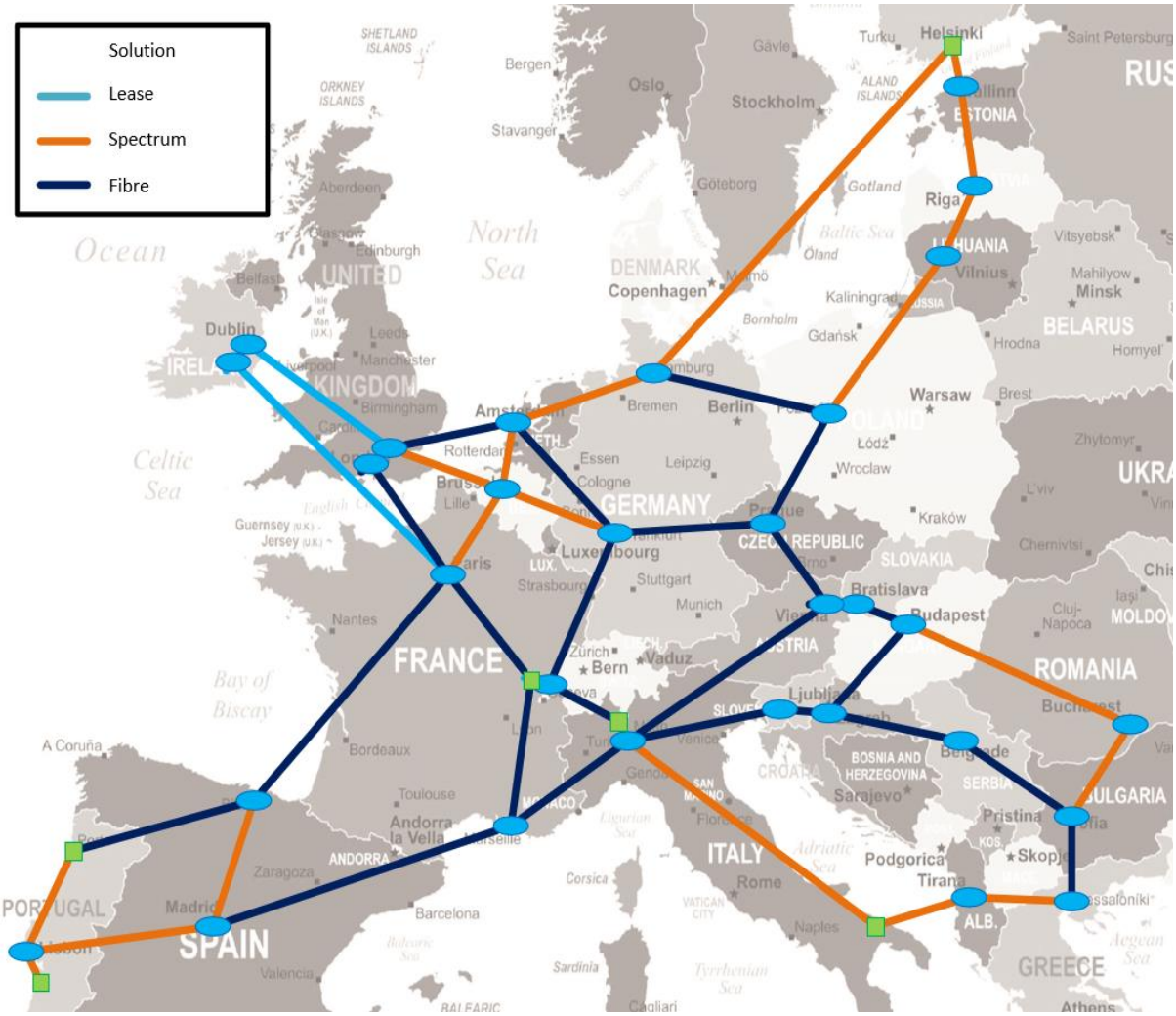


Figure 8.11: Planned expansion of the GÉANT network in 2020–22

8.9.2.2 *Packet Layer*

The GÉANT packet layer consists of 10 Juniper MX960s and 17 MX480s. Based on the technical and operational testing and financial analysis carried out, the Juniper MX480s will be replaced with a Juniper MX204 solution in the 17 locations where they are currently deployed.

The existing Juniper MX480s are using the old generation of modular port concentrator (MPC), which will no longer be supported, and the capital cost to replace those cards with newer-generation MPCs is more than the cost of the Juniper MX204s. The MX204s also use significantly less space and power. By replacing the 17 MX480s with Juniper MX204s the power consumption will be reduced by over 66%.

The annual support cost for MX204s is also significantly lower and by replacing the MX480s with MX204s GÉANT will reduce the Juniper maintenance cost for these locations by 79%.

The Juniper MPC10 is expected to be released in March 2019 and, based on the hardware roadmap from Juniper and forecast traffic growth, GÉANT will be able to overcome the slot capacity issue in the MX960 platform and keep the existing Juniper MX960s running until at least 2021.

Further investigatory work will continue in 2019 to find a suitable packet solution post 2021.

8.10 Network Services

IP has historically been at the core of the services delivered by the NRENs. In 2018, this remained the case. While IPv4 is still the bread-and-butter protocol (offered by 85% of survey respondents), the IPv6 service is now available at 78% of NRENs (down slightly from 82% in 2017). However, most NRENs provide many more services to their users. The most ubiquitous network services continue to be monitoring, troubleshooting tools and NetFlow data. The next most common set of services remain virtual private networks (VPNs), which enable users to send and receive data across shared or public networks as if they were directly connected to the private network. These include L2 and L3 VPNs. Continuing the rise in popularity seen in recent years, optical wavelengths (lambdas or lambda switching) are now offered as a service by just under half of the responding NRENs, while security and research platforms are also important offerings.

An extremely varied and rich set of above-the-net services (services that operate as an application on the IP layer and may incorporate cloud compute and storage) are being offered by NRENs. They include: videoconferencing, virtual dedicated networks, remotely triggered black hole (RTBH) filtering, IPTV, cloud services, eduroam, CloudStorage [eduroam; CloudStor], hosted IP telephony, software distribution depository, cloud data storage, purchasing and admin, and digital exams.

End-User Network Services	% of NRENs Offering
eduroam	88%
IP connectivity	88%
IPv4	85%
Ipv6	78%
Network monitoring	78%
Virtual circuit/VPN	61%
Multicast	59%
DDoS mitigation	56%
NetFlow tool	49%
End-user monitoring/troubleshooting tool	46%
Optical wavelength	44%
Quality of Service (QoS)	34%

End-User Network Services	% of NRENs Offering
Software as a Service (SaaS)	32%
Managed router service	29%
Remote access VPN server	29%
PERT	27%
Disaster recovery	15%
SDN testbed	15%

Table 8.2: NRENs' end-user network services – percentage of survey respondents

9 Cloud Services

2018 saw the accelerated adoption of cloud services across the community with increases in Infrastructure as a Service (IaaS) and Platform as a Service (PaaS).

The IaaS Framework has been taken up by 300 institutions across 18 countries, consuming €13 million of commercial cloud services [IaaS Framework]. 2019 is likely to be the period when the question asked by institutions will change from "Why should we use cloud services?" to "Why shouldn't we use cloud services?"

Of the European NREN Compendium survey respondents almost all now deliver cloud services to users (either at an institutional or end-user level), in particular through the IaaS Framework. This shows that the service portfolios of NRENs are expanding, both in terms of breadth and by moving up the value chain.

9.1 Cloud Service Portfolios

According to the data the NRENs provided about their cloud service portfolio (summarised in Figure 9.1 below), Infrastructure as a Service (IaaS) is the most common service provided, with 58% declaring that they are currently providing such services and a further 7% indicating they are planning to roll out IaaS in the future. This is closely followed by cloud storage (53% and 9%, respectively). Software as a Service (SaaS) is less common (33% and 12%, respectively).

These figures seem to suggest a decrease in the offer of cloud services by NRENs compared with the 2017 results. However, this correlates with a change in survey methodology for this question and is most likely a product of that change.

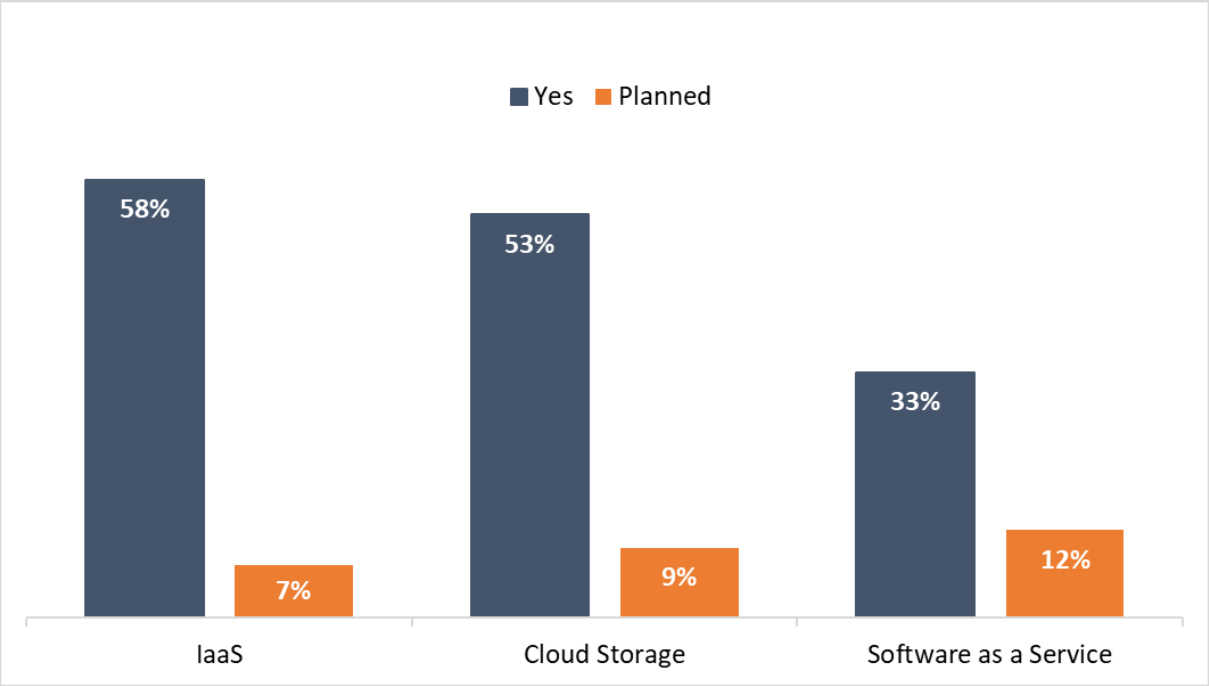


Figure 9.1: Availability of cloud services from NRENs

9.1.1 Infrastructure as a Service (IaaS)

The IaaS area of cloud services offers NRENs the opportunity to expand their support of institutions in a scalable and cost-effective manner and to add value to their proposition without constraining institutions to a single platform.

9.1.1.1 *The GÉANT IaaS Framework*

Underpinning and enabling these services is the IaaS Framework, an EU-compliant procurement framework for cloud infrastructure as a service created by GÉANT in 2016. The Framework allows the NRENs to act as brokers for third-party cloud providers, either as a referrer or as reseller. As a referrer (the preferred role, adopted by 94% of survey respondents), the NREN helps to set up the contract between the supplier and the cloud user; as a reseller (adopted by 6% of respondents), it is the NREN that has the contractual relationship with both supplier and user. (Further information about the NRENs' role within cloud service delivery is given in Section 9.3.)

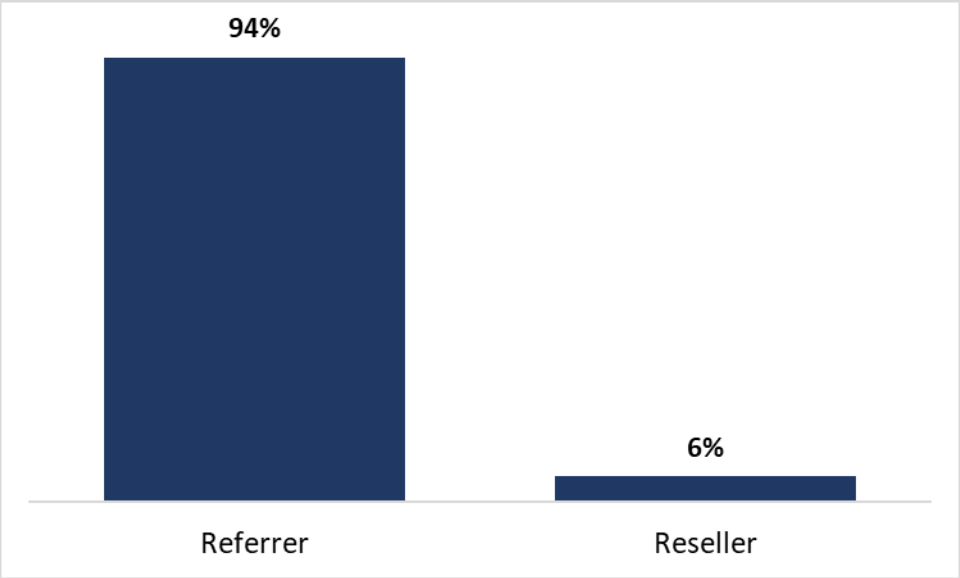


Figure 9.2: Role of NRENs in the procurement of cloud services through the GÉANT IaaS Framework

9.1.2 Software as a Service (SaaS)

The adoption of Software as a Service (SaaS) solutions across the R&E community is more challenging. This is due to two key factors:

- **Complexity**. The range of SaaS solutions tends to require very specific skills and expertise to operate.
- **Diversity**. The wide diversity of software solutions required within the European R&E context results in a very diffuse application set.

This complexity and diversity of solutions reduces the scalability and cost-effectiveness with which NRENs can offer these services to institutions.

With the File Storage sub-sector, however, the NRENs are able to provide a level of scalabilty to the offerings that can generate benefits. This can be seen by the growth in both in-house SaaS services and outsourced offerings (ownCloud and Nextcloud [ownCloud; Nextcloud]).

In order to support NREN adoption of SaaS solutions, GÉANT has dedicated resources to four key focus areas within SaaS:

- Collaboration suites.
- Learning management platforms.
- File sync and share.
- Web- and videoconferencing.

It is anticipated that this will result in accelerated take-up of SaaS services.

9.2 Issues Affecting Adoption

Despite the growth in interest and adoption, European research and education institutions are still somewhat reluctant to adopt cloud services and are lagging behind other sectors. There are a number of factors affecting this:

- **Legislation and Regulations**. With data privacy laws being strengthened in the EU and at country level, there is a direct impact on cloud delivery. In particular, the new EU General Data Protection Regulation (GDPR) has direct implications for:
  - Institutions using clouds: data controllers.
  - Providers offering these clouds: data processors.

  These issues affect both in-house and externally sourced services but with in-house services there is a perception that the risks are lower. With externally sourced services, contracts have to be checked and revised, and processes on the supply and demand side have to be changed.

- **Standardisation**. Data interoperability and portability between different clouds are still in their infancy. Lack of standards and supplier willingness lead to data islands and vendor lock-ins.

- **Scalability**. As cloud services develop from "commodity" infrastructure platforms into more complex managed software offerings, it is likely that NRENs will face scalability issues since the need to support multiple software platforms will require substantial resources.

- **Uncertainty and Risk Aversion**. Many institutions are adopting a "me second" approach to cloud adoption – waiting for other institutions to be the leaders. GÉANT will continue to share user experience and coordinate best practice examples to reduce the uncertainty of cloud adoption.

9.3 The Role(s) of NRENs

With the growth in demand for cloud services across R&E, it is clear that NRENs will have a significant and substantial role in their delivery. There are four key types of role that NRENs can play:

1. **Centre of excellence**. In this role, NRENs can leverage the knowledge and expertise they have gained to advise institutions on the best cloud adoption path. This approach minimises the cloud adoption learning curve amongst user groups and reduces the need for relearning (in particular, relearning the same mistakes) within groups that are "self-similar". This will maximise the knowledge capital of the region and group. In addition, NRENs themselves can share their expertise with other NRENs across the community.

2. **Framework referrer**. Either through the established GÉANT managed frameworks or, potentially, in-country (using nationally arranged frameworks), NRENs can leverage the combined buying power of their user bases and reduce the procurement costs through establishing and promoting framework purchasing agreements. The institutions would then contract directly with the cloud service provider for services.

3. **Reseller**. Where permitted by the NREN's policies, it could be possible for NRENs to act as resellers of services, taking on the contractual relationships and acting as an intermediary for users. This model would result in the NREN purchasing/negotiating via the framework agreement and then reselling services. There could be advantages to this approach (such as simplicity and certainty for the provider, resulting in better terms) but it could result in higher risks to the NREN.

4. **Systems integrator**. Within the SaaS-type models, NRENs could potentially take lower-level services and develop higher-level, value-add facilities on top. Some facilities may be suited to this model (email, file storage, etc.) but there could be both financial and manpower cost implications to this approach, which would limit its attractiveness for most NRENs.

NRENs can (and often will) perform multiple roles according to the particular cloud service. The role(s) played will depend on both the requirements of their users, the regulations controlling the operation of the NREN, and the skills and resources available to the NREN.

9.4 Summary

The service landscape and procurement models for cloud services to support research and education have now matured considerably, and cloud services are becoming significant value-added service propositions for many NRENs as they lend themselves to new delivery models for R&E services and extend the NREN further up the value chain.

It is recognised that there are still inhibitors to the adoption of cloud services, and it will be necessary for GÉANT and the NRENs to work together to reduce the impact of these issues and to ensure a clear, consistent and scalable cloud service strategy is put in place. The more prominent of these inhibitors are arguably now largely within the sphere of awareness and uncertainty rather than of legislation, standardisation and scalability.

Many NRENs are positioning themselves as centres of excellence to enable further uptake of cloud services by institutions. Their unique role as vendor-neutral advisors is a significant value-added service, and frameworks such as the IaaS Framework further reduce cost and complexity for institutions.

9.5 The Future – Moving to OCRE

The Open Clouds for Research Environments project (OCRE) will be the successor to the GÉANT IaaS Framework [OCRE]. OCRE aims to accelerate cloud adoption in the European research community by bringing together cloud providers, Earth Observation (EO) organisations and the research and education community, through ready-to-use service agreements and €9.5 million in adoption funding. This approach, which is being supported by GÉANT and the NRENs, will be the principle focus of new cloud adoption in the future.

OCRE was launched in January 2019, and will run a pan-European tender to establish framework agreements with cloud service providers that meet the specific requirements of the research

community, saving institutions the time-consuming and complex process of doing this themselves. Benefiting from the learning experiences of the GÉANT IaaS Framework, OCRE should further expand cloud adoption.

Appendix A Contact List

Table A.1 below lists the GÉANT Association Members and other international respondents, and contains links to their respective websites (see also [ASSOCIATION].

Short Name	Full Name	Country	Website
AARNet	Australia's Academic and Research Network	Australia	https://www.aarnet.edu.au/
ACOnet	Vienna University Computer Centre	Austria	www.aco.net
AMRES/UoB	Akademska mreža Republike Srbije / Univerzitet u Beogradu	Serbia	www.amres.ac.rs
ANA/RASH	Academic Network of Albania / Rrjeti Akademik Shqiptar	Albania	https://www.rash.al/home-en/
ANAS	Institute of Information Technology of the Azerbaijan National Academy of Sciences	Azerbaijan	http://science.gov.az/
ARNES	Academic and Research Network of Slovenia	Slovenia	www.arnes.si
ASNET-AM	Institute for Informatics and Automation Problems	Armenia	www.asnet.am
UIIP NASB	UIIP NASB	Belarus	www.uiip.bas-net.by
Belnet	Belnet	Belgium	www.belnet.be
BREN	Bulgarian Research and Education Network	Bulgaria	www.bren.bg
CARNet	Hrvatska akademska I istrazivacka mreza	Croatia	www.carnet.hr
CEDIA	Ecuadorian Consortium Foundation for the Development of Advanced Internet	Ecuador	https://www.cedia.edu.ec/en/
CESNET	CESNET, zajmove sdruzeni pravnickych osob	Czech Republic	www.ces.net
CyNet	ΚΥΠΡΙΑΚΟ ΕΡΕΥΝΗΤΙΚΟ ΚΑΙ ΑΚΑΔΗΜΑΪΚΟ ΔΙΚΤΥΟ (KYPRIAKO EREVNITIKO KAI AKADIMAIKO DIKTYO)	Cyprus	www.cynet.ac.cy
DFN	Verein zur Förderung eines Deutschen Forschungsnetzes e.V.	Germany	www.dfn.de
EENet	EENet	Estonia	www.eenet.ee

Short Name	Full Name	Country	Website
FCT | FCCN	Fundação para a Ciência e a Tecnologia | Computação Cientifica Nacional	Portugal	www.fct.pt
GARR	Consortium GARR	Italy	www.garr.it
GRENA	Georgian Research and Educational Networking Association	Georgia	www.grena.ge
GRNET	Greek Research and Technology Network	Greece	www.grnet.gr
HEAnet	HEAnet Limited	Ireland	www.heanet.ie
Ministry of Education and Science	Ministry of Education and Science	Latvia	http://www.lumii.lv
IUCC	Inter University Computation Centre	Israel	www.iucc.ac.il
Jisc	Jisc Collections and Janet Limited	UK	www.ja.net
KREONET		Korea	https://www.kreonet.net/
LITNET	Kauno Technologijos Universitetas	Lithuania	www.litnet.lt
MARnet	Macedonian Academic and Research Network	Former Yugoslav Republic of Macedonia	www.marnet.mk
MREN	Javna Ustanova Univerziteta Crne Gore Podgorica	Montenegro	www.mren.ac.me
KIFÜ (formerly NIIFI)	Kormányzati Informatikai Fejlesztési ÜgynökségNemzeti	Hungary	http://kifu.gov.hu/kifu/
NORDUnet (Representative Member)		Denmark, Finland, Sweden, Norway, Iceland	www.nordu.net
PCSS	Poznan Supercomputing and Networking	Poland	www.man.poznan.pl
RedIRIS/RED.ES	Entidad pública empresarial RED.ES	Spain	www.rediris.es
RENAM	Research and Educational Networking Association of Moldova	Moldova	www.renam.md
RENATER	Groupement d'Intérêt Public Réseau National de Télécommunications pour la Technologie, l'Enseignement et la Recherche	France	www.renater.fr
REANNZ	Kiwi Advanced Research and Education Network	New Zealand	https://reannz.co.nz/about/
RESTENA	Réseau Téléinformatique de l'Education Nationale et de la Recherche	Luxembourg	www.restena.lu
RoEduNet	Agentia de Administrare a Retelei Natinale de	Romania	www.nren.ro

Short Name	Full Name	Country	Website
	Informatica Pentru Educatie si Cercetare		
SANET	Slovak Academic Network Association	Slovakia	www.sanet.sk
SARNET	Academic and Research Network of the Republic of Srpska	Bosnia & Herzegovina	http://www.jusarnet.net/
SURFnet	SURFnet B.V.	Netherlands	www.surfnet.nl
SWITCH	SWITCH	Switzerland	www.switch.ch
TARENA	Tajikistan National Research and Education Network	Tajikistan	http://www.tarena.tj/
ULAKBIM	Turkiye Bilimsel Ve Teknolojik Arastirma Kurumu	Turkey	www.ulakbim.gov.tr
UoM	L-Università ta' Malta	Malta	http://www.um.edu.mt/itservices/research
URAN	Association of Users of Ukrainian Research and Academic Network	Ukraine	www.uran.net.ua

Table A.1: List of 2018 Compendium survey respondents

Appendix B Compendium Contributors

Sebastiano Buscaglione, Senior Network Engineer (GÉANT), has several years of experience working in large-scale service provider networks. Before joining DANTE (now GÉANT) in 2012, he worked as part of the AT&T Global Operations department supporting global enterprise VPN services. His main interests are extraction and analysis of network data and its use in driving optimisation in network architectures. Sebastiano's career path includes networking at the CISCO Networking Academy within London Metropolitan University, and industry certifications, such as CCNP and MEF-CECP.

Vincenzo Capone, Senior Technical Business Development Office (GÉANT), is responsible for user support for network solutions provided to pan-European and international scientific groups and collaborations, and in Science and Research engagement activities, with a background in computer science and networking. Previous positions include the Department of Physics at the University of Naples, where Vincenzo was the Network Architect and manager in charge of the computing resources for physics experiments, and Technical Associate to the ATLAS experiment collaboration at CERN.

Guy Roberts, Senior Network Architect (GÉANT), is responsible for the introduction of new technology into the transport layers of the GÉANT network. Guy is co-chair of the Network Service Interface working group in the Open Grid Forum. Guy received his BEng degree from RMIT University in Australia and his PhD in photonics from the University of Cambridge.

Daniel Wustenberg, Community Research Officer (GÉANT), is responsible for collecting, collating and analysing information from and about the NREN community to provide GÉANT and the NRENs with business intelligence. He runs the yearly NREN Compendium survey as one of his main responsibilities. He has several years' experience in market research in different settings and joined GÉANT in 2018.

Cloud Services:

Karl Meyer, Product Marketing and Management Officer (GÉANT), has spent the past 20 years working within the Internet industry in both technical and sales and marketing roles and was Director of Channel Marketing Strategy. Karl has an MBA from the Open University, with an emphasis on International Enterprise Development and Knowledge Management.

References

[AfricaConnect2]	https://www.africaconnect2.net/Pages/Home.aspx
[ASSOCIATION]	GÉANT Association Members: https://www.geant.org/About/Membership/Pages/MAandGAreps.aspx
[BELLA]	http://www.bella-programme.eu/index.php/en/
[BELLE2]	https://www.belle2.org/project/super_kekb_and_belle_ii/
[CANARIE]	https://www.canarie.ca/network/
[CAREN]	https://caren.geant.org/pages/home.aspx
[CERN]	https://home.cern/
[CLARIN]	https://www.clarin.eu/
[CloudStor]	https://www.aarnet.edu.au/network-and-services/cloud-services-applications/cloudstor
[COMPENDIUM]	https://compendium.geant.org/
[COPERNICUS]	https://www.copernicus.eu/en
[DARIAH]	https://www.dariah.eu/
[DGDEVCO]	https://ec.europa.eu/europeaid/general_en
[EaPConnect]	https://www.eapconnect.eu/
[eduroam]	https://www.eduroam.org/
[EGI]	https://www.egi.eu/
[ESA]	https://www.esa.int/ESA
[ESnet]	https://www.es.net/
[EUDAT]	https://www.eudat.eu/
[EUMEDCONNECT3]	https://www.eumedconnect3.net/pages/home.aspx
[EUMETSAT]	https://www.eumetsat.int/website/home/index.html
[GÉANT]	https://www.geant.org/
[GEO]	https://www.earthobservations.org/index.php
[GN4-2]	https://www.geant.org/Projects/GEANT_Project_GN4-2/Pages/Home.aspx
[GN4-3]	https://www.geant.org/Projects/GEANT_Project_GN4-3
[IaaS Framework]	https://clouds.geant.org/
[Infinera]	https://www.infinera.com/
[Infinera-DNA]	https://www.infinera.com/products/infinera-management-suite/#2
[Internet2]	http://www.internet2.edu/
[IPv4]	https://tools.ietf.org/html/rfc791
[IPv6]	https://datatracker.ietf.org/doc/rfc8200/
[ISCED 2011]	http://www.uis.unesco.org/Education/Documents/isced-2011-en.pdf
[ITER]	https://www.iter.org/
[JIVE]	https://www.fch.europa.eu/project/joint-initiative-hydrogen-vehicles-across-europe
[Juniper]	https://www.juniper.net/uk/en/
[LHC]	https://home.cern/science/accelerators/large-hadron-collider

[LIGO-Virgo] https://ligo.org/
[NETCONF] https://tools.ietf.org/html/rfc6241
[NEXPReS] https://www.geant.org/People/research_communities/Pages/NEXPReS.aspx
[Nextcloud] https://nextcloud.com/
[NOvA] https://novaexperiment.fnal.gov/
[NSI] https://redmine.ogf.org/projects/nsi-wg
[OCRE] https://www.ocre-project.eu/
[ONOS] http://onosproject.org/
[OpenFlow] https://www.opennetworking.org/sdn-resources/openflow/
[ownCloud] https://owncloud.org/
[PCEP] https://tools.ietf.org/html/rfc5440
[PRACE] http://www.prace-ri.eu/
[SERVICES] https://compendiumdatabase.geant.org/reports/nrens_services
[SKA] http://skatelescope.org/
[TEIN4] http://www.tein.asia/main/?mc=0
[Virgo] http://www.virgo-gw.eu/
[WMO] https://public.wmo.int/en

Glossary

API	Application Programming Interface
AUP	Acceptable Use Policy
AW	Alien Wave or Wavelength. Data transmission laser light from third-party equipment; an alien wave system multiplexes alien light together with local signals using DWDM.
CCNP	Cisco Certified Network Professional
CERN	European Organisation for Nuclear Research
CLARIN	Common Language Resources and Technology Infrastructure
DARIAH	Digital Research Infrastructure for the Arts and Humanities
DCI	Data Centre Interconnect
DDoS	Distributed Denial of Service
DG DEVCO	EC Directorate-General for International Cooperation and Development
DNA	Digital Network Administrator
DTN	Data Transmission Network
DWDM	Dense Wavelength Division Multiplexing
EaPConnect	Eastern Partnership Connect
EC	European Commission
eduroam	education roaming. The secure, world-wide roaming access service developed for the international research and education community.
EGI	European Grid Infrastructure
EO	Earth Observation
ESA	European Space Agency
EUDAT	European Data Infrastructure
EUMETSAT	European Organisation for the Exploitation on Meteorological Satellites
FTE	Full-time equivalent
Gbps	Gigabits per second
GDPR	General Data Protection Regulation
GEO	Group on Earth Observations
GMPLS	Generalised MPLS
GN4-2	GÉANT Network 4 Phase 2 project, part-funded from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No.731122
GN4-3	GÉANT Network 4 Phase 3 project, part-funded from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 856726
IaaS	Infrastructure as a Service
IETF	Internet Engineering Task Force
IP	Internet Protocol
IPTV	Internet Protocol Television
IPv4	Version 4 of the Internet Protocol (StB IETF), a connectionless protocol used on packet-switched networks. Employs 32-bit IP-addresses.

IPv6	Version 6 of the Internet Protocol (StB IETF), The successor to IPv4, employing a 128 bit IP-address. In addition to a larger addressing space, IPv6 deals with addresses in a hierarchal manner and improves route aggregation.
IRU	Indefeasible Rights of Use
ISCED	International Standard Classification of Education The classification is: Level 8: Doctoral or equivalent level Level 7: Master's or equivalent level Level 6: Bachelor's or equivalent level Level 5: Short-cycle tertiary education Level 4: Post-secondary non-tertiary education. This can include, for example, short vocational training programmes. Level 3: Upper secondary education Level 2: Lower secondary education Level 1: Primary or basic education Level 0: Early childhood or pre-primary education The different institutions types are classified as follows: Universities and other (ISCED 6–8) Further education (ISCED 4–5) Secondary schools (ISCED 2–3) Primary schools (ISCED 1) Research institutes Libraries, museums, archives, cultural institutions Non-university public hospitals Government departments (national, regional, local) International (virtual) research organisations For-profit organisations
ITER	International Thermonuclear Experimental Reactor
IX	Internet Exchange
JIVE	Joint Initiative for hydrogen Vehicles across Europe
JRA	Joint Research Activity
JRA1 T1	GN4-2 JRA1 Network Infrastructure Evolution T1 Evolving the Shared Optical Infrastructure
L*n*	Layer *n*
LHC	Large Hadron Collider
LIGO	Laser Interferometer Gravitational-Wave Observatory
MEF	(formerly) Metro Ethernet Forum
MEF-CECP	MEF Carrier Ethernet Certification Program
MPC	Modular Port Concentrator
MPLS	Multiprotocol Label Switching
NETCONF	Network Configuration Protocol. NETCONF provides mechanisms to install, manipulate, and delete the configuration of network devices. It uses an XML-based data encoding for the configuration data as well as the protocol messages. The NETCONF protocol operations are realised as remote procedure calls (RPCs).
NEXPReS	Novel Explorations Pushing Robust e-VLBI Services
NFV	Network Function Virtualisation. Network architecture that uses virtualisation to connect network and communications services.
NOC	Network Operations Centre

NOvA	NuMI Off-axis ν_e Appearance
NREN	National Research and Education Network
NSI	Network Service Interface. An open generic network service interface that can be called by a network external entity such as end users, middleware, and other network service providers to enable interoperability between dynamic circuit services.
NuMI	Neutrinos at the Main Injector
OCRE	Open Clouds for Research Environments project. OCRE aims to accelerate cloud adoption in the European research community by providing a framework for providers and users of cloud services and Earth Observation (EO).
OEO	Optical to Electrical to Optical
OLS	Open Line System
ONOS	Open Network Operating System. A software-defined networking operating system for service providers.
OpenFlow	A communications protocol that gives access to the forwarding plane of a network switch or router over the network
ownCloud	A self-hosted file sync and share server
PaaS	Platform as a Service
PB	Petabyte (10^{15} bytes of data)
PCC	Path Computation Client
PCE	Path Computation Element
PCEP	Path Computation Element Protocol. PCEP is a protocol for communications between a Path Computation Client (PCC) and a Path Computation Element (PCE), or between two PCEs. Such interactions include path computation requests and path computation replies as well as notifications of specific states related to the use of a PCE in the context of Multiprotocol Label Switching (MPLS) and Generalised MPLS (GMPLS) Traffic Engineering.
PERT	Performance Enhancement Response Team
PRACE	Partnership for Advanced Computing in Europe. The mission of PRACE (Partnership for Advanced Computing in Europe) is to enable high impact scientific discovery and engineering research and development across all disciplines to enhance European competitiveness for the benefit of society.
QoS	Quality of Service
R&E	Research and Education
RFC	Request for Comments. A formal document drafted by the IETF that describes the specifications for a particular technology. When an RFC is ratified, it becomes a formal standards document.
RPC	Remote Procedure Call
RTBH	Remotely Triggered Black Hole
SaaS	Software as a Service
SDN	Software-Defined Networking
SKA	Square Kilometre Array. An international project to build the world's largest radio telescope.
T	Task
T&I	Trust and Identity
VLBI	Very Long Baseline Interferometry
VPN	Virtual Private Network
XML	Extensible Markup Language

WMO	World Meteorological Organisation
WP	Work Package
WP7	GN4-3 WP7 Network Core Infrastructure and Core Service Evolution and Operations
YoY	Year-on-Year